# Flood Risk Assessment in Bangladesh and People`s Adjustment Scenarios: A Case Study in Brahmaputra-Jamuna Floodplain

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# Abstract

Bangladesh is certainly one of the most impressive floodplain and delta areas in the world. The interaction between the rapidly increasing population, the intensity of agricultural production, the extreme variability of precipitation, and the unusual dynamics of the river systems makes flood management in Bangladesh a truly challenging task. We are well aware of the fact that a large number of highly qualified institutions and authors have tackled issues concerning monsoonal floods in Bangladesh, not only from the natural and social science point of view but also from the technical and engineering science side. The riverine country Bangladesh has been experiencing floods more frequently than ever before in the recent years. The present study undertakes a detailed assessment of flood risks of the Brahmaputra-Jamuna Floodplain (Map 6.3), the study area for this research. An attempt has been undertaken in this research to develop a GIS model using ArcGIS 10 Modelbuilder option. The underlying objective was to contribute to the flood management system in the country. The model involved the analysis of the hydrologic, topographic and the local resident's coping capacity variables. Combining the weight of the above variables throughout the study area the model was able to demarcate flood risk zones of various intensity. Uniform flood risk was not found into the whole area. Some parts of the area are identified as high risk zones, some are moderate risk zones and others are risk free or low risk zones. Flood intensity and duration of the area is controlled mainly by the hydrological and topographical characteristics of the catchment area. The effect of river morphology and dynamics and precipitation trends of the area were found fluctuating with season. Coping strategies and options of the local residents were found to be poor and inadequate and are mainly based on indigenous knowledge. Almost all of the peoples found were not afraid of flood and they take it as a routine problem that happens almost every year. No unusual measures are taken to survive during the flood period except storing and preserving dry foods and medicine after a flood warning is received. A Hazard Intensity Surface Index has been prepared for the area combining all the variables that contribute to the overall hazard potential of the study area. Thus the study area has been categorized into several belts with different hazard potentials (Map 4.9). In the case of human adjustment, people themselves take measures that save and reduce the loss and damage. The help received from government

sources were found to be very inadequate and untimely. Also, the most poor are the ones who are deprived due to the relief distribution system at the local level. Notwithstanding the need for greater sophistication, it is likely that, the flood protection, mitigation and risk assessment model have been developed and expected to acknowledge the problem and considered here to successfully deal the flood problems of the study area. Moreover, the suggested models to analyze the risk of flood should be considered rudimentary, and are presented solely to illustrate the concept.

## ACRONYMS

| | |
|---|---|
| ADAB | Association of Development Agencies in Bangladesh |
| ADB | Asian Development Bank |
| AFPM | Active Flood Plain Management |
| BADC | Bangladesh Agricultural Development Corporation |
| BARC | Bangladesh Agricultural Research Council |
| BCAS | Bangladesh Center for Advanced Studies |
| BIDS | Bangladesh Institute of Development Studies |
| BIWTA | Bangladesh Inland Water Transport Authority |
| BKB | Bangladesh Krishi Bank |
| BDM | Bangladesh Meteorological Department |
| BRDB | Bangladesh Rural Development Board |
| BRE | Brahmaputra Right Embankment |
| BWDB | Bangladesh Water Development Board |
| CIDA | Canadian International Development Agency |
| DTW | Deep Tube-Well |
| DFFW | Directorate of Flood Forecasting and Warning |
| DLE | Dhaleshari Let Bank |
| DND | Dhaka-Narayanganj-Demra Irrigation Project |
| EEC | European Economic Community |
| EIP | Early Implementation Project |
| EPWAPDA | East Pakistan Water and Power Development Authority |
| ERR | Economic Rate of Return |
| FAO | Flood Action Plan |
| FCD | Flood Control and Drainage |
| FCDI | Flood Control and Drainage Irrigation |
| FFYP | Forth Five Year Plan |
| FPCO | Flood Plan Coordination Organization |
| GIS | Geographic Information System |
| GUP | Gram Union Parishad |
| HYV | High Yielding Variety |
| IBRD | International Bank for Reconstruction and Development |

| | |
|---|---|
| IDA | International Development Association |
| IDP | International Development Project |
| IECO | Institutional Energy Consultant Organization |
| IPCC | Intergovernmental Panel on Climate Change |
| IPM | Integrated Pest Management |
| IRRI | International Rice Research Institute, Philippines. This term is used for high yielding varieties of rice |
| ISPAN | Irrigation Support Project for Asia and the Near East |
| JRCB | Join River Commission of Bangladesh |
| LIV | Local Improved Varieties |
| LLP | Low Left Pumps |
| LGED | Local Government and Engineering Department |
| MLE | Meghna Left Embankment |
| MPO | Master Plan Organization |
| MRE | Meghna Right Embankment |
| MTFPP | Medium Term Flood Production Plan |
| NERP | Noth-East Regional Water Management Project |
| NGO | Non Government Organization |
| NWP | National Water Plan |
| RHDIS | Recorded Highest Discharge |
| RHFL | Recorded Highest Flood Level |
| SFYP | Second Five Year Plan |
| TFYP | Third Five Year Plan |
| TYP | Two Year Plan |

# Glossary

| | |
|---|---|
| **Upazila** | Small Administrative of the Country (Thana) |
| **Boro** | Rice sawn transplanted and maturing in the dry monsoon season |
| **Char** | Newly emerged land in a river channel |
| **Cross dam** | An embankment built across a river |
| **Dal** | Pulses |
| **Fitkiri** | Alum to clean polluted water; one type of chemical |
| **Haor** | A bowl-shaped depression between the natural levees of a river mostly found in the eastern region of greater Mymensingh and the Greater Sylhet District. |
| **Traces** | Physiographic unit of the country having special character |
| **Jotedars** | Large influential landowners |
| **Kharif** | Wet growing season |
| **Khas** | Under Government ownership |
| **Mahajan** | Traders who stocks |
| **Neem** | (Azadirachta indica) Indigenous medicinal plant |
| **Rabi** | Dry growing season |
| **Ring Dam** | Officially called the Dhaka Integrated Town Projection Embankmen |
| **Aman** | A team used in eastern India and Bangladesh for rice crop sown in monsoon and harvested after monsoon. |
| **Ashtomashi Ban** | Embankments meant to last for eight months of the year |
| **Aus** | Rice Crop planted before the wet monsoon season and maturing immediately before or in the well monsoon. |
| **Bannya** | Bengali name for Flood |
| **Rainy Session** | Bengali name for normal Flood |
| **Beel** | A natural wetland depression which generally retains water throughout the year |
| **Srotte** | Bengali name of Flow of water |

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## 1.0 Introduction

Bangladesh is a land of rivers with numerous intricate river system three of the world`s largest rivers, the Ganga, the Padma and the Meghna. Almost all the stream flows through Bangladesh originated from the upstream catchment in India, Nepal, Bhutan and China. Peak flow of these rivers mainly depends on the annual rainfall in the catchment area mainly located outside the boundary of the country Bangladesh. About 80% area of the country is comprised of floodplains while only 8% is traces (Barind terraces and Madhupur Tract area) and 12% is hills (T. Tingsanchali & F. Karim, 2004). Flooding in Bangladesh is caused by several factors. These include huge amount of inflows from upstream catchment, low floodplain gradients, cyclonic storms, drainage congestion in older floodplain areas, effects of confluence of the major rivers and siltation in dry seasons (Rahman, 1996). Once every 10 years roughly one-third of the country gets severely affected by floods, while in catastrophic years such as 1988, 1998, 2004, and 2007 more than 60% of the country was inundated that is area of approximately 100,000 square kilometers for duration of nearly 3 months (CEGIS, 2010).

The increase volume of rainfall caused by climate change during the past decades has intensified the flood problem in Bangladesh (Mirza et al. 2003). The population expected to be hardest hit by flood disaster is the poor people who lack adequate means to take protective measures and who also have very little capacity to cope with the loss of property and income (IPCC, 2001). A range of studies have recently focused on understanding how different groups of people and communities perceived and respond to flooding risks, especially in flood prone countries (Rasid and Paul 1993). Since the mid 1990s, the concept of social vulnerability is used to describe and analyze the exposure and coping mechanisms of groups and individual to environmental risk, primarily in the context of climate change and flooding hazards in developing countries (e. g. Blaikie et. al., 1994 ; Few, 2003) in which Bangladesh is included.

Usually a flood is associated with dramatic congestion arising from the intense surface flow and heavy overland runoff caused by higher rainfall in the catchments area. The causes of occurrence and the nature of floods are highly regulated and immensely characterized by the climatic condition, hydrological situation and physical settings of an area. Considering this aspect Bangladesh is mostly a vast flat land where floods have always a recurrent phenomenon. The study area (Brahmaputra-Jamuna Floodplain) is one of the most flood prone areas of Bangladesh where almost every year flood takes place and the people of the area living with vulnerability of this natural hazard. Now time claims the assessment of risk of the area for the safety and security of lives and properties. In this study an attempt has been made using variables from social, economical and environmental aspects that may be of use to assess flood risk in the Brahmaputra-Jamuna floodplain. Further, coping strategies of communities have also been studied.

**1.1 Floods Estimation**

Flood estimation and flood risk assessment has traditionally been the domain of hydrologists, water resources engineers, geographers, environmental scientists and statisticians, and disciplinary approaches have abounded. Dominant views have been shaped; one example is the catchment perspective: floods are formed and influenced by the interaction of local, catchment-specific characteristics, such as meteorology, topography and geology. These traditional views have been beneficial, but they have a narrow framing. In this study I have distinguished traditional views with broader perspectives that are emerging from an improved understanding of the geographical context of floods. It is endeavored in extending the traditional system boundaries (local catchment, recent decades, hydrological/hydraulic processes) opens up exciting possibilities for better understanding and improved tools for flood risk assessment and management. Statistical approaches in flood estimation need to be complemented by the search for the causal mechanisms and dominant processes in the atmosphere, catchment and river system that leave their fingerprints on flood characteristic. [Merz, B., Aerts, J., Arnbjerg-Nielsen, K., Baldi, M., Becker, A., Bichet, A. L. M., Brauer, A., Cioffi, F., Delgado, J.M., Gocht, M., Guzzetti, F., Harrigan, S., Hirschboeck, K., Kilsby, C., Kron, W., Kwon, H.-H., Lall, U., Merz, R., Nissen, K., : 2014.]

Natural climate inconsistency leads to time-varying flood characteristics, and this variation may be partially quantifiable and predictable, with the perspective of a dynamic, climate informed flood risk management. Efforts are needed to fully explanation for factors that contribute to changes in all three risk components (hazard, exposure, vulnerability), and to better understand the interactions between society and floods.

### 1.2 Flood Risk Assessment

Flood risk assessment is an essential pre-requisite for efficient flood management. The concept is becoming popular in the flood management policies of all the major countries (Meyer, V. et.al. 2009; Hall, J.W. et.al. 2003; Gouldby, B. et.al. 2007; Jonkman, S.N. et.al. 2008). The unusual rise in flooding events in recent years in almost all continents usually attributed to various climate change aspects have generated an increased attention of academics, professionals and policy-makers to various aspects of flood risk assessment. This has resulted in the emergence and development of a robust area of research into flood risk assessment. This has also been largely facilitated by the emergence and advancement of newer data-acquisition and data processing and modeling techniques. The rapid advancement of satellite based technologies and the tremendous advancement in spatial data analysis and modeling have enabled numerous researchers into developing accurate flood risk models on which rational flood management can be taken.

Risk is the chance or possibility of suffering, loss, injury, damage etc. In another word, risk is someone or something likely to cause loss, injury, damage etc. There are different definitions of risk for each of several applications. The widely inconsistent and ambiguous use of the word is one of several current criticisms of the methods to manage risk. In one definition, "risks" are simply future issues that can be avoided or mitigated, rather than present problems that must be immediately addressed. However, general usage tends to focus only on potential harm that may arise from a future event, which may accrue either from incurring a cost or by failing to attain some benefit. One of the first major uses of this concept was at the planning of the Delta Works in 1953, a flood protection program in the Netherlands, with the aid of the mathematician David van Dantzig. The kind of risk analysis pioneered here has become common today in fields like nuclear power, aerospace and the chemical industry.

Risk assessment is a step in a risk management procedure. Risk assessment is the determination of quantitative or qualitative value of risk related to a concrete situation and a recognized threat (also called hazard). Quantitative risk assessment requires calculations of two components of risk: $R$, the magnitude of the potential loss $L$, and the probability $p$, that the loss will occur. Risk, as shown in the disaster risk equation, increases as hazardous events become more common, people become more vulnerable and their capacity to cope decreases.

With reference to natural hazards, most available definitions of risk are expressed as a product of two or more components. In general, risk is the likelihood or probability of hazard occurrence of a certain magnitude. One of the simplest and common definitions of risk, the one preferred by many risk managers, is the likelihood of an event occurring multiplied by the consequences of that event (Paul and Rasid 2014) :

Risk = (likelihood of Hazard Occurrence)(Consequence)

**Lowarnce's (1976)** definition of risk is similar to the above definition. He define risk as "a measure of probability and severity of harm". By severity he means expected loss, vulnerability, or consequences of occurrence of an extreme event. He substitutes consequence by severity or magnitude of an event :

Risk= (Probability of occurrence of an extreme event)(Magnitude) .

According to **Mc Verry and Van Dissed (1994) and Twigg (1998),**

Risk = (Hazard Probability )=(Vulnerability).

However, the difficulty in expressing risk of hazard using probability and consequences dimensions lies in the fact those identical values may represent either high probability-low consequence or low probability high consequence risk.

Definition provided by **Fouriner d'Albe (1979)** is till now more acceptable and seems to more effective in assessing risk especially indentifying natural hazard risk as :

R= (Hazard probability x Expected loss)/Preparedness (coping capacity)

Or,

$$R = \frac{H \times V}{C}$$ *Where,*

$R$ = risk,

$H$ = frequency or magnitude of hazard,

$V$ = vulnerability level,

$C$ = capacity to cope

For the practical application of flood risk assessment, flood damage has to be estimated for flood events of different probability in order to construct a damage-probability curve. The risk or the annual damage (rough calculation) can be expressed using the following equations (DVWK 1985; Equations. 1 and 2):

$$D = \sum_{i=1}^{k} \mathrm{D(í)} \times \Delta Pi \qquad (1)$$

$$\mathrm{D(í)} = \frac{\mathrm{D(Pí{-}1)+D\ (Pí)}}{2a} \qquad (2)$$

Where D is the annual average damage, D (í) is the mean damage of 2 known curve, and $\Delta Pi$ = [Pí -Pí -1] the probability of the interval between those points.

This shows that the ex-ante evaluation of flood damage is as essential part of risk assessment. A large variety of approaches currently exists for the estimation of flood damage. Usually they deploy the following kind of input data in order to estimate flood damage (Messner, et al. 2007) :

a) Inundation characteristics, such as data especially on the estimated area and inundation depth of a flood event, calculated by hydrodynamic models;
b) Information on number and type of the exposed elements at risk (people, properties, biotopes, etc.), usually gathered from land use data sources;
c) Information concerning the value of these elements at risk (either in monetary or nonmonetary terms);
d) Information on the susceptibility of these elements at risk, usually expressed by depth-damage relationships.

Apart from these general components, damage evaluation approaches differ considerably in detail. Regarding their spatial scale and accuracy level the existing methods can be broadly differentiated into macro, meso, and micro-scale approaches (Messner et al. 2007). Macro-scale approaches often rely on land use information with a low spatial resolution and/or low typological differentiation on order to reduce the effort of analysis and hence permit considering large river basins as a whole (IKSR 2001; Sayers et al 2002). Micro scale approaches on the other hand try to achieve more accurate results b applying very detailed, object-oriented land use data, as well as value and susceptibility information (Volker Meyer et al. 2008). In this study Micro scale approaches has been taken into consideration to analysis the LANDSAT image of the study area in different aspects.

### 1.3 Flood Management Policy and Strategy in Bangladesh

Conscious and active flood management policy and strategy in this country can be traced back to the sixties when the United Nations commissioned a mission led by Mr. Krugg just after two consecutive devastating floods in 1954 and 1955. The commission studied the flood problem and suggested remedial measures. The mission report was finalized in 1957. It mainly focused on protecting the agricultural lands from the floods as agriculture was the mainstay of the economy of the country at that time. Moreover self sufficiency in food was the cornerstone of government policy. Keeping in view these objectives a Water development master Plan was prepared in 1964 and structural options having large project portfolios were given propriety. Accordingly, since the early sixties , the government started implementing large scale projects with the objective of flood protection, improved drainage and providing irrigation facilities.

After the disastrous flood s of 1987 and 1988, the government undertook a 5 year (1961-96) massive study project known as Flood Action Plan (FAP). The FAP had 26 components, with 12 main studies and 14 supporting studies. The Bangladesh Flood and Water Management Strategy (BFWMS) was formulated on the basis of FAP studies in 1995. Follow up to this was the National Water Management Plan (NWMP) : a 25 year programme cross cutting different sectors of the national economy. The GOV formulated a National Water Policy. NWMP was approved in 2004. The programme period was divided into three phases, e.g. short term for 5 years, medium for 10 years and long term for 25 years. NWMP has 84 programmes cross-cutting 11 different sectors of the economy.

Every year huge loss of life and property occurs due to floods. The main reason is the unplanned development and habitations in the flood plains. Although in the NWP it has been envisaged to have a coordinated development and settlement in the floodplains it is not at all practiced (pp. 64, Hossain, ANHA, 2006). This unplanned development in the floodplains is causing an increase in the flood risk to the livelihood of the people and vital economic infrastructure. Assessment of risk is important for taking decisions regarding any development activities in the risk zones. This is primary for planning, design, implementation and protection of any investment and also for saving lives and the livelihood of the people living in those areas.

In Bangladesh, there is no method or practice in place to assess risks in a comprehensive manner. Immediate actions for flood mitigation thus would require risk mapping.

Model-GIS interface and Digital Elevation Models (DEM) are widely used to assess risks and develop flood-plain zoning maps all over the world. This major constraint to developing such maps is the 50-year old topographic maps and land elevation data. A comprehensive programme should be immediately taken to update existing topographic information and land elevation data and to develop flood zoning maps and risk assessment in flood prone areas.

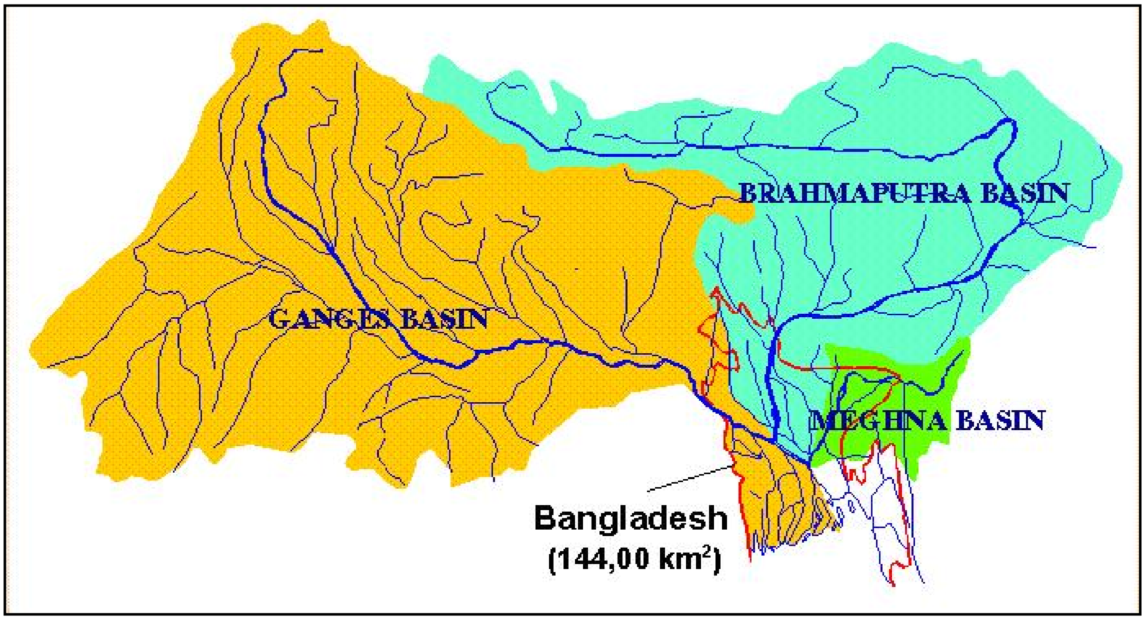
### 1.4 Details of the study area (Brahmaputra-Jamuna Floodplain)

This study takes a vast area for the general consideration of flood risk assessment. In view of the large scale approach it is important to define sub-regions for the details study which allows taking a case study in the Brahmaputra-Jamuna Floodplain located only in the geographical unit of Bangladesh.

Old Brahmaputra Floodplain A remarkable change in the course of the Brahmaputra took place in 1787. In that year, the river shifted from a course around the eastern edge to the western side of the Madhupur Tract. This new portion of the Brahmaputra is named the Jamuna. The old course (Old Brahmaputra) between Bahadurabad and Bhairab shrank through silting into a small seasonal channel only two kilometres broad. The old river had already built up fair high levels on either side over which the present river rarely spills. The Old Brahmaputra floodplain stretching from the southwestern corner of the Garo Hills along the eastern rim of the Madhupur Tract down to the Meghna river exhibits a gentle morphology composed of broad ridges and depressions. The latter are usually flooded to a depth of more than one metre, whereas the ridges are subject to shallow flooding only in the monsoon.

Jamuna (Young Brahmaputra) Floodplain an alternative name used for the mighty Brahmaputra river, because the Jamuna channel is comparatively new and this course must be clearly distinguished from that of the older one. Before 1787, the Brahmaputra's course swung east to follow the course of the present Old Brahmaputra. In that year, apparently, a severe flood had the effect of turning the course southward along the Jenai and Konai rivers to form the broad, braided Jamuna channel. The change in course seems to have been completed by 1830.

**Figure 1.2 : Catchment area of the three major rivers (The Padma, the Meghna and the Jamuna) of Bangladesh**




*Source : jrcb image, 2014*

Due to the upliftment of the two large Pleistocene blocks of the Barind and Madhupur, the zone of subsistence between them was turned in to a rift valley and became the new course of the Brahmaputra as the great Jamuna. Both the left and right banks of the river are included in this sub-region. The Brahmaputra-Jamuna floodplain again could be subdivided into the Bangali-Karatoya floodplain, the Jamuna-Dhaleshwari floodplain, and diyaras and Chars.

The right bank of the Jamuna was once a part of the Tista floodplain, and now through the Bangali distributary of the Jamuna is a part of the bigger floodplain. Several distributaries of the Jamuna flow through the left bank floodplain, of which the Dhaleshwari is by far the largest; this floodplain is sub-classed as the Jamuna-Dhaleshwari floodplain. The southern part of this sub-region was once a part of the Ganges floodplain. Along the Brahmaputra-Jamuna, as along the Ganges, there are many diyaras and chars. In fact, there are more of them along this channel than in any other river in Bangladesh. There is a continuous line of chars from where this river enters Bangladesh to the off-take point of the Dhaleshwari. Both banks are punctuated by a profusion of diyaras. The soil and topography of chars and diyaras vary considerably. Some of the largest ones have point bars and swales. The elevation between the lowest and the highest points of these accretions may be as much as 5m. The difference between them and the higher levees on either bank can be up to 6m. Some of the ridges are shallowly flooded but most of the ridges and all the basins of this floodplain region are flooded more than 0.91m deep for about four months (mid-June to mid-October) during the monsoon.

The Ganges-Brahmaputra-Meghna (GBM) river basin is a transboundary river basin with a total area of just over 1.7 million $km^2$, distributed between India (64 percent), China (18 percent), Nepal (9 percent), Bangladesh (7 percent) and Bhutan (3 percent) (Table 1). Nepal is located entirely in the Ganges river basin and Bhutan is located entirely in the Brahmaputra river basin. The GBM river system is considered to be one transboundary river basin, even though the three rivers of this system have distinct characteristics and flow through very different regions for most of their lengths. They join only just a few hundred kilometres upstream of the mouth in the Bay of Bengal. Not only is each of these three individual rivers big, each of them also has tributaries that are important by themselves in social, economic and political terms, as well as for water availability and use. Many of these tributaries are also of a transboundary nature (Biswas, after 2006). The GBM river system is the third largest freshwater outlet to the world's oceans, being exceeded only by the Amazon and the Congo river systems (Chowdhury and Ward, 2004).

### 1.5 Aim and Objectives of the study

The main aim of the study is to assess flood risk and analyze the mode of human adjustment in the Brahmaputra-Jamuna flood plain. However specific objectives of the study are:

- To develop a Model for Flood Risk Assessment in the Brahmaputra-Jamuna flood plain;
- To assess flood vulnerability in the Brahmaputra-Jamuna flood plain;
- To investigate the current coping strategies or adjustments of the vulnerable; population in Brahmaputra-Jamuna flood plain and
- To suggest improvements for flood management in the study area.

### 1.6 Methods of Study

The methodology of investigation of the present study involves multistage complex analytical procedure of analysis and experimentation. Both primary and secondary data sources have extensively been used in this study. The primary data were generated mainly for the purpose of understanding the adjustment mechanism, and people`s perception. One the other hand the secondary data have been used to reveal the various hydrological situation, physiographic condition, population settlement etc. and also to prepare vulnerability index and to analyze the risk of the study area.

#### 1.6.1 Developing a Model for Flood risk assessment

To prepare the model for the assessment of risk of the study area (Brahmaputra-Jamuna basin), the relevant data and information have been collected and analyzed. Among the collected data and information, SRTM data through image processing, hydrological data, distance from the river, population density, population coverage and information on various coping strategies of the local people have been taken into consideration. The whole study area consisting 19 units (upazila wise, with a few exceptions in fixing the upazila boundary upon LGED) and each unit has been taken into consideration in analyzing the above mentioned variables. In the first step of modeling (figure 1.1) the DEM data used to calculate different values regarding elevation, settlement coverage, and river distance.

### 1.6.1.0 Value/Weight calculation of data for the model

Areas above twenty meter **elevation** from the sea level considered as areas with very low risk as risk value is 5 and risk index is 1. 16 to 20 meters elevated area considered as risk value 4 and risk index 2 indicates risk level low. Elevation levels 11 to 15 meters, 6 to 10 meters, and 1 to 5 meters have been considered accordingly risk value 3, 2 and 1 where, risk indexes are 3, 4 and 5 and risk levels are medium, high and very high. Upazilawise feature data have been prepared to reveal the elevation and categorized it for the whole study area and given input into the model.

**Settlement** coverage data were categorized into two classes. Forty (40) percent weight has been given for the population density and sixty (60) percent weight has been given for the population coverage. Upzilawise population density data were collected from BBS and for the purpose of settlement coverage data, SRTM image were taken into consideration.

**Hydrological** characteristics of the study area were analyzed. Secondary data collected from BWDB were given input into the model. Peak level of water and distance from the river were calculated through the model. **Peak level** data were taken from BWDB and distance from the river calculated from the SRTM image. Peak level compared with danger level (as of BWDB) and categorized into four groups. Two river stations data were taken into consideration where peak levels were 20.61, 14.02, 18 and 15.12 meters and danger levels were 19.1, 12.5, 17 and 13.75 meters.

For the purpose of calculation of **distance** from the river, five clusters have been taken into consideration. Distance from 0 to 10 miles from the Jamuna river considered as risk value 1, risk index 5 and risk level very high. Accordingly for the risk value 2, 3, 4 and 5 risk index are 4, 3, 2 and 1 where risk levels are high, medium, low and very low. Using the aforesaid data hydrological situation was projected through the developed model.

In analyzing the coping capacity of the local people through the proposed model five variables have been considered as indicators of level of their coping strategies. These are awareness, education level, economic strength, use of indigenous knowledge, and relief system.

**Awareness** level low considered as index 1. Awareness level medium, high and very high were considered accordingly index 2, 3 and 4. All nineteen upazila were validated according to these indexes and categorized through the model.

To measure the **education level,** literacy rate have been considered for people of seven years old and above. 0 to 20 percent literacy rate considered as index 1, 21 to 40 percent considered as index 2 and 41 to 60 percent, 61 to 80 percent and more that 80 percent considered as index 3, 4 and 5. Index 5 to 1 indicates coping capacity is downward from higher to inferior.

**Economic strength** were categorized as high, medium and low and the index was given accordingly 1, 2 and 3 where level of strength high for 1, medium for 2 and low for 3. Uses of indigenous knowledge were calculated as well as economic strength like high, medium and low and the index were same as 1 for high, 2 for medium and 3 for low.

**Relief systems** were also considered through the model as coping strategy. Five categories were made of the collected data through field survey as very good for index 1, good for index 2, satisfactory for index 3, not good for index 4 and bad for index 5. According to the indexes mentioned above, all 19 upazilas were categorized and taken into consideration through the model in assessing the flood risk of the study area.

### 1.6.2 Methods of analysis of flood risk of the study area includes three main steps :

(1) Determination of probability of flooding :

(2) Simulation of flood characteristics :

(3) Assessment of the consequence :

In this study risk estimate has been done fully probabilistic analysis in which all possible loads in the flood system, the resistance of the system, flood patterns, possible breaches, and their consequences are included. Such an approach would require a numerical elaboration and very large number of simulations. Due to limited time and resources a simplified approach has been chosen in this study. A limited number of flood scenarios has been selected and elaborated. Furthermore some parameters have also been taken into consideration to assess flood vulnerability.

To assess flood risk of the study area, four parameters (effective factors) have been taken into consideration. These are hydrological analysis of the concerned river(s), analysis of topographical situation, analysis of settlement pattern and revealing the coping strategies of the local people.

- For the purpose of hydrological analysis of the study area, secondary data and information from BWDB, IWM and IWFM etc. have been collected and analyzed. Variation of the water level, discharge and river width have been given emphasis.
- To assess flood vulnerability, topographic analysis, changing nature of flood, settlement pattern, and coping strategies of the local people of the study area have been analyzed in detailed.
- To analyze topography of the study area, relevant data from LANDSAT -7 (GLOVIC, USGS) were used.
- For the purpose of exposing (revealing) the coping strategy of the local people, questionnaire survey were conducted. Field observation, Participatory Survey and Focus Group Discussion (FGD) were also made.

**1.6.2.1 Stages of Investigation**

The stages of methods of investigation can be categorized into the following steps:

a) Collection and analysis of secondary data;
b) Selection of the study area;
c) Questionnaire survey and field obsercvation;
d) Preparation of maps and diagrams and
e) Analysis of findings using some appropriate quantitative techniques and GIS technology.

**a) Collection and analysis of Secondary data**

Secondary data (flood data, elevation data, population and settlement data etc.) and other relevant information were gathered from different authentic sources. These are :

i) SRTM (Shuttle Radar Topographic Mission) data, SPARRSO (Space Research and Remote Sensing Organization) Satellite Imageries; LANDSAT-7, USGS and CEGIS maps were collected and analyzed.

ii) Meteorological and climatological data were collected from Meteorological office, Dhaka for various climatic data from 1949 to 2011.

iii) Hydrological data were collected from the Bangladesh Water Development Board (BWDB), Dhaka to understand the spatio-temporal configuration of inundation and to reveal the extent of flood levels in different year of the study area. The river station (hydrological gauze reaching point) Bahadurabad at Jamuna river has been given emphasized for analysis purpose. Analyzed data and information presented through different statistical and graphical methods.

iv) Old and new maps and hydrological charts were also collected and analyzed. Among those flood vulnerable map of Bangladesh, Normally flooded area map of Bangladesh, Inundated areas in different years prepared by BWDB, IWM, IWFM are note worthy. Books, Reports, Articles and Thesis prepared by different authorities and scholars are also collected and analyzed. FAP reports and Research based published and unpublished articles were also extensively used in this purpose.

i) Both pictorial and mathematical procedures have been adopted to interpret the water level of the river Brahmaputra-Jamuna river system. It includes the analysis of maximum, minimum and average water level as well as discharge. It also includes the frequency and probability analysis of flood. In analyzing the flood hazard of the study area for a long period (1949-2001)

**b) Selection of the Study area**

In the present study the whole country (Bangladesh) was brought under consideration for general discussion on flood risk. However for the purpose of case study and risk analysis the Brahmaputra-Jamuna Floodplain was selected and in-depth investigation has been made. The floodplain (Brahmaputra-Jamuna Floodplain) is usually partly flooded almost every year and considered one of the most flood prone areas of Bangladesh. Centering this area, flood behavior and vulnerability has been studied and flood risk has been assessed.

**c) Questionnaire Survey and field observation**

In order to generate primary data involving flood adjustment and risk assessment, some scientific questionnaires were prepared. Among these questionnaire for flood affected people and expertise opinions are important ones. Samples for questionnaire survey were selected from the flood affected people from the study area (Vij, Brahmaputra – Jamuna Basin) of different categories. Samples were selected purposively covering all the affected areas so that they could represent flood affected people from all categories. The detail investigation regarding human adjustment to flood was undertaken in 2012 along the Brahmaputra and Jamuna River Bank during the month May to August. In the study area, a total number of 300 households were interviewed. The survey had two broad sections: (a) flood situation as a hazard as perceived by the people, damage caused by it and the local level mechanism to adjust with this hazard; and (b) Socio-economic condition of the respondent's vis-à-vis incidence of flood in the study area. During the survey period, an extensive field visit was undertaken in the whole region in order to understand the overall flood situation. Besides, interviews were taken with local leader and teacher, on the issues related to flood in their respective areas. Information thus drawn had lent qualitative support to those obtained through questionnaire survey.

Needless to say that due to some unavoidable circumstances long term investigation was not possible and small group of population were interviewed. Focus group discussion and participatory survey were also made to collect primary data and information while visiting (as a part of field observation) the study area for the purpose of conducting survey. Telephonic survey with the aristocrat people of the study area was also conducted to understand the policy of flood mitigation both existing and near future.

**d) Preparation of maps**

To prepare maps of the study area (Brahmaputra –Jamuna Floodplain) like upazila wise Elevation maps, Settlement maps, Contour maps, Flood hazard map, Flood vulnerability map etc. Digital Elevation Model (DEM) data were used from Earth Explorer and then converted to SRTM.

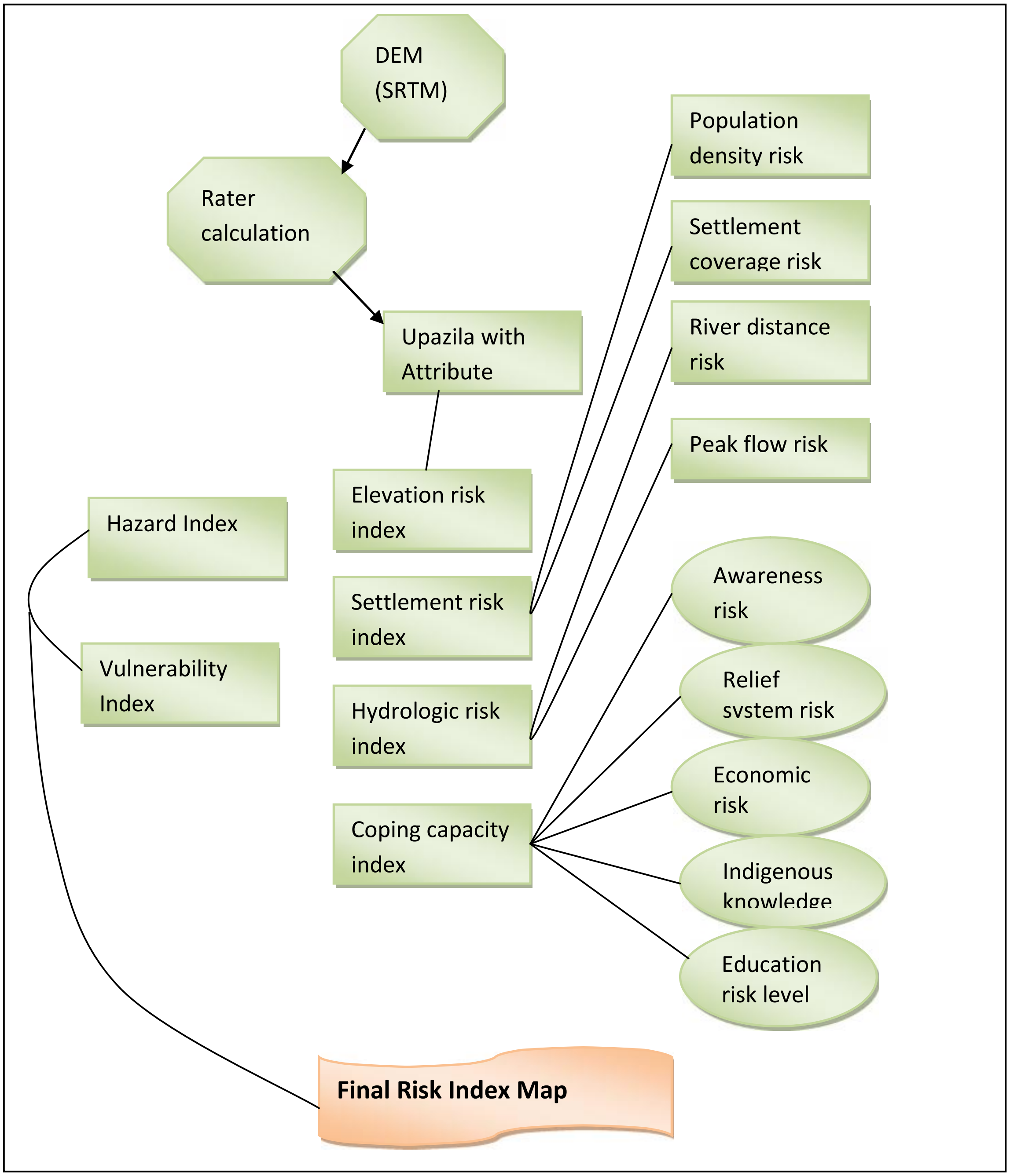
Downloaded image were processed to identify the boundary of the study area and sub-divided (of the study area) using Raster Clipping Methods (RCP). Aoi files (from shape files) were used to subset the image and elevation maps of the divided units were prepared using Geoprocessing tools. In order to prepare settlement maps (of all the units of the study area) digitized shape of LGED and Google Earth were used. Arc-info and Arc-view software were used to prepare the maps.

In addition to that flood maps of Bangladesh of different years have been collected and analyzed. Taking information and data from the maps new maps for the study area were prepared using computer based software. On the basis of the result of analysis flood hazard and vulnerability maps were also prepared. Statistical analysis and Geospatial analysis were given preference in this case.

**e) Analysis of Findings Using Appropriate Statistical Techniques**

In the present study some advanced quantitative techniques were used. In order to find out the complex and intricate interrelationship between various climatological and hydrological parameters like rainfall, discharge of water, flood stages and seasonality, duration of flood, water level, frequency of occurrence of flood etc. statistical methods like Multivariate Factor Analysis and Correlations analysis were used. In this stage a computer based ANOVA program and SPSS programs were used. For the graphical presentation of the data and information MS Word, MS Excel and MS Power Point software were utilized. Appropriate graphic/matrix was also applied using GIS technology for the representation of different data.

**Figure 1.1 : Flow chart of the image processing and preparation of maps**

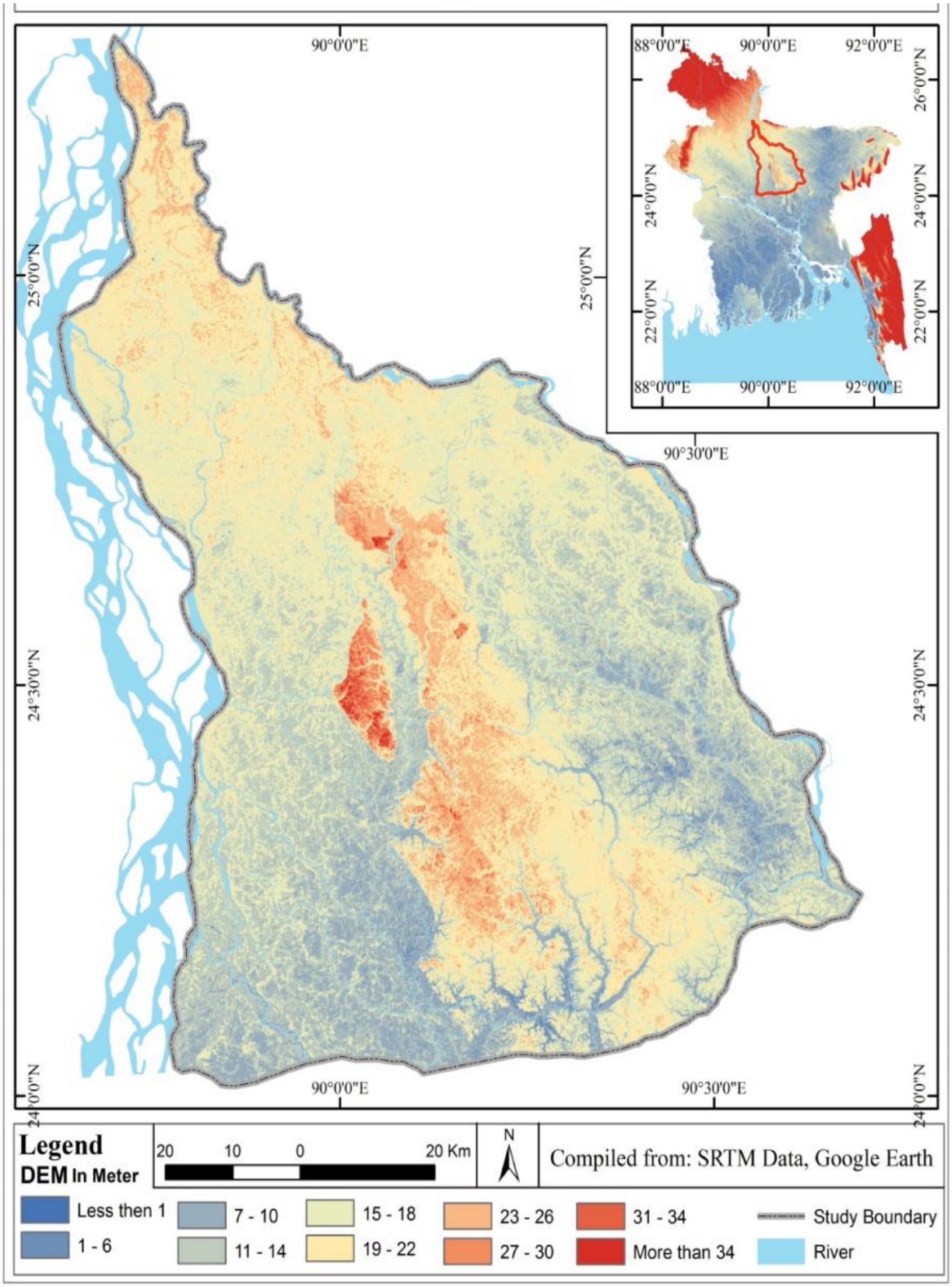



*Source : Self developed*

**1.7 Physiography of the Brahmaputra-Jamuna Floodplain**

The study area includes Madhupur Tract in the centre and Barind Tracts in the north-west. Terraces occupy about 8% of the country. These areas are not true alluvial terraces but are almost level surfaces appearing above the recent deposits. The Madhupur Tract is closely dissected and broke by faults.

**Figure 1.3 : Physiographic condition of the Brahmaputra-Jamuna Floodplain**




*Source : Prepared from SRTM Data*

The Barind Tract is composed of an uplifted and locally titled series of fault block interrupted by major river valleys occupying fault troughs. There are numerous natural depressions some of which are abandoned channels formed as a result of change in river courses, and some have been formed in the process of delta building and as a result of tectonic movements of earth. The southern portion of the study area is comparatively lower than that of northern part. Western and Eastern part of the area (Brahmaputra-Jamuna Basin) are considered as low area and flood prone area of the country. A ridge between these two part (eastern and western part) found lies from north to south that are almost flood free zone as this ridge is topographically high. The physiographic conditions of the study area are shown in the map (Figure 1.3).

**1.9 Significance of the study**

Flood is a common phenomenon which is recurring as hazards almost every year in Bangladesh. The country has to face the loss and damage of this obvious natural calamity. It is observed that the overall flood situation of the country is deteriorating gradually. Its intensity and frequency of occurrences are increasing year to year. It is badly needed to reduce the loss and damage of flood. To bring an effective control over the flooding situation of the country both the long term and short term control measures should be taken serious research and investigation activities should be coquetted to understand the various dimension and behavior of flood. Till to date a few scientific studies have so far been done of this hazardous environmental disaster of Bangladesh. But no specific study on flood risk assessment of the Brahmaputra-Jamuna Floodplain is done. Flood risk assessment and identification of vulnerabilities is now a world-wide requirement. Hence the country Bangladesh is yet to do the details study of flood risk assessment as a flood prone land where almost every year flood occurs and caused to losses and damages a huge amount of lives and properties. Moreover the study area is one of the most flood prone areas that included normally flooded region of Bangladesh. The assessment of flood risk and analysis of hazard and vulnerability of the area will definitely open a new dimension of flood mitigation and planning of all concerned.

### 1.10 Overview of the Chapters

In the present study attempts have been made to analyze flood as a natural hazard and to assess risk of flood in the study area. Whole study has been presented according to chapters (sections) for the purpose of maintaining sequential discussion.

First chapter contains conceptual discussion on flood, flood risk, risk assessment etc. This chapter is also decorated with aim, objectives, methodology and significance of the study. Brief discussions on the study area were also inserted in this chapter.

Second chapter of the study is completely on literature review. Summaries of some related studies in this regards with the name of authors mentioning year of study have been included. In this case most recent studies have been taken into consideration and furnished firstly. Historical information on flood activities have also included in this chapter.

Third chapter is on the developed risk model specification and validations. The data and information used in the developed model have been logically analyzed form the legalization ground of the model. Each section of the model described about use of data and process of analysis especially GIS based utilization of the data and preparation of model.

Fourth chapter provide flood hazard analysis and flood disaster in Bangladesh especially in the study area. In this case variables of hazard analysis were discussed in detailed and presented in different form. Hazard parameters like topography, hydrology, and settlement patterns of the study area have been discussed in detail. Hazard index have and hazard map have been prepared and finally hazard category of the study area have been identified.

Fifth chapter goes for the analysis of flood vulnerability of the study area as well as Bangladesh. Vulnerability in respects of elevation, hydrology, and settlement have been discussed in this chapter. Flood damages, vulnerability operationalization and assessment of vulnerability are given priority in discussion. Vulnerability maps in several aspects have been prepared and inserted in this chapter.

Sixth chapter of this study contains the discussion of coping capacity or coping strategy of the local people of the study area. Different variables like education, economic strength, indigenous knowledge, people’s awareness, and relief system have been given emphasized to analyze the coping capacities or strategies of the local people.

Seventh chapter provides risk analysis of the Brahmaputra-Jamuna Floodplain. Final results of hazard and vulnerability analysis as well as the output of the developed model have been shown in this chapter.

Eights chapter goes to reveal human adjustment scenarios of the study area. Adaptation and mitigation phenomenon have been given preference for the purpose of adjustment analysis. Coping strategies have also been taken seriously that these have practical implications as adaptation measures.

Concluding chapter (chapter nine) investigate the potentials of adaptive management for dealing with flood as a natural hazard especially for reducing future risk. Some findings and recommendations have also inserted with need for further study in this regards.

Because of recent devastating floods in Bangladesh as well as the study area, future risk analysis have been focused in this study for the purpose of reducing losses and damages of this obvious natural calamity.

## 2.0 Introduction

The study area Brahmaputra-Jamuna Floodplain consists of 5, 52,000 Sq. km, a small part of Bangladesh. There is no specific study on flood risk assessment of this particular area. Some combined study including the study area [Brahmaputra-Jamuna Floodplain] found in different aspects. Flood control, flood management and flood mitigation have been given emphasis on those studies. The history of flood of Bangladesh as well as the study area represents great change in the livelihood of the local people. The devastating flood of 1954 and 1955 affected the eastern part of Pakistan and India. The then Government of Pakistan and India agreed upon to investigate jointly the problem. However, nothing substantial came out except a few meetings at Experts and Ministers level. The East Pakistan Flood Commission was set up in December, 1955 to look into the flood problem and suggest remedial measures. A Flood Control Organization was created under a separate Chief Engineer in the Irrigation Department of the Provincial Government. Studies on flood in Bangladesh found categorized into individuals and organizational. However, some important studies on flood research in Bangladesh are furnished below:

## 2.1 Individual research on flood and flood risk

**Rasid and Paul (2014),** attempted to provide a broader global context of climate change for explaining the root causes of climate change and its impacts on Bangladesh in their book titled “Climate Change in Bangladesh : Confronting Impending Disaster”. They have used relevant materials from some of these sources but have drawn heavily from their own work on climatic disaster in Bangladesh. The book is also made an attempted to synthesize and integrate the existing knowledge into a coherent whole. The authors emphasized in explaining climatic hazards and disaster, and provide the pertinent data and interpretation on Bangladesh. However, the book found resourceful especially for vulnerable study in Bangladesh.

**Bimal Kanti Paul (2014**), focused on manifested threats to human and their welfare due to natural hazards and disaster in Bangladesh. He uses an integrative approach to provide a comprehensive context for natural hazards and disaster along with important emergency management issues related to extreme events. He also address socio-cultural, political, and physical components of the disaster process, and assess social vulnerability as well as the risk that natural hazards pose. His book titled "Environmental Hazards and Disasters : Contexts, Perspectives and Management" offers and overview of the key issues related to natural hazards and disasters, and provides operational definitions, ans methodologies that are useful for addressing hazards-related issues.

**Pervin Hasina, Islam M. Nazrul, Mahsum Abdullah (2013)**

This study is mainly based on secondary information. River discharge, annual temperature and rainfall data are used to realize the climate change of the study area. From the data analysis it was observed that temperature and rainfall are increasing day by day as well as flood frequency. Recently floods are occurring more frequently than the previous years. These frequent floods cause damage of lives and properties in Tangail District. From the analytical result of the study, believed because of climate change temperature and rainfall are changing and frequency of flood is increasing. It is also said in this study that, climate change becomes the most vulnerable issue to the environmental specialist, geographers, politicians, policy makers, and the other stakeholders. Climate change has a great impact on Bangladesh especially in Tangail District because it is situated in the influence zone of the Brahmaputra-Jamuna river system, which is one of the largest river systems in the world.

**Md. Aboul Fazal Younus and Nick Harvey, (2013)** In their study titled "community-based flood vulnerability and adaptation assessment : a case study from Bangladesh" it is said that, The Intergovernmental Panel on Climate Change (IPCC) (2007, 2012:11) warned that the mega deltas in South Asia (e.g. the Ganges Brahmaputra Meghna River Basin) will be at great risk due to increased flooding, and the region's poverty would reduce the capacity of the inhabitants to adapt to change. This paper provides a "bottom up" impact approach which focuses on a methodological contribution for assessment of vulnerability and adaptation (V & A) in a riverine flood-prone area, "Islampur" in Bangladesh, where various impact assessment guidelines have been taken into consideration. In this study the evaluation of V & A assessments at community level has been accomplished mainly by a weighted matrix index value derived from two participatory rapid appraisals (PRAs). Based on the distribution pattern of various weighted value indices of V & A issues, the required adaptation techniques can be adopted for immediate policy-making, and appropriate actions should be undertaken through establishing Community-Based Adaptation Committees (CBAC).

**Graciela Peters-Guarin, Michael K. McCall and Cees van Westen (2012)** in their study titled "Coping strategies and risk manageability: using participatory geographical information systems to represent local knowledge" it is said that, the accumulated knowledge and perceptions of communities 'at risk' are key elements in managing disaster risk at the local level. This paper demonstrates that local knowledge of flood hazards can be structured systematically into geographic information system (GIS) outputs. When combined with forecasting models and risk scenarios, they strengthen the legitimacy of local knowledge of at-risk populations. This is essential for effective disaster risk reduction practices by external actors, local non-governmental organizations (NGOs) and municipal authorities. The research focused on understanding coping strategies and 'manageability' of flood hazards as defined by communities. 'Manageability' is how people experience flooding in relation to their household capacity and the coping mechanisms available. The research in the Philippines highlights the significance of localized factors, including socioeconomic resources, livelihoods, seasonality and periodicity, for understanding manageability. The manageability concept improves practice at the municipal level by legitimizing local coping strategies, providing better indicators, and developing understanding of flooding as a recurrent threat.

**A.K. Gain and M.M. Hoque (2012)** in their study titled "Flood risk assessment and its application in the eastern part of Dhaka City, Bangladesh" it is said that, traditional flood design methods are increasingly supplemented by risk-oriented methods based on comprehensive risk analysis. This analysis requires: (1) the estimation of flood hazard that represents intensity of a flood, (2) estimation of vulnerability, e.g. percentage of damage to total property as a function of flood depth and duration, and (3) the consequences of flooding, e.g. loss of life and damage to property.

In this study, flood hazard maps of the Balu-Tongikhal River system within the eastern part of Dhaka City are prepared using geoprocessing tools and a hydrodynamic model. The raster-based vulnerability maps and expected damage maps of several return period floods are then produced. In comparison with the classical inundation maps, these damage maps generate more information about the flooding events. Consequently, the produced maps are useful in evaluating policy alternatives and minimizing property loss because of floods in the study area.

**Muhammad Masood and Kuniyoshi Takeuchi (2010)**

In their article titled "Assessment of flood hazard, vulnerability and risk of mid-eastern Dhaka using DEM and 1Dhydrodynamic model" It is observed that about 60% of the eastern Dhaka regularly goes under water every year in monsoon due to lack of flood protection. Experience gathered from past devastating floods shows that, besides structural approach, non-structural approach such as flood hazard map and risk map is effective tools for reducing flood damages. In this study, assessment of flood hazard by developing a flood hazard map for mid-eastern Dhaka (37.16 km2) was carried out by 1 D hydrodynamic simulation in the basis of digital elevation model (DEM) data from Shuttle Radar Topography Mission and the hydrologic field-observed data for 32 years (1972-2004).

A flood hazard map was prepared according to the simulation result using the software ArcGIS. Finally, to assess the flood risk of that area, a risk map was prepared where risk was defined as the product of hazard (i.e., depth of inundation) and vulnerability (i.e., the exposure of people or assets to flood). These two maps should be helpful in raising awareness of inhabitants and in assigning priority for land development and for emergency preparedness including aid and relief operations in high-risk areas in the future.

**William E. Lovekamp,** (Department of Sociology & Anthropology, Eastern Illinois University) February, 2010 in his research titled "GENDER AND DISASTER: A SYNTHESIS OF FLOOD RESEARCH IN BANGLADESH" Tried to synthesizes the literature on the intersection of gender and disasters in Bangladesh using a nine-stage typology of disaster preparedness, response, and recovery. By highlighting what is known about gender differences in the various phases of the disaster process, this paper illuminates areas in need of more thorough examination. Most importantly, this paper calls for an acceptance and integration of gender and women's voices into all phases of the disaster process and illustrates the importance of gender in disaster research.

**Sebastian Scheuer, Dagmar Haase and Volker Meyer (2009)**

In their study "Exploring multicriteria flood vulnerability by integrating economic, social and ecological dimensions of flood risk and coping capacity: from a starting point view towards an end point view of vulnerability" they present an approach to modelling multi-criteria flood vulnerability which integrates the economic, social and ecological dimension of risk and coping capacity. We start with an existing multicriteria risk mapping approach. The term risk is used here in a way that could be called a starting point view, looking at vulnerability without considering coping capacities. We extend this approach by a multicriteria modeling of coping capacities towards an end point view of vulnerability. In doing so, we explore a way to differentiate coping capacity from flood risk in each of the dimensions of vulnerability. The approach is tested in an urban case study, the city of Leipzig, Germany. Our results show that it is possible to map multicriteria risks as well as coping capacities and relate them in a simple way. However, a detailed calculation of end point vulnerability would require more detailed knowledge on the causal relationships between risk and coping capacity criteria and their relative importance.

**Shitangsu Kumar Paul and Jayant K. Routray (2009)** "Flood proneness and coping strategies: the experiences of two villages in Bangladesh" This paper explores peoples' indigenous survival strategies and assesses variations in people's ability to cope with floods in two flood-prone villages in Bangladesh. It reveals that people continuously battle against flood vulnerability in accordance with their level of exposure and abilities, with varied strategies employed at different geophysical locations. The paper reports that people in an area with low flooding and with better socioeconomic circumstances are more likely to cope with impacts compared to people in areas with high and sudden flooding. Similarly, households' ability to cope varies depending on people's socioeconomic conditions, such as education, income and occupation. Although floods in Bangladesh generate socioeconomic misery and cause damage to the environment, health and infrastructure, people's indigenous coping strategies have helped them to reduce significantly their vulnerability. Such flood-mitigating strategies should be well recognized and emphasized further via proper dissemination of information through an early warning system and subsequently external assistance.

**Volker Mayer et al. (2008)** focused on flood risk assessment in Europe River Basin-Concept, Methods, and Challenges Exemplified at the Mulde River. Three problems in the practical application of flood risk assessment particularly on the river basin scale, are discussed : first uncertainties in flood risk assessment, second, the inclusion of social and environmental flood risk factors; and third, the consideration of the spatial dimension of flood risk. In the second part of the study a multi criteria risk mapping approach has been introduced that is intended to address these three problems.

**Roy Brouwer, Sonia Akter, Luke Brander, and Enamul Haque ( 2007)**

In an article titled "Socioeconomic Vulnerability and Adaptation to Environmental Risk: A Case Study of Climate Change and Flooding in Bangladesh" the authors investigate the complex relationship between environmental risk, poverty, and vulnerability in a case study carried out in one of the poorest and most flood-prone countries in the world, focusing on household and community vulnerability and adaptive coping mechanisms. Based upon the steadily growing amount of literature in this field they develop and test their own analytical model. In a large-scale household survey carried out in southeast Bangladesh, authors asked almost 700 floodplain residents living without any flood protection along the River Meghna about their flood risk exposure, flood problems, flood damage, and coping mechanisms. Novel in our study is the explicit testing of the effectiveness of adaptive coping strategies to reduce flood damage costs. They showed that, households with lower income and less access to productive natural assets face higher exposure to risk of flooding. Disparity in income and asset distribution at community level furthermore tends to be higher at higher risk exposure levels, implying that individually vulnerable households are also collectively more vulnerable. Regarding the identification of coping mechanisms to deal with flood events, authors looked at both the *ex ante* household level preparedness for flood events and the *ex post* availability of community-level support and disaster relief. It is found in this study that somewhat paradoxically that the people that face the highest risk of flooding are the least well prepared, both in terms of household-level *ex ante* preparedness and community-level *ex post* flood relief.

**Roy Brouwer et al. (2007)** investigate the complex relationship between environmental risk, poverty, and vulnerability in a case study carried out in Bangladesh considering one of the poorest and most flood prone countries of the world, focusing on household and community vulnerability and adaptive coping mechanisms. A analytical model on environmental risk due to climate change and flooding has also been developed in this study. It is mentioned in that somewhat paradoxically that the people that face the highest risk of flooding are least well prepared, both in terms of household-level ex ante preparedness and community-level ex post flood relief.

**Aimilia Pistrika and George Tsakiris (2007)** proposed a comprehensive way for defining and assessing flood risk and vulnerability in the flood prone areas. The suggested methodology follows a three-step assessment approach : a) annualized hazard incorporating both probabilities of occurrence and the anticipated potential damages, b) vulnerability (exposure and coping capacity) in the flood prone areas and c) annualized flood risk (estimates on annual basis). The methodology of the study includes aims to assist water managers and stakeholders in devising rational flood protecting strategies.

**Rob and M. S. Islam (2007**), have investigate flood hazards, Vulnerability and human adjustment in Bangladesh. The study reveal some clear cut facts about the flood behaviour of Bangladesh. The climatic condition, geographical and hydrological situation of the country have been influencing

**Md. Israt Rayhan and Ulrike Grote (2005)**

**Studied "**Assessing Household Vulnerability and Coping Strategies to Floods: A Comparative Study of Flooded and Non-flooded Areas in Bangladesh, 2005" shown some demographic, socioeconomic and community variables along with flood shock variables have a noteworthy impact on flooded and non-flooded households' income. Estimates of a multinomial logit model illustrate that flood height, duration and loss of working days are significant for the poor households' income deterioration, whereas non-poor households are significantly affected by flood duration and loss of assets during floods. To assess households' vulnerability to floods this study incorporates four methodologies from the poverty dynamic literature.

**Md. Israt Rayhan and Ulrike Grote (2005)**

"Assessing Poverty, Risk and Vulnerability: A study on the Flooded Households in Rural Bangladesh."

This study is set forth to examine the poverty, risk and vulnerability for flood hazards in the year 2005. Cross sectional household survey was carried out after two weeks of the flood in four districts and 600 rural households were interviewed through three stages stratified random sampling. A utilitarian approach is used to assess flood vulnerability and its components: poverty, idiosyncratic and aggregate risks to capture the effect of flood on household's welfare. To estimate the correlates of flood vulnerability, a set of fixed households' characteristics are used as explanatory variables. The results depict that elimination of poverty would increase household welfare and thus lessen vulnerability mostly amongst its components. Poverty and idiosyncratic flood risk are positively correlated and highly significant. Households with higher educated members, male headed and owner of the dwelling place are less vulnerable to idiosyncratic flood risk. Possession of arable land and small family size can reduce the poverty and aggregate flood risk.

**M Ferdous and Mubarak Hossain (2005)**

This paper is directed to compare probability distribution functions for the study on flood frequency analysis at different rivers in Bangladesh. To analyze this issue they use5 sets of data of annual maximum runoff of different main rivers in Bangladesh. They also compare three widely used distributions. These are: (l) Log Normal (Two parameters L,N 2 and three parameters L,N 3); (2) Extreme value Type-l (EVl) or Grumble and (3) Log-person type-3 (LP3) distributions. The parameters of the distributions have been estimated by using the method of moments and method of maximum likelihood.

**Tawatchi Tingsanchali and Mohanned Fazlul Karim(2004)** studied on 'Flood hazard and risk analysis in the southwest region of Bangladesh. In this study flood hazard and risk assessment was conducted to identify the priority areas in the southwest region of Bangladesh for flood mitigation. Simulation of flood flow of Gorai and Arial Khan river system and its floodplains was done by using a hydrodynamic model. Flood duration were determined using satellite images of the observed flood in 1988 which has a return period close to 100 years. Flood hazard assessment, the hazard index and the hazard factors for depth and duration of flooding were determined in this study.

**MD. Rashed Chowdhury and Neil Ward (2004),** The title of their study was **“**Hydrological variability in the greater Ganges-Brahmaputra-Meghna Basin”. It is said in this study that, the flows of the Ganges, Brahmaputra and Meghna (GBM) are highly seasonal, and heavily influenced by monsoon rainfall. As a result, these rivers swell to their banks and often overflow during the monsoon months. This is most pronounced in the downstream regions, particularly in Bangladesh, which is the lowest riparian country. The objective of this paper is to study this hydro-meteorological variability in the greater GBM regions, including the headwater regions in India and their role in stream flows in Bangladesh, and explore the large-scale oceanic factors affecting this hydrometeorological variability. Global precipitation data, Bangladesh rainfall and stream flow records have been analyzed and related to large-scale climate patterns, including upstream rainfall, regional atmospheric circulation and patterns of sea-surface temperature. The findings have quantified how the stream flows of these rivers in Bangladesh are highly correlated with the rainfall in the upper catchments with typically a lag of about 1 month. Therefore, stream flows in Bangladesh could be reasonably estimated for 1 to 3 months in advance (especially for the Ganges and Brahmaputra rivers) by employing simple correlation, if rainfall data from countries further up are available on a real-time and continuous basis. In the absence of rainfall data, stream flow forecasts are still possible from unusually warm or cold sea-surface temperatures in the tropics. The study concludes that hydro-meteorological information flow between Bangladesh and other neighboring countries is essential for developing a knowledge base for evaluating the potential implications of seasonal stream flow 2004 Royal Meteorological forecast in the GBM basins in Bangladesh. Copyright Society.

**J.W. Hall et al. (2003)** in their study titled “A methodology for national-scale flood risk assessment” focused on providing consistent information to support the development of flood management policy, allocation of resources and monitoring of the performance of flood mitigation activities. It also represents the process of fluvial and coastal flooding over liner flood defense systems in sufficient detail to test alternative policy options for investment in flood management.

**Md. Monirul Islam and Kimiteru Sado (2000)** evaluated the flooded area and flood hazard assessment in Bangladesh using remote sensing (RS) data with GIS. Image data from National Oceanographic and Atmospheric Administration (NOAA). Advanced Very High Resolution Radiometer (AVHRR) was used to analyze Bangladesh historic floods. New flood hazard maps were prepared and elevation height data were ranked by flood affected frequency.

**Bimal Kanti Paul (1997), D**epartment of Geography, Kansas State University, Manhattan, KS 66506, U.S.A. in his research titled "Flood Research in Bangladesh in Retrospect and Prospect : A Review" presented main findings of flood research conducted so far in Bangladesh. The paper emphasizes unconventional findings and points out how some of these findings differ from the popular perceptions regarding some important aspects of flooding. The available studies clearly suggests that research into the impact of flooding on human settlement and other relevant aspects is much less developed in Bangladesh than the body of literature focusing on human adjustment to flood hazard. The paper identifies flood research gaps in the context of Bangladesh and suggests a new arena for future research.

**Ben Wisner, Piers Blaikie, Terry Cannon, and Ian Davis (1994)** Written a book titled **'At Risk'** where they focus on what makes people vulnerable. Often this means analyzing the links between poverty and vulnerability. It also included different social groups that suffer more in extreme events like women, children, the frail and elderly, ethnic minorities, illegal immigrants, refugees, and people with disabilities. It also mentioned in this book that vulnerability has also been increased by global environment change and economic globalization. It is an irony of the 'risk society' that efforts to provide 'security' often create new risk.

The new edition of 'At Risk' confronts a further ten years of ever more expensive and deadly disasters since it was first published and discusses disaster not as an aberration, but as a signal failure of mainstream 'development'. Two analytical models are provided as tools for understanding vulnerability. The other uses the concepts of 'access' and livelihood to understand why some households are more vulnerable than others. The book then concludes with strategies to create a safer world.

**Azam (1991)** suggested a multi-sector growth model in order to analyze macro economic impact of the FAP in the short and long run, with special reference to the impact of risk on the growth path.

**Maurice and Diallo (1991)** attempted to quantify the macro –economic impact on growth prospects. The study recommended that the long-term impact on growth prospects be taken into consideration along with the standard method of economic analysis when evaluating flood control projects in Bangladesh.

**The study by Thompson (1990),** which is a follow-up research of his PhD dissertation, has reviewed existing appraisal and evaluation methods, and suggested various improvements to such methods, particularly in relation to flood control agricultural projects of Bangladesh. The study suggested that appropriate standard data bases be developed towards an improvement of project appraisals and understanding of the benefits and limitations of flood mitigation choices in Bangladesh.

**Rob, M. D. A. (1990) Asian Profile Vol. 18 No. 4 pp. 365-378 "** Flood hazards in Bangladesh: nature, causes and control."
This paper commences with a brief history of floods and flood damage in Bangladesh. It then classifies floods into five types: general or monsoonal; flash floods; high intensity rainfall floods; cyclonic surges; accidents. Seven flood vulnerable areas are identified, mostly confined to hydrologically distinct basins and plains. The following causes of floods are examined: excessive local rainfall; cross boundary run-off; low elevation and flatness; decaying channels and situation; rise of sea level; tectonic situation; human interference (embankments, canals, deforestation). Various curative or preventive measures are proposed: stream bank protection; embankments; excavations; flood shelters; town and village protection works. It is concluded that floods have become a recurring hazard for the country; there is a gradual deterioration. A precise national flood control policy is called for.

**The study by Shahabuddin (1989),** based on his PhD research, included econometric models to delineate the role of risk in the resource allocation of small farmers in Bangladesh. The French Engineering Consortium (1989) studied macroeconomic effects of flood control projects in Bangladesh. The study inferred that the average annual cost of flooding on GDP is in the rage of 0.8%. Hossain (1990) analyzed fluctuations (from estimated trends) in food grain productions at the national and regional levels to explain the production instability caused by natural hazards.

**Paul (1984)** studied post-flood agricultural adjustments. The study concluded that floods are not necessarily harmful. Normal floods are rather beneficial to agriculture. Abnormal floods, however, cause adjustment problems to farmers. Montgomery (1985) studied crop losses caused by floods, through analyzing deviations from trend. Murshid (1987) assessed the relative role of weather hazards and technology (seed-fertilizer-water) in affecting the output instability of food grain. The study concluded that weather-related factors are still dominant in Bangladesh agriculture.

**Professor Dr. M Mozzammel Hoque, and others IWFM, BUET**

A study tilled "Development of Flood Hazard and Risk Maps with Effect of Climate Change Scenario" was done by Professor Dr. M Mozzammel Hoque, and others IWFM, BUET. The principal aim of the study was to prepare flood hazard, vulnerability and risk maps in Bangladesh. Since types of mitigation approaches in general would differ depending on the type of flood, the extent of risks different geographical areas are exposed to and the desired levels of protection for life, property, vital infrastructure, agriculture and wetlands, three different types of floods (river flood, flash flood and cyclonic storm surge flood) were thus considered in three different hydrologic regions in three pilot study sites: Sirajganj Sadar Upazila in Sirajganj district (river flood), Baniachang Upazila in Habiganj district (flash flood) and Barguna Sadar Upazila in Barguna district (storm surge flood). When considering the effects of climate change, it is important to consider the dynamic nature of flood risks. For example, sea level rise (SLR) and changes in storm intensity, occurring as a result of climate change, will cause changes in the areas susceptible to flooding. This study took into account the effect of climate change on flood hazard and risk maps. For the cases in the fluvial zone, climate change scenarios for Bangladesh were considered principally based on previous studies on climate change and impacts. A number of impact scenarios (on climatic and hydrologic parameters) were

selected for analysis. For the case in the tidal zone under the effect of storm surge flood, predictions of sea level rise were considered in deriving the hazard and risk maps.
The result of the study indicates that for all land use classes, flood affected area increases with the increase of return period and flood depth in Sirajgang Sadar. It is also noticeable that inundated areas become doubled for both agricultural and rural settlement land use classes with the increase of return periods. Water bodies become inundated much more than that of any other classes of land use especially for medium to very high classes of flood.

**Shivananda Patro, Chandranath Chatterjee,* Rajendra Singh and Narendra Singh Raghuwanshi (***Agricultural & Food Engineering Department, Indian Institute of Technology, Kharagpur—721302, West Bengal, India)* Wrote an article presents a detailed review on the issues and constraints of hydrodynamic modelling of floods in data-poor countries with large flood-prone rivers. A one-dimensional (1D) hydrodynamic model is used to simulate the river flows with limited available data in the delta region of Mahanadi River basin in India. The shuttle radar topography mission digital elevation models (SRTM DEM) was analyzed and compared with the elevations derived from available topomaps and measured river cross-sections. Subsequently, the SRTM-derived river cross-section elevation values are refined for use in the hydrodynamic model. The 1D hydrodynamic model is set up and calibrated using the refined cross-sections derived from SRTM DEM along with the measured ones and all available river discharge as well as water-level data at different gauging sites for the monsoon period (June–September) of the year 2004. The calibrated set up is validated using both discharge and water-level data for the same period for the years 2001 and 2002. The performance of the calibration and validation results of the hydrodynamic model is evaluated for all the years using different performance indices. The model-simulated discharge and water levels are found to be in close agreement with the observed ones. The study demonstrates the usefulness of using the SRTM DEM to derive 2009 river cross-sections for use in hydrodynamic modelling studies (Copyright John Wiley & Sons, Ltd.).

**Aimilia PISTRIKA, George TSAKIRIS**

"Flood Risk Assessment: A Methodological Framework" The concepts of hazard, vulnerability and risk have been extensively used in various disciplines with a different meaning, impeding cross-disciplinary cooperation for facing hazardous events. Even for natural hazards, such as floods, no unique definitions and assessment procedures have been widely accepted. In this paper we propose a comprehensive way for defining and assessing flood risk and vulnerability in the flood-prone areas. The suggested methodology follows a three-step assessment approach: a) annualized hazard incorporating both probabilities of occurrence and the anticipated potential damages b) vulnerability (exposure and coping capacity) in the flood-prone areas and c) annualized flood risk (estimated on annual basis). The methodology aims to assist water managers and stakeholders in devising rational flood protecting strategies.

## 2.2 Organizational Research

**The British Medical Journal reports** (BMJ, 2000).

The British Medical Journal reports that most floods occur in developing and tropical regions, where the public health impact is substantial. These floods cause almost half of all deaths from natural disasters. However the problems associated with flooding and deaths of health not only depends on the characteristics of flooding, but also determined by the privileged socio-economic and community health (BMJ, 2000). Therefore, the problems of health-related flooding in Bangladesh has also accelerated by poverty, poor state of public health infrastructure, low life expectancy, severe child malnutrition, low government expenditure on health (United UU. $2 per person per year, the World Bank, 2002, cited in MoEF, 2005) and water supply and poor sanitation conditions in the country.

**UK Essays.com** : The free essay has been submitted to by a student "Risk Assessment And Flood Management In Bangladesh Environmental Sciences Essay" Studies support that Bangladesh suffers floods on an increasing basis and with the flood of climate change in expected to increase (Mclean & Moore 2005; Agrawala et al, 2003; IPCC, 2001). This coursework sets out a proposed framework for providing aid in terms of land, shelter, water supply and sanitation for fifty thousand families and the financial risks associated with this. These families originally occupied land in Chittagong, Bangladesh, before they become refugees in their own country. Preliminary research into the existing culture within Bangladesh, inclusive of Chittagong, shows the customs and way of life of its citizens. In terms of the Bangladeshi refugees positively accepting the aid provisions, this research outlines the way to reduce the risk of negative response. As will be further described, the aid provided aims to engage the refugees into taking ownership of the scheme in order to increase the security and further develop settlement within the proposal.

**World Health Organization (WHO)**

According to the world Health Organization (WHO), the main risk factor for outbreaks associated with flooding is the contamination of drinking water facilities. People affected by floods in Bangladesh are very Vulnerable to water-borne diseases during flooding. In Bangladesh, 80% are related diseases inadequate water supple and sanitation.

**NASA Image (August 3, 2007 (3.56 MB JPG) and May 1, 2007 (3.11 MB JPG)**

A large portion of Bangladesh was awash with floods when the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite captured the top image on August 3, 2007. The low-lying nation is an alluvial delta, and therefore, is extremely prone to flooding. In July 2007, heavy monsoon rains filled the Brahmaputra, Padma, and Meghna Rivers, leading to the floods shown here. The Jamuna, a branch of the Brahmaputra River, arcs through the center of the scene, its braided waterways woven into a single thread where the river is overflowing. A branch of the Jamuna flows east into the Meghna River. The wetlands that surround these rivers are full of water, and the rivers themselves are swollen. The Padma River, formed by the convergence of the Ganges and Jamuna Rivers, is also flooded.

The severity of the floods can be seen in the contrast between the top image and the lower image, which was taken on May 1, 2007, before the monsoon rains began. In the dry season, the course of each river is clearly defined, not blurred by excess water. The images were made with infrared and visible light to increase the contrast between water and earth. In this type of image, water is black or blue, where colored with sediment. Plant-covered land is bright green, and bare earth or lightly vegetated areas are tan. Light blue and white clouds dot the scene. In the lower image, red dots mark the location of fires.

This study also deals with the query whether crop diversification would be an option for mitigating flood risk for farmers and concludes with the finding that mix-crop culture with cash and staple crops would lessen households' vulnerability. In the time of the flooding, rural people in Bangladesh suffer from the lingering effects of labor market disruption, price fluctuations, and consumption deficiency. Households initiate coping with borrowing money after the realization of floods and gradually lead to cope with savings and selling assets as the duration of flood increases, which is illustrated from a tobit model approach. In addition, empirical analyses explain that the decision to migrate is often guided by the aspiration to replenish asset values damaged by the floods, as rural-urban migration emerges as a source of credit. Participation in social networks plays an important role for the households during flood crisis to get information about potential host areas for migration.

**The study by HIID/ESCAP (1988),** sponsored by the Planning Commission, carried out an extensive survey in order to assess flood damages and their distributional impacts caused by the 1988 flood. Employment and output multipliers have been constructed by using the national 1-O table. One of the important conclusions of the study was that the poor are more vulnerable to floods. The extent of distress sales by the poor was about 2.5 times that of the non-poor.

### 2.3 Bangladesh Flood Action Plan (FAP)

The strategic and options for flood control in Bangladesh have debated for many years. Following the proposal of a Master Plan prepared in the mind-1960s, some major embankments combining the functions of flood control, drainage and irrigation were built along the banks of the main rivers. With the side-spread advent of small scale irrigation since the early 1970s, the strategy of water control tended to change to construction of small-scale early implementation projects (EIP) that could provide rapid results towards mainly protecting agriculture. Since then, the issue of flood control has been frequently overlooked. However, the 1987 and 1988 floods –the most severe floods on record in

Bangladesh, created awareness both at home and abroad and called for solutions. Subsequently, in collaboration with a few foreign countries, the World Bnak framed a Flood Action Plan (FAP) for the development of a long term comprehensive system of flood control and drainage works.
Covering a five-year period 1990-95, the Flood Action Plan in all comprised 26 components, concerning planning, supporting activities, high priority and regional studies which are expected to provide grounds for setting the foundations of the long-term program. Some of the studies are completed while some remain in progress. The reports and studies so far represent different approaches to the flood problem.

FPCO (1992a, FAP-12) and FPCO (1992b, FAP 13) evaluated 17 completed FCD/I projects using formal survey methods and rapid rural appraisal methods, the former concentrating on agricultural impacts and the latter operation and maintenance. FAP-12 stressed the need for research to provide comprehensive data and methodology which could be used consistently across FCD/I project appraisals in Bangladesh. FPCO (1992d, FAP-114) aimed at assessing the flood response practices adopted by floodplain users. The GOB-UNDP (1989) projects emphasized comprehensive structural solutions, recognizing the needs of major drainage works along with the construction of flood embankments. The approach of control flooding was also recommended in some areas to facilitate normal agricultural crops and ground water recharge. Rogers et all's (1989) Eastern Waters Study analyzed the drawbacks that the construction of embankments and dams are less feasible in economic, technical and ecological terms than other methods. The study presented a series of alternatives emphasizing non-structural measures. The Japan Ministry of Foreign Affairs (1989) found it important to protect some urban centers and areas, including the capital city.

### 2.3.1 FAP-Project Assessment Guidelines/ FAP Urban Production Studies

There exists a number of documents in the form of guidelines on appraisal methods and economic analyses for FCD/I projects. These are, among others, FPCO Guidelines for Project Assessment (1991a; 1992e); Shahabuddin and Raman (1992); MPO Investment Analysis Model (1991); and GOB-Republic of France's Pre-feasibility Study for Flood Control in Bangladesh (1989). It is important to present at this stage a brief description of the guidelines on appraisal methods, recommended in these documents in order to provide the rationale of the current research.

**2.3.2 FPCO Guidelines (1991a; 1992e)** are designed for the principles to be used in economic and financial analysis of investment projects under the Flood Action Plan. The guidelines, however, concentrate on the evaluation methods of agricultural protection schemes that are principally aimed at reducing potential crop losses. The documents is based on the standard techniques of cost-benefit analysis (in relation to e.g. cropping pattern, costs of production, economic prices of agricultural commodities, and conversion factors) of agricultural investment projects, as used by organizations such as the World Bank.Annex-3 of the documents outlines some general principles on the post-project assessment of non-agricultural/fisheries flood damage, principally concerning direct benefits from flood protection in 'with' (W) and 'without (WO) situations. The guidelines delineate the widely accepted principles of estimating mathematical expectation of annual flood damage in W and WO cases, without spelling out any assessment methods/principles whatsoever of how to assess the non-agricultural damages (e.g. to residential and commercial sectors). Nonetheless, the direct damages (e.g. embankments and roads) are recommended for inclusion in the economic analysis. It is, however, suggested that 'direct' loss data are collected from secondary sources such as relevant Ministries /Agencies (e.g. MRR, MLF, BWDB). In particular, it is suggested that the damage data on fisheries be collected from District or lower level, available in summarized forms from the Ministry; a careful scrutiny, however, is stressed to 'reconcile inconsistencies and inaccuracies' in such data. It is also suggested that the damages caused due to economic and social interruptions of activities are 'difficult to assess and should not be included in the analysis.

**2.3.3The document, GOB Republic of France (1989)** (Pre-feasibility Study for Flood Control in Bangladesh) strongly suggests that the indirect benefits induced by flood protection/control to non-agricultural sectors be considered. The study maintains that although Bangladesh is generally well furnished with statistical information and documentations, the information in regard to flood damages (on particularly non-agricultural sectors) are 'incomplete, inconsistent and partially incorrect', As also discussed in Chapter 1 on the rationale of the current research, the assessment of such losses in Bangladesh has been based on arbitrary calculations without representing any scientific basis. There is no systematic way of collecting flood damage information on annual basis on particularly non-agricultural sectors. Only in exceptional floods are some loss assessments carried out on an adhoc and emergency basis 'with a view to mobilizing external and internal support.'

However, **GOB-Republic of France (1989)** suggests that flood damages be collected from various 'reports' 'prepared' by various institutions and agencies, who generally maintain the damage records in physical, but not monetary terms (e.g. number of people affected, houses damaged),. As the records are largely prepared based on visual assessment of affected properties, it is suggested to 'review' and analyze such cautiously' before using this. It is recommended to use 'best possible guesses; from damage records of past floods, in appraising flood protection projects.

## 2.4 Before Independent

### 2.4.1 Krug Missions Report

Towards the end of 1956, the Government obtained the services of a UN Technical Assistance Mission (Krug Mission) for the study of the flood problems of the country.

The Mission dealt with the history , causes, frequency, magnitude and effects of floods and practicability of various methods of protection against flood damages in the country and submitted its report in the year 1957. The report pointed out the need for hydrological investigations and recommended for setting up a Water and Power Development Authority for taking up implementation of water and power development projects on a comprehensive and unified basis.

### 2.4.2 The principles points of recommendations of Krug Mission were as follows :

Feasibility study of flood dykes on the banks of major rivers including flushing sluices and drainage regulations and if found feasible, implementation of these on a priority basis.

- To take up and implement smaller flood control, drainage and irrigation projects.
- To take up a feasibility study of construction of barrage on the Teesta for irrigation and flood control.
- To raise the level of homesteads in flood affected areas above flood level or to rehabilitate them on flood dykes.

- To identify areas where flood control cannot be effectively done and industries, vital installation etc. should not be constructed in such areas.

Co-operation should be established with India and other courtiers for development of comprehensive flood forecasting in the common rivers.

### 2.4.3 Creation of EPWAPDA

In pursuance to the recommendation of the Krug Mission the East Pakistan Water & Power Development Authority (EPWAPDA) was set up in 1959 and the Irrigation Department of the Provincial Government was subsequently merged with the EPWAPDA. With the creation of EPWAPDA, the Flood Control Organization also ceased to exist.

### 2.4.4 EPWAPDA Master Plan, 1964

The EPWAPDA, with the help of the General Consultant IECO, prepared a Master Plan for water resources development of the country. This plan truly marked the beginning towards formulation of an integrated plan for flood control and development of water resources of the country. The said Master Plan organized the limited hydrological data available at that time and recommended, with emphasis for systematic and scientific hydrological data collection and processing.

The master Plan included a portfolio of 58 water resources development projects including 3 barrages on major rivers for implementation spread over 20 years beginning from 1963. These projects envisaged flood protection for 5.8 million hectares of land. Irrigation within these flood protection area was also envisaged.

### 2.4.5 General Hardin`s Report and Professor J. Thijsse`s Report

General John R. Hardin, an Ex-Chairman of Mississippi River Commission visited the country in January, 1963 and submitted a report in February, 1963 which closely paralleled the findings of the Krug Mission in the analysis of flooding and possible means of reducing the damages. The report proposed channel improvements and confinement of river flows within embankments. Sluice and fuse – plugs in the dykes were recommended to release water into protected areas to balance the load and avoid overtopping of dykes when the flood flows exceed design limit. Such an approach recognized the need for an immediate start despite paucity of data.

Professor J. Thijsse of the Netherlands also studied the problem and submitted a report in 1964. The report rules out reservoir storage and suggested that the existing distributaries of the main river system be maintained as long as possible. Channel improvement and embankments were mentioned as means for reducing flood hazards. But he also advised against early confinement of unstable rivers between embankments without study.

### 2.5 Flood control plan of East Pakistan, September 1968

In August, 1968, the planning Department, Government of East Pakistan, formed a committee to formulate a comprehensive flood control plan for East Pakistan. The Committee consisted of eight members. In preparation of the comprehensive Flood Control Plan the Committee took into consideration the Master Plan of Water Development of EPWAPDA, 1964, Flood Protection Plan of EPWAPDA, 1967, the Krug Mission report, General Hardin`s report, Professor Thijsse`s report and the points raised in the note of Mr. M. M. Ahmed, Deputy Chairman, Planning Commission, Government of Pakistan, dated 5.8.1968. The Flood Control Plan presented there, it was claimed, the culmination of years of investigation, research, studies and experience in some flood control projects under implementation at that time.

The said plan proposed five types of flood protection works such as Embankment, Channel Improvement and opening of off take of spill channels, River Training, Estuarine works and Protection of important cities and towns. Recommendations were also made for investigation and Studies and for Training. Out of the comprehensive total plan a priority program was also provided. An abstract of the program is given below.

**Table : 2.1 : Abstract of Flood control plan of East Pakistan, September 1968**

| Project Type | No. of Project for the comprehensive plan | No. of Project for priority plan |
|---|---|---|
| A. Embankment | 51 | 24 |
| B. Channel Improvement and Opening of Off take of Spill Channel | 29 | 14 |
| C. River Training | 23 | 6 |
| D. estuarine Work | 2 | 2 |
| E. Protection of Important Cities and Towns | 10 | 10 |

*Source : K. Nabi, 2000*

Most of the Embankment projects and some of the City protection Scheme have been done. But most of the Channel Improvement projects and River Training Works have not been implemented.

**2.6 Review of EPWAPDA Master Plan by IBRD**

In March 1964, the Government of Pakistan officially requested the World Bank to review the East Pakistan Water and Power Development Authority (EPWAPDA) Master Plan prepared by International Energy Consultant Organization (IECO) as the first step towards programming as action plan. The World Bank review was not completed until the autumn of 1965 and official discussion between the Government and the Bank did not take place until early 1966. Two "Agreed Statements" dated March 1 and September 23, 1966 emerged from these meetings. These Statements committed the World Bank in principle to take an active role both in studying and financing of the development of the water and the agriculture sectors in the region, which is now Bangladesh.

Despite numerous Bank missions the first significant attempt to fulfill this commitment in any comprehensive sense, was the preparation of the "Action Program" by the World Bank, Which was presented to the Pakistan Consortium in 1970.

However, the War of Liberation began before the resulting investment program really could gain any momentum. Meanwhile, a major desk study was undertaken (the Nine Volume Sector Study) and was presented in 1972 by the International Bank of Reconstruction and Development (IBRD).

The IBRD Mission reviewing the Master Plan appreciated the efforts towards the integrated approach, but made, inter alias, the following observations:

The plan overestimate food grain requirements while underestimated production potential without such major projects. Data were inadequate to embark on massive investment projects along such big rivers. The implementation plan exceeded EPWAPDA`s capability and resources.

The plan did not consider changes in river regimes due to problem works in India. Subsequently, the investment program of water development received priority in small scale projects with irrigation components in comparison to investment in large scale flood control projects as was envisaged in the EPWAPDA Master Plan.

## 2.7 Problems of Damage Data Collection and Assessment

The review of literature suggests that the assessment of flood damages, which is **sine aqua non** (condition that cannot be done without essential condition) to flood defense appraisal methods, has long been a formidable task. For the economic analysis of any floodplain management, the single most essential figure is the estimate of Expected Annual Damage (EAD), the estimate of EAD for a stream reach involves four major inputs (1) the elevation of properties (2) stage-frequency curves for the stream reach (3) potential damage information for properties and (4) land-use category of the properties. Among these, flood risk assessment is recognized to be the major outstanding technical problem.

### 3.0 Introduction

Risk assessment refers to the determination of risk or a formal method for establishing the degree of risk an individual or a community faces from single or multiple hazards. A risk assessment can be either quantitative or qualitative. In the former case, as attempt is made to numerically determine probabilities of occurrence for extreme events and the likely extent of losses should a particular event takes place. Qualitative risk analysis, which is used more orten, involves neither estimating probabilities nor prediction of losses. Instead, qualitative methods involve defining the various threats, determining the extent of vulnerabilities, and devising countermeasures should an event occur.

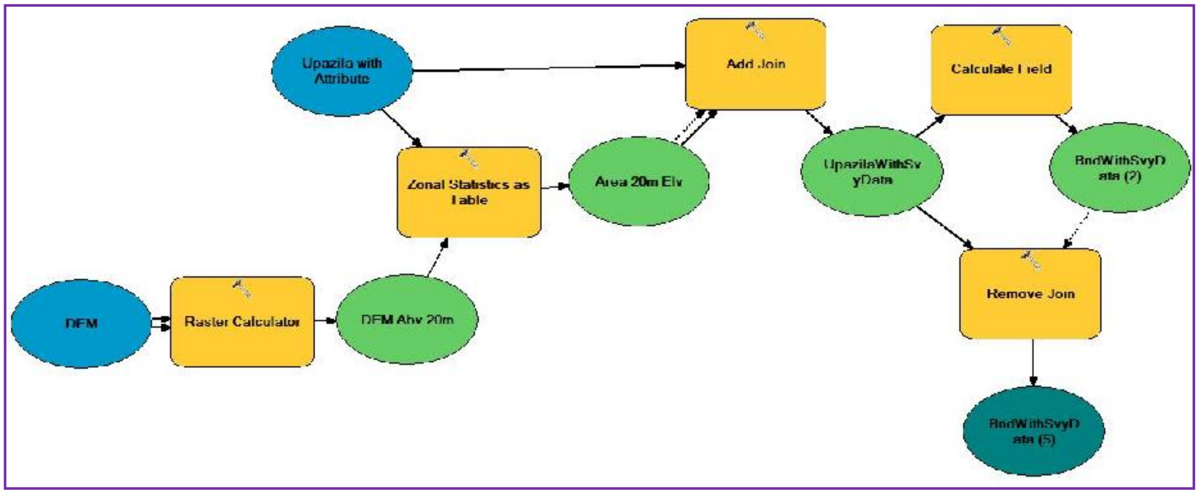
Flood risk assessment is an approach that assesses risk and damage caused by flooding. Since its introduction (White, 1945), the problem of computing risk measures associated to flood events is extremely important not only from the point of view of civil protection systems but also because of the necessity for the study area of insuring against the damages. In this study an integrated strategy for flood risk assessment through model and seeking solution of the flood problems is given emphasizes.

A model for flood risk assessment of the study area has been developed which come together in a conditional approach that the information usually available in this setup. To set up the variables of the developed model, existing related models have been examined and analyzed for the purpose of showing applicability of flood risk assessment in the study area.

### 3.1 Preparation of Model for the assessment of flood risk of the Brahmaputra-Jamuna Floodplain.

To prepare the model for the assessment of risk of the study area (Brahmaputra-Jamuna Floodplain) firstly, the relevant data and information have been collected and analyzed. Among the collected data and information, SRTM data, hydrological data, distance from the river, population density, population coverage and information on various coping strategies of the local people have been taken into consideration. The whole study area consisting 19 units (upazila wise, with a few exceptions in fixing the upazila boundary upon LGED) and each unit has been taken into consideration in analyzing the above mentioned variables. In the first step of modeling (figure 3.1) the DEM data used to calculate different values regarding elevation and settlement coverage. Areas above twenty meter elevation from the sea level considered as areas with very low risk.

**Figure 3.1: First steps of modeling SRTM converted into DEM and Upazilawise Raster conversion.**



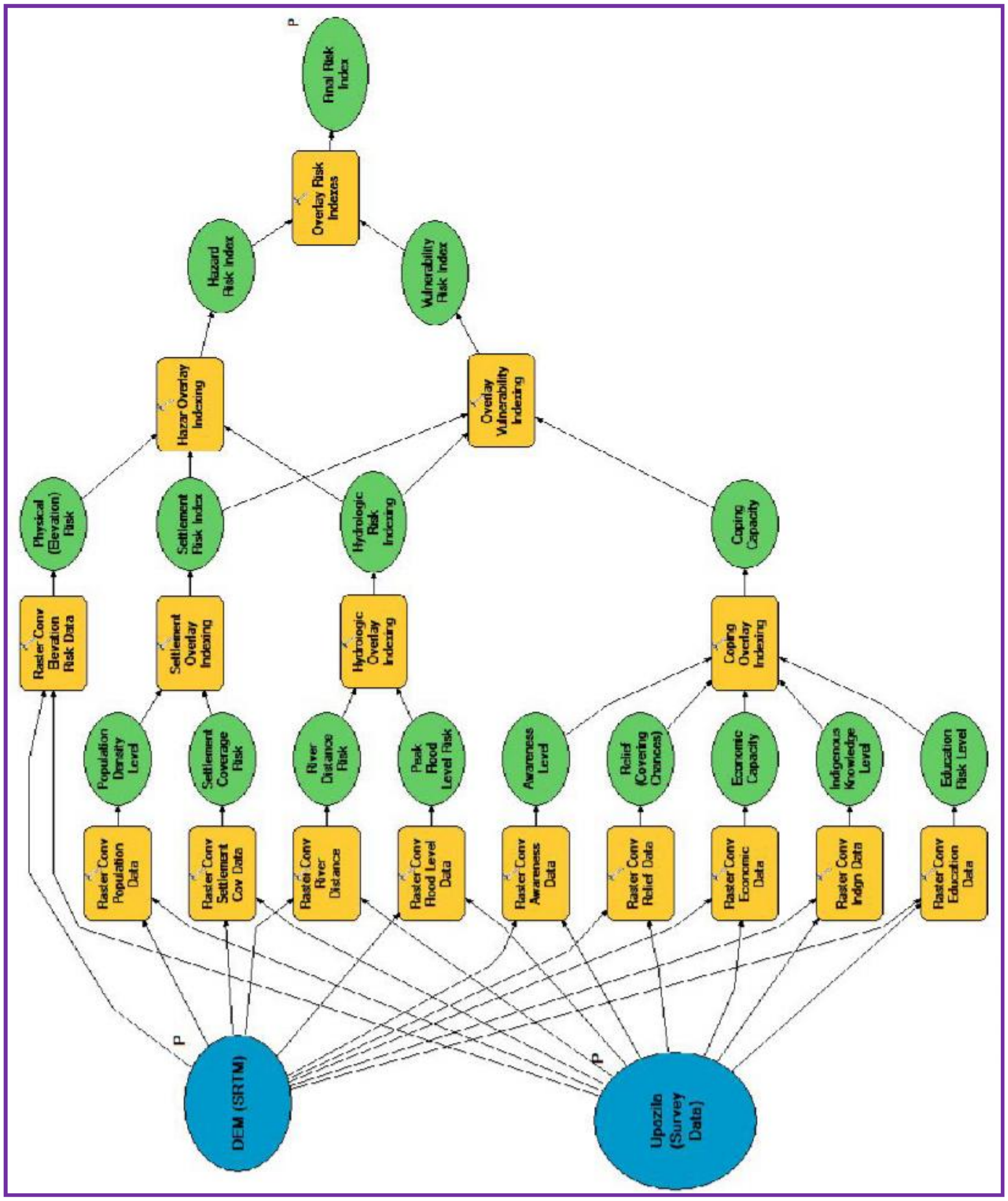

*Source : Self developed*

## 3.2 Proposed Model prepared for risk assessment of the Brahmaputra-Jamuna Floodplain

Four variables, topographic conditions, hydrological situation, settlement scenarios and coping strategies of the local people have been taken into consideration to build up the prepared model. Each of the above mentioned variables were elaborately discussed to reveal the actual scenarios of the study area in related field.

Risk perception which is commonly used in reference to natural hazards, refers to the subjective judgment that individuals makes about the characteristics and severity of risk (Slovic, 1992, 1999). It reflects the decision-maker's own interpretation of the likelihood of being exposed to the conditions propagating risk. Keeping this in mind, the variables of the model have been furnished and analysis was done. Risk includes hazard and vulnerability of a particular area. In this model hazard and vulnerability index have been prepared considering all the variables. In that case topography, hydrology, population settlement, population coverage and coping strategies of the people of the study area were analyzed in detailed. Each variable of the model has been described in validating the model as furnished below:

**Figure 3.2 : GIS based proposed model developed for risk assessment of the Brahmaputra-Jamuna Floodplain**




*Source : Self developed*

Data and information used in this model are given below in tabulating form. The contribution of each variable in assessing flood risk in the study area has been considered both qualitative and quantitative aspects. Qualitative risk assessment used more frequently in analyzing coping strategies of the local people of the study area. Depending on the result of the analysis, flood hazard index have been prepared and flood vulnerability of the study area were determined. Role of the variables of flood risk assessment of the Brahmaputra-Jamuna Floodplain explain below:

### 3.3 Model Specification and Validation

In the past, flood management has considered on providing protection against floods through technocratic measures such as storm surge barriers and dike (Aerts and droogers. 2004). Later fuelled by the knowledge that the above mentioned measures will be much more expensive and it is also established that, the probability of flooding can never be reduce to zero. Considering the phenomenon, it was observed that flood risk assessment could be the first step in reducing flood risk. There is currently in international shift towards a integrated system of flood risk assessment (Few, 2003, Mery et. al 2004, De Brujin, 2005, Budhale et. al 2006). In this context flood risk defined as the probability of flooding multiplied by the potential consequence such as economic damages or losses of lives (Smith, 1994). The proposed model has been developed in an integrated approach of variables those have direct influence on occurrence of flood and strategies of coping with floods in the study area.

#### 3.3.1 Topographic analysis

Topographic analysis gives a general understanding about an area, its land form and ground surface variability (terrain). These are basically represented in the form of slope, feature, hill shade, contour, directional flow (curvature), area, volume, profile and steepest path. Topographic analysis gives us the power to effectively relate our data to real world topographic surfaces and analyze how these varied surfaces will affect our data. It helps in more realistic representation of the area by bridging the gap between static two-dimensional features and realistic three-dimensional model, helpful in better planning and management.

In its contemporary definition, topographic mapping shows relief. USGS topographic maps show relief using contour lines. The USGS calls maps based on topographic surveys, but without contours, "planimetric maps." These maps show not only the contours, but also any significant streams or other bodies of water, forest cover, built-up areas or individual buildings (depending on scale), and other features and points of interest.

Digital Elevation Models, for example, have often been created not from new remote sensing data but from existing paper topographic maps. Many government and private publishers use the artwork (especially the contour lines) from existing topographic map sheets as the basis for their own specialized or updated topographic maps (San Jose 2006).

For the purpose of using topographical data in the proposed model, satellite images were collected, processed and constructed into a spatial database using GIS and image processing. According to elevation of the study area risk index has been prepared and shown into map. Raster elevation ranked as 20 meter and above height from the sea level is 5 in values, and 1 is in risk rank while very low in risk index. The estimated values, ranks and risk index are given in the following table.

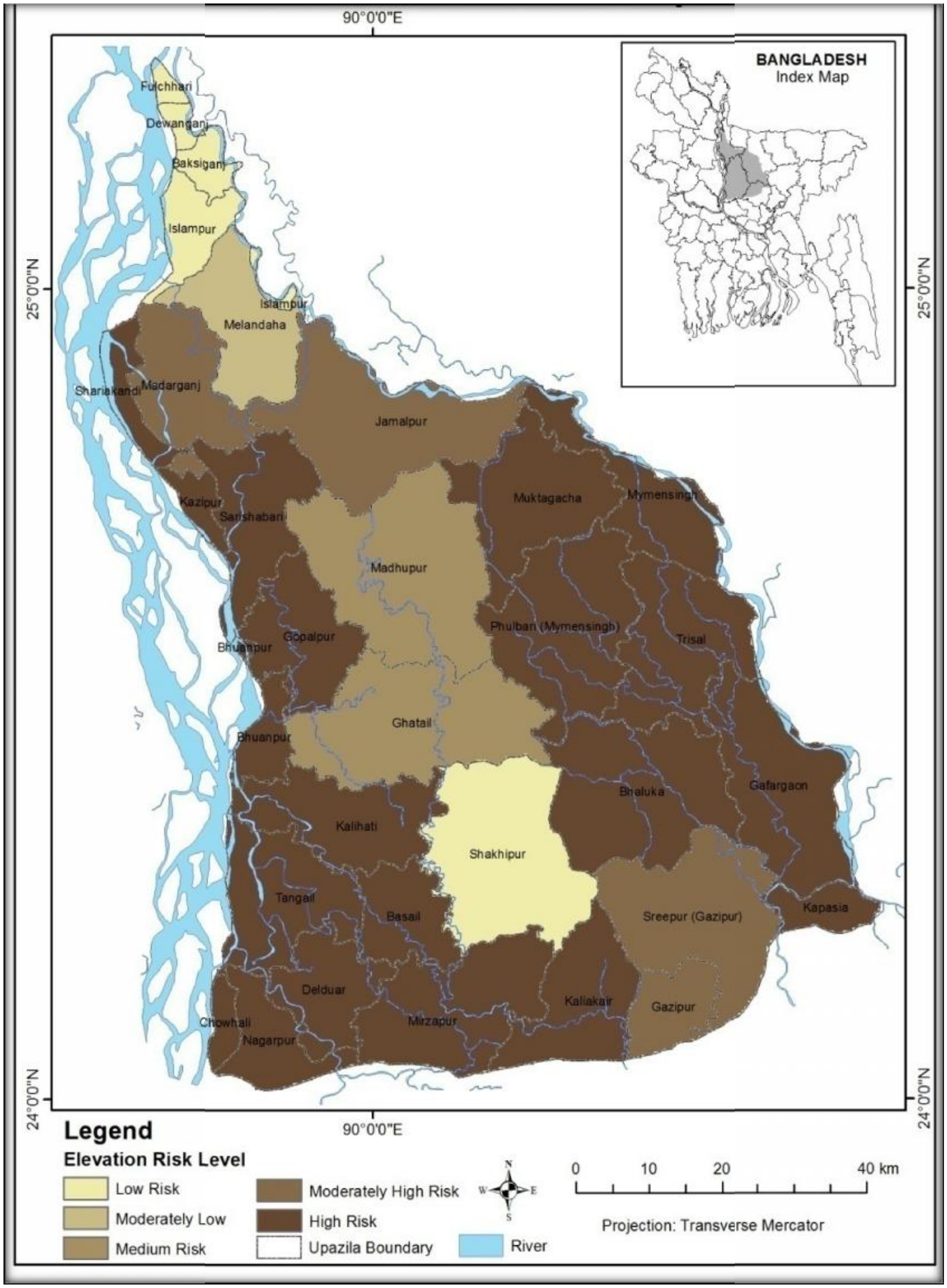
**Table 3.1 : Elevation value, rank and index used in the model.**

| Elevation in meter | values | Rank | Risk index |
|---|---|---|---|
| 1-5 | 1 | 5 | Very high |
| 6-10 | 2 | 4 | High |
| 11-15 | 3 | 3 | Medium |
| 16-20 | 4 | 2 | Low |
| 20 + | 5 | 1 | Very low |

*Source: Based on Tawatchai Tingsanchali, Wiley and Sons Ltd. 2005.*

SRTM data have been used for elevation analysis. The whole study area divided into 19 units and further details of each unit have been analyzed.

**Figure 3.3 : Elevation Risk map of the Brahmaputra-Jamuna Floodplain**




*Source : Produced as of Arc GIS model*

### 3.3.2 Settlement analysis

Settlement, locality or populated place are general terms used in geography, statistics, archaeology, landscape history and other subjects for a permanent or temporary community in which people live or have lived, without being specific as to size, population or importance. A settlement can therefore range in size from a small number of dwellings grouped together to the largest of cities with surrounding urbanized areas.

The term is used internationally in the field of geospatial modeling, and in that context is defined as "a city, town, village, or other agglomeration of buildings where people live and work". A settlement conventionally includes its constructed facilities such as roads, enclosures, field systems, boundary banks and ditches, ponds, parks and woods, wind and water mills, manor houses, moats, churches etc. that plays a vital role in flooding as well as the assessment of flood risk.

Population density of the study area provided further evidence of the problems especially in the case of losses of live due to flooding. In 1901 an average of 216 persons inhabited one square kilometer in Bangladesh. By 1951 that number had increased to 312 per square kilometer and, in 1988, reached 821. By the year 2000, population density was projected to exceed 1,000 persons per square kilometer. But in some parts of the study area found population more than 2000 per square kilometer. To assess the flood risk on population settlement, upazilawise population density and prepared index used in the model as follows: (table 3.2).

**Table 3.2 : Upazilawise Population density in the study area**

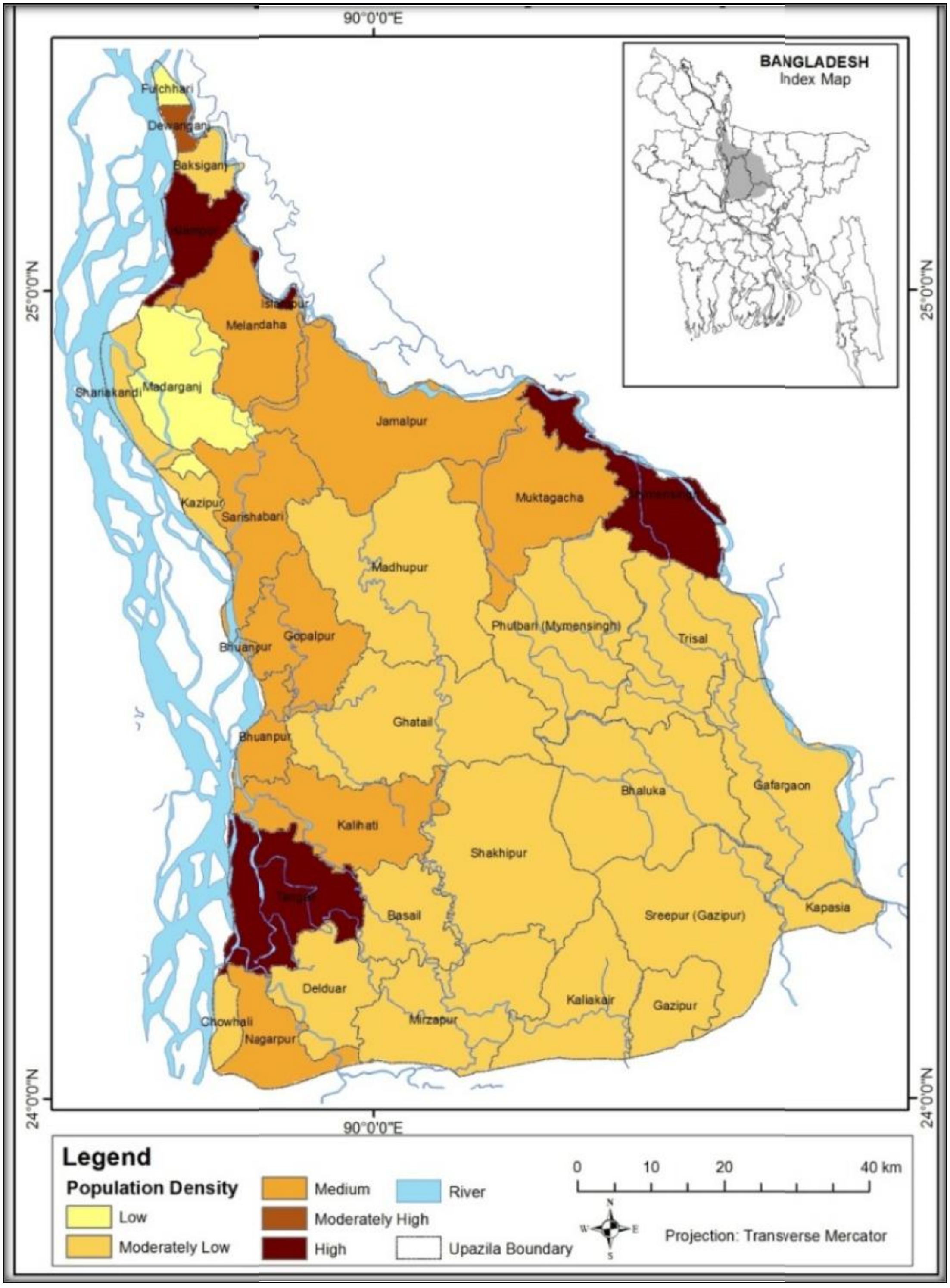
| Sl. No. | Name of the Upazila | Area (Sq. km) | Total population | Density per sq. km | Density index (*) |
|---|---|---|---|---|---|
| 1. | Basail | 157.78 | 148555 | 941 | 2 |
| 2. | Delduar | 184.54 | 175684 | 952 | 2 |
| 3. | Ghatail | 451.30 | 341376 | 756 | 2 |
| 4. | Gopalpur | 193.37 | 252747 | 1307 | 3 |
| 5. | Kalihati | 301.22 | 354959 | 1178 | 3 |
| 6. | Madhupur | 500.67 | 375295 | 749 | 2 |

| | | | | | |
|---|---|---|---|---|---|
| 7. | Mirzapur | 373.89 | 337496 | 902 | 2 |
| 8. | Sakhipur | 429.63 | 220281 | 512 | 2 |
| 9. | Tangail Sadar | 334.26 | 680518 | 2035 | 5 |
| 10. | Bhaluka | 444.05 | 264991 | 596 | 2 |
| 11. | Gafargaon | 401.16 | 379803 | 946 | 2 |
| 12. | Muktagacha | 314.71 | 321759 | 1022 | 3 |
| 13. | Fulbari | 402.41 | 345283 | 858 | 2 |
| 14. | Trisal | 338.98 | 336797 | 993 | 2 |
| 15. | Jamalpur Sadar | 489.56 | 501924 | 1025 | 3 |
| 16. | Madargonj | 225.38 | 24306 | 107 | 1 |
| 17. | Melandaha | 239.65 | 262478 | 1095 | 3 |
| 18. | Sharishabari | 263.48 | 289106 | 1097 | 3 |
| 19. | Kaliakair | 314.14 | 232915 | 741 | 2 |
| * Population density Index 100-500 = 1, 501-1000 =2, 1001-1500 =3, 1501-2000=4, 2000+ = 5 | | | | | |

*Source : modified after BBS, 2011*

The table shows that Tangail Sadar upazila has a population density of 2035 person per square kilometer. On the other hand some of the upazilas have population about 500 to 700 of the same. On the basis of population density index, population density map of the study area is prepared through the developed model (figure 3.4).

**Figure 3.4 Population density map of the Brahmaputra-Jamuna Floodplain**

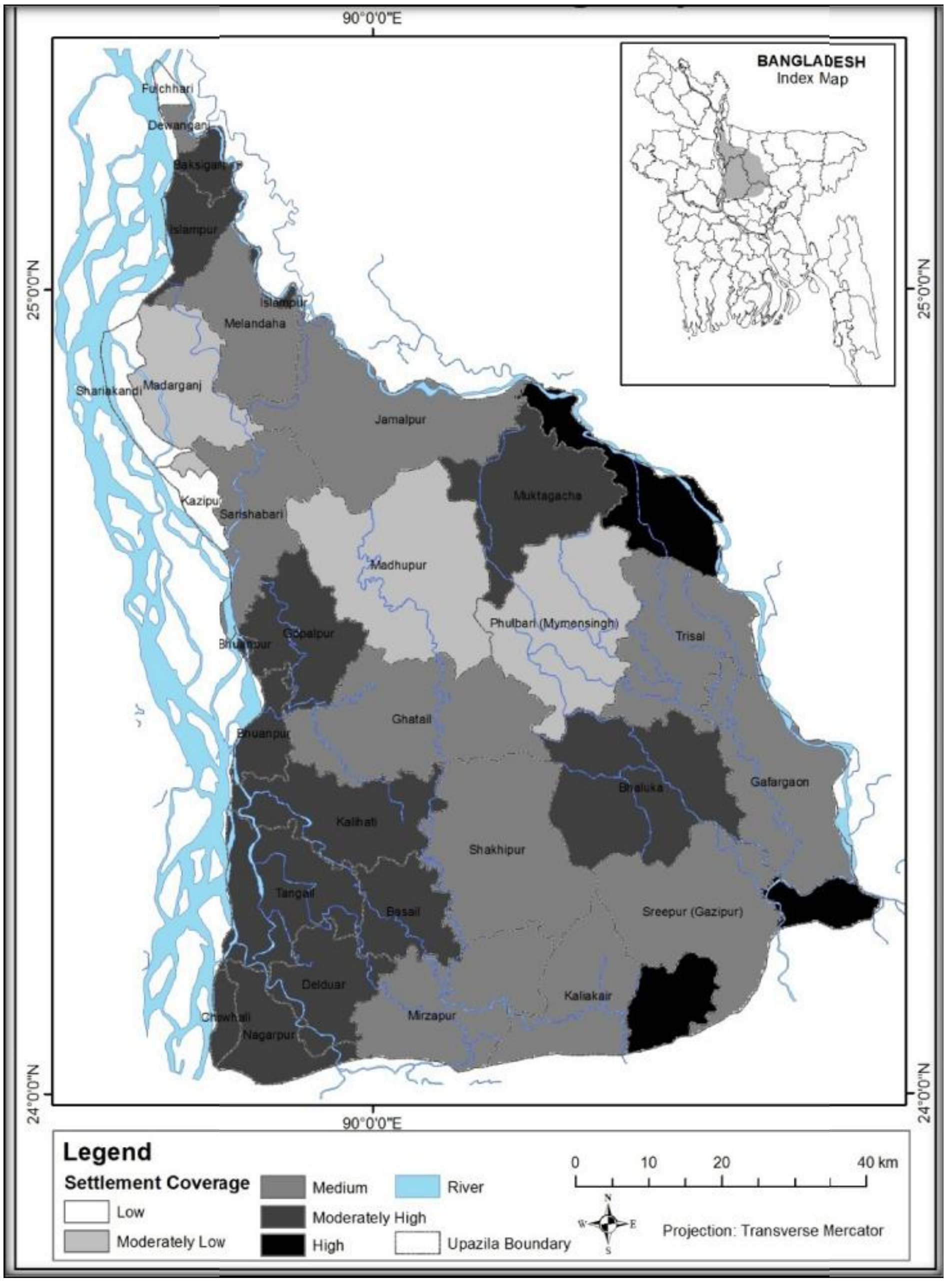



*Source : Produced as of Arc GIS model*

### 3.3.3 Area covered by human settlement

Area covered by human settlement in a particular upazila is an important variable to measure the level of flood vulnerability of the study area. Downloaded SRTM image has been used to identify the percentage of coverage of each upazila and categorized into index as high, moderately high, medium, moderately medium and low. Depending on the index a map of settlement coverage prepared as follows :

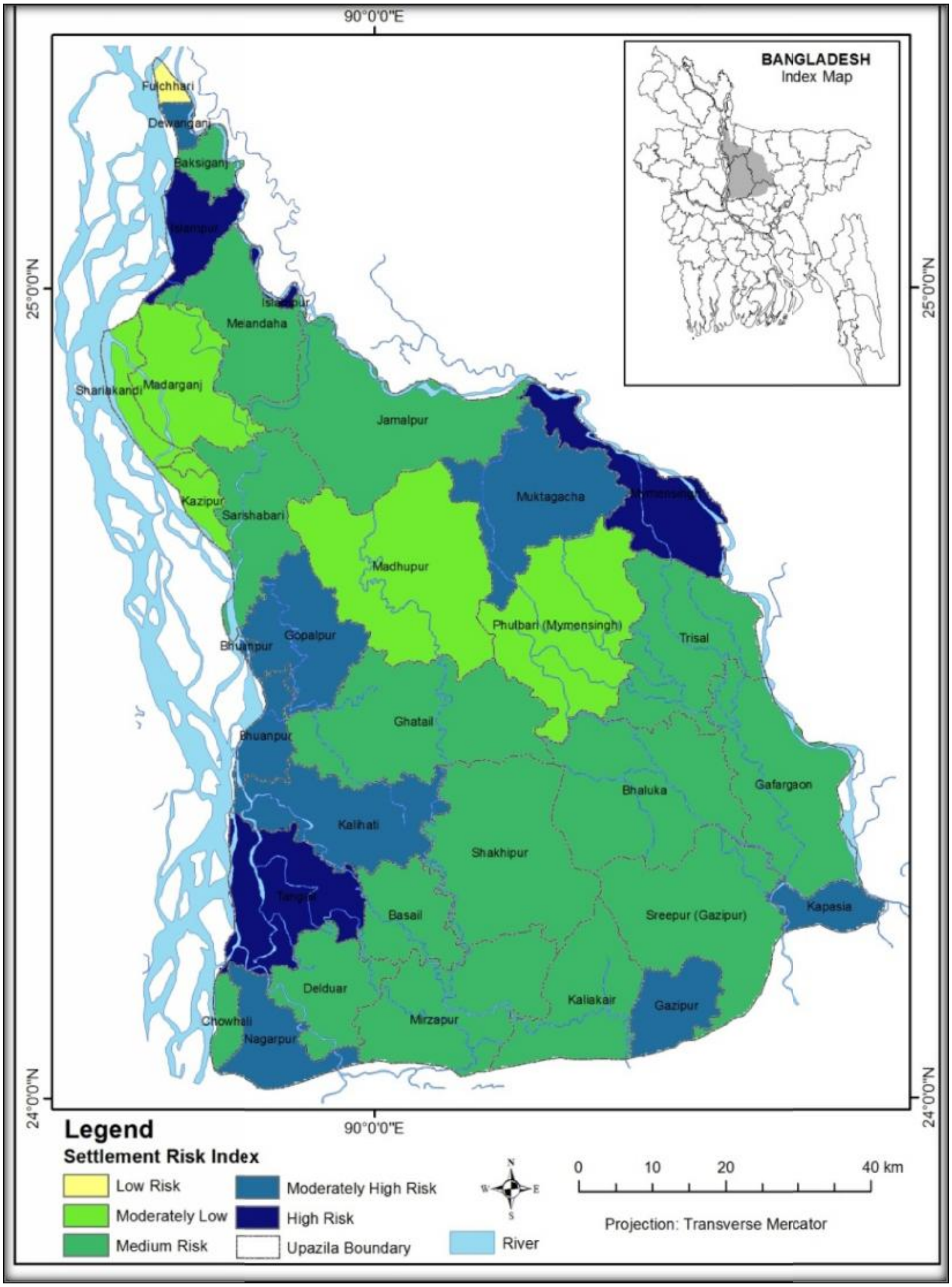
**Figure 3.5 Settlement coverage map of the Brahmaputra-Jamuna Floodplain**




*Source : Produced as of Arc GIS model*

For the purpose of assessment of vulnerability based on population overlay of the study area, population density and area coverage have been taken into consideration as variables.

**Figure 3.6 Settlement risk map of the Brahmaputra-Jamuna Floodplain**




*Source : Produced as of Arc GIS Model*

Forty percent weight has been given to population density and rest sixty percent given to area coverage while developing the model. Based on the given weight a vulnerability map on population settlement is prepared. The prepared map shows that maximum of the area (upazila) in under medium vulnerable.

### 3.3.4 Hydrological analysis

Flood vulnerability of any catchment or basin area or floodplain depends on the hydrological characteristics of it's own. Water level of the Jamuna river in terms of physical parameter exceeds the danger level as well as the coping capacity of this floodplain inhabitants. Considering the aspect, peak level of water flow, and distance from river been chosen as variables in assessing the flood risk of the Brahmaputra-Jamuna Floodplain.

**Table 3.3 : Hydrological data used in the model**

| Sl. No. | Name of the Upazila | Area (Sq. km) | Peak level of water | Danger level | Distance from the Jamuna river (miles) | Distance Rank * |
|---|---|---|---|---|---|---|
| 1. | Basail | 157.78 | 20.61 | 19.1 | 24 | 3 |
| 2. | Delduar | 184.54 | 20.61 | 19.1 | 15 | 1 |
| 3. | Ghatail | 451.30 | 20.61 | 19.1 | 20 | 1 |
| 4. | Gopalpur | 193.37 | 20.61 | 19.1 | 5 | 1 |
| 5. | Kalihati | 301.22 | 20.61 | 19.1 | 4 | 1 |
| 6. | Madhupur | 500.67 | 20.61 | 19.1 | 23 | 2 |
| 7. | Mirzapur | 373.89 | 20.61 | 19.1 | 26 | 3 |
| 8. | Sakhipur | 429.63 | 20.61 | 19.1 | 28 | 3 |
| 9. | Tangail Sadar | 334.26 | 20.61 | 19.1 | 11 | 1 |
| 10. | Bhaluka | 444.05 | 20.61 | 19.1 | 32 | 4 |
| 11. | Gafargaon | 401.16 | 14.02 | 12.5 | 54 | 5 |
| 12. | Muktagacha | 314.71 | 14.02 | 12.5 | 37 | 4 |
| 13. | Fulbari | 402.41 | 14.02 | 12.5 | 34 | 4 |

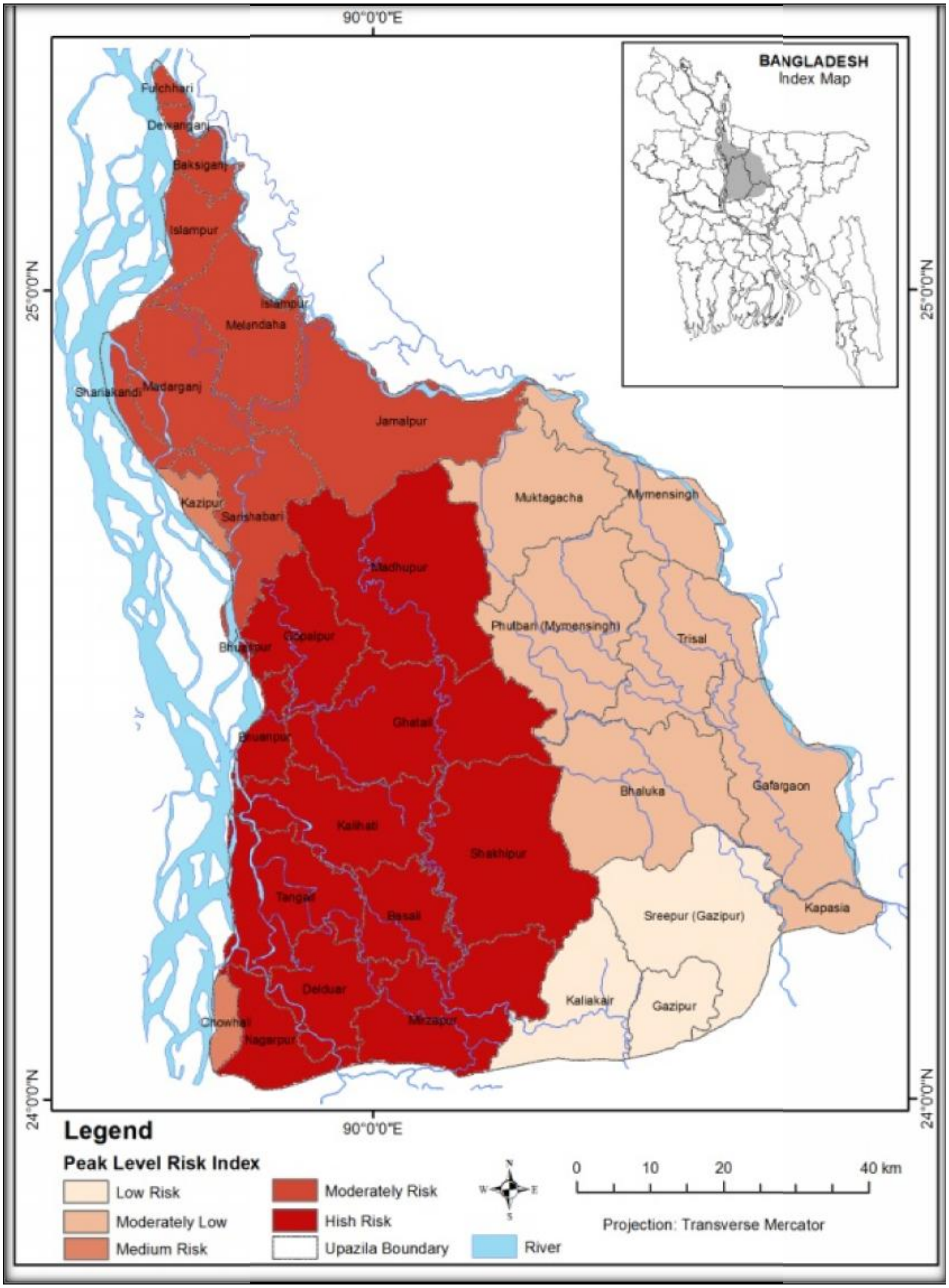
| | | | | | | |
|---|---|---|---|---|---|---|
| 14. | Trisal | 338.98 | 14.02 | 12.5 | 42 | 5 |
| 15. | Jamalpur Sadar | 489.56 | 18.00 | 17 | 25 | 3 |
| 16. | Madargonj | 225.38 | 18.00 | 17 | 6 | 1 |
| 17. | Melandaha | 239.65 | 18.00 | 17 | 16 | 2 |
| 18. | Sharishabari | 263.48 | 18.00 | 17 | 9 | 1 |
| 19 | Kaliakair | 314.14 | 18.00 | 17 | 41 | 5 |
| * Distance Index = 0-10 = 1, 11-20 = 2, 21-30 = 3, 31-40 = 4, 41+ = 5 | | | | | | |

*Source : Modified after BWDB and SRTM*

To reveal the actual scenario of hydrological risk through the developed model, peak level of water of the Bahadurabad and Mymensingh Stations were used. Distance from the river of each unit of land (upazila) calculated and in this case the river Jamuna has been taken into consideration as river. Upazilawise hazard index have been prepared on the basis of peak level of water and distance from the river (Table 3.1).

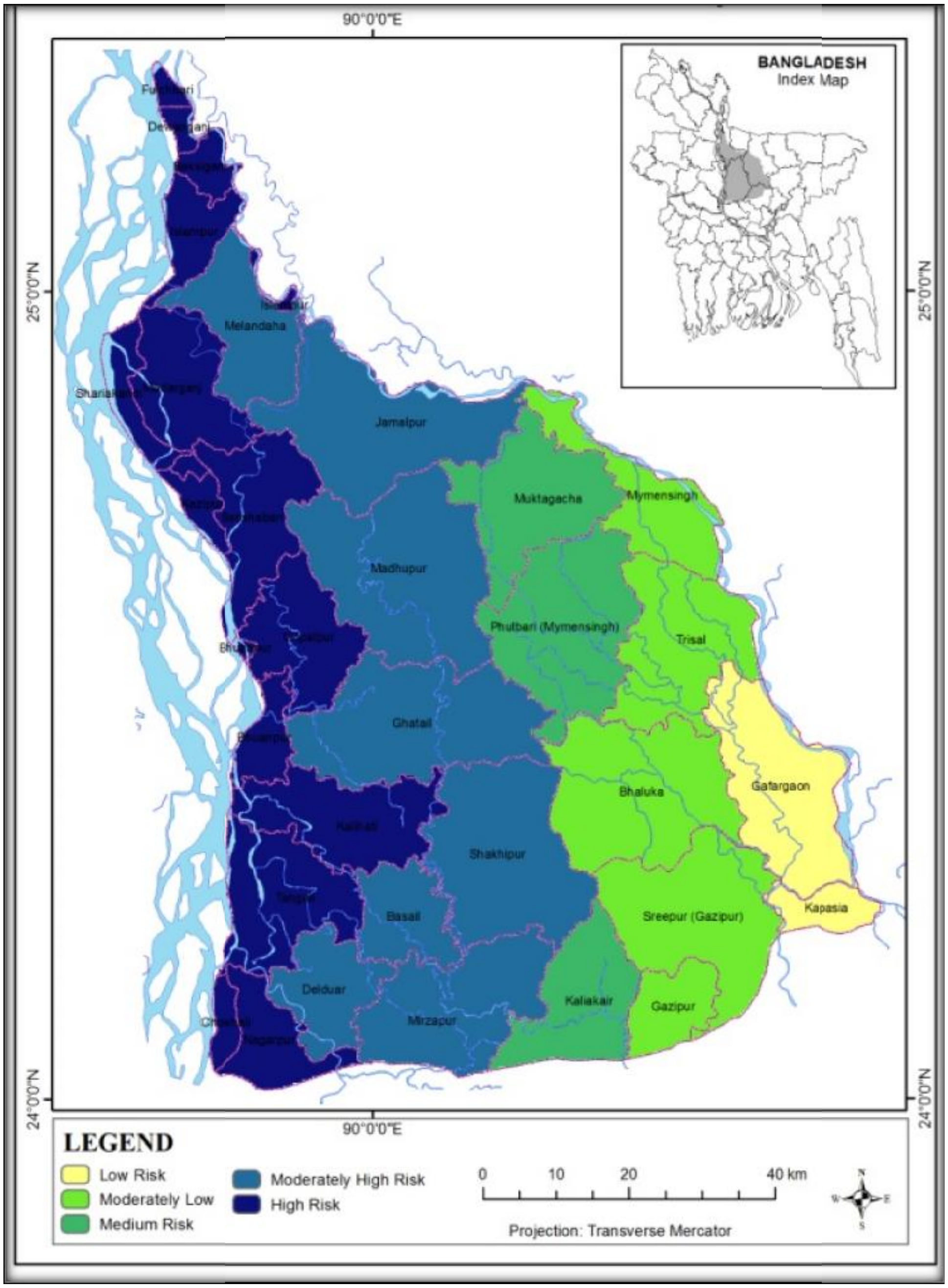
Using the peak level and river distance data through model, risk maps of peak level and river distance were prepared (Figure 3.7).

**Figure 3.7 : Peak level risk map of the Brahmaputra-Jamuna Floodplain**




*Source : Produced as of Arc GIS Model*

**Figure 3.8 : Flood risk map based on distance from the river of the Brahmaputra-Jamuna Floodplain**




*Source : Produced as of Arc GIS Model*

### 3.3.5 Analysis of Coping Capacity

Coping capacity are commonly termed coping strategies or coping skills. Unconscious or non conscious strategies are generally excluded. The term coping generally refers to adaptive or constructive coping strategies, i.e. the strategies reduce the level of vulnerability. However, some coping strategies can be considered maladaptive, i.e. vulnerability levels increase. Maladaptive coping can thus be described, in effect, as non-coping. Furthermore, the term coping generally refers to reactive coping, i.e. the coping response follows the hazard (Otto Fenichel, 2006).

The present study is an approach to modelling multicriteria flood vulnerability which integrates the topographic, economic and hydrological dimensions of risk, and coping capacity . The modelling started with an existing multicriteria risk mapping approach. The term risk is used here in a way that could be called a starting point view, looking at vulnerability without considering coping capacities. The approach is extending by a multicriteria modelling of coping capacities towards an end point view of vulnerability. In doing so, I have investigate a way to differentiate coping capacity from flood risk in each of the dimensions of vulnerability. The approach is tested through a field survey in the study area (Brahmaputra-Jamuna floodplain). The results show that it is possible to map multicriteria risks as well as coping capacities and relate them in a simple way. However, a detailed calculation of end point vulnerability would require more detailed knowledge on the causal relationships between risk and coping capacity criteria and their relative importance. Using survey data the following table has been prepared with index value and used in the developed model for the purpose of identification of coping capacities of the local people of the study area.

Coping capacities or coping strategies are highly complementary since greater resilience is achieved when vulnerability is reduced. Flood vulnerability of the study area found more severe than previous. People of the study area adapted various strategies to cope with flood of their own and also with the help of different organizations. Coping strategies of the local people used in the developed model as furnished in the table below: (table 3.4).

**Table 3.4 : Coping capacity variables and index (upazilawise)**

| Sl. No. | Name of the Upazila | Variables of measuring coping capacity | | | | |
|---|---|---|---|---|---|---|
| | | **Awareness** | **Relief system** | **Economic strength** | **Use of Indigenous knowledge** | **Education level** |
| | | **Index** | **Index** | **Index** | **Index** | **Index** |
| | | Very high=1<br>High=2<br>Medium=3<br>Low=4 | Very good=1<br>Good=2<br>Satisfactory=3<br>Not good=4<br>Bad=5 | High= 3<br>Medium=2<br>Low=1 | High=1<br>Medium=2<br>Low=3 | Very high=5<br>High=4,<br>Medium= 3<br>Low=2<br>Very low= 1 |
| 1. | Basail | 2 | 2 | 1 | 2 | 2 |
| 2. | Delduar | 2 | 2 | 2 | 2 | 2 |
| 3. | Ghatail | 2 | 2 | 2 | 3 | 2 |
| 4. | Gopalpur | 3 | 2 | 1 | 3 | 2 |
| 5. | Kalihati | 2 | 2 | 1 | 2 | 2 |
| 6. | Madhupur | 1 | 2 | 2 | 1 | 2 |
| 7. | Mirzapur | 1 | 3 | 2 | 1 | 2 |
| 8. | Sakhipur | 2 | 3 | 2 | 2 | 2 |
| 9. | Tangail Sadar | 2 | 4 | 3 | 3 | 2 |
| 10. | Bhaluka | 2 | 1 | 2 | 2 | 2 |
| 11. | Gafargaon | 2 | 4 | 2 | 2 | 2 |
| 12. | Muktagacha | 3 | 3 | 2 | 1 | 2 |
| 13. | Fulbari | 3 | 3 | 3 | 1 | 3 |
| 14. | Trisal | 3 | 3 | 2 | 2 | 2 |
| 15. | Jamalpur Sadar | 3 | 3 | 3 | 3 | 3 |
| 16. | Madargonj | 2 | 2 | 2 | 3 | 2 |
| 17. | Melandaha | 2 | 1 | 1 | 3 | 2 |
| 18. | Sharishabari | 2 | 2 | 2 | 1 | 2 |
| 19. | Kaliakair | 2 | 1 | 3 | 2 | 4 |

*Index of economic strength rank based on monthly income taka 15000+=3, 10-15=2, 0-10=1*

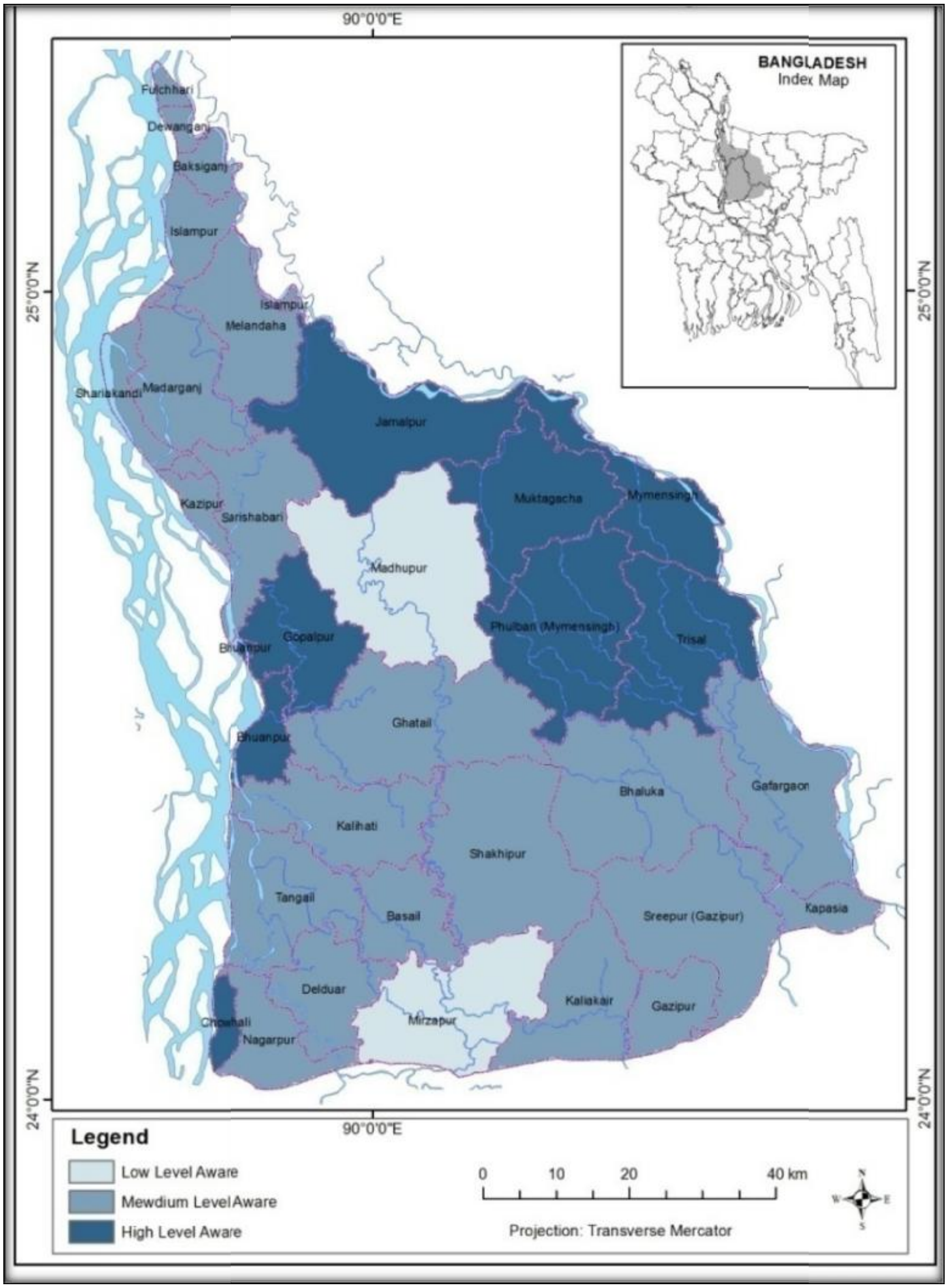
*Index on education(% of 7+ aged), 0-20=1, 21-40=2, 41-60=3, 60-80=4, 80+=5*

*Source : Prepared from survey data.*

### 3.3.6 Awareness of people

Flooding can be a local disaster affecting a single neighborhood, or very large, impacting entire river basins across many district or upazila in Bangladesh.

**Figure 3.9 Awareness level map of the local people of the Brahmaputra-Jamuna Floodplain**




*Source : Produced as of Arc GIS Model*

Some floods develop slowly, but flash floods can develop in just a few minutes without any rain. Residents should know if their neighborhood is at risk for flooding and be alert to the possibility of a flood.

Listen to local radio or TV stations for possible warnings or other critical information from the national weather service as well as meteorological Department of Bangladesh, people could get more information about the intensity or possibility of flood or any kind of natural hazard. Awareness of the local people of the study area inserted in the above table (table 3.4) shown in the following map (figure 3.9).

The map shows that maximum portion of the study area included at the level of medium awareness category. Second highest is highly aware people and a little portion is included in low awareness group.

### 3.3.7 Relief system

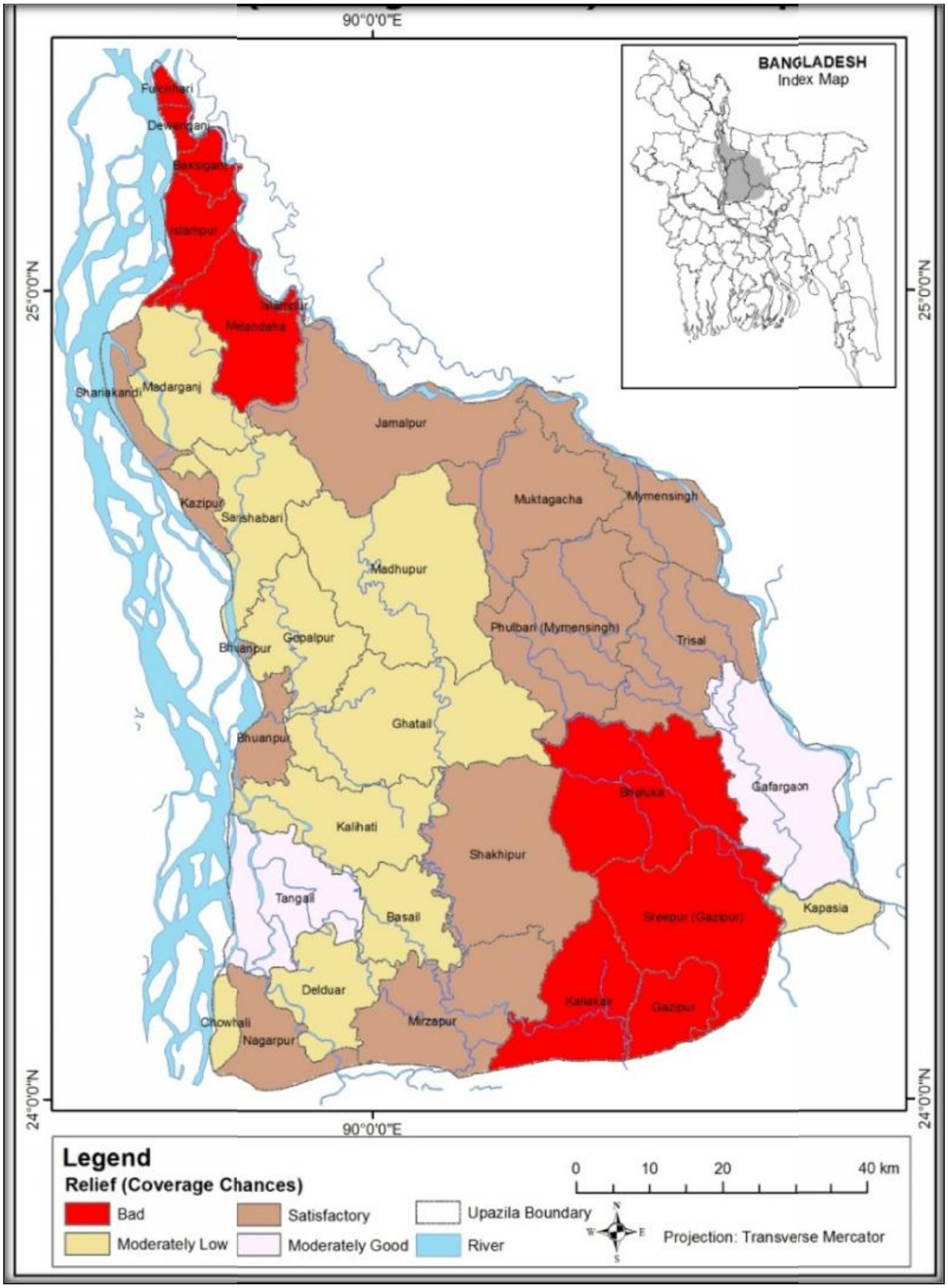
Emergency relief system to the affected community of any flooded area can save life and can reduce the losses and damages. Generally supply of foods, water and medicine during, and immediate after the flood is considered the most important coping strategy which can reduce the risk of flood damages. Relief systems scenarios of the study area were collected through questionnaire and participatory survey.

Flood relief seemed a critical issue in the study area because of its huge scale of operations. Consequently, many flood victims fail to obtain adequate relief, despite concentrated efforts by government relief agencies, NGOs, private institutions and individuals.

Food, water, money and clothing were the most important relief foods found in the study area served during the flood period. Drinking water is a major issue in Bangladesh during the flood disaster. NGOs and several organizations tried to address this issue by providing relief package that included water purifying tablets, oral saline and safe drinking water.

The collected data and information were used in the model and map on relief system has been produced (figure 3.10).

**Figure 3.10 Relief system map of the Brahmaputra-Jamuna Floodplain**

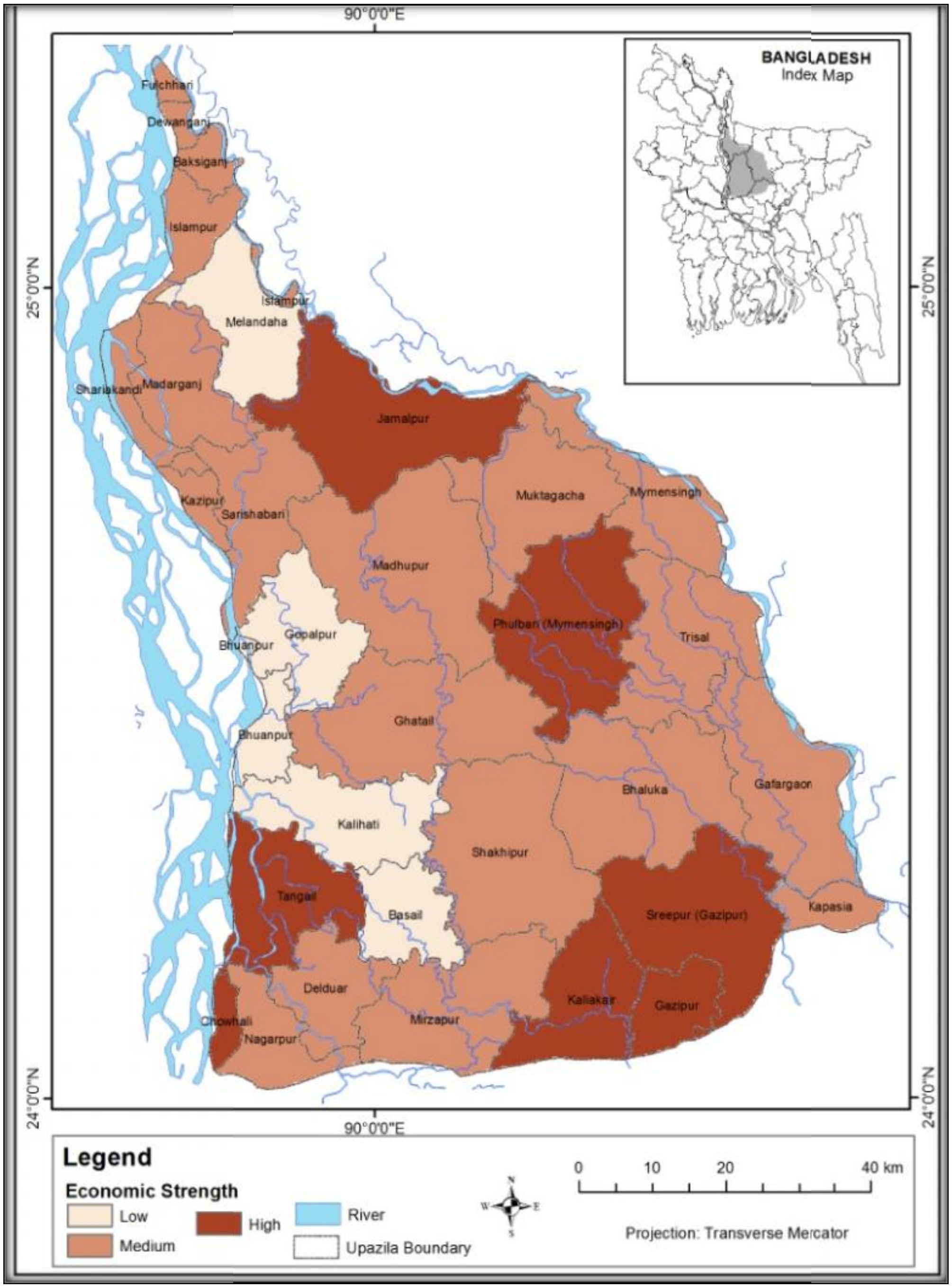



*Source : Produced as of Arc GIS Model*

### 3.3.8 Economic Strength

Economic capacity or economic strength of the affected people is an important measuring scale of coping capacity of any flood affected area. It is observed that, poor people are always more vulnerable and suffers more than comparatively rich people. It could be said that economic strength directly controls the coping strategy of the affected people.

**Figure 3.11 Map on economic strength of the local people of the study area**



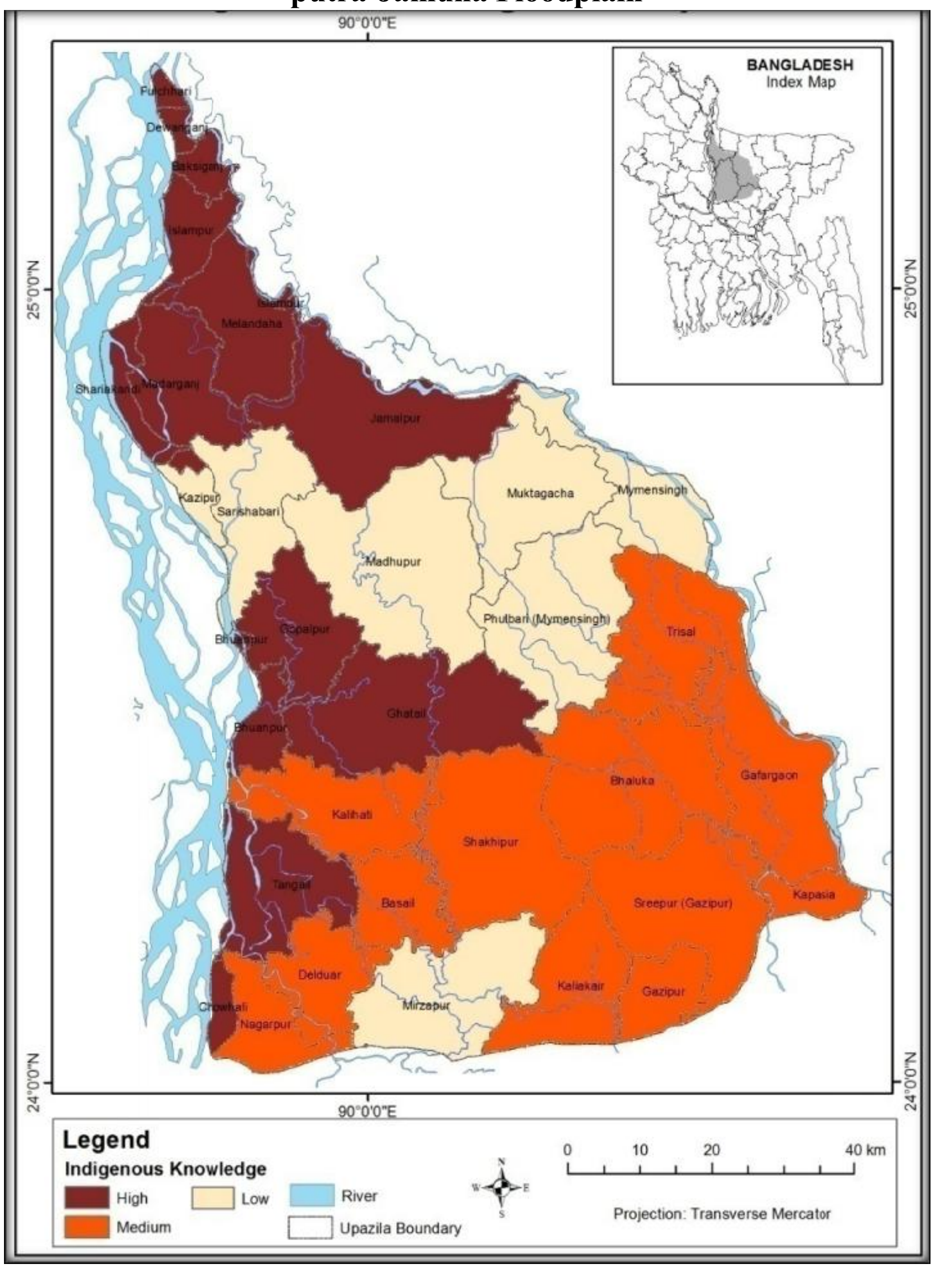

*Source : Produced as of Arc GIS Model*

The economic strength of the study area based on monthly income is measured and categorized as high, medium and low. The people earning taka more than fifteen thousand considered and high strength group and ten thousand to fifteen thousand, and one thousand to ten thousand respectively considered as medium and low strength groups (table 3.4).

### 3.3.9 Use of Indigenous knowledge

Indigenous knowledge gives power to the affected people to cope them with disaster as like as flood.

**Figure 3.12 : Map on use of indigenous knowledge of the local people the Brahmaputra-Jamuna Floodplain**




*Source : Produced as of Arc GIS Model*

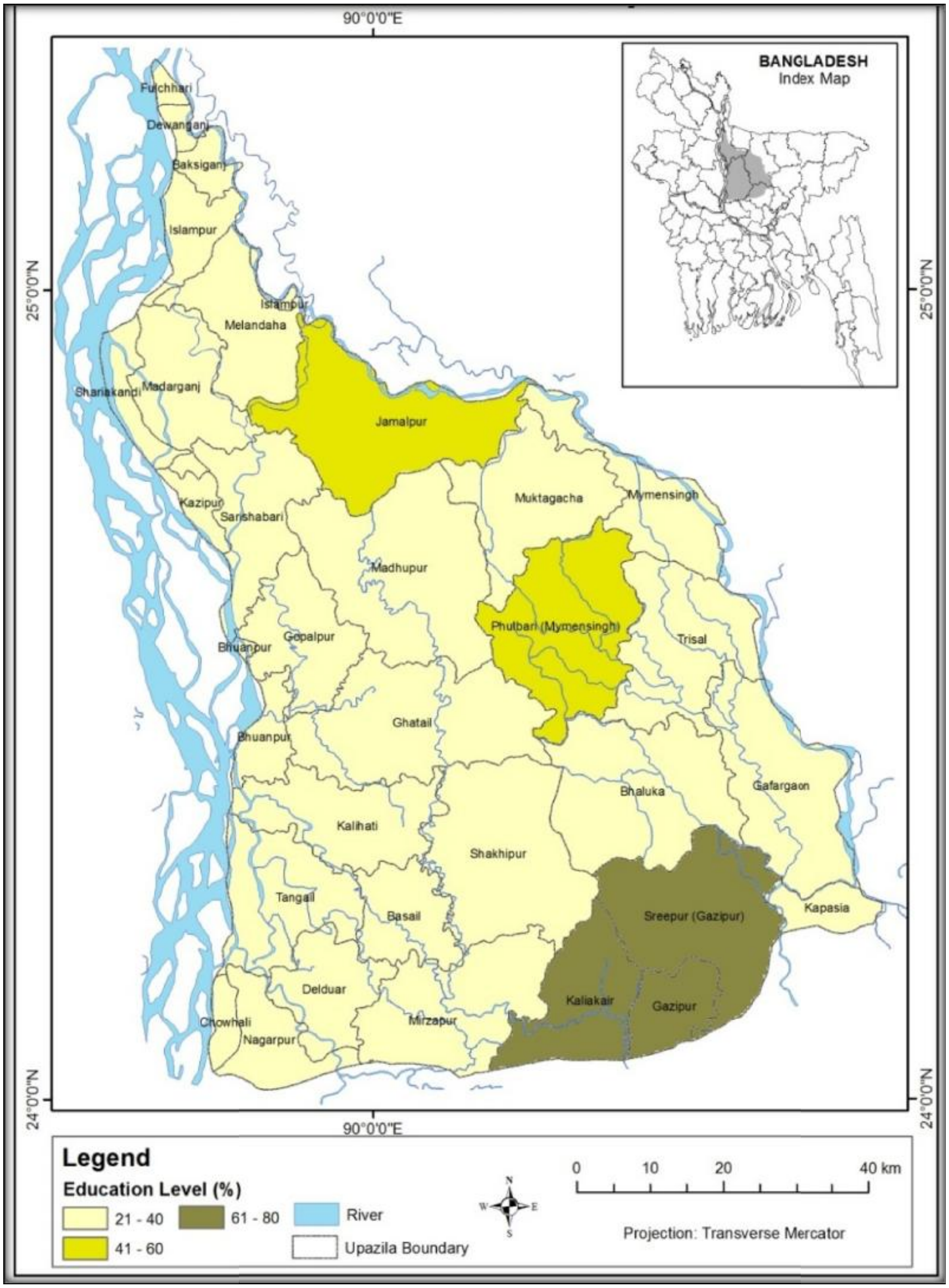
To take immediate action for the purpose of saving lives and properties indigenous knowledge has no alternatives especially in case of flood disaster. Peoples of the study area using indigenous knowledge in different purposes form different aspects. An index of using indigenous knowledge is prepared based the survey (table 3.4). This index has been prepared fully based on field observation of the study area. Indigenous knowledge includes use of battery or oil operated light in spite of heaving electricity, preserving dry food before the occurrence of flood, higher plinth of houses, changing mode of transport etc. The prepared index considering all these variable were inserted into the model and prepared a map as follows:

### 3.3.10 Educational risk level

**Education** in its general sense is a form of learning in which the knowledge, skills, and habits of a group of people are transferred from one generation to the next through teaching, training, or research. Education frequently takes place under the guidance of others, but may also be autodidactic. Any experience that has a formative effect on the way one thinks, feels, or acts may be considered educational. Education is commonly divided into stages such as preschool, primary school, secondary school and then college, university or apprenticeship.

Implication of educational knowledge and influence of education observed in the study area (Brahmaputra-Jamuna floodplain) and prepared an index for the model using the collected data. Educational index prepared as Very high=5, High=4, Medium= 3, Low=2, Very low= 1. Percent of literacy decorated as 0-20=1, 21-40=2, 41-60=3, 60-80=4, 80+=5. Map produced through the developed model using the above mentioned index is shown in figure 3.13.

**Figure 3.13 Education level map of the Brahmaputra-Jamuna Floodplain**




*Source : Produced as of Arc GIS Model*

**3.4 Concluding remarks** : Risk assessment should thought of as a dynamic, ongoing process, not as a one-time project. The process is described as a set of steps that are continually repeated. In context of natural hazards, risk management refers to both mitigation-actions taken to reduce the threats to life, property, and environment post by extreme event – and preparedness – ensuring the readiness of individuals and communities to forecast, take precautionary measures and respond to an impending disaster (Christopols *et al*., 2001). The present study endeavored to assess the risk estimating the challenges relates to flood events of the study area analyzing the past and future events. To reach the goal of the study, focus has been given to determining acceptable risk assessment through the developed model as stated above.

## 4.0 Introduction

Recent natural hazard literature indicates that there have been several changes in the body of knowledge. For instance, much attention is now being directed towards the understanding of human vulnerability to natural hazards along with other changes (White et al. 2001) . As Parker (2000 ) noted, two factors may have contributed to these changes. Firstly, natural hazard interpretation was viewed as agent specific during much of the twentieth century, and hazards were described as natural phenomena or a threat to the society linked with human modification of the environment.

Secondly, a new approach called social agent emerged to interpret a natural hazard that underpins the concept of vulnerability. The basic premise of the social agent approach is that disaster is the interaction of hazards and people's vulnerability (Cannon 2000 ) produced by society (Parker 2000 ) .

As there are several approaches to evaluate the societal risk of natural hazards, the different notions of natural hazards are blurred, making it increasingly difficult to separate natural hazards from technological hazards or social hazards such as violence and war (Pelling 2003 ; Mitchell 1999a, b ; Burton et al. 1993 ) . With the increasing focus of an interdisciplinary flavor in the natural hazard domain, demarcation between the terms may be somewhat difficult when a particular hazard research entails two disciplines, in which case both are multidisciplinary in nature. New approaches have evolved with the advancement of technology, and they have provided ample opportunities to integrate environmental, social, economic, and other parameters to describe societal vulnerability to natural hazards (Taubenböck et al. 2009) . As a result, multiple meanings of key terminologies have mainly originated from epistemological orientations and methodological practices (Mustafa 2005 ; Cutter 1996).

To understand the different notions associated with natural hazard literature, a number of terminologies are in use to describe hazard, vulnerability, and risk. The definition of these terminologies and a review of the existing models of hazards and vulnerability could be useful in constructing a conceptual framework for this study.

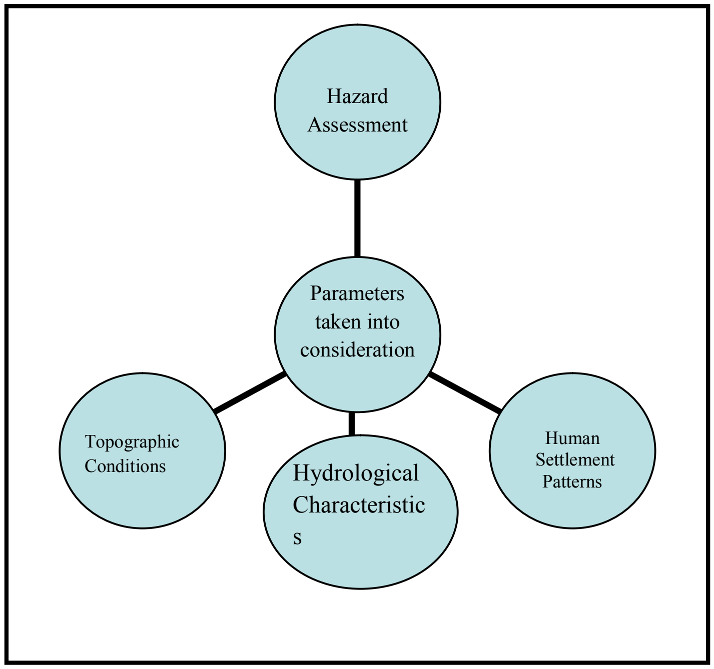
## 4.1 Flood hazard assessment

Flood hazard is categorized based on the level of difficulties in daily life and or damage to properties. In general, flood hazard is classified as low, medium and high (United Nations, 1991; ESCAP, 1991: New South Wales Government, 1986). For flooding of small extent, the difficulties are not significant and the area is in the medium hazard category where potential damage to properties is moderate and vehicle movement is disrupted. In case of high hazard, the damage to properties is extensive and the movement of human lives is not safe. The term ‘very high hazard’ is used in this study to distinguish excessive flooding depths or durations due to catastrophic floods in Bangladesh in which a one-storey building is submerged under water and human lives are under threat. This classification is similar to that of Chowdhury and Karim (1997).

### 4.2 Hazard parameters

Flood hazard assessment is the estimation of overall adverse effects of flooding for a particular area. It depends on many parameters such as depth of flooding, duration of flooding, flood wave velocity and rate of rise of water level. One or more parameters can be considered in the hazard assessment depending on the characteristics of study area. Unites Nations, (1991), Chowdhury, and Karim (1997) considered only depth of flooding as a hazard parameter. Islam and Sado (2000) considered both depth and duration of flooding in estimation the hazard parameter. In the present study, the area is very large floodplain with multi dimensional topography and human settlement pattern. Considering the characteristics of the study area three major parameters namely, hydrological characteristics of rivers, topography and human settlement have been taken into consideration for the hazard assessment. Water level and discharge are generally included in analyzing the flood situation of the study area.

**Figure 4.1: Parameters of Hazard Analysis**




*Source : Self developed*

### 4.3 Elevation and Hazards concentration

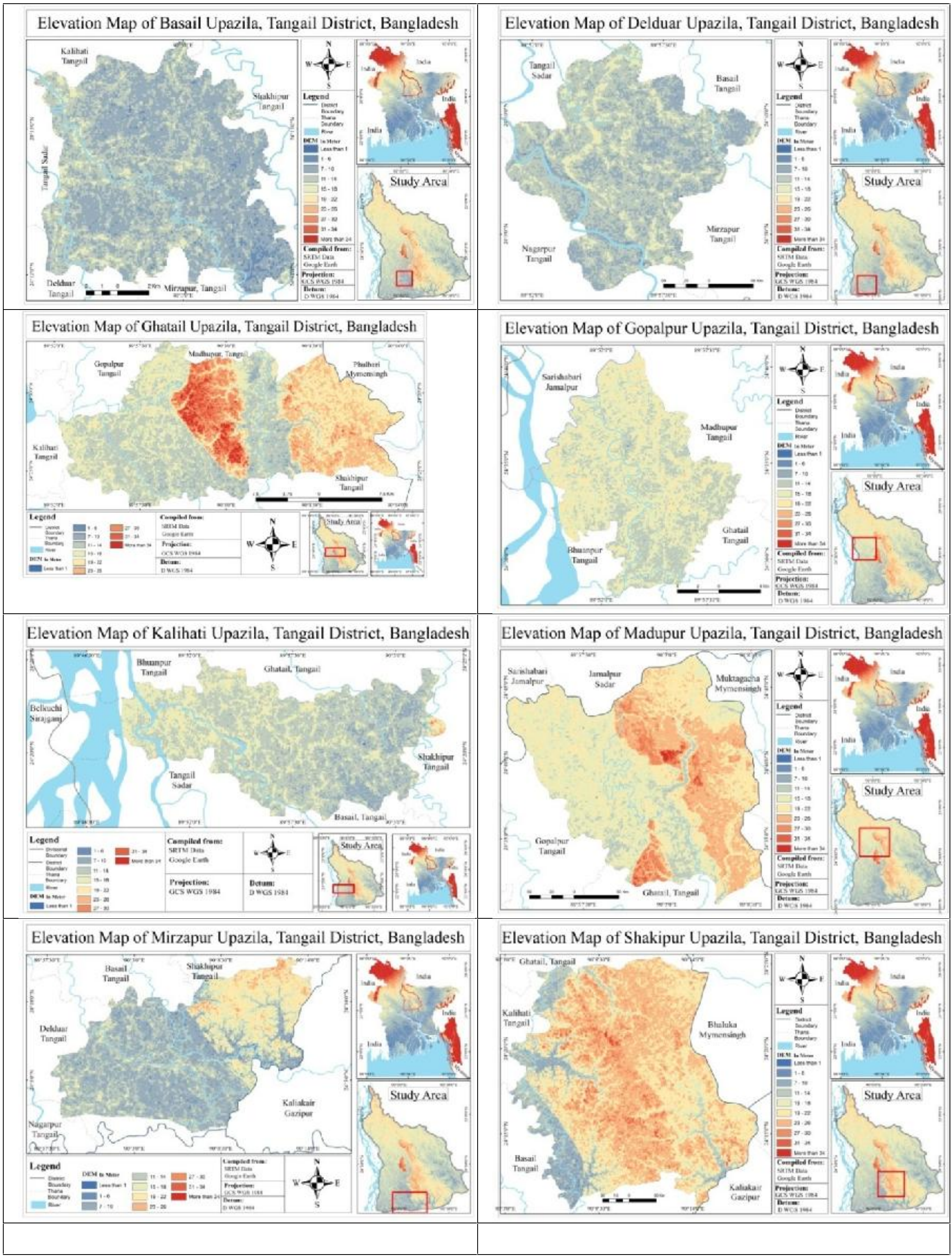
Elevation or topography refers to the study of surface shape and features of the Earth and other observable astronomical objects including planets, moons, and asteroids. It is also the description of such surface shapes and features (especially their depiction in maps). In general, topography is concerned with local detail including not only relief but also natural and artificial features, and even local history and culture.

In modern usage, this involves generation of elevation data in electronic form. It is often considered to include the graphic representation of the landform on a map by a variety of techniques, including contour lines, hypsometric tints, and relief shading. In this study to assess the hazard index or flood risk of the study area mainly elevation of land or land level is given emphasize in analyzing topography.

#### 4.3.1 Upazilawise Elevation Analysis

For the purpose of topography or elevation analysis of the Brahmaputra-Jamuna floodplain, the whole basin has been divided into 19 units following upazila boundary of LGED with some few exceptions. Upazilawise elevation maps are given below :

**Figure 4.2 : Upzilawise elevation map of the study area**

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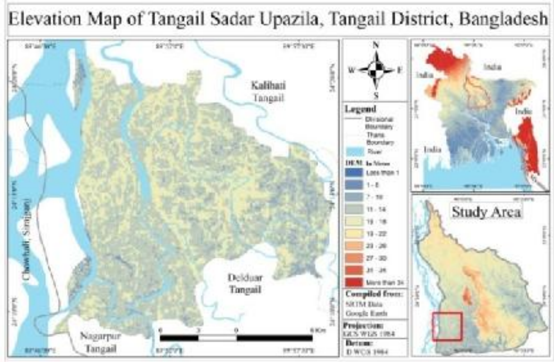


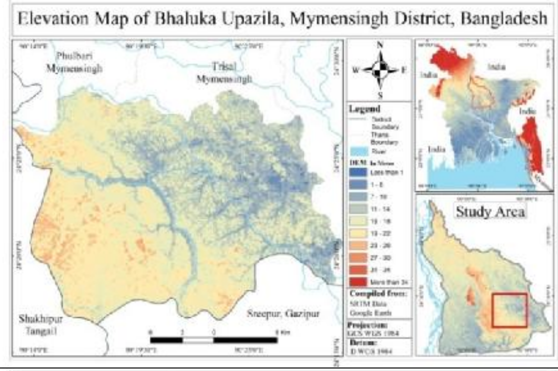


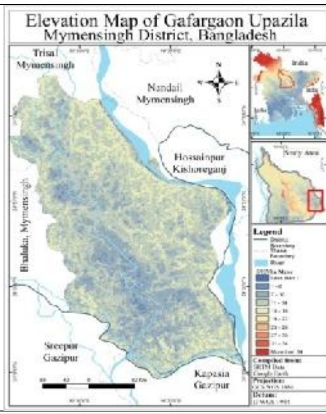


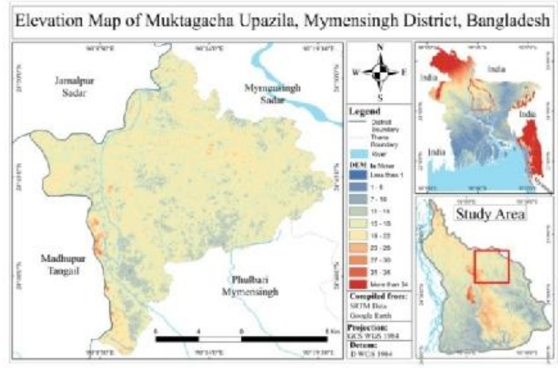


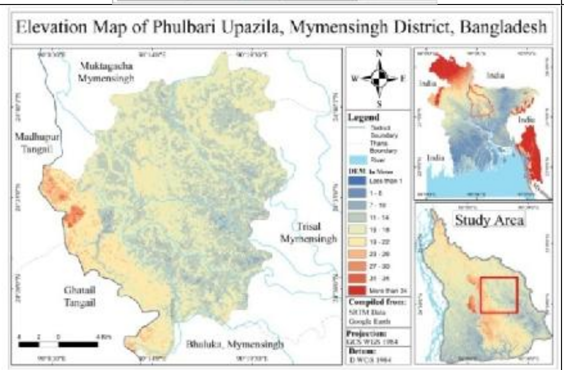


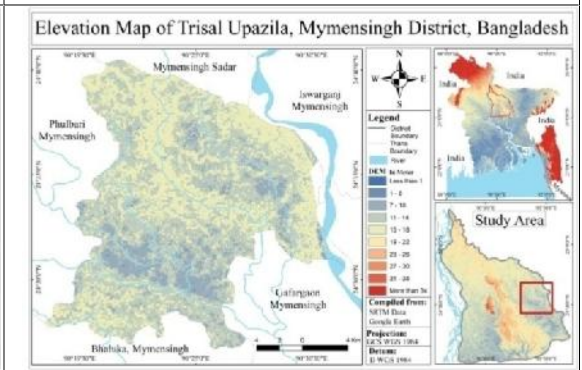


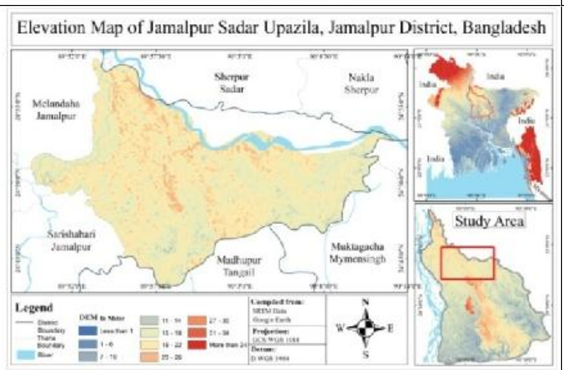


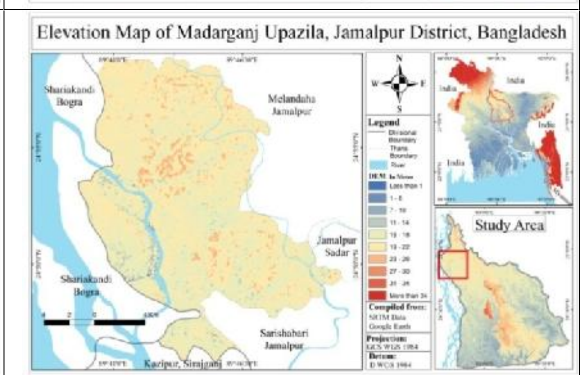


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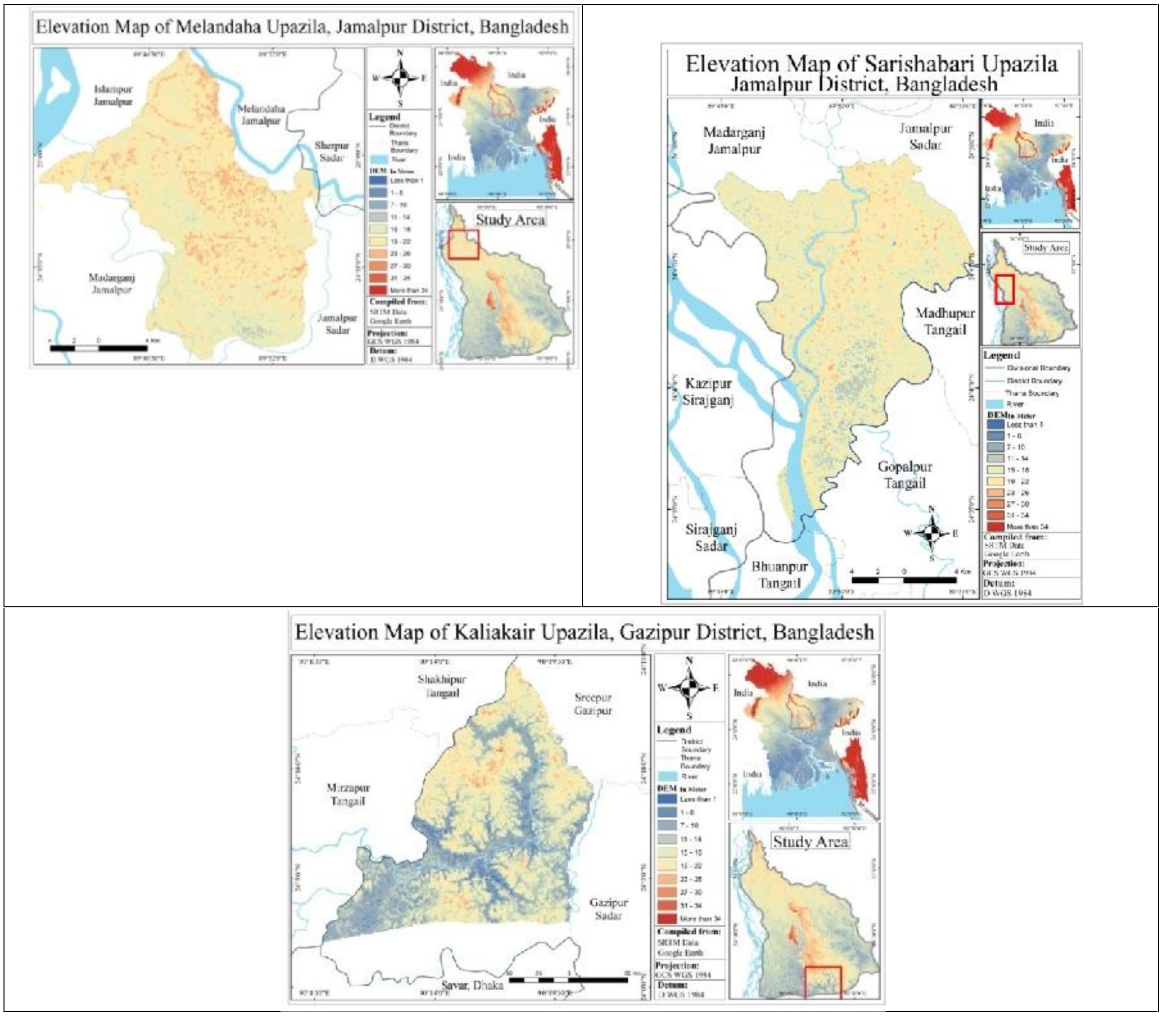



*Source : Prepared for SRTM data*

### 4.3.2 Description of elevation (upazilawise)

**Basail Upazila**

The highest value of the contours of Basail upazila found 15 to 16 meters and lowest is less than one metre. Maximum land of the upazila found lies between 7 to 10 meters. The area with less than one metre elevation found vulnerable to flood. The past history of the flood and the analysis of the water level show a functional relationship in between elevation and inundation in this area.

The Basail upazila located in the southern portion of the study area (Brahmaputra Jamuna Flood Plain) is adjacent to the west of the Pleistocene Traces of Madhupur. The river Dhaleshwari flowed by the eastern side of the upazila and this river has a great influence to flooding. Analyzing the elevation map of the upazila it has been observed that the south-eastern part is comparatively low in elevation. Flooding in different magnitude in this area is a major hazard. All most all of the parts of this upazila with some few exceptions has an experience of flooding. A large portion of the upazila especially in the south-eastern part are elevated less than one meter is highly vulnerable to flood.

**Delduar upazila**

Delduar upazila is located in the south western part of the study area which is one of the lowest parts in respects of elevation. A mixed topographical condition found in this upazila that contains a large portion of land elevated in between 7 to 14 meters. A spread discontinuous land found over the upazila contains 15 to 18 meters height. The Jamuna river flowed by the western side of it. In respect of elevation the upazila is highly vulnerable to flood. The average elevation of the upazila is 3.6 meter while the lowest areas are about 1.5 meter and the highest elevated areas are almost 15 to 18 meters.

**Ghatail upazila**

Ghatail Upazila is bounded by Gopalpur and Madhupur upazilas on the north, Fulbaria and Bhaluka upazilas on the east, Kalihati and Sakhipur upazilas on the south, Bhuapur and Gopalpur upazilas on the west. Main rivers are Bangshi, Jhenai, Lohajang, Salisundar.

Ghatail upazila has an exceptional topography within the study area having a large highly elevated land (more than 34 meter height) in the middle portion and a medium high area (23 to 26 meter) in the eastern part of it. Both the high and medium high land area considered as part of Madhupur Traces formed in Pleistocene period. Rest of the areas are found elevated between 7 to 15 meters. The south-western part is comparatively less elevated. Considering the elevation, the upazila is partly flood free but less elevated are could be inundated by the high peak of the adjacent river.

**Gopalpur upazila**

Keeping similarities with the characteristics of flood plain, the upazila Gopalpur found almost overall plain land. Maximum lands are found elevated in between 15 to 18 meters. A little portion of the southern part of the study area found 11 to 14 meters high in respect of elevation. Though the upazila is comparatively elevated, the area is vulnerable to flood as a connected part of the river Jamuna. Very little and insignificant parts of the area found elevated more than 23 maters that lies in scattered form.

**Kalihati Upazila**

Kalihati upazila is topographically low in the eastern part which lies between 1 to 7 meters in elevation. The eastern part of the upazila found elevated from 11 to 18 meters only a few exceptions in the middle-eastern small piece of land located in the border line with Shakhipur upazila which seems to be elevated about 15 to 19 meters. The Brahmaputra river flowed by the western side of the upazila.

**Madhupur Upazila**

Madhupur is bounded by Jamalpur Sadar upazila to the north, Gopalpur and Ghatail upazilas to the south, Muktagachha and Fulbaria upazilas to the east. Sarishabari and Gopalpur upazilas to the west. Main rivers are Jhinai, Bangshi, Banar and Atrai. It is one of the most elevated upazila of the study area. The elevation pattern of Madhupur upazila shows that the total area of it is comparatively higher than other upazila having a ridge that lies from north to south adjacent to eastern upazila boundary. The elevation of this ridge is about 23 to 34 meters while the western part of this upazila found 15 to 18 meters high. A mentionable portion to the middle of the southern part of the upazila is high land having an elevation of 27 to 30 meters.

**Mirzapur Upazila**

In analyzing the elevation of the Mirzapur upazila it is found that the north eastern part of the upazila is comparatively higher than other part of it which observed 19 to 26 meter high. On the other hand the middle and the western part of the upazila is considerably low land. Maximum of this upazila especially western and middle part is elevated in between 1 to 10 meters. The low laying areas (western part) of the upazila included in the normal flooded areas of the country has an experience of inundation almost every year.

**Shakipur Upazila**

The Shakhipur upazila is containing maximum of its area high land which elevated in between 19 to 33 meters. The western part of the upazila has some small area having elevation about 7 to 10 meters. Middle portion of the upazila found comparatively higher. In an average the upazila seems flood free area as a part of Madhupur Traces.

**Tangail Sadar upazila**

The Tangail upazila is comparatively low laying part of the study area which lies within 01 to 18 meters high. The upazila is located in the eastern bank of the mighty river Jamuna which has a great influence to flood. But in analyzing the hazard index the upazila found medium hazardous as some protective measures have been taken to control. However the topographic situation of the upazila found quite plain. Elevation exists comparatively lesser in the eastern part and the middle portion of the upazila seems higher than other parts.

**Bhaluka Upazila**

The Bhaluka upazila is separated into two units in respects of elevation. The north-eastern part of the upazila observed lower than south-western part. The highest elevation found 23 to 26 meters and the lowest found about 01 meter. The variation of topography has a significant role on agriculture and natural disasters as well as flood. The low laying part of the upazila is more vulnerable to flood. On the other hand the highly elevated area as a part of traces areas of Bangladesh considered as no flooding zone.

**Gafargaon Upazila**

The upazila Gafargaon is one of the small parts of the study area that is considered as low land. Most of the area found elevated less than 6 meters of which some areas are less than one meter high. The northern part is a little higher than western and southern part which lies between 15 to 18 meters. The upazila seems a plain land in general with some few exception in elevation between Beel area and residential area.

**Muktagacha Upazila**

The upazila Muktagacha considered as a high land in the Brahmaputra-Jamuna flood plain. The average elevation of the upazila is in between 15 to 22 meters with a few exceptions in a little ridge located adjacent to Madhupur upazila in the western side of it. The overall topography found plain land with high quality of soil fertility. A small part of southern portion of the upazila is low land having an elevation about 9 to 11 meters.

**Fulbaria**

The Phulbari upazila has mixed topography having low elevation in the eastern side and high topography in the western part. Eastern side is comparatively lower than other parts of the upazila and most of this part found elevated between 7 to 16 meters. On the other hand the western and south western part of the upazila is quite high having elevation about 19 to 29 meters. The middle portion of the upazila found elevated in between 15 to 22 meters.

**Trisal Upazila**

Trisal upazila located in the eastern border of Brahmaputra-Jamuna basin has found a mixed topographic condition. Before the most southern part to the north found a large area less elevated than other part of the upazila. The northern part of the upazila is comparatively higher and has about 15 to 18 meter elevation where as the southern lower part lies between 1 to 10 meters. The river Brahmaputra (old Brahmaputra) followed by the eastern side of the upazila and has a great influence to flooding. Almost all parts of the upazila found a plain land with beel, Haor and some back swamp area. Topographically the upazila found steeper from north to south with undulating trend.

**Jamalpur Sadar**

Jamalpur upazila is one of the flood free zones of the study area. The upazila found elevated in between 15 to 26 meters from the sea level. The middle portion of the upazila found higher than eastern and western part which found about 23 to 26 miters high. The eastern part has a plain land with high density of population where as the middle portion is topographically undulating with a little variation of elevation. Overall area found moderately elevated in comparing with other part of the study area.

**Madarganj**

Madarganj upazila is elevated in between 15 to 26 meters. The northern part of the upazila is comparatively higher than other parts. On the other hand the western part adjacent to Bogra zila is less elevated (11 to 18 meters). With some few exceptions the total area of the upazila found plain land. The mighty river Jamuna followed by the western side which has a great role in flooding in this region. Topographically the upazila found more steeper from south to north.

**Melandaha**

In analyzing the elevation of the Melandah upazila it is observed that the whole area of the upazila has an undulating trend with a little variation of elevation. Most of the area found lies between 19 to 26 meters high. The eastern and middle parts of the upazila are higher than (23 to 26 meter high) southern part (19 to 22 meter high). Of course some of the areas are found elevated from 11 to 14 meters high. Though the area is comparatively higher than other part of the study area the area has an experience of flooding due to river situation. However the total area of the upazila found complex topographic conditions.

**Sharishabari**

The upazila Sarishabari is completely a plain land that has less steeper from north to south. Most of the area observed elevated from 19 to 22 meters. Only a few area of southern part of the upazila has an elevation of 11 to 14 meters. Topographically the upazila is steeper from south to north keeping similarities with the topography of the region of Bangladesh. The Jamuna river located adjacent to the western part of the upazila.

**Kaliakair Upazila**

Kaliakair upazila is the only upazila that has a great variation in elevation. Some of the areas are less than 10 meters high and some of the areas have more than 30 meters height. Continuation of elevation is rare in this upazila. Low land found about 1 to 6 meters which are most vulnerable to flood. Though the upazila has a trend of gradient lesser from north to south, but the discontinuation of the gradient represents a variety of topographic condition.

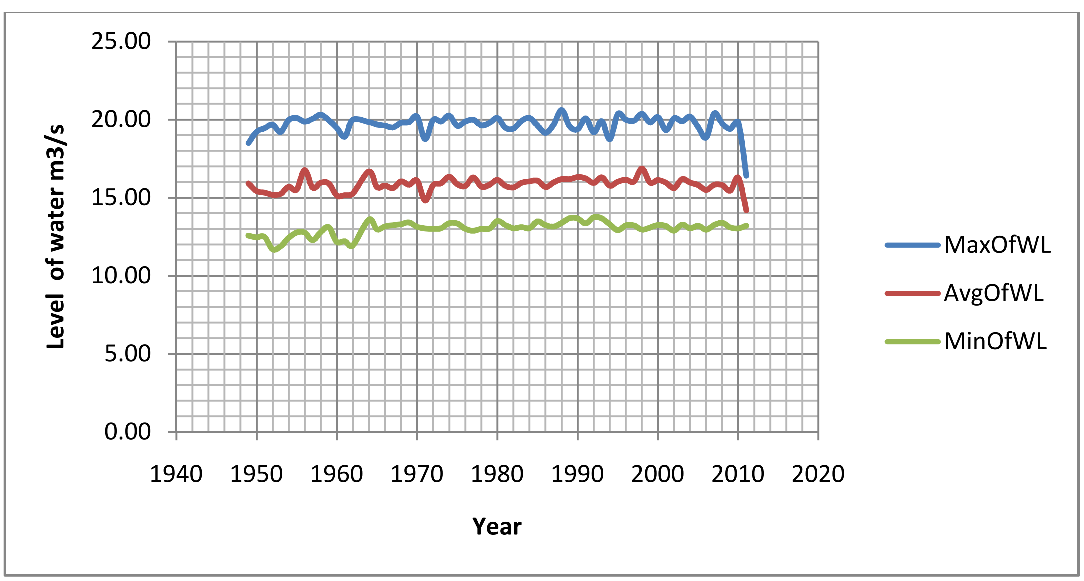
### 4.4 Hydrological Characteristics and Hazard concentration

Floodplains are land areas adjacent to rivers and streams that are subject to recurring inundation. Owing to their continually changing nature, floodplains and other flood-prone areas need to be examined in the light of how they might affect or be affected by development. This section presents an overview of the important concepts related to flood hazard assessments of the Brahmaputra-Jamuna Floodplain.

#### 4.4.1 Water Level Analysis

The hydrological parameter represents moderately fluctuating in maximum and minimum level of water with some few exceptions in the year 1988, 1998 and 2008. The history of the flood shows that the area becomes partly inundated almost every year and the intensity of the flood depends on the level of water, discharge and volume of precipitation of the basin area.

**Figure 4.3 : Maximum, Minimum and Average level of water at Bahadurabad Station in the river Brahmaputra-Jamuna from 1949 to 2011**




*Source : Prepared from BWDB data*

### 4.4.2 Analysis of Maximum and Minimum Water Level at Bahadurabad Station

To analyze the maximum and minimum water level data have been taken from BWDB for the period of 1949 to 2011. A decadal graphical presentation of the water level has been furnished below. For the first decade of 1949 to 1960 the maximum water level crossed the linear level in 1955 and 1957 while severe floods have been recorded. After that in the decade of 1961 to 70 the flood situation of the river basin was almost normal and no historical severe flood was occurred. The interaction between discharge and flood occurrence could easily be guessed from the statistics of the decade. Thus there found decadal variation in water discharge and level of water in the Brahmaputra and Jamuna river. The average elevation of the buffer area of the river is not same. Due to the fact some of the buffering zones were inundated for a short span of time, but no damaging flood was recorded.

Other significant changes of water level found in the decades of 1980 to 1990, 1991 of 2000 and 2001 to 2011. In these decades discharge of water varied and crossed the linear level in 1988, 1995, 1998, 2007 and 2010. The water level sometimes caused devastating flood in the study area especially in the years 1988, 1998 and 2007. The average water level maintained was up to 14.20 to16.87 m3/s. But at the period of devastating flood years the maximum flow of the river Brahmaputra-Jamuna were 20.6, 20.37 and 20.41 respectively for the years 1988, 1998 and 2007.

The ten years highest historical discharges for the River Station Bahadurabad for the decade 2001 to 2011 are shown in figure 3.8. The maximum discharges have been estimated and recordkeeping were done in different dates of different months at several years of the decade. Even though some of the recorded discharge may have some error, the table does indicate that major flooding on the Brahmaputra Basin. It is not new that flood will occur again and in the future in this basin. It should be mentioned that the past flooding record in this basin has coincide with major flooding in Bangladesh.

### 4.4.3 Peak Level of water

The peak stage recorded in the year 1988 at Bahadurabad Station and was 20.61 cm where the danger level was 19.50 cm. The level of water crossed the danger also in 1998, 2004 and 2008 in different months. In the study area almost all the existing rivers flowed above danger level with a little exception. The Teesta, Buriganga, Brahmaputra, Jamuna rivers flows above danger level in monsoon period. Some of the year the flood phenomenon becomes top most hazard of the area as it damages life and properties. In 1955, 1957 and 1958 the peak level was accordingly 20.10, 20.05 and 20.32 cm and identified as peak stage in the river. After a long period again in 1970 the peak level recorded 20.20 cm. It is observed that after 3-5 years a peak level crossed the danger level with severity of flood in this basin. Peak level above 20 cm was found in the following manner :

**Table 4.1 : Peak Level of water crossed danger level (above 20 cm) from 1949 to 2011 at Bahadurabad Station.**

| Year | Peak Level (above 20 cm) | Year | Peak Level (above 20 cm) |
|---|---|---|---|
| 1955 | 20.10 | 1991 | 20.08 |
| 1957 | 20.05 | 1995 | 20.36 |
| 1958 | 20.32 | 1998 | 20.37 |
| 1970 | 20.20 | 2000 | 20.16 |
| 1974 | 20.26 | 2002 | 20.09 |
| 1980 | 20.10 | 2004 | 20.19 |
| 1984 | 20.10 | 2007 | 20.40 |
| 1988 | 20.61 | | |

*Source : Prepared from BWDB data*

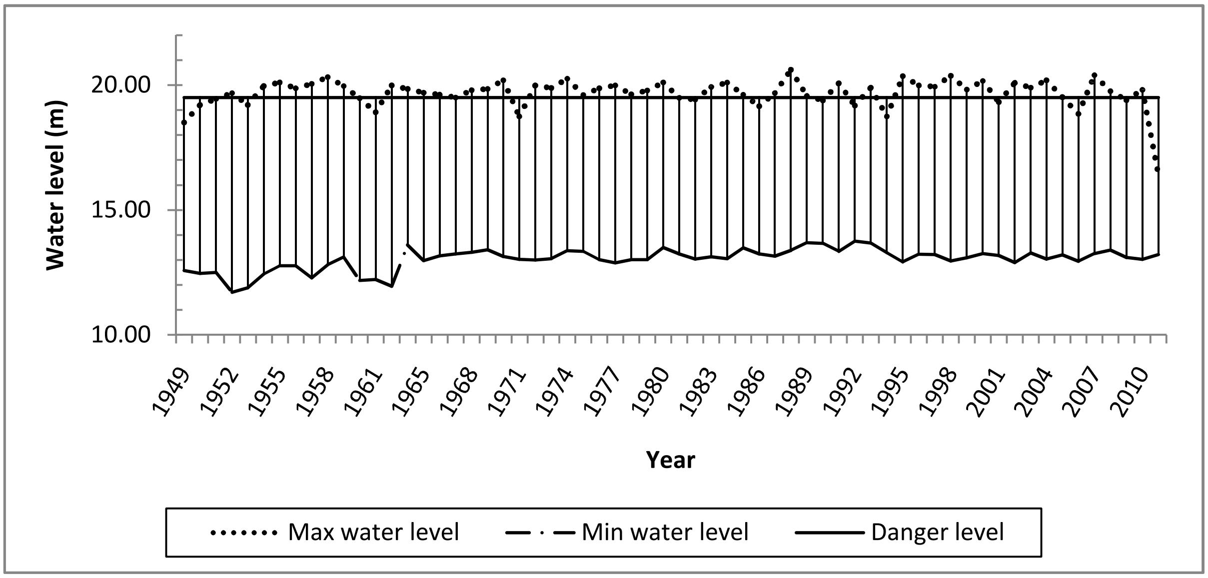
### 4.4.4 Maximum, minimum and average water level at Bahadurabad Station

The water level (maximum, minimum and average) of the basin area has an experience of concentrated high, low and medium volume of water in fluctuating trends. The station Bahadurabad observed significant peak in 1958, 1970, 1974, 1988, 1995, 1998 and 2007. All these year the water level crossed the danger level and inundated the adjacent areas. The comparative hydrograph for average, maximum and minimum water levels are given below for the period of 1949 to 2011.

### 4.4.5 Variation of Water level

The most important phenomenon for the risk assessment of flood of the study area is the analysis of variation of water level and discharge of water in the river. As shown in figure 3.9 the level of water frequently varied in different years and significant turned out have been noticed. This may be a key variable for the occurrence of flood for one dimensional hydraulic approach. It also was observe that the level of water depends on the climatic condition of the catchment area as well as the study area which directly related with the volume of precipitation and supply of ice melted water.

**Figure 4.4 : Maximum and Minimum water level at Bahadurabad Station form 1949 to 2010**




*Source : prepared from BWDB data*

In addition to the flow from upstream in India as well as flow along the main channel river basin, there are several tributaries contribute discharge of the Brahmaputra Jamuna river basin. The basin, especially south of Tibet is characterized by high levels of rainfall. Kangchenjunga (8,586m) is the only peak above 8,000m and the highest point within the Brahmaputra basin. It has been categorized in the estimation of Institute of Water and Flood Management (IWFM) and the wing of the Ministry of Disaster Management that the floods of 1988, 1998 and 2008 were the most devastating floods. In observing the river situation of the study area at that time was found significant variation of water level and discharge while water level exceeded the danger level for a long period of time.

**Table 4.2: Comparison of water level of the three devastating floods at Bahadurabad Station.**

| River | Station | Recorded maximum | Danger level | Peak of the year (m) | Days above danger level |
|---|---|---|---|---|---|

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **(m)** | **(m)** | 2008 | 1998 | 1988 | 2008 | 1998 | 1988 |
| Jamuna | Bahadurabad | 20.62 | 19.5 | 19.75 | 20.37 | 20.62 | 9 | 66 | 27 |

*Source: BWDB flood report, 2008*

The above table shows that the level of water passed danger level in 1988, 1998 and 2008. The most peak level was in 1988 but the duration of the devastating flood was longer in 1998 (66 days) than 1988 (27days). The normal flood stay period of the Bahadurabad Station in Brahmaputra river is about 15- 20 days (from BWDB data).

**Table 4.3 : Flood level and duration in major rivers in Bangladesh**

| **River** | **Gauge Station** | **Mean Bank level (MBL) (PWD) (m)** | **Maximum flood level in specified years (PWD) (m)** | | | | **Continuous duration of flood in days above (MBL)** | | **Flood longest continuous duration above MBL before 1998** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1998 | 1988 | 1987 | 28 Year aver age | 1998 | 28 Yr. average | Year | Duratio n in days |
| Jamuna | Bahadurabad | 48.0 | 93.6 | 98.3 | 73.0 | 67.1 | 77 | 21 | 1966 | 46 |
| Ganges | Harding Bridge | 43.0 | 80.3 | 71.8 | 75.8 | 52.3 | 34 | 14 | 1980 | 40 |
| Padma | Baruria | 75.0 | 136.5 | 132. 0 | 113. 0 | 89.7 | 115 | 21 | 1980 | 57 |

*Source : A.K.M Saiful Islam & J. H. Chowdhury, 2002*

The most remarkable feature of flood situation of the three major rivers of Bangladesh is its very long duration as can be seen from the above table. The long duration of high discharge during 1998 flood in the Jamuna, Padma and Lower Meghna is unprecedented.

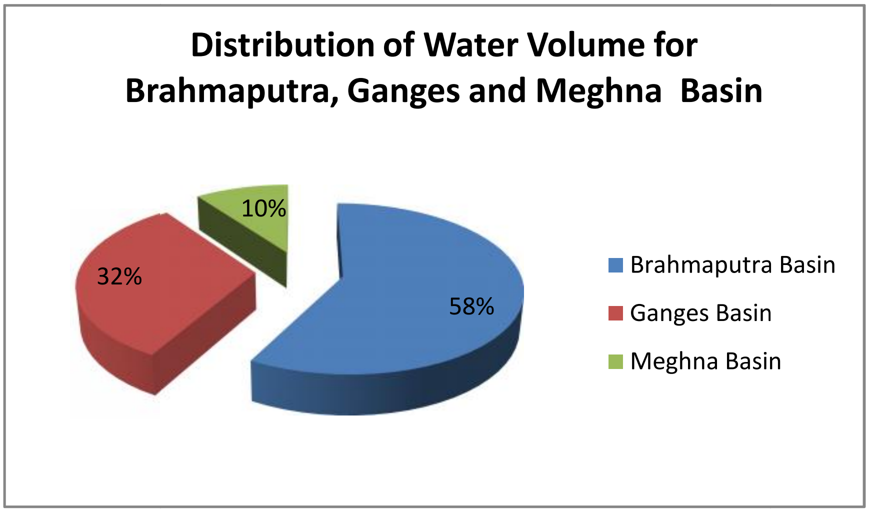
The 1998 flood level at Bahadurabad corresponding to duration of 30 days or more has a return period of greater than 100 years. At Chandpur, the return period of both peak magnitude and duration for 1998 flood has exceeded 100 years. The flood 1998 could be of an example to express the discontinuation of discharge and flow of water in the Brahmaputra river.

### 4.4.6 Distribution of Water Volume

In analyzing the water volume of Brahmaputra, Jamuna and Meghna basin it was found that about one billion m3 water pass over in every year. The highest volume of water (58%)

passed through the Brahmaputra river while Ganges and Meghna basin pass respectively 32% and 10%. Distribution of water volume is as follows :

**Figure 4.5 : Distribution of water volume of three major Basin**




*Source : prepared from hydrological data of BWDB*

As the highest volume of water passing through the Brahmaputra basin, the probability of flood of the basin is higher than that of others two. In the period of high discharge, when cross the danger level residents of low lying areas began shifting to safer places as flood water inundated huge area. Brahmaputra- Jamuna floodplain is one of the most dynamic hydrological system of the world that is a tender landmass framed by three major rivers (Brahmaputra, Jamuna and Burigonga) and fluid landscape. This floodplain is frequently hit by the flood that has serious impact on the livelihood of major population to a great extent. Displacement due to flood and erosion along with inadequate facilities/supports during and after major disasters creates hardship and life-threatening problems to the population specially the poor, women and children.

### 4.4.7 Discharge Analysis

The longitudinal annual average discharge of the river station Bahadurabad Ghat (located in the river Brahmaputra-Jamuna) varies from 16.87 to 14.20 m3/s. The water surface elevation is undulating and for the average discharge for a long period of time (1940 to 2011). The farmers of Bangladesh accommodates to seasonal flooding successfully. These seasonal floods are the result of seasonal variation of hydrological characters of rivers like monthly flow, discharge, water level etc. The river Brahmaputra within the boundary of Bangladesh plays a vital role for the seasonal flooding with its peak level of water. There is very strong relationship between long-term average precipitation and stream flow. Figure 3.10, 3.11 and 3.12 shows the result of watershed precipitation of the river Jamuna. A dike line is also important for the inundation of the area provides geo-information of the dike along the river horizontally and must be complemented with information on the dike height. In the study area the dike line data is not available.

### 4.4.8 Numerical Results

It is analyzed dynamically the numerical results of the discharge of water in ten years interval basis. In the decade 1949 to 1960 the maximum and minimum flow varies in a significant level. For the year 1954, 1955 and 1958 the maximum and minimum level of discharge was comparatively higher. The flood history of the above mentioned years shows that there were severe floods in 1954, 1955 and 1959 and it could easily be remarked that the causes of flood was high discharge of the river. Moreover the contribution of the basin rainfall was also taken as contributing factors for flood. Figure 3.3 shows the maximum and minimum water level of the river Jamuna.

The maximum discharge in the Brahmaputra Basin was ascertained in different years and in different months. The above table represents the scenarios of monthly discharge of water from 1976 to 2012 where the highest discharge were in the month of July almost every year with some few exception in 1986 and 1987 while the discharge of water for the month of September represents almost equal to the month of July. The lowest level was in the month of June in 1990 and April in 1989. In the monsoon the river discharge found higher than other seasons of Bangladesh due to direct influence o climatic reasons.

In this basin, almost all the rivers flowed above its respective danger level except Brahmaputra and Noonkhawa, Teesta and Kaunia, Old Brahmaputra at Mymensingh and Jamalpur and Burigonga at Dhaka for one to six weeks during the monsoon in 2008. The flood phenomenon was not severe in this basin in comparison with other flooding year like 1998 and 2004. The historical flood of the Brahmaputra Basin represents the three major floods includes some important stations. Comparative water level of the three major flood are given below:

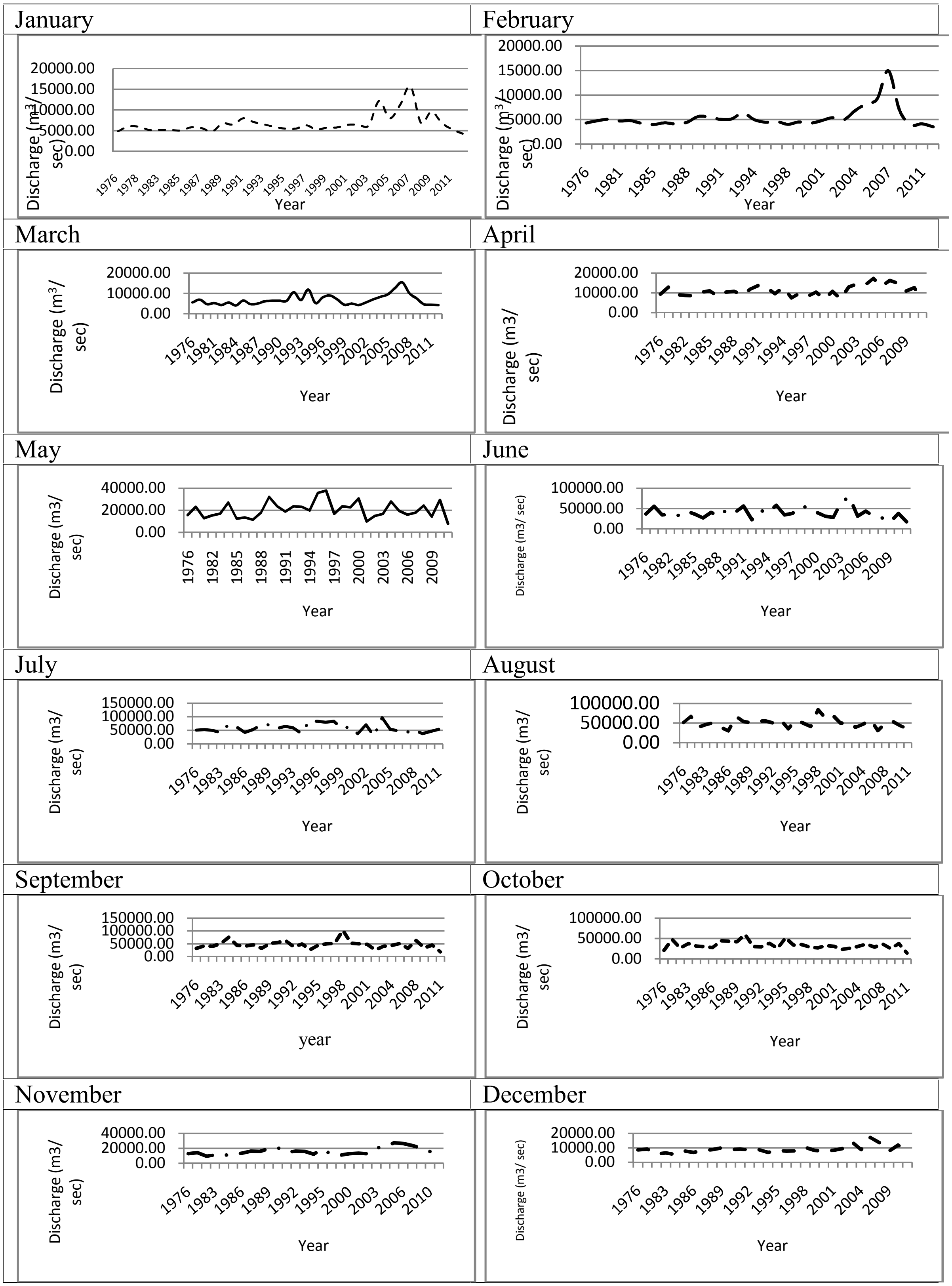
**Table 4.4 : Comparison of Water Level of the historical events of three major floods in 1988, 1998 and 2008 of some important stations in Brahmaputra Basin.**

| Sl No | River | Station | Recorded Maximum (m) | Danger Level (m) | Peak of the Year (m) | | | Days above Danger level | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2008 | 1998 | 1988 | 2008 | 1998 | 1988 |
| 1 | Dharla | Kurigram | 27.66 | 26.50 | 26.98 | 27.22 | 27.25 | 11 | 30 | 16 |
| 2 | Teesta | Dalia | 52.97 | 52.25 | 52.42 | 52.50 | 52.89 | 2 | - | 8 |
| 3 | Teesta | Kaunia | 30.52 | 30.00 | 28.91 | 29.91 | 30.43 | - | - | 38 |
| 4 | Brahmaputra | Noonkhawa | 28.10 | 27.25 | 26.82 | 27.35 | NA | - | - | NA |
| 5 | Brahmaputra | Chilmari | 25.06 | 24.00 | 24.02 | 24.77 | 25.04 | 1 | 22 | 15 |
| 6 | Jamuna | Bahadurabad | 20.62 | 19.50 | 19.75 | 20.37 | 20.62 | 9 | 66 | 27 |
| 7 | Jamuna | Serajgonj | 15.12 | 13.75 | 14.33 | 14.76 | 15.12 | 19 | 48 | 44 |
| 8 | Jamuna | Aricha | 10.76 | 9.17 | 9.82 | 10.76 | 10.58 | 21 | 68 | 31 |
| 9 | Old Brahmaputra | Jamalpur | 18.00 | 17.00 | 16.97 | 17.47 | 17.83 | - | 31 | 8 |
| 10 | Old Brahmaputra | Mymensingh | 14.02 | 12.50 | 11.89 | 13.04 | 13.69 | - | 33 | 10 |
| 11 | Burigonga | Dhaka | 7.58 | 6.00 | 5.72 | 7.24 | 7.58 | - | 57 | 23 |
| 12 | Lakhya | Narayangonj | 6.71 | 5.50 | 5.91 | 6.93 | 6.71 | 37 | 71 | 36 |
| 13 | Turag | Mirpur | 8.35 | 5.94 | 6.10 | 7.97 | NA | 13 | 70 | NA |
| 14 | Tongi Khal | Tongi | 7.84 | 6.08 | 6.20 | 7.54 | NA | 12 | 66 | NA |
| 15 | Kaligonga | Taraghat | 10.39 | 8.38 | 9.29 | 10.21 | 10.39 | 24 | 66 | 65 |

*Source : Annual Flood Report, BWDB, 2008*

Monthly highest discharge of the Bahadurabad station exceeds the danger level in the period of 1976 to 2011 several times. This means the discharge of water and the level of water found in changing nature every year and every month. The monthly recorded highest discharge of water of the same station is graphically presented.

**Figure 4.6 : Monthly highest discharge of the Bahadurabad from 1976 to 2011**




*Source : Prepared from BWDB data*

### 4.4.9 Area affected by flood in Bangladesh (Statistics of flooding)

Many parts of the Asia during monsoon frequently suffer from severe floods. Bangladesh experiences floods almost every year with considerable damage. The flood of 1987, 1988, 1998, 2004 and 2007 flood caused heavy damaged but the flood of 2008 was not sever and stayed little time. Flood statistics for Bangladesh are available since 1976 and are summarized in table below :

**Table 4.5: Year wise flood affected area in Bangladesh(1975-2008)**

| Year | Food affected area | | Year | Food affected area | |
|---|---|---|---|---|---|
| | sq km. | % | | sq km. | % |
| 1975 | 16,600 | 11 | 1992 | 2,000 | 1.4 |
| 1976 | 28,300 | 19 | 1993 | 28,742 | 20 |
| 1977 | 12,500 | 8 | 1994 | 419 | 0.2 |
| 1978 | 10,800 | 7 | 1995 | 32,000 | 22 |
| 1979 | --- | --- | 1996 | 35,800 | 24 |
| 1980 | 33,000 | 22 | 1997 | --- | --- |
| 1981 | --- | --- | **1998** | **1,00,250** | **68** |
| 1982 | 3,140 | 2 | 1999 | 32,000 | 22 |
| 1983 | 11,100 | 7.5 | 2000 | 35,700 | 24 |
| 1984 | 28,200 | 19 | 2001 | 4,000 | 2.8 |
| 1985 | 11,400 | 8 | 2002 | 15,000 | 10 |
| 1986 | 6,600 | 4 | 2003 | 21,500 | 14 |
| 1987 | 57,300 | 39 | 2004 | 55,000 | 38 |
| **1988** | **89,970** | **61** | 2005 | 17,850 | 12 |
| 1989 | 6,100 | 4 | 2006 | 16,175 | 11 |
| 1990 | 3,500 | 2.4 | **2007** | **62,300** | **42.21** |
| 1991 | 28,600 | 19 | 2008 | 33,655 | 22.8 |

*Source: BWDB, 2008.*

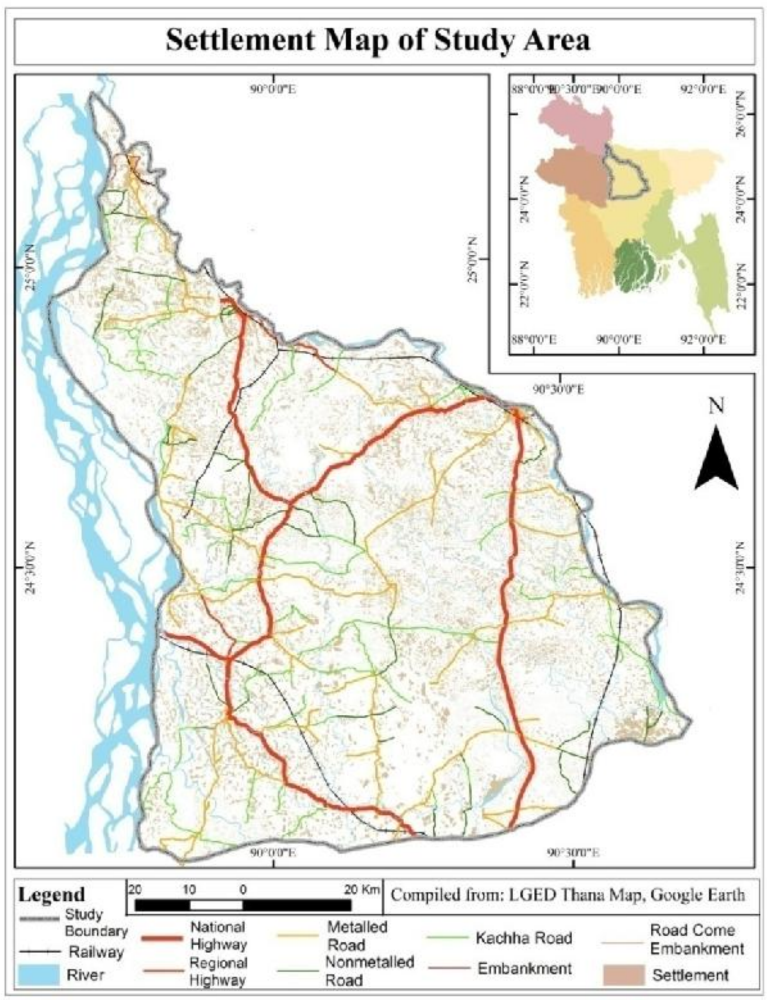
## 4.5 Household Parameter and Hazard concentration

### 4.4.1 Settlement Pattern of the Study area

The Brahmaputra Jamuna basin found mixed types of population density all over the area. Some area found very densely populated, on the other hand some area found scattered types of human settlement. Some of the traces area found almost settlement less. Flood vulnerability and adaptation is one of the major criterions to develop human settlement in this area.

Adaptation in human settlement is at present the prime need of the study area as well as Bangladesh due to the fact that a large portion of the country's population is exposed to the risk of inundation and it is not possible to retreat the entire affected population considering the high population density of the country. Adaptation measure in agriculture is already in progress which in fact widens the opportunity for settlement adaptation in the study area. Structural and non structural measures of copping practiced by the local community to reduce vulnerability of their built environment to existing water related hazards can also serve as means of adapting to anticipated flood vulnerability. The settlement scenarios of the Brahmaputra-Jamuna Flood Plain has been analyzed based on LGED upazila boundary and SRTM data given below :

**Figure 4.7 : Settlement Pattern of the Brahmaputra-Jamuna Basin**




*Source : Prepared from SRTM data*

**Table 4.6 : Upazila wise household and population density**

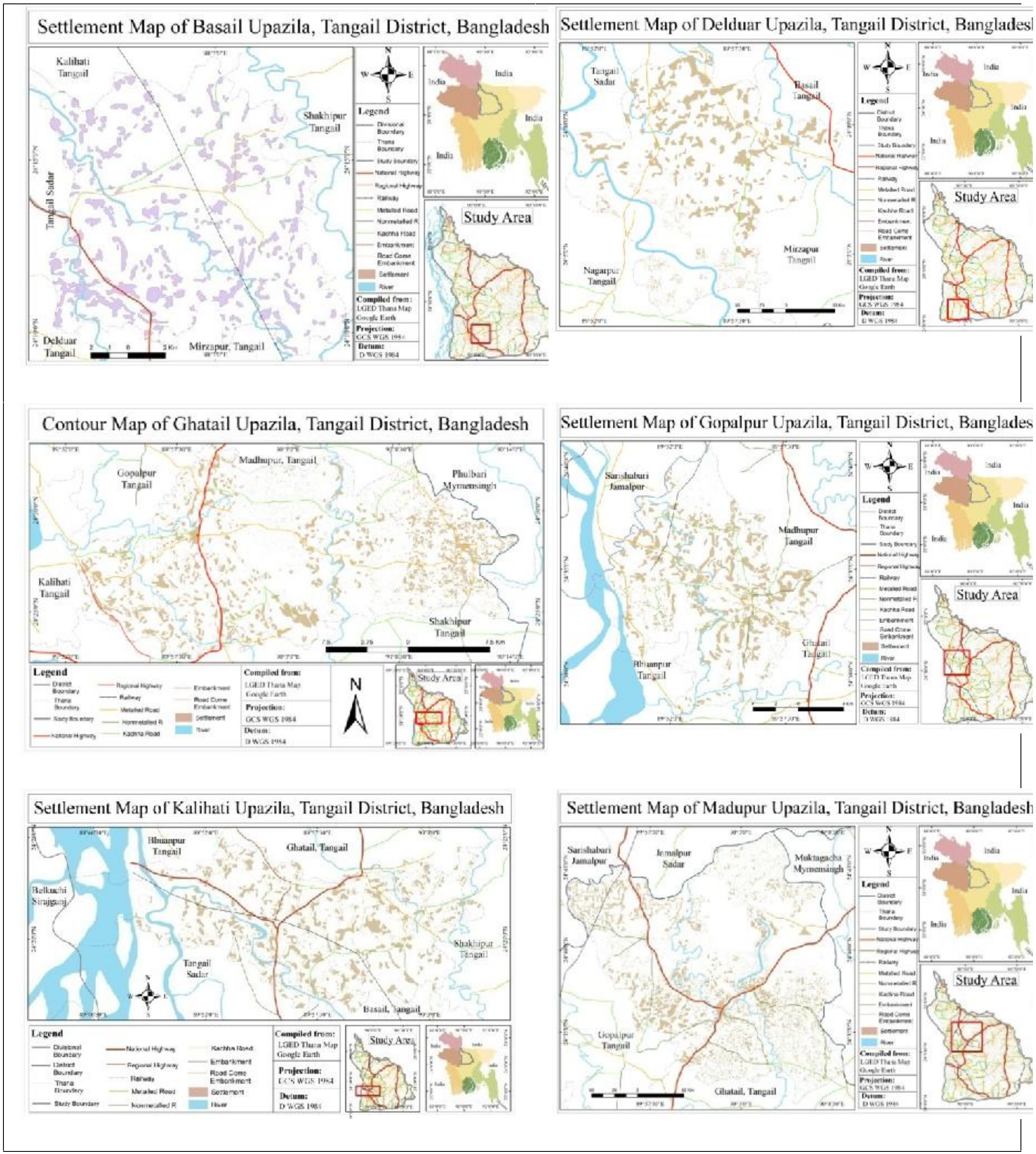
| Sl. No. | Name of the Upazila | Area (Sq. km) | Unit of House hold | Total population | Density per sq. km |
|---|---|---|---|---|---|
| 1. | Basail | 157.78 | 27481 | 148555 | 941.5325 |
| 2. | Delduar | 184.54 | 32696 | 175684 | 952.0104 |
| 3. | Ghatail | 451.30 | 68153 | 341376 | 756.4281 |
| 4. | Gopalpur | 193.37 | 49976 | 252747 | 1307.064 |
| 5. | Kalihati | 301.22 | 65035 | 354959 | 1178.404 |
| 6. | Madhupur | 500.67 | 74984 | 375295 | 749.5856 |
| 7. | Mirzapur | 373.89 | 61479 | 337496 | 902.6612 |
| 8. | Sakhipur | 429.63 | 44314 | 220281 | 512.7226 |
| 9. | Tangail Sadar | 334.26 | 69783 | 680518 | 2035.894 |
| 10. | Bhaluka | 444.05 | 53222 | 264991 | 596.7594 |
| 11. | Gafargaon | 401.16 | 73130 | 379803 | 946.7619 |
| 12. | Muktagacha | 314.71 | 64044 | 321759 | 1022.398 |
| 13. | Fulbari | 402.41 | 68469 | 345283 | 858.0378 |
| 14. | Trisal | 338.98 | 79941 | 336797 | 993.5601 |
| 15. | Jamalpur Sadar | 489.56 | 102579 | 501924 | 1025.255 |
| 16. | Madargonj | 225.38 | 41058 | 24306 | 107.8445 |
| 17. | Melandaha | 239.65 | 55954 | 262478 | 1095.256 |
| 18. | Sharishabari | 263.48 | 58254 | 289106 | 1097.26 |
| 19. | Kaliakair | 314.14 | 45565 | 232915 | 741.4369 |

*Source : BBS, 2010*

### 4.5.2 Upazilawise Settlement Pattern

For the detail analysis of density of population or settlement coverage of the Brahmaputra-Jamuna Floodplain, the study area has been divided into 19 units (following Upazila boundary with a little exception) and settlement scenarios for the each units are described below:

**Figure 4.8 : Upazilawise settlement coverage map**

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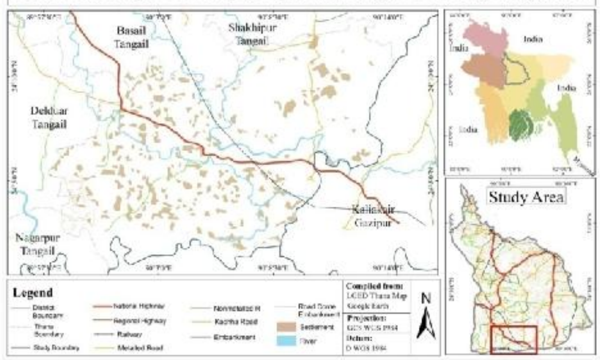
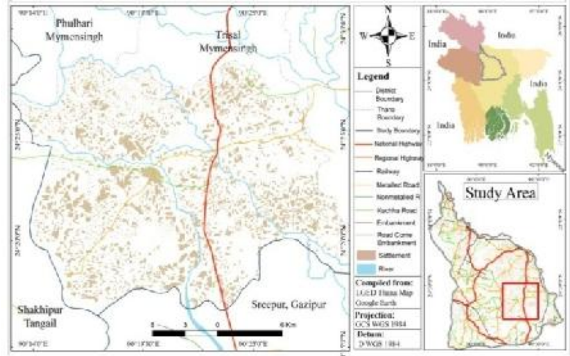
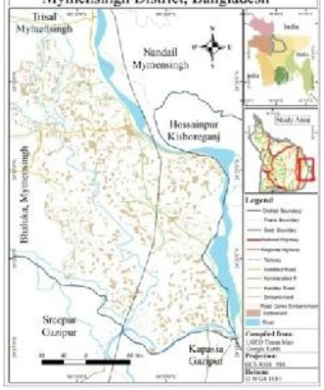
Settlement Map of Mirzapur Upazila, Tangail District, Bangladesh



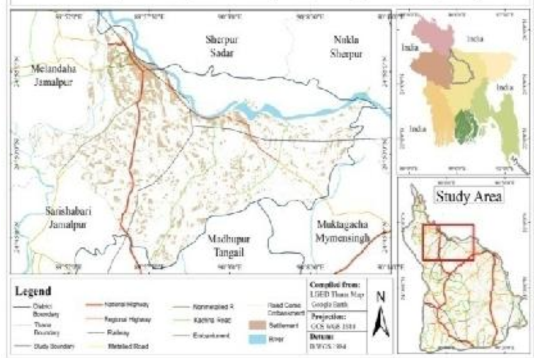

Settlement Map of Bhaluka Upazila, Mymensingh District, Bangladesh



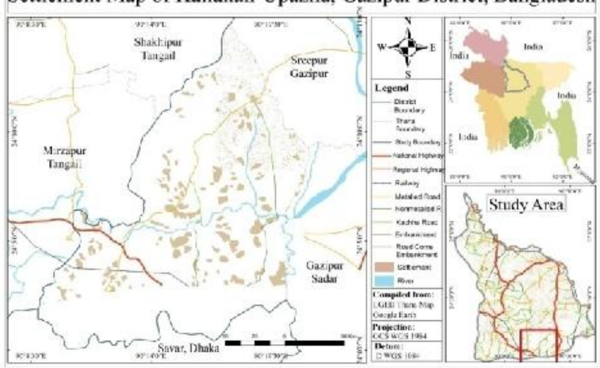

Settlement Map of Gafargaon Upazila Mymensingh District, Bangladesh



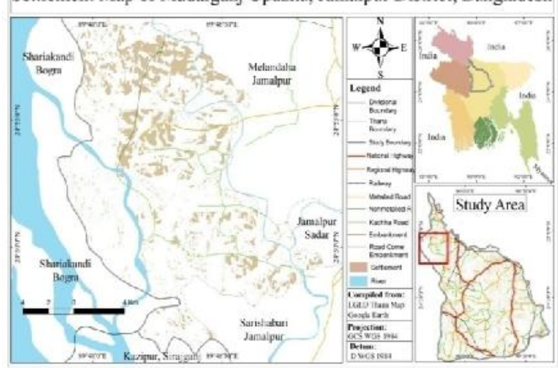

Settlement Map of Jamalpur Sadar Upazila, Jamalpur District, Bangladesh



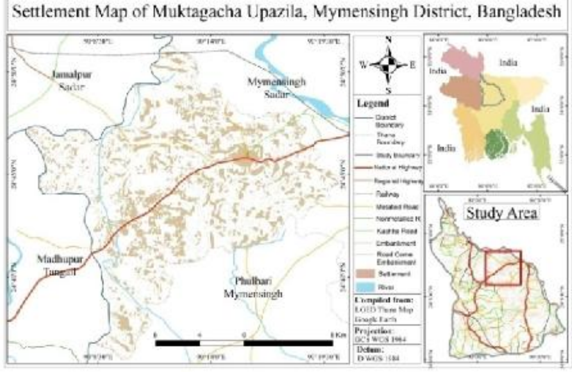

Settlement Map of Kaliakair Upazila, Gazipur District, Bangladesh



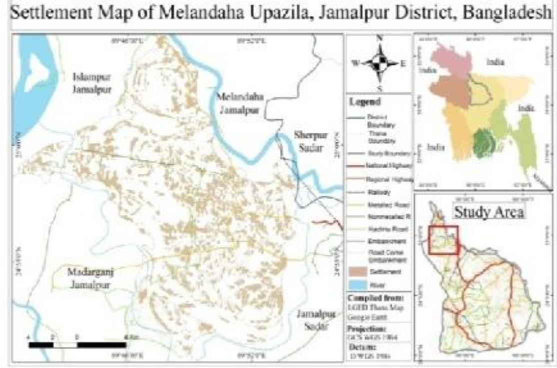

Settlement Map of Madarganj Upazila, Jamalpur District, Bangladesh




Settlement Map of Muktagacha Upazila, Mymensingh District, Bangladesh




Settlement Map of Melandaha Upazila, Jamalpur District, Bangladesh



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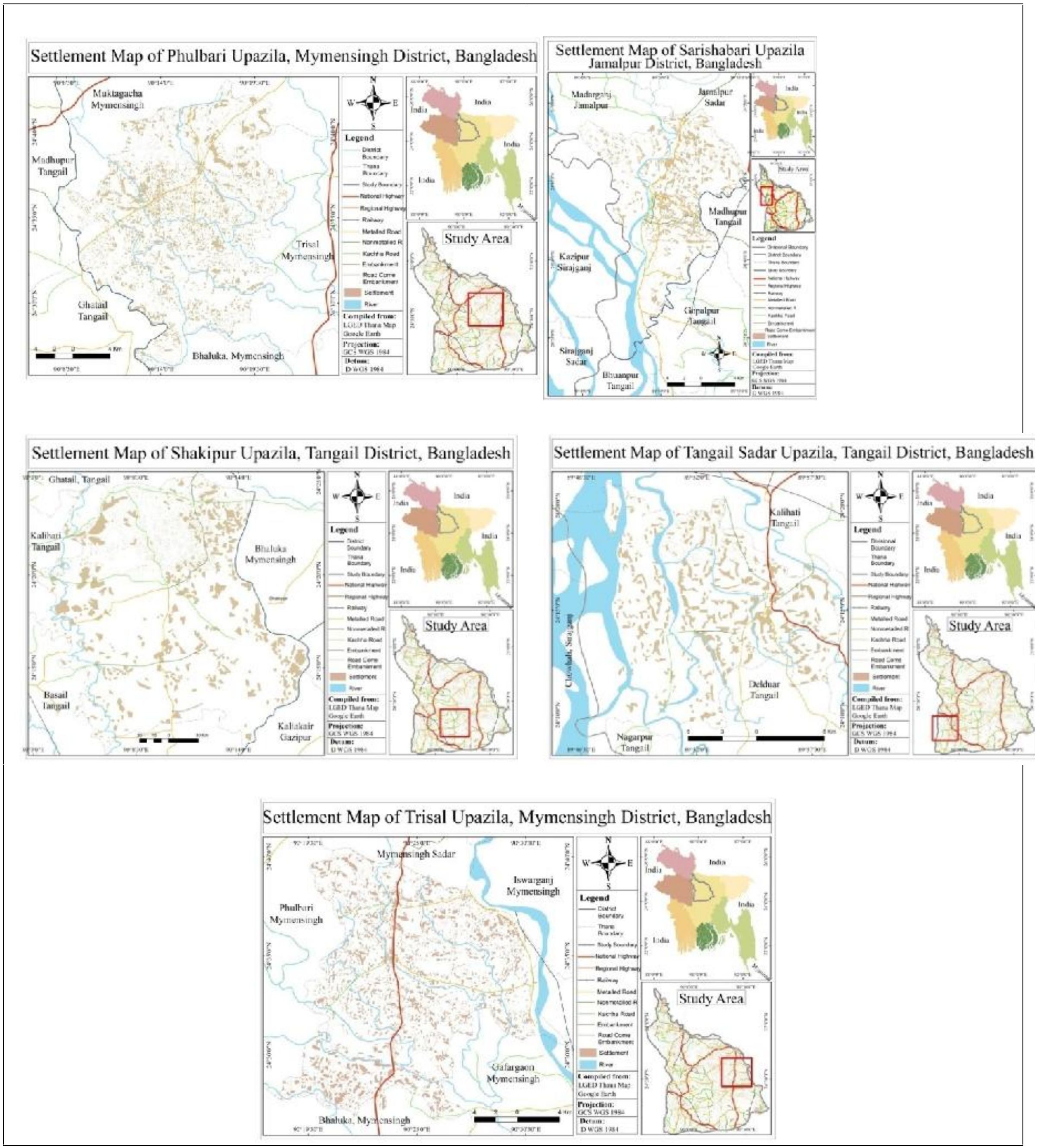



*Source : Prepared from SRTM data*

### 4.5.3 Description of elevation (upazilawise)

**Basail Upazila**

Settlement of the Basail Upazila found scattered in the whole area of the Upazila. It is found that the land with high risk of flood also using as residential area. On the other hand some risk free zones of the flood[lain (study area) are free of habitation. This is happening due to ownership of the land and due to lack of knowledge of flood loss prevention and the susceptibility to flooding correctly.

**Delduar Upazila**

The upazila Delduar located at the south-western part of the study area consisting almost plane land all over the area with a little exception in the north-eastern part of it. The settlement mostly found in the northern part of the upazila and scattered in shape. Most of the area found 7 to 10 metre in elevation. Some of the north western part of the upazila also found 15 to 18 metre elevated. The southern part of the upazila has a few numbers of human settlements.

**Ghatail Upazilla**

The settlement map of the upazila Ghatail shows that human settlement developed depending on the topographic condition of the upazila. The middle portion of the upazila containing a part of the Madhupur Traces (a major physiographic unit of Bangladesh) found almost free of human settlement. The eastern part of the upazila found densely populated and the western part is medium dense area. The main landscape type of the area has a great influence in the development of settlement as observed the pattern of the human settlement.

**Gopalpur Upazilla**

The settlement map of the Gopalpur upazila shows the scenarios that the middle portion of the upazila is comparatively heavily populated. The population density of the northern part of the upazila is found less than central part. The southern part of the upazila is less elevated and the human settlement is also found lesser than western and eastern part.

**Kalihati Upazilla**

Kalihati upazila of the study area found sparsely distribution of population. Small town and slum dwellers are found noticeable. The settlements of the western part of the upazila found most unstable as a result of channel shifting of the Brahmaputra-Jamuna river. The northern and eastern part of the upazila found comparatively less populated area.

**Madhupur Upazilla**

Human settlements in the Madhupur upazila have an antiquated history. The present vegetation cover and the landscape indicate several millennia of human activity and interference, and they have derived their character from the pattern of human settlements.

A large area of the upazila is covering natural vegetation where found almost settlement free. A major part of the upazila was initially unsuitable for human occupation. The northern and eastern part of the upazila found very scattered settlement while the western part found densely populated. The elevation and vegetation coverage found a dominating role in developing human settlement in this upazila.

**Mirzapur Upazilla**

The land elevation pattern of the Mirzapur upazila acted as an important factor in the initial stage of settlement development since a greater part of the upazila is higher in elevation than other parts. The north-eastern part of the upazila found a lesser amount of settlement comparing with the eastern and southern parts. A scenario of sporadic settlement in the north-eastern part is observed. Huge area in the north-eastern part found empty settlement where forest coverage and elevated land is observed.

**Bhaluka Upazila**

The scenarios of the settlement of Bhaluka upazila is little more exception. In the town area dense settlement are found especially developed in the road side. The western and south western parts of the upazila are comparatively higher than the north-eastern part. Settlements are found dense in the south western part keeping similarities with the elevation of land.

**Gafargaon Upazila**

The upazila Gafargaon is comparatively lower in elevation from its adjacent area. The middle portion of the area is lower than western and eastern parts. In this area flood frequency found vulnerable from the past history. The upazila found gradually shrinkage of agricultural land in the north and human settlement of the upazila same is found scattered.

**Jamalpur Sadar**

The settlement scenario of Jamalpur upazila shows an exception to other upazila of the district (Jamalpur). The northern part of the upazila is over populated and the other three sides (eastern, western and southern) of the upazila are found low density of human settlement. The upazila is almost flood free zone of the study area. The northern part is developed in respect of utility services and urbanization. It is also a vital cause of gathering human settlement.

**Kaliakair Upazila**

The upazila kaliakair is located in the southern part of the study area surrounded by Savar to the south, Gazipur and Sreepur to the East, Shakhipur and Mirzapur to the north-west. The settlement pattern of the upazila found similar to the Gopalpur upazila of the study area. North and north-eastern parts of the upazila are found dispersed settlement. The middle portion of the upazila found high density with cluster in pattern.

**Madargonj Upazila**

The Madargonj upazila of Jamalpur district found exception in the trend of human settlement. The evidence of settlement found dominating role of river in the development and expansion of the same. As the area is entirely located in the Barind Tract (one of the major physical feature of the country) it has influence of elevation pattern in developing human settlement. It is found that the density of population is in declining trend from the north towards the south of this upazila. Northern part is highly populated while the southern part observed dispersed settlement.

**Melandaha Upazila**

The upazila Melandaha found a traditional pattern of human settlement. Middle portion of the upazila is densely populated while northern and western parts found reduction of settlement. Major pockets of human settlement existed along the fertile valleys of agricultural value. There is evidence of some sporadic settlement in the western part of the upazila. River valleys along the natural levees have the most important influence on developing human settlement in this upazila as agricultural potential exist because of the regular renewal of soil.

**Muktagacha Upazila**

The middle portion of the upazila found dense settlement while a small number of dwellings grouped together living in the western part of the upazila. Both towns and villages are found. The topographic condition of the upazila has a great influence to build up human settlement pattern. A small ridge located in the western part of the upazila found almost settlement free.

**Phulbari Upazila**

Settlement pattern of the upazila Phulbari found very common with other parts of the country Bangladesh. Due to geographical scene the western and the south-western parts of the upazila found almost settlement free as the area is higher in elevation. The middle part of the upazila found populated place is defined as a place or area with clustered and scattered buildings and a permanent human population (city, settlement, town, village or hamlet).

**Sharishabai Upazila**

Sarishabari upazila of Jamalpur district has an exceptional pattern of human settlement. The southern part of the upazila found almost settlement free. The middle and middle-eastern part of the upazila found cluster population while the southern part found almost population free. The north eastern part of the upazila is higher in elevation that makes the area more suitable for the development of human settlement. Other parts are found dispersed settlement.

**Shakipur Upazila**

The shakipur upazila of Tangail district found exception in developing human settlement due to its topographic conditions. Most of the area is high land and some of the area is higher covered with natural forest. Human settlement found developed in the north eastern and eastern parts of the upazila. Some clustered settlement found in the north western part while the southern and middle parts of the upazila found almost less populated.

**Tangail Sadar Upazila**

The land elevation pattern of Tangail Sadar upazila acted as an important factor in the initial stage of settlement development in the area, since the greater part of the upazila is riverine, wet, and low-lying plains must originally have consisted of forest and marshes and were infested with killer animals throughout the prehistoric period. Even in the historical past, a major part of the area was initially unsuitable for human occupation. But now the upazila found developing in agriculture, urbanization, and industrialization which have been playing vital role in developing human settlement. The number of population is increasing day by day.

**Trisal Upazila**

Trisal upazila relatively older and elevated areas were thought to be the places of early human occupancy in Bengal. Available evidence gives an indication that during the Pleistocene period Paleolithic culture was present in the older and the low mountainous areas in and around the region now forming Bangladesh. It also seems that the Barind Terrace may have been one of the few places where settlements first developed. The south was either marshy or estuarine and deeply forested and unfit for human habitation for long. Trisal is one of the areas of ancient settlements of the study area where scattered settlement found all over the upazila.

### 4.6 Hazard Index Identification

In a land unit, flooding of different depths and duration may occur. So, it is essential to estimate the mean hazard index (MHI) for each land unit. The MHI was calculated separately for depth and duration considering the percentage of land under each category. According to the Hydrological Process (John Wiley & Sons, Ltd. 2005) the MHI is furnished by the following equation :

$$\{ \sum_{i=1}^{n} (HI)_i \, A_i \} / \sum_{i=1}^{n} (H) A_i$$

Where, (HI) = Hazard Index of land area Ai of hazard category

n = is the total number of land areas in the land unit.

Hazard Index for the study area in analyzing the depth and duration of flooding are shown below :

**Table 4.7 : Hazard index for depth of flooding**

| **Depth (D) of flooding (m)** | **Flood Depth category** | **Hazard category** | **Hazard Index** | |
|---|---|---|---|---|
| | | | Alternative 1 | Alternative 2 |
| $0< D \leq 0.6$ | 1 | Low | 1 | 2 |
| $0.6< D \leq 1.0$ | 2 | Medium | 2 | 3 |
| $1.0< D \leq 3.5$ | 3 | High | 3 | 4 |
| $3.5< D$ | 4 | Very High | 4 | 5 |

*Source : Based on Tawatchai Tingsanchali, Wiley & Sons Ltd.2005*

**Table 4.8 : Hazard index for duration of flooding**

| **Duration of flooding** | **Duration category** | **Hazard category** | **Hazard Index** | |
|---|---|---|---|---|
| | | | Alternative 1 | Alternative 2 |
| Short | 1 | Low | 1 | 0 |
| Medium | 2 | Medium | 2 | 1 |
| Long | 3 | High | 3 | 2 |
| Very Long | 4 | Very High | 4 | 3 |

*Source : Based on Tawatchai Tingsanchali, Wiley & Sons Ltd.2005*

## 4.7 General Hazard Index

According to the above mentioned index of hazard, the whole area were taken into consideration in respects of all parameters deliberated in this study. Each of the upazila of the study area brought under analysis of hazard identification in respects of elevation, settlement, and water volume categorized as follows :

**Table 4.9 : Upzilawise Hazard Index and Hazard Category of the study area**

| Sl. No. | Name of the Upazila | Area (Sq. km) | Percentage | Hazard Index | Hazard category | Comments |
|---|---|---|---|---|---|---|
| 1. | Basail | 157.78 | 2.48 | 4 | Very high | Whole area |
| 2. | Delduar | 184.54 | 2.90 | 3 | High | Whole area |
| 3. | Ghatail | 451.30 | 7.10 | 1 | Low | Middle and eastern part |
| | | | | 2 | Medium | Western and middle part |
| 4. | Gopalpur | 193.37 | 3.04 | 1 | Low | Whole area |
| 5. | Kalihati | 301.22 | 4.74 | 2 | Medium | Western part |
| | | | | 3 | High | Eastern part |
| 6. | Madhupur | 500.67 | 7.87 | 1 | Low | North-eastern part |
| | | | | 2 | Medium | South-western part |
| 7. | Mirzapur | 373.89 | 5.88 | 1 | Low | North-eastern part |
| | | | | 4 | Very high | Western and southern part |
| 8. | Sakhipur | 429.63 | 6.75 | 3 | High | Western part with a few exception |
| | | | | 1 | Low | North, South and Eastern part |
| 9. | Tangail Sadar | 334.26 | 5.25 | 2 | Medium | Rest of the area |
| | | | | 3 | High | Eastern part |
| 10 | Bhaluka | 444.05 | 6.99 | 2 | Medium | Rest of the area |
| | | | | 4 | Very high | North-eastern region-Partly |
| 11 | Gafargaon | 401.16 | 6.30 | 4 | Very high | Southern and middle portion of the upazila |
| | | | | 3 | High | North-eastern part |
| 12 | Muktagacha | 314.71 | 4.94 | 1 | Low | Northern part |
| | | | | 2 | Medium | A few portion of south & south eastern part |
| 13 | Phulbari | 402.41 | 6.32 | 1 | Low | Western part |
| | | | | 2 | Medium | Middle-eastern part |
| 14 | Trisal | 338.98 | 5.32 | 2 | Medium | Northern part |
| | | | | 3 | High | Middle- Southern part |
| 15 | Jamalpur Sadar | 489.56 | 7.70 | 1 | Low | Whole area |
| 16 | Madargonj | 225.38 | 3.54 | 1 | Low | Whole area |
| 17 | Melandaha | 239.65 | 3.77 | 1 | Low | Whole area |

| | | | | | | |
|---|---|---|---|---|---|---|
| 18 | Sharishabari | 263.48 | 4.14 | 1 | Low | Maximum of the upzilla |
| | | | | 2 | Medium | A little portion of southern part |
| 19 | Kaliakair | 314.14 | 4.93 | 2 | Medium | Middle western part |
| | | | | 4 | Very high | South-western and |
| 20 | Bhuapur | | | 3 | High | Whole area |
| 21 | Nagarpur | | | 4 | Very high | Whole area |
| 22 | Gazipur | | | 1 | Low | Whole area |
| 23 | Sreepur | | | 2 | Medium | Whole area |
| | Total | 6360.18 | 100% | | | |

*Source : Prepared based on hazard index*

In a land unit, flooding of different depths and durations may occur. So it is essential to estimate the mean hazard index for each land unit. Keeping this in mind hazard index for 19 unit of the study area (upazila wise) was calculated separately based on elevation, settlement, depth of water and duration of flooding. Vulnerability Map of the study area according to hazard index has been prepared (figure 6.5)

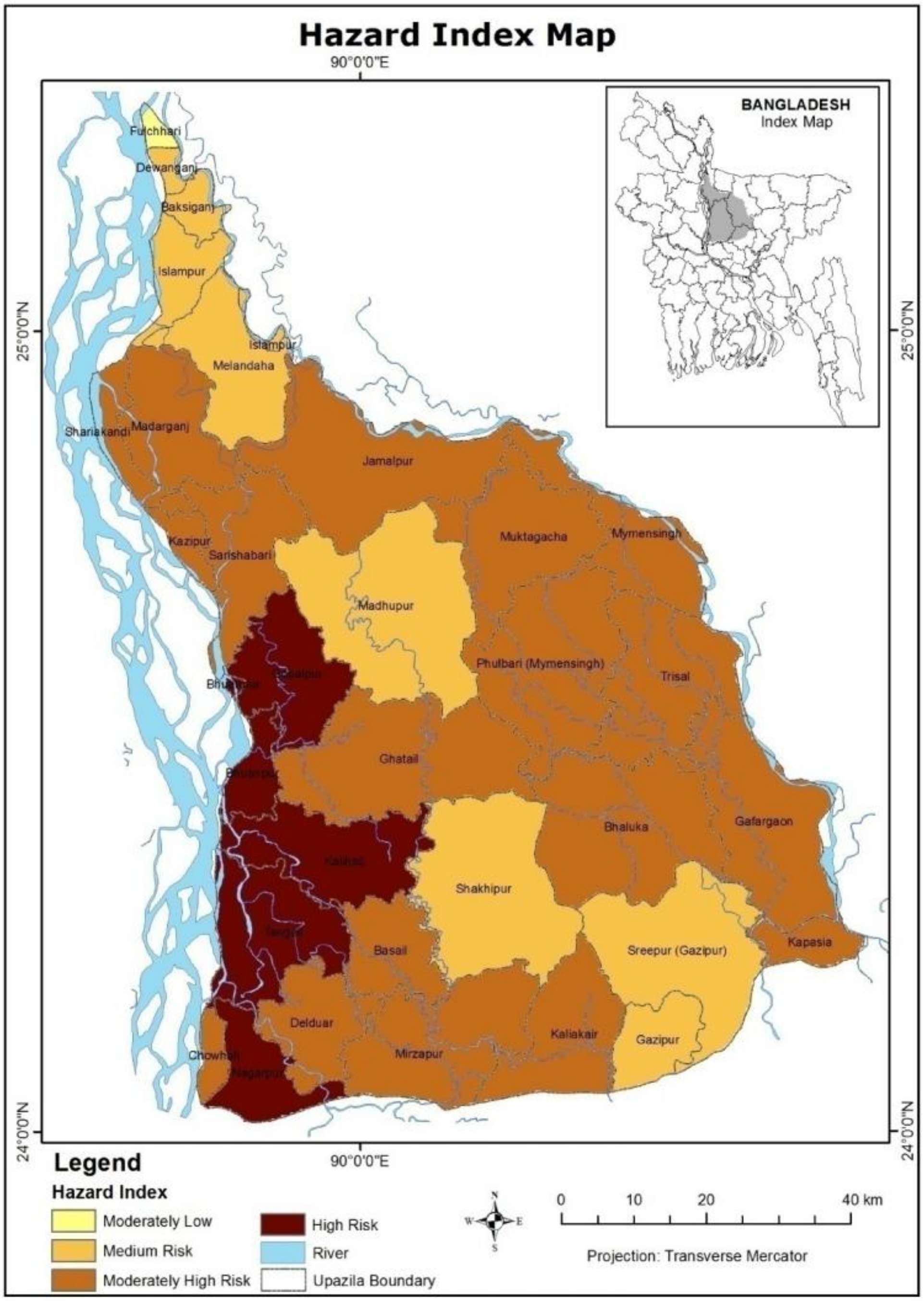
**4.7 Preparing flood Hazard maps**

The most effective way of reducing the risk to people and property is through the production of flood hazard maps. Most countries in the developed world will have produced maps which show areas prone to flooding events of known return periods. In Bangladesh, the Environment Agency, CEGIS, SPARRAO, BWDB, IWM, DMB, etc. organizations have produced maps which show areas at risk and normally flooded areas of the country.

By identified areas of known flood risk, the most sustainable way of reducing risk is to prevent further development in those known flood risk areas. It is important for risk communities to develop a comprehensive flood management plan. Those communities that participate in the national flood control program must agree to regulate development in the most flood prone areas. Communities should assign a floodplain administrator to oversee the management of the floodplain development permit process. In considering the intensity of flood of the study area, a hazard map has been prepared so that the people of the study area can have a prior idea about the flood hazard and can identify flood prone area with determination of flood intensity.

The flood hazard map of the study area prepared considering all parameters through the model is given below:

**Figure 4.9 : Flood Hazard Map for the Brahmaputra-Jamuna River basin**




*Source : Produced as of Arc GIS model*

The above hazard map shows that maximum parts of the study found moderately hazardous. A major portion in the south-western part especially Tangail, Kalihati, Bhuapur, Nagarpur and Gopalpur are highly hazardous.

### 4.9 Hazard Characterization and Concluding remarks

Hazards associated with flooding can be divided into primary hazards that occur due to contact with water, secondary effects that occur because of the flooding, such as disruption of services, health impacts such as famine and disease, and tertiary effects such as changes in the position of river channels. Throughout the last century flooding has been one of the most costly disasters in terms of both property damage and human casualties. Major floods in the study area, for example, flood in 1987, 1988, 1998, 2004 and 2007 killed many people and damaged huge properties.

It is seen in the study area that peoples (human) can modify the landscape in many ways. Sometimes humans attempt to modify drainage systems to prevent flooding, but sometimes these efforts have adverse effects and actually help to cause flooding in other areas. Any modification of the landscape has the potential to cause changes in the drainage system, and such changes can have severe consequences.

Whenever humans modify the landscape in any way changes are to be expected in the way water drains from the land. Unless careful consideration is given to the possible drainage consequences, such landscape modifications can result in higher incidence of flooding considered as vulnerability. Any kind of development on floodplains should therefore be undertaken only with great care.

## 5.0 Introduction

Vulnerability refers to the inability to withstand the effects of a hostile environment. A window of vulnerability (WoV) is a time frame within which defensive measures are reduced, compromised or lacking. In relation to hazards and disasters, vulnerability is a concept that links the relationship that people have with their environment to social forces and institutions and the cultural values that sustain and contest them. The concept of vulnerability expresses the multi-dimensionality of disasters by focusing attention on the totality of relationships in a given social situation which constitute a condition that, in combination with environmental forces, produces a disaster.

It's also the extent to which changes could harm a system, or to which the community can be affected by the impact of a hazard or exposed to the possibility of being attacked or harmed, either physically or emotionally: "we were in a vulnerable position".

Vulnerability research covers a complex, multidisciplinary field including development and poverty studies, public health, climate studies, security studies, engineering, geography, political ecology, and disaster and risk management. This research is of importance for determining the index of vulnerability trying to reduce the same – especially as related to flood hazard.

## 5.1 Concept of vulnerability

Literature suggest that there are several lineages on the theoretical construct of vulnerability, which may be divided into three major premises (Müller 2012 ; Lankao and Qin 2011 ; Cutter et al. 2008, 2009 ; Taubenböck et al. 2008 ; O'Brien et al. 2007 ; Polsky et al. 2007 ; Adger 2006 ; Eakin and Luers 2006 ; Birkmann 2006 ; Greiving et al. 2006 ; Mustafa 2005 ; Hogan and Marandola 2005 ; Wisner et al. 2004 ; UN/ISDR 2004 ; Oliver-Smith 2004 ; Bankoff et al. 2004 ; Pelling 2003 ; Turner et al. 2003 ; Bankoff 2001 ; Mitchell 1999a ; Lewis 1999 ; Hewitt 1997 ; Dow and Downing 1995 ; Watts and Bohle 1993 ; Burton et al. 1993 ; Dow 1992 ; Liverman 1990a, b ; White and Haas 1975 ; Timmerman 1981 ) . The first of these stems from the risk and hazard paradigm, which is based on human–nature interaction. This theoretical construct usually answers questions relating to the nature of the hazards, the people that live in hazardous places, and the probable effects. Here, vulnerability is viewed as an outcome of the hazard and is determined by exposure, sensitivity, and potential consequences. The second lineage emphasizes the social dimension of hazards and is rooted in the notion of political economy and political ecology. This theme broadly examines power structure, distribution of resources, and the cultural and economic aspects of a community. This establishes the area that is highly vulnerable, how and why a particular community is vulnerable, and why the effects of hazards on a community or individuals are uneven.

The third lineage utilizes the concept of resilience science to comprehend societal vulnerability to global and climate change. As noted by Eakin and Luers ( 2006 , p. 371), 'in this paradigm vulnerability is seen as a dynamic property of a system in which humans are constantly interacting with the biophysical environment.' Using socioecological system properties, this interdisciplinary and integrative approach aims to develop ideas that can support the goals of sustainability (Adger 2006 ) .

While the concept of vulnerability has extensively been used in hazard research and other disciplines, it lacks an acceptable de fi nition (Cutter et al. 2009 ; Adger 2006 ; Green 2004 ; Weichselgartner 2001 ; Cutter 1996 ; Wisner 1993 ). The conceptualization of vulnerability varies with the topic, discipline, organization, and/or researcher, reflecting different ideological and disciplinary perspectives (Birkmann 2006 ; UN 2003 ; Parker 2000 ; Cutter 1996 ; Dow 1992 ) . Although there is no intention to review existing definitions related to vulnerability, a comparative evaluation of few definitions may facilitate to recognize the differences. For instance, Dow ( 1992 ) defined vulnerability to hazards as 'people's differential incapacity to deal with hazards, based on the position of groups and individuals within both the physical and social worlds.' Cutter (1996 ) defined vulnerability to environmental hazard as a 'potential for loss.' The United Nations Environment Programme (UNEP) (2003 ) defined vulnerability as the 'manifestation of social, economical, political structure and environmental settings.' Odeh ( 2002 ) referred vulnerability to as 'the combined effect of hazards and exposures in a given region.' Due to its multifaceted nature, indicators that are used to characterize vulnerability to environmental hazards depend on various factors such as the perspective of research and scale of the study (Fekete et al. 2010; Adger 2006 ; Green 2004 ) . A wealth of literature exists on the concept of vulnerability and its development (Cutter et al. 2009 ; Birkmann 2006 ) .

### 5.2 Vulnerability assessment and Flood risk

The growing interest in adaptation policies in the context of flood risk assessment, especially among developing countries, is making vulnerability assessment a very active area of research. Understanding present day vulnerabilities and adaptation potential among local communities is increasingly being considered as a pre-requisite to such assessments. This study focuses on understanding and quantifying flood vulnerability of the Brahmaputra-Jamuna Floodplain considering hazard index and coping capacity of the local people. The study analyzed vulnerability in each upazila in the study area and prepared a vulnerability index map.

The empirical analysis is carried out using upazila level data and vulnerability assessment is presented for each upazila but could be undertaken at different levels and for other areas to provide a more detailed and more useful assessment of vulnerability.

One of the best-known definition of vulnerability was formulated by the International Strategy for Disaster Reduction (ISDR, 2004), which regards it as "a set of conditions and processes resulting from physical, social, environmental and economical factors, which increase the susceptibility of a community to the impact of hazards". A basic consensus has emerged, that the concept of vulnerability addresses a double structure consisting of an external side (exposure) (Bohle, 2004), and also that vulnerability is multidimensional and differential, scale-depended (with respect to time, space, units, individual, household, region etc).

Generally, the vulnerability of an area against a certain hazard is not easily assessed. It depends on different parameters like ;

- Possibility of hazard,
- Capacity to adopt,
- Social and Cultural practices,
- Physical or Topographical condition etc.

The most appropriate approaches for the case of vulnerability of the society and cultural heritage are thought to be qualitative (Laoupi and Tsakiris, 2007). Given the above thought vulnerability assessment of the study area depends on the following factors :

i) The Exposure of the system (E)

ii) The initial coping capacity (resource availability) of the system (S)

iii) The magnitude and intensity of the hazardous event (Qmax)

iv) The social response of the system (early warning system, indigenous experience, public awareness etc.) (SF)

v) The fuzziness of the interrelated sides of vulnerability (coping capacity & exposure) (I)

and therefore in mathematical terms vulnerability can be expressed as the following function :

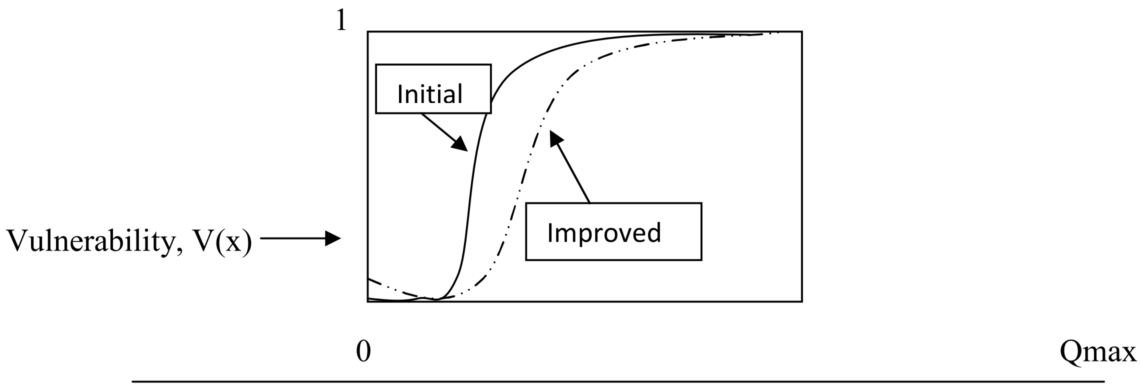
$$V = f(E, S, SF, Qmax, I)$$

Vulnerability analysis of the study area of flood hazard considers the population and structures as risk within the affected area. In the starting of the analysis, a reference level of the system's vulnerability should be determined that usually refers to existing flood protection system of the affected area. The vulnerability analysis evaluates the potential costs of flooding in terms of damages to buildings, crops, roads, bridges and critical infrastructure. Normally the analysis is carried out for various probabilities of flood occurrence, historical analysis of flood and hazard index.

The aim of the additional recovery and protection works is to reach a lower level of the system's vulnerability. Consequently, this analysis is valuable for reaching at decision about the desired level of flood protection. Ideally, this study should initiate a public process to establish the "acceptable level of risk" that would refer to the flood discharge magnitude appropriate for the delineation of the study area.

A comprehensive measure of the improvement of the system is the ratio of predictable consequences after the improvement divided by the initial potential consequences. The following figure depicts a simplified representation of vulnerability and its reduction versus the magnitude of the hazardous phenomenon. As it can be seen the improvement of the capacity of the system is schematically represented by a shift of the vulnerability curve to the right.

**Figure : 5.1 Vulnerability vs magnitude of the phenomenon for the initial and the improved capacity for the system.**




*Source : prepared Based on Tsakairis, 2006*

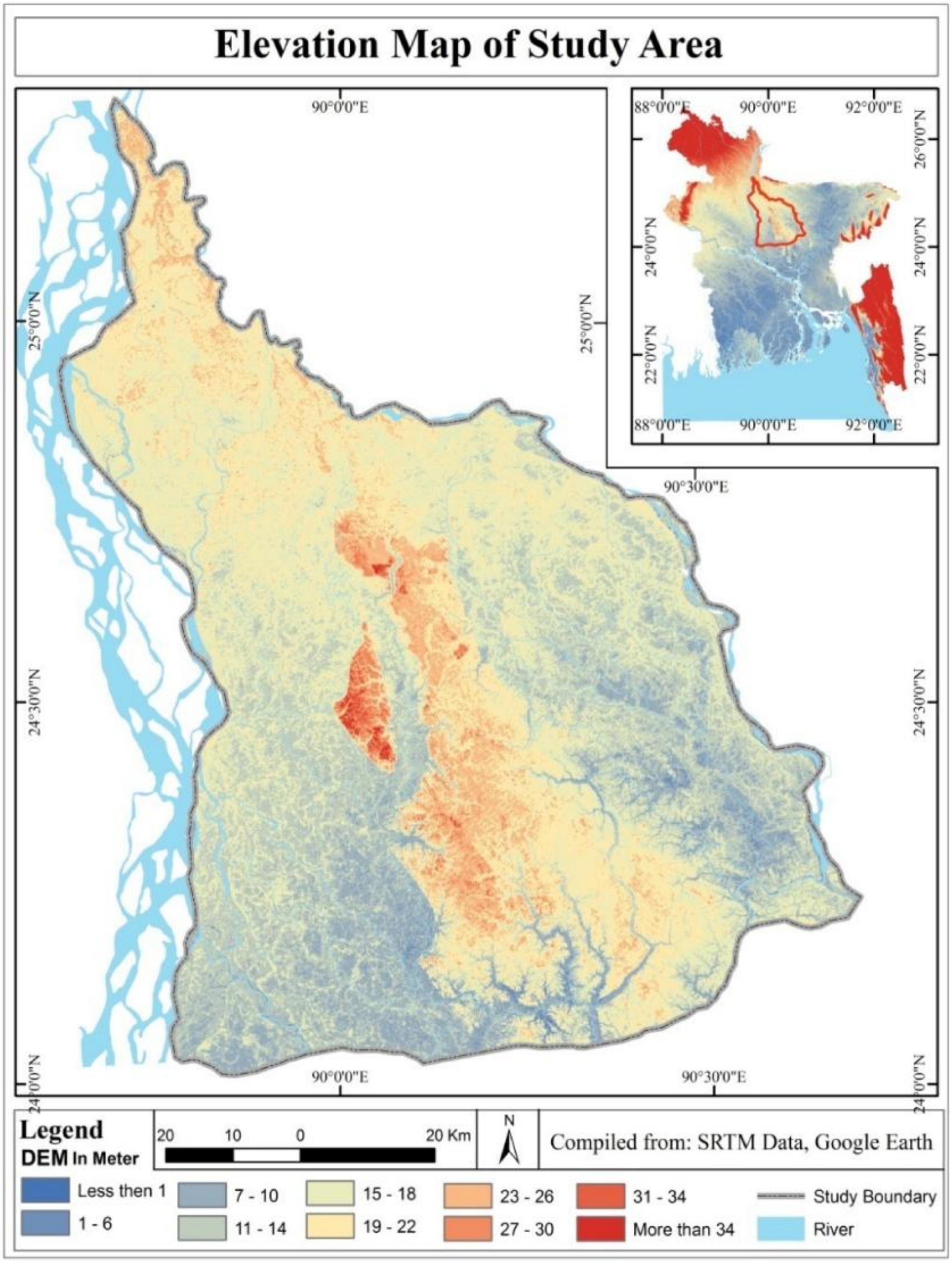
The vulnerability function could be treated as a function between 0 and 1 (figure. 5.1). This vulnerability function is a scientific principle that could be dealing as the level of understanding the physical process involved in occurrence of flood and their casual relationship.

### 5.3 Elevation or Topographic Vulnerability

The elevation of a geographic location is its height above a fixed reference point, most commonly a reference geoid, a mathematical model of the Earth's sea level as an equipotential gravitational surface. Elevation, or geometric height, is mainly used when referring to points on the Earth's surface, while altitude or geopotential height is used for points above the surface. The study of the distribution of elevations on the surface of the Earth is called Hypsography. Although the term is sometimes also applied to other rocky planets such as Mars or Venus. The term originates from the Greek word "hypsos" meaning height. Most often it is used only in reference to elevation of land but a complete description of Earth's solid surface requires a description of the seafloor as well. Related to the term hypsometry, the measurements of these elevations of a planet’s solid surface are taken relative to mean datum, except for Earth which is taken relative to the sea level.

The study area comprised the Pleistocene Terrace (2 to 0.1 million years before present and an average 1.5 to 6 m higher than the level of the lands formed in the Recent Age - it is even 15 to 30 m higher than the MSL on the western part of the Barind Tract) were possibly relatively accessible to human occupancy in the first stage of settlement development. The archaeological and anthropogeographic evidence in Bangladesh and the adjacent areas in India indicate the validity of this supposition.

**Figure 5.2 Elevation map of the Study area**




*Source : Prepared form SRTM data*

The area found gently splatters from north to south and have ridge lies on the same direction with variation of topography. Some parts of the study area found flood free zone and some are being inundated almost every year.

According to existing elevation, the south-eastern and the south-western parts of the study area are topographically lower than the middle portion. The rivers of the study area found dominating role in the development and expansion of human settlement that has a major contribution in the process of vulnerability assessment. It is observed that the study area represents multidimensional elevation within the boundary.

### 5.4 Hydrological Vulnerability

Bangladesh is naturally susceptible to flooding because of its geographical situation in a tropical monsoon climate and its low-laying topographic setting consisting largely of alluvial floodplains of the Ganges, the Brahmaputra and the Meghna rivers and their tributaries and distributaries. Yet, the floodplain residents of Bangladesh have adjusted admirably well to normal flood regimes. In defining the so-called normal floods, often called "Borsha" in Bengali, two critical elements are the elevation of dwelling structure and the depth of floodwater in the rice fields (Rasid and Paul, 1987).

The Brahmaputra River is one of the few rivers in the world that exhibit a tidal bore. A tidal bore is a tidal phenomenon in which the leading edge of the incoming tide forms a wave (or waves) of water that travel up a river or narrow bay against the direction of the current.

Climate change poses a serious threat to the people living in the low-lying areas of the Ganges-Brahmaputra Delta. According to the IPCC Fourth Assessment Report, more than 1 million people in the Ganges-Brahmaputra Delta will be directly affected by 2050 from risk through coastal erosion and land loss, primarily as a result of the decreased sediment delivery by the rivers, but also through the accentuated rates of sea-level rise.

In recent years soil erosion caused by deforestation in the valleys of Tibet and north-east India has caused frequent flooding of the delta region in Bangladesh on a massive scale. During the monsoon season (June–October), floods are a common occurrence in the study area (Brahmaputra-Jamuna Floodplain). Deforestation in the Brahmaputra watershed has resulted in enlarged siltation levels, flash floods, and soil erosion in critical downstream habitat. Occasionally, massive flooding causes huge losses to crops, life and property. Periodic flooding is a natural phenomenon which is ecologically important because it helps maintain the lowland grasslands and associated wildlife. Periodic floods also deposit fresh alluvium replenishing the fertile soil of the Brahmaputra River Valley. Flood control measures are taken by water resource department of Bangladesh but until now the flood problem remains unsolved. At least a third of the land of the study area has been eroded by the mighty river. Recently it is suggested that a highway protected by concrete mat along the river and excavation of the river bed can control flood hazard.

### 5.4.1 Seasonal Distribution of river flow

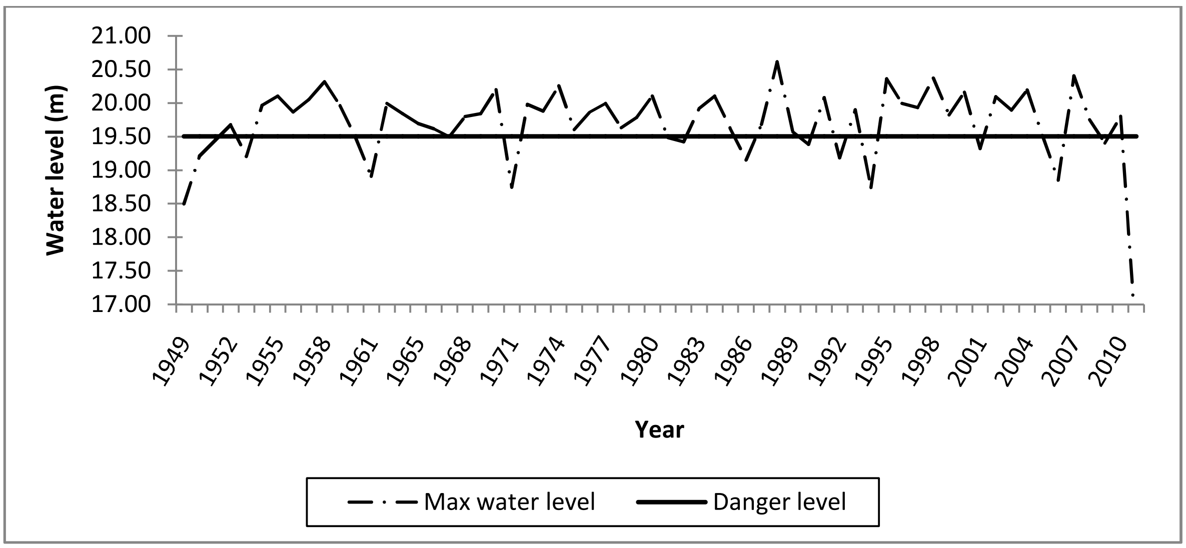
The Yamuna River flows to the west and south of the Ganges and joins it almost halfway down its course. The Yamuna receives a number of rivers of central India. To the north of the Ganges, the large tributaries are Ramganga, Gomati, Ghagra, Gandak, Saptkosi, and the Mahananda. Beyond the Mahananda the river enters its own delta, formed by its distributaries, and then merges into the combined delta of the Ganges, Brahmaputra, and Meghna rivers.

Bangladesh, being the downstream and deltaic portion of a huge watershed, is naturally vulnerable to the water quality and quantity that flows into it from upstream. All major rivers flowing through Bangladesh have their origins outside its borders, and, therefore, any interventions in the upper riparian regions have a significant impact on Bangladesh. Through its complex network of river systems, Bangladesh drains roughly 1.76 million km2 of catchment areas of the Ganges, Brahmaputra, and Meghna rivers, of which only 7 percent lies in Bangladesh (IUCN). This physical characteristic severely limits the degree of control and management of the inflow water in the monsoon and dry season. The extreme variation of the temporal and spatial occurrence of rainfall is a major constraint to the development of agriculture, which dominates the economy.

Although still a point of controversy, one of the causes of increased flooding in Bangladesh can be traced to Nepal and India (Assam), where the majority of the rivers originate. Massive deforestation of the mountainsides has significantly reduced the Himalaya's capacity to absorb the monsoon rains, and it has greatly increased the amount of eroded soil that is carried by the flood waters.

Seasonal flow of the river doesn't represent the same scenarios all over the year. Executive engineer, Flood Control Division, BWDB informed that both Ganga and Yamuna flows above the danger level of 84.73 metres and continued to rise by 3cms and 6cms respectively. Monthly flow discharge has the trend to increase water from the month of May and exists up to September if any unusual behavior doesn`t found. Seasonal distribution of maximum water level of Bahadurabad Station at Jamuna rivers shows a highly fluctuating trends (figure 5.2)

**Figure 5.3 : Maximum water level at Bahadurabad Station form 1949 to 2010**




*Source : prepared from BWDB data*

### 5.4.2 Impacts on Destructiveness of flood

The flood disaster in Bangladesh especially in the Brahmaputra-Jamuna floodplain relates to their destructiveness. To put it simply, it is observed that the floods in Bangladesh become increasingly more destructive in recent years. Compared to most of the hydrological data on floods, the areal extent of flooding provides a relatively simple measure for assessing recent changes in Bangladesh. The following statistics of Bangladesh Bureau of Statistics (BBS) give us the inconsistency of flood scenarios in Bangladesh.

**Table 5.1 : Areas Inundated by High-Magnitude Floods in Bangladesh 1954-2007**

| Year | Inundated Area (%) |
|---|---|
| 1955 | 35 |
| 1974 | 37 |
| 1984 | 34 |
| 1987 | 39 |
| 1988 | 56 |
| 1998 | 69 |
| 2004 | 38 |

*Source : GOB (2009), Hofer and Messerli (2006), Siddique and Chowdhury (2000), Brammer (1990), Miah (1988).*

Since flood is an annual event in Bangladesh, all of them may not be characterized as high-magnitude floods. On further review of the data foe larger areas of inundation, only seven out of these 24 flood inundated as least one-third of Bangladesh, providing a more significant threshold for high –magnitude floods in Bangladesh (table 5.1).

Duration of flood is also influenced by topography because flood water would persist for a longer duration in depressions. Structural depression in the Brahmaputra-Jamuna floodplain plays a significant in its flood depths and duration. For the Brahmaputra, the 1998 flood was the most catastrophic event as the flood lasted for 57 days, compared to only 7 days in 1987 and 15 days in 1988. The literature on flood damage in Bangladesh is extensive. Yet, one of the problems with this information is its inconsistency attributable largely to varied sources. Flood duration above danger level for the three major floods is as follows:

**Table 5.2 : Flood Duration above Danger level : 1987 1988 and 1998**

| Floodplain (gauging station) | Duration Above the danger level (days) 1987 | 1988 | 1998 |
|---|---|---|---|
| Brahmaputra (Bahadurabad) | 7 | 15 | 57 |
| Ganges (Harding Bridge) | 24 | 22 | 26 |
| Meghna (Bhairab Bazar) | 58 | 76 | 67 |
| Buri Gonga (Dhaka City) | 17 | 23 | 58 |

*Source : Rashid and Paul (2014) after Ahmed and Mirza (200)*

Danger level refers to the river level of overflowing the bank or an equivalent level marked on the gauge, when flood water in expected to overflow the bank.

### 5.4.3 Flood damages and vulnerability

Perhaps the most reliable source of flood damage is the Bangladesh Bureau of Statistics (BBS). In the past, other government agencies, such as the Bangladesh Water development Board (BWDB), Ministry of Irrigation (MOI), President's Flood Information Cell (in 1988), provided information on flood damage that did not match either the formal or the substance of the BBS data for a variety of reasons (inconsistent time frame for the data, for example). Media reports during real-time events also contribute another type of information on flood damage in different parts of the country. Some of the research monographs by independent scholars have contribute significant amounts of valuable field work-based data on flood damage but most often they represented limited geographical area (e.g. monographs by Ninno et al. 2001, Hossain et al. 1987 and Hye et al. 1986).

Annual loss of rice crops due to flood damage, published by the Bangladesh Bureau of Statistics (BBS) since 1962, is perhaps the most reliable and dependable source of information on flood damage in Bangladesh. Based on 27 years of BBS data 1962 to 1988), it is found from the research of Rasid and Paul (1993) that, the average annual loss of rice crops due to flooding during this period was 0.47 million metric tons, which amounted to approximately 4 percent of the national rice production. Since Bangladesh is a major rice producer with an annual production of about 10-15 million metric tons, a loss of 4 percent my sound to be a relatively small amount, contrary to the popular assumption of massive crop losses due to flooding. However, data on average losses are misleading because most of the losses are borne by a limited number of severely-affected districts during catastrophic floods (Paul and Rashid, 2014).

Data are thus not only skewed geographically but also by few catastrophic events. Thus, rice crop losses in 1987 (1.3 million tons) and 1988 (2.1 million tons) were about three to five time higher than the average. Expressed in another way, compared to the 27 years average of 4% , the 1988 losses amounted to a staggering 14% of the national rive crop production (Paul and Rasid, 1993). The losses in 1998 were almost identical, where as in

1987 about 10% of production was lost. Three other floods damaged more than one million metric tons each : flood of 1962, 1968 and 1984. Thus compared to an average loss of 4 % the BBS data provide evidence of increasing rice crop losses during catastrophic flood events in the last quarter of the 20th century (Table 5.1).

Flood have also been responsible for fewer deaths of human lives, livestock and also other damages. In 1988, there were several cases of fatal snake bites as people came on contact with venomous snakes inside their homes with rising water levels. However, to have a scenario of damage vulnerability selected categories of flood damage are given below :

**Table 5.3 : Selected Categories of Flood Damage : Historic Floods of 1987, 1988 and 1998**

| Nature of damage | 1987 | 1988 | 1998 |
|---|---|---|---|
| Rice production lost (million metric tons) | 1.3 | 2.1 | 2.04 |
| Human live lost | 1657 | 2379 | 1050 |
| Livestock lost (thousands) | 65 | 172 | 27 |
| Huses (totally/partially damage) (millions) | 2.5 | 7.2 | 1.0 |
| Highways/roads damaged (miles) | 10315 | 8078 | 9320 |
| Embankments damaged (miles) | 795 | 1237 | 1243 |
| Number of people affected (million) | NA | 45 | 30 |
| Number of people displaced (million) | NA | NA | 1.0 |
| Damage estimates (billions of US $) | NA | 1.2 | >2.0 |

Source : GOB (2009), Ninno et al. (2001). Siddique and Chowdhury (2000). Paul and Rasid (1993), Brahmmer (1990).

The above table provides information evidence of increasing destructiveness of flood in Bangladesh in the last two decades of the 20th century. Intensity of all above mentioned three flood were found severe in the study area and damages were comparatively more than other regions of Bangladesh as the local people opined in the period of surveying.

The high-magnitude of floods of the past is examples of their destructive power giving us some ideas about what might happen due increase of flood water. Vulnerability of the people of the study area could be taken into a scale from the past magnitude of flood of Bangladesh.

### 5.4.4 Scenario on regional cooperation on hydrological view

It has been highlighted that the three river systems are responsible for the occurrence of floods in the States of Uttar Pradesh, Bihar and West Bengal in India and Bangladesh. The flood occurs in a limited time frame of 2 to 3 monsoon months when the space becomes unlimited due to the favorable hydrological environment. The situation is worst in Bangladesh due to the combination of discharge in three major rivers. Individual efforts of each country to mitigate the flood hazards by adopting preventive measures by way of both structural as well as non-structural measures did not prove much effective so though the flood hazards could be minimized effectively in a limited space, especially in Bangladesh.

But in Bangladesh floods continue to remain as a menace till now without many effective measures. The structural measures adopted in India are construction of dams, reservoirs and barrage, construction of flood levees by jacketing the river basins, protective measures of riverbank by revetment, spurs, and bed bars either individually or in combination. The non-structural measures are advancing pre-flood warnings, post-flood rescue and rehabilitation measures etc.

The flood hazards of the two countries can perhaps be mitigated by joint efforts of the two countries at appropriate technical as well as administrative levels. In the existing geographical scenario of the two countries, being mostly covered by the flood plains of the different rivers originating from the largest mountain range of the world, it is unimaginable to avoid floods completely. The people of the two countries will have to live with the floods. However, its intensity, severity and frequently can perhaps be minimized with the joint efforts of the two countries.

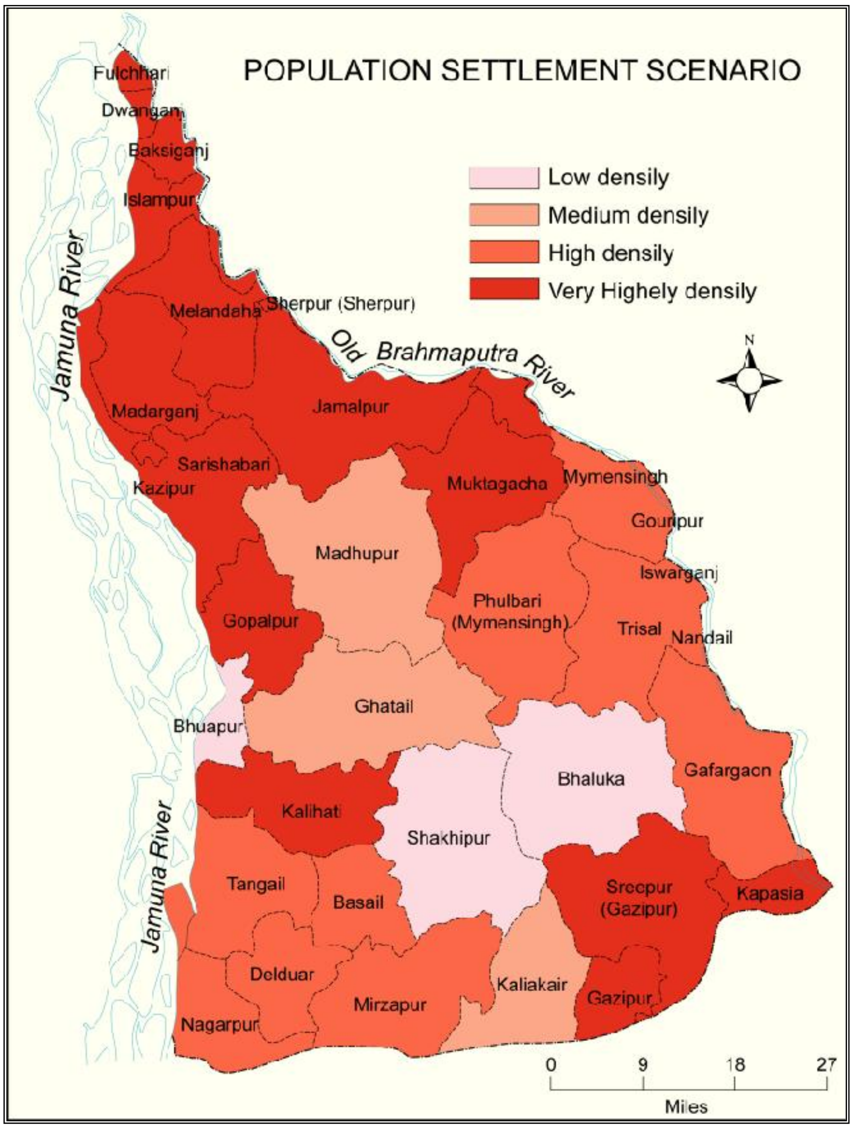
## 5.5 Settlement vulnerability

### Analysis of Settlement

The study area has found varieties of population structure especially in the settlement or household pattern. In analyzing the household pattern and population density it is observed that only two upazila (Shakhipur and Bhaluka) out of nineteen have the density below 600 person per square km. Ghatail, Madhupur and Kaliakair upazila have a density of population from 600 to 800 persons per square km. while Basail, Delduar, Mirzapur, Gafargaon, Fulbari and Trisal upazila found population density per square km. is about

800 to 1000. More population density found in Sharishabari, Melandaha, Jamalpur Sadar and Kalihati upazila where 1000 to 1200 people lives per square km.. The Only upazila Gopalpur is the densest part as there the population density is more than 1200 per square k. m. Relatively small towns are growing up in most cases as administrative centers and geographically suitable localities for inland transportation and commercial facilities. There was no particular concentration of towns in any part of the study area. This small area found varieties of population density in respect of settlement. Some parts of the area found comparatively denser than other parts especially rural based part of the study area. Population settlement scenarios of the study area are furnished below in Figure 6.5.

**Figure 5.4 : Population Settlement Scenarios of Brahmaputra Basin**

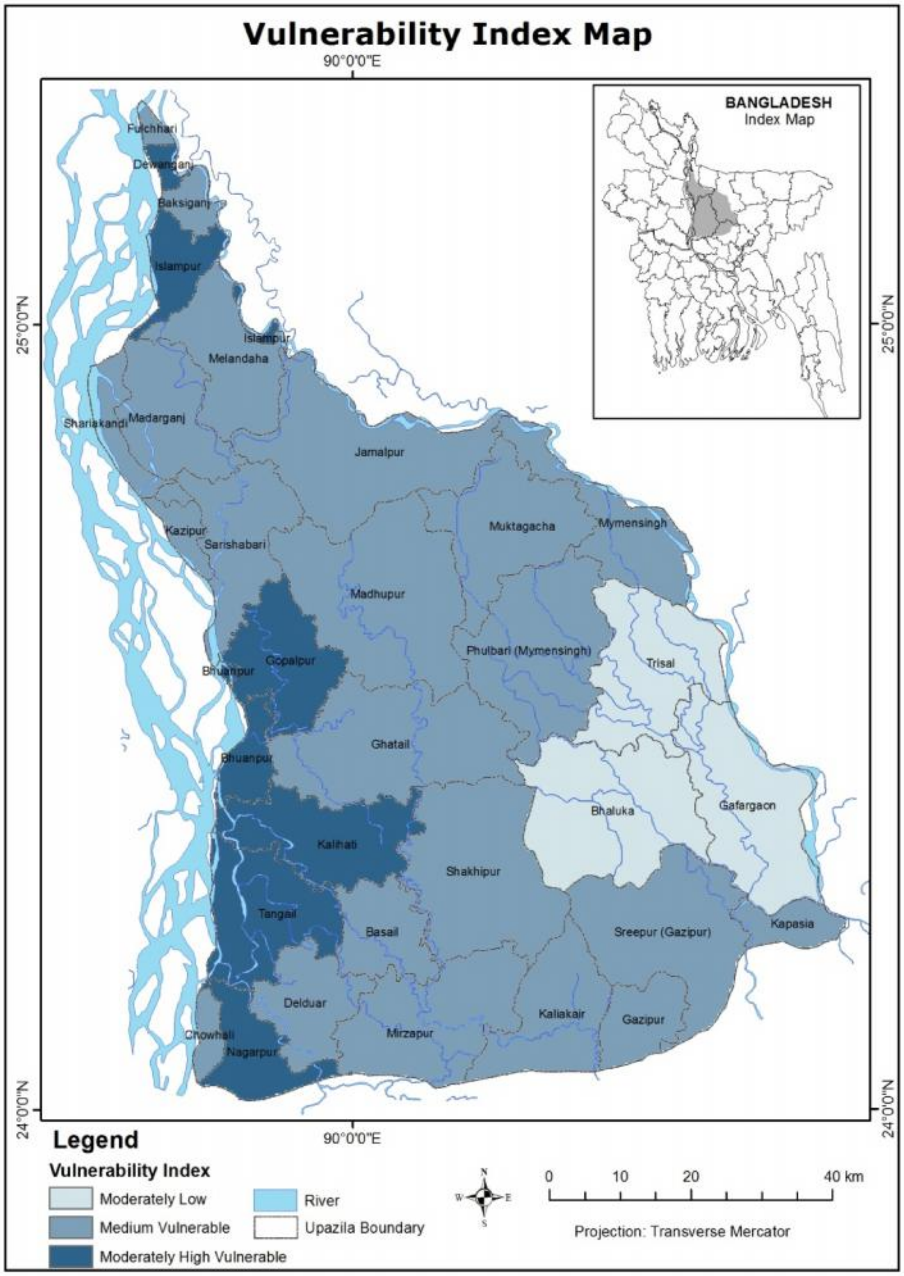



*Source : Prepared from BBS data, 2012*

## 5.6 Upazilawise Vulnerability index

Vulnerability index shows that among the 19 units (upazila) of land Gopalpur, Bhuapur, Delduar, Kalihati, Tangail, and Islampur area are moderately high vulnerable. Among the other upazilas Trisal, Bhaluka and Gafargaon are low vulnerable and the others upazila found medium vulnerable.

**Figure 5.5: Vulnerability Map of the Study Area**




*Source : Prepared on the basis of vulnerability index*

**Table : 5.4 Upzilawise vulnerability index**

| Name of Upazila | Level of Vulnerability | Name of Upazila | Level of Vulnerability |
|---|---|---|---|
| Basail | Medium | Gafargaon | Low |
| Nagarpur | Moderately high | Muktagacha | Medium |
| Ghatail | Medium | Fulbari | Medium |
| Gopalpur | Moderately high | Trisal | Low |
| Kalihati | Moderately high | Jamalpur Sadar | Medium |
| Madhupur | Medium | Madargonj | Medium |
| Mirzapur | Medium | Melandaha | Medium |
| Sakhipur | Medium | Sharishabari | Medium |
| Tangail Sadar | Medium | Kaliakair | Medium |
| Bhaluka | Low | Bhuapur | Moderately high |

*Source : Self prepared based on collected & analyzed data.*

## 5.7 Operationalizing Vulnerability

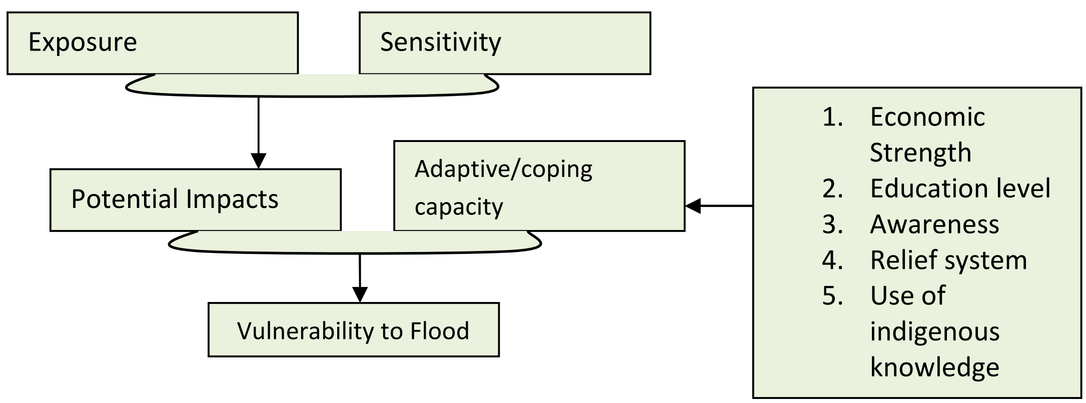
An operational approach could help rapid assessment of vulnerability and adaptive capacity. While there are a number of studies assessing vulnerability in the recent past, most of them using broad indicators to arrive at regional-level vulnerability to flood hazard. Since it is not quite clear what exactly one means by flood vulnerability in this study it is difficult to interpret the overall vulnerability index developed. Hence the approach of this study is to further narrow down and identify meaningful 'stimulus' that drive the vulnerability assessment. That is, the study aims to assess vulnerability due to specific stimulus like floods.

The study uses the vulnerability definition of International Strategy for Disaster Reduction (ISDR, 2004) it is as "a set of conditions and processes resulting from physical, social, environmental and economical factors, which increase the susceptibility of a community to the impact of hazards". Another vulnerability definition adopted by IPCC (McCarthy et al., 2001) – namely, vulnerability of an entity is a function exposure, sensitivity and adaptive capacity, which in turn are defined as:

**Exposure** – represents the magnitude and frequency of the stress experienced by the entity

**Sensitivity** – describes the impact of stress that may result in the reduction of wellbeing due to a crossover of a threshold (below which the entity experiences lower wellbeing)
**Adaptive capacity** – represents the extent to which an entity can modify the impact of a stress to reduce its vulnerability.
The following schematic diagram illustrates this approach:

**Figure 5.6: Conceptualization of vulnerability to flood**




*Source : Developed after Fuzzy Inference System*

The above mentioned studies have typically adopted simple aggregation procedure (that is either geometric or arithmetic mean) to sum over various indicators while estimating the vulnerability index. Fuzzy sets, on the other hand, allow for gradual transition from one state to another while also allowing one to incorporate rules and goals, and hence are more suitable for modeling references and outcome that are 'ambiguous'. While the use of two valued logic would be limited to determining only whether vulnerability exists or not, a multi valued logic can be used to assess the 'degree' of vulnerability – that is, it is also possible to attach linguistic values such as 'low', 'moderate', and 'high' to certain index value ranges.
Indices constructed based on fuzzy logic make quantitative inferences from linguistic statements. Moreover, fuzzy inference system enables the modeler to analyze the interaction among several indicators. Given these advantages, this study demonstrates use

of an alternative approach that is based on fuzzy inference system, for developing vulnerability indices. Another missing element in the literature is precise identification of the indicator set. The present study attempts to systematically develop such an indicator set by precisely identifying the cause of vulnerability of an entity and the outcomes with respect to which the entity's vulnerability status is determined.

To operationalize vulnerability, it is defined in terms of three 'dimensions' – exposure, sensitivity and adaptive/coping capacity. These dimensions in turn are characterized by various components' and finally various 'measures' are identified to quantify the components. Thus the contribution of the study is:

• To conceptualize vulnerability to floods using clearly defined outcome(s) of interest and the associated preference. In the empirical analysis in the chosen high vulnerable areas the impact of flooding on agricultural sector is considered as the outcome of interest. Focus on specific outcome enables meaningful choice of indicators as illustrated in the empirical analysis.

• Illustrate various aggregation procedures in the vulnerability assessment. Specifically fuzzy inference system based aggregation are contrasted with simple averaging (using either geometric or arithmetic) of normalized variables (similar to the procedure adopted in the estimation of various human development indices).

• Illustrate the contrast between vulnerability defied in 'general' terms and vulnerability defined with reference to specific stress and outcome. Vulnerability assessment is carried out for the same regions for comparability.

It may be noted that the analysis presented in this study is carried out using upazila level data. Future refinements include, among other things, vulnerability assessment at a district level. Such analysis would enable one to clearly identify which upazilas are highly vulnerable, which are moderately vulnerable and which are low vulnerable.

### 5.8 Vulnerability Assessment – Fuzzy Inference System

Quantifying vulnerability is difficult due to several reasons: (a) Many factors may contribute towards the vulnerability and also in complex ways; (b) Knowledge about the determinants of vulnerability is typically vague; (c) Possibility of non-linear relationships between the determinants and vulnerability (for example, while a very high level of income inequality in a society can be associated with vulnerability, a small decline in the inequality may not lead to corresponding decline in the vulnerability); and (d) Lack of knowledge on weights to be attached to these determinants.

For these reasons the methodology adopted in this study focuses on a range of determinants of the vulnerability and makes use of linguistic models of vulnerability. Use of different factors for capturing the vulnerability is not new, but identification and use of different measures as per the conceptualization of the vulnerability outlined in the previous section is not very common (Acosta-Michlik et. al, 2004, O'Brien et al., 2004b, and Brenkert and Malone, 2004). Further, application of fuzzy set theory to translate the inexact linguistic statements into quantitative estimates is relatively limited in the vulnerability literature. This section describes the fuzzy inference system and illustrates its use in assessing sensitivity and adaptive capacity indices and vulnerability to flood in the study area.

**5.9 Theoretical Perspective of Vulnerability and Adaptive Capacity**

There exists an increasing amount of literature about the operationalization of the concept of social and economic vulnerability to flood risk. Generally, vulnerability is seen as the outcome of a mixture of environmental, social, cultural, institutional, and economic structures, and processes related to poverty and risk, not a phenomenon related to flood risk only. Definitions of vulnerability focus on risk and risk exposure on the one hand, and coping and adaptation mechanisms on the other (e.g., Pelling, 1999). Besides risk exposure, adaptive capacity is seen as a key component of the concept of vulnerability (e.g., Adger, 2000; IPPC, 2001). Empirical studies focus more and more on variations in both exposures to natural hazards and people's capacity to cope with these hazards (Few, 2003). Adaptive capacity is considered a process of adaptation (over time) to structural and/or incidental sources of environmental stress (e.g., Nishat et al., 2000), consisting of distinct social, economic, technological, institutional, and cultural adaptive mechanisms (e.g., Cardona, 2001). Social mechanisms refer, for example, to social networks of relatives and neighbors, economic mechanisms to livelihood diversification or savings, technological mechanisms to technical measures to prevent flooding such as embankments or terps (mounds of earth), institutional mechanisms to (in)formal political-organizational structures and associated collective action to ameliorate vulnerability (including, for instance, access to productive assets or community microcredit systems), and cultural mechanisms to perceptions and beliefs about the nature and avoidance of flooding.

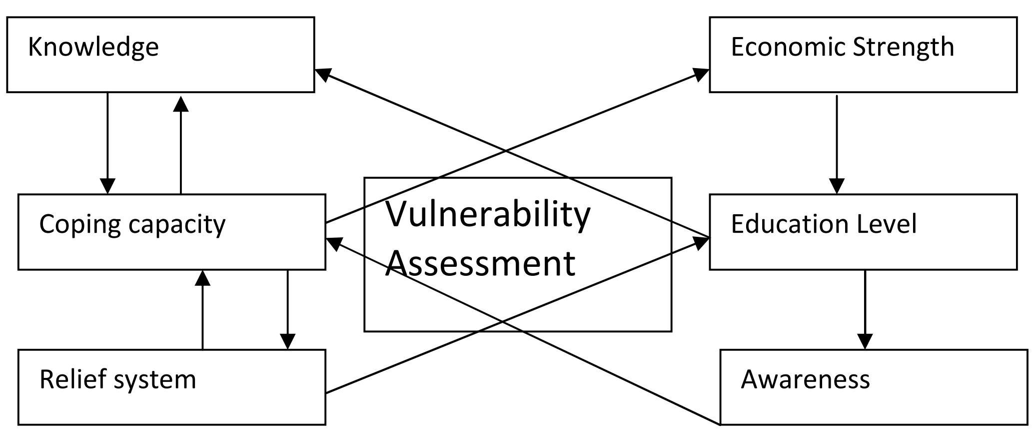
Another distinctive feature of the concept of vulnerability is the level or scale of analysis. Variation in social and economic vulnerability to environmental risk can, for example, be explained at the level of the individual household or the community. In some studies, even national indicators are compiled and used (Vincent, 2004). Adger (1999) argues that individual vulnerability is determined by other factors than collective (community) vulnerability, but uses similar indicators for both levels of analysis (e.g., income either measured at individual household level or at the level of a region or country).

It is observed that the relationship between vulnerability and poverty is not as straightforward as expected. The poor are indeed more exposed to risks of flooding, but the claim that they are therefore also more likely than the wealthy to suffer when flooding strikes (e.g. Few, R. 2003).) is rejected in this study.

### 5.10 Analytical Model of Socioeconomic vulnerability to flood risk

The analytical "model" of socioeconomic vulnerability to flood risk exposure in our case study is shown in Fig. 1. Central to the concept of vulnerability are, as mentioned, the exposure to risk and the adaptive capacity to risk.

**Figure 5.7 : Analytical Model of Socioeconomic vulnerability to flood risk**




*Source : Self Prepared*

### 5.11 Concluding remarks :

vulnerability assessments have become an integral part of hazard research. Vulnerability analysis can support the formulation of a resilient society. Therefore, an integrative approach that comprises hazards and vulnerability should be considered, so the risk of natural hazards as well as flood risk can be estimated and communicated. A growing body of literature suggests that geospatial techniques can significantly contribute to the deeper understanding of flood hazard, risk, and vulnerability. As described, these techniques are capable of adding value in each stage of the emergency flood management/disaster cycle through spatial analyses. The most important outcome of the geospatial approach is a series of maps encompassing the spatial distribution of hazard, risk, and vulnerability, which is known to provide better representation.

## 6.0 Introduction

The concept flood risk assessment is becoming popular in the flood management policies of all the major countries (Meyer, V. et.al. 2009; Hall, J.W. et.al. 2003; Gouldby, B. et.al. 2007; Jonkman, S.N. et.al. 2008). The unusual rise in flooding events in recent years in almost all continents usually attributed to various climate change aspects have generated an increased attention of academics, professionals, researchers and policy-makers to various aspects of flood risk assessment. This has resulted in the emergence and development of a strong area of research into flood risk assessment. Flood risk assessment of the study area completely based on identified vulnerability and hazard index and considering the coping strategies of the local people. This has also been largely facilitated by the emergence and advancement of newer data-acquisition and data processing and modeling techniques. The rapid advancement of satellite based technologies and the tremendous advancement in spatial data analysis and modeling have enabled numerous developments in accurate flood risk assessment as well as rational flood management.

## 6.1 Concept of Risk

Risk is viewed as the probability of occurrence or the degree of loss of a specified element expected from a specific hazard (Schneiderbauer and Ehrlich 2004). While risk measurement differs according to discipline, in hazard research, risk is equal to the product of two or three factors (Crichton 2002, 2007 ; Kohler et al. 2005 ; ADRC 2005 ; Kron 2005 ; Wisner et al. 2004 ; UN/ISDR 2004 ) , although different views exist (Chakraborty et al. 2005 ) . For example, Crichton (2002) illustrates risk with a triangle in which hazard, exposure, and vulnerability contribute independently (see Fig. 2.1). Conversely, Asian Disaster Reduction Center [ADRC] (2005) describes risk as the overlapping areas of three factors—hazard, exposure, and vulnerability— that act simultaneously to generate the risk of natural hazards, which can be expressed as:

Risk = hazard x vulnerability (2.1)

Risk = hazard x exposure x vulnerability (2.2)

While hazards are a potential threat to populations and the environment, risk is the interplay between hazard and vulnerability. *Elements at risk* , a frequently used term in hazard research, enables the estimation of economic losses from an extreme event (Meyer et al.

2009 ) . It is usually not included in the risk equation; rather, it is part of the vulnerability and exposure analysis (Fedeski and Gwilliam 2007).

However, according to the United Nations Disaster Relief Coordinator Office (United Nations Development Programme [UNDP] 1992) , risk is the function of elements at risk (e.g., population), hazards, and vulnerability. It differs from the concept of others, who de fi ne risk as a product of hazard and vulnerability (see Wisner et al. 2004) . The risk to a particular community varies over time and time and depends on their socioeconomic, cultural, and other attributes (Wisner et al. 2004 ; Cannon 2000) , signifying that the risk of natural hazards depends on both the hazard and the capability of the community to withstand shocks from disaster.

**6.2 Flood Risk Analysis**

According to EU Directive (COM, 2006) for flood management, "flood risk" is the likelihood of a flood event together with the actual damage to human health and life, the environment and the economic activities associated with that flood event. In this study flood risk can be considered as the actual threat, in other words the real source of flood hazard to the study area.

The qualification of flood risk results either in monetary units, if the losses are measurable, or in qualitative terms (e. g. allocation in classes) in the case of intangible damages (social, environmental, cultural) to the affected areas.

In general, risk as a concept incorporates the concepts of hazard {H} (initiating event of failure modes) and vulnerability {V} (specific space/time conditions). It is customary to express risk (R) as a function relationship of hazard (H) and vulnerability (V).

$$\{R\} = \{H\}*\{V\} \qquad (1)$$

In which the symbol * represents a complex function incorporating the interaction of hazard and vulnerability. Consequently in mathematical terms it can be expressed as

$$\{R\} = \{H\}x\{V\} \qquad (2)$$

Since vulnerability is a dimensionless quantity (Villagran, 2006), risk could be measured in the same units as hazard. In quantitative terms, annualized risk can be estimated as the product of probability of occurrence of the hazardous phenomenon and the actual consequence, combined over all scenarios. According to the methodology of estimating average (annualized) hazard, the excepted value of flood risk can be calculated as follows :

$$E(X) = \int x.v(x).f(x)dx$$

Where,

X is the actual flood damage caused by the flood hazardous phenomenon'

f(x) is the p. d. f. that describes this phenomenon and

v(x) is the vulnerability of the system towards the corresponding magnitude of the phenomenon. It is obvious that such an estimation involves major restrictions as :

- can be applied only on hazards of natural origin due to probabilistic analysis;
- although it abides to a general methodological framework, it is highly case-specific;
- Highly dependable on expert's judgment
-

### 6.3 A methodology for assessing flood risk

Based on the ANCOLD Guideline 2003 there is a basic consensus towards the methodological framework of risk identification and estimation. In this context, the general methodological framework for risk assessment can be, more or less determined and it is given by the following steps :

1. ***Risk identification*** : refers to the identification of the hazard source
2. ***Risk analysis or estimation*** : refers mostly to the probabilistic quantification of the average annualized risk and it is measured in the same units as hazard. It involves the estimation of the probability of occurrence of the hazardous phenomenon, the estimation of the actual consequences and the vulnerability estimation of the affected system over the selected scenarios.
3. ***Risk evaluation*** : refers to the identification of the local society's tolerable risk policies and criteria as well as to the comprehension of the local society's perception of the hazard impacts by the decision makers. One's willingness to pay for risk reduction is controlled by the perceived and not the actual risk. Simultaneously the perceived risk reflects the human attitude towards various kinds of risks and it is therefore of high importance to assess it.
4. ***Risk assessment*** : refers to the evaluation of the tolerability of the estimated risks based on the local society's acceptability criteria. The comparison of the estimated

risk with acceptable ones results in the decision of what risk will be acceptable in the particular affected system and what risk reduction measures will be applied; if needed.

For the present study, risk analysis has been done mainly in structural and non- structural measures that are human settlement, flood frequency and occurrence, evacuation policy, adaptation measures, coping strategy etc. Physiographic conditions and hydrological parameters have also been taken into consideration to depict the real scenarios of the study area. The variables of the study area taken into consideration analyzed in detailed. Processed data and information have been used in the developed model and finally a risk map has been prepared using the following speculation :

$$\textbf{Risk} = \frac{\text{Hazard x Vulnerability}}{\text{Coping capacity}}$$

Based on the speculation final risk has been calculated through the model. Calculation of data and procedures of data and information input are described in details in the methodology of this study. The developed model have run using Arc GIS and final flood risk map have been produced. In the case of final output of the flood risk map two major variables Hazard and Vulnerability have been considered.

Similarly, in calculating hazard and vulnerability, both ordinal and nominal values were calculated through the model. The values used in the model were collected from the study area and from different organizations.

## 6.4 Hazard Identification

Hazard Identification is one interface between risk assessment and risk management where the problems that the assessment is intended to address are identified and specific questions about model design are resolved. End points in this assessment include possibility of occurring of flood analyzing prehistory (hydrological characteristics), possibility of economic losses considering coping capacity and number of vulnerable population (settlement coverage and population density). Geographical location and elevation were also considered for the purpose of hazard identification.

### 6.5 Assessment of Flood Risk through Flood Modeling

Flood modeling can be used to analyze and predict flood events. Detailed flood models can play a key role in helping to protect people and property from the potentially devastating effects of flooding. Quite simply a flood model determines the volume and passage of water which would be expected during a major flood event.

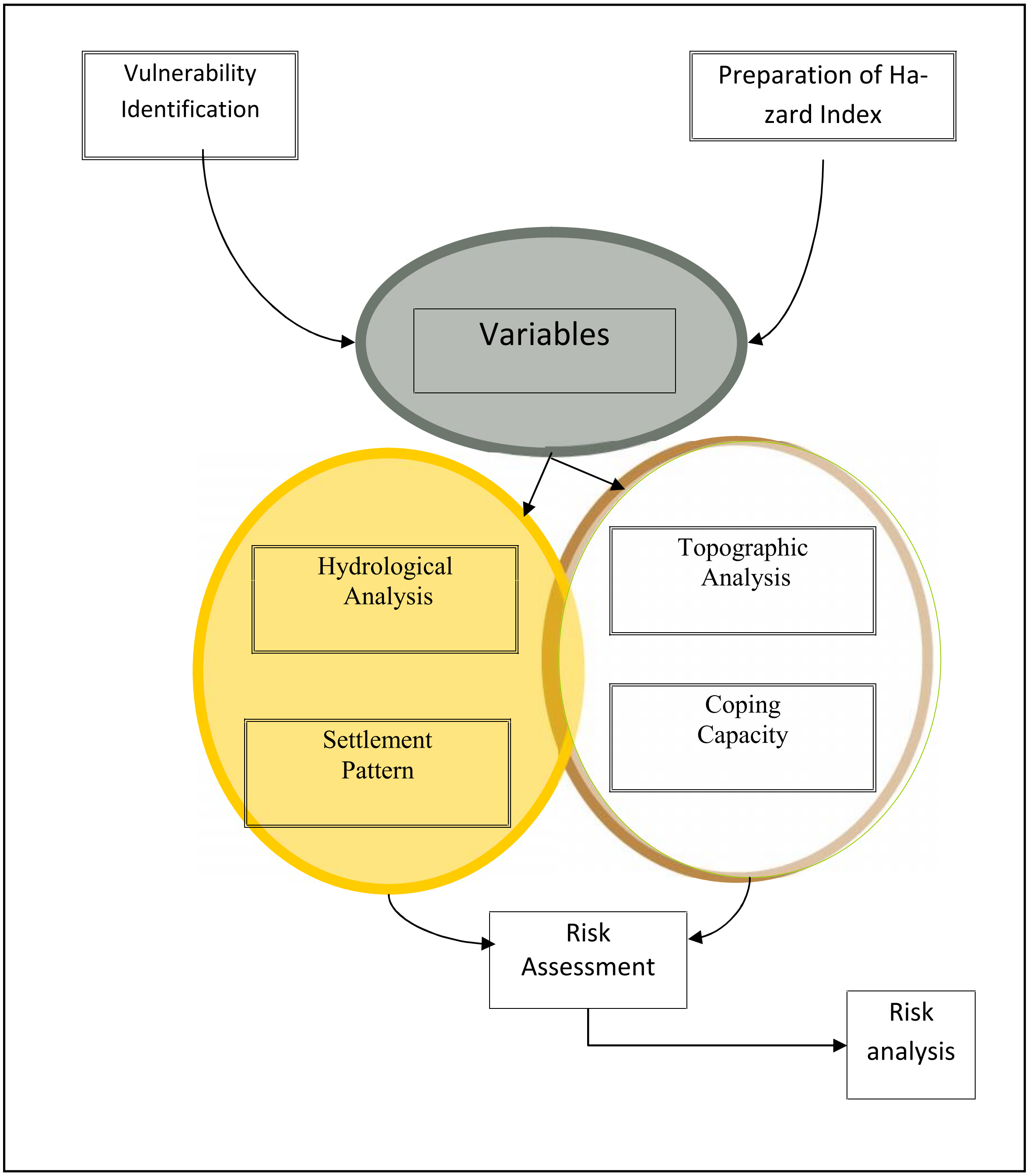
Depending on the application and level of complexity required, different flood models examine flood risk at different scales with varying levels of accuracy, from detailed, single site analyses to wide-area, catchment-based studies. There tends to be a trade-off between the cost of the modeling exercise and its resolution. Increasing resolution increases cost in terms of data collection, processing and the sophistication of the model required.

Flood modeling can be undertaken using 1-dimensional, 2-dimensional or 3-dimensional (1-d, 2-d or 3-d) modeling techniques:

- 1-D Hydrodynamic Flood Models are applied to cross-sectional data of the river channel and floodplain. This technique effectively "fills in" the floodplain with the available level of excess / overbank water calculated at a specific point in the channel (hence, 1-dimensional) but does not consider the way in which the water will behave between the sampled cross sections, or when manipulated by obstacles on the floodplain.
- 2-D Flood modeling differs from 1-d flood modeling in that it simulates differing flow conditions across a potential floodplain, represented as a 2-dimensional grid of cells. A 2-d Hydrodynamic Model divides the floodplain into a gridded domain (down-stream and cross-stream directions) – complex obstacles such as buildings can be taken into account.
- 3-D river flood modeling allows flows in 3-directions to be modeled (i.e. downstream direction; cross-stream and vertically through the channel) within a 3-d gridded domain. This is useful for studies of complex flow structures (e.g. turbulence, eddy dynamics) or for detailed, site specific flood modeling and risk assessment studies.

To obtained an effective result for flood risk assessment of the study area, appropriate modeling policy has been given priority. The following methodological framework has been prepared to analyze the risk of flood of the study area.

### 6.1 Understanding Flood Risk (influencing factors)




*Source : Self developed*

### 6.6 Integrated Risk Assessment Model

Vulnerability is considered as part of the disaster risk reduction approach, and risk is the product of hazard, exposure, vulnerability, and coping capacity (Davidson 1997). Davidson in his own model proposed four broad frameworks that exhibit the disaster risk of a given community. First, hazard is the probability or severity of an event. Second, exposure characterizes structure, population, and economy. Third, Conceptual framework for disaster risk reduction (Adapted from Davidson 1997), vulnerability encompasses physical, social, economic, and environmental aspects.

Fourth, capacity and mitigation measures include physical planning, social capacity, economic capacity, and management. Using these four measures, it is possible to determine community's vulnerability to hazards and take the necessary actions to lessen the risk of disaster. The proposed model was mainly developed to assess the flood risk of the Brahmaputra-Jamuna Floodplain; hence, all these above mentioned components are applicable to single hazard investigation.

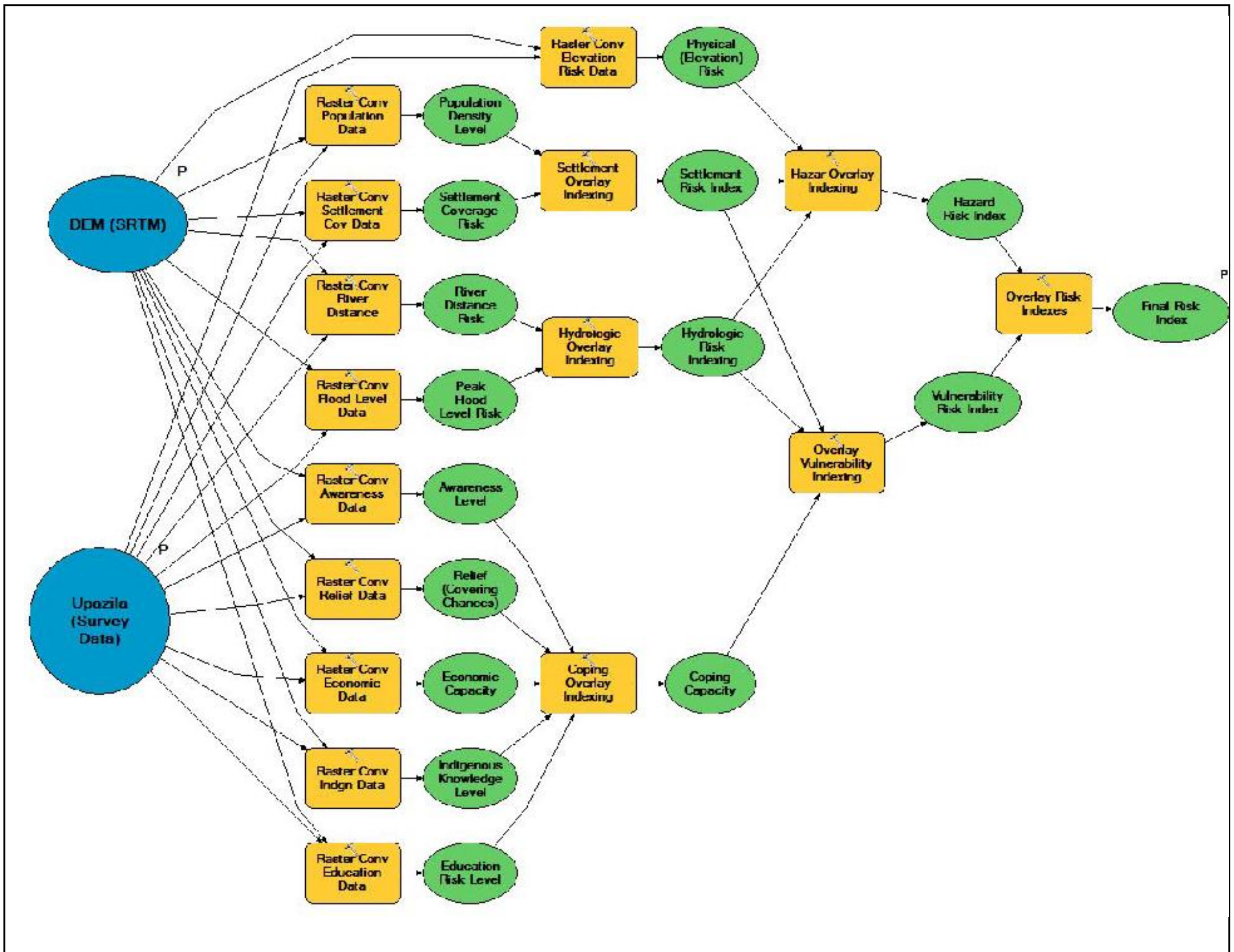
The assessment of risk rather than vulnerability, and risk is seen as the product of hazard and vulnerability. The model is based on three important principles.

**First,** a single hazard perspective is used rather than a multi-hazard.

**Second,** it is only applicable for hazards that have spatial relevance, such as flood. Spatially non-relevant hazards such as disease earthquake or cyclone cannot be used.

**Third**, the model may be useful to determine community risk by integrating hazard and vulnerability; however, it is unable to recognize individuals' risk. An important Pitfall of this model is that it requires copious data to operationalize the concept.

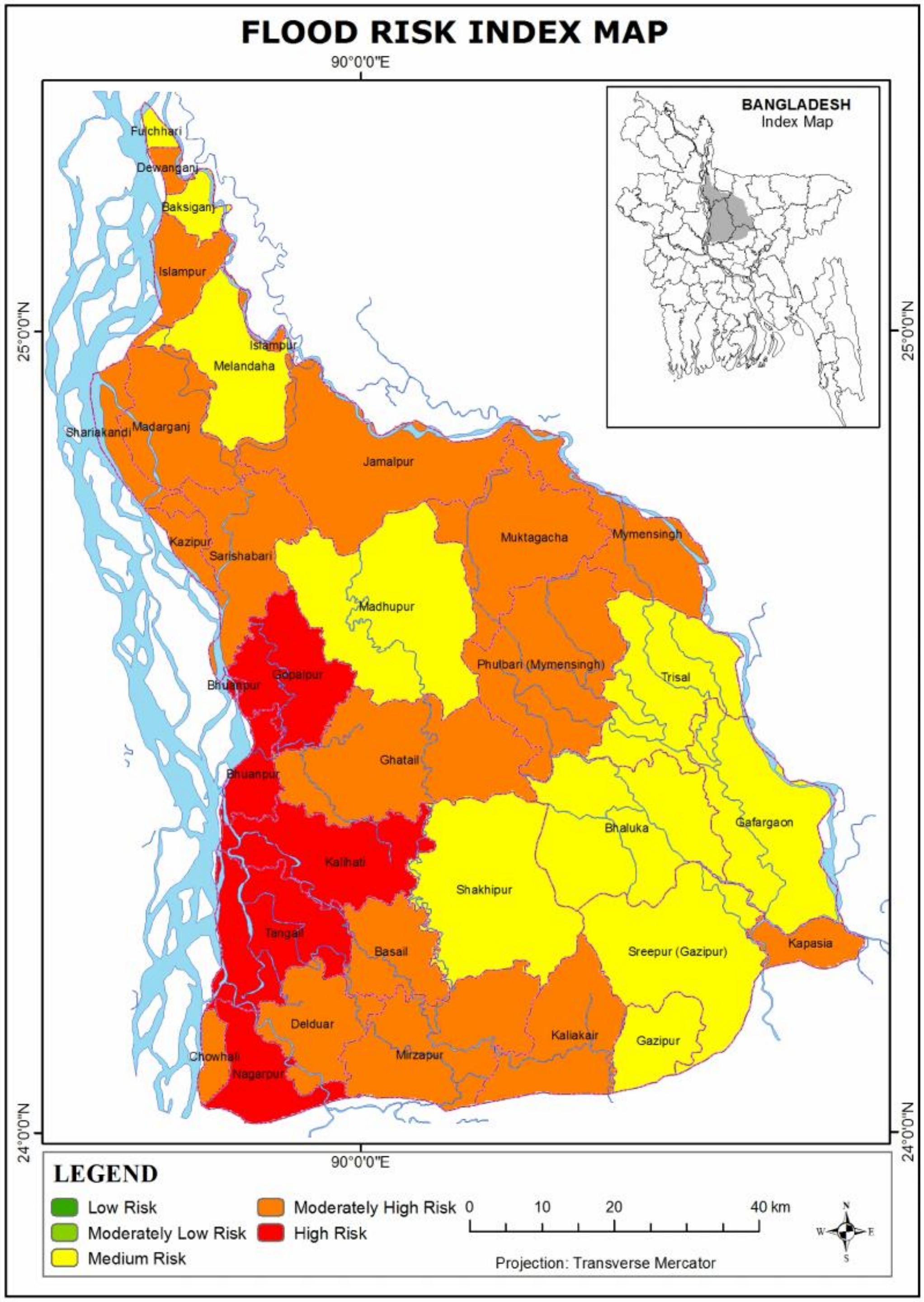
**Figure 6.2 :Proposed Model for Risk Assessment of the Brahmaputra-Jamuna Flood-plain**




*Source : Self developed*

The Validation and Specification of the model described before. Using the hazard and vulnerability index final flood risk map of the Brahmaputra-Jamuna Floodplain have been prepared as follows :

**Figure : 6.3 Risk Assessment Map of the Brahmaputra-Jamuna Floodplain**




*Source : Developed as of Arc GIS model*

The map is a result of integrated analysis of all components has been considered to assess flood risk of the study area. To assess the flood risk, identification of hazard and vulnerability index has been given preference with coping strategies of the local people.

### 6.7 Flood risk assessment in futures analysis

In general, however, we pursue and deploy science and technology to advance our economies and societies. We can summarised the output (O) an economy as being :

$$O = NE * T * H * X$$

Where,

NE = Natural Endowment

T = Technology

H = Human inputs of labour and capital

X = some other factor which may include institutional form and other factors such as social capital and social adaptability.

Hence, the role of T is to maximise the ratio of O to NE * H, given that NE is permanently fixed and H is relatively fixed in the short term.

Most households are involved in agricultural activities to support their livelihood. Approximately 20% of the sample population consists of day laborers. Almost all households own the house they live in, and about 62% (field survey data) owns the land they grow their crops on. Almost all houses are made of tin (both roof and walls) and a water-sealed latrine is the most important sanitary facility in dwellings. About one in every third household has electricity. Most households get their drinking water from a private or collective tube well and use leaves and cow dung as their main source of energy. (Evans et al, 2004, Foresight. Future Flooding, Scientific Summary: Volume I, 30)

### 6.8 Concluding remarks

Bangladesh is a low land country. Most of it is located within the flood plains of three great rivers, which is the Ganges, the Brahmaputra, and the Meghna, their tributaries, and distributaries. The river systems drain a total area of about 1.72 million square kilometers in India, China, Nepal, Bhutan, and Bangladesh. Only 8% of this area lies within Bangladesh. As a result, huge inflows of water, which Bangladesh has no control, enter the country. The lack of control is a critical problem because Bangladesh has an agrarian economy dependent on water. At different times and in an unpredictable manner it has too much or too little water. The intricate network of alluvial rivers carries a huge annual discharge and sediment load, causing channel shifting and bank erosion. Withdrawals in upstream areas seriously affect socioeconomic growth, the environment, and the ecology. The habitat of fish, which is a major source of protein for the rural poor, is under threat from the increasing conversion of land to agricultural use. Inland navigation is hindered by blockages in the river delta. Meanwhile, the need for pure water is increasing along with the salinization of the coastal belt and the degradation of ecosystems. The study area is included one of the most vulnerable parts of Bangladesh comprising the basin of the river Brahmaputra and Jamuna. The southern part of the study area found more vulnerable to flooding as topographically lower than northern and middle part. Almost every year the vulnerable part are being inundated and considered as a hazardous part of the basin.

## 7.0 Introduction

Flood in Bangladesh has become almost a recurrent feature, and most of the districts of Bangladesh facing the consequences of the phenomenon have affected negatively a large number of populations. Despite its recurrent nature, the flood conditions are perceived in different ways by the people. Each year in Bangladesh, normally 18% of the country is flooded and 55% during the severe flood. The onset of flood in Bangladesh starts with flash flood in the month of April and May. Moreover, the country also experience rainfall flood, river flood and storm surge flood. Geographically, the study area is located in the North-Middle region of Bangladesh. The inhabitants, who are living along in this area (Brahmaputra –Jamuna flood plain) have the experience about the nature of it and they well adjusted with its nature. Hydrologically, the study area is located in the North-Middle region of Bangladesh.

When households suffer a shock such as the floods, they do not remain inactive but employ several coping strategies. These coping strategies are fallback mechanisms for when habitual means of meeting needs are disrupted (Frankenberg, 1992). The first thing households do when they suffer a shock is to attempt to minimize risks and manage losses to ensure some minimal level of sustenance. The second strategy employed by households in distress is divestment, or the gradual disposal of assets.

The detail investigation regarding human adjustment to flood was undertaken in 2013 along the Brahmaputra and Jamuna River Bank during the month May to August. In the study area, a total number of 300 households were interviewed. The survey has been conducted only observing coping strategies or human adjustment perspective. During the survey period, an extensive field visit was undertaken in the whole region in order to understand the overall flood situation. Besides, interviews were taken with local leader and teacher, on the issues related to flood in their respective areas. Information thus drawn had lent qualitative support to those obtained through questionnaire survey.

This chapter looks at the kinds of adjustment strategies that have been employed by people of the study area before, during and after floods.

### 7.1 Coping Strategies of the People of the Brahmaputra Jamuna floodplain

Coping strategies are run away mechanisms for when habitual means of meeting needs are disrupted (Frankenberg, 1992). The first thing households do when they suffer a shock is to attempt to minimize risks and manage losses to ensure some minimum level of sustenance. The second strategy employed by family unit in distress is the gradual disposal of assets. Coping strategies of the local people of the study area have been found in different scale (observed issues) at different area of level of vulnerability. However, five major phenomena (awareness, economic strength, education, use of indigenous knowledge and relief system) have been taken into consideration to assess/determine the coping capacity of the people of the study area described below:

#### 7.1.1 People awareness

Awareness of people found depending on their (local people) educational qualification and experiences of treatment natural hazards. This study has an indication on educational qualification of the study area that shows highly educated (among the level of education) people are living in the less vulnerable area (city area) and very few cases they needed to be more aware of flooding. On the other hand the high vulnerable area has a big amount of people with low profile of education are found aware of flood from the view of their experience. Though the people are illiterate or at the level of primary education, their awareness level on flooding is comparatively higher than the people of low vulnerable portion of the study area.

#### 7.1.2 Economic Strength

Economic capacity is an important determinant of coping capacity as it represents the availability of resources and scope of resource mobilization. The extent of economic capacity is measured through per capita income – which represents the ability to access resources that are useful for adaptation, and inequality measure – which represents the degree of cohesiveness of society for adaptation. Both these indicators reflect entity's control on influencing the outcome (or shortfall in outcome induced by the shock) and hence capture its adaptive capacity on economic dimension. In the study area it is found that, poor people are very much afraid about the damage of their assets due to floods. If there is a chance of flood they tried their best to protect their assets (house, livestock, agricultural land, crops etc.). But if it is felt that they may not be able to protect assets then they dispose or sell their assets even though they get lesser price. In the case of wealthy people this scenarios are little more exception. They are supposed to get assets/properties with lesser price or to give mortgage with interest/benefit. Coping strategies of the poor people are different from the wealthy people because of the necessity of their daily needs especially at the period of flooding and after the losses and damages of the same.

### 7.1.3 Education

The degree of educational capacity is assessed through percentage of literate population in the society – which indicates the adaptability of population to both adverse impacts caused by shocks and the opportunities created, and the proportion of expenditure on education in total public expenditure – which represents the investment in human capital. Again both the indicators reflect the extent of influence that an entity can exercise on its outcome and hence qualify as adaptive capacity.

Level of education of the people of Brahmaputra Jamuna floodplain varies from one to another upazila. Gagipur, Tangail sadar, Fulbari, Mymensingh sadar upazilas found comparatively high literacy rate than more vulnerable upazilas like Basail, Mirzapur, Kalihati, Melandaha, Bhuapur.

### 7.1.4 Use of Indigenous knowledge

Use of indigenous knowledge as well as human capacity is used as one of the important dimensions of adaptive or coping capacity as it captures the inherent adaptive capacity of vulnerable population. The degree of human capacity is assessed through percentage of literate population in the society, frequency of flood that handled by the people – which indicates the adaptability of population with adverse impacts of flood. Again the indicators reflect the extent of influence that a person can exercise on its outcome and hence qualify as adaptive capacity indicators.

### 7.1.5 Relief System

Relief system of the study area is used as a determinants of coping capacity as because this is considered as most expensive and essential phenomenon to save life during and an immediate after the occurrence of flood.

The understanding of relief system in different upazila has been measured from the public opinion collected through focus group discussion and participatory survey.

## 7.2 Coping strategies : Adaptation and Mitigation

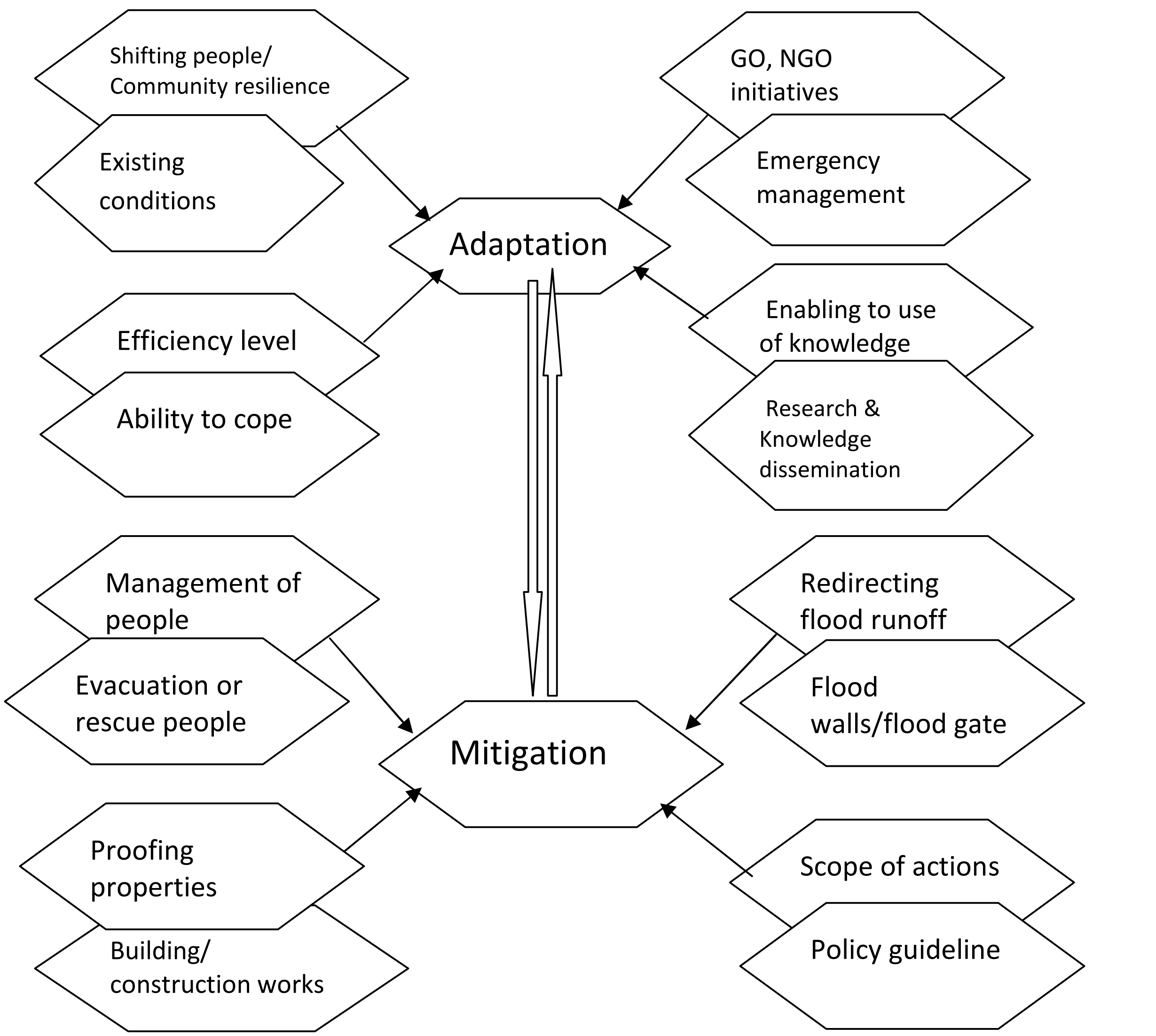
**Flood adaptation** refers to understanding how floods impact communities provides approaching on policies aimed at reducing the impact of future flood events. Climate change scenarios suggest an increase in extreme rainfall events, contributing to a greater frequency of riverine and flash floods. At the same time, Emergency Management need to shift people in its policies for hazard mitigation towards building resilient communities. The experiences of psychological, financial and social stress within the communities preparing for, dealing with, and recovering from the floods provides information to planners and emergency managers. This study looked at the factors to make people enabling household adaptation strategies in the flood-affected communities of Brahmaputra-Jamuna Floodplain.

**Flood mitigation** involves the managing and control of flood water movement, such as redirecting flood run-off through the use of floodwalls and flood gates, rather than trying to prevent floods altogether. It also involves the management of people, through measures such as evacuation and dry/wet proofing properties for example. The prevention and mitigation of flooding can be studied on a number of levels: individual properties, small communities and whole towns or cities. The costs of protection rise as more people and property are protected.

When more homes, shops and infrastructure are threatened by the effects of flooding, then the benefits of greater protection is worth the additional cost. Temporary Flood Defenses can be constructed relatively quickly in certain locations and provide protection from rising flood waters.

Rivers running through large urban developments will often have been controlled and channeled. These channels or canals will have a fixed capacity and if flood water flows exceed this capacity then the city will flood. Over time defenses will have been constructed to minimize the effects, and this will generally be through raising the sides of the river channel with embankments, walls or levees. The large number of people and huge value of infrastructure at risk in cities means that protection works of high cost can be justified.

**Figure 7.1 : Coping Strategies of the local people**

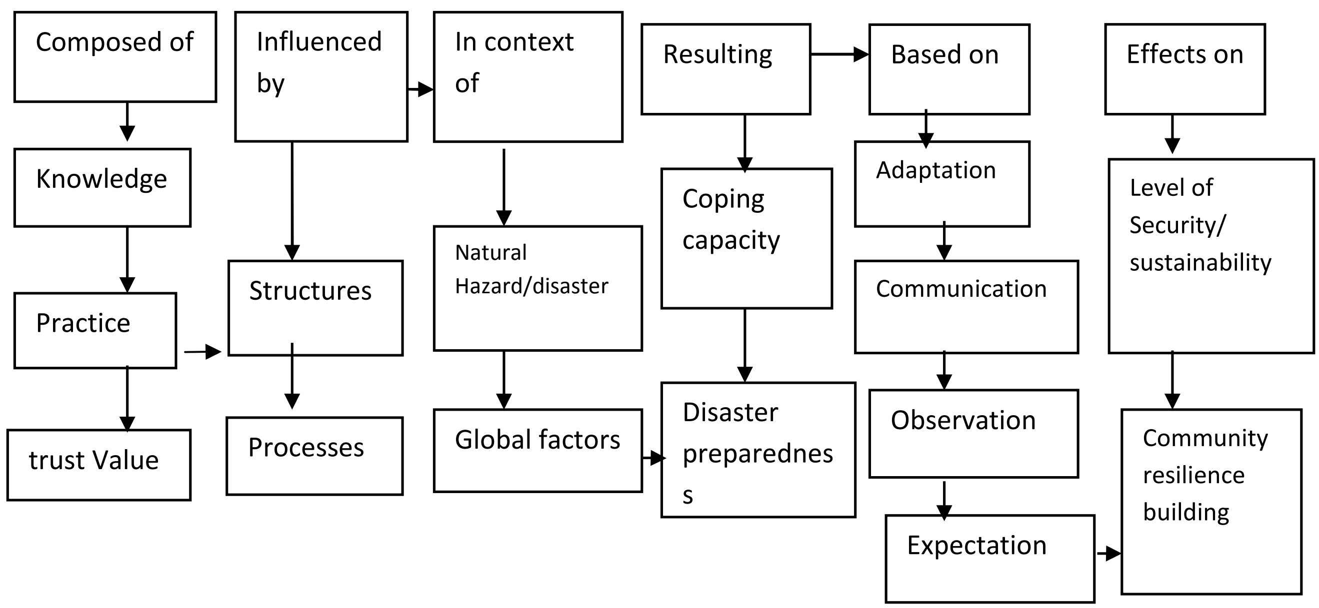



*Source : self developed*

## 7.3 Local knowledge system

Local knowledge system observed an integrated arrangement of knowledge, practice, process and capacity of the local people which brings result on the natural hazards especially in flooding. Observed mitigation and adaptation processes have direct effect on their level of security and community resilience building. Observed local knowledge system of the study described in figure 7.7 as below.

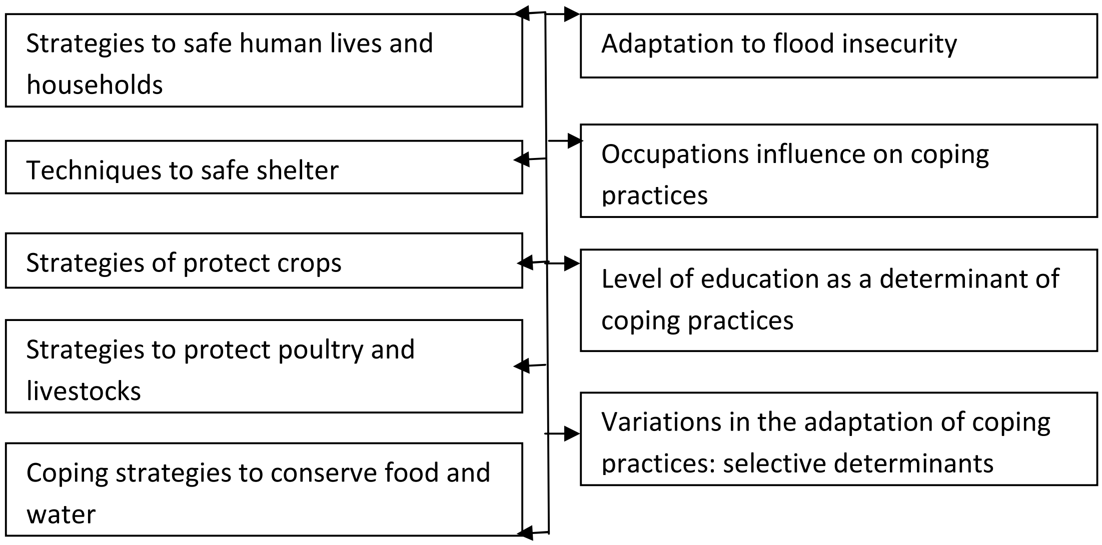
**Figure 7.2 : Observed knowledge system of the study area**




## 7.4 Use of indigenous knowledge

People of the study area are supposed to use indigenous knowledge in their occupation and daily life. Strategies are used to safe their live and households. They used to safe their shelter and to protect crops and live stocks. It varies upon the educational quality of the affected people. Some of them found well prepared in coping practices and some of them are moderately conscious about flood hazard. Occupation the peoples also has a great influence to make them well prepared in coping practice. Indigenous flood prevention and coping strategies presented below in figure 7.8.

**Figure 7.3 Indigenous flood prevention and coping strategies.**




### 7.5 Adaptation to flood : Measures taken by the people before flood

Generally in the monsoon period floods occur in the study are. The frequency of flood in this area is less than that of eastern part (Sylhet region) of Bangladesh. Before flood the people takes some preparation to minimize losses as describe below.

#### 7.5.1. Dry food reserves

Most of the people who have been affected by floods frequently said that they have reserve dry foods before flood. Dry foods like- chira, muri, biscuits, sugar, rice, pulses, salt, oil etc. are collected and preserved by them. After analyzing the field data it has been found that almost 75% people of the study areas are preserving dry food before flood. It should be mentioned that some of them reserved rice for the whole year or for six months in a year as tradition either flood occurs or not. But some of the poor people don’t have any reserve food due to their economic condition. While the poor people receiving the prediction of flood they tried to collect some food from market or from the rich people, though it is uncertain to collect food for the period of flood.

### 7.5.2. Household Preparation

When there is a possibility of floods, people of the study area practice some local coping strategies to protect their household from the damage caused by flood. Almost 77% of the respondents (231 out of 300) replied that they repair their household and rising up the ground level. The following steps are taken by the people to protect house hold:

- Repair the house (roof, wall).
- Raising the ground level.
- Higher plinth of the rooms
- Making temporary mancha/shade.
- To minimize soil erosion planting grass/trees beside home.

**Figure 7.4 Higher plinth of the rooms**

**Figure 7.5 Repair houses**

### 7.5.3. Taking steps to protect livestock

Livestock (cattle, buffalo, goats, chicken, ducks, hens etc.) are too much vulnerable to flood. Excessive flood sometimes caused to death of livestock. It causes huge economic loss to the owner of livestock. For this reason to protect livestock people take some measures before flood like Livestock are sent to the flood free area or making temporary mancha/shade where livestock are kept during flood etc. Although people take protective measures but sometimes it becomes very difficult to protect livestock. So people in the study area are seen to sell their livestock even they received less price than they demand. The obtained data on protecting livestock from the field survey are given below:

**Table 7.1 : Taking steps to protect livestock before flood.**

| ID | Frequency | Percentage (%) |
|---|---|---|
| Livestock are sent to the flood free area | 141 | 47% |
| Making mancha/shades | 24 | 8% |
| Sell livestock | 30 | 10% |
| Taking with themselves | 87 | 29% |
| Doesn't have livestock | 18 | 6% |
| Total | 300 | 100% |

*Source: Field Survey,2013.*

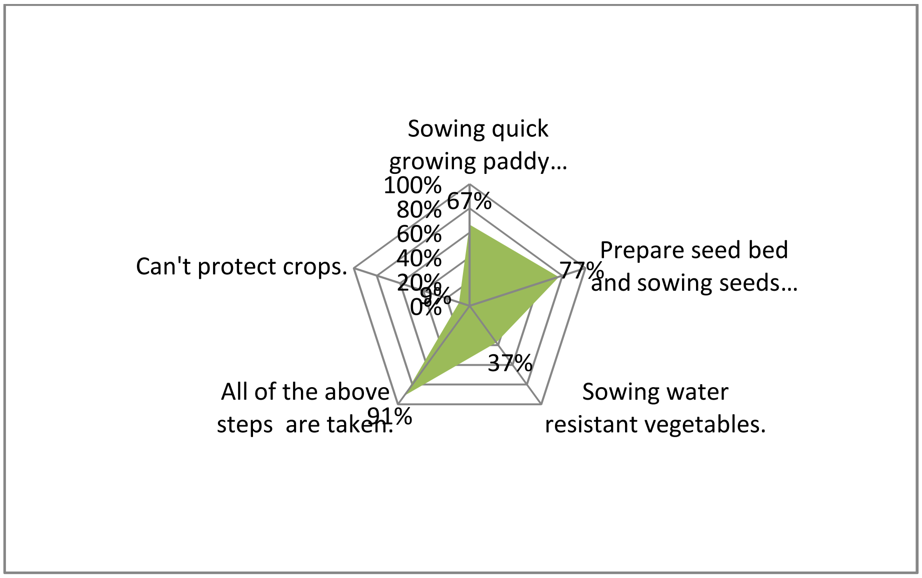
**Figure 7.6 Taking steps to protect livestock before flood**

### 7.5.4. Crop production

Agricultural sector is highly affected than any other sectors due to flood. Flood washed away crop fields with green or ripe corps. Farmers sometimes don't have anything to do to protect their crops. It is observed that farmers of the study areas could not plant their usual crops and can't protect crops, but they sometimes take the following measures or changing the cropping pattern to protect crops before flood:

- Sowing quick growing paddy and leafy vegetables.
- Prepare seed bed and sowing seeds in high place.
- Sowing water resistant vegetables.

**Figure 7.8: Measures taken to protect crops.**



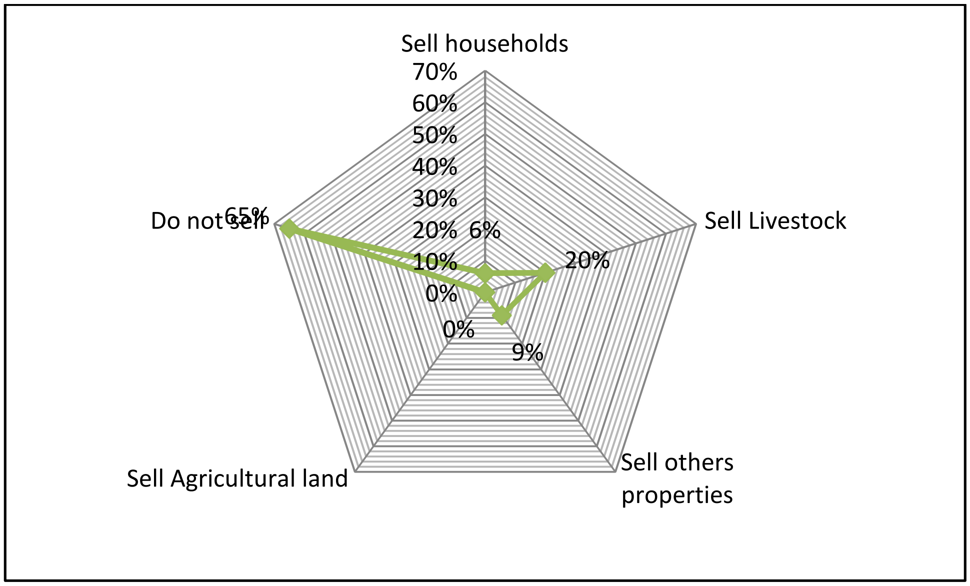

*Source: Field Survey, 2012.*

Analysis of the data contained in figure 7.1 shows that 91 percent of the respondents take multistep to protect their crops from the effect of flood. But a little portion of the people i.e. 9 percent although they tried their best but most of the time they failed to protect their crops.

### 7.5.5. Removal of assets

Poor people are very much afraid about the damage of their assets due to floods. If there is a chance of flood they tried their best to protect their assets (house, livestock, agricultural land, crops etc.). But if it is felt that they may not be able to protect assets then they dispose or sell their assets even though they get lesser price. Poor people who sell their all of the assets they have to take shelter in town or in the shelter center with their whole family for a long period of time. When they go to town they have to search for jobs like rickshaw pulling, day laborer, hawker etc. Many of the people do not sell their assets and try their level best to save or protect. Collected data regarding asset removal are furnished below :

**Figure 7.9: Rate of disposition or removal of assets of the people of study area**




*Source: Field Survey,2013.*

The above graph shows that 20% of the respondents sell their livestock at the period of flooding finding no other way. On the other hand 65% of the flood affected people do not sell their properties. At the same time it is found that 6% of the respondents sell their household to meet up crisis. The whole area is not representing the same scenarios as the flood intensity and damages differ from place to place.

### 7.5.6. Preservation of seeds

Preservation of seeds is a continuous process of the people of the study area. Most of the farmers found to preserve agricultural seeds. They do that because they are feared that they could not get seeds for cultivation after flood. Besides this farmers are habituated to preserve seeds from long day back for cultivation purpose. While surveying it is found that about 47 percent of the respondents preserve seeds keeping these in mind that in the period of flooding seeds may not be available and also may be costly. Some of the poor farmer does so because they don't have money to buy seeds. Some of the respondents opined that they don't preserve seeds as they have no flood protected place to preserve seeds.

### 7.6 Measures taken by the people during flood

During flood the stranded people have to suffer more. They have to lead an inhuman life due to unavoidable circumstances. Although some steps they used to take to minimize sufferings, losses and damages. The steps discussed below:

#### 7.6.1. Taking shelter to the nearby flood free area or flood shelter centers

During flood when the households are gone under water the trapped people have to leave their houses and to take shelter nearby highway, school, flood shelter centers, at the top of roof etc. In the study area a few number of disaster shelter centers found, so the flood affected people are taking shelter in the nearby school which is built on highland. Because of the absence of shelter centers, flood affected people have to suffer more and losing their lives and properties. Sometimes flood affected people are going to towns and nearby flood free villages for shelter and in post flood period they come back to their own village. It is observed that almost 38% people of the study area take shelter to nearby flood free areas.

#### 7.6.2. Taking children and aged people to the safer areas

During flood time children and old people are most vulnerable. They have to suffer more than the working group. This group of peoples (children, old) is victim to water borne diseases which suffers them a lot and even causes to death. So during flood this group of people is sent to the safer areas which are flood free. Almost 50% respondents said that they took their children and old people to nearby safe area. It is exception in some part of the study area as those areas are flood free zone.

#### 7.6.3. Collecting pure drinking water and medicine

During flood period drinking water are highly polluted. Polluted water always caused water borne diseases. So stranded people are seen to collect pure drinking water from the tube wells which are not go under water. Medicine is the inseparable part during flood time. Flood affected people are suppose to collect medicine and saline during flood. The frequency of flood is more in some parts of the study area while some parts are found not vulnerable to flood.  The affected people collect pure drinking water (tube well water) from different part of their upazila or nearby villages/mohallas. Table 7.2 represents the source of drinking water of the affected people of the study area.

**Table 7.2: Source of pure drinking water during flood of the people**

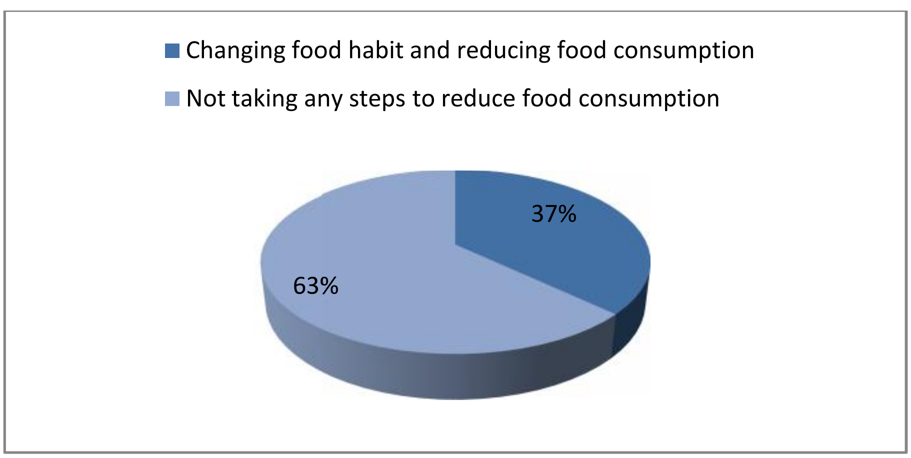
| Sources | Frequency | Percentage (%) |
|---|---|---|
| Tube well | 249 | 83% |
| Other sources | 51 | 17% |
| Total | 300 | 100% |

*Source: Field Survey, 2013*

### 7.6.4. Changing food habit and reduce food consumption

During the flood period most of the poor people in the study area are suppose to change their food habit (eating less preferred and less expensive foods) and also reduce food consumption (reduce the number of meals eaten a day). Generally the poor people in this area are seemed to changing food habit and reducing food consumption. Rich people are sometimes reluctant to changing food habit and food consumption, but when a flood is occurred rich people are also seen to changing their food habit and reserving foods especially dry foods. The stranded people are sometimes bound to reduce food consumption and to change food habit due to unavailability of food during flood period.

**Figure 7.10 : Changing food habit and reducing food consumption.**




*Source: Field Survey,2013*

The above figure shows that 37% peoples of the study found to change their food habit and reduce food consumption. On the other hand 63% people do not take steps in changing food habit and food consumption. Both rich and poor people found enthusiastic of the less consuming food because of unusual situation owing to flood. Most of the poor people found have no reserve food and they are not in position to reserve dry food in respect of economic conditions. They depend on the mercy of floods.

### 7.6.5. Changing occupation

Most of the farmers are bound to change their occupation as cultivation activities are stopped during flood period. To meet the necessity of their family they need to earn and become engaged in a work other than their occupation. Changing occupation depend on the availability of work in their surrounding area or the place they are living. Many people migrate from village to nearby urban area or in the capital city. Some of them found engaged in fishing (catch and sell), boating, rickshaw puller, daily labor, etc. The survey data found that about 18% of the people are temporarily changed their occupation during the flood period. After flood these group of people are suppose to join their old jobs.

### 7.6.6. Co-operation with local people and receiving relief from the Government and Non-Governmental Organization (NGO)

People of the affected area are served with relief by the govt. organizations (GO), Non Government Organization (NGO) and some local rich people. But some of the respondents suppose to raise their finger with complain that they are not served with that type of aid by any type of organization. From the answer of the local interviewees of it is found that very poor people and some farmers are served with reliefs (foods, clothes, medicine, agricultural seeds, saline etc). The amount of assistance is too little. After analyzing the field data it has been found that almost 38% people of the study area received relief and assistance from different organizations. The local people are helping each other during flood. They take initiatives to drain out flood water. All these tasks are performed voluntarily with community participation.

### 7.6.7. Changing the mode of transportation

During flood period communication system hampered greatly. Road transports could not run. This situation is more frequent in the most vulnerable parts of the study area like kalihati, Basail, Delduar, Nagarpur and Mirzapur upazila. Boat, Engine boat, raft (vela) etc. are used as the mode of transportation. Besides this people have the tendency to collect rubber tubes to make raft with that. However, to adopt in the revealed situation due to flood, people of the affected area do as per need for the transportation purpose.

## 7.7 Measures taken by the people after flood

In the post flood period the poor people who were being affected have been found more suffered. They don't have work, houses are damaged, scarcity of pure drinking water, and suffered by water borne diseases etc. This picture is more frequent in almost all over the affected area. After flood to manage house hold, poor people are to borrow money from various NGOs, Govt. organizations and rich money lenders.

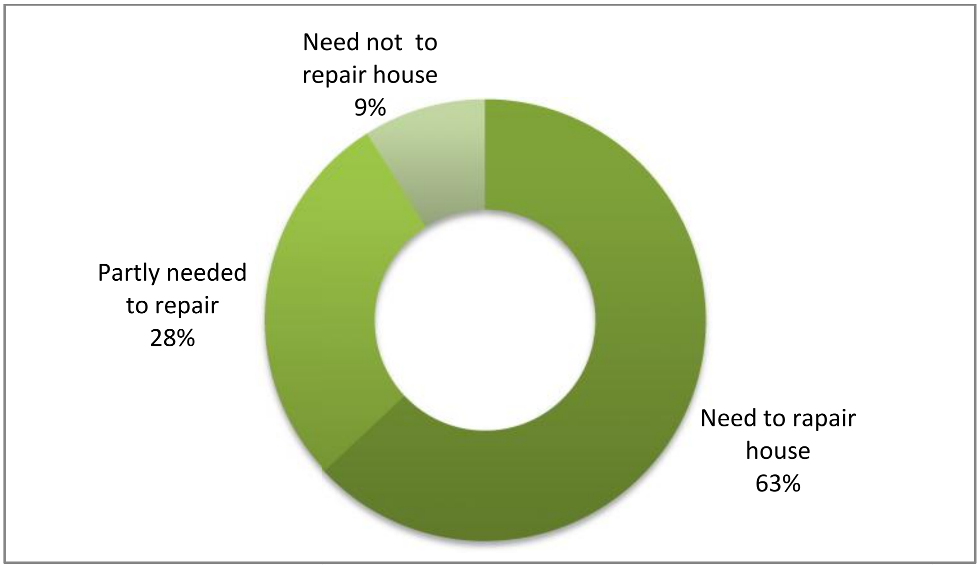
### 7.7.1. Loan

About 33% of the respondents in the study area answered that they took cash loan from various organizations to buy food, repairing house and other purposes. Another 13% of the respondents answered that they also borrow money for the same purposes from their relatives and rich money lenders.

### 7.7.2. Household repairing

After flood the main task of the flood affected people is to repair house. A 63% of the respondents said that they have to repair their house in the post flood period. But a large number (37%) of the respondents said that after flood they do not repair their houses. This indicates that the whole area do not affected with same severity and damages and losses varies in different parts of the study area. However the household repairing data collected through questionnaire survey presented below :

**Figure 7.11: Repairing of household by the people in the post flood period**




*Source: Field Survey, 2013*

### 7.7.3. Searching of jobs

People in Kalihati Upazilla are suffered more after flood. Poor people don't have jobs. For this the immediate task of the people is to search for jobs. People of Ghatail Upazilla are also suffered from the scarcity of jobs.

### 7.7.4 Crops diversification

Farmers of the study areas cultivate various types of crops based on the topographic and climatic conditions and trends of flood. They cultivate crops by rotation on high land, after harvesting ginger, onion, garlic and tomato, and cucumber plants as mixed crops. Short duration vegetables are also incorporated into the gap between two major crops. Aman harvest and Boro planting on the medium high land is also found in different areas.

### 7.7.5 Crops strategies and process

The adjustment processes of farmers in different disasters especially with flood are more innovative than the government or non-governmental agencies. Their patterns of choice of adjustments found very effective and dynamic in nature. Farmers developed these adjustments for successful adaptation by themselves (Hafiza, 2004). They participate in sharing their own activities to ensure the protection of the crops damaged by flood. Farmers harvest their mature crops with the help of neighbors and relatives during early flash flood or extreme flood situation. With the help of neighboring farmers, they protect the Aman field from flood wave or floating weeds, debris, rats and stem borers. They face shortage of seeds after flood, especially the small and marginal farmers. Big or rich farmers (owner of a large quantity of land) hold adequate reserve stocks of seed to re-sow or replant their own land. Poor farmers sometime borrow seeds from neighbors or often travel together long distances to obtain seed or seedlings're-sowing or replanting in an Emergency.

### 7.7.6 Using battery or oil operated electronics

The affected people of the study area found dynamic in nature in respect of adjustment phenomenon. After flooding, most of the affected areas become disconnected from electricity. At that time local people use battery operated lights or oil operated generators or electronics to met up the necessity of lighting. Farmers also found to use generator for irrigation purpose in the dry season.

### 7.7.7 Use preserved food

During flood they use their preserve food drinking water. But drinking water are highly polluted. Polluted water causes water borne diseases. So people collect pure drinking water from the tube wells which are not go under water. Medicine is the inseparable part during flood.

### 7.7.8 Others

After flood people of these two areas are seen to repair roads, embankments, culverts, bridges which were being damaged by floods. These work demands huge money and resources. Most of the times these work are done by the Local Government. Sometimes NGOs and local people are organized to repairing the damaged structures. In case of separation, people of the area opined that they develop team work at the period of flooding together to repair damaged structures.

### 7.8 Peoples opinion about Flood

Most of the People in study area said that flood is a common phenomenon to them. They can't avoid flood hazard. So they have to exercise coping with floods. They said that structural management (building shelter centers, flood control embankments, dredging of rivers etc.) of controlling floods can minimize losses but this is very expensive. Sometime there is huge corruption seen in these sectors. So they think that non-structural measures (coping with floods, training about floods, mass communication, flood warning and preparedness) can help more to minimize losses. Most of the flood affected and non affected people mentioned at present the coping capacity to flood has been increasing and also the social media and NGOs also playing a significant role for training of the people about floods and make them aware and prepare.

### 7.9 Participatory survey: Floods: threat or opportunity?

After a long day travelling, we arrived in Kalihati upazila at Tangail district where we visited purposively and were welcomed by the local people who helped us providing information on flood scenarios. They took us to Beltia village, where about 2100 households live and increasingly affected by floods and erosion. More frequent floods have turned many of the local people from landlords to landless. And the flood erosion has impacted livelihoods by washing away productive arable lands. We observed a demolished road by the flood in Beltia village (figure 7.5).

**Figure 7.12 : Demolished road at Beltia village of Kalihati upazila in Tangail district.**

*Source : The Daily Star, June 28, 2013*

It is observed that sometimes the villagers have taken some adopting measure with the help of different organizations and by their won initiatives.

There is a clear and present need to adapt to these flood risk and impacts to survive. And the community (villagers) has admirably risen to the challenge. With technical support from different organizations, farmers of the village have begun floating garden and confine fish culture to turn the flooding from a threat to an opportunity as adaptation measures. They grow leafy vegetables such as Cancong and red amaranthus. This type of farming has helped farmers to both meet their family's nutritional needs and earn some money by selling surplus vegetables and compost to the nearby market.

**Figure 7.13 Floating garden in the study area**

Source : Collected from field

It is not just flooded lands that are being put to productive use. Farmers have started making more out of the sandbars by growing pumpkin and squash. This cultivation has been possible because the floods have deposited rich alluvial soil on the previously unproductive sandbar. The farmers are investing huge effort into making this land fertile and productive and their hard work is paying off. This 'community-based adaptation' has helped diversify livelihoods and provide money to buy livestock such as goats and cattle. But its future remains uncertain because the farmers have no formal rights to use the land — although the community remains hopeful that, if they lobby, the government will soon hand over the rights.

## 7.6 Analysis of coping strategy

To analyze the coping strategy of the people of the study area, mitigation and adaptation measures have been given preference. Adaptation includes existing condition of the area, initiatives taken by the Government and NGO, level of efficiency of the local people and use of indigenous knowledge. On the other hand mitigation procedure includes scope of action, measures already taken, participation of peoples and lacking/hampering. Figure 7.6 shows detail analysis of coping strategy.

## 7.9 Concluding remarks

For many poor people in Bangladesh, severe flooding has become a line of attack of life. Year after year, the floods destroy homes and crops, often hitting the poorest, who live in villages and charlands of the Brahmaputra-Jamuna. Flooding in Bangladesh killed many people, damaged million homes, and wiped out over a million hectares of crops. Most of the deaths were not due to drowning, but to disease, spread by the shallow stagnant water that covers everything. People of this area now feel to develop simple and affordable flood resistant dealings.

Different methods have been found adapted to save the local people from flood – like building walls to techniques for mixing soil and cement together, they designed to ensure that, though the floods come and go, the house will stay standing. People are aware of flood and now they are habituated to cope with natural disaster as well as flood.

## 8.0 Introduction

Flood risk assessment depends on various parameters. Of these parameters, hydrological conditions, topographical situation, human settlement, coping capacity etc. were taken under consideration in this study for analyzing the flood risk. Appropriate figures and maps have been prepared to represent the real scenarios of the study area. Depending on the collected data and information (both primary and secondary) a hazard maps and risk assessment model have been prepared and also proposed for the study area. Considering the widespread flooding in Bangladesh, as seen in 1988 and 1998 and 1991 caused widespread destruction in one of the least developed countries in the world, some recommendations have also given for the study area those expected to bring good result in this regards. Risk assessment for each land unit was performed considering flood hazard and vulnerability. The vulnerability factors were considered to be simply proportional to population density. Flood hazard maps and flood risk maps will definitely help the responsible authorities to better comprehend the inundation characteristics of the study area and to protect against inundation. In addition, the general public of the study area can get information about flood risk warning before the real event comes. Three of the world's mightiest river systems and being situated in the world's largest delta, river bank erosions are taking away precious land from the small nation with a growing population every year. The economic development of the rural sphere is largely intertwined, as every year the common people lose property and livelihood.

According to flood history eighteen major floods occurred in the 20th century. Those of 1951, 1987, and1988 were of catastrophic consequence. More recent floods include 2004, 2007 and 2010. According to the local people of the study area flood frequency is also high in those period. In 1998, over 75% of the total study area was flooded. It was similar to the catastrophic flood of 1988 in terms of the extent of the flooding. A combination of heavy rainfall within and outside the country and synchronization of peak flows of the major rivers contributed to the river. But a flood phenomenon is today common in this region (Brahmaputra-Jamuna river basin) and it creates a huge damages and losses. But situation is improved today than before because people of this area are more aware about flood. They take different steps for adjustment with flood as a natural hazard.

### 8.1 Major Findings

1. The flood history of Bangladesh shows that the study area in one of the most flood prone area with some few exceptions due to topographic conditions. All major historic floods inundated the area partly and sometimes catastrophically.
2. Topographically the area consisting some flood free zone and some area highly risky zone. Variation of the elevation of land has a great contribution in case of inundation, losses and damages. The lowest hazard zones are located in the middle and northern parts of the study area which have higher ground elevation. The high and very high hazard zones are located in the southern and south-eastern part of the study area while the highest hazard zones are located in the south-western part which topographically low and adjacent to the mighty river Jamuna.
3. Most of the time the area being inundated due to high discharge of river water coming from the upstream catchment area. During the monsoon season (June–October), floods are a common occurrence. Water level and the discharge of water found a fluctuating tendency over a long period of time.
4. Local Govt. and the people of the study area have the intention how effectively flood mitigation procedures can be adopted and can reduce the risk as a landform of downstream. But felt upset as there need a bold decision from the Central Government level.
5. Vulnerability index shows that among the 19 units (upazila) of land Mirzapur, Delduar, Kalihati, Tangail, and Islampur area are highly vulnerable. The other upazilas Gopalpur, Phulbari, Bhaluka, Gafargaon, Kaliakair, Trisal and Kapasia are found highly vulnerable. Rest of the land units are moderately vulnerable of which Jamalpur, Muktagaccha, Sarishabari, Melandaha found low vulnerable.
6. People of the study area are familiar to flood and habituated to cope with the same, but it is observed that, coping capacity of the local people are not at satisfactory level. A major

portion of the local people doesn't have proper knowledge on adaptation and mitigation procedure in a scientific manner.

7. In the period of flooding, local people suffers mainly lack of food including pure water, medical services, communication problem, residential problem and water born diseases. Relief and economic assistant served ever past seemed insufficient to the local people. Security and sanitation problems are also mentioned as major problems during the flood time.
8. Flood protection activities both form the Government and from the side of local people have been found in the study area. The steps taken like construction of barrage and dam don't found appropriate measure for the whole area. On the other hand indigenous knowledge of the people in controlling flood water and reduce the damages and losses found more effective.
9. Most of the time people of the study area depend on their fate in protecting their agricultural product. Quick pass of flood water or resistant of flood water to enter the crop field felt a new concept to the local people. It depends upon the severity of the flood and duration of flood.
10. Flood damages road, agriculture field, create riverbank erosion an on-going problem in this area. Suffering of poor people cause to change their occupation. As a result temporary and permanent migration is taking place in the nearby city, pourashava or in the capital city.
11. Flood shelter centres are not found available in the high vulnerable part of the study area which cause the flood affected people to suffer more. Recently some initiatives have been taken to protect the affected people and to save agricultural crops giving emphasis to the most affected areas. Flood forecasting and warning system, construction of embankment and sluice gate etc. could be mentioned as approved initiatives.
12. People are highly resilient and self-reliant, and they have a number of coping strategies such as advance selling of labour or migration, although these options are not open when so much of the country is similarly affected. Whilst the immediate national response was fair given the circumstances and resource constraints, the overall response was not equal with the needs in any sector.

13. The greatest area of concern is that the flood will push large numbers of the poorest families deeper into poverty. They will need targeted assistance if they are to avoid this, including food relief, support to agriculture employment opportunities and micro-credit. In addition, many will not be able to rebuild their homes without external assistance.
14. Urgent response actions are still required in some areas in terms of bulk food relief and supplementary feeding for vulnerable groups, support to housing rehabilitation and sanitation, and emergency healthcare interventions.
15. Employment generation, whether through Food / Cash for Work or support to cottage industries, and widespread provision of affordable credit will be essential for recovery from the floods. In all cases the new infrastructure should be able to resist future major flooding.

### 8.2. Recommendations

Based on the lesson learned in this research, the following recommendations are provided for future elaboration :

1. **The role of scientific principles for the flood risk assessment should be enhanced**
   By following the concept of appropriate scientific methods, the need based flood controlling measures could be taken. Appropriate modeling in the process of designing and application of flood control measures is required. Any excessively complex method should not be enhanced which may make too hard to employ to the user.

2. **Geophysical politics and bold political decision is required**
   Because of the fact that including the main river (Jamuna) of the study area, 54 rivers originate and locate outside Bangladesh, mainly in India and Nepal. Therefore geophysical politics for the neighbouring co-operation regarding permanent solution of flood problem is urgently required.

3. **Quantitative relationship between flow velocity and flood damage should be established.** Although the effect of flow velocity is incorporated in the hydrological

analysis and risk matrix in this research, a clear and direct relationship between flow velocity and resulting damage remains lacking. Thus future work should focus on establishing the quantitative relationship between damage and velocity. Historical measurement of flood loss at flooding areas could contribute to establishing such relationship. Quantitative inclusion of other important variables such as flood duration should also be considered.

4. **GIS technology can provide approximation of hydraulic and physiographic characteristics**

   In hydraulics, the flow velocity is largely determined by the slope (gravity component driving the flow) and roughness of the flow area (resistance component opposing the flow), so an indication for the velocity characteristics could be obtained using slope roughness of the flooding area, which is information that is readily available from GIS system that are becoming more widely available in practice. Moreover, the topographical analysis and the elevation measurement of the study area had done using GIS technology. It could be one of the most appropriate technologies in analysing hydraulic and topographic measurement.

5. **A sound scientific risk assessment model should be applied**

   General conception regarding flood control and loss assessment is now well known to the affected people and to the policy makers also. Appropriate scientific modelling showing the relationship among the variables and steps of standard activities may be furnished through a newly developed model for the study area.

6. **Reduce of conceptual uncertainty analysis is needed**

   It has been found that uncertainty analysis is of a great benefit to both the development and implementation authorities. This could be overcome by using appropriate method of flood frequency and intensity measurement, damage analysis, identifying losses of lives and properties etc. on an integrated system, particularly when large computations are needed. In that case two or three dimensional analysis is required.

7. **Seeking international co-operation in implementing international river lows**

   Adequate pressure should be given on implementation the international river low for the permanent solution of the flood problem. We must seek help and co-operation from various international forums to create impact over our neighbouring countries to force them to abide by the international river lows.

8. **Temporary shelter could be made to protect the affected people**

   Until the permanent solutions of the flood protections are not achieved, some temporary shelters to the affected people could be made. School, Community hall, Market place must be built up on high land in the rural area so that the victims can take shelters in the crisis moment.

9. **Emergency Plans**

   Most of the respondents and aristocrats (civil society) of the study area highlighted the necessity of the inclusion of local representative and other vulnerable group in the design of different stages of planning. In rural areas, where Community Based Rehabilitation (CBR) committees and other local based community organizations may be in place, disaster preparedness should be conceptualized and implemented with the involvement of all community members. Their participation is crucial to ensure smooth access to disaster awareness, preparedness, mitigation, evacuation and relief.

10. **Specific Training on disaster mitigation and preparedness is required**

    Inclusion of the local people in specific training program on the disaster mitigation and planning is required. A twin track approach is needed. Vulnerable populations are as important as training emergency planners and responders from governmental and other agencies. Providing training in accessible format for the people of the study area is strongly recommended to reduce the damages and losses of flood.

11. **Early emergency communication system could be adopted**

End to end early warning system deliver accurate warning information of potential hazard dependably and in a timely manner to both authorities and population at risk. In order to prepare them for the danger and act according to mitigate and avoid the hazard early emergency system need to adopt in the study area. Of course a feasibility study in developing the above mentioned system is required in this regard.

12. **Dissemination of information**

    The need to disseminate information on locations of potential assistance and bring awareness to the procedures that one should follow in the case of emergency since many people are not aware of the available resources or plans.

13. **Combination of activities among Government, Local administration and warlords**

    It is recommended that in the period of flooding Government might have control over the capital of the country but the rest of the country (applicable to the study area) may be in the control of either rebel forces or local warlords. It must be kept in mind that in such situations, there is no type of government structure to use and all planning for disaster relief may have to come for local communities or agencies outside the country.

14. **Training and equipping the local people to cope with the flood**

    It was observed that training is linked to mitigation as well as to reduce the risk of flood. Equipping people with the resources to cope with the effects of flood, using locally available resources and skills, is essential in the management and mitigation of future flood.

### 8.3 People's Perception on Flood

The majority of the respondents agreed on that governments, civil society and activists need to work together to establish standards in mitigation, response, management and rehabilitation plans through dialogue and legislative measures, affordable and appropriate technology in communication, mobility and related needs for the people of the study area. The solutions should be benevolent and compassionate for all concerned. Bangladesh is a disaster prone area. Flood is a common environmental problem in this area and every year it creates a huge problem in this country. Sometime flood blesses for this country, because flood wash away all pollutants and it brings huge sediment and this sediment increase soil fertility. So agriculture fields are prepared for huge amount of crops production. But maximum time flood is lessons for this country because it damage huge amount of property, crops, roads, disconnect electricity, pollute drinking water and also environment by degrading sanitation. So people of this country try to adjust with this problem by taking different steps and try to survive with this obvious natural calamity. Respondents of the study area stressed main issues and problems of economic and social recovery and reconstruction.

### 8.4 Flood Adjustment measures

People of the study area have become habituated with flood. They know will how to cope with the adverse effect of floods. When flood water rises, people firs try to collect their belongings and move to the higher and safer parts of their homes. If the water reaches there too, they take shelter on the table, cot, platform or other raised fittings if there are any within the household, and stay there until the water level falls. When that fail or if the households doesn't have any furniture off which people can sit on, they try to build raised bamboo plat forms known as 'mancha' within their homes where all the members of the households huddle together waiting for the flood water to reduce. If the flood water rises further and forces them from their homes, people take shelters in the high roads or embankments and make temporary huts with straw and bamboo frame where they stay until the end of the crisis. In some cases they take shelter in high public building if there any in the locality. Some move out of the village and take temporary relief camps usually set up by the Government during that period. In some highly flood affected area the effected people pass long time in the shifted sport e.g. road and embankments etc.

Finding shelter for domestic animal is even more difficult than for people. People first try to put their livestock on some high ground in or around their living quarters. If that fail they drive them to the nearest high land or embankment where the animals may be unprotected and exposed to sun and rain sometimes for days on end. As a result the incidence of death among domestic animals in the flood affected regions is found to be quite high.

It is observed from the field visit and participatory survey that majority of the people in the flood affected area do not seem to lack confidence in meeting the challenge of floods.

As a matter of fact, more than 75 percent of the people interviewed by the researcher opined that they are able to overcome the flood problems in their regions. This does not mean that they can become better off or remain as well of as before flood. The development of potential opportunities to mitigate flood and to reduce the risk of flood is required for the study area as early as possible.

**8.5 Need for further study**

The word flood is very familiar to all categories of people of the study area as it occurs almost every year in the area. When comes it becomes harmful for the people, for the society and for the environment directly or in directly. It is observed that every year local peoples, GO and NGOs takes some measures to save the affected people and provide some necessary help including rescue and evacuation. Huge quantity of money, time and manpower are spent, but sufferings of the people and, losses of livestock and animal are found increasing in trend. It may be because of devastating floods becoming more severe and number of population is increasing day after day. For an example, the flood of 1998 established as a devastating flood which caused a huge amount of losses and damages in the study area. But in the next time in 2004 another flood occurred and indicated that, it crossed all previous record in respect of inundation, losses and sufferings. Although flood protection and mitigation activities are continuing in the study area but fruitful result in this sector is still need to be developed to the ordinary people of the study area. Sector wise individual research should be done for the achievement up to the expectation. Some important sectors need to be developed are mentioned below:

(1) To protect the study area from intensive floods Bangladesh has to improve the present data processing and information system for flood forecasting and warning system especially in the flood prone area. Vulnerable people should be identified and special treatment of the vulnerable group need to be adopted. It has been observed that lack of actual information regarding river discharge, water level, rainfall etc. people have not been able to undertake appropriate measures to protect livestock and themselves.

(2) From the field study and questionnaire survey it is observed that understanding the warning system and dissemination of information are also major problems in

the study area. In that case more scientific and technological measures could be taken. Further research and critical analysis in this regards are necessary to implement the scientific and technology based strategy and activities.

(3) Another vital point is that very high volume of water flow of the river Brahmaputra and Jamuna comes from outside Bangladesh. From the technical point of view, flood control, mitigation, risk assessment etc. could most rationally be achieved by a combination of the technical measures with bilateral co-operations. In that case international co-operation of the neighbouring countries would be of a great benefit for both of the countries. Further research with geopolitical aspects is required in this case. It is strongly recommended that geopolitics and international policies need to be taken seriously in this regards so that all concerned vulnerable people of the countries would be benefited.

(4) The studies of the hydrological characteristics of the concerned rivers for the development of water resource management procedure and for future planning are essential. To analyze the vulnerability and risk of flood of the study area, accurate hydrological and geomorphologic data and information are required. Depending on that data and information a long term future planning could be developed. Only further research and analysis with recent data and information can find out the appropriate suggestion in this regards.

(5) Identification of vulnerable group analysis of hazard index, coping capacity measurement and finally risk analysis are now the demand of time of the study area. Vulnerable group of people always to seek new policy, new measure, new concept to adopt themselves and to reduce their losses. Further research and scientific analysis can fulfil their demand and can find out ne idea for the people. The development of potential opportunities that may present in before the flood, during the flood and after the flood could be strengthening through vigorous research.

### 8.6 Final Comments and Conclusions

The objectives of the study reflect that flood risk assessment and human adjustment scenarios analysis is the main task focusing the study area (Brahmaputra-Jamuna River Basin). Keeping this in mind the whole area has been divided into 19 units for topographic analysis and elevation maps have been prepared depending upon the SRTM (converted to DEM) data and images. Hydrological analyses have been made using secondary data from BWDB. The information sharing and the exchange of views were done in the period of survey of the study area. Depending on the collected information and data, and observing the situation from the real world, Hazard and vulnerability map prepared those shows the result of the study. Moreover, the specific analysis on hydrological characteristics, topographical situation, and population settlement and, hazard, vulnerability and risk analysis expected to add a new dimension in this study.

A model has been developed using Arc GIS and final risk has been assessed through this model to reach the goal of this research. Collected relevant data and information were used to complete this model.

After forty one years of self-governing of the country, the study area is still under threat of flood. It may mentioned that some projects on flood control have been implemented, economic losses have been identified after each flood, some more steps related to reduce flood risk have been taken. But still now the impact of flood to the people of the study area is severe. Causes and effect of flood are analyzed in various ways. Recommendations have also made from different corners, social and economic impacts are also analyzed, yet the area (study area) need solution of flood related problem. Even though it is not easy to assess the accurate risk of the study area, we can get a comprehensive view through this study. The Government, concerned agencies and authorities may have some new ideas so that they could prepare appropriate planning.

Starting with international minimum standards on the flood risk assessment there is a need to ensure an inclusive result that is not based to the local people. Dynamic research and massive analysis can provide fundamental help in this regards.

**REFERENCES**

Adenine s (1991). Floods, People and the Environment. Research and Advisory Services, Dhaka.

Ahmad Q K, Warrick R A, Eric ken NJ and Miraza M P (1996). The Implications of Climate Change for Bangladesh: A Synthesis, In R A Warrick and Q K Ahmad (eds) The Implications of Climate and Sea-level Change for Bangladesh. Kluwer Academic publishers, London, 1-34.

Ahmad S M and Ahamad F (1988). An investigation on Floods in the Monu and Khoai Rivers. Final Report, Institute of Flood Control and Drainage Research. Bangladesh University of Engineering and Technology.

Ahmad M (1989). Deluge in the delta, In M Ahmad (ed), Flood in Bangladesh, Community Development Library, Dhaka, 3-40

Ahmed Imtiaz (1999). Living With Floods : An exercise in Alternatives, The University Press Limited, Dhaka, Bangladesh.

Aitken A P (1976). A Stage-damage Curve for the Brisbane River, Snowy Mountains Engineering Corporation, Australia.

A.K. Gain and M.M. Hoque (2012), Flood risk assessment and its application in the eastern part of Dhaka City. Dhaka, Bangladesh.

Alam M S and Chowdhury A H (1992). Perception and Adjustment to Flood Hazards in the metghna-Dhonagoda Flood Plain, The Jahangirnagar Review, Vols XII & XIV, Savar, Dhaka.

Alam S M N (1990). Perceptions of Flood Among Bangladeshi Villagers, Disasters, 14(4), 354-57.

Alamgir M, Salimullah M, Islam K M N, Roy D K, Bhuiyan K, Islam A B M S, Rahman M and Rahman M (1977a). Famine 74- The Political Economy of Mass starvation in Bangladesh, A Statistical Annexe, Part II, BIDS, Dhaka.

Alamgir M, Salimullah M, Islam K M N, Roy D K, Bhuiyan K, Islam A B M S, Rahman M and Rahman M (1977b). Famine 74- The Political Economy of Mass starvation in Bangladesh, A Statistical Annexe, Part II, BIDS, Dhaka.

Alamgir M, (1980). Famine in South Asia: Political Economy of Mass Starvation, Oelgeschlager, Gunn and Hein Publishers, Cambridge, Massachusetts

Aimilia Postrika and George Tsakiris (2007). Flood risk assessment : A methodological Framework, National Technical University. Greece.

A. Pistrika (2010), Flood Damage Estimation based on Flood Simulation Scenarios and a GIS Platform. E. W. publication, Athens Greece.

Appelbaum S J (1985) Determination of Urban Flood Damages, Journal of the ASCE Water Resources Division 111(3), 269-282

Asaduzzaman M (1989). Feeding Our Future Towns: An Overview of Urbanization and Associated Food Policy Issues, Bangladesh Planning Commission, Food Strategies in Bangladesh, Medium and Long Term Perspectives, University Press Limited, Dhaka

Asaduzzaman M (1993). Sea Level Rise in Bangladesh: Socio-economic Issues and Implications, Paper presented to the IOC/UNDP Workshop on Impact of Rise in Sea Level and Temperature Increases due to Global Warming on coastal Zone in the South Asian Sea Region, January, Dhaka

Asaduzzaman M (1994). The Flood Action Plan in Bangladesh: Some Lessons of Past Investments, Working Paper, 94.3, Center for Development Research, Denmark.

Asian Development Bank-ADB (1994). Climate Change in Asia: Bangladesh Country Report, Regional Study on Global Environmental Issues, Manila, Philippines.

Ahmed Asib (2011). Agricultural adjustment in flood prone areas in Comilla of Bangladesh: A geographical study, Journal of Development and Agricultural Economics Vol. 3(12), pp. 602-609,26 October,2011Available online at http://www.academic journals.org/JDAE.

Azam J-P (1991). Feasibility Study for the Macroeconomic Analysis of the Bangladesh Flood Action Plan, Dhaka

Ackleson SG, Klemas V, McKim HL, Merry CJ (1985) A comparison of SPOT simulator data with Landsat MSS imagery for delineating water masses in Delaware Bay, Broadkill River and adjacent wetlands. Photogramm Eng Remote Sens 51(8):1123–1129

Adam S, Wiebe J, Collins M, Pietroniro A (1998) Radarsat fl ood mapping in the Peace-Athabasca delta, Canada. Can J Remote Sens 24(1):69–79

Adger W (2006) Vulnerability. Glob Environ Chang 16(3):268–281

Akter T, Simonovic SP (2005) Aggregation of fuzzy views of a large number of stakeholders for multi-objective fl ood management decision making. J Environ Manage 77(2):133–143

Alcántara-Ayala I (2002) Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. Geomorphology 47(2–4):107–124

Alexander D (1993) Natural disasters. UCL Press Limited, London

Alexander D (2000) Confronting catastrophe: new perspectives on natural disasters. Oxford University Press, New York

Ali A, Quadir DA, Huh OK (1989) Study of river fl ooding hydrology in Bangladesh with AVHRR data. Int J Remote Sens 10(12):1873–1891

Anderson MB (1992) Metropolitan areas and disaster vulnerability: a consideration for developing countries. In: Kreimer A, Munasinghe M (eds) Environmental management and urban vulnerability.

The World Bank, Washington, DC, pp 77–92

Apel H, Thieken A, Merz B, Blöschl G (2006) A probabilistic modelling system for assessing flood risks. Nat Hazard 38(1–2):79–100

Asian Disaster Reduction Centre (ADRC) (2005) Total disaster risk management – good practice.

ADRC, Kobe, Japan. Available at http://www.adrc.or.jp/

Azar D, Rain D (2007) Identifying population vulnerable to hydrological hazards in San Juan, Puerto Rico. GeoJournal 69(1–2):23–43

Bangladesh bank (1994), Economic Trends (Monthly Bulletin), Statistics Department, Various monthly issues, Dhaka

Bangladesh Bureau of Statistics (BBS). Various Yearly Issues, Statistical Year Book of Bangladesh, Government of the People's Republic of Bangladesh (GOB0), Dhaka

Bangladesh Bureau of Statistics BBS (1976). Agricultural Production Levels in Bangladesh, 1947-72, Statistics Division, GOB, Dhaka

Bangladesh Bureau of Statistics BBS (1988). Report on Bangladesh census of Manufacturing Industries (1947-88), GOB, Dhaka

Bangladesh Bureau of Statistics BBS (1991). Statistical Year Book of Bangladesh, GOB, Dhaka

Bangladesh Bureau of Statistics BBS (1993b). The Year Book of Agricultural statistics of Bangladesh, Statistics Division, GOB, Dhaka.

Bangladesh Bureau of Statistics BBS (1993c). Twenty Years of National Accounting of Bangladesh (1972/72-1991/92), GOB, Dhaka.

Bangladesh Bureau of Statistics BBS (1993d). Bangladesh Population Census, 1991, Vol2, Union Statistics, December, Dhaka.

Bangladesh Bureau of Statistics BBS (2011). Statistical Year Book of Bangladesh, GOB, Dhaka

Bangladesh Water Development Board, BWDB (1992), Meghna River Bank Protection, Final Report, FAP-9BB, Vol 1, Main Report, Haskoning, Delft Hydraulics, Bangladesh Engineering and Technological Services, February.

Bangladesh Unnayan Parishad (BUP) (1988). Early Implementation Projects on Flood Control Drainage Improvement and Irrigation, GOB, Government of the Netherlands, Government of Sweden.

Bedell J R, Giodani B, Amour J L, Tavormina J and Bell T (1977). Life Stress and the Psychosomatic and Medical Adjustment of Chronically III Children. Journal of Psychosomatic Research 21, 237-242.

Bimal Kanti Paul (2014). Environmental Hazards and Disaster , Context, Perspectives and Management. Wiley Blackwell, Kansas State University, A John Wiley and Sons, Ltd.

Benin L (1985). Medical Consequences of Natural Disasters, Springer-Veiag, New York

Blaikie P, Cannon T, Davis I and Wisber B (1994). AT Risk: Natural hazards, vulnerability, and disasters, Rutledge, London, UK

Blalock Jr H M (1972). Social Statistics, Second Edition, International Student Edition, University of Washington

Brammer H (1990a). Floods in Bangladesh I- Geographical Background to the 1987 and 1988 Floods, The Geographical Journal, Vol 156, No 2, 12-22

Brammer H (1990b). Floods in Bangladesh II- Flood Mitigation and Environmental Aspects, The Geographical Journal, July, Vol 156, No 1, 158-156

Brammer H, Asaduzzaman M and Sultana p (1996). Effects of Climate and Sea-level Changes on the Natural Resources for Bangladesh, In R A Warrick and Q K Ahmad (eds) The Implications of Climate and Sea-level Change for Bangladesh, Kluwer Academic Publishers, London, 1430203.

Bryman A (1988). Quantity and Quality in Social Research, Unwin Human Ltd, London, UK.

Buehler B (1975). Monetary Values of Life and Health, ASCE Journal of the Hydraulics Division, Vol 101, January

Burton I (1986), Foreword, In E C Penning-Rowsell, D J Parker and D M Harding (eds) Floods and Drainage: British Policies for Hazard Reduction, Agricultural Improvement and Wetland Conservation, Allefn and Unwin, London

Burton I and Kaes R W (1964). Perception of Natural Hazards in Resource Management, Natural Resources Journal 3, 412-41

Bankoff G (2001) Rendering the world unsafe: 'vulnerability' as Western discourse. Disasters 25(1):19–35

Bankoff G, Frerks G, Hilhorst D (2004) Mapping vulnerability: disasters, development & people. Earthscan, London

Barroca B, Bernardara P, Mouchel JM, Hubert G (2006) Indicators for identification of urban fl ood vulnerability. Nat Hazard Earth Syst Sci 6(4):553–561

Barton IJ, Bathols JM (1989) Monitoring floods with AVHRR. Remote Sens Environ 30(1):89–94

Birkmann J (ed) (2006) Measuring vulnerability to natural hazards: towards disaster resilient society. United Nations University Press, Tokyo .

Birkmann J (2007) Risk and vulnerability indicators at different scales: applicability, usefulness and policy implications. Environ Hazard 7(1):20–31.

Bizimana JP, Schilling M (2010) Geo-information technology for infrastructural fl ood risk analysis in unplanned settlement: a case study of informal settlement fl ood risk in the Nyabugogo flood plain, Kigali city, Rwanda. In: Showalter PS, Lu Y (eds) Geospatial techniques in urban hazard and disaster analysis. Springer, Dordrecht, pp 99–124

Blasco F, Bellan MF, Chaudhury MU (1992) Estimating the extent of floods in Bangladesh using SPOT data. Remote Sens Environ 39:167–178

Bocco G, Sanchez R, Riemann H (1995) GIS affects flood planning efforts. GIS World 7(3):32–35

Bollin C, Hidajat R (2006) Community-based risk index: pilot implementation in Indonesia. In:

Birkmann J (ed) Measuring vulnerability to natural hazards: towards disaster resilient society. United Nations University Press, Tokyo, pp 271–289

Boruff BJ, Cutter SL (2007) The environmental vulnerability of Caribbean island nations. Geogr Rev 97(1):932–942

Boruff BJ, Emrich C, Cutter SL (2005) Erosion hazard vulnerability of US coastal counties. J Clim Res 21(5):932–942

Boyle SJ, Tsanis IK, Kanaroglou PS (1998) Developing geographic information system for land use impact assessment in flooding condition. J Water Resour Plan Manage 124(2): 89–98

Brimicombe AJ, Bartlett JM (1996) Linking geographic information systems with hydraulic simulation modelling for fl ood risk assessment: the Hong Kong approach. In: Goodchild

MF, Steyaert L, Parks BO, Josnston CO, Maidment DR, Crane MP, Glendinning S (eds) GIS and environmental modelling: progress and research issues. Wiley, New York, pp 165–168

Brivio PA, Colmbo R, Maggi M, Tomasoni R (2002) Integration of remote sensing data and GIS for accurate mapping of fl oded areas. Int J Remote Sens 33(3):429–441

Büchele B, Kreibich H, Kron A, Thieken A, Ihringer J, Oberle P, Merz B, Nestmann F (2006) Flood-risk mapping: contribution towards an enhanced assessment of extreme events and associated risks. Nat Hazard Earth Syst Sci 6(4):485–503 64 2 Hazards, Risk, and Vulnerability

Burton C, Cutter SL (2008) Levee failures and social vulnerability in the Sacramento-San Joaquin Delta area. Nat Hazard Rev 9(3):136–149

Burton I, Kates R, White GF (1993) The environment as hazard, 2nd edn. Guilford Press, New York

Clay E J (1985). The 1974 and 1984 Floods in Bangladesh: From Famine to Food Crisis Management, Food Policy, 10(3), 202-6

Clay E J (1986). Rural public Works and Food for Work: A Survey. World Development 14, 10/11: 237-52

Cly E J and Khan M S (1977). Agricultural Employment and Under-employment in Bangladesh: The Next Decade, Paper No 4, BARC, Dhaka

Chao Zhang, Tomoharu Hori, Jiquan Zhang et al. (2003). GIS and flood inundation Model-based flood risk assessment in urbanized area. Yat-sen University Press. Vol. 1. Japan.

Compartmentalization Pilot Project, Cpp (1992). Tangail CPP Interim Report, Mathematical Modeling (Annex 4), FAP- 20, Government of Bangladesh

Compartmentalization Pilot Project, Cpp (1994). Tangail Town Integrated Water Management and Development Study, FAP- 20, Final Report, Vol 1 and 2, Resource Planning and Management Consultants.

Cuddy J D A and Valle P A D (1978). Measuring the Instability of Time Series Data. Oxford Bulletin of Economics and Statistics, 40(1), February, 79-84

Cannon T (2000) Vulnerability analysis and disasters. In: Parker DJ (ed) Floods, vol 1. Routledge, London, pp 45–55

Carrara A, Guzzetti D (eds) (1995) Geographical information systems in assessing natural hazards. Kluwer Academic Publishers, Dordrecht

Chakraborty J, Tobin GA, Montz BE (2005) Population evacuation: assessing spatial variability in geophysical and social vulnerability to natural hazards. Nat Hazard Rev 6(1):23–33

Chen Y-R, Yeh C-H, Yu B (2011) Integrated application of the analytical hierarchy process and the geographic information system for flood risk assessment and fl ood plain management in Taiwan. Nat Hazard 59(3):1261–1276

Chubey MS, Hathout S (2004) Integration of RADARSAT and GIS modelling for estimating future Red River fl od risk. GeoJournal 59(3):237–246

RE, Schwartz HE (1998) Assessing the vulnerability of coastal communities to extreme storms: the case of Revere, MA, USA. Mitig Adapt Strat Glob Chang 3(1):59–82

Coppock JT (1995) GIS and natural hazards: an overview from a GIS perspective. In: Carrara A, Ad Guzzetti F (eds) Geographical information systems in assessing natural hazards. Kluwer Academic Publishers, Dordrecht, pp 21–34

Corbley KP (1993) Remote sensing and GIS provide rapid response for flood relief. Earth Obs Mag 2:28–30

Cova TJ (1999) GIS in emergency management. In: Longley PA, Goodchild MF, Maguire DJ, Rhind DV (eds) Geographical information systems, management and application. Wiley, Chichester, pp 845–858

Cova TJ, Church L (1997) Modeling community vulnerability evacuation using GIS. Int J Geogr Inf Sci 11(8):763–784

Crevier Y, Pultz TJ (1996) Analysis of C-band SIR-C radar backscatters over a flooded environment, Red River, Manitoba. In: Applications of remote sensing in hydrology, proceedings of the third international workshop, NHRI symposium no. 17, Greenbelt, MA, pp 47–60

Crichton D (2002) UK and global insurance response to flood hazard. Water Int 27(1):119–131

Cutter SL (1996) Vulnerability to environmental hazards. Prog Hum Geogr 20(4):529–539

Cutter SL (2003a) The vulnerability of science and the science of vulnerability. Ann Assoc Am Geogr 93(1):242–261

Cutter SL, Finch C (2008) Temporal and spatial changes in social vulnerability to natural hazards. Proc Natl Acad Sci 105(7):2301–2306

Cutter SL, Mitchell JT, Scott MS (2000) Revealing the vulnerability of people and places: a case study of Georgetown county, South Carolina. Ann Assoc Am Geogr 90(4):713–737

Cutter SL, Boruff BJ, Shirley WL (2003) Social vulnerability to environmental hazards. Soc Sci Q 84(2):242–261

Cutter SL, Barnes L, Berry M, Burton C, Evans E, Tate E, Webb J (2008) A place-based model for understanding community resilience to natural disasters. Glob Environ Chang 18(4):598–606

Cutter SL, Emrich CT, Webb JJ, Morath D (2009) Social vulnerability to climate variability hazards: a review of literature. Final report to Oxfam America. Available at http://adapt. oxfamamerica.org/resources/Literature_Review.pdf . Accessed 2 Apr, 2011

Davis D W (1978). Comprehensive Flood Plain Studies Using Spatial Data Management Techniques, Water Resources Bulletin, AWRA, 14 June, 587-604

Davis S A (1988). National Economic Development Procedures Manual, Urban Flood Damage, US Army corps of Engineers, Virginia

Davis I (1977). Emergency Shelter, Disasters 1 (1), 23-40

Davis I (1978). Shelter After Disaster, Oxford Polytechnic Press, Heading ton, Oxford

In I Davis (ed) Disasters and the Small Dwelling, Paragon Press, Oxford, 11-24

Davis I (1983). Disasters as Agents of Change? Or: Form Follows Failure, Habitat Intl. 1(5/60, 277-310

Davis I (1984). Housing and Natural Hazards, In I J Miller (ed) The International Karakoram Project, Vol 2 Cambridge University Press, Cambridge, 200-27

Davis I (1984b). Prevention is better than cure, Ideas, RRDC Bulletin 18, October, 3-7

Davis I (1987). Safe Shelter Within Unsafe Cities: Disaster Vulnerability and Urbanization, Open House International 12(3), 5-15

Dempster J I M and Brammer H (1992). Flood Action Plan - Bangladesh, Outlook on Agriculture, December, Vol 21 No 4

Durking MS, Khan N and Davidson L L (1993). The Effects of a Natural Disaster on Child Behavior: Evidence for Post-traumatic Stress, American Journal of Public Health, 1549-1553

Dworkin J (1974). Global Trends in Natural Disasters, 1947-1973, Natural Hazard Research, Working Paper No 26, Institute of Behavioral Science, University of Colorado, Boulder.

Dang NM, Babel MS, Luong HT (2011) Evaluation of flood risk parameters in the Day river flood diversion area, Red River delta, Vietnam. Nat Hazard 56(1):169–194

Demirkesen AC, Evrendilek F, Berberoglu S, Kilic S (2007) Coastal flood risk analysis using Landsat-7 ETM + imagery and SRTM DEM: a case study of Izmir, Turkey. Environ Monit Assess 131(1–3):293–300

Dewan AM, Yamaguchi Y (2008) Effects of land cover changes on flooding: example from Greater Dhaka of Bangladesh. Int J Geoinf 4(1):11–20

Dewan AM, Yeboah KK, Nishigaki M (2005) Flood mapping and damage evaluation in Greater Dhaka, Bangladesh with remote sensing. Asian Pro fi le 33(5):495–512

Dewan AM, Yeboah KK, Nishigaki M (2006) Using synthetic aperture radar (SAR) data for mapping river water flooding in an urban landscape: a case study of Greater Dhaka, Bangladesh. Hydrology, Water Resour 19(1):44–54

Dewan AM, Islam MM, Kumamoto T, Nishigaki M (2007) Evaluating flood hazard for land-use planning in Greater Dhaka of Bangladesh using remote sensing and GIS techniques. Water Resour Manage 21(9):2101–2116

Dow K (1992) Exploring differences in our common future(s): the meaning of vulnerability to global environmental change. Geoforum 23(3):417–436

Dow K, Downing TE (1995) Vulnerability research: where things stand. Hum Dimens Q 1:3–5

Dutta D, Herath S, Musiake K (2003) A mathematical model for flood loss estimation. J Hydrol 277(1–2):24–49

Dutta D, Khatun F, Herath S (2005) Analysis of flood vulnerability of urban buildings and population in Hanoi, Vietnam. Seisan Kenkyo 57(4):150–154

Dymon UJ (1990) The role of emergency mapping in disaster response. Quick response report no. 42.

Eakin H, Luers A (2006) Assessing the vulnerability of social-environmental systems. Ann Rev Environ Resour 31:365–394

Elahi M K and Rogge J R (1990). Erosion, Flood and Population Displacement in Bangladesh, River Bank Erosion Impact Study, Jahangirnagar University, Savar, Dhaka.

Ellson R W, Milliman J W and Roberts E C (1983). Assessing the Regional Economic Effects of Earthquakes and Earthquake Predictions, Working Paper in Economic, College of Business Administration , University of South Carolina, USA

Engman ET, Gurney RJ (1991) Water resources management and monitoring. In: Engman ET, Gurney RJ (eds) Remote sensing in hydrology. Chapman Hall, London, pp 193–210

Emery J (1986). Disaster, Distress, Disease, A Background Report for the Social Costs of Sewers study, flood Hazard Research Centre, Middlesex Polytechnic Institute Financial Times (1996). Various Daily Issues.

Fedeski M, Gwilliam J (2007) Urban sustainability in the presence of flood and geological hazards: the development of a GIS-based vulnerability and risk assessment methodology.

Flood Hazard Research Centre (1986). Westgate Back Flood Relief Scheme, Cost Benefit Assessment, Middlesex Polytechnic, June.

Flood Hazard Research Centre (1986). Lower Clone Study, Technical Avvexe, Flood Damage Assessment, Middlesex Polytechnic, July.

Flood Plan Coordination Organization, FPCO (1991a). Guidelines for Economic Analysis, Bangladesh Action Plan for Flood Control, Ministry of Irrigation, Water Development and Flood Control, Dhaka, May.

Flood Plan Coordination Organization, FPCO (1991b). Master Plan for Dhaka Protection Project (Study in Dhaka Metropolitan Area), Bangladesh FA P-8A, Main Report, JICA, November

Flood Plan Coordination Organization, FPCO (1991c). Dhaka Integrated Flood Protection, FAP-8B, Final Report, Ministry of Irrigation, Water Development and Flood Control, Louis Berger International, Dhaka, September

Flood Plan Coordination Organization, FPCO (19912a). FCD/I Agricultural Study, FAP-12 Final Repot, Vol, Main Report, ODA-JK and JICA-UK Japan, Bangladesh Flood Action Plan, GOB.

Flood Plan Coordination Organization, FPCO (19912b). FCD/I Operation and Maintenance Study, FAP-13 Final Repot, Vol, Main Report, ODA-UK and JICA-Japan, Bangladesh Flood Action Plan, GOB. Dhaka

Flood Plan Coordination Organization, FPCO (19912c). Flood Response Study, FAP-14, Conference Briefing Notes, ISPAN, Dhaka

Flood Plan Coordination Organization, FPCO (1992d). Flood Response Study, FAP-14, Final Report and Planning Guidelines, ISPAN, Dhaka

Flood Plan Coordination Organization, FPCO (1992e). Guidelines for Economic Analysis, Bangladesh Action Plan for Flood Control, Ministry of Irrigation, Water Development and Flood Control, May, Dhaka

Flood Plan Coordination Organization, FPCO (1992f). Secondary Towns Integrated Flood Protection, FAP-9A, Final Report, Main Report, Vol 1A, Ministry of Irrigation, Water Development and Flood Control, Hal crow and Partners

Ford D T and Davis D W (1983). Hydrologic Engineering Centre Planning Models, Technical paper No.92 US Army Corps of Engineers, Hydrologic Engineering Centre, December, Davis, California

Ford ham M H (1992). Choice and Constraint in Food Hazard Mitigation: The Environmental Attitudes of Flood Plain Residents and Engineers, PhD Thesis, School of Geography and planning, Middlesex polytechnic, UK

Fordham M, Herring A, ketteridge A-M parker D and penning- Rowsell E (1994). Euro flood Technical Report Full Flood Impacts, In A-M Ketteridge and C Green (eds) The technical Annex for the Full Flood Impacts Module. The Europe-wide project for Flood Hazard Research and policy Making

French Engineering Consortium (1998). Pre-feasibility Study for Flood Control in Bangladesh, Bangladesh Water Development Board in association with BETS, Vol 2, Dhaka

Fekete A, Damm M, Birkmann J (2010) Scales as a challenge for vulnerability assessment. Nat Hazard 55(3):729–747

Few R (2003) Flooding, vulnerability and coping strategies: local responses to a global threat. Prog Dev 3(1):43–58

Gagey, N F (1989). Report on Macroeconomic Effect of a Flood Control Project in Bangladesh, Ministry of Finance, Paris, France

Gain AK, Hoque MM (2012) Flood risk assessment and its application in the eastern part of Dhaka city, Bangladesh. J Flood Risk Manage. doi: 10.1111/jfr3.12003

Gao J, Nickum JE, Pan Y (2007) An assessment of flood hazard vulnerability in the Dongting lake region of China. Lakes Reserv Res Manage 12(1):27–34

Government of the People's Republic of Bangladesh (GOB) and Republic of France (1989). Pre-feasibility study for Flood Control in Bangladesh, Vol 1: Executive Summary

Government of Bangladesh-United Nations Development Programmed, GOB-UNdP (1989). Bangladesh flood Policy Study, Final Report, Ministry of Planning, Dhaka

Government of the People's Republic of Bangladesh. Population Census Reports, Various Censuses, Bangladesh Population Census, Dhaka

Green C H (1998). The Relationship between the Magnitude of Flooding, Stress and Health, Flood Hazard research Center, Middlesex University, UK

Green C H (1993). The Human Aspects of Flooding, Flood Hazard Research Center, Middlesex University, UK

Green C H (1995a). Assessing Vulnerability to Flooding: Notes and Network, Flood Hazard Research Center, Middlesex University, UK

Green C H (1995b). Sources of Uncertainty in the Appraisal of Flood Alleviation Schemes, Flood Hazard Research Center, Middlesex University, UK

Green C H (1997, Forthcoming). The Economics of Water and the Environment, London, Uk

Green C H, Parker D J, Thompson P M, and Penning-Rowell E C (1983). Indirect Losses from Urban Flooding: An Analytical Framework, Geography and Planning paper No 6, Middlesex Polytechnic, UK

Graciela Peters-Guarin, Michael K. McCall and Cees van Westen (2012). Coping strategies and risk manageability, Deltares, Delft, Netherlands.

Green C H, Penning-Rowsell(1988a). Flooding and Quanification of ' intangibles`, Proceedings of the ISEM Annual Symposium 1988, Lodon

Green C H, Tunstall S, Emery J P and Bossman-Aggrey P (1988b). Evaluating the No monetary Impacts of Flooding, paper presented to the Annual Meeting of the Society for Risk Analysis, UK

Green C H and Hering A (1993). Full Flood Impacts, Euro flood, Annual Repo9rt, March, Munich, Germany

Grigg N S and Helweg O J (1975). State-of-Art of Estimation Flood Damage in Urban Areas, Water Resources Bulletin, American Water Resources Association, American Water Resources Association, 11(2), 379-390

Gujrat D (1987). Basic Econometrics, McGraw-Hill Book Company, London, UK

Gianinetto M, Villa P (2011) Mapping hurricane Katrina's widespread destruction in New Orleans using multisensor data and the normalized difference change detection (NCCD) technique. Int J Remote Sens 32(7):1961–1982

Gianinetto M, Villa P, Lechi G (2006) Post fl ood damage evaluation using Landsat TM and ETM + data integrated with DEM. IEEE Trans Geosci Remote Sens 44(1):236–243

Gillespie TW, Chu J, Elizabeth F, Thomas D (2007) Assessment and prediction of natural hazards from satellite imagery. Prog Phys Geogr 31(5):459–470.

Godschalk DR (1991) Disaster mitigation and hazard management. In: Drabek TE, Hoetmer GJ (eds) Emergency management: principles and practice for local government. International City Management Association, Washington, DC, pp 131–160

Gokon H, Koshimura S (2012) Mapping of building damage of the 2011 Tohoku earthquake tsunami in Miyagi prefecture. Coast Eng J 54(1):1–12

Green C (2000) Handbook of water economics: principles and practice. Wiley, Chichester

Green C (2004) The evaluation of vulnerability to fl ooding. Disast Prev Manage 13(4):323–329

Greene R, Devillers R, Luther JE, Eddy BG (2011) GIS-based multiple-criteria decision analysis, Geogr Compass 5(6):412–432

Greiving S, Fleischhauer M, Luckenkotter J (2006) A methodology for an integrated risk assessment of spatially relevant hazards. J Environ Plan Manage 49(1):1–19

Gunes AE, Koval JP (2000) Using GIS in emergency management operations. J Urban Plan Dev 126(3):136–149

Hander J W (1979). Flood Risk Maps, and Local Attitudes to Floods and Flood Mitigation, As Part of National Flood Reeducation Program, MA Research Paper, Department of Geography, University of Toronto

Handmer J W (1988). The Flood Threat: Social and Institutional Aspects, Paper presented at Flood Preparedness Arrangements Workshop, Mt Macedonia, Australian Counter Disaster College

Handmer J W (1995). Managing Vulnerability in Sydney: Planning or Providence? In Wolf Tietze (ed) GeoJournal, Disaster Vulnerability of Majesties, November, 355-364

Handmer J W and Milne J (1981). Flood Maps as Public Information, In Proceedings of the Floodplain Management Conference, May 7-10, Canberra.

Handmer J W and Parker DJ (1991). British Disaster Planning and Management: and Initial Assessment, Flood Hazard Research Cenrtre.

Harding D M and Parker D J (1974). Flood Hazard at Shrewsbury, U K, In G F White (ed) Natural Hazards: Local, National, Global, Oxford University Press, New Youd, 43-52

Harding DM And Proter E A (1969). Flood Loss Information and Economic Aspects of Food Plani Occupancy, Introductory Note for Informal Discussion, Institution of Civil Engineers, Hydrological Group, November, London

HIDD/ESEPP (1988). The Extent and the Distribution of the 1988 Flood Damages in Bangladesh, Planning Commission (Bangladesh), Dhaka

Higgins R J (1981). An Economic Comparison of Different Flood Mitigation Strategies in Australia, PHD Thesis, School of Civil Engineering, University of New South Wales

Higgins R J and Robinson D J (1981). An Economic Comparison of Different Flood Mitigation Strategies in Australia : A Case Study, Australian Water Resources Council, Technical Paper No 65.

Homan A G and Waybur B (1960). A Study of Procedure in Estimating Flood Damage to Residential, Commercial and Industrial properties in California, Stanford Research Institute, Menlo Park

Hossain M, Islam A A T M and Shah S (1987). Floods in Bangladesh - Recurrent Disaster and People`s Survival, University Research Centre, Dhaka

Hossain M, Chowdhury O H and Quashem M A (1987). Impact of (1984). Impact of 1984 Floods: Impressions from Field visits, BIDS, Dhaka

House M A (1989). A water Quality Index for the Classification and Operational Management of Rivers. In V H Laikari (ed), River Basin Management, Pergamon Press, Oxford, UK

Hydrologic Engineering Center (1982). Structure Inventory for Damage Analysis SID: User Manual, Water Resources Support Center, US Army Corps of Engineers

Hye H A, Solaiman and Karim M R (1984). Flood 1984, BARD, Dhaka

Haque CE (1997) Hazards in fickle environment: Bangladesh. Kluwer Academic Publishers, Dordrecht

Haque AN, Grafakos S, Huijsman M (2012) Participatory integrated assessment of flood protection measures for climate adaptation in Dhaka. Environ Urban 24(1):197–213

Henry J-B, Chastanet P, Fellah K, Desnos Y-L (2006) Envisat multi-polarized ASAR data for flood mapping. Int J Remote Sens 27(10):1921–1929

Hess LL, Melack JM (1994) Mapping wetland hydrology and vegetation with synthetic aperture radar. Int J Ecol Environ Sci 20:197–205

Hess LL, Melack JM, Filoso S, Wang Y (1995) Delineation of inundated area and vegetation along the Amazon fl oodplain with SIR-C synthetic aperture radar. IEEE Trans Geosci Remote Sens 33(4):896–903

Hewitt K (1997) Regions of risk: a geographical introduction to disasters. Longman, Essex

Hill AA, Cutter SL (2001) Methods for determining disaster proneness. In: Cutter SL (ed) American hazards capes: the regionalization of hazards and disasters. The Joseph Henry Press, Washington, DC, pp 37–60

Hogan DJ, Marandola E Jr (2005) Towards in interdisciplinary conceptualization of vulnerability. Popul Space Place 11(6):455–471

Hoque R, Nakayama D, Matsuyama H, Matsumoto J (2011) Flood monitoring, mapping and assessing capabilities using RADARSAT remote sensing. GIS Ground Data Bangladesh 57(2):525–548

Horritt MS, Mason DC, Luckman AJ (2001) Flood boundary delineation from synthetic aperture radar imagery using a statistical active contour model. Int J Remote Sens 22(13): 2489–2507 Inland Water Directorate (1985). Federal Guidelines for the National Flood Damage Reduction Program, Water Planning & Management Branch, Environmental Conservation Service, Environment, Canada

Institution of Civil Engineers (1980). Flood Studies Report- Five Years On, Seminar Proceedings, Thomas Telford Ltd, London

Intergovernmental Panel on Climate Change- IPCC (1990). Policymakers Summary, In J T Houghton, G J Jenkins and J J Ephraums (eds) Climate Change: The IPCC Scientific Assessment, Cambridge University Press, Cambridge, UK

Islam Md. Monirul & Sado Kimiteru (2000). Flood Hazard Assessment in Bangladesh using NOAA AVHRR data with geographical information system. Department of Civil Engineering, Kitami Institute of Technology, 165 Koen-cho, kitami, Hokkaido, Japan.

Islam K M N (1995). Impacts of Flooding at macro Level in Bangladesh, Paper presented to EU-ERASMUS Conference, September, Jean Monet University at St Etienne, France

Islam K M N (1996a). Linkages and Impacts of Flooding at Macro level - A Case Study of Bangladesh, Research Report No 146, August, BIDS, London

Islam K M N (1996b). The Role of Perception and Human Factors in Flood Losses, Paper Presented to EU - EUASMUS Conference, September, London

Islam K M N (1997a, forthcoming). Health Aspects of Flooding - Evidence from Macro-level Data on Incidence of Diseases in Bangladesh, Research Report, BIDS, Dhaka

Islam K M N (1997b). The Role of Perception, Warning and Human Factors in Flood Losses, Research Report 152, BIDS, March, Dhaka

Islam K M N (1997c). Non-agricultural Impacts of Flooding in Urban Areas of Bangladesh A Review (in Bengali), Bangladesh Unnayan Samikha, Vol 14, BIDS, February.

Islam K M N (1997d, forthcoming). The Damage-reducing Effects of Flood Warnings- A Case study of Bangladesh Households, Geo-care Journal, Dhaka

Islam K M N (1997e). Linkages and Impact of Flooding-Evidence from Macro-level Data in Bangladesh, Working Paper No 30, School of Geography and Environmental management, Middlesex University, Enfield, April

Islam K M N (1997f, forthcoming)- Link Between Floods and Incidence of Diseases- Some Evidence from Macro Level Data in Bangladesh, Bangladesh Medical Research Council Bulletin, Dhaka.

ISPAN (1991), Flood Proofing, FAP Supporting Study No 23, Eastern Water Initiative, USAID

ISPAN (1992), FAP-14; Flood Response study, Draft Final Report and Planning Guidelines, Dhaka.

Ives J D (19890. Deforestation in the Himalayas- The Cause of Increased Flooding in Bangladesh and Northern India? Land Use Policy, July

Imhoff ML, Gesch DB (1990) The derivation of a sub-canopy digital terrain model of a flooded forest using synthetic aperture radar. Photogramm Eng Remote Sens 56(8):1155–1162

Imhoff ML, Vermillion C, Story MH, Choudhury AM, Gafoor A, Polcyn F (1987) Monsoon flood boundary delineation and damage assessment using spaceborne imaging radar and Landsat data. Photogramm Eng Remote Sens 53(4):405–413

Intarawichian N, Dasananda S (2010) Analytical hierarchy process for landslide susceptibility mapping in lower Mae Chaem watershed, Northern Thailand. Suranaree J Sci Technol 17(3):277–292

Islam MM, Sado K (2000a) Development of flood hazard maps of Bangladesh using NOAA AVHRR with GIS. Hydrol Sci J 45(3):337–355

Islam MM, Sado K (2000b) Flood hazard assessment in Bangladesh using NOAA AVHRR data with geographical information system. Hydrol Process 14(3):605–620

Islam MM, Sado K (2000c) Satellite remote sensing data analysis for flood damage zoning with GIS for fl ood management. Ann J Hydraul Eng (JSCE) 44:301–306

Islam MM, Sado K (2002) Development of priority map flood countermeasures by remote sensing data with geographic information system. J Hydrol Eng 7(5):346–355

Islam AS, Bala SK, Haque MA (2010) Flood inundation map of Bangladesh using MODIS time series data. J Flood Risk Assess 3(3):210–222

James L D (1974). The Use of Questionnaires in Collecting Information for Urban Flood Control Planning, Environmental Resources Center, Georgia Institute of Technology, Atlanta.

James L D and Lee R R (1971). Economics of Water Resource Planning, McGraw-Hill, New York.

Johnston J (1972). Econometric Methods, McGraw-Hill Kogakusha Ltd, London, Uk

Japan Ministry of Foreign Affairs (1989). report on Survey of Flood Control Planning in Bangladesh, Dhaka.

Jones-Lee M W (1976). The Value of Life, University of Chicago Press, Chicago, USA

Jonkman N., Matthijs Kok et al. (2008). Flood Risk Assessment in the Netherlands : A case Study for Dike Ring South Holland. Delft University, Faculty of Civil Engineering and Geosciences, Delft, the Netherlands.

Jain V, Sinha R (2003) A geomorphological manifestations of the flood hazards: a remote sensing based approach. Geocarto Int 18(4):51–60

Jain SK, Singh RD, Jain MK, Lohani AK (2005) Delineation of flood-prone areas using remote sensing techniques. Water Resour Manage 19(4):333–347

Jha AK, Bloch R, Lamond J (2012) Cities and flooding: a guide to integrated urban flood risk management for the 21st century. The World Bank, Washington, DC

Johnson GO (1992) GIS applications in emergency management. URISA J 4(1):66–72

Kanji G K (1993). 100 Statistical Tests, Sage Publications, UK

Kates R W (1962), Hazard and Choice Perception in Flood Plain Management, Research Paper 74, University of Chicago.

Kates R W (1965). Industrial Flood Losses: Damage Estimation in the Lehigh Valley, University of Chicago, Department of Geography, Research Paper 98.

Kates R W (1971). Natural Hazards in Human Ecological Perspective: Hypotheses and Models, Economic Geography. 47, 438-51

Kausher A, Kay R C, Asaduzzaman M and Paul S (1996). Climate Change and Sea-level Fise: The Case of the Coast, In R A Warrick and Q K Ahmad (eds) The Implications of Climate and Sea-Level Change for Bangladesh, Kluwer Academic Publishers, London, 335-396.

Ketteridge A-M and Green C H (eds) (1994). Technical Annex for the Full Flood Impacts Module, The Europe-wide project for flood hazard research and policy making, FHRC.

Khan M M I (1991). The Impact of Local Elites on Disaster Preparedness Planning: The Location of Flood Shelters in Northern Bangladesh, Disasters, 15(4), 340-354.

Kazmierczak A, Cavan G (2011) Surface water flooding risk in urban communities: analysis of vulnerability, hazard and exposure. Landscape Urban Plan 103(2):185–197

Kiage LM, Walker ND, Balasubramanian S, Babin A, Barras J (2005) Applications of Radarsat-1 synthetic aperture radar imagery to assess hurricane-related flooding of coastal Louisiana. Int J Remote Sens 26(24):5359–5380.

Kienberger S (2012) Spatial modelling of social and economic vulnerability to floods at the district level of Buzi, Mozambique. Nat Hazard. doi: 10.1007/s11069-012-0174-9

Kiunsi RB, Mechack V, Uhinga G, Mayunga J, Mulenge F, Kabali C, Sigalla N, Bilia M (2006) Disaster vulnerability assessment: the Tanzania experience. In: Birkmann J (ed)

Measuring vulnerability to natural hazards: towards disaster resilient society. United Nations University Press, Tokyo, pp 227–245.

Kohler A, Jülich S, Bloemertz L (2005) Guidelines risk analysis – a basis for disaster risk management, GTZ.

Kron F (2005) Flood risk = hazard*values*vulnerability. Water Int 30(1):58–68

Kubal C, Haase D, Meyer V, Scheuer S (2009) Integrated urban fl ood risk assessment – adapting a multi-criteria approach to a city. Nat Hazard Earth Syst Sci 9(6):1881–1895

Leigh C and Low K S (1983). Attitudes and Adjustments to Flood Hazard in Mixed Ethnic Community in Malacca Town, Peninsular Malaysia, Singapore Journal of Tropical Geography 4(1), 40-51.

Loraine N S R (1954). Convey Island Flood Disaster, February, 1953, Medical Officer, 91: 59-62

Lankao PR, Qin H (2011) Conceptualizing urban vulnerability to global change and environmental change. Curr Option Environ Sustain 3(3):142–149

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Lawal DU, Matori A-N, Hashim AM, Chandio IA, Sabri S, Balogun A-L, Abba HA (2011) Geographic information system and remote sensing applications in flood hazards management: a review. Res J Appl Sci Eng Technol 3(9):933–947

Leconte R, Pultz TJ (1991) Evaluation of Radarsat for flood mapping using simulated satellite SAR imagery. Can J Remote Sens 17(3):241–249

Levy JK, Hartmann J, Li KW, An Y, Asgary A (2007) Multi-criteria decision support systems for flood hazard mitigation and emergency response in urban watersheds. J Am Water Resour Assoc 43(2):346–358

Lewis J (1999) Development in disaster-prone places: studies of vulnerability. Intermediate Technology Publications, London

Liu Z, Huang F, Liu L, Wan E (2002) Dynamic monitoring and damage evaluation of flood in north-west Jilin with remote sensing. Int J Remote Sens 23(18):3669–3679

Liverman DM (1990a) Vulnerability to global environmental change. In: Kasperson RE,

Long NT, Trong BD (2001) Flood monitoring of Mekong River delta, Vietnam using ERS SAR data. A paper presented at the 22nd Asian conference of remote sensing, Singapore, 5–9 November

Longhurst R (1995) The assessment of community vulnerability in hazard prone areas. Disasters 19(3):269–270

Lorenz N, Van Dijk M, Kwadijk J (2001) Use of remotely sensed images by SPOT in hydrologic modeling. In: Van Dijk M, Bos MG (eds) GIS and remote sensing techniques in land and water management. Kluwer Academic Publishers, Dordrecht, pp 39–53

Master Plan Organization, MPO (1986).National water Plan, Ministry of Irrigation, water development and Flood Control, Dhaka

Master Plan Organization, MPO (1990). National water Plan, Ministry of Irrigation, Water development and Flood Control, Dhaka

Master Plan Organization (1991).The Investment Analysis Model, Technical Report No 26, Ministry of Irrigation, Water development and Flood Control, Dhaka

Mayer Volker, Dagmar Haase et al. (2009). Flood Risk Assessment in Europe River Basin- Concept, Methods, and Challenges Exemplified at the Mulde River. Integrated Environmental Assessment and Management –Volume 5, Number 1-pp. 17-26.

Maurice J and diallo A (1991).Controlled Flooding in Bangladesh- An Attempt to Quantify the Macroeconomic Impact on Growth Prospects. Dhaka

Muhammad Masood and Kuniyoshi Takeuchi (2010). Assessment of flood hazard, vulnerability and risk of mid-eastern Dhaka using DEM and 1Dhydrodynamic model. Dhaka, Bangladesh.

Md. Aboul Fazal Younus and Nick Harvey, (2013). Community-based flood vulnerability and adaptation assessment : a case study from Bangladesh. Intergovernmental Panel on Climate Change (IPCC) (2007, 2012:11).

Miah M M (1988a). The 1987 Flood in Bangladesh, A Hydro morphological Study, Bangladesh- Canada Agricultural Sector Team, Dhaka.

Miah M M (1988b). Flood in Bangladesh, A Hydro morphological Study of the 1987 Flood, Academic Publishers, Dhaka.

Mitchell J K (1989). Hazard Research, In G L Gaile and C J Willmott (eds) Geography in America, Columbus, 410-424.

Montgomery jR (1985). The Bangladesh Floods of 1984 in Historical Context, Disasters 6(3): 163-172

Maantay J, Maroko A, Culp G (2010) Using geographic information science to estimate vulnerable urban populations for flood hazard and risk assessment in New York City. In:

Mallinis G, Gitas IZ, Giannakopoulos V, Maris F, Tsakiri-Strati M (2011) An object-based approach for flood area delineation in a transboundary area using ENVISAT ASAR and Landsat TM data. Int J Digit Earth. doi: 10.1080/17538947.2011.641601

Malnes E, Guneriussen T, Høgda KA (2002) Mapping flood-area by Radarsat in Vanjø, Norway. In: Proceedings of 29th international symposium on remote sensing of the environment, Buenos Aires, Argentina, 4–8 April

Mark O, Weesakul S, Apirumanekul C, Aroonnet SB, Djordjevic S (2004) Potential and limitations of 1D modelling of urban flooding. J Hydrol 299(3–4):284–299

Marwade V, Cook A, Coonrod J (2008) GIS techniques for creating river terrain models for hydrodynamic modelling and fl ood inundation mapping. Environ Model Software 23(10–11):1300–1311

Mason DC, Horritt MS, Dall' Amico JT, Scott TR, Bates PD (2007) Improving river fl ood extent delineation from Synthetic Aperture Radar using airborne laser altimetry. IEEE Trans Geosci Remote Sens 45(12):3932–3943

Mason DC, Speck R, Devereus B, Schumann GJ-P, Neal JC, Bates PD (2010) Flood detection in urban areas using TerraSAR-X. IEEE Trans Geosci Remote Sens 48(2):882–894

Masood M, Takeuchi K (2012) Assessment of flood hazard, vulnerability and risk of mid-eastern Dhaka using DEM and 1D hydrodynamic model. Nat Hazard. doi: 10.1007/s11069-011-0060-x

Meyer V, Scheuer S, Haase D (2009) A multicriteria approach for flood risk mapping exemplified at the Mulde river, Germany. Nat Hazard 48(1):17–39

Mitchell JK (1999a) Natural disasters in the context of mega-cities. In: Mitchell JK (ed) Crucibles of Hazard: mega-cities and disasters in transition. United Nations University, Tokyo, pp 15–55

Mitchell JK (1999b) Megacities and natural disasters: a comparative analysis. GeoJournal 49(2):137–142

Mitchell JK, Devine N, Jagger K (1989) A contextual model of natural hazards. Geogr Rev 79(4):391–409

Mongkolsawat C, Thanajaturon T (2006) Predicting the recurrent flood extent and damage assessment in Chi watershed, northeast Thailand using multi-temporal Radarsat and Landsat data. In: Proceedings of the first international conference on science and technology for sustainable development of the Greater Mekong Sub-region, Khon Khen, Thailand, 15–16 August. Available at http://202.28.94.77/research/i_proceed/2549/7_Predicting.pdf

Moore GK, North GW (1974) Flood inundation in the southeastern United States from aircraft and satellite imagery. Water Resour Bull 10(5):1082–1096

Morelli S, Segoni S, Manzo G, Ermini L, Catani F (2012) Urban planning, flood risk and public policy: the case of the Arno River, Firenze, Italy. Appl Geogr 34(1):205–218

Morita M (2011) Quanti fi cation of increased flood risk due to global climate change for urban river management planning. Water Sci Technol 63(12):2967–2974

Müller A (2012) Areas at risk – concept and methods for urban flood risk assessment: a case study of Santiago de Chile. Franz Steiner Verlag, Stuttgart

Mustafa D (1998) Structural causes of vulnerability to flood hazard in Pakistan. Econ Geogr 74(3):289–305

National Science Foundation (1980). A Report on Flood Hazard Mitigation, Washington

Nasreen Mahabuba (1999). Coping with floods : Structural Measures or Survival Strategies. The University Press Limited. Dhaka-1000, Bangladesh.

Nagarajan R, Marathe GT, Collins WG (1993) Identification of flood prone regions of Rapti river using temporal remotely-sensed data. Int J Remote Sens 14(7):1297–1303

NASA (1998) SAR references. http://southport.jpl.nasa.gov/science/SAR_REFS.html. Accessed 30 July, 2003

Nico G, Pappalepore M, Pasquarieloo G, Re fi ce A, Samarelli S (2000) Comparison of SAR amplitude and coherence flood detection methods-a GIS application. Int J Remote Sens 21(8):1619–1631

Nyarko BF (2002) Application of a rational model in GIS for flood risk assessment in Accra, Ghana. J Spat Hydrol 2(1):1–14

J`Jai A, Tapsell S M, Taylor D, Thompson P M and Penning-Rowsell E C (1990). FLAIR, Flood Hazard Research Centre, Middlesex University, UK.

Neal J and parker D J (1988).flood Plain Encroachment: A Case study of ditched, Middlesex polytechnic school of Geography and planning paper No 22, UK

North D and Bibby S (1990). The Economic Regeneration Benefits, Herne Bay Coastal protection Benefit assessment, Planning Research Centre, Middlesex poly technique, UK

O'Brien K, Leichenko R, Kelkar V, Venema H, Aandahl G, Tompkins H, Javed A, Bhadwal S, Barg S, Nygaard L, West J (2004) Mapping vulnerability to multiple stressors: climate change and globalization in India. Glob Environ Chang 14(4):303–313

Oberstadler R, Honsch H, Huth D (1997) Assessment of the mapping capabilities of ERS-1 SAR data for fl ood mapping: a case study in Germany. Hydrol Process 11:1415–1425

Odeh DJ (2002) Natural hazards vulnerability assessment for statewide mitigation planning in Rhode island. Nat Hazard Rev 3(4):177–187 70 2 Hazards, Risk, and Vulnerability

Oliver-Smith A (2004) Theorising vulnerability in a globalised world: a political ecological perspective.

In: Bankoff G, Frerks G, Hilhort D (eds) Mapping vulnerability: disasters, development & people. Earthscan, London, pp 10–24 In: Proceedings of the NASA/JPL Aircraft SAR workshop, USA, pp 37–38

Ormsby JP, Blanchard BJ, Blanchard AJ (1985) Detection of lowland flooding using active microwave systems. Photogramm Eng Remote Sens 51(3):317–328

Parker D J (1976).Socio-economic Aspects of Flood plain Occupancy, PhD Thesis, Department of Geography, University j College of W wansea, University of Wales

Parker D J (1991a) Explaining Environmental Disasters and Accidents, In C Fox and J Blumhof (eds) Global Environments, Third Edition, Uk, 18-47

Parker D J (1991b) The Damage-reducing Effects of Flood Warnings, Publication No 197, Flood Hazard Centre, Middlesex University, UK

Parker D J (19912b) The Mismanagement of Hazards, In D J Parker and J W Handmer (eds) Hazard Management and Emergency Planning: Perspectives on Britain, James and James, London.

Parker K J (1995). Floodplain Development Policy in England and Wales, Applied Geography, Vol 15, No 4, 341-363

Parker D J and Penning-Rowsell E C (1972). Problems and Methods of Flood Damage Assessment, Report 3, Middlesex Polytechnic Flood Hazard Research Centre, UK

Parker D J and Harding D M (1979). Natural Hazard Evaluation, Perception and Adjustment, Geography 64 (4), November, 307-16

Parker D J and Penning-Rowsell E C (1981), The Indirect Benefits of Flood Alleviation: Their Significance, Investigation and Estimation, Paper Presented to Cornfield Conference of River Engineers, Cornfield

Parker D J and Penning-Rosell E. C (1982). Flood Risk in the Urban Environment Geography and the Urban Environment, Vol 5, John Willey & Sons, New Uork

Parker D J, Green C H and Thompson P M (1987). Urban Flood Protection Benefits- A Project Appraisal Guide, Gower Technical Press, UK

Parker D J and Sewell W R D (1988). Evolving Water Institutions in England and Wales : An Assessment of Two Decades of Experience, Natural Resources Journal 28, 751-85

Parkder D J and Thompson P M (1991). Floods and Tropical Storms, The Challenge of African Disasters, UNITAR, WHO, 38-52).

Parker D J and Penning-Rowsell E C (1991). Institutional Design for Effective Hazard Management: Flood Warnings and Emergency Response, Paper presented to the ESRC/LSE Seminar on Rethinking System Failure, Hazard Management and Emergency Planning: Perspectives on Britain, James and James, London.

Paul and Rasid (2014). Climate Change in Bangladesh : Confronting Impending Disasters, Lexington Books, Polymouth, UK.

Parker D J andd Handmer J W (eds0 (1992). Hazard Management and Emergency Planning: Perspectives on Byitain, James and James, London

Parker D J and Tap sell S (1995a). Hazard Transformation and Hazard Management Issues in the London Mega city, In Wolf Tietze (ed) Geojournal, November, Kluwer Academic Publishers, London

Parker D J and Tapsell S (1995b). Disater Vulnerability of Megacities: An Expanding Problem that Requires Rethinking and Innovative Responses, In Wolf Tietze (ed) Geojournal, November, Kluwer Academic Publishers, London

Parker D J, Islam K M N and Chan N W (1997). Reducing Vulnerability following Flood Disaters: Issues and Practices, In Adenrele Awotona (ed), Reconstructing After Disater: Issues and Practices, University of Newcastle upon Tyne

Parker D J and Handmer J W (1997), forthcoming). Exploring Informal Warning Systems, Londonk

Paul B K (1984). Perception of and Agricultural Adjustments to Floods in Jamuna Flood Plain, Bangladesh Human Ecology, Vol 12, No 4

Paul B K (1993). Flood Damage to Rice Crop in Bangladesh, The Geographical Review, American Geographical Society, New York, 150-159

Palmann C, Mavromatis S, Hernandez M, Sequeira M, Brisco B (2008) Earth observation using radar data: an overview of applications and challenges. Int J Digit Earth 1(2):171–195

Pandey AC, Singh SK, Nathawat MS (2010) Waterlogging and fl ood hazards vulnerability and risk assessment in Indo Gangetic plain. Nat Hazard 55(2):273–289

Pantaleoni E, Engel BA, Johannsen CJ (2007) Identifying agricultural flood damage using Landsat imagery. Precis Agric 8(1–2):27–36

Parker DJ (2000) Floods, vol I and II. Routledge, London

Pelling M (1997) What determines vulnerability to fl oods: a case study in Georgetown, Guyana. Environ Urban 9(1):203–226

Pelling M (2002) Assessing urban vulnerability and social adaptation to risk. Int Dev Plan Rev 24(1):59–76

Pradhan B (2009) Flood susceptible mapping and risk area delineation using logistic regression, GIS and remote sensing. J Spat Hydrol 9(2):1–18

Profeti G, Macintosh H (1997) Flood management through Landsat TM and ERS SAR data: a case study. Hydrol Process 11:1397–1408

Rahman MR, Saha SK (2007) Flood hazard zonation – a GIS aided multi-criteria evaluation (MCE) approach with remotely sensed data. Int J Geoinf 3(3):25–35

Penning-Rowsell E C (1976). The Effects of Flood Damage on Land Use Planning, Geographical Polemical, 34, 139-153

Penning-Rowesll E C and Chatter ton J B (1977). The Benefits of flood Alleviation: A Manual of Assessment Techniques, Gower Press, Far borough

Penning-Rowsell E C, Chatter ton J B and Parker D J (1978). The Effects of Flood warning on Flood Damage Reduction, A Report for the Central Water Planning Unit, Flood Hazard Research Centre, U K

Penning-Rowsell E C, Parker D J, Crease D and Mattison C (1983). Flood Warning Dissemination: An Evaluation of Some Current Practices in the Severn Trent Water Authority Area, Flood Hazard Research Centre, Middlesex Polytechnic, UK

Penning-Rowsell E C (1983). Flood Alleviation Benefit-cost Analysis: Cranfield conference Papers, Middlesex Polytechnic, Enfield

Penning-Rowsell E C, Parker D J and Harding D M (1986). Floods and Drainage, Gewrage Allen and Unwin, London

Penning-Rowsell E C, Chatterton J B, Day H J, Ford D T, Greenway m A, Smith D I Wwwd T R and Witts R C (1987). Comparative Aspects of Computerized Flood Plain Data Management, Jurnal of Water Resources Planning and Management, American Society of Civil Engineers

Penning-Rowsell E C and Green C H (1990). Benefit-cost Analysis of Flood Asseveration: A Changing Art, Flood Hazard Research Centre

Penning-Rowsell E C, Green C H, Thompson P M, Coker A M, Tunstall S M, Richards C and Parker D J (1992a). The Economics of Coastal Management, A Manual of Benefit Assessment Techniques, Belhaven Press, London, UK

Penning-Rowsell E C, Winchester P, Black more G, Parker D J, North D, Witts R, Karol D Twomey G, Green C H, Taylor D and Mason R (1992b). Datchet, Wray bury, Stains & Chertsey Flood Plain Plan Study, Benefit refinement Report and Assessment of Benefits of Lower Standard of Protection, Flood Hazard Centre, Middlesex University, UK

Planning Commission, Bangladesh (1988). The Extent and the Distribution of the 1988 Flood Damages in Bangladesh, HIID/ESEPP Report No 15, Dhaka

Planning Commission, Bangladesh (1990). The Fourth Five Year Plan (1990-95), Ministry of Planning, Government of the People`s Republic of Bangladesh, Dhaka.

Porter E A (1970). The Assessment of Flood Risk for Land Use Planning and Property Management, PhD Thesis, University of Cambridge

Prasad T, Penning-Rowsell E C, Verdhen A and Thompson P M (1995). Impact of Floods in North Bihar, Final Report, Joint Research in Water Management, Centre for Water Resources Studies, Flood Hazard Research Centre

Prasad K (1981). Economic Aspects of Floods, Economics and Rural Development, Indian Institute of Public Administration, New Delhi

Rahman A (1996). Peoples` Perception and Response to Flooding : The Bangladesh Experience, Journal of Contingencies and Crisis Management, December, 4(4), 198-207

Brahman K M and Islam K M N (1988). Agricultural Tools and Implements Industry in Bangladesh: A Case Study, BIDS, Working Paper 7, Dhaka.

Rangarajan C (1982). Agricultural Growth and Industrial Performance in India, Research Report 33, October, 1982, International Food Policy Research Institute.

Rasid H (1993). Preventing Flooding or Regulating Flood Levels? Case studies on Perception of Flood Alleviation in Bangladesh, Natural Hazards, 8: 39-57, Kluwer Academic Publishers

Rob M A & Islam Md Serajul (2007). Flood Hazards in Bangladesh : Vulnerability and Human Adjustment. An M. Phil Thesis, In the Department of Geography and Environment, University of Dhaka, Bangladesh.

Rattien S (1990). The Role of the Media in Hazard Mitigation and Disaster Management Disasters, 14(1), 36-45

Roberts D B (1968). Assessment of Flood Damage, Paper presented to the Conference of River Authority Engineers, Cranfield.

Rogers P, Lydon P and Seckler D (1989). Eastern Waters Study: Strategies to Manage Flood and Drought in the Ganges-Brahmaputra Basin, ISPAN, Dhaka

Roy Brouwer, Akter Sonia et al. (2007). Socioeconomic Vulnerability and Adaptation to Environmental Risk : A Case Study of Climate Change and Flooding in Bangladesh. Risk Analysis, Vol. 27, No. 2. Rural Industries Study Project, RISP (1981). Rural Industries Studies, Final Report, Bangladesh Institute of Development Studies, Dhaka

Rango A, Anderson AT (1974) Flood hazard studies in the Mississippi River Basin using remote sensing. Water Resour Bull 10(5):1060–1081

Rango A, Solomon VV (1974) The utility of short wavelength remote sensing techniques for the monitoring and assessment of hydrological parameters. In: Proceedings of 11th international symposium on remote sensing of environment, Ann Arbor, MI, pp 55–64

Rashed T, Weeks J (2003a) Assessing vulnerability to earthquake hazards through spatial multicriteria analysis of urban areas. Int J Geogr Inf Sci 17(6):547–576

Rashed R, Weeks J, Couclelis H, Herold M (2007) An integrative GIS and remote sensing model for place-based urban vulnerability analysis. In: Mesev V (ed) Integration of GIS and remote sensing. Wiley, Chichester, pp 199–224.

Rasid H, Pramanik MAH (1990) Visual interpretation of satellite imagery for monitoring floods in Bangladesh. Environ Manage 14(6):815–821.

Rejeski D (1993) GIS and risk: a three-culture problem. In: Goodchild MF, Parks BO, Steyaert LT (eds) Environmental modelling with GIS. Oxford University Press, New York, pp 318–331.

Shahabuddin Q and Rahman K M (1992). Special study on Economics, Estimation of Economic Prices of Selected Commodities for Use in FAP Planning Studies, Final Report, April, Dhaka.

Smith K (1979). Human dimensions of the Flood Hazard, Water, July, 7-10

Smith K (1992). Environmental Hazards: Assessing Risks and Reducing Disasters Rutledge, London.

Smith K and Tobin G A (1979a). Human Adjustment to the Flood Hazard, Long man, London.

smith D I, Den Extern P, Dowling M A, Jelliffe P A, Munro R G and Martin W C (1979b0. Flood Damage in the Richmond River Valley, New South Wales, ANU, Australia.

Smith D I (1881). Actual and Potential Flood Damage: a Case Study for Urban Lissome, NSW, Australia, Applied Geography, 1 (1), 31-39.

Smith D I, (1981). Assessment of Urban Flood Damage, Proceedings, Flood Plain Management Conference, Australian Water Resource Council.

Smith D I, Lustig T L and Handmer J W (1983). Tangible Urban Flood Damage: An Outline Manual, Proceedings, Second National Conference on Local Government Engineers, Institution of Engineers, Canberra, 376-381

Smith D I and Greenway M A (1984a). Urban Flood Damage: The Assessment of Tangible Effects in Australia, Australian National University

Smith D I and Greenway M A (1984b). commercial and Industrial Flood Damage, A Case study for the Taminda Estate-Tamworth NSW, CRES Working Paper, Canberra

Smith D I and Handmer J W (ed) (1986). Flood Warning in Australia, Centre for Resource and Environmental Study, Australian National University

Smith D I, Green way M A Handmer J W and Lustig T L (1987). The Sidney floods of 1986-Losses, Pay-outs and the Futute, Paper presented to the 27th Annual Conference of Flood Mitigation Authorities of New South Wales

Smith D I and Greenway M (1988). The Computer Assessment of Urban Flood Damage: ANUFLOOD, Desk-top Planning, Hargreen, Melbourne

Smith D I, Handmer J W, Greenway M A and Lusting T L (1990). Losses and Lessons from the from the Sydney Floods of August 1986, Vol 2 CRES, ANU, Canberra

Smith D J G and Viljeon M F (1981). Guidelines for Assessing Flood Damage in South Africa, Water Resources Commission, Pretoria

Sobhan R (1991). The Politics of Hunger and Entitlement, In A Sen and J Dreze (eds) The Political Economy of Hynger, University Press Ltd, Dhaka, 96-7

Sorensen J H and White G F (1980). Natural Hazards, In Altman A and J F Whole will (eds), Human Behaviour and Environment: Advances in Theory and Research, Environment and Culture, Vol 4, 279-318, Plenum Press, New York

Sorkin, A L (1982). Economic Aspects of Natural Hazards, Lexington Books, D C Health and Company, Toronto, USA

Suleman M S, jal A, Green C H and Penning-Rowsell E C (1988). Potential Flood Damage Data: A Major Update, Flood Hazard Research Centre, Middlesex Polytechnic, Uk.

Sultana P, Thompson P M, Daplyn M G (1995). Rapid Rural Appraisal, Impact of Surface Water Management Projects of Agriculture in Bangladesh, Project Appraisal, December.

Sadars R, Tabuchi S (2000) Decision support system for flood risk analysis for the river Thames, United Kingdom. Photogramm Eng Remote Sens 66(10):1185–1193.

Sakamoto T, Nguyen NV, Kotera A, Ohno H, Ishitsuka N, Yokozawa M (2007) Detecting temporal changes in the extent of annual fl ooding within the Cambodia and the Vietnamese Mekong delta from MODIS time-series imagery. Remote Sens Environ 109(3):295–313.

Sanyal J, Lu XX (2004) Application of remote sensing in flood management with special reference to Monsoon Asia: a review. Nat Hazard 33(2):283–301

Sanyal J, Lu XX (2005) Remote sensing and GIS-based flood vulnerability assessment of human settlements: a case study of Gangetic West Bengal, India. Hydrol Process 19(18):3699–3716.

Sanyal J, Lu XX (2006) GIS based flood hazard mapping in Gangetic West Bengal. Singap J Trop Geogr 27(2):207–220.

Sanyal J, Lu XX (2009) Ideal location for flood shelter: a geographic information system approach. J Flood Risk Assess 2(4):262–271.

Scheuer S, Haase D, Meyer V (2011) Exploring multicriteria flood vulnerability by integrating economic, social and ecological dimensions of flood risk and coping capacity: from a starting point view towards an end point view of vulnerability. Nat Hazard 58(2):731–751.

Schneiderbauer S, Ehrlich D (2004) Risk, hazard and people's vulnerability to natural hazards: a review of de fi nitions, concepts and data. European Commission – Joint Research Centre (ERCJRC), Brussels.

Schumann G, Baldassarre GD (2010) The direct use of radar satellites for event-specific flood risk mapping. Remote Sens Lett 1(1):75–84.

Sebastian S, Haase D, Meyer V (2011) Exploring multicriteria flood vulnerability by integrating economic, social and ecological dimensions of flood risk and coping capacity: from a starting point view towards an end point view of vulnerability. Nat Hazard 58(2):731–751.

Sheng Y, Su Y, Xiao Q (1998) Challenging the cloud-contamination problem in flood monitoring with NOAA/AVHRR imagery. Photogramm Eng Remote Sens 64(3):191–198.

Showalter PS (2001) Remote sensing's use in disaster research: a review. Disast Prev Manage 10(1):21–29.

Showalter PS, Lu Y (eds) (2010) Geospatial techniques in urban hazards and disaster analysis. Geotechnologies and the environment, vol 2. Springer, Dordrecht.

Simonovic SP (1993). Flood control management by integrating GIS with expert systems:

Shitangsu Kumar Paul and Jayant K. Routray (2009). Flood proneness and coping strategies: the experiences of two villages in Bangladesh. Kioto University, Japan.

Winnipeg city case study. In: HydroGIS'93: applications of geographic information systems in hydrology and water resources. IAHS Pub no. 211. International Association of Hydrological Sciences, Oxford.

Sinha R, Bapalu GV, Singh LK, Rath B (2008) Flood risk analysis in the Kosi river basin, North Bihar using multi-parametric approach of analytical hierarchy process (AHP). J Indian Soc Remote Sens 36(4):293–307

Sirikulchayanon P, Sun W, Oyana TJ (2008) Assessing the impact of the 2004 tsunami on mangroves using remote sensing and GIS. Int J Remote Sens 29(12):3553–3576

Smith DI (1981) Actual and potential flood damage: a case study for urban Lismore, NSW, Australia. Appl Geogr 1(1):31–39

Smith LC (1997) Satellite remote sensing of river inundated area, stage and discharge: a review. Hydrol Process 11:1427–1439.

Smith K, Ward R (1998) Floods: physical processes and human impacts. Wiley, Chichester .

Solberg SAH, Jin AK, Taxt T (1994) Multisource classification of remotely sensed data: fusion of Landsat TM and SAR images. IEEE Trans Geosci Remote Sens 32(4):768–778

Solbø S, Solheim I (2004) Towards operational flood mapping with satellite SAR. In: Envisat/ERS symposium, Salzburg .

Solbø S, Pettinato S, Paloscia S, Santi E, Brusotti P, Solheim I (2004) Mapping of flooding in the Alessandria area with ERS. In: Proceedings of IGARSS 2004, Anchorage, Alaska, pp 4689–4692.

Sonia Akhtar, Roy Brouer E. Hqu et al. (2007), Socioeconomic Vulnerability and Adaptation to Environmental Risk : A Case Study of Climate Change and Flooding in Bangladesh. Amsterdam, The Netherlands.

Srivastava YK, Pal DK, Das RK, Sudhakar S, Adiga S, Venkatachary KV, Srivastava SK (2000).

High resolution remote sensing data and GIS techniques in updating of infrastructures details for flood damage assessment – a case study. http://www.gisdevelopment.net/aars/acrs/ 2000ts8/hami0002pf.htm . Accessed 2 Aug, 2004.

Su M-D, Kang J-L, Chang L-F, Chen AS (2005) A grid-based GIS approach to regional flood damage assessment. J Marine Sci Technol 13(3):184–192.

Suriya S, Mudgal BV (2012) Impact of urbanization on flooding: the Thirusoolam sub watershed – a case study. J Hydrol 412–413:210–219.

Thirlwall A P (1989). Growth & Development-With Special Reference to Developing Economies, Fourth Edition, The Macmillan Education Ltd, Uk.

Thompson P M (1989). The Impact of Flood Control on Rural Development in Bangladesh: Post-evaluation of Chandpur Irrigation Project, PhD Thesis, School of Geography and Planning, Middlesex Polytechnic.

Thompson P M (1990). The Impact of Flood Control on Agriculture and Rural Development in Bangladesh: Post-evaluation of Chandpur Irrigation Project, Flood Hazard Research Centre, Middlesex Polytechnic.

Thompson P M and Penning-Rowsell E C (1991a). Socio-economic Impacts of Floods and Flood Protection: A Bangladesh Case Study, No 185, Flood Hazard Research Center

Thompson P M and Penning-Rowsell E C (1991b). Socio-economic Impacts of Floods Protection: A Bangladesh Case Study, In Varley A (ed) Disasters, Development and Environment: 81-97.

Thompson P M and Sultana P (19796). Distributional and Social Impacts of Flood Control in Bangladesh, The Geographical Journal, March, 1-13.

Torterotot J.P, Kauark-Leite L A and Roche P-A (1992). Analysis of Individual Real-time Responses to Flooding and Influence on Damage to Households, Paper presented to the Third International Conference on Floods and Flood Management, Florence.

Tunstall S, Green C H and Lord J (1988). The Evaluation of Environmental Goods by the Contingent Valuation Method, Flood Hazard Research Centre, Middlesex University

Tanavud C, Yongchalermchai C, Bennui A, Densreeserekul O (2004) Assessment of flood risk in Hat Yai Municipality, Southern Thailand, using GIS. J Nat Disast Sci 26(1):1–14

Tate E, Burton CG, Berry M, Emrich CT, Cutter SL (2011) Integrated hazard mapping tool. Trans GIS 15(5):689–706

Taubenböck H, Post J, Roth A, Zosseder K, Strunz G, Dech S (2008) A conceptual vulnerability and risk framework as outline to identify capabilities of remote sensing. Nat Hazard Earth Syst Sci 8(3):409–420

Thomas DSK, Mitchell JT (2001) Which are the most hazardous states? In: Cutter SL (ed) American hazardscapes: the regionalization of hazards and disasters. Joseph Henry Press, Washington, DC, pp 115–156

Timmerman P (1981) Vulnerability, resilience and the collapse of society. Environmental monograph. Institute for Environmental Studies, University of Toronto, Toronto

Tingsanchali T, Karim MF (2005) Flood hazard and risk analysis in the southwest region of Bangladesh. Hydrol Process 19(10):2055–2069

Townsend PA (2001) Mapping seasonal fl ooding in forested wetlands using multi-temporal RADARSAT SAR. Photogramm Eng Remote Sens 67(7):857–864

Townsend PA, Walsh SJ (1998) Modeling fl oodplain inundation using an integrated GIS with radar and optical remote sensing. Geomorphology 21(3–4):295–312

Töyora J, Pietroniro A, Martz LW (2002) A multi-sensor approach to wetland fl ood monitoring. Hydrol Process 16:1569–1581

Tralli DM, Blom RG, Zlotnicki V, Donnellan A, Evans DL (2005) Satellite remote sensing of earthquake, volcano, fl ood, landslide and coastal inundation hazards. ISPRS J Photogramm Remote Sens 59(4):18198

Tran P, Shaw R, Chantry G, Norton J (2009) GIS and local knowledge in disaster management: a case study of fl ood risk mapping in Vietnam. Disasters 33(1):152–169

Turner BL, Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, Kasperson JX, Luers A, Martello ML, Polsky C, Pulsipher A, Schiller A (2003) A framework for vulnerability analysis in sustainability science. Proc Natl Acad Sci 1000(14):8074–8079

UNICEF Evaluation Team (1993).Health Effects of the 1991 Bangladesh Cyclo9ne: Report of a UNICEF Evaluation Team, Disasters, 17(2), 153-165

United Nations (1994). Stop Disasters, Newsletter of the International Decade for National Disaster Reduction, Jan/rob, No 17, UN IDNDR Secretariat, Geneva

United Nations (1989). Prospects of World Urbanization, Population Studies, Department of International Economic and Social Affairs, New York

US Army Corps of Engineers (1968). Water Resources Policies and Authorities: Flood Plain Management Services Program, Washington

US Army Corps of Engineers, USACE (1970). Guidelines for Flood Insurance Studies, Washington

US Army Corps (1975) Social Impact Assessment-An Overview, Institute of Water management, Virginia

US Army Corps of Engineers (1977). Expected Annual flood Damage Computation, Users Manual, The Hydrologic Engineering Centre, Davis, California

US Army Corps of Engineers (1981). DAPROG 2- Flood Damage Assembly Program, Users Manual, The Hydrologic Engineering Centre, Davis, California

US Army Corps of Engineers (1982) Structure, Inventory for Damage Analysis (SID), User`s Manual, The Hydrologic Engineering Centre, Davis, California

US Army Corps of Engineers (1983) Seminar Proceedings: Implementation of Nonstructural Measures, Virginia

US Department of Agriculture, Conservation Service (1970). Floodwater Damage Estimates, Residential and commercial Property, EWP Technical Service Center, Texas

Uitto JI (1998) The geography of disaster vulnerability in megacities. Appl Geogr 18(1):7–16

United Nations (UN) (2003) Guidelines for reducing flood losses. Available at http://www.un.org/esa/sustdev/publications/ fl ood_guidelines.pdf . Accessed 12 Jan, 2009

United Nations Development Programme (UNDP) (1992) An overview of disaster management, 2nd edn. UNDP, Washington, DC

United Nations Environmental Program (UNEP) (2003) Assessing human vulnerability to environmental change: concepts, issues, methods and case studies. UNEP, Nairobi

UN/ISDR (International Strategy for Disaster Reduction) (2004) Living with risk: a global review of disaster reduction initiatives. United Nations Publications, Geneva

van der Sande CJ, de Jong SM, de Roo APJ (2003) A segmentation and classification of IKONOS-2 imagery for land cover mapping to assist flood risk and flood damage assessment. Int J Appl Earth Observ Geoinf 4(3):217–229

Van Maanen J, Dabbs J M Jr and Faulkner R R 91982). Varieties of Qualitative Research, Sage, Beverly, DA

Wadge G, Wislocki AP, Pearson EJ (1993) Spatial analysis in GIS for natural hazard assessment. In: Goodchild MF, Parks BO, Steyaert LT (eds) GIS and environmental modelling. Oxford University Press, New York, pp 332–338

Waisurasingha C, Aniya M, Hirano A, Sommut W (2008) Use of Radarsat-1 data and a digital elevation model to assess fl ood damage and improve rice production in the lower part of the Chiriver basin, Thailand. Int J Remote Sens 29(20):5837–5850 Waite WP, Macdonald HC, Kaupp VH, Demarcke JS (1981) Wetland mapping with imaging radar. In: International geoscience and remote sensing symposium, Washington DC, 8–10 June, pp 794–799

Wang Y (2004) Using Landsat 7 TM data acquired days after a flood event to delineate the maximum flood extent on a coastal floodplain. Int J Remote Sens 25(5):959–974

Wang J-F, Li L-F (2008) Improving tsunami warning systems with remote sensing and geographical information systems input. Risk Anal 28(6):1653–1668

Wang Y, Hess LL, Filso S, Melack JM (1995) Understanding the radar backscattering from flooded and non- flooded Amazonian forest: results from canopy backscatter modeling. Remote Sens Environ 54(3):324–332

Wang Y, Colby JD, Mulcahy KA (2002) An efficient method for mapping flood extent in a coastal floodplain using Landsat TM and DEM data. Int J Remote Sens 23(18):3681–3696

Wang Y, Li Z, Tang Z, Zeng G (2011) A GIS-based spatial multi-criteria approach for flood risk assessment in Dongting lake region, Hunan, Central China. Water Resour Manage 25(13):3465–3484

Watts MJ, Bohle HG (1993) The space of vulnerability: the causal structure of hunger and famine. Prog Hum Geogr 17(1):43–67

Webster TL, Forbes DL, Dickie S, Shreenan R (2004) Using topographic lidar to map flood risk from storm-surge events for Charlottetown, Prince Edward Island, Canada. Can J Remote Sens 30(1):64–76

Webster TL, Forbes DL, MacKinnon E, Roberts D (2006) Flood-risk mapping for storm-surge events and sea level rise using lidar for southeast New Brunswick. Can J Remote Sens32(2):194–211

Weichselgartner J (2001) Disaster mitigation: the concept of vulnerability revisited. Disast Prev Manage 10(2):85–94

Weng Q (2001) Modeling urban growth effects on surface runoff with the integration of remote sensing and GIS. Environ Manage 28(6):737–748

Werner MGF (2001) Impact of grid size in GIS based flood extent mapping using a 1D flow model. Phys Chem Earth Part B: Hydrol Oceans Atmos 26(7–8):517–522

White GF (ed) (1974) Natural hazards: local, national, global. Oxford University Press, New York

White GF, Haas JE (1975) Assessment of research on natural hazards. MIT Press, Cambridge

White GF, Kates RW, Burton I (2001) Knowing better and losing even more: the use of knowledge in hazards management. Environ Hazard 3(3–4):81–92

Wiesnet DR, McGinnis DF, Pritchard JA (1974) Mapping of the 1973 Mississippi River floods by NOAA-2 satellite. Water Resour Bull 10(5):1040–1049

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Willett K, Sharda R (1991) Using the analytical hierarchy process in water resources planning: selection of fl ood control projects. Socioecon Plann Sci 25(2):103–112

Williamson AN (1974) Mississippi river fl ood maps from ERTS-1 digital data. Water Resour Bull 10(5):1050–1059

Wisner B (1993) Disaster vulnerability: scale, power and daily life. GeoJournal 30(2):127–140

Wisner B, Blaikie P, Cannon T, Davis I (2004) At risk: natural hazard, people's vulnerability and disasters, 2nd edn. Routledge, Abingdon

Wu SY, Yarnal B, Fisher A (2002) Vulnerability of coastal communities to sea-level rise: a case study of Cape May County, New Jersey, USA. Clim Res 22:255–270

Yahaya S (2008) Multicriteria analysis for fl ood vulnerable areas in Hadejia-Jama' Are river basin, Nigeria. ASPRS annual conference, Oregon, April 28–May 2

Yalcin G, Akyurek Z (2004) Analysing fl ood vulnerable areas with multicriteria evaluation. Available at http://www.isprs.org/proceedings/XXXV/congress/comm2/papers/154. pdf . Accessed 15 Jan, 2012

Yamagata Y, Akiyama T (1988) Flood damage analysis using multitemporal Landsat thematic mapper data. Int J Remote Sens 9(3):503–514

Yoon DK (2012) Assessment of social vulnerability to natural disasters: a comparative study. Nat Hazard 63(2):823–843

Wajed A (1986). A Report on Control of Flash Flood in Bangladesh, Bangladesh Water Development Board, Dhaka

Walker P 91994). comment: There are No Natural Disasters, Geographical, The Royal Geographical Society Magazine: 9, July

Walsh J R (1935). The Capital Concept Applied to Man, Quarterly Journal of Economics, 255-285

Ward R (1978). Floods, A Geographical Perspective, The Macmillan Press Ltd. UK

Warrick R A and Ahmad Q K (eds) (1996). The Implications of Climate and Sea-level Change for Bangladesh, Kluwer Academic Publishers, London

Waterstone M (1978). Hazard Mitigation Behavior of Urban Flood Plain Residents, Working Paper 35, Institute of Behavioral Science, Boulder, Colorado

Weick K E (1985). Systematic Observational Methods, In G Lindzey and E Aronson (eds). The Handbook of Social Psychology, third Edition, Random House, New York

Wessex Water Authority (1974). Land Drainge Appraisal, Bristol

Wessex Water Authority (1977). Land Drainge Appraisal, Bristol

Wessex Water Authority (1983). Gillingham Flood Alleviation Appraisal, Poole, Dorset

White G F (1945). Human Adjustments to Floods: A Geographical Approach to the Flood Problem in the United States, University of Chicago, Department of Geography, Research Paper No 29, Chicago

White G F (1964). Choice of Adjustment to Floods, Research Paper No 93, Department of Geography, University of Chicago

White G F (1973). Natural Hazards Research, In R J Charley (ed) Directions in Geography, Methuen, London, 193-216

White G F 9ed) (1974). Natural Hazards: Local, National, Global, Oxford University Press, New York

White (1980). Overview of the Flood Insurance Program, Housing and Urban Affairs, University of Colorado, Institute of Behavioral Science

White G F, Clef W C, Hudson J W, Mayer H M, Shaffer J r and Volk D J (1958). Changes in Urban Occupancy of Flood Plain in the United States, Research Paper No 57, Department of Geography, University of Chicago

World Bank (1982). Bangladesh Transport Sector Memorandum, South Asia Projects Department, Power and Transportation Division.

William E. Lovekamp, (2010). GENDER AND DISASTER: A SYNTHESIS OF FLOOD RESEARCH IN BANGLADESH, Department of Sociology & Anthropology, Eastern Illinois University, February.

World Bank (1985). Bangladesh Economic and Social Development Prospects, Vol iii, Report 5409, April.

World Bank (1989). Bangladesh Action Plan for Flood control, Main Report, Dhaka

World Bank (1992). World Development report, Development and the Environment, World Development Indicators

World Bank (1993). World Development Report, Investing in Health, World Development Indicators

World Bank (1994). World Development Report, Infrastructure for Development, World Development Indicators

World Bank (1995). Social Indicators of Development, A World Bank Report

World Commission on Environment and Development (1987). Our Common Future, Brandt land Report, Oxford University Press, UK

World Disasters Report (1994), World Disasters Report. Various Issues van Oosterom P, Zlatanova S, Fendel EM (2005) Geo-information for disaster management. Springer, Berlin van Westen CJ (1993) Remote sensing and geographic information systems for geological hazard mitigation. ITC J 4:393–399

Zahran S, Brody SD, Peacock WG, Vedlitz A, Grover H (2008) Social vulnerability and the natural and built environment: a model of fl ood causalities in Texas. Disasters 32(4):537–560

Zerger A (2002) Examining GIS decision utility for natural hazard risk modelling. Environ Model

Software 17(3):287–294

Zerger A, Smith DI (2003) Impediments to using GIS for real-time disaster decision support. Comput Environ Urban Syst 27(2):123–141

Zerger A, Wealands S (2004) Beyond modelling: linking models with GIS for fl ood risk management. Nat Hazard 33(2):191–208

Zhang J, Hori T, Tatano H, Okada N, Matsumoto T (2003) GIS and fl ood inundation model-based fl ood risk assessment in urbanized fl oodplain. In: Cheng Y et al (eds) GIS and RS in hydrology, water resources and environment, vol 1. Sun Yat-sen University Press, Guangzhou, pp 92–99

Zheng N, Takara K, Yamashiki Y, Tachikawa Y (2009) Large scale quantitative vulnerability analysis for regional fl ood hazards. Annuals of Disaster Prevention and Research Institute, Kyoto University, No. 52B, Japan

Zhou YC, Qing CW (1999) Deciding the fl ood extent with RADARSAT SAR data and image fusion. http://www.gisdevelopment.net/aars/acrs/1999/ps3/ps3999.shtml . Accessed 11 July, 2003

Zhou C, Luo J, Yang C, Li B, Wang S (2000) Flood monitoring using multi-temporal AVHRR and

Zaman M Q (1991). The Displaced Poor and Resettlement Policies in Bangladesh, Disaster, 15(2), 115-125

END