VULNERABILITY ASPECTS OF HOUSING IN BANGLADESH DUE TO MULTIPLE NATURAL HAZARDS

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The thesis titled **"Vulnerability Aspects of Housing in Bangladesh due to Multiple Natural Hazards"**, submitted by **Musa. Shammi Akther, Roll No. 040404218F, Session April 2004,** has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering (Geotechnical) on 20th August, 2008.

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It is hereby declared that except for the contents where specific reference have been made to the work of others, the studies contained in this thesis is the result of investigation carried out by the author. No part of this thesis has been submitted to any other University or other educational establishment for a Degree, Diploma or other qualification (except for publication)

Signature of the Candidate

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LIST OF NOTATIONS

WT	*weighting factor*
R	*Risk*
fr	*frequency of disaster*
TR	*total Risk*
Rci	*risk for cyclone*
Rti	*risk for tornado*
Rfi	*risk for Flood*
Rei	*risk for earthquake*
V_{max}	*wind speed in kph*
m	*storm surge in meter*
M	*earthquake magnitude*
T	*return period*

LIST OF ABBREVIATIONS

ADPC	*Asian Disaster Preparedness Center*
BBS	*Bangladesh Population Census*
BNBC	*Bangladesh National Building Code*
BMTPC	*Building Materials and Technology Promotion Council*
BWDB	*Bangladesh Water Development Board*
BAS	*Bangladesh Academy of Sciences*
CHCDA	*Country of Hawaii Civil Defense Agency*
DMB	*Disaster Management Bureau*
EIA	*Environmental Informatics Archives*
ESC	*European Seismological Commission*
FAP	*Flood Modeling and Management*
FFWC	*Flood Forecasting & Warning Centre*
GSB	*Geological Survey of Bangladesh*
ISEIS	*International Society for Environmental Information Sciences*
ISCPDL	*Indian Standard Code of Practice for Design Loads for buildings and Structures*
IAEE	*International Association of Earthquake Engineering*
MFAT	*Ministry of Foreign Affairs Thailand*
NAP	*National Action Programme*
NBS	*US National Bureau of Standard*
NPDM	*National Plan for Disaster Management*
STP	*Storm Track Prediction (STP) Model*
SRDI	*Soil Resources Development Institute*
SPARRSO	*Space Research and Remote Sensing Organization*
WFP	*World Food Programme*
WMO	*World Metrological Organization*

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ABSTRACT

As a first step in disaster mitigation, this study aims to identify and evaluate the natural hazards in Bangladesh. The major hazards namely earthquake, flood, cyclone and tornado of Bangladesh were studied. This includes study of geological, topographical, hydrological and seismo tectonic setup in Bangladesh, probable major hazard sources, existing hazard zoning maps etc. A detailed disaster database including damage data of earthquake, flood, cyclone and tornado was compiled. These data were collected from various sources. Different intensity scales for these disasters were also reviewed. The collected damage data, damage scenario and models were used to develop and propose intensity scales for earthquake, flood, cyclone and tornado for Bangladesh.

Total risks for earthquake, flood, cyclone and tornado with the variables of those natural hazards occurrence, were estimated for different areas of Bangladesh. A new district wise tornado hazard zoning map was proposed based on the frequency of occurrence. The digitized maps of earthquake, cyclone, tornado and flood hazards were presented in this study as Vulnerability Risk Areas of Bangladesh, wherein the risk score was tabulated for different districts of Bangladesh. Based on estimated risk score of earthquake, cyclone, tornado and flood hazards a multi-hazard map of Bangladesh was proposed.

The housing types of Bangladesh were categorized based on Bureau of Statistics data. The housing vulnerability table for each district was prepared based on risk of damage for different housing types. At a glance the tables will show the percent areas of the district most susceptible to earthquake, cyclone, tornado and flood hazards for different housing categories.

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Bangladesh is one of the most natural disaster prone areas in the World. The different types of disasters like flood, cyclonic storms, tidal surges, droughts, tornadoes, riverbank erosion, earthquake, etc. occur in Bangladesh regularly and frequently. The most devastating cyclones and floods of the world occurred in Bangladesh. The 1988 flood killed 1517 people and nearly half of the population was affected (Hossain, 2006). The 1970 cyclone killed almost 500,000 people (Karim, 1996). About 1300 people were killed by tornado at Saturia of Manikganj district in Bangladesh in 1989 (EIA, 2004). The 1897 Great Indian Earthquake with a magnitude of 8.7, which is of the strongest earthquakes in the world killed 1542 and affected almost the whole of Bangladesh (Oldham, 1899). Crop and livestock loss was extremely high.

Major factors responsible for disasters in Bangladesh are flat topography, rapid run-off and drainage congestion, low relief of the floods plains, low river gradients, heavy monsoon rainfall, and enormous discharge of sediments, funnel shapes and shallow Bay of Bengal etc.

Cyclones and floods are major disasters in Bangladesh. But other disasters are also creating severe damages. Drought leaves a permanent damage and encourages the desertification process that is going on in some parts of North Bengal. River erosion takes away thousands of hectares of land every year in a country where land is the scarcest resource. Earthquakes may cause millions and billions of Taka worth of damage. Perhaps the most disturbing but ignored fact about disasters is that they are all linked to each other.

At times, some areas normally subjected to drought situation have got flooded in certain years. Hazards like earthquakes, landslides, etc. occur quite suddenly but they are restricted in their impact in terms of time. The extent of the impact of an earthquake depends on its magnitude. Natural calamities may be broadly grouped into major and minor types depending upon their potential to cause damage to human life and property. While natural hazards like earthquakes, droughts, floods, Tornadoes and cyclones could be regarded as major landslides, riverbank erosion, groundwater contamination, fires, tsunamis etc., whose impact is localized and intensity of the damage is much less can be categorized as minor hazards. So far as damage to housing and infrastructure is concerned, floods, cyclones, tornadoes and earthquakes turn out as the four major disasters confronting the country.

The hazards earthquakes, cyclones, tornadoes and floods are called natural since they result from natural phenomena connected with the earth's interior and the atmosphere, unaffected and uncontrolled by man. They become disasters when they impact on vulnerable habitat containing unsafe buildings and the infrastructure whose collapse or damage leads to adverse social, economic and health consequences.

Considering the major disasters of Bangladesh, disaster mitigation is needed and should be undertaken. Generally the hazards should be evaluated. In particular, the first step in disaster mitigation is to recognize the existence of these risks. The next step is to quantify the risks and to minimize the effects. The total elimination of risks may be difficult and impractical. Moreover in developing countries like Bangladesh, economic considerations usually take precedence over safety and engineering design.

Generally, the outcome of a hazard assessment is presented on a map in which locations or zones with different levels of hazard potential are identified. Multihazard hazard maps are practical tools in disaster mitigation planning, design of structures because they provide important guidance when it is not feasible to do the hazard assessment at particular sites. These maps give a good indication on the area extent of expected high risk areas for overall natural disaster. The risk score is the indicator of the severity of areas affected by overall natural disaster situation for a particular area. Intensity scales gives the damage severity of disasters. Intensity scales are subjective and depend upon social condition and construction status of a country, they need revising from time to time. Regional effects must be accounted for. There exists no individual hazard intensity scale to identify the type of particular hazard for Bangladesh. The information on the possible intensities that may be obtaining in the event of natual hazards and the resulting risk levels to housing and buildings will be very useful to the country and national authorities, the planning commission, the members of country legislatures and the disaster managers at different levels. Vulnerability Atlas is a useful tool to evolve disaster mitigation and preparedness strategies in natural hazard prone regions.

This study aims to present the identification of multihazard prone areas of Bangladesh as well as housing vulnerability tables for each district, indicates the level of risk to which different damage types could be subjected to during the occurrence of natural hazards in future.

This study will find out the disaster prone areas of Bangladesh and also the damages, history, severity of these areas, intensities of those natural disasters and housing vulnerability. GIS based disaster database is very crucial and an important aspect for environmental management strategy for planning and disaster mitigation, preparedness and preventive actions. The information will assist the environmental management, different field of sciences such as engineering, agriculture, fisheries, and policy making and planning of Bangladesh and should be an integral part of the whole process of economic and social development in Bangladesh. The findings of this study would benefit engineers and city planners. They constitute a fundamental means which should guide officials at the national and regional levels in the formulation of development strategies in multihazard active zones, land use management, revision and enforcement of appropriate building codes and formulation of plans for mitigating measures against hazard risks affecting the region considered.

1.2 SCOPE AND OBJECTIVES OF PRESENT RESEARCH

Bangladesh is a developing country with numerous problems like overpopulation, poverty, complex socio economic structure, frequent disasters, low level industrial base, and resource constrains, lack of appropriate infrastructural and institutional facilities, dearth of trained manpower, etc. These problems are complicated and compounded with the occurrences of regular and frequent disasters impeding the overall socio-economic development efforts of the country. Exploring the historical disaster database one can imagine the damages that occurred due to natural calamities.

- To develop a complete district wise database for different disaster of Bangladesh.
- Identification of vulnerable areas with reference to natural hazards causing damage to the housing stock and the related infrastructure, such as earthquake, cyclones, tornadoes, floods , tsunamis etc. A basic requirement in this regard is to prepare what can be called a Vulnerability Atlas, showing the areas vulnerable on account of one or more natural disasters capable of damaging housing stock and related infrastructure.
- To analyze the existing hazard maps of Bangladesh & update.

- To develop a multi hazard map for whole Bangladesh.
- Implementation of hazard intensity scales for different disaster respect of Bangladesh.
- Earthquake, cyclones/windstorms, tornadoes, floods and as well as the district- wise housing vulnerability tables.
- To formulate planning, land use and structural consideration for housing or industrialization policies for prevention and mitigation of disaster impacts.

All this analysis will be useful to engineers, planners, emergency personnel, government officials, and anyone else who may be concerned with the potential consequences of hazard mitigation activity in a given region. And it will be helpful the general people also, who will be affected by disaster.

- The results will be presented in the form of multi hazard maps and Housing Vulnerability Table.
- Hazard intensity scales for different disaster respect of Bangladesh which will be helpful for loss estimation.
- Hazard maps and Housing Vulnerability Risk Table methodology will be used for estimating potential damage and loss to existing as well as for planning location and construction of future buildings.
- Guidelines for design and land use for different hazards.
- Hazard maps will be helpful for the decision-makers who are involved in disaster mitigation.

1.3 METHODOLOGY

A proper methodology is always necessary for the successful completion of a research work. It is helpful regarding the organization of the experiences, observations, examinations and analysis of found data and information and their logical interpretation in a systemic process to achieve the ultimate goal and the objectives of the research. The following objectives are proposed for the successful implementation of the research work.

- Literature Survey

An extensive survey of all the available and relevant literature was made to analyze the findings and recommendations of different journals, research publications and study reports related with this research topic. At the same time this tool of literature survey has been used to collect secondary data and information also.

- Data Collection

Secondary data and information have been collected from the census report as well as various government, non-government and international organizations such as Bangladesh Meteorological Department (BMD), SPARRSO, Disaster Management Bureau (DMB) and concerned non-government organizations (NGO). Besides this, some and information was collected from the CDMP/ UNDP projects and web sites of different organizations.

- Identify the disaster prone areas for multi hazard with GIS

The study has been executed exploring the historical disaster events, duration and damages information and Geographic Information System (GIS). As GIS is a powerful planning tool which has been used to identify the disaster prone area in Bangladesh, the large amount of disaster data were collected from different organizations and sources. Again the zoning maps of different organization prepared in different time were also collected. Further the disaster data and zoning maps were analyzed and comparing the data and zoning map, all the zoning maps were digitized separately. Further this database was converted into GIS database. The location, type, year and damages etc were digitized to put the database into GIS system. Based on the available historical data gathered from different sources the disaster prone area of Bangladesh has been identified through GIS based analysis. Then using GIS a multi hazard map is prepared.

- Housing Vulnerability Table

The housing types of Bangladesh were categorized based on Bureau of Statistics data. The housing vulnerability table for each district was prepared based on risk of damage for different housing types. At a glance the tables will show the percent areas of the district most susceptible to earthquake, cyclone, tornado and flood hazards for different housing categories.

Figure 1.1 shows the flow diagram of this thesis.

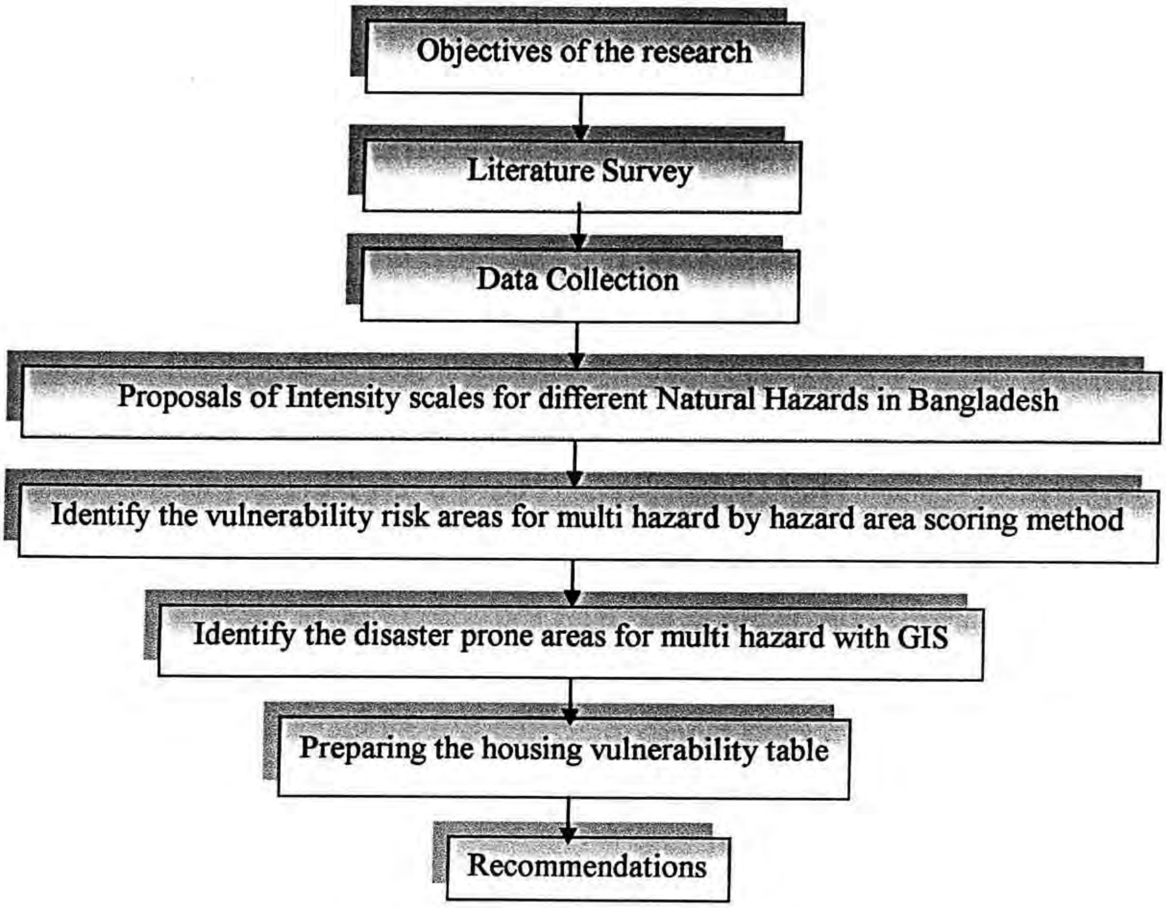


Figure 1.1 Flow Diagram of the thesis

1.4 OUTLINE OF THE STUDY

The remaining of the thesis consists of five chapters.

Chapter two reviews the multihazard related literature of Bangladesh. This chapter also provides short description of some historical disasters of Bangladesh.

Chapter three deal with the proposals of Intensity scales for different Natural Hazards in Bangladesh.

Chapter four deals with the vulnerability risk areas of Bangladesh due to multiple natural hazards. Multihazard evaluated by hazard area scoring method.

Chapter five deals with the housing vulnerability table of various districts of Bangladesh.

Chapter six presents the conclusions, recommendations and limitations of the study.

CHAPTER 2
LITERATURE REVIEW

2.1 GENERAL

Disaster is an adverse happening; sudden misfortune; catastrophe. Bangladesh is most vulnerable to several natural disasters and every year natural calamities upset people's lives in some part of the country. The major disasters concerned here are the occurrences of flood, cyclone and storm surge, flash flood, drought, tornado, riverbank erosion, and landslide. These extreme natural events are termed disasters when they adversely affect the whole environment; including human beings, their shelters, or the resources essential for their livelihoods.

The geographical setting of Bangladesh makes the country vulnerable to natural disasters. The mountains and hills bordering almost three-fourths of the country, along with the funnel shaped Bay of Bengal in the south, have made the country a meeting place of life-giving monsoon rains, but also make it subjected to the catastrophic ravages of natural disasters. Its physiography and river morphology also contribute to recurring disasters. Abnormal rainfall and earthquakes in the adjacent Himalayan range add to the disaster.

Since Bangladesh is a disaster prone country, it is subject to colossal damages to life and property almost every year. The different types of disasters and their impact on the affected areas, previous historical events has been broadly summarised as in the accompanying chapter as a literature review.

2.2 OVERVIEW OF BANGLADESH

2.2.1 Geography

With an area of about 144,000 sq. kilometers and situated between $20^0 34''$ and $26^0 38''$ north latitudes and between $88^0 01''$ and $92^0 41''$ east longitude. Bangladesh occupies a unique geographic location-spanning a stretch of land between the mighty Himalayan mountain chain on the north and the open ocean on the south. It is virtually the only drainage outlet for a vast river basin complex made up of the Ganges, Brahmaputra and the Meghna and their network.

Three broad physiographic regions are discernible- flood plains, occupying about 80%; terraces about 8% and hills about 12% of the land area, Each of these regions exhibits its own geo-morphological characteristics, which make convenient at further sub-division into 20 generalised physiographic units.

The country criss-crossed by a network of rivers - the Padma, the Jamuna, the Teesta, the Brabmaputra, the Surma, the Meghna and the Karnaphuli and their tributaries numbering about 230 is experiencing its rivers being flattened by heavy silts deposited by these rivers during the rainy season resulting in recurrence of floods almost every year. (CountryPaper: Bangladesh, 2006).

2.2.2 Climate

The climate of Bangladesh is tropical and humid. It has mainly four seasons, e.g. Pre-monsoon (March to May), Monsoon (June to September), Post-monsoon (October to November), Dry (December to February). Its climate is influenced by the Indian Ocean monsoon climate. Average annual rainfall is between 2200-2500 mm but the maximum range is between 1200 to 6500 mm. About 80% of the rainfall occurs during monsoon i.e. from June to September. Average temperature varies from 25^0C to 35^0C during the year. Sometimes it falls below 10^0C during the winter. (Hossain, 2004).Figure 2.1 shows the location map of Bangladesh included Asian countries.

Figure 2.1 Location of Bangladesh included Asian Countries (Ministry of Foreign Affairs Thailand, 2007)

2.2.3 Topography of Bangladesh

Topography is mostly flat excepting some part in the northeast and southeast, which are hilly. Figure 2.2 shows topography of Bangladesh. Entire country is a delta formed by the deposition of sediment carried by the three large river systems e.g. Ganges, Brahmaputra and Meghna. Some older deposits also exit in the central and western part of the country. Hilly areas occupy 12%, terrace areas 8% and flood plain 80% of the country. Land elevation varies from -3m to 90m MSL. More than 50% of the flood plain is within 5m MSL. (Hossain, 2004)

- Land elevation of 50% of the country is within 5 m of MSL
- 68% of the country is vulnerable to flood
- 20-25% of the area is inundated during normal flood (Hossain, 2004)

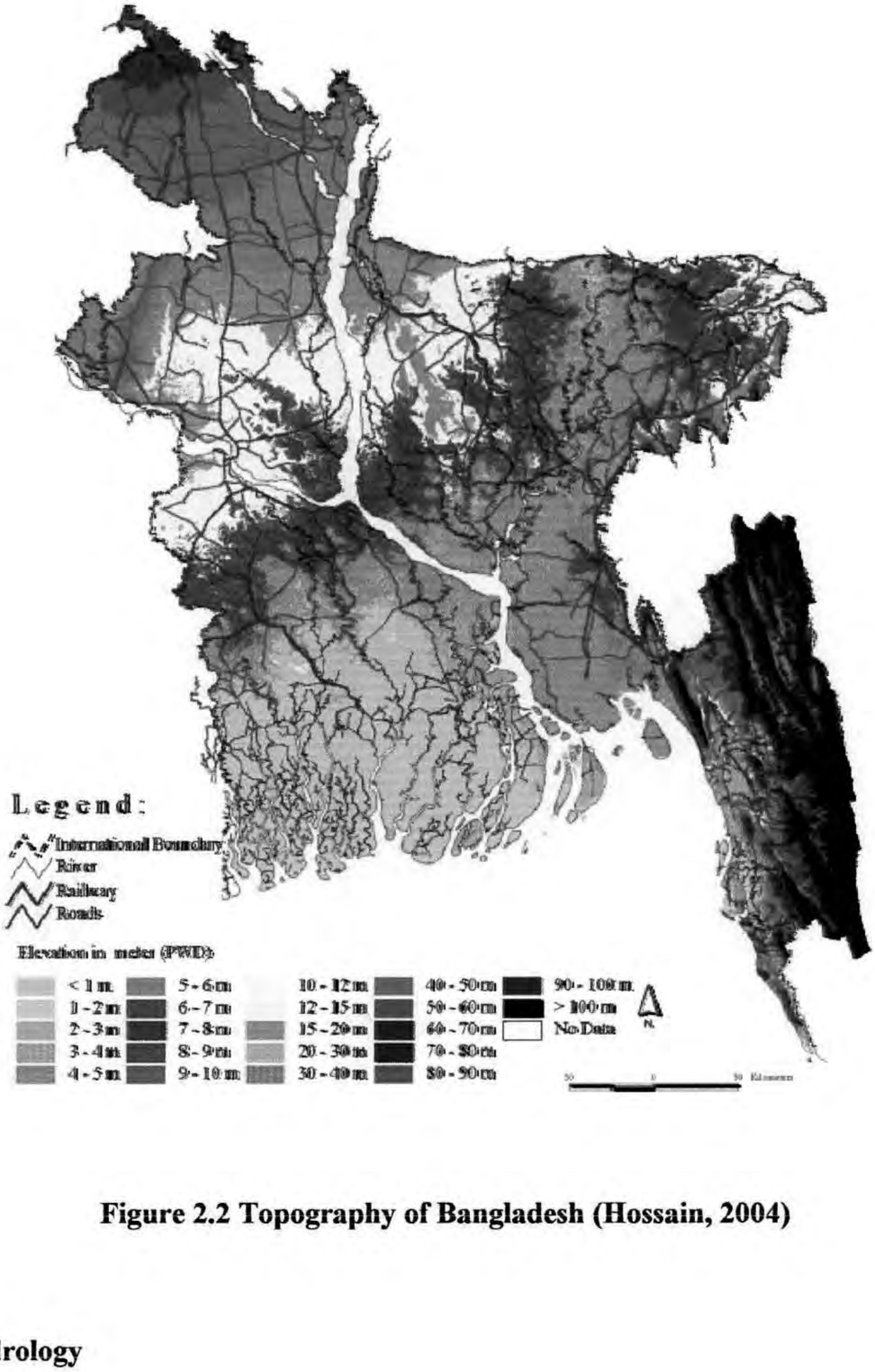


Figure 2.2 Topography of Bangladesh (Hossain, 2004)

2.2.4 Hydrology

Bangladesh has unique hydrological regime. It has 230 nos. rivers of which 57 are trans-boundary Rivers. In all most all cases Bangladesh is a lower riparian country. A picture of its river system is also given in the figure. 2.3.

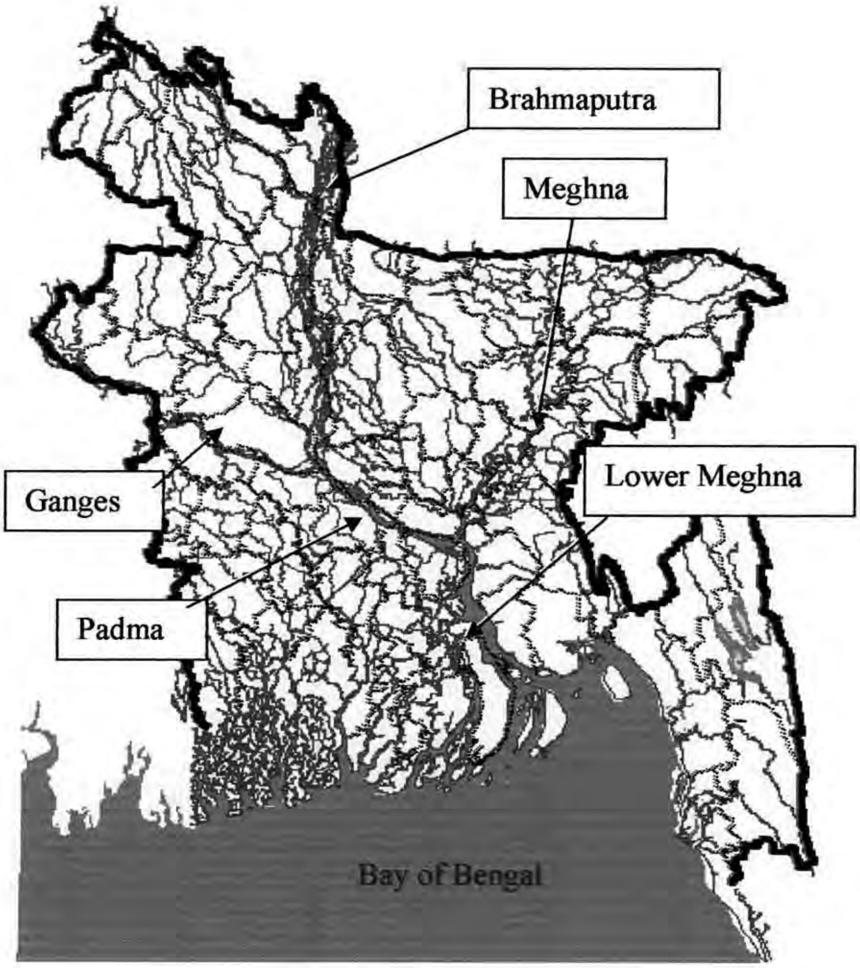


Figure 2.3 River system of Bangladesh (after Hossain, 2004)

Three large rivers systems e.g. Ganges, Brahmaputra and Meghna, in the world covering a combined total catchments area of about 1.7 million sq. km. extending over Bhutan, China, India and Nepal, flow through this country. Out of these huge catchments only 7% lies in Bangladesh and 93% outside the country. Rivers are classified into three broad categories e.g. More, Semi Major and Minor depending on the flow range. Water surface slopes of the major rivers are very flat e.g. av. slope of Ganges is 5-6 cm/km, av. slope of Brahamaputra is 8-9 cm/km and av. slope of Meghna is 4-3.5 cm/km. When south westerly monsoon sets in the Bay of Bengal then, sea level rises by about 1m than the normal. As a result during monsoon water surface slopes of the rivers become much flatter impeding evacuation of flood flow to the sea, causing flood to spread over the low-lying lands for relatively longer duration. Annual flow volume of the rivers is to the tune of 1200 billion m^3, 80% of the flow passes during June to September. (Hossain, 2004)

2.3 NATURAL DISASTERS OF BANGLADESH

The inclement weather systems, which are of course seasonal, make Bangladesh the most victims of natural calamities, causing at times colossal loss of lives and properties. Most of Bangladesh's densely settled population of 130 million people lives in the delta of the great Ganges and Brahmaputra river systems and is at significant risk from multiple forms of natural hazard. Riverine floods, tropical cyclones (sometimes accompanied by devastating storm surges), flash flooding, erosion, and drought have caused severe economic and social disruption and considerable loss of life in recent decades. (Bangladesh Country Paper, 2004).Furthermore, Bangladesh is in a zone of very high seismic activity. The major natural hazards of Bangladesh may be classified as follows:

1. Geological hazards
    - Earthquake
    - Landslides
    - River Bank Erosion
2. Hydrological hazards
    - Flood
    - Tsunami
3. Climatic and Atmospheric hazards
    - Drought
    - Heat wave
    - Tropical Cyclones and storm Surge
    - Tornadoes/ Thunderstorms
    - Cold wave
4. Biospherical hazards
    - Epidemic / Disease
    - Famine
5. Other hazards
    - Bombing/Terrorism
    - Firing
    - Arsenic contamination of groundwater

Table 2.1 shows the causes of direct and indirect hazards.The primary and secondary hazards are also presented by the table:

Table 2.1 Causes of Direct and Indirect Hazards

Primary Hazard	Secondary Hazards	Cause
Hydrometeorologic hazard		
hurricane force winds;	Fires	high sea surface temperatures
storm surges	Flooding	low pressure systems
landbourne flashfloods;		high rates of run-off
	droughts and related food insecurity;	Reduced rainfall-reduced aquifer recharge
Geological hazards		
earthquakes;	subterranean cavity collapses	tectonic displacement
riverbank erosion;	accelerated sedimentation in the harbour	exposure of erodeable earth materials
slope instability		steep slopes clastic sediments and slope disturbance or loading
Technological hazards		
groundwater contamination;	Epidemics	high faecal coliform
boatwrecks and,		overcrowding of boats
fires;		poor storage of fuel

The different types of disasters and their impact on the affected areas can broadly be summarised as in the accompanying Table 2.2.

Table 2.2 Types of Disasters and their Impacts in Specific Disaster Prone Areas

Types of	Disaster	Areas Affected Impact
Flood	Floodplains of the *Brahmaputra Jamuna*, the *Ganges-Padma* and the *Meghna river* system	Loss of agricultural production, disruption of communication and livelihood system, injury, damage and destruction of immobile infrastructure, disruption to essential services, national economic loss, evacuation, and loss of human lives and biodiversity, displacement and sufferings of human population and biodiversity
Cyclone and Storm Surge	Coastal areas and offshore islands	Loss of agricultural production, disruption of communication and livelihood system, damage and destruction of immobile infrastructure, injury, national economic loss, loss of biodiversity and human lives, need for evacuation and temporary shelter
Tornado	Scattered areas of the country	Loss of human life and biodiversity, injury, damage and destruction of property, damage of cash crops, disruption in lifestyle, damage to essential services, national economic lossand loss of livelihood
Drought	Almost all areas, especially the Northwest region of the country	Loss of agricultural production, stress on national economyand disruption in life style
Flash Flood	Haor Basins of the North-east region and South-eastern hilly areas	Damage of standing crops, disruption in life style, evacuation and destruction of properties

Types of	Disaster	Areas Affected Impact
Hail Storm and Lightning	Any part of the country	Damage and destruction of property, damage and destructionof subsistence and cash crops and loss of livelihood
Erosion	Banks of the Brahmaputra-Jamuna, the *Ganges-Padma* and the *Meghna* river systems	Loss of land, displacement of human population and livestock, disruption of production, evacuation and loss of property
Landslide	Chittagong and Chittagong Hill Tracts	Loss of land displacement of human population and livestock, evacuation, damage of property and loss of life
Earthquake	Northern and central parts of the country	Damage and destruction of property, loss of life and change ingeomorphology

2.4 EARTHQUAKE

2.4.1 Definition

An earthquake is a phenomenon that results from a sudden release of stored energy that radiates seismic waves. At the Earth's surface, earthquakes may manifest themselves by a shaking or displacement of the ground and sometimes tsunamis. 90% of all earthquakes - and 81% of the largest - occur around the 40,000km long, which roughly bounds the Pacific Plate. Many earthquakes happen each day, few of which are large enough to cause significant damage. Figure 2.4 shows a devastation caused by an earthquake.

Bangladesh is a moderately seismic region. It is a fact that earthquakes do not occur just anywhere. They tend to cluster around defined areas or lines. Figure 2.5 shows plate boundaries and earthquake epicenters of the world. Bangladesh and its adjoining areas is situated in the northeast part of the Indian subcontinent where earthquake frequently occur. This regions lie along the border of Eurasian and Indo- Australian plates.

Figure 2.4 The aftermath of an earthquake

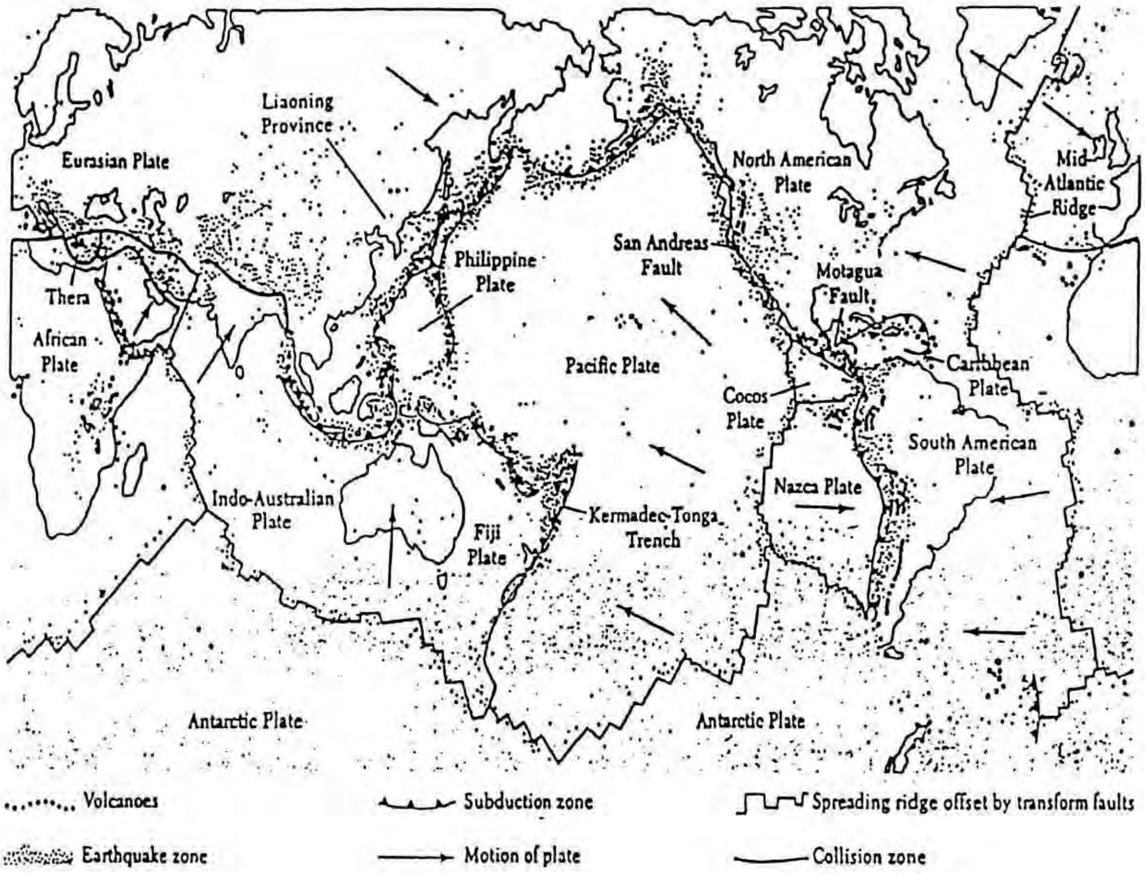


Figure 2.5 Earthquake Epicentres for the World (after Bolt, 1987b)

2.4.2 Regional Tectonics

Plate tectonics provides a physically simple mechanism for large-scale horizontal motions of separate portions of the earth's crust. One of the central concepts of plate tectonics is that a small number of large plates of high strength lithosphere, move rigidly with respect to one another at rates of 1 to 20 cm/year over the low-strength asthenosphere. According to Molnar and Tapponnier (1975) for the past 40 million years the Indian subcontinent has been pushing northward against the Eurasian plate at a rate of 5 cm/year, giving rise to the severest earthquakes and most diverse land forms known. Figure 2.6 shows India's northward drift over the last 70 million years.

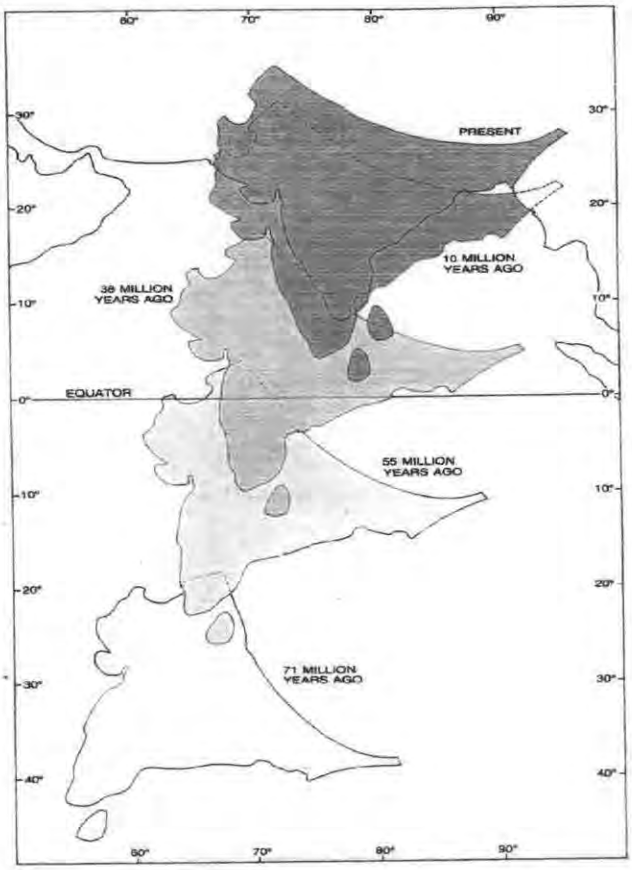


Figure 2.6 India's northward drift over the past 70 million years (after Molnar and Tapponnier, 1975)

The region of northeastern India, northern Burma and Southwestern China is tectonically and seismically one of the most interesting active plate boundaries. The region comprises the Himalayas, the Indo-Burma Ranges, and the Tripura folded belt, the Bengal Basin, the Shillong Plateau and the Assam Valley.

Bangladesh occupies major part of the Bengal Basin. It is a rifted eastern marginal basin of Indian plate that is gradually shortening due to the subduction of the Indian plate and overriding of the Burmese plate from the east.

2.4.3 Seismo Tectonic Setup

Bangladesh is divided into three major tectonic zones (Khandaker, 1989):

(1) The Shelf zone: It consists of mainly the northwestern part of the country including the districts of Rangpur, Dinajpur and Bogra.

2) The Hinge zone: It passes through Calcutta, Pabna, and Mymensingh and extends further NE across the Dauki fault.

(3) The Bengal Foredeep zone: It comprises of the rest area of the country and occupies the area between the Shelf zone in the west and Arakan-Yoma Hill range in the east. The deep basin area of the foredeep is composed of the Surma Basin or Sylhet Trough, Faridpur Trough and the Hatia Trough.

The generalized Tectonic map of Bangladesh and adjoining areas are given in Figure 2.7.

The junction between the platform and the foredeep running southwest from Mymensingh to Calcutta (the Hinge line) is considered to be a zone of weakness; however, no association of the hinge with earthquakes has so far been established. The Foredeep is terminated in the northeast by a major fault, the Dauki fault-at the southern margin of the Shillong Plateau. Some major earthquakes can be related to this fault. There are numerous faults particularly in the eastern part of the folded flank of the Foredeep. Here again there is no association with any major earthquake. Most recorded earthquakes had epicenter further east in Burma.

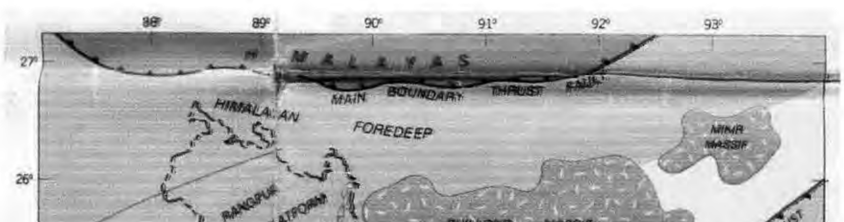


Figure 2.7 Generalized Tectonic Map of Bangladesh and Adjoining Areas (After GSB, 1990)

The eastern margin of the Indian plate is supposed to run through Myanmar, not far from the Bangladesh border, and northeast Assam (Arunachal Prodesh) is considered to be a corner of the northern and eastern margins of the plate.

The Himalayan arc can be regarded as one of the most intensely active seismic regions of the world. In northeast India the Shillong plateau and adjacent syntaxis between the two arcuate structures is one of the most unstable regions in the Alpine-Himalayan belt and faced three major earthquakes of magnitude greater than 8.0 within the last two hundred years (1897, 1934, and 1950).

Northeast India can be broadly classified into four geotectonic units (Das, 1992), namely, (i) Arunachal Himalayas, (ii) Lohit Himalayas, (iii) Patkoi-Naga-Lushi-Arakan Yoma (Indo-Burma) hill ranges and (iv) Shillong Plateau-Assam basin. The region of Shillong Plateau-Assam basin has been identified as one of potential sites for severest earthquakes.

Shillong massif and its northeasterly projected spur form the basement on which the alluvium and unfolded Tertiary formations of Assam basin have been deposited. It forms a wedge shaped triangular crustal block bounded by Arunachal Himalaya towards northwest, Lohit Himalaya towards northeast, the Indo-Burma folded belt towards southeast, the Bengal Burma basins on the south and Rajmahal-Garo-Sylhet gap towards the west. The contacts of these geotectonic units with the Shillong plateau are marked by conspicuous thrust and tear faults. Two prominent tectonic features forming the boundary of Shillong plateau towards west and south are the Dhubri and Dauki tear faults, respectively. The plateau is bounded towards northwest by the Main Boundary Fault, towards northeast by Paleozoic and Precambrian formation of Mishmi and Lohit thrusts, towards southeast by Tertiary group of Naga thrust belts and on the south by Cambrian formation of Dauki tear fault, which merges towards east with the Haflong-Disang thrust zone. This complex tectonic regime surrounding Shillong Plateau reveals that the area has experienced great compressive stresses and resulting north-eastward drift of Indian plate along with westward overriding of Burmese plate.

At present, the southernmost thrusting in the Himalaya-Shillong Plateau region could be taking place along the southern fringe of the plateau coinciding with the Dauki fault.

Currently, it is believed that the Shillong plateau has a thrust plane beneath it and is undergoing southward thrusting against a concept of vertical tectonism along the Dauki fault.

The Shillong plateau and its adjoining region including the northeastern part of Bangladesh have high seismic status. The seismic activity along the Dauki-Haflong fault zone is comparatively lower and a seismic gap has been postulated along this fault zone. The major earthquakes that have affected Bangladesh since the middle of the last century are presented in Table 2.3.

Table 2.3 Great historical earthquakes in and around Bangladesh

Date	Name	Epicentre	Magnitude (M)
10-01-1869	Cachar Earthquake	Jantia Hill, Assam	7.5
14-07-1885	Bengal Earthquake	Sirajgonj, Bangladesh	7.0
12-06-1897	Great Indian Earthquake	Shillong Plateau	8.7
18-07-1918	Srimangal Earthquake	Srimangal, Sylhet	7.6
02-07-1930	Dhubri Earthquake	Dhubri, Assam	7.1
15-01-1934	Bihar-Nepal Earthquake	Bihar, India	8.3

2.4.4 Major Seismic Sources

Bolt (1987a) analyzed different seismic sources in and around Bangladesh and arrived at conclusions related to maximum likely earthquake magnitude (Bolt, 1987a). Bolt identified the following four major sources:

(i) Assam fault zone
(ii) Tripura fault zone
(iii) Sub- Dauki fault zone
(iv) Bogra fault zone

A brief description of geology, tectonics of the individual fault zone is given below:

(i) Assam fault zone: The east-west fault separates the Assam fault zone separates the Assam fault zone from sub-Dauki fault zone. This zone consists of Archaean Proterozoic basement

complex and characterized by the maximum concentration earthquake events. The hypocenters beneath the Shillong plateau are shallow focus in origin and are scattered. Only a few epicenters appear on or close to Dauki fault indicate that this fault is relatively seismically inactive during the recent time. But it was active sice the Jurassic and was the main architect for the evolution of Shillong plateau. The great earthquake of 1897 originated in the Asam fault zone. A number morphotectonic lineament has been identified from the study of the satellite imagery.Most of the lineaments trend NE-SW with a few trending N-S. The N-S trending Brahmaputra fault is present along the course of Brahmaputra River. The fault dips steeply to the north. This zone is characterized by scattered shallow depth earthquake probably due to prevalent upward forces existing below the Shillong Plateau.

ii) Tripura fault: This zone is characterized by high concentration of earthquake events. A number of morphotectonic lineaments have been identified. Among these the Kopili lineament trending NW-SE is remarkable and is geologically recent in origin. Seismic section reveals that this lineament is the surface expression of deep seated subvertical fault and termed as the Kopili fault, which belongs to the category of high angle reverse fault. At the north of this zone Halflong-Dissang thrust is present. Morphotectonic lineaments around the Halflong-Dissang thrust zone trend NE-SW, E-W and NW-SE. Mikir hill is present to the northeast corner of the Halflong-Dissang thrust, which separates the Shillong plateau by Kopili fault.

iii) Sub-Dauki fault zone: This zone covers the southern part of Dauki fault and eastern part of Bogra fault zone and bounded by longitude 90°E and 92°E. The morphotectonic lineaments trend NNW- SSE and NW-SE. The Sylhet plain covers the area and comprises the vast alluvial tract and the linear belts of folded Tertiary rocks trending N-S and NNE-SSW. Sylhet lineament of 180 km long trending NE-SW is the subsurface expression of deep seated high angle reverse fault having a dip of about 70° towards southeast and as named as Sylhet fault. A number of epicenteres fall on or close to this fault and some of them were of damaging character. Among them the earthquake of 1845 and Srimangal earthquake of 1918 are remarkable.

iv) Bogra fault zone: This is the westernmost area bounded by latitude 20°N and 28°N, and longitude 87°E and 90°E. The area is covered with thick deposits of alluvium. The main boundary fault of Himalayan ranges occurs in the north of this fault zone. A number of morphotectonic lineaments have been identified from the study of satellite imagery. These are mostly oriented NW/ NNW- SE/SSE. One such lineament is Teesta lineament. Gupta and Nandi seismic activity in the Garo-Rajmahal gap is related to the activity along the Jamuna fracture which is the surface manifestation of apparently deep seated sub-vertical fault. Most of the earthquakes along this fault are shallow in depth. But one earthquake had a depth of hypocentre of 100 km. The 1885 earthquake of magnitude 7.0 was originated in this fault.

The magnitudes of earthquake suggested by Bolt (Table 2.4) are the maximum magnitude generated in these blocks as recorded in the historical seismic catalogue. The historical seismic catalogue of the regions covers approximately 250 years of (starting 1762) recent seismicity of the region and such a meagre data base does not provide true picture of seismicity of the tectonic provinces. For example, the Assam and Tripura fault zones contain significant faults capable of producing magnitude 8.6 and 8.0 earthquakes respectively in future. Similarly maximum magnitude of 7.5 in Sub- Dauki fault zone and Bogra fault zones are not unlikely events.

Table 2.4 Significant seismic sources and maximum likely earthquake magnitude in Bangladesh (after Bolt, 1987a)

Location	Maximum likely earthquake magnitude
A. Assam fault zone	8.0
B. Tripura fault zone	7.0
C. Sub-Dauki fault zone	7.3
D. Bogra fault zone	7.0

After a thorough review of available data, Ali and Choudhury (1992) recommended magnitudes of Operational Basis Earthquakes and Maximum Credible Earthquakes (Table 2.5). The depth of focus of earthquakes is also given in this table.

Table 2.5 Operational basis earthquake, maximum credible Earthquake and depth of focus of earthquakes for different seismic sources (after Ali and Chowdhury, 1992)

Location	Operational basis earthquakes (Richter)	Maximum credible earthquakes	Depth of focus (km)
A. Assam fault zone	8.0	8.7	0-70
B. Tripura fault zone	7.0	8.0	0-70
C. Sub-Dauki fault zone	7.3	7.5	0-70
D. Bogra fault zone	7.0	7.5	0-70

2.4.5 Damage due to some large Historical Earthquakes

2.4.5.1 Cachar Earthquake of 1869

The Cachar earthquake of 10th Jan 1869 occurred at 5 hr (GMT) is the first and one of the most destructive seismic events that North-East of Indo-Bangladesh experienced in the last two centuries. According to the seismic history of the region this zone has been the site of high seismic status due to Dauki fault. The main shock was strong enough to cause the collapse of many local traditional dwellings in Shilchar, Monipur and upper Burma region. This shock was followed by a series of aftershocks and the earthquake was associated with significant ground surface rupture. Details of casualties and homeless among the population and cost of damage were not communicated. The earthquake is classified as a heavy destructive event with a focal depth of about 56 km. Compilation and detailed analysis of the macroseismic information inferred from contemporary accounts have led to a re-estimation of intensities. Maximum intensity has been re-evaluated at Io=IX~X (ESC, 1993) and allocated to Monipur and Shilchar. From the intensity data an isoseismal map has been drawn and macroseismic epicentre is located slight east of Silchar at (24.750 N, 93.250 E).

2.4.5.2 Bengal Earthquake of 1885

There were no seismographic records available for the Bengal earthquake of 1885. Only the felt reports and observed damage to buildings, boundary walls, factory chimney, tomb, and cemetry, tower like octagonal mandirs with conical apex, earth fissures and vents were described in the report on the Bengal earthquake by Middlemiss (1885). According to the report, this earthquake was felt with violence throughout the Bengal province. The extent of felt areas extended west-ward into Chota Nagpur and Bihar, northwards into Shikim and Bhutan, and eastward into Assam, Manipur and Burma.

The area over which it was sensibly felt may be roughly 6, 00,000 sq. km.An irregular line through Daltongunge (in Palamow), Durbhanga (in Bihar). Darjeeling, Sibsagar, Manipur and Chittagong were the limit of area from which reports of the shock had been received. Bolt (1987) showed this line as an isoseismal of radius 490 km and recalculated the magnitude of the earthquake (Ms) using Ambrasey's formula. For this earthquake, the magnitude was found to be 7.0.

2.4.5.3 Great Earthquake of 1897

Oldham (1899) as the head of the Geological Survey of India directed and personally investigated the Great Indian earthquake of 1897. The area over which the shock was felt amounted to not less than 31, 20,000 sq. km. This does not include the detached areas near Ahmedabad or any part of the Bay of Bengal, or the large area in Tibet and Western China, over which the shock was certainly sensible. If the area included in these tracts are taken into consideration, the total area over which the shock was felt amounts to 45,50,000 sq. km., while the area over which known serious damage to masonry buildings occurred was not less than 3,77,000 sq. km.

2.4.5.4 Srimangal Earthquake of 1918

Stuart (1920) drew the isoseismal map for this earthquake. He drew the isoseist on the intensity scale originally adopted by Oldham in his investigation of the Great Indian Earthquake of 1897.

The greatest damage occurred in the tea garden areas of the Balisera, Doloi and Luskerpore valleys. The epicentral area of the earthquake was located at the Balisera vally and part of the Doloi vally. With few exceptions, all brick buildings were found to be destroyed within this area. Water and sand spouted up to a to be destroyed within this area. Water and sand spouted up to a height of several feet and numerious vents occurred in the ground in various places. The intensity of the shock was so great that it was impossible to stand on foot.

2.4.5.5 Dhubri Earthquake of 1930

The earthquake originated near the north-western end of the Garo- hills and the adjoining valley of the Brahmaputra River, a short distance to the south of Dhubri town. The disturbed area of the earthquake was about 3, 35,000 sq. km. This earthquake had disastrous results in northern Bengal and in Western Assam, and was felt very distinctly over a wide area, extending from Dibrugarh and Manipur in the east, to Chittagong and Calcutta in the south, to Patna in the west, and beyond the frontiers of Nepal, Sikkim and Bhutan in the north.

2.4.5.6 Bihar-Nepal Earthquake of 1934

The area of greatest devastation was in north Bihar and Nepal, but the damage gradually diminished into adjacent provinces. The shock was felt by persons over a distance of up to 1600 km.From the central tract as far as Peshwar in the north-east, Fort-hertz in the east, Akyab in the south-east, Bezwada and Ongole in the south and Bombay in the south-west. It was felt over an area of approximately 4,920,000 squara kilometers in India and Tibet. The earthquake affected the three main geological units of India: the peninsula, the Gangetic alluvium and the Himalaya.

Over a large area roads were badly damaged, railway tracks were completely destroyed, and telegraph and telephone communications were entirely dislocated. Dunn et al. (1934) were deputed to investigate the destruction and damage pattern of the affected areas and compare the individual investigation. They made a precise isoseismal map of the central region using Mercalli scale. Immediately after the field work was completed, preliminary reports were submitted to the respective Government by different investigators.

2.4.6 Damage Due to Some Recent Earthquakes

2.4.6.1 Sylhet Earthquake of 1997

In 1997 a damaging earthquake of body-wave magnitude 5.6 has occurred in Bangladesh. It has taken place in early morning of May 8. It caused moderate damage mainly to Sylhet area, north-east of capital Dhaka and about 200 km away. The epicentral location (24.894N, 92.250E) is close to Kanaighat, a small town in Sylhet region. Extensive damage to brick masonry structures (e.g. Police station, Jaintia college, etc.) and cracking of a number of buildings (e.g. Sylhet Air Port Building, Grameen Bank Building at Borolekha, police station at Moulvibazar etc.) in the epicentral region have occurred and even in the city Dhaka minor cracks is observed in some structures.

2.4.6.2 Chittagong Earthquake of 1997

In November 21, 1997 another damaging earthquakes of body-wave magnitude 6 have occurred in Bangladesh. During this earthquake, 23 people were killed after collapse of an under-construction building in Chittagong. In Chittagong many low to middle rise buildings have suffered minor cracks although major damage has not been observed. The epicentral area (22.225N, 92.743E) is close to Ruma in Bandarban district of Chittagong Hill Tracts region. Many houses are damaged and old trees are uprooted in the epicentral region. Partial collapse of a long earthen dam (Prantik Lake) has been observed.

2.4.6.3 Moheskhali Earthquake of 1999

On July 22, 1999, at 4:42 pm (local time), an intense earthquake shook the island of Moheskhali causing damage to several houses and some buildings, killing 6 people and injuring 200 people. The main damage has been reported to be in Shaplapur and Huanok Unions.

Field visits have been made to Dineshpur and Kaidabad under Shaplapur Union, where heavy damage has been reported. Cracking and spalling in reinforced concrete columns at the beam-column joint of a cyclone shelter at Dineshpur has been observed. Several rural houses with mud walls and thatched or tin roof construction have been severely damaged. At Kaidabad EU cyclone shelter is also badly damaged.

Bara Maheshkhali and Huanok Union are also visited. Severe cracking have formed in many mudwall houses of the area. The cracking pattern has similarity with that observed in Shaplapur. Some landslides are also observed which could have been triggered by the earthquake. The few buildings in Bara Moheshkhali were not damaged. However minor plaster cracking has occurred in some cases.

The hypocentre of the earthquake has been initially estimated to be at 21.47°N, 91.90°E (focal depth = 10 km, origin time 16:42:12). The focal depth of this earthquake was quite shallow. The location of the hypocenter has later been corrected to be at 21.54°N, 91.88°E. The magnitude of the main shock was 5.1 on bodywave magnitude scale. Three more aftershocks of smaller intensity have occurred in the same island on the following night.

2.4.6.3 Rangamati Earthquake of 2003

A moderate earthquake occurred in the Chittagong Hill Tracts near the Bangladesh-India border on 26 July 2003 at 05:18 AM local time causing some damage to property and 3 people were killed and 25 injured by this earthquake. The earthquake had a magnitude of Mw=5.7 and was felt at many places in south-eastern Bangladesh.

2.4.7 Seismic Zoning Maps

The first seismic zoning map of the subcontinent (Figure 2.8) has been compiled by the Geological Survey of India in 1935 (Choudhury, 1994). Three zones have been indicated in the maps, viz. liable to severe damage, liable to moderate damage and liable to slight damage. Areas which suffered moderate to severe damage in the past earthquakes with intensity approximately higher than Rossi-Forel VII (equivalent to Modified-Mercalli scale of VIII) within the first zone are also shown. This qualitative map has been based mainly on records of earthquake occurrence in the past. A major part of Bangladesh (in the north, northeast, and southeast) is shown under the "liable to severe damage".

In the sixties, the Meteorological Department has prepared a zoning map (Figure.2.9), which has been later adopted by the Bangladesh Meteorological Department (Choudhury, 1994). The country has been divided into four zones, viz. major damage (seismic factor g/5 to g/10), moderate damage (g/10 to g/15), minor damage (g/15 to g/20) and negligible damage (g/20≥). In the mid-seventies, when a number of large industrial complexes have been designed, the need for a more detailed investigation of seismic risk has been felt.

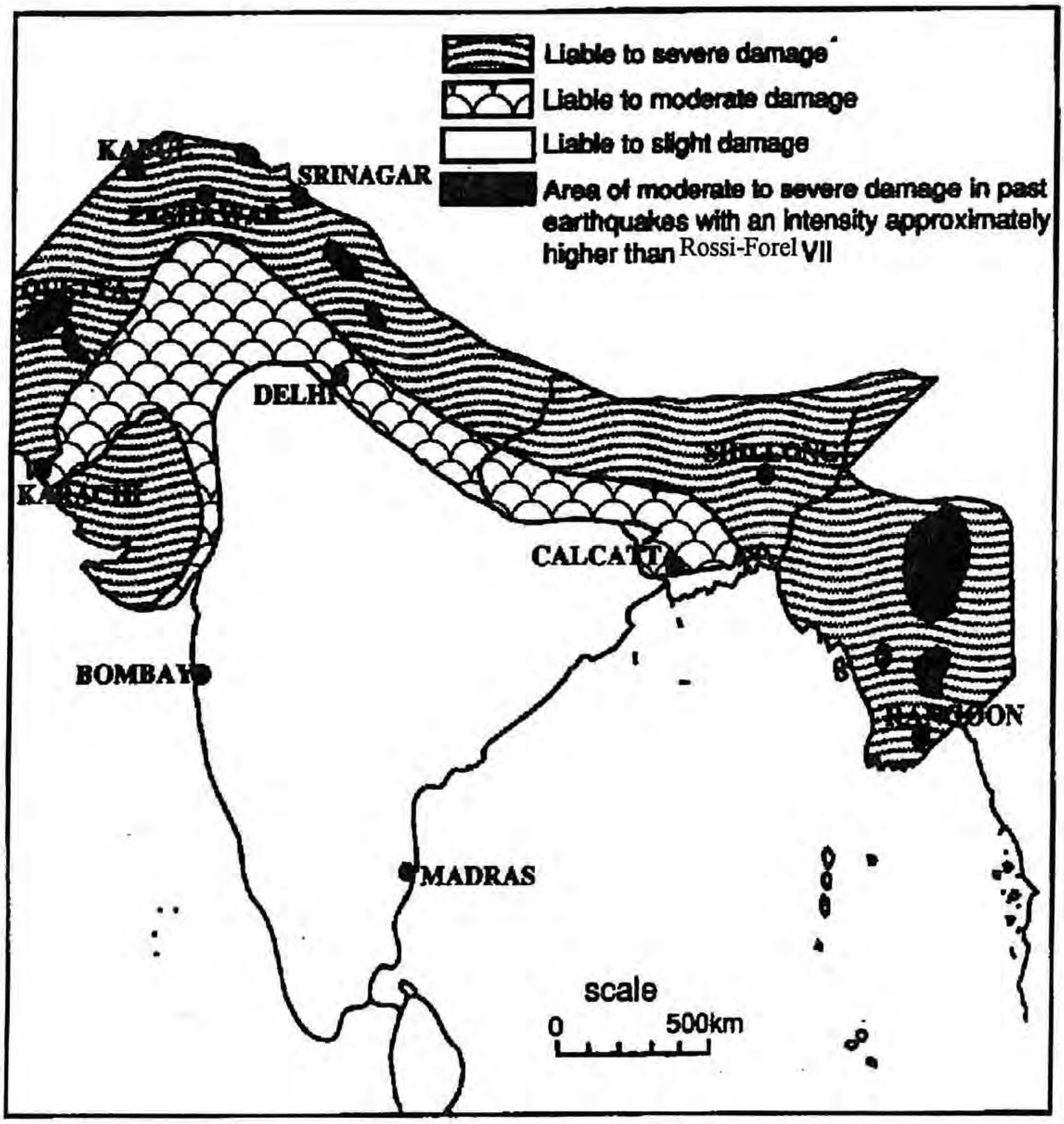


Figure 2.8 Seismic Zones of Indian Subcontinent Compiled by the Geological Survey of India in 1935 (after Choudhury, 1994)

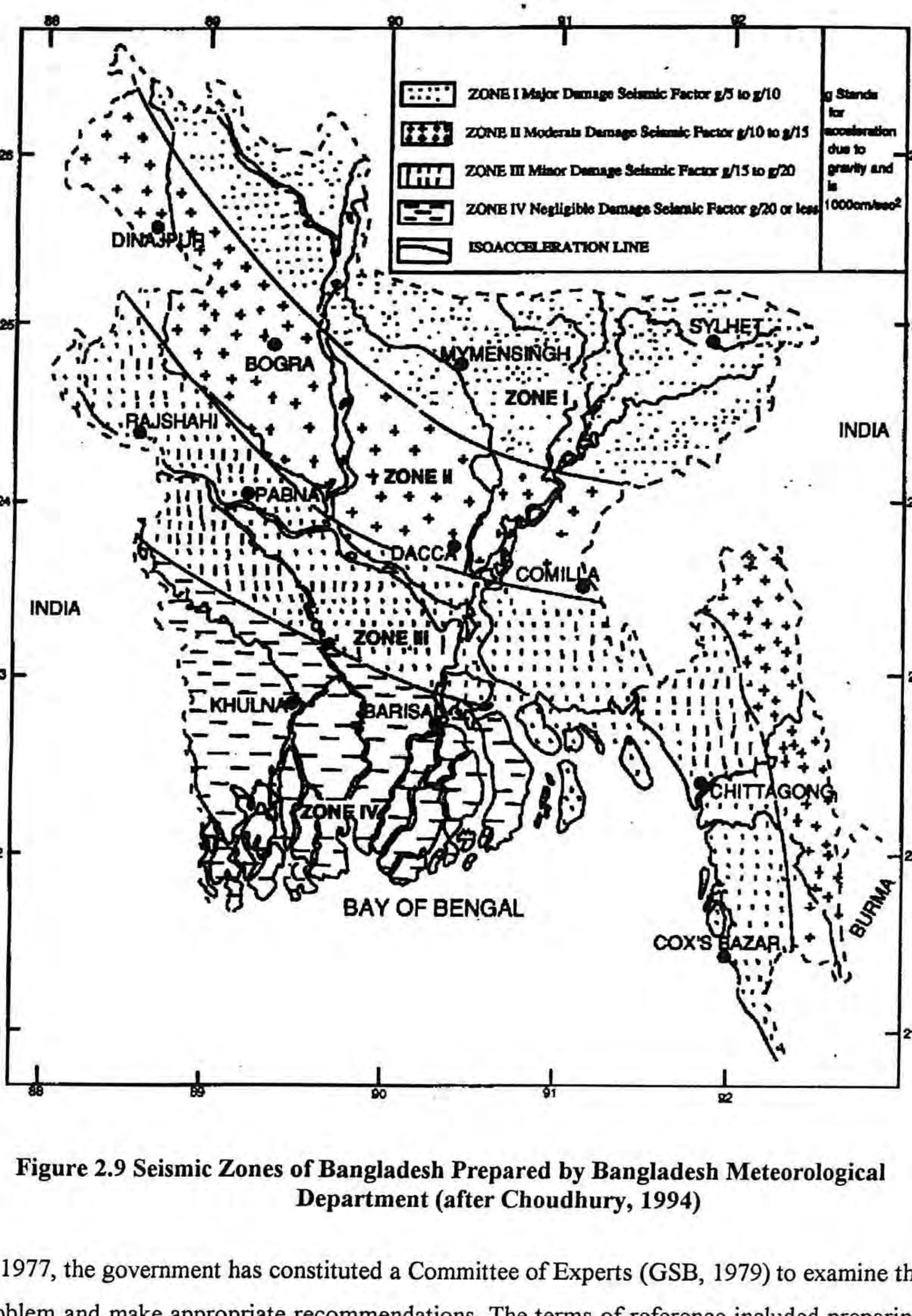


Figure 2.9 Seismic Zones of Bangladesh Prepared by Bangladesh Meteorological Department (after Choudhury, 1994)

In 1977, the government has constituted a Committee of Experts (GSB, 1979) to examine the problem and make appropriate recommendations. The terms of reference included preparing seismic zoning maps, preparing an outline of a building code for earthquake resistant design of structures, proposing means of educating the masses about the hazard and precautionary measures to minimize damage, and recommending facilities for observation, analysis and interpretation of relevant data. The committee, after reviewing all the available information has prepared a seismic zoning map (Figure2.10).

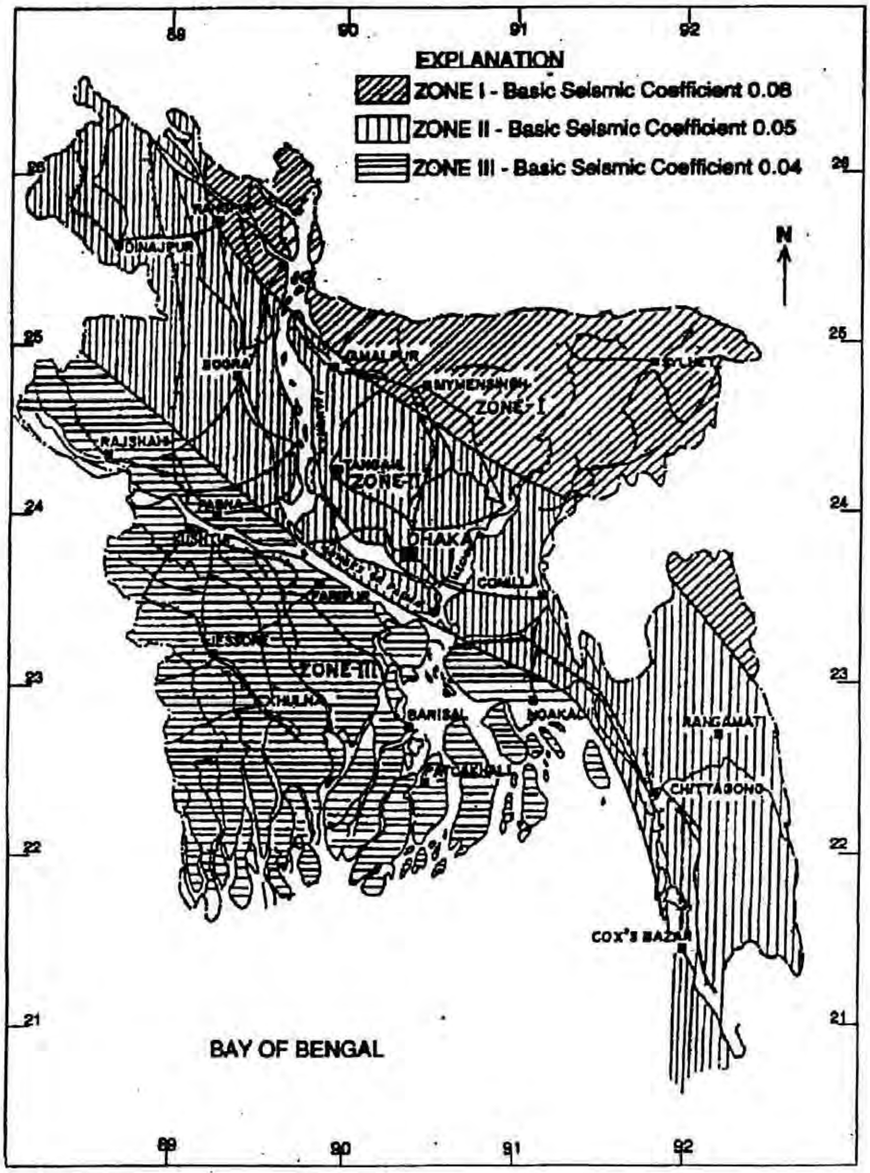


Figure 2.10 Seismic Zoning Map of Bangladesh (after GSB, 1979)

In the Bangladesh National Building Code (BNBC) published in 1993, a new seismic zoning map for Bangladesh has been presented. The pattern of ground surface acceleration contours having 200 year return period (Hattori, 1979) forms the basis of this seismic zoning map. The proposed BNBC zoning map is shown in Figure. 2.11.

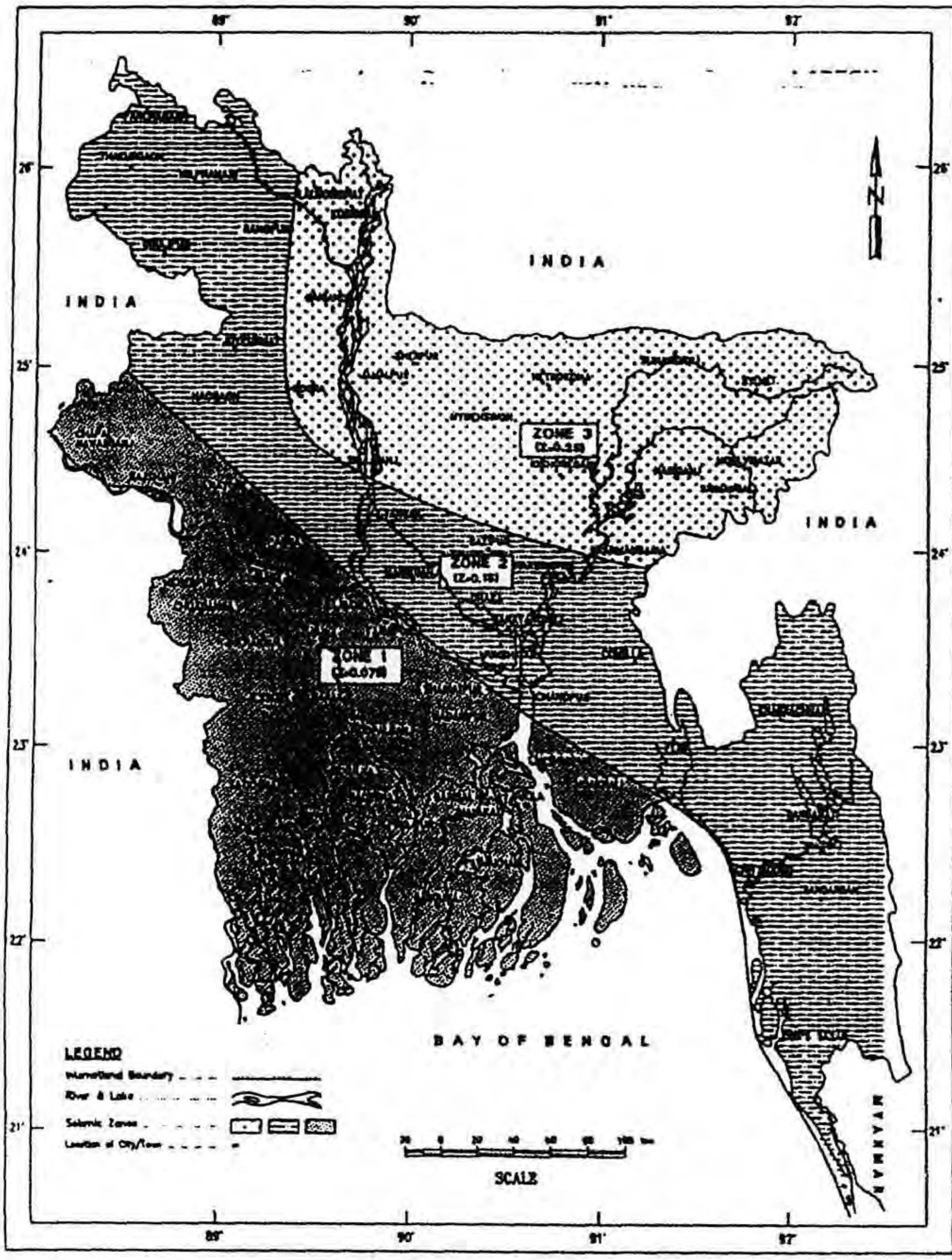


Figure 2.11 Seismic Zoning Map of Bangladesh (after BNBC, 1993)

2.4.8 Seismicity of Bangladesh

Four great earthquakes of magnitude exceeding 8 during 1897, 1905, 1934, 1950 and another 10 earthquakes exceeding magnitude 7.5 have occurred in the Himalayan belt during the last 100 years. The earthquake history of Bangladesh and surrounding region indicates that the country is seismically active.

2.4.9 Earthquake Intensity Scales

There are different Earthquake Intensity Scales like The Mercalli Scale, Japanese Seismic Intensity Scale, MSK intensity scale, The European Macroseismic (EMS, 1998) intensity scale. Those are described in the Appendix 1, 2, 3 and 4.

2.5 LANDSLIDES

2.5.1 Definition

A landslide is a disaster which occur involving actual elements of the ground, including rocks, trees, and parts of houses, and anything else which may happen to be swept up. Landslides can be caused by earthquakes, volcanic eruptions, or general instability in the surrounding land. Mudslides, or mud flows, are a special case of landslides, in which heavy rainfall causes loose soil on steep terrain to collapse and slide downwards.

2.5.2 Historical Landslide of Bangladesh

- The 2007 Chittagong Mudslide occurred in the port city of Chittagong in south-eastern Bangladesh. On 11 June 2007, heavy monsoon rainfall caused landslides that engulfed slums around the hilly areas of the city. Experts had previously warned the increasing likelihood of landslides due to the Bangladesh government's failure in curbing the illegal hill cutting taking place in Chittagong.

One third of Chittagong, a city of five million residents, came under water due to heavy rainfall and tidal water.The flash floods in the hills caused mud slides and rubble to bury shanties at the foot of the hills near Chittagong Cantonment. Many residents took refuge in local mosques after losing their homes in the disaster. The death toll was reported 128, including at least 59 children, with more than 150 injured. The government asked the local authorities to evacuate 8,000 people from Lebubagan, the worst hit area. The country-wide death toll for floods and landslides were nearly 130 on June 12, 2007 according to Reuters. Most of the deaths were as a result of the landslides or building collapsing due to the rain.

Total rainfall over Bangladesh from June 4 through June 11, 2007, based on measurements from the Tropical Rainfall Measuring Mission Satellite is shown in Figure 2.12. The heaviest rainfall, of up to 500 mm (20 inches), is shown in red. Orange, yellow, green and blue indicate rainfall up to 400, 300, 200 and 100 mm respectively. Figure 2.12 also shows the Bangladeshi rescue workers recover bodies after a landslide in Chittagong. Hundreds of police, soldiers and emergency workers were digging through piles of mud in southeastern Bangladesh on Tuesday as the toll from landslides rose close to 100 (AFP).

Figure 2.12 Tropical Rainfall Measuring Mission satellite and Bangladeshi rescue workers recover bodies after a landslide in Chittagong.

- 1968 At Kaptai-Chandraghona road where the protective vegetation is removed, the soil gets exposed to the monsoon rains and eroded rapidly. This resulted in landslides, and the loose soil washed down the slopes and carried by rivers into the kaptai lake. As a result, the reservoir silted up and the authorities confirmed that in its 30 years existence it had lost about 25% of its volume due to siltation.
- 1970 Similar event along Ghagra-Rangamati road.
- 1990 Occurred on May 30, 1990. Affected the link road embankment at Jhagar beel area of Rangamati district.
- 1997 A major landslide occurred in July 1997 at Charaipada of Bandarban. The total area affected by it was about 90,000-sq m. If such a landslide occurred in Bandarban Town and any other urban or semi-urban centre, the devastation would be tremendous.
- 1999 Two big landslides one in Bandarban and the other one in Chittagong occurred

on 11 and 13 August 1999 respectively claiming the life of 17 people. Out of 17 fatalities, 10 were in Chittagong and the rest in Bandarban district. Heavy and incessant rainfall at that time was one of the causes of sliding. This landslide affected Lama thana and the Aziz Nagar union of Bandarban district. Aziz Nagar is almost an inaccessible rugged hilly terrain. Landslide badly affected the villages of Chittaputti, Monargiri, Meounda, Muslimpara, Sonaisari, Bazapara, Kalargiri, Maishkata, Aungratali, Chionipara, and Kariungpara. The 11 August landslide was followed again on 15 August at Chittaputti area. At least 50 houses were completely vanished under the solid earth and 300 houses were partly damaged. About 283.50 ha of cultivated land, 810 ha of household garden, and 50 km unmetalled road were crushed. Road communication between Bandarban headquarters and remote thanas became snapped. Especially, Aziznagar-Bazalia road had been closed for traffic due to falling of huge mass of earth over the road at 25 places. Chittagong landslide location was at Gopaipur under Chittagong Kotwali Thana. The slides crushed two thatched houses at the foot of the hill claimed the lives of the inmates of the houses who were asleep.

- 2000 At least 13 people were killed and 20 injured in landslide incidents on the Chittagong University campus and other parts of Chittagong City on Saturday, the 24 June 2000. The incident was caused due to the deluge of mud and water that swamped various part of the port city amid torrential rain. The landslides damaged property worth several lacs of taka in those places.

2.6 RIVER BANK EROSIONS

2.6.1 Definition

Riverbank Erosion is an endemic and recurrent natural hazard in Bangladesh. When rivers enter the mature stage (as in the case with the three mighty rivers, Ganges, Brahmaputra and meghna) they become sluggish and meander or braid. These oscillations cause massive riverbank erosion. Figure 2.13 shows the river bank erosion of Bangladesh. River erosion occurs generally during and after floods. Bare soil (without root fibre) in the river banks is mainly responsible for river erosion. Proper river training and bank protection by planting fibrous plants can stop river erosion.

Figure 2.13 Riverbank Erosion of Bangladesh

2.6.2 History of Riverbank Erosion of Bangladesh

Riverbank erosion is a big problem on the banks of the Meghna and Jamuna. Many villages are engulfed by rivers and resulting that they become landless.

Every year, millions of people are affected by erosion that destroys standing crops, farmland and homestead land. It is estimated that about 5% of the total floodplain of Bangladesh is directly affected by erosion. Some researchers have reported that bank erosion is taking place in about 94 out of 489 upazilas of the country. A few other researchers have identified 56 upazilas with incidence of erosion. At present, bank erosion and flood hazards in nearly 100 upazilas have become almost a regular feature. Of these, 35 are severely affected. For example, a newspaper report stated that over 25,000 families were rendered homeless in June 1993 by riverbank erosion in 16 districts Table 2.6 shows some data about people made homeless by river erosion. Table 2.7 gives the Bank erosion/accretion along the Jamuna, Ganges, Padma, Upper Meghna and Lower Meghna rivers for the period of 1984-93. Table 2.8 is the change of width of the rivers of 1992.

Table 2.6 People Made Homeless by River Erosion (Source: HUGHES et al., 1994)

SL. No.	Date	No. Of People Made Homeless	Location
1	November 1991	4000	Along the Jamuna and Padma
2	January 1992	10,000	Along the Jamuna
3	1991-1992	40,000	In the Kurigram District(northern Bangladesh)
4	June-August 1992	30,000	Along the Padma near Dhaka

Table 2.7 Bank erosion/accretion along the different rivers for the period 1984-93 (Source ISPAN, 1995)

		Jamuna	Ganges	Padma	Upper Meghna	Lower Meghna
Bank erosion rate (m/yr)	Left	100	-20	38	7	66
	Right	84	56	121	-9	182
Maximum bank erosion rate (m/yr)		784	665	620	NA	824
Bank erosion (ha/yr)		5,020	2,240	1,800	48	1,172
Bank accretion (ha/yr)		890	1,010	233	49	402

Table 2.8 Change of width of the rivers (Source ISPAN, 1995)

		Jamuna	Ganges	Padma	Upper Meghna	Lower Meghna
Average width (m)	1984	9,720	4,367	5,689	3,406	6,661
	1993	11,220	4,693	7,116	3,391	8,897
Rate of change of width (m/yr)		184	36	159	2	248

In recent years, human interventions in the Jamuna are growing. Construction of the Bangabandhu Jamuna Bridge and bank protection structures at Sirajganj, Sariakandi and Bahadurabad will doubtless have some influence on the changes of the width of the river. These types of structures are reducing the freedom of the river to widen through bank erosion.

2.6.3 Riverbank Erosion Map of Bangladesh

River erosion occurs generally during and after floods. So in flooding area erosion area is situated. The Riverbank Erosion map of DMB is identified the riverbank erosion area of Bangladesh along the different rivers is shown in Figure 2.14.

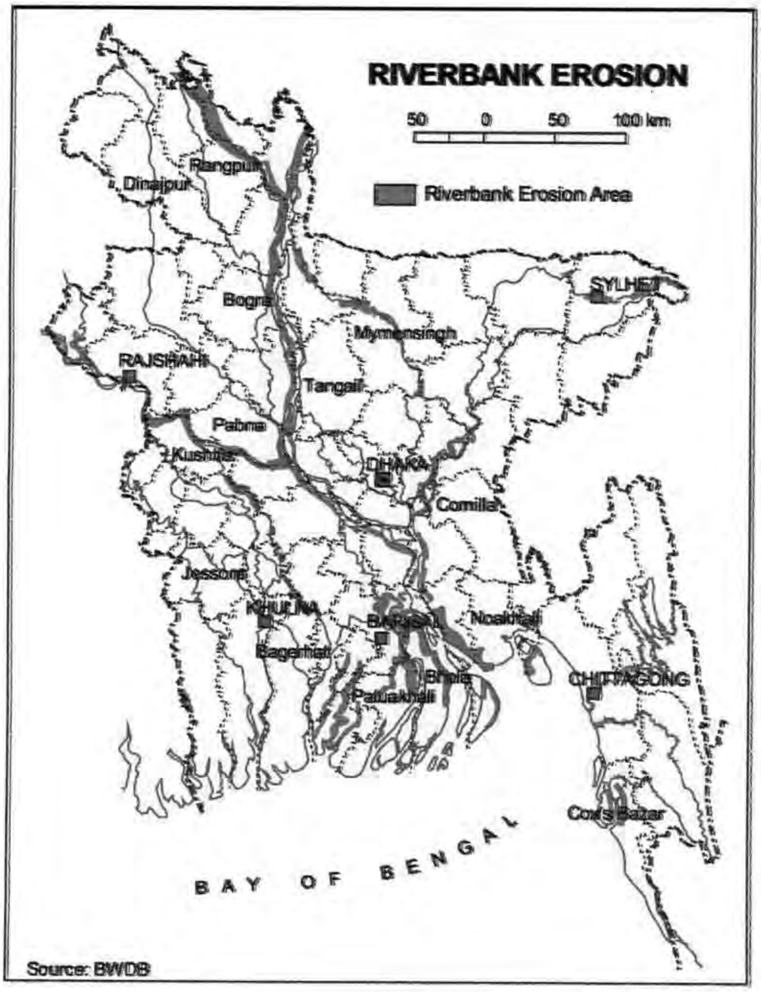


Figure 2.14 Riverbank Erosion Map of Bangladesh (DMB, 1993)

2.7 DROUGHT

2.7.1 Definition

Drought is a prolonged, continuous period of dry weather along with abnormal insufficient rainfall. It occurs when evaporation and transpiration exceed the amount of precipitation for a reasonable period. Drought causes the earth to parch and a considerable hydrologic (water) imbalance resulting water shortages, wells to dry, depletion of groundwater and soil moisture, stream flow reduction, crops to wither leading to crop failure and scarcity in fodder for livestock. Drought is a major natural hazard faced by communities directly dependent on rainfall for drinking water, crop production, and rearing of animals. Since ancient times droughts have far-reaching effects on mankind. Large land areas often suffer damages from dust storms and fire. Drought could be the reason for migration of early human communities. It has long been considered to be a natural hazard responsible for ups and downs of many civilisations of the world. If there is deficiency of rainfall over a period of long time, moisture supply from soil and environment fails to meet the optimum water need of plants. If this situation continues for fairly long time, plant leaves wilt and may reduce agricultural production significantly. This phenomenon is known as drought. Droughts in Bangladesh are transient in nature. Permanent drought is seen in desert areas where agriculture is only possible through irrigation throughout the year. Seasonal drought occurs in the semi-arid regions. Agriculture is possible by irrigation during that dry period. It is very temporary. But invisible drought is very dangerous. Farmers can hardly notice the weakening of plants. But crop production becomes less than expectation. Bangladesh experienced severe droughts in 1979, 1992 and 1994. Impact of 1979 drought was very severe. Government, agriculturists and planners were very much embarrassed. With proper water management agricultural drought can be combated.

2.7.2 Chronology of droughts of historical significance

- **1791** Drought affected Jessore district. Prices had risen to twice and three times of their usual levels.
- **1865** Drought proceeding famine occurred in Dhaka.
- **1866** Severe drought in Bogra. The rice production of the district was hit hard and the price went up three times its normal level.
- **1872** Drought in sundarbans. The rainfall was deficient and in several lots the crops suffered to a great extent.
- **1874** Bogra was affected and the crop failure was much greater. The rainfall was extremely low.
- **1951** Severe drought in northwest Bangladesh and substantially reduced rice production.
- **1973** One of the severest in the present century and was responsible for the 1974 famine in northern Bangladesh.
- **1975** This drought affected 47% of the entire country and caused sufferings to about 53% of the total population.
- **1978-79** Severe drought causing widespread damage to crops. Reduced rice production by about 2 million tons and directly affected about 42% of the cultivated land and 44% of the population. It was one of the severest in recent times.

- **1981** Severe drought adversely affected crop production.
- **1982** Caused a total loss of rice production amounting to about 53,000 tons. In the same year flood damaged about 36,000 tons of rice.
- **1989** Most of the rivers in NW Bangladesh dried up and several districts, such as Naogaon, Nawabganj, Nilpahamari and Thakurgaon; dust syndrome occurred for a prolonged period due to drying up the topsoil.
- **1994-95** This drought was followed by that of 1995-96, caused immense damage to crops, especially in the case of rice and jute the main crops of NW Bangladesh. These are followed by bamboo-clumps, a major cash earning crop of many farmers in the region. In the recent times, this was most persistent drought in Bangladesh.

2.7.3 Drought Prone Area of Bangladesh

BARC has reviewed this concept and produced three different maps for Rabi, Pre-Kharif and Kharif seasons (After NAP 2005). The drought severity classes defined in the maps are slight, moderate, severe and very severe related to the yield losses of 15-20%, 20-35%, 35-45%, and 45-70% respectively for different crops (Karim and Iqbal, 2001). Areas (in M ha) affected by drought in different crop seasons are given in Table 2.9.

Table 2.9 Summaries of Drought Severity Areas in Bangladesh by Crop Season, In M ha. (After NAP, 2005)

Drought Class	Rabi	Pre-Kharif	Kharif
Very Severe	0.446	0.403	0.344
Severe	1.71	1.15	0.74
Moderate	2.95	4.76	3.17
Slight	4.21	4.09	2.90
No Drought	3.17	2.09	0.68
Non-T.Aman	4.71		

The northwestern part is prone to drought mainly because of rainfall variability in the premonsoon and the post-monsoon periods. Inadequate pre-monsoon showers, a delay in the onset of the rainy season or an early departure of the monsoon may create drought conditions in Bangladesh, and adversely affect crop output. Since it puts severe strain on the land potential, it acts as a catalyst of land degradation through reduced soil moisture and water retention, increased soil erosion, decline in soil organic contents and overexploitation of sparse vegetation. Human interventions in the form of land abuse and mismanagement have exacerbated these actions during the spells of periodic droughts. An analysis of the relative effects of flood and drought on rice production between 1969-70 and 1983-84 shows that drought is more devastating than floods to aggregate production (World Bank, 2000).

Figure 2.15 shows the area of dry regions of Bangladesh. Figure 2.16 shows the Kharif Drought Prone Area and 2.17 shows the Rabi and Pre Kharif Drought Prone Area of Bangladesh.

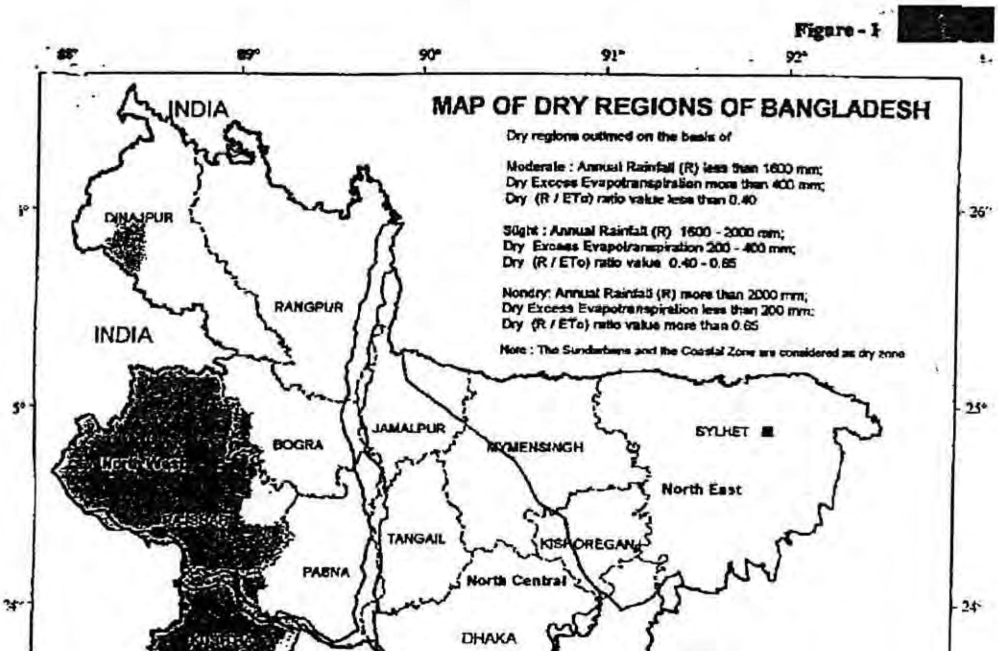


Figure 2.15 Map of Dry Region of Bangladesh (MEF, 2001)

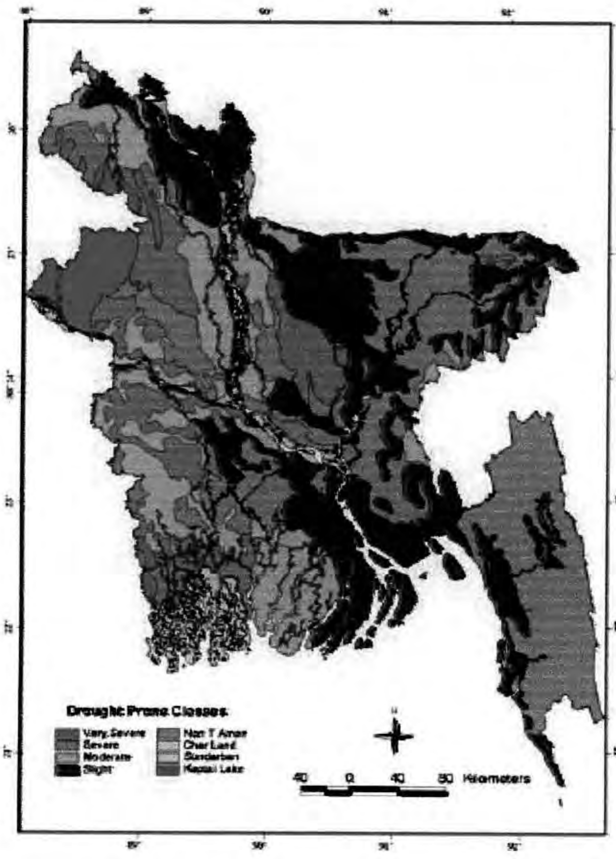


Figure 2.15 Drought prone (Kharif) areas of Bangladesh (NPDM, 2006)

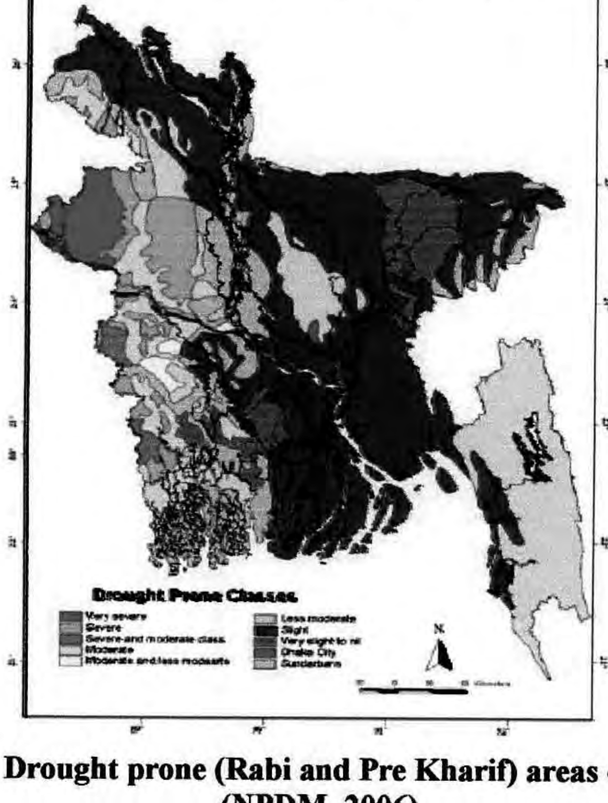


Figure 2.16 Drought prone (Rabi and Pre Kharif) areas of Bangladesh (NPDM, 2006)

2.8 HEAT WAVES

2.8.1 Definition

A heat wave is a prolonged period of excessively hot weather, which may be accompanied by high humidity. A heat wave is a day (or days) of very hot weather, most likely over 110^0F. There is no universal definition of a heat wave; the term is relative to the usual weather in the area. Temperatures that people from a hotter climate consider normal can be termed as heat wave in a cooler area if they are outside the normal climate pattern for that area. The term is applied both to routine weather variations and to extraordinary spells of heat which may occur only once a century. Severe heat waves have caused catastrophic crop failures, thousands of deaths from hyperthermia, and widespread power outages due to increased use of air conditioning. Figure 2.18 shows the heat wave condition.

2.8.2 Heat Waves in Bangladesh

Heat waves occur in Bangladesh during April and May. If there is no rain or if no cloud forms for long time during this time, the sandy regions (Rajshahi division and northern Khulna division) become heated. If it continues for long time over a large area, heat wave condition occurs. Generally it originates from Bihar which has extreme climates (very hot in summer). Heat low is found to develop over Bihar and West Bengal. Adiabatic warming takes place due to descending motion of air parcel.

The followings are criteria of heat wave:

Heat Wave	Maximum Temperature Range
Mild heat wave	36 – 38° C
Moderate heat wave	38 – 40° C
Severe heat wave	40 – 42° C
Extreme heat wave	over 42° C

Highest maximum temperature of 45.1° C was recorded at Rajshahi on 18 May 1972.

Elderly and sick people suffer most in heat wave. Some of them may die by sun stroke or heat stroke. (BMD, 2006)

2.8.3 Recent Heat Waves in Bangladesh

- At the end of May 2007, a heat wave left at least 26 people dead. According to hospital sources most victims of the heat were rice farmers working in terraces exposed to the blazing sun for long periods. Nearly 200 people, including several children, were admitted to hospitals with symptoms of stroke. According to the meteorological office in Dhaka many northern towns showed day temperatures reaching over +40 °C (104 °F), which is not normal in the Bangladeshi summer. Additionally, there was a high level of humidity.
- June 2003, easing a heat wave that has killed 42 people. The downpour came as a monsoon started hitting the Bangladesh coast, the Meteorological Department said, adding that the rain was expected to bring down temperatures that had climbed as high as 40^0C (104^0F).
- June 2005, News agencies have reported that thirty people have died in Bangladesh because of tremendous heat waves. Daily life in Bangladesh has been badly affected by an unusually hot weather. Some diseases have also spread. Today the highest temperature in Bangladesh was 43 ^{0}C.
- May 2004, Heat wave death toll rises to 21 in Bangladesh temperatures soared to 41^0C (105 ^{0}F).

2.9 COLD WAVES

2.9.1 Definition

A cold wave is a weather phenomenon that is distinguished by marked cooling of the air, or the invasion of very cold air, over a large area. It can also be a prolonged period of excessively cold weather, which may be accompanied by high winds that cause excessive wind chills, leading to weather that seems even colder than it is.

2.9.2 Cold Wave in Bangladesh

Cold waves occur in Bangladesh during winter (January and February). If there is extreme dryness for long time during this time, maximum and minimum temperature both comes down and closer, the sandy regions (particularly, northern parts of Bangladesh) become cold

losing energy by evaporation. If it continues for long time over a large area, cold wave condition occurs. Generally it originates from Bihar which has extreme climates (very cold in winter). Sub-continental high (anti-cyclone) takes position over northern Madhya Pradesh, Bihar and adjoining West Bengal extending ridge to northwestern part of Bangladesh. Adiabatic cooling takes place due to descending motion of cold heavier air parcel.
The followings are criteria of cold wave:

Cold Wave	Minimum Temperature Range
Mild cold wave	08 – 10° C
Moderate cold wave	06 – 08° C
Severe cold wave	04 – 06° C
Extreme cold wave	below 04° C

The lowest minimum temperature of 2.8° C was recorded at Srimangal on 04 February 1968. Elderly and sick people suffer most in cold wave. Poor people are the worst victim of cold wave. Some people die every year in the northern part of Bangladesh in winter cold wave. (BMD, 2006)

2.9.3 Recent Cold Waves in Bangladesh

- January 2006, United Nations agencies, local and international non-governmental organizations (NGOs) are supporting the Government of Bangladesh in responding to a recent cold wave that has hit the country, killing more than 130 people and affecting at least 100,000 since early January.During the current cold wave, temperatures of 5 degrees Celsius have been recorded in three northern districts, reportedly the lowest temperatures in 38 years. A number of districts have been affected, including Panchagarh, Thakurgaon, Dinajpur, Nilphamari, Lamonirhat, Gaibandha, Kurigram, Rangpur, Joypurhat, Bogra, Chapainowabganj, Serajganj, Rajshahi, Pabna, Mymensingh, Jamalpur, Kishorganj, Sherpur, Gazipur, Shariatpur, Rajbari, Gopalganj, Jhalokathi, Khulna, Brahmanbaria, Sylhet, Moulavibazar and Sunamganj.

- From 15 December 2002 to early February 2003, a severe cold spell swept Bangladesh, a country with a tropical monsoon climate where winters are generally mild and short. Single figure temperatures were recorded throughout the country. The Meteorological

Department reported that the temperatures dropped to $4^{0}C$ in some areas, and to 8-11 ^{0}C in others. According to the same source this was one of the coldest waves since 1968.

2.10 ARSENIC CONTAMINATION OF GROUNDWATER

2.10.1 Definition

Arsenic contamination of groundwater is a natural occurring high concentration of arsenic in deeper levels of groundwater, which became a high-profile problem in recent years due to the use of deep tubewells for water supply in the Ganges Delta, causing serious arsenic poisoning to large numbers of people. A study in the year of 2007 found that over 137 million people in more than 70 countries are probably affected by arsenic poisoning of drinking water. Arsenic is a carcinogen which causes many cancers including skin, lung, and bladder as well as cardiovascular disease.

2.10.2 Arsenic contamination of groundwater in Bangladesh

The story of the arsenic contamination of the groundwater in Bangladesh is a tragic one. Diarrheal diseases have long plagued the developing world as a major cause of death, especially in children. Prior to the 1970s, Bangladesh had one of the highest infant mortality rates in the world. Ineffective water purification and sewage systems as well as periodic monsoons and flooding exacerbated these problems. As a solution, UNICEF and the World Bank advocated the use of wells to tap into deeper groundwater for a quick and inexpensive solution. Millions of wells were constructed as a result. Because of this action, infant mortality and diarrheal illness were reduced by fifty percent. However, with over 8 million wells constructed, it has been found over the last two decades that approximately one in five of these wells are now contaminated with arsenic above the government's drinking water standard (NPDM, 2006). Figure 2.18 shows the arsenic contamination status in Bangladesh.

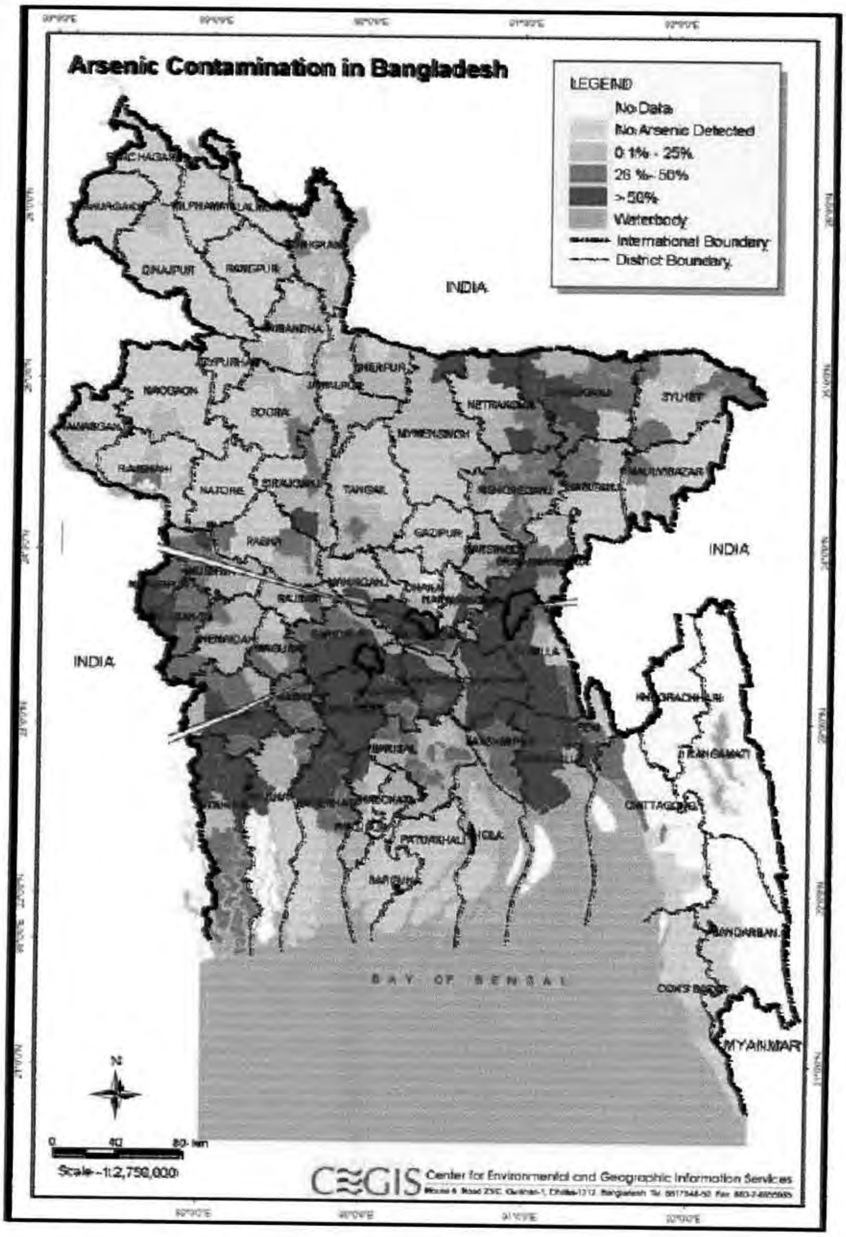


Figure 2.18 Arsenic contamination statuses in Bangladesh (NPDM, 2006)

2.11 FLOOD

2.11.1 Definition

Flood is relatively high flow of water that overtops the natural or artificial banks in any of the reaches of a stream. When banks are overtopped, water spreads over the floodplain and generally causes problems for inhabitants, crops and vegetation. Since floodplain is a desirable location for man and his activities, it is important to control floods so that the damage does not exceed an acceptable level. Figure 2.19 shows the typical flood damage of Bangladesh.

Figure 2.19 Typical Flood Damages

2.11.2 Flood in Bangladesh

Floods are more or less a recurring phenomenon in Bangladesh and often have been within tolerable limits. But occasionally they become devastating. Each year in Bangladesh about 26,000 sq km, 18% of the country is flooded. During severe floods, the affected area may exceed 55% of the total area of the country. In an average year, 844,000 million cubic metre of water flows into the country during the humid period (May to October) through the three main rivers the Ganges, the Brahmaputra-Jamuna and the meghna. This volume is 95% of the total annual inflow. By comparison only about 187,000 million cu m of streamflow is generated by rainfall inside the country during the same period. In Bangladesh, the definition of flood appears differently. During the rainy season when the water flow exceeds the holding capacity of rivers, canals (khals), beels, haors, low-lying areas it inundates the whole area causing damage to crops, homesteads, roads and other properties. In the Bangladesh context there is a relation between inundation and cropping.

2.11.3 Types of Flood

Bangladesh generally experiences five types of flood and those are as follows:

i) Flash Flood
ii) Rainfed Flood
iii) River Flood
iv) Storm Surge and Tidal Flood
v) Urban floods

Area affected by these four types of flood in Bangladesh is shown in Figure. 2.20.

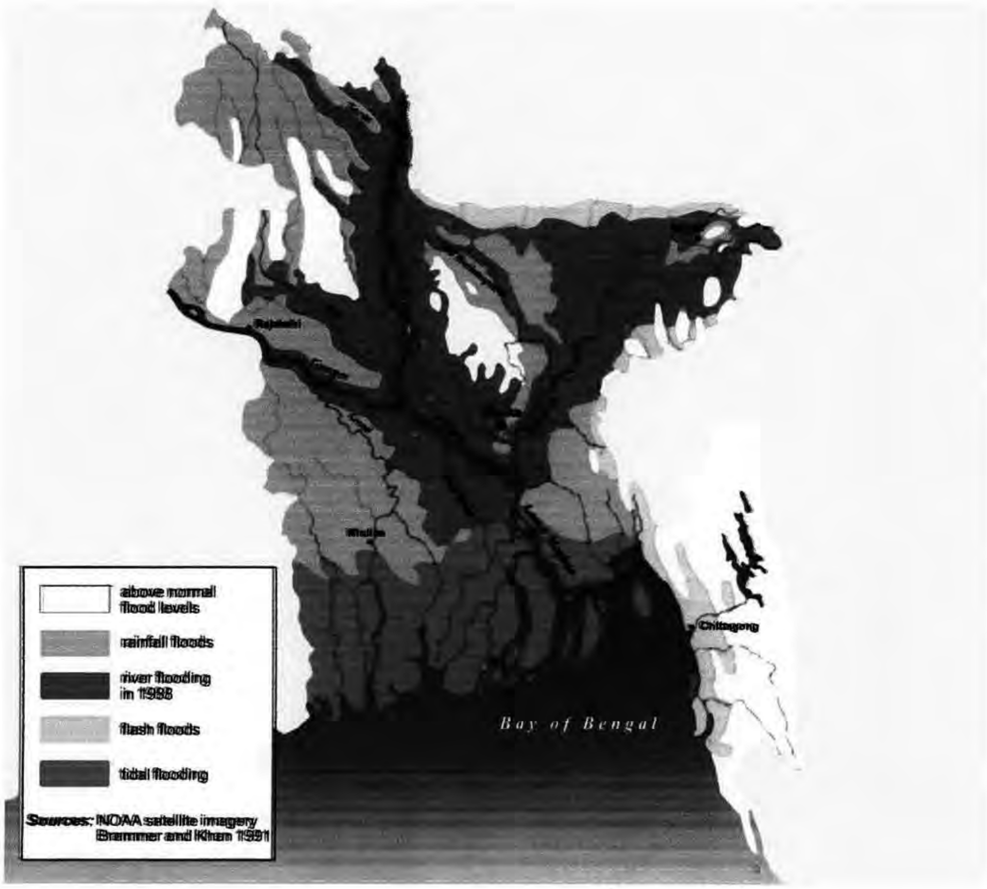


Figure 2.20 Different Types flood Area in Bangladesh (after Hossain, 2004)

2.11.3.1 Flash Flood

This type of flood is characterized by rapid rise and fall in water levels. Flash flood can occur within a time-period between few minutes to few hours. This type of flood occurs mostly in some northern most area, north-central part, northeastern part and southeastern part of the country. In the northern most, north-central and northeastern parts land areas of the country are at the foothills where the hilly catchments lie in India. If it rains heavily in the Indian parts of the catchments the run-off quickly accumulates and flow to Bangladesh. It is very difficult to provide forecast on flash flood but early warning with a short lead time may be provided Flash flood starts on the northeast and north central from mid-April i.e. before the on-set of the southwesterly monsoon. In the northern and southeastern areas it starts with the on-set of the southwesterly monsoon.

2.11.3.2 Rain-fed Flood

This kind of flood generally occurs in many parts of the country but one prevalent in the moribund Gangetic deltas in the south-western part of the country where most of natural drainage systems are being deteriorated due to fall in up-land inflow in the main river Ganges. This kind of flood also occurs in the flood plains where natural drainage systems have been disturbed either due to human interferences e.g. construction of unplanned rural roads and illegal occupation of river courses etc. or due to gradual decay of the natural drainage system. When intense rainfall takes place in those areas, natural drainage system cannot carry the run-off generated by the storm and causes temporary inundation in many localities.

2.11.3.3 River Flood

The word flood is generally synonymous with the river flood. River flood is a most common phenomenon in the country from time immemorial. Normally, 20-25% of the area is inundated during monsoon season along the river. In case of extreme flood events 35-70% of the country is inundated extending the areas far beyond the riverbanks. Four worst floods experienced by the country in last 16 years, in 1987, 1988, 1998 and last one of 2004. Flood of 1998 was the severest one in terms of magnitude and duration (Hossain, 2004). The area affected by flood in 1998 is shown in figure 2.21 which is the example of river flood.

It was observed that extreme flood events occurred due to excessive rainfall in the catchments. When water levels in the three major rivers rise simultaneously and cross the danger marks, then extreme flood events usually occur all over the country. This was observed during the three flood events occurred in 1987, 1988, 1998 and 2004. Water levels crossing the danger marks start occurring from mid-July and continue till mid-September. Duration of the extreme flood events usually extends from 15 days to 45 days, the longest one occurred during 1998.

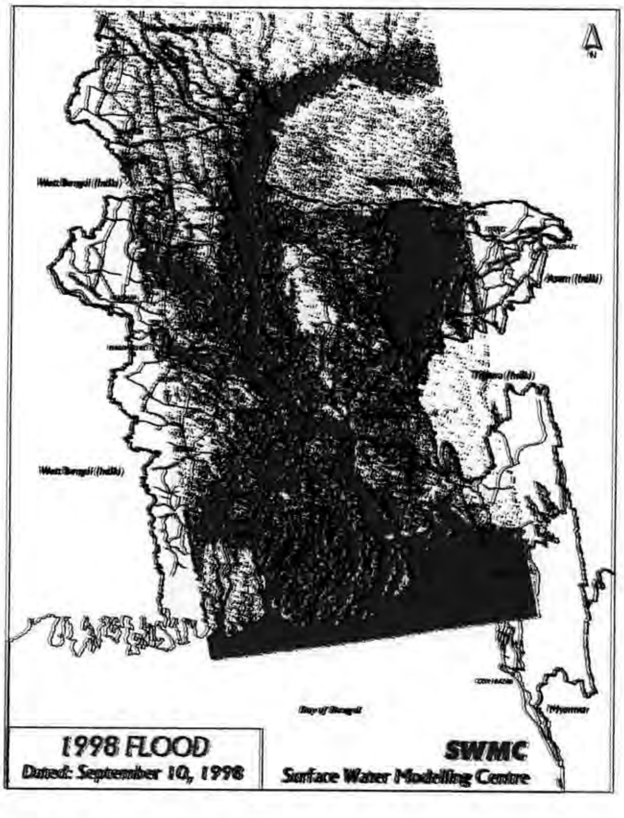


Figure 2.21 Area affected by River Flood in 1998 (after Hossain, 2004)

2.11.3.4 Flood due to Storm Surges

This kind of flood mostly occurs along the coastal areas of Bangladesh over a coastline of about 800 km along the southern part. Continental shelves in this part of the Bay of Bengal are shallow and extended to about 20-50 km. Moreover, the coastline in the eastern portion is conical and funnel like in shape. Because of these two factors, storm surges generated due to any cyclonic storm is comparatively high compared to the same kind of storm in other parts of the world. In case of super cyclones hitting coast of Bangladesh maximum height of the surges were fond to be 10-15 m, which causes flooding in the entire coastal belt. Worst kind of such flooding of 10 Nov. 1970, 30 April 1991 and 15 Nov. 2007 caused loss of 300,000, 130,000 and upto 10,000 human lives respectively (Hossain, 2004). Apart from the effect of cyclone, coastal areas are also subjected to tidal flooding during the months from June to September when the sea is in spate due to southwesterly monsoon wind. Incidence of this kind of flooding is now increasing.

2.11.3.5 Urban Flooding

Besides four types of floods, another kind of flood i.e. urban flooding is becoming more prevalent in urban areas now-a-days. Due to rapid urbanization through filling-up of low lying areas, natural drainage systems in those areas are being destroyed causing urban flooding. This is very acute in major metropolis i.e. Dhaka, Chittagong, Khulna, Rajshahi, Sylhet etc. This phenomenon has also been gradually observed in other towns e.g. Mymensingh, Jessore, Comilla, Noakhali, Rangpur etc. Urban flooding is posing serious threat to the integrity of the pavements of the roads, health and hygiene and environmental conditions of the towns and cities. It is pertinent to note that urban planning must take into consideration the issues of stormwater drainage and filling-up of the low lying areas in and around the cities and towns. (Hossain, 2004)

2.11.4 Major Causes of Floods in Bangladesh

- Large volume of flow from trans boundary rivers in very short period of time (June-October)
- Intensive rainfall within the country
- Very flat topography
- Higher sea level during monsoon
- Synchronization of flood peaks
- Siltation of the drainage routes
- Breaching and overtopping of flood protection embankments
- Human intervention and encroachment of rivers and floodplains

Floods differ in location, timing, intensity and duration.

2.11.5 Overview of some historical flood event

- ***The 1987 Floods***

The 1987 floods occurred due to very heavy rainfall in the northwest region of Bangladesh and in West Bengal in India from July to September. The flood effects were further aggrevated due to high water level in Ganges River, which retarded drainage from Atrai basin. Although, Brahmaputra flood was moderate, the devastation became severe due to breach in the Brahmaputra right embankment that inundated very extensive areas in Bogra and Sirajganj. The highest recorded peak flow in Ganges River at Hardinge Bridge was

76,000m3/s and at Bahadurabad on Brahmaputra was 74,000m3/s. Although high floods were experienced in other areas in Bangladesh, but not as extensively like in the Northwest region. Nearly 39% of the country was inundated.

- ***The 1988 Floods***

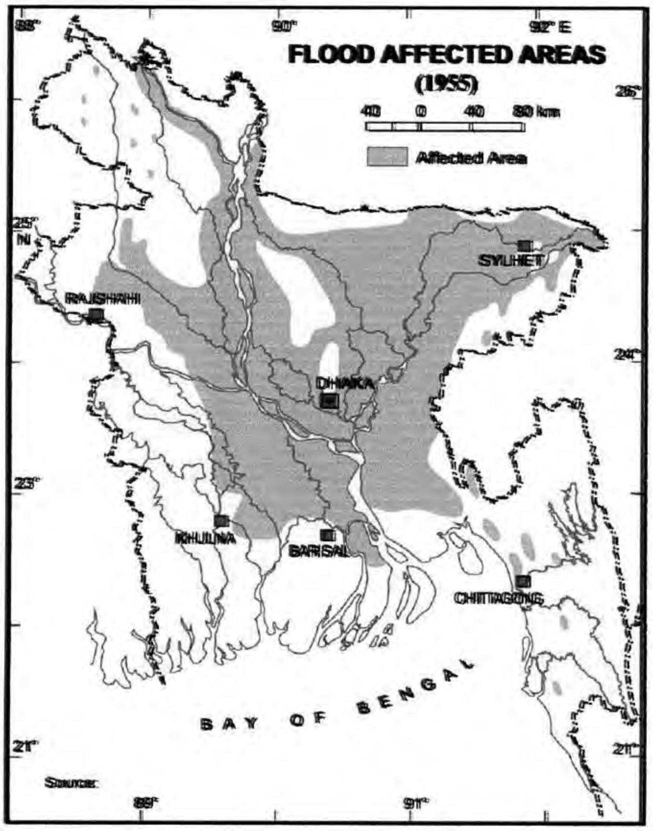
The 1988 flood by contrasts to the 1987 was mainly caused by very heavy rainfall in the upper catchments of Ganges, Brahmaputra and Meghna River Basins. The flood peak of Brahmaputra was the highest recorded. The flood peak of Ganges River was also high but not as 1987. The situation became devastating due to the synchronization of flood peaks of all the three major rivers-Brahmaputra, Ganges and Meghna in late August and the first week of September. The highest recorded peak flow in the Barhmaputra River at Bahadurabad was 98,600m^3/s and in the Ganges River at Hardinge Bridge was 72,300m^3/s. In Meghna River at Bhairab Bazar the peak flow was 19,800m^3/s which also the highest recorded since then. Nearly 61% of the country was inundated in 1988 floods.

- ***The 1998 Floods***

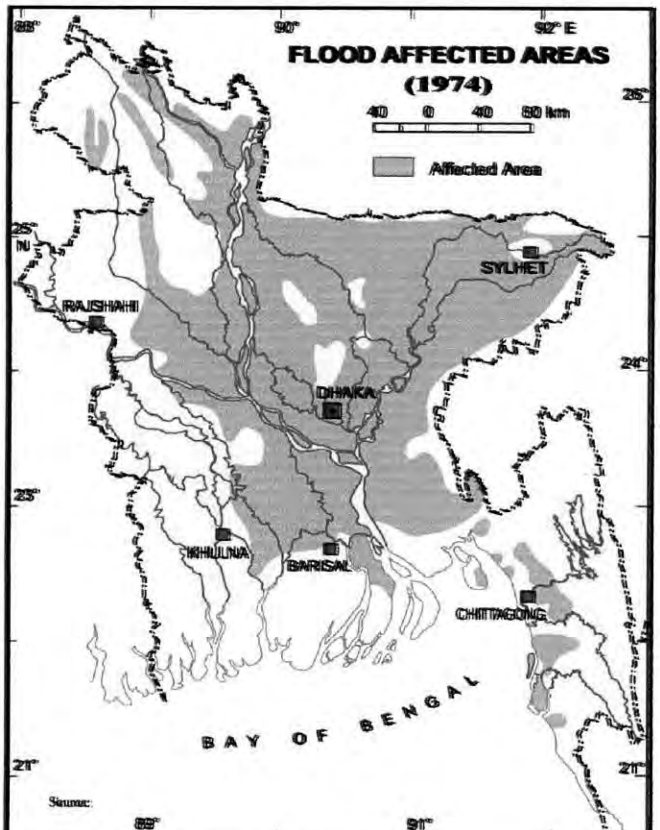
In 1998, all the factors which influence the occurrence of floods were more or less present. Most important was the four successive flood waves in Brahmaputra River between June to September. Successive flood waves did not allow the river water level to recede sufficiently to accommodate the next flood before the previous was drained. At the sametime, during 1998, the broad-scale sea-level rise at the head of the bay was >30cm that retarded the flood flow to the Bay. The devastation became severe in early September when the flood peaks of the Ganges, the Brahmaputra and the Meghna River synchronised. Around 68% of the country was inundated. The flood duration was exception; The Brahmaputra was above danger level for more than 57 days.

- ***The 2004 Floods***

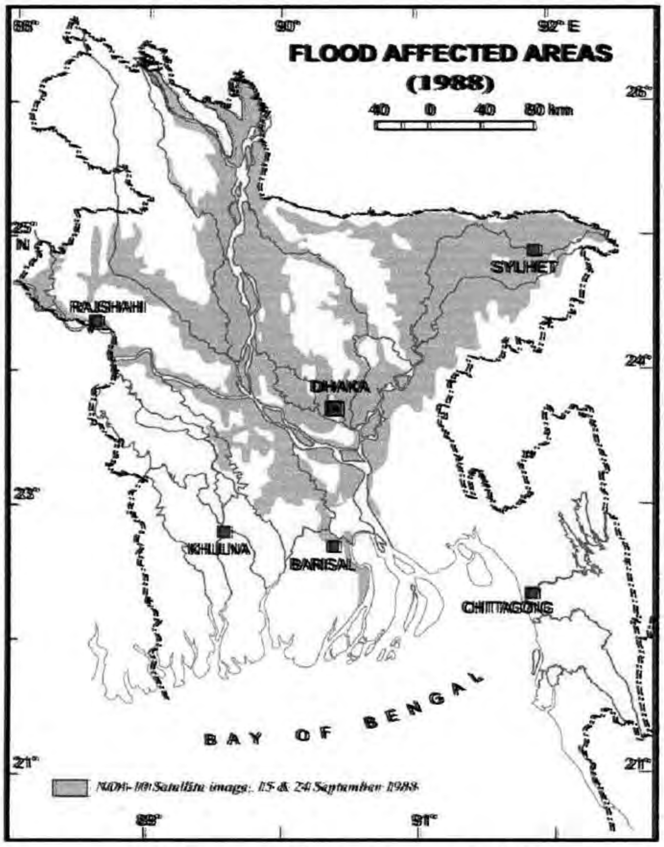
The floods of 2004 started in April with extensive areas in the northeast of Bangladesh inundated by flash floods from the hilly catchment in northeastern India. The north-eastern part of the country experienced about 1.5 times the monthly rainfall of April. Again most of the rainfall of the month occurred within short span of time stretching from 11th April to 20th April resulting in severe flash floods in the area. Actually, Surma River at Sylhet crossed the recorded highest water level in April. The Brahmaputra received 5 consecutive flood peaks



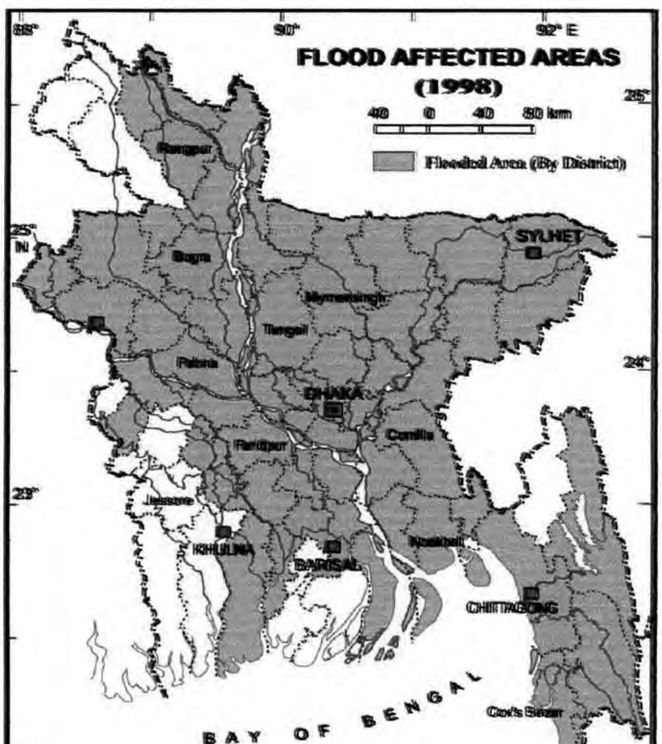
(a) Flood Affected Areas 1955



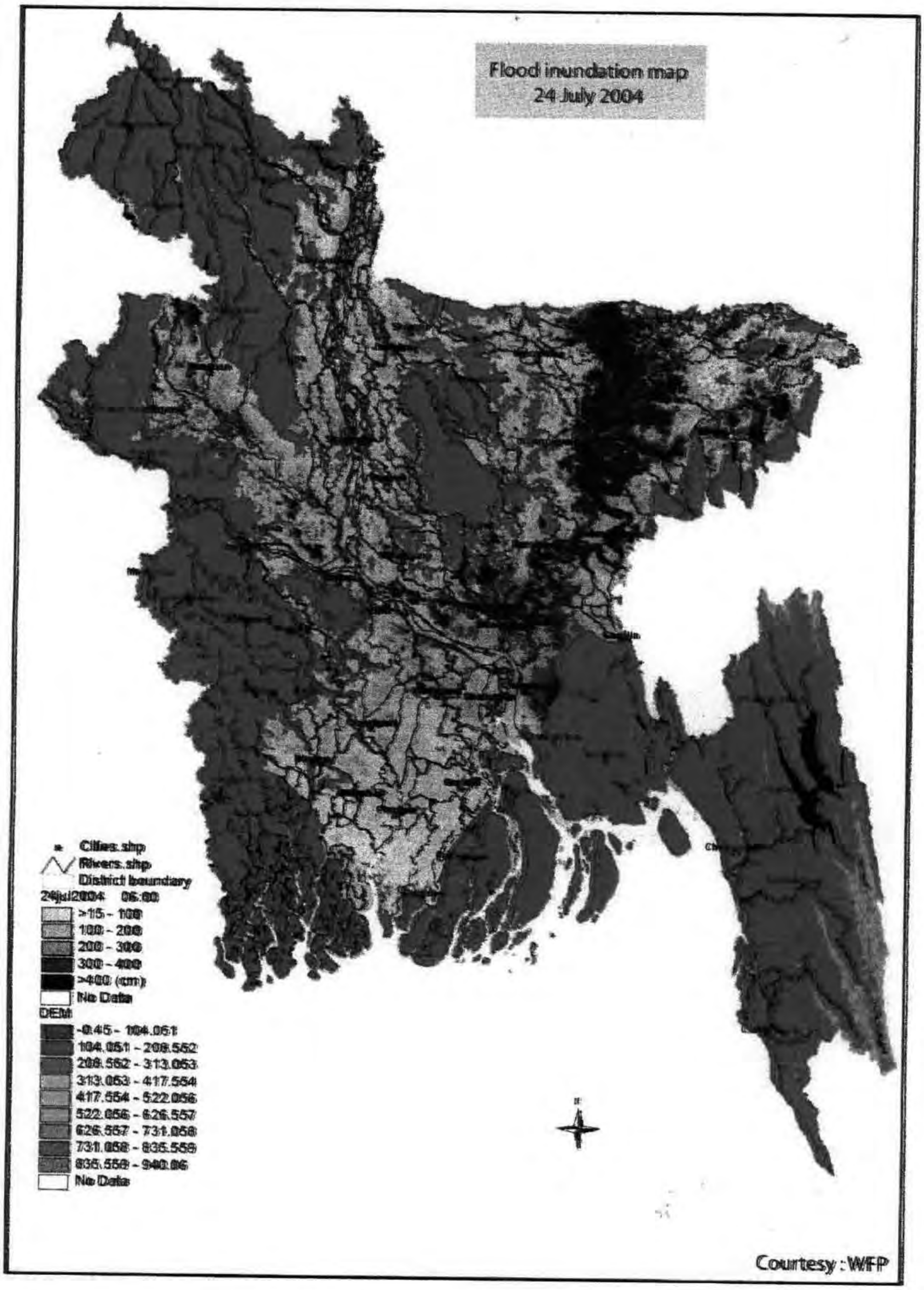
(b) Flood Affected Areas 1974



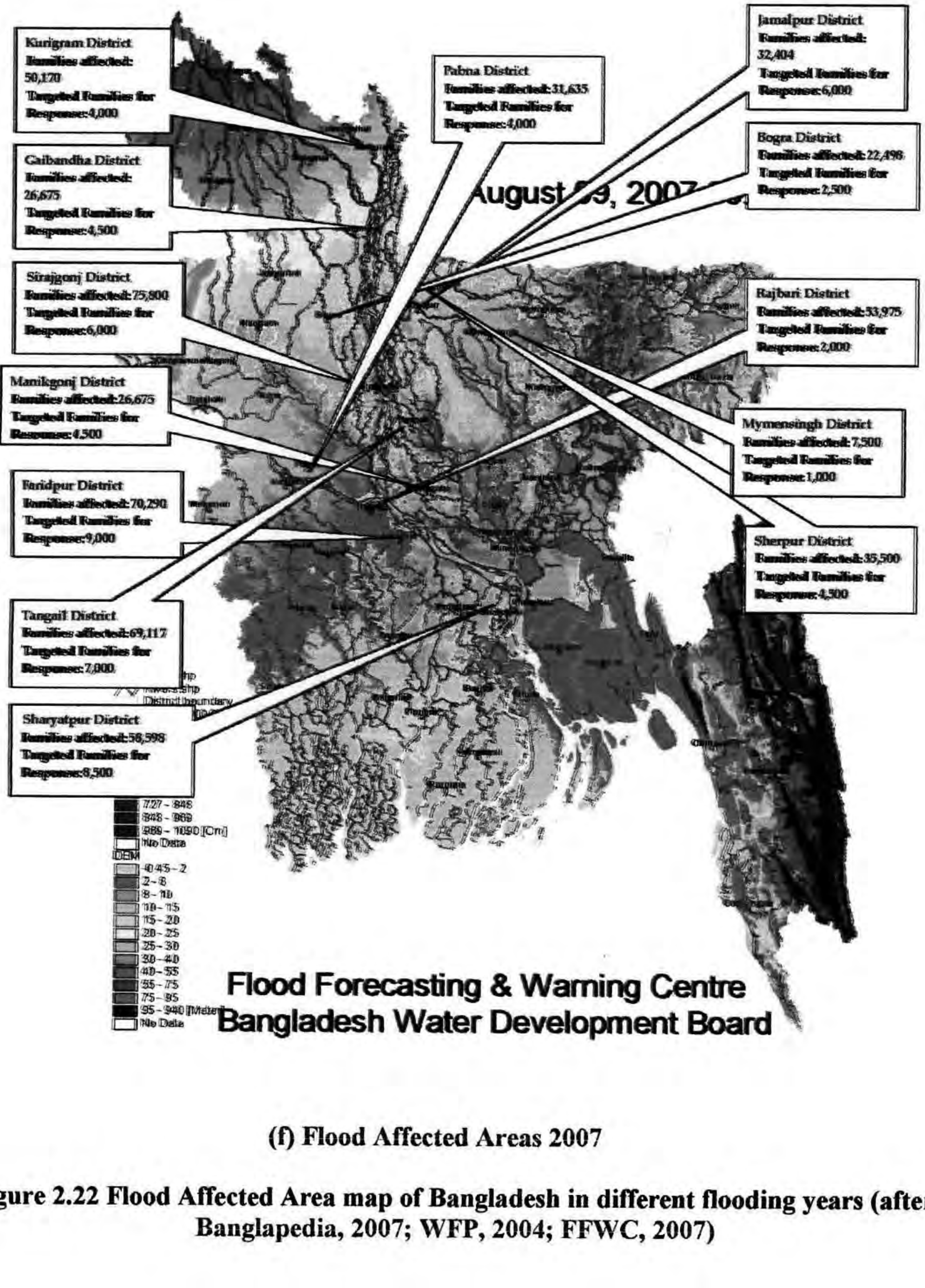
(c) Flood Affected Areas 1988



(d) Flood Affected Areas 1998



(e) Flood Affected Areas 2004



(f) Flood Affected Areas 2007

Figure 2.22 Flood Affected Area map of Bangladesh in different flooding years (after, Banglapedia, 2007; WFP, 2004; FFWC, 2007)

2.11.7 Land Types

In order to understand the flood problem and its management, it is better to understand the land types. Seasonal flooding regime has been characterized by means of inundation land types. Categories and detailed description of land type is given in Table 2.10.

Table 2.10 Inundation land type (after NAP, 2005)

Land Type	Features
Highland (H)	Land which is the above normal inundation level and would normally not develop wetland conditions unless rainwater is ponded
Medium Highland – 1 (MH1)	Land which normally is inundated less than 30 cm deep
Medium Highland – 2 (MH2)	Land which normally is inundated between a depth of 30cm and 90 cm
Medium Lowland (ML)	Land which normally is inundated to a depth between 90cm and 180 cm
Lowland (LL)	Land which normally is inundated to a depth between 180cm and 300 cm
Very Low Land (VLL)	Land which normally is inundated to a depth more than 300cm

2.11.8 Frequency of Flood

Scenarios on flood inundation with the floods of different frequencies have been developed for 2, 5, 10, 20, 50, 100 and 500 yr are given in Table 2.11.

Table 2.11 Return Period of Different Flood Dimension in Bangladesh (after World Bank, 1989)

T (Return Period in yr)	Affected Area(% of the country)	Return Period(yr)	Affected Area(% of the country)
2	20	50	52
5	30	100	Around 60
10	37	500	Around 70
20	43		

2.11 BOMBING/ TERRORISM

2.12.1 Definition

Terrorism is a form of unconventional warfare. The exact definition of the term is widely disputed; generally, it is used to describe a broad range of activities, usually involving violence, conducted against a group or state. Few words are as politically or emotionally charged as terrorism

2.12.2 Some Terrorist events of Bangladesh

- On 12 January 2005, bomb blasts at two separate cultural events in Sherpur and Jamalpur districts injured 25 and 10 respectively.

- Bomb blasts on 15 January 2005 at Jatra performances at Bogra and Natore killed two and injured over 70 people.
- On 17 August 2005, around 500 bomb explosions occurred at 300 locations in 63 out of the 64 districts of Bangladesh. At least two people have been killed and 50 others injured in a series of small bomb blasts across Bangladesh. The bombs were exploded within a half hour period starting from 11:30 am. A terrorist organization, Jama'atul Mujahideen Bangladesh (JMB) claimed responsibility for the bombings.
- Blasts later in the year were more deadly "killing judges, lawyers, policemen and common people". It killed two judges in Jhalakathi in South Bangladesh on November 14 2005.

2.12 FAMINE

2.13.1 Definition

Famine is a state of extreme starvation suffered by the population of an area due to scarce food supply. It appears in times when crops fail or food cannot be supplied where it is required. Crop failures stemming from adverse climatic or topographic imbalances like droughts, floods, tidal surges, excessive rainfall etc as well as animal or plant diseases, plagues of locusts and other insects and rodents normally get the blame for famines. In many instances, famines were caused by poor transport and communication and absence of well established channels of trade system.

2.13.2 Historical Famine in Bangladesh

- ***The famine of 1770*** occurred in 1769 and 1770. It is popularly known as Chhiyattarer Manvantar (The Great Famine of 1176 Bangla Year). It was the worst famine in Bengal in the 18th century. The excessive rainfall in 1770 did not relieve the people from the sufferings of drought of the year before; on the contrary, it caused overflowing of rivers and damaged standing crops. The existing revenue system of land and activities of middlemen in the foodgrain market further deteriorated the situation.

- ***The famine of 1866*** Although Orissa was the main disaster zone, part of Bengal was also affected. Famine affected areas experienced a sharp decline in real wages of agricultural labourers.

- ***The famine of 1896-98*** affected Bengal along with provinces such as Bihar, Bombay, Oudh, Central Provinces and Punjab. In Bengal the failure of rainfall was the triggering factor.

- ***The Great Bengal Famine of 1943*** was one of the worst famines to have struck this region. A series of crop failures beginning from 1938 and other disruptive events accompanying the Second World War precipitated this famine.

- ***The famine of 1974*** There was a shortage of food in 1974 throughout the world. However, unlike some other countries that suffered from food scarcity, the situation in Bangladesh was rooted in the historic evolution of the society and others germinated from poor management of the food distribution system in the face of severe floods. According to some estimates, more than one million people died during the period from July 1974 to January 1975.

2.14 TORNADO

2.14.1 Definition

A tornado is a violent whirling wind, accompanied by a funnel-shaped cloud extending down from a cumulonimbus cloud. Commonly known as a twister, a tornado has an average width of a few hundred metres, but can be anywhere from a few metres to a kilometre wide where it touches the ground. It can move over land for distances ranging from short hops to many kilometres, causing great damage wherever it descends.

Tornadoes form when two masses of different temperatures and humidity meet. If the lower layers of the atmosphere are unstable, a strong upward movement of warmer air is formed. This starts to spiral as it rises, and intensifies. Only a small percentage of these systems develop into the narrow, violent funnels of tornadoes. Figure 2.23 shows the violent, twisting funnel of a tornado and a tornado descended from a cumulonimbus cloud.

Figure 2.23 The violent, twisting funnel of a tornado and a tornado descended from a cumulonimbus cloud

2.14.2 Tornadoes in Bangladesh

Due to its geographic location next to the Bay of Bengal and down to the Himalayas, tornadoes in Bangladesh are a natural phenomenon rather than mere surprise.Tornado It occasionally occurs in Bangladesh during the pre-monsoon hot season, especially in the month of April when the highest temperature is normally recorded. The diameter of a tornado varies from a few metres to about two kilometres. The rotating winds attain velocities of 300 to 480 km/hr and the updraft at the centre may reach 320 km/hr. A tornado is usually accompanied by thunder, lighting, terrifying roaring and heavy rain. Tornado is a very short-lived disturbance which may last 10-20 minutes and the length of their travel path may vary from 10 to 15 km. Although small in size, wherever they hit, they make a complete devastation. They are more common in the central part of Bangladesh than in the other areas. Most of the severe tornadoes are recorded in the district of Faridpur, Rajbari, Gopalganj, Madaripur, Pabna, Gazipur, Tangail and Dhaka areas. In Bangladesh, a tornado is often misinterpreted as a nor'wester or an ordinary thunderstorm or even with a cyclone although none of these is similar to each other. Figure 2.24 shows the damages occur by Tornado.

Figure 2.24 Damages occurred by Tornado

2.14.3 Nor'wester, Tornadoes and Cyclones

Nor'wester or ordinary thunderstorms have straight line winds, while in tornadoes and in cyclones, the wind is rotating. It can be tracked down easily by looking at their damage patterns even if there is no satellite or radar image is available. It is easy to distinguish between a tornado and cyclone as cyclones are formed in Deep Ocean, synoptic in scale and their duration is much longer than tornadoes. While tornadoes are usually formed in the ground, they can easily cross over the water and strike the nearest river or reservoirs. Tornadoes on water are commonly known as "water sprout". Figure 2.25 shows a waterspout near the Florida Keys.

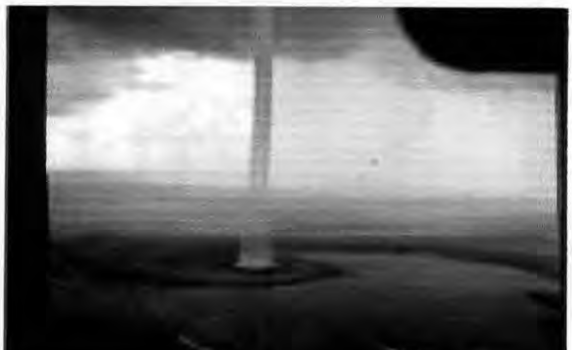


Figure 2.25 A waterspout near the Florida Keys.

2.14.4 Two tornado seasons

Most of the tornadoes occur in Bangladesh in the late spring and early summer months i.e. from March through May; thus it can be called as the 'Tornado Season'. First twenty days of April can be considered as the most dangerous in the terms of the killer tornado occurrences.

In Bangladesh, due to the orbital movement of the earth the wind changes direction twice a year - once when the Tropic of Cancer starts moving towards the sun in March-May, and once when it starts moving away from the sun in October-November. The transitional periods are usually referred to as pre-monsoon (March-May) and post-monsoon (October-November). These two transitional periods are characterized by local severe thunder storms - including severe local storms, tornadoes and cyclones. The frequency of devastating pre-monsoon local storms usually reaches its peak in April, while a few occur in May and the least in March. Post-monsoon storms are usually weaker and they are fewer in number. They are smaller in size, and hence cause less devastation.

In the documented tornadoes, most of the tornadoes occurred in the afternoon and evening, especially the most catastrophic tornadoes with a peak around 4.30 pm. A few violent tornadoes occurred between 9 pm and 12 am (Islam, 2007).

2.14.5 Tornado types

Based on their intensities and power of destruction, tornadoes can be categorised into three groups - weak, strong and violent. Nearly 70 percent of all tornadoes are weak tornadoes, resulting in less than five percent of tornado deaths. Their lifetime is 1-10 minutes with wind speeds of less than about 180 kph. Strong tornadoes comprise 28 percent of all tornadoes and result in nearly 25 percent of all tornado deaths. They may last 20 minutes or longer, with wind speeds of 180-350 kph. Only two percent of all tornadoes are classified as violent in nature, but result in around 70 percent of all deaths. They can last over 60 minutes and involve winds of over 350 kph. Generally, tornado-producing thunderstorms form during the afternoon hours.

2.14.6 Causes of Tornado

Tornadoes are formed from a violent thunderstorm called "supercell" which tends to be accompanied by large hail and lighting. There are several conditions required to be present in the weather to form a supercell thunderstorm. One obvious condition is the presence of a 'dry line'.A dry line is an imaginary line on the ground which divides two immediate regions based on temperature and moisture differences. In the late spring and early summer months, such a dry line often exits to the western side of Bangladesh (Figure 2.26). During this time

Northern India is heated and dried up quickly as it is closer to the desert condition and to the Himalayas, but in Bangladesh lots of moisture remain in the weather because of its proximity to the Bay of Bengal. Also as shown in Figure 2.26, the mid-upper tropospheric flow known as the 500 mb jet splits around the Tibetan Plateau allowing the westerlies region implies strong influence of regional topography on the local atmosphere. The dryline separates the hot and dry EML source region and the most air over Bangladesh. Tibetan Plateau enhances the mid level flow over north India and Bangladesh. Nocturnal storms over the Khasi Hills near Cherrupunji leave outflow boundaries over northern Bangladesh. These nocturnal storms are probably caused by the low level jet impinging on the Khasi Hills of Meghalaya, India. A front of sorts often stretches across central Bangladesh.

In general, at the end of winter season in Bangladesh, the southerly warm wind tends to flow from the Bay of Bengal which carries a lot of moisture and when it confronts with the cold, dry winter air that still remains in the atmosphere, makes the weather very unstable. That's why many thunderstorms locally known as 'kalbaishakhi' or 'nor'westers' are often seen in Bangladesh around this time which are the result of this unstable weather.

On a given day, with the presence of necessary weather conditions especially the dry line, these thunderstorms can be turned into supercell thunderstorms and produce tornadoes (Finch, 2007).

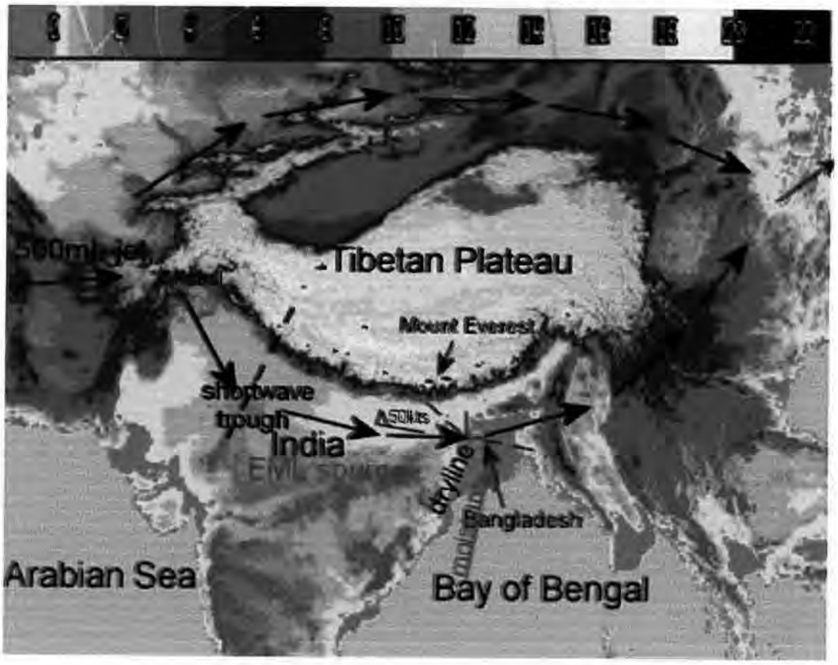


Figure 2.26 Dry lines (Finch, 2007)

2.14.7 Historical Tornadoes of Bangladesh

Appendix 17 presents short description of some historial Tornadoes of Bangladesh. Figure 2.28 shows the Tornado over Bangladesh since 1951 to 2004.

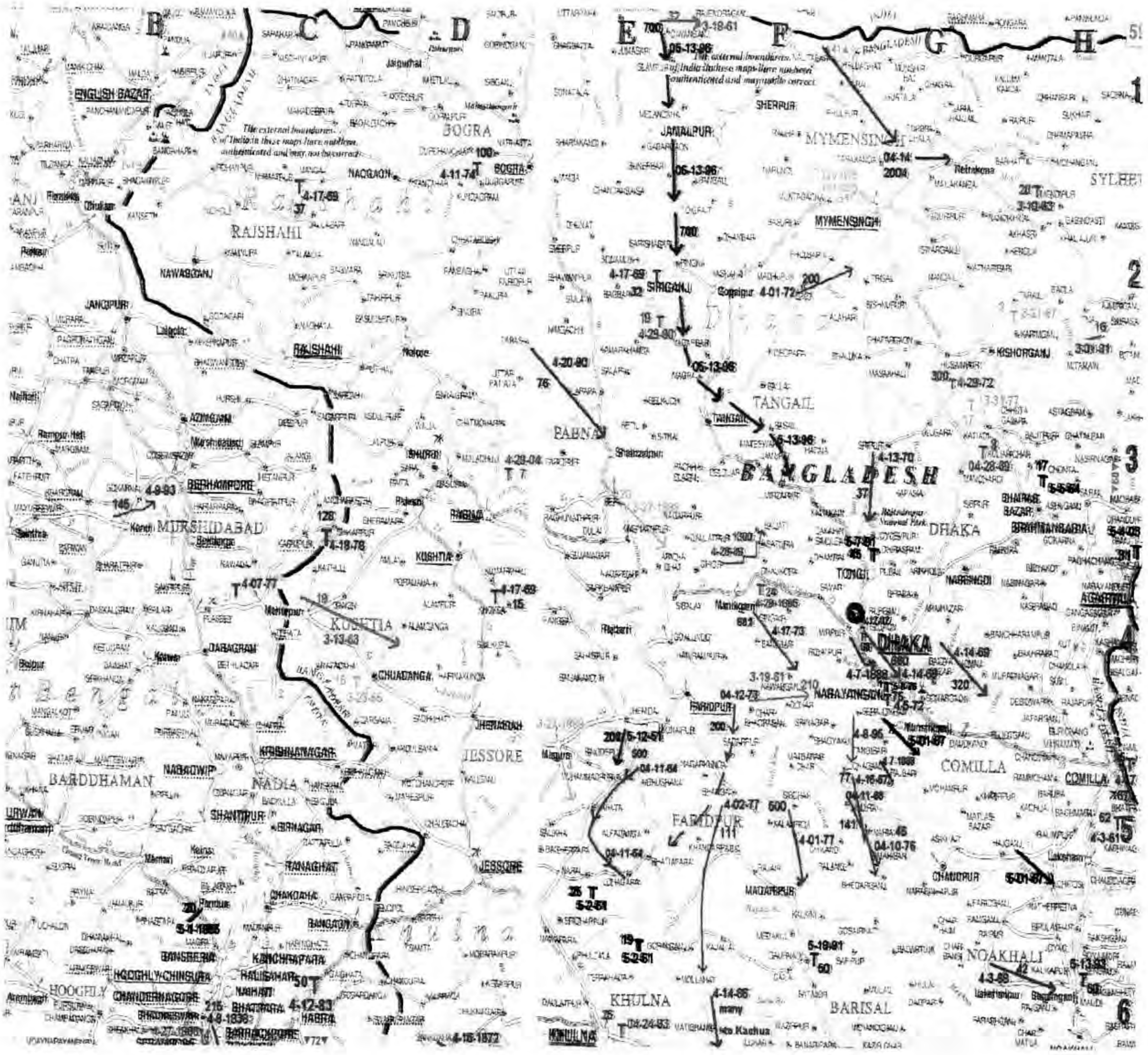


Figure 2.27 Tornadoes over Bangladesh (after Finch, 2007)

2.14.8 Tornado Hazard Maps

The existing tornado hazard map of DMB, GoB (DMB, 1993), is shown in Figure 2.28. The tornado prone area of Bangladesh can be identified from this hazard map.

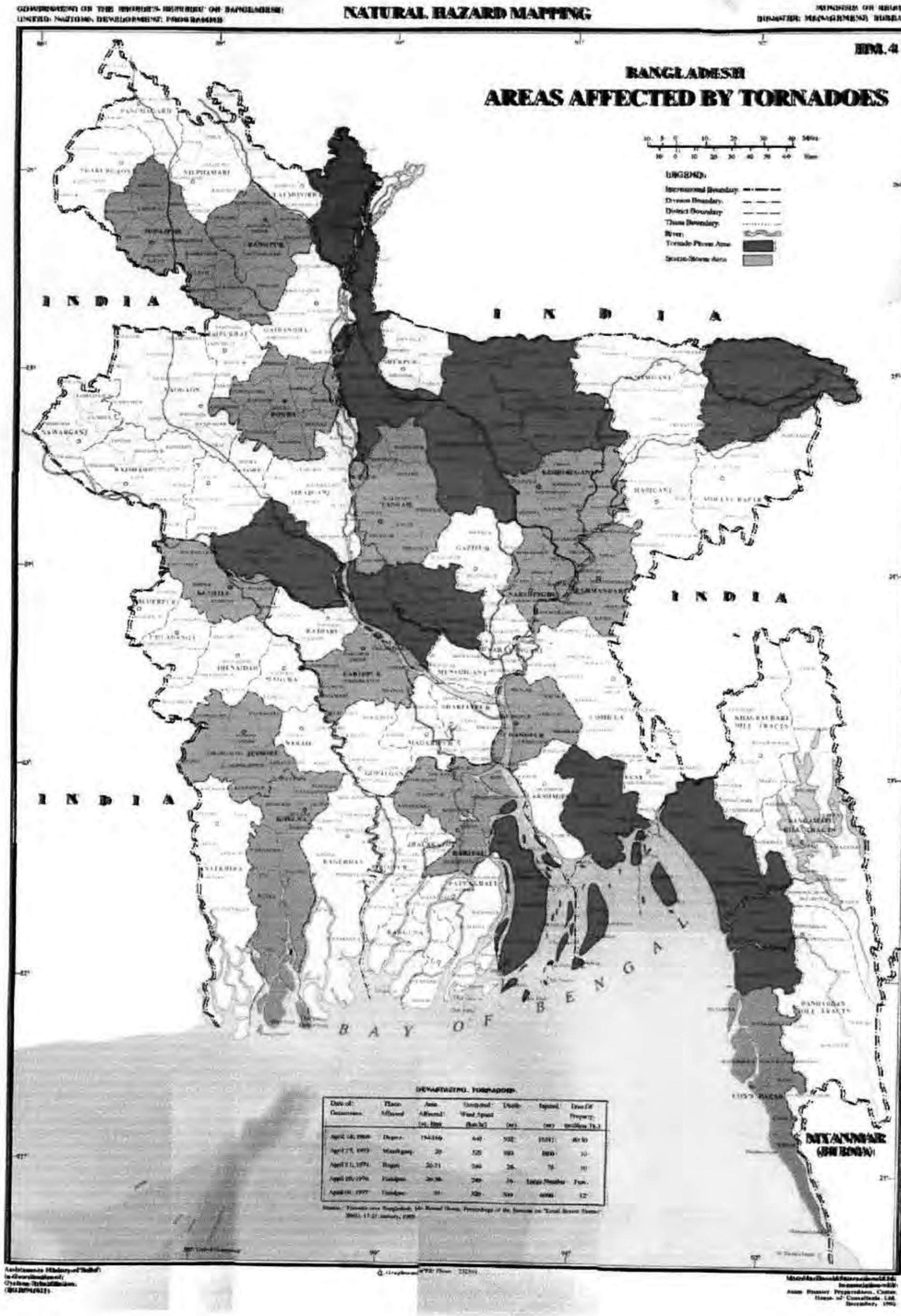


Figure 2.28 Areas Affected by Tornadoes (DMB, 1993)

2.14.9 Tornado Intensity Scales

The Beaufort scale, The TORRO tornado intensity scale, The Fujita tornado intensity scale (F-Scale), The Enhanced Fujita tornado intensity scale (EF-Scale) is described in Appendix 8, 9, 10 and 11, respectively.

2.15 CYCLONE

2.15.1 Definition

In meteorology, a cyclone is an area of low atmospheric pressure characterized by inward spiraling winds that rotate counter clockwise in the northern hemisphere and clockwise in the southern hemisphere of the Earth. Figure 2.29 shows this formation of tropical cyclone.

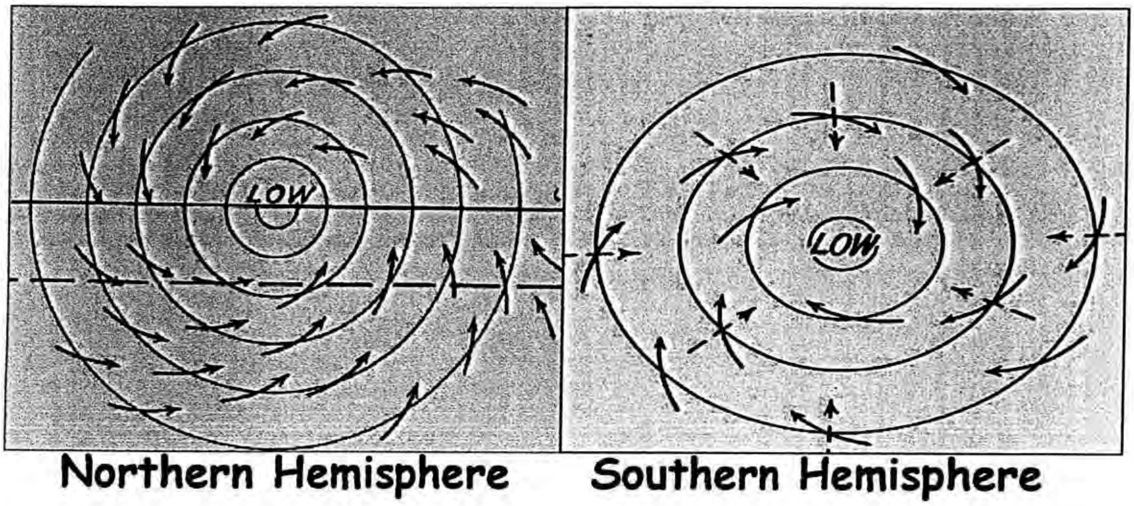


Figure 2.29 Formation of a tropical cyclone (after Nishat, 2007).

The following conditions are essential for the formation of a tropical cyclone (cyclogenesis).

i) Sea surface temperature (SST) should not be below 27° C (for supplying moisture)

ii) There should be little or no vertical wind shear (for vertical growth)

iii) There should be baroclinic zone i.e. inter-section of pressure surface and density surface (for more inter-action)

iv) The sea-surface region should be beyond 6° latitude (for more Coriolis' force and hence for more spinning).

Of course, for extra-tropical storms, SST is not that important as there are strong Coriolis' force and relatively high pressure at mid latitudes. Figure 2.30 shows the Diagrammatic Conception of a Cyclonic Storm and Swelling of Sea Surface in Deep Sea.

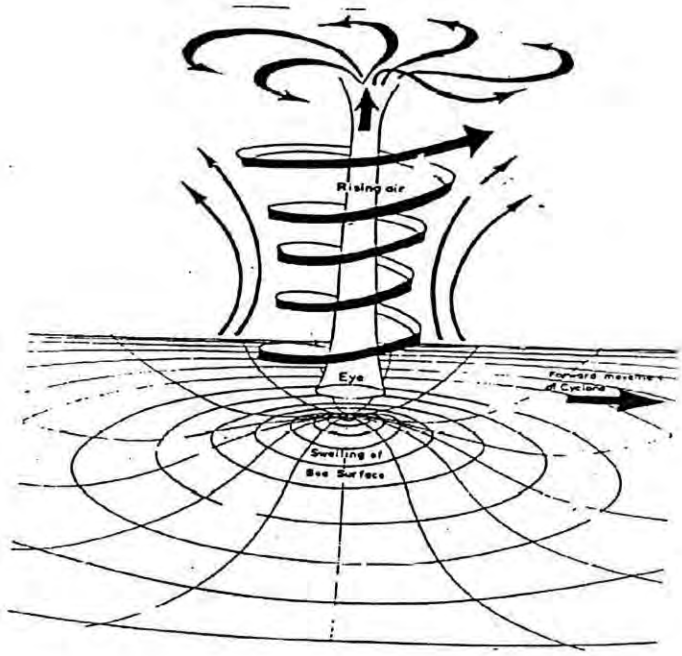


Figure 2.30 Diagrammatic Conception of a Cyclonic Storm and Swelling of Sea Surface in Deep Sea (after Karim, 1996)

2.15.2 Cyclones in the Bay of Bengal

The Bay of Bengal which is the south of Bangladesh is one of the favorable tropical cyclogenisis areas on the earth. Figure 2.31 shows Cyclone Sidr in the Bay of Bengal. Unfortunately two distinctly different types of cyclones form in this region (Karim, 1996). These are:

a) ***Warm-cored tropical cyclone*** forming in the pre and post monsoon seasons and is embedded in a basic barotropic current. Those cyclones mainly form between the latitudes 5^0-16^0 norths and initially they move in a north-westerly direction and afterward frequently recurve towards the north or north-east to strike the coast within an average period of life between three to five days.

b) ***Cold cored monsoon depression*** forming during the monsoon season (June-September). They are formed in a baroclinic current with basic westerlines in lower and easterlies in upper levels i.e. in the presence of a strong vertical shear. These depressions usually form 20^0 north and move to the westerly or north westerly direction to hit the upper coast of India mostly.

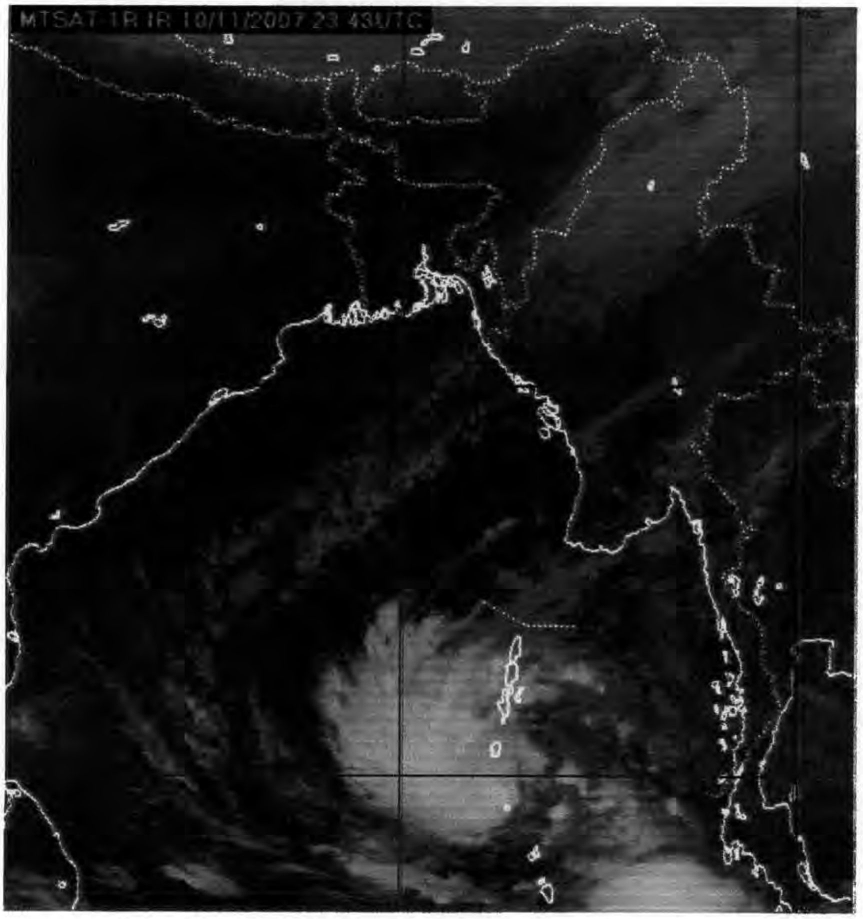


Figure 2.31 Cyclone Sidr in the Bay of Bengal (BMD, 2007)

2.15.3 Tropical Cyclone Season in Bangladesh

Months of mid March to May (Pre-monsoon) and mid September to mid December (Post monsoon) are cyclone seasons in Bangladesh. Monsoon depressions/ storms are not so destructive which give more rain than wind. Cyclones hardly form during monsoon due to strong vertical wind shear.

2.15.4 Classification

Cyclones in Bangladesh are presently classified according to their intensity and the following nomenclature is in use by Bangladesh Metreological Department in Table 2.12.

The criteria followed by the Meteorological Department of India to classify the low pressure systems in the Bay of Bengal and in the Arabian Sea as adopted by the World Meteorological Organisation (W.M.O.) are given in Table 2.13.

Table 2.12 Classification of Cyclone Disturbance (after BMD, 2006)

SL. No.	Category	Associated Wind Speed (km/hr)
1.	Depression	winds upto 62 km/hr
2.	cyclonic storm	winds from 63 to 87 km/hr
3.	severe cyclonic storm	winds from 88 to 118 km/hr
4.	Severe cyclonic storm of hurricane intensity	winds above 118 km/hr

Table 2.13 Categories of Tropical Disturbances (after WMO)

SL. No.	Types of Disturbances	Associated wind speed in the Circulation
1.	Low Pressure Area	Less than 17 knots (< 31 kmph)
2.	Depression	17 to 27 knots (31 to 49 kmph)
3.	Deep Depression	28 to 33 knots (50 to 61 kmph)
4.	Cyclonic Storm	34 to 47 knots (62 to 88 kmph)
5.	Severe Cyclonic Storm	48 to 63 knots (89 to 118 kmph)
6.	Very Severe Cyclonic Storm	64 to 119 knots (119 to 221 kmph)
7.	Super Cyclonic Storm	120 knots and above (222 kmph and above)

2.15.5 Storm Surge in Bay of Bengal with Return Period

Storm surges In addition to the waves associated with winds, abrupt surges of water known as storm surges are associated with cyclones. They strike the coast nearly at the same time that the centre of the storm crosses the coast. In Bangladesh the maximum height of this storm surge has been reported to be as high as 13m. Most of the damage during a cyclone is done by the storm surges, which sometimes wash over entire offshore islands and large areas on the coast (Nishat, 2007). Surge Height at the sea coast locations of Bangladesh are given in the Table 2.14.

Table 2.14 Surge Height at the Sea Coast (after Nishat, 2007)

Region	Surge Height at the sea coast along with 90% confidence limits(m)		
	20 year return period	50 year return period	100year return period
Teknaf to Cox's Bazar	2.7±0.7	3.7±0.8	4.5±1.3
Chakaria to Anwara, and Moheshkhali to Kutubdia Islands	4.3±0.9	5.8±1.3	7.0±1.6
Chittagong to Noakhali	4.8±1.0	6.5±1.4	7.8±1.8
Sandip, hatiya and all islands in this region	4.8±1.0	6.5±1.4	7.8±1.8
Bhola to Barguna	3.8±0.8	5.1±1.1	6.2±1.5
Sharankhola to shymnagar	3.1±0.7	4.3±1.0	5.2±1.2

2.15.6 Major Cyclonic Storms and Tracks

Appendix 12 presents a chronology of major cyclonic storms. Cyclone may hit Bangladesh Coast at any place.The tracks of different major cyclones are given in the Figure 2.32.

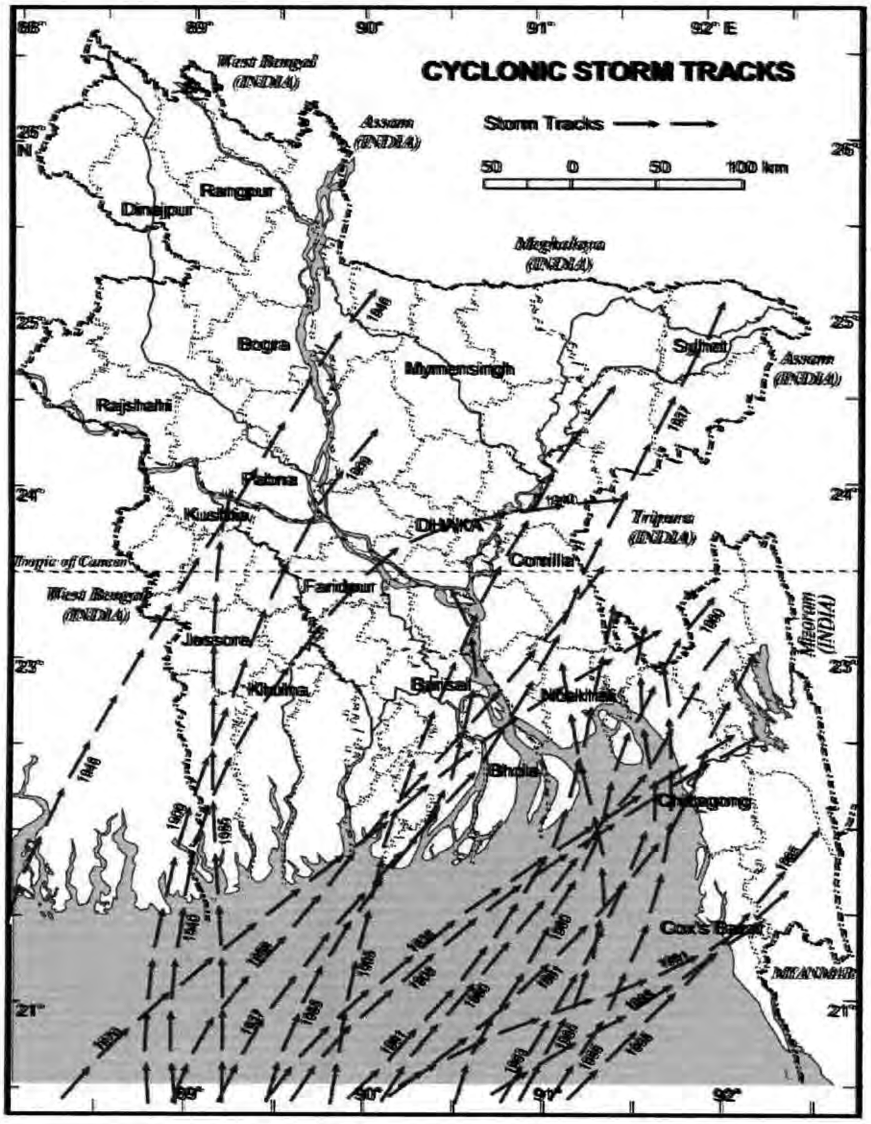


Figure 2.32 Cyclonic Storms Tracks (after BMD)

Recently Cyclone Sidr is the fourth named storm of the 2007 North Indian Ocean cyclone season. The storm formed in the central Bay of Bengal, and quickly strengthened to reach peak sustained winds of 215 km/h (135 mp/h), which would make it a Category-4 equivalent tropical cyclone on the Saffir-Simpson Scale. The storm eventually made landfall near Bangladesh on November 15. The track of the cyclone Sidr is given in Figure 2.33.

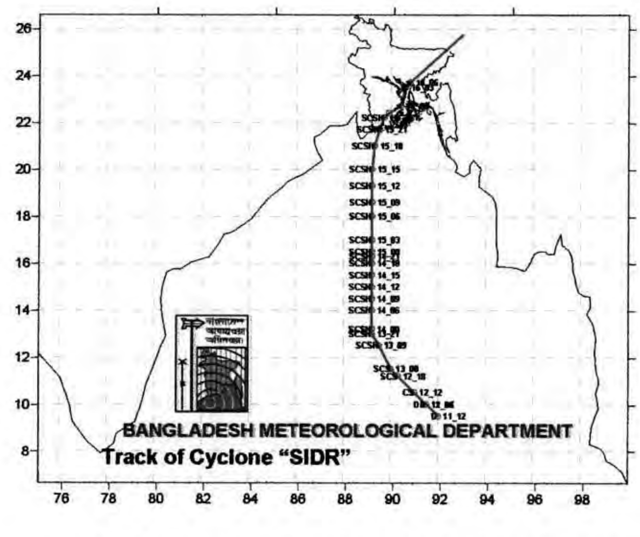


Figure 2.33 Track of Cyclone Sidr (BMD, 2007)

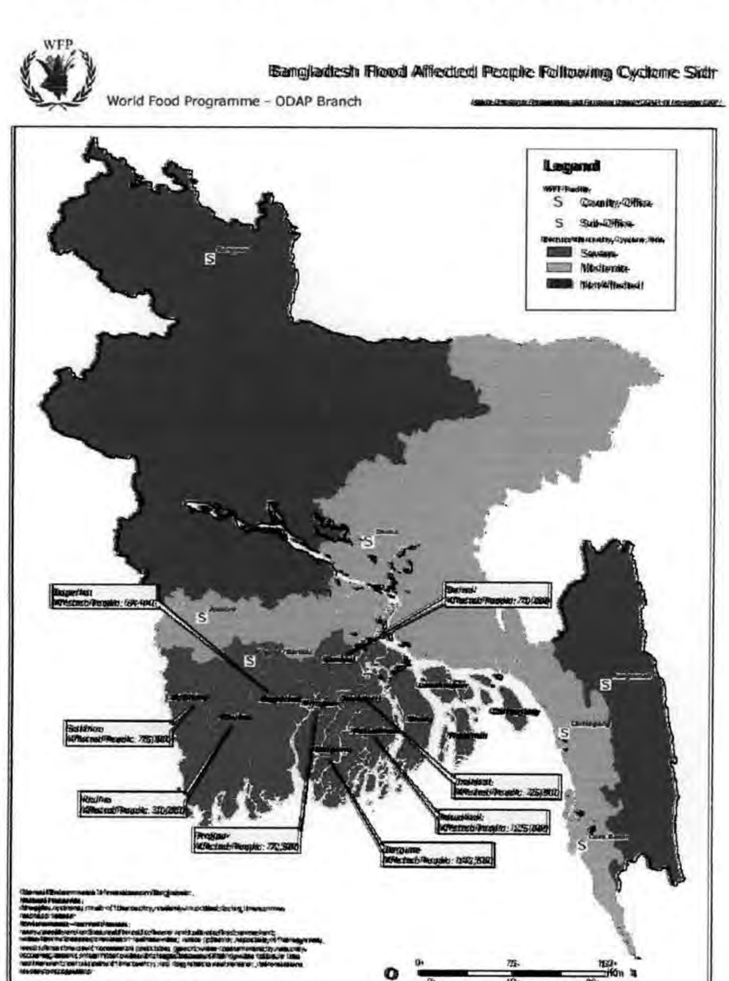


Figure 2.34 Affected Area of Cyclone Sidr (after World Food Programme - ODAP Branch, 2007)

The storm caused large-scale evacuations in Bangladesh. So far, 3,447 deaths have been blamed on the storm, with that number expected to rise. The affected area of cyclone Sidr is shown in Figure 2.34. Save the Children estimated the number of deaths to be between 5,000 and 10,000, while the Red Crescent Society reported on November 18 that the number of deaths could be up to 10,000. As of November 19, international groups have pledged US$25 million to repair the damage. Figure 2.35 shows the images of Cyclone Sidr as it crossing from the Bay of Bengal through Bangladesh.

Figure 2.35 Damage images of Cyclone Sidr

2.15.7 Cyclone Risk Map

Figure 2.36 shows the cyclone affected area map of Bangladesh prepared by SPARRSO. According to the map the coastal portion of Bangladesh divided into three areas: High Risk Area, Risk Area and High Wind Area.

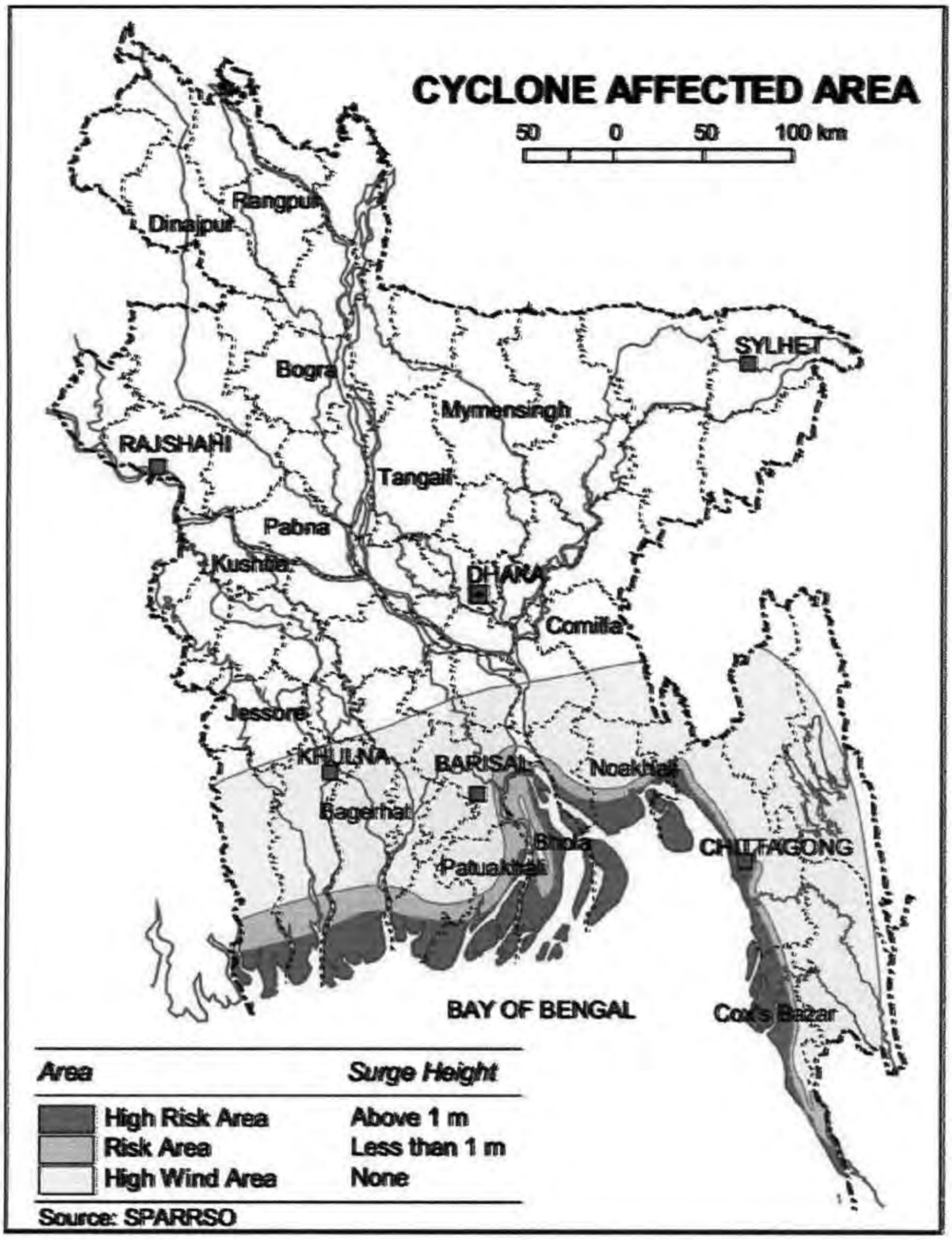


Figure 2.36 Cyclone Affected Area (SPARRSO, 1993)

2.15.8 Cyclone Intensity Scales

Saffir-Simpson Hurricane Scale is a 1-5 rating based scale, on a hurricane's present intensity, used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf in the landfall region. Appendix 13 presents the Saffir-Simpson Hurricane Scale.

2.16 TSUNAMIS

2.16.1 Definition

Figure 2.37 The tsunami caused by the December 26, 2004.

The phenomenon we call "tsunami" is a series of traveling ocean waves of extremely long length generated by disturbances associated primarily with earthquakes occurring below or near the ocean floor. Underwater volcanic eruptions and landslides can also generate tsunamis. In the deep ocean, their length from wave crest to wave crest may be a hundred miles or more but with a wave height of only a few feet or less. They cannot be felt aboard ships nor can they be seen from the air in the open ocean. In deep water, the waves may reach speeds exceeding 500 miles per hour. Fig. 2.37 shows the tsunami caused by the December 26, 2004 earthquake strikes Ao Nang, Thailand.

There is comparatively moderate possibility of Tsunami Hazard Occurrence in and around Bangladesh, but high degree of demographic, economic and infrastructural vulnerabilities (population density in coastal belt is very high, main tourism industries are based in coastal zone, majority of fisherman living in coastal zone, poverty is high in coastal zone).

Bangladesh occupies the most active tectonic boundary zone between Indian Plate and Myanmar Plate that stretches up to Sumatra via Andaman-Nicobar zone of severe seismicity (Figure 2.38). There are two zone of torsion along this tectonic boundary.

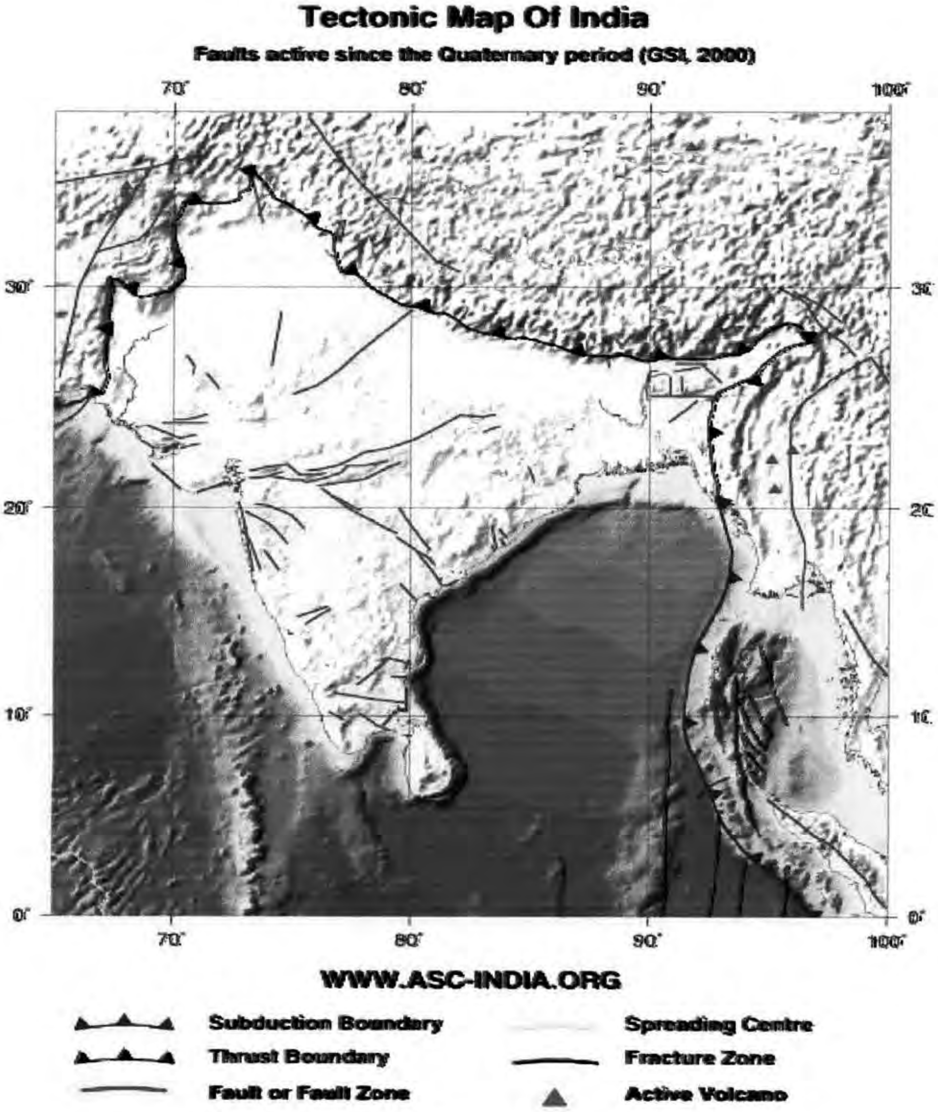


Figure 2.38 Tectonic Map of India (GSI, 2000)

2.16.2 Major Tsunamis of ASIA

- 1524 Near Dabhol, Maharashtra
- 02 April 1762, Arakan Coast, Myanmar
- 16 June 1819 Rann of Kachchh, Gujarat
- 31 October 1847 Great Nicobar Island
- 31 December 1881Car Nicobar Island
- 26 August 1883 Krakatoa volcanic eruption
- 28 November 1945 Mekran coast, Baloch
- The 2004 Indian Ocean earthquake was an undersea earthquake that occurred at 00:58:53 UTC December 26, 2004, with an epicentre off the west coast of

Sumatra, Indonesia. The earthquake triggered a series of devastating tsunamis along the coasts of most landmasses bordering the Indian Ocean, killing more than 225,000 people in eleven countries, and inundating coastal communities with waves up to 30 meters (100 feet). It was one of the deadliest natural disasters in history. Indonesia, Sri Lanka, India, and Thailand were hardest hit.With a magnitude of between 9.1 and 9.3, it is the second largest earthquake ever recorded on a seismograph. (Amateur Seismic Centre, India 2007)

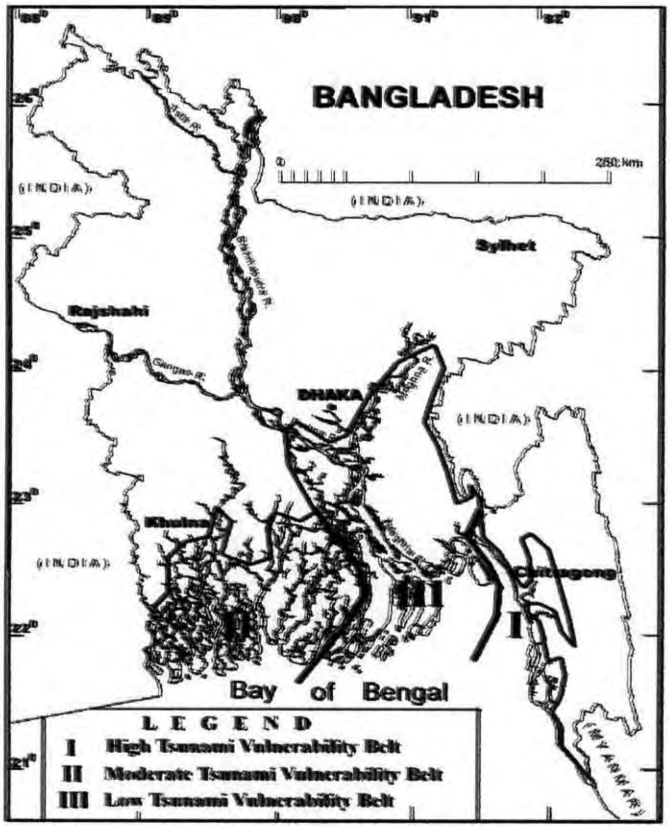
2.16.3 Tsunami vulnerability map of Bangladesh

Considering the state of tsunami vulnerability and potential seismic sources the coastal belt of Bangladesh can be divided into three Tsunami Vulnerability Coastal Belts. (Figure 2.39)

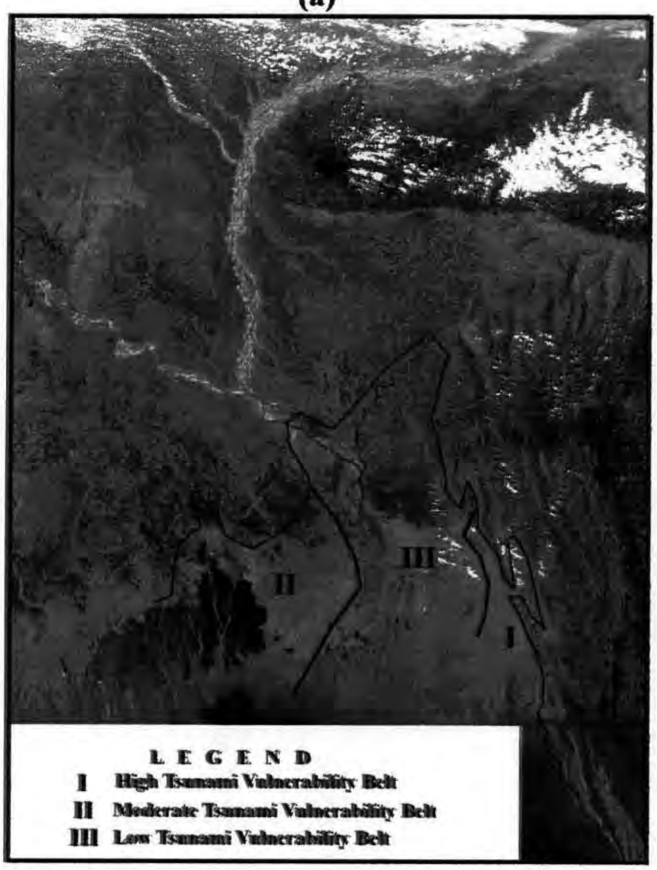
1. Tsunami Vulnerability Coastal Belt - I of Chittagong-Teknaf coastline – Most vulnerable. The intra-deltaic coastline is very close to the tectonic interface if Indian and Burmese plates. The active Andaman-Nicobar fault system is often capable of generating tsunami waves.

2. Tsunami Vulnerability Coastal Belt - II of Sundarban-Barisal coastline – Moderately vulnerable. This old deltaic belt is extremely vulnerable to local tsunamis due to presence of Swatch of No Ground.

3. Tsunami Vulnerability Coastal Belt - III of Barisal-Sandwip estuarine coastline – Low vulnerability. The estuarine coastal belt considered to be less vulnerable due to presence numerous islets and shoals in the upper regime of the continental shelf. (Karim et.al. 2005)



(a)



(b)

Figure 2.39 Tsunami vulnerability map of Bangladesh (after Karim et.al., 2005)

CHAPTER 3

PROPOSAL OF INTENSITY SCALES FOR DIFFERENT NATURAL HAZARDS IN BANGLADESH

3.1 GENERAL

Natural processes such as tropical Cyclones, Floods, Tornadoes, Earthquake, and the like are an enduring condition around the human environment. Natural hazards become disasters when they intersect with the human environment. In Bangladesh, natural disasters have left a profound imprint causing devastating loss of life, property, economy and community.

Bangladesh is one of the most natural disaster prone countries in the World. Floods, cyclonic storms, tidal surges are the major disasters and droughts, tornadoes, riverbank erosion, earthquake are other types of disasters in the country. All these disasters are occurring in Bangladesh regularly and frequently. Intensity scales are subjective and depend upon social condition and construction status of a country, they need revising from time to time. Regional effects must be accounted for. There are no existences of individual hazard intensity scale to identify the type of particular hazard in Bangladesh. This chapter studied different disasters in Bangladesh and their corresponding scales all over the world, and proposed suitable intensity scales for different disaster in Bangladesh.

3.2 INTENSITY SCALES AND MODELS

3.2.1 Tropical Cyclones

Hurricanes, tropical storms and typhoons are collectively known as tropical cyclones. These cyclones are defined as low-pressure areas of closed circulation winds that originate over tropical waters (FEMA, 1997). Tropical storms have sustained surface wind speed that ranges from 39 to < 74 mph and that hurricanes have a minimum sustained surface wind speed of at least 74 mph.

3.2.1.1 Cyclone Track Forecasting Model

The storm track prediction is really intriguing as well as challenging. Many models have so far been developed over the globe for predicting Tropical Cyclone (TC) motion. There are five basic types of track guidance models in operational use at the National Hurricane Center (NHC) of USA, as described by Neumann (1988). They are 1) statistical, 2) statistical-synoptic, 3) statistical-dynamical, 4) barotropic-dynamical and 5) baroclinic- dynamical.

Being a Third World Country, Bangladesh does not have any infra structure to run or develop large numerical models. Besides, numerical models do not necessarily give good forecast of tropical cyclone (TC) motion. Nevertheless, Storm Warning Center (SWC) of Bangladesh Meteorological Department (BMD) has two PC-based storm track prediction models – (1) Storm Track Prediction (STP) Model (Debsarma, 1988-1994) and (2) Steering and Persistence (STEEPER) Model (Debsarma, 1995).

3.2.1.1.1 Storm Track Prediction (STP) Model

It is a small-scale statistical-dynamical model. It differs from CLIPER in respect of regression. CLIPER model uses linear regression whereas STP model (Debsarma, 1988-1994) uses quadratic regression. From the historical data, storm tracks over the Bay of Bengal seem to be approximately parabolic. A small segment of the storm track may be linear or non-linear. So, the 'least square parabola' makes the 'best fit' of the input data set. Hence STP model produces better track than CLIPER. This model has shown promising results for the forecast of cyclones movement twenty-four hour ahead of landfall.

3.2.1.1.2 Steering and Persistence (STEEPER) Model

Steering Layer: First divergent (anticyclonic) layer in the upper atmosphere is considered to be the steering layer (or floor). This layer varies from cyclone to cyclone depending upon its vertical stratification. "The stronger the storms the higher the steering levels" is the rule, in general.

The STEEPER Model (Debsarma, 1995) is a development over the STP Model. Tropical cyclones are assumed to follow the well-known persistence method and steering wind of the first divergent layer in the Bay of Bengal. Storm positions are obtained from SYNOPTIC charts, radar/ satellite imageries and steering information is taken from the first anticyclonic (divergent) layer atop the last level of cyclonic circulation of Constant Pressure (CP) charts. Then simple dynamics is applied to them for determining motion of the storm. The drawbacks of the STP model have been remedied in the STEEPER model (Debsarma, 1995). In the STEEPER model kriging technique is utilized by using WinSurfer Version-8 to compute the zonal (U-component) and meridional (V-component) components of the steering wind field.

3.2.1.2 Debsarma's Storm Surge Model (1993)

This is a Storm Surge Forecast Model based on Reid (1956) and Breitschneider (1966) empirical formula. If the model is run a LOGO of the Storm Surge Model appears a fierce wind blowing sound is heard until a key is pressed. Then it will ask for maximum expected wind speed Expected Central Pressure (ECP) of the cyclone and point of intersection of the storm track and 200m bathimetric contour. The model will give a tabular forecast for:

1. Chittagong
2. Cox's Bazar
3. Kutubdia
4. Sandwip
5. Hatia and
6. Khulna

In Saffir-Simpson Hurricane Scale (Appendix 13), a 1-5 rating based on a hurricane's present intensity, used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf in the landfall region. Comparing with historical database with the Suffir-Simpson Hurricane Scale and using STP model (Storm Track Prediction) of Cyclone, an intensity Scale for Bangladesh is proposed (Debsarma, 1988).

Also a Storm Surge Forecast (SSF) model (Debsarma, 1993) based on wind speed, central pressure and 200m bathymetric contour for Chittagong, Cox's Bazar, Kutubdia, Sandwip, Hatia, and Khulna can be generated. Table 3.1 presents predicted highest storm surges for those areas based on the SSF model.

Table 3.1 Predictable Storm surge of Bangladesh by Debsarma's Model

SL. No.	Wind Speed (kph) Vmax	Expected Central Pressure (ECP)	Location	Storm Surge (m)	
				Above tide level	Above Mean Sea level
1.	153	976	Chittagong	3.04	6.62
			Cox's Bazar	2.28	4.54
			Kutubdia	2.59	6.21
			Sandwip	3.12	7.61
			Hatia	2.98	6.75
			Khulna	2.61	5.53
2.	177	966	Chittagong	3.93	7.51
			Cox's Bazar	2.97	5.23
			Kutubdia	3.36	6.98
			Sandwip	4.03	8.52
			Hatia	3.86	7.63
			Khulna	3.38	6.30
3.	209	948	Chittagong	5.25	8.23
			Cox's Bazar	3.98	6.24
			Kutubdia	4.50	8.12
			Sandwip	5.38	9.87
			Hatia	5.15	8.92
			Khulna	4.52	7.44
4.	220	942	Chittagong	5.73	9.31
			Cox's Bazar	4.35	6.61
			Kutubdia	4.92	8.54
			Sandwip	5.88	10.37
			Hatia	5.63	9.40
			Khulna	4.94	7.86
5.	249	924	Chittagong	7.08	10.66
			Cox's Bazar	5.40	7.66
			Kutubdia	6.09	9.71
			Sandwip	7.25	11.74
			Hatia	6.95	10.72
			Khulna	6.12	9.04
6.	>250	924	Chittagong	7.13	10.71
			Cox's Bazar	5.43	7.69
			Kutubdia	6.13	9.75
			Sandwip	7.30	11.79
			Hatia	7.00	10.77
			Khulna	6.16	9.08

Compairing Safir Simpson Hurricane Scale and Table 3.1, a cyclone scale for Bangladesh is proposed in Table 3.2.

Bangladesh needs to develop a damage risk level table from previous damage study. Due to limited data identification, the actual damage risk level is not possible. So Saffir-Simpson Hurricane Scale with some modification suggested by expert based on cyclone damage data of 1991 (LGEB, 1991) is adopted as shown in Table 3.3.

Table 3.2 Cyclone Intensity Scale for Bangladesh

Scale Number (Category)	Expected Central Pressure		Wind Speed		Maximum possible Storm Surge (MSL)	
	(mbar)	(in)	(mph)	(kph)	(m)	(ft)
1	>=976	>=28.94	74-95	119-153	<7	<22
2	966-975	28.50-28.91	96-110	154-177	8-9	23-29
3	948-965	27.91-28.47	111-130	178-209	10-11	30-32
4	923-947	27.17-27.88	131-155	210-249	12-13	33-42
5	<924	<27.17	>155	>249	>13	>42

Table 3.3 Details Cyclone Intensity Scale for Bangladesh

Damage Risk Level	Intensity	Description
Very Low Damage Risk (VL)	Category 1	Winds 74-95 mph (64-82 knots or 119-153 km/hr) - Storm surge maximum below 12 ft above normal. No real damage to building structures. Damage primarily to fishing boats, trees near coastal. Some damage to poorly constructed signs. Also, some coastal road flooding and minor pier damage.
Low Damage Risk (L)	Category 2	Winds 96-110 mph (83-95 knots or 154-177 km/hr) - Storm surge may maximum 12-18 feet above normal. Some roofing material, door, and window damage of buildings. Considerable damage to trees with some trees blown down. Somefishing boats missing. Considerable damage to poorly constructed signs, and piers. Small craft in unprotected anchorages break moorings.
Moderate Damage Risk (M)	Category 3	Winds 111-130 mph (96-113 knots or 178-209 km/hr) - Storm surge may reach maximum 16-18 ft above normal. Tin roof, wooden supports blown off. Tin shed cottage industry totally damage. Crack in wall and beam and floor settled of some godown. Some structural damage to small residences and utility buildings with RCC roof and wall crack. Extensive damage to doors and windows of one storey buildings and General damage of doors-windows of some two storey residential buildings. Some damage of boundary wall and steel gate. Some retaining wall washed away and some damage to toe of wall. Wooden jetty totally damage. Some electrical works damage. Major damage to lower floors of structures near the shore.
High Damage Risk (H)	Category 4	Winds 131-155 mph (114-135 knots or 210-249 km/hr) - Storm surge may reach maximum within 18-25 ft above normal. More extensive curtain wall failures with some complete roof structure failures on small residences. Semi pucca tin roof totally destroyed. Roofs blown away and windows-doors damaged of dormitory and community centre. Single storey buildings totally collapse. General damage to interior of cyclone shelter. RCC pillars crack. Doors and windows of two storey cyclone shelter destroy. Complete roof failure of many residential and industrial buildings. Trees and all signs are blown down. Major damage to lower floors of structures near the shore.
Very High Damage Risk (VH)	Category 5	Winds greater than 155 mph (135 knots or 249 km/hr) - Storm surge may maximum greater than 25 ft above normal. Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All trees and signs blown down. Severe and extensive window and door damage. Stairs, auditorium and toilet block severely damage. Some one storey buildings and boundary walls collapse. Some two storey buildings destroy.

* The storm surge height obtained in the model is valid for the shoreline. The height will decay as the surge advances into the the coastal localities.

3.2.2 Tornadoes

A Tornado is a rapidly rotating vortex of air extending ground-ward from a cumulonimbus cloud. Tornadoes can reach wind speeds in excess of 300 mph causing various intensities of destruction within its path. Often tornadoes are related to larger vortex formations and as a result often form in convective cells (CHCDA, 2005).

The Fujita-Pearson Tornado Scale measures the damage severity of a tornado. The historical data of Bangladesh is similar as the Fujita-Pearson Tornado Scale. So for Bangladesh this scale can be adopted. The description of this scale is given in Table 3.4.

Table 3.4 Fujita-Pearson Tornado Scale (after FEMA, 1997)

Scale Value	Wind Speed (mph)	Intensity	Type of Damage
F0	40-72	Light Damage	Some damage to chimneys; tree branches broken off, shallow-rooted trees pushed over, sign boards damaged.
F1	73-112	Moderate Damage	Roof surfaces peeled off; mobile homes pushed off foundations or overturned; moving automobiles pushed off roads.
F2	113-157	Considerable Damage	Roofs torn from houses, mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light-object missiles generated.
F3	158-206	Severe Damage	Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.
F4	207-260	Devastating Damage	Well-constructed houses levelled; structures with weak foundations blown off some distance; cars thrown; large missiles generated.
F5	261-318	Incredible Damage	Strong frame homes lifted off foundations and carried considerable distances to disintegrate; automobiles-size missiles fly through the air in excess of 100 yards; trees debarked.
F6	>318	Inconceivable Damage	These wind speeds have rarely been recorded. The area of damage would be completely obliterated and unrecognizable. Large missiles would be thrown in excess of 100 yards.

3.2.3 Flood

Flooding occurs in floodplains when prolonged rainfall over a short period causes rivers or streams to overflow. Flash floods, specifically, occur within six hours of a rain event, after a dam or levee failure or following a sudden release of water held by a debris jam. In addition, development in the flood hazard area can increase the overall height and speed of flooding bringing it to areas that were not originally susceptible.

3.2.3.1 Flood Classification map of Bangladesh

Depth classification maps rate also similar to flood depth maps, but instead of using a constant depth increment for showing different depths, depths are grouped into different classes. Depth classification maps can be based on flood depth maps or duration depth maps. Figure 3.1 shows a depth classification map based on the flood phase categories for the Tangail compartment using the peak flood levels from the 1993 flood.

Figure 3.1 Depth Classification Map (after FAP25, 1994)

Table 3.5 presents the Bangladesh flood phase classification, which groups flood depths into five classes, F0 to F4 (FAP25, 1994):

Table 3.5 Bangladesh flood phase classification

SL. No.	Class	Flood Phase	Depth Range
1.	F0	Non-flood	< 0.3m including flood-free ground
2.	F1	Shallow Flood	0.3m to 0.9m
3.	F2	Medium Flood	0.9m to 1.8m
4.	F3	Deep Flood	1.8m to 3.6m
5.	F4	Very Deep Flood	>3.6m

No such data exists for whole Bangladesh. It is not possible for this study to establish such table for whole Bangladesh. For proper identification of hazard area such data of flood for whole Bangladesh is needed.

1998 flood is the extreme flooding in Bangladesh. The flood hazard map prepared by FFWC, BWDB Dhaka, has been used as a reference. According to the hazard map the whole area is divided in four zones based on water level as shown in Figure 3.2. Table 3.6 presents four flood water levels of Bangladesh based on 1998 flood.

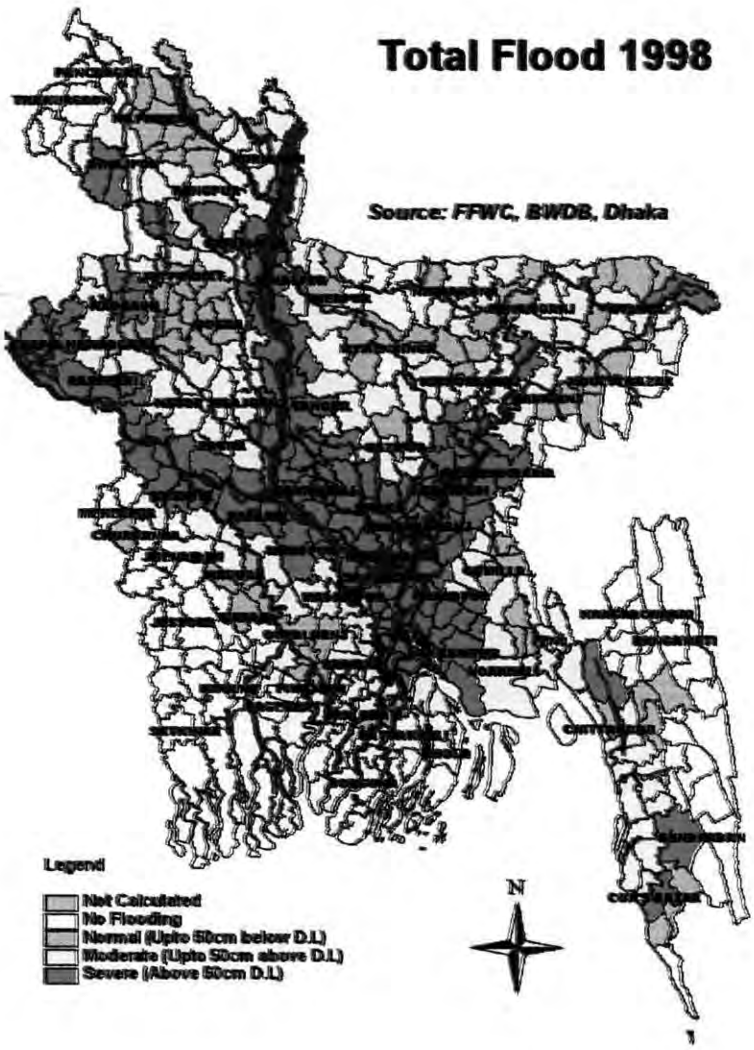


Figure 3.2 1998 flood affected area (FFWC, 1998)

From the data of Flood Forecasting & Warning Centre, Bangladesh, Updated on 13th August, 2007 the maximum water level table shown in Appendix 14.

Table 3.6 Flood Water level of Bangladesh

SL. No.	Area	Water Level
1.	Severe Flooding Area	Above 50cm DL
2.	Moderate Flooding Area	Up to 50cm above DL
3.	Normal Flooding Area	Within 50cm DL
4.	No Flooding Area	Below 50cm DL

No Detailed building damage reports under flooding was recorded so far. Flood intensities in terms of depth of water velocity of flow or time duration of inundation are not yet defined. In the absence of such data, no definite recommendation about damage risk levels could be made. The following damage risks have been drafted by the BMPTC (1997) to develop the Vulnerability Atlas of India, based on understanding of material behavior under submergence. Table 3.7 is used for the intensity of Bangladesh. Comparing the above tables and our historical damage data an intensity table for Bangladesh is proposed as shown in Table 3.8.

Table 3.7 Damage Risk Table for Flood

Sl. No.	Damage Type	Description
1.	Very High Damage Risk (VH)	Total collapse of buildings; roof and some walls collapse; floating away of sheets, thatch, etc; erosion of foundation; severe damage to lifeline structures and systems.
2.	High Damage Risk (H)	Gaps in walls; punching of holes through wall by flowing water; parts of buildings may collapse; light roofs float away; erosion of foundation, sinking or tilting; undercutting of floors, partial roof collapse.
3.	Moderate Damage Risk (M)	Large and deep cracks in walls; bulging of walls; loss of belongings; damage to electric fittings.
4.	Low Damage Risk (VL)	Small cracks in walls; fall of fairly large pieces of plaster.
5.	Very Low Damage Risk (L)	Fine cracks in plaster; fall of small pieces of plaster.

Table 3.8 Flood intensity of Bangladesh

SL No	Area Type	Water Level	Damage Type	Description
1.	Severe Flooding Area		Very High Damage Risk (>3m above DL)	Total collapse of buildings; roof and some walls collapse; floating away of sheets, thatch, etc; erosion of foundation; severe damage to lifeline structures and systems.
		Above 50cm DL	High Damage Risk (<3m above 50cm DL)	Gaps in walls; punching of holes through wall by flowing water; parts of buildings may collapse; light roofs float away; erosion of foundation, sinking or tilting; undercutting of floors, partial roof collapse.

SL No	Area Type	Water Level	Damage Type	Description
2.	Moderate Flooding Area	Up to 50cm Above DL	Moderate Damage Risk	Large and deep cracks in walls; bulging of walls; loss of belongings; damage to Electric fittings.
3.	Normal Flooding Area	Within 50cm DL	Low Damage Risk	Small cracks in walls; fall of fairly large pieces of plaster.
4.	No Flooding Area	Below 50cm DL	Very Low Damage Risk	Fine cracks in plaster; fall of small pieces of plaster.

3.2.4 Earthquakes

Earthquakes are geologic events that involve movement or shaking of the earth's crust. Earthquakes are usually caused by the release of stresses accumulated as a result of the rupture of rocks along opposing fault planes in the earth's outer crust. These fault planes are typically found along borders of the earth's 10 tectonic plates.

The areas of greatest tectonic instability occur at the perimeters of the slowly moving plates, as these locations are subjected to the greatest strains from plates traveling in opposite directions and at different speeds. Deformation along plate boundaries causes strain in the rock and the consequent buildup of stored energy. When the built-up stress exceeds the rocks' strength, a rupture occurs. The rock on both sides of the fracture is snapped, releasing the stored energy and producing seismic waves, generating an earthquake.

Earthquakes are measured in terms of their magnitude and intensity. Magnitude is measured using the Richter scale, an open-ended logarithmic scale that describes the energy release of an earthquake through a measure of shock wave amplitude. Each unit increase in magnitude on the Richter scale corresponds to a 10-fold increase in wave amplitude. Intensity is most commonly measured using the Modified Mercalli Intensity (MMI) Scale. It is a 12-level scale based on direct and indirect measurements of seismic effects. There is another seismic Intensity scale name Japanese seismic intensity Scale, 0-VII levels. The MSK 1964 intensity scale is more comprehensive and describes the intensity of earthquake more precisely. EMS 1998 is the updated scale of MSK scale. In this study EMS 98(European Macroseismic Scale) was used.

CHAPTER 4
VULNERABILITY RISK AREAS OF BANGLADESH DUE TO MULTIPLE NATURAL HAZARDS

4.1 GENERAL

One of the tasks assigned to this study was to identify vulnerable areas with reference to natural hazards causing damage to the housing stock and the related infrastructure, such as earthquake, cyclones, tornadoes, floods etc.

In this regard, the author identified four natural hazards which are the most common and damaging in Bangladesh, namely earthquake, cyclones, tornadoes and floods. It is noted that the zoning maps on micro level for the five hazards are available for the country as a whole. To make the information readily available to the planners, administrators and disaster managers, it was considered necessary that the maps should be prepared on larger scale, district-wise, showing all the administrative units, namely the district boundaries, for easy identification of the areas covered by the zones of various intensity levels.

Furthermore, it was also noted that the census of housing 2001 contains good enough descriptions of the house types with numbers in each district which could be analyzed and tabulated in a form which will be suitable for estimating the risk levels under different types and intensities of natural hazards.

The maps of identification of hazard zone boundaries of each district of the country have been published by different organization. The various house types have been derived from 1991 census of housing related to the predominance of roof and wall materials. A combination of local hazard intensity and vulnerability of existing house types based on observed performance has been used for preparing out risk analysis as indicated in the district-wise tables. The Vulnerability thus provides all information at the micro-level for use by the authorities concerned with natural disaster mitigation, preparedness and preventive actions.

Creating hazard maps will assist us to determine which areas are susceptible to individual hazards or multiple hazards that have been identified. The appropriate decision makers can use maps that depict individual hazards or a combination of hazards. This study identified district wise natural hazards, their hazard risk and finally developed combined hazard map. The multi-hazard maps determine which areas are susceptible to the most destructive hazards in order to determine where to concentrate and fund hazard mitigation measures such as developing property protection ordinances or encouraging development in less hazard-prone areas.

In any programme of disaster prevention, mitigation and preparedness, the first and the foremost task is to identify the vulnerable areas where the impact of natural disasters namely, earthquakes, cyclones, tornadoes and floods could reach disastrous magnitude for the affected communities. Equally important is to identify the man-made buildings and structures and infrastructures which will be exposed to the hazards, to assess the vulnerability of these exposures and determine the disaster risk to the communities. Preparation of the Vulnerability Atlas of Bangladesh is an attempt to fulfill these requirements.

Therefore, with the available information, it became possible for this study to embark on the huge task of preparing the Vulnerability Atlas of Bangladesh. The salient features of the Vulnerability Atlas now available are described in the following articles. Also housing vulnerability tables are described.

4.2 METHODOLOGY

In order to locate highest-risk areas, it may be helpful to first develop a risk-prioritization scheme. It is possible to develop such a scheme using publicly available data, although local data — data collected from local agencies — will almost always be more detailed and more accurate. In this study following natural disasters were studied:

- Tornado
- Earthquake
- Cyclone and
- Flood

Every community has unique or unusual hazards that need to be considered. Historical records and information from local experts is used to provide estimates of the zones or locations potentially at risk to such events. As no digital (geographic information systems or

GIS) data are available for Bangladesh, to construct risk maps showing estimates of hazard extents and magnitudes by digitizing paper maps. Even some paper maps have to be modified to gather data. Following steps were followed for hazard assessment of each district area of Bangladesh:

1. Locate, gather, and process data
2. Assign scores to risk areas (higher rankings should indicate higher risk)
3. Identify high-risk locations (areas with highest scores)
4. Propose a multi hazard map for Bangladesh

4.3 DATA SOURCES

The data were collected from Bangladesh Meteorological Department (BMD), SPARRSO, Disaster Management Bureau (DMB) and concerned non-government organizations (NGO), Cyclone Preparedness Programme (CPP), geological information from the Geological Survey of Bangladesh (GSB). Information from local and environmental organizations, international Journals, local newspapers and many study reports were collected. Personal contacts with experts concerned were also made.

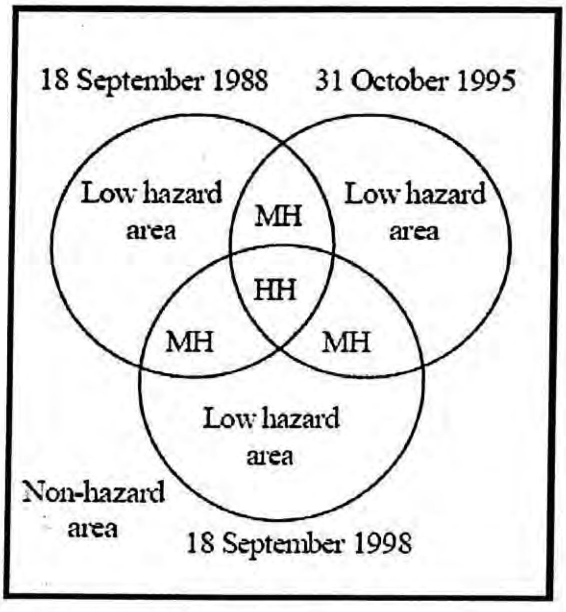
4.4 HAZARD AREA SCORING METHODS

Assign scores within risk areas, where possible. Within risk areas there could be additional boundaries representing varying degrees of risk. These varying degrees of risk should be represented in risk areas both graphically (additional boundaries on the maps) and through some type of relative scoring system (higher scores for higher risk areas). For example, Cyclone maps are generally created for five different categories of storm. Category 1 storms are generally associated with the least severe winds and storm surge while Category 5 storms are considered the most severe for these hazards. Generally, those areas subject to storm surge in the lower category storms are also projected for inundation in all of the higher categories. When developing a relative priority scoring system for storm surge inundation, Category 1 storm surge areas would therefore have the highest risk of being flooded since they are at risk of inundation in all storm events.

The general concept in relative priority scoring system for natural hazard risks is that locations with no consideration for risk will be given a score of 0 and each incremental increase in risk adds 1 point. A multiplier or weighting factor is calculated based on frequency of events (NOAA, 2007).

4.5 CONCEPT OF HAZARD AFFECTED FREQUENCY

Frequency is the occurrence of a disaster in a particular area. To explain this issue for a particular disaster, occurrence of flood in a particular area per year can be used. Estimated flooded areas for September 18, 1988, October 31, 1995, and September 18, 1998 are 34.7, 27.7 and 36.1%, respectively, when the drainage network map was superimposed onto the flood season images. Figure 4.1 shows the concept of the frequency (Islam and Sado, 2000).



MH: Medium hazard area

HH: High hazard area

○: Water area in each image

□: Whole area of Bangladesh

Figure 4.1 Concept for flood-affected frequency (after Islam and Sado, 2000)

The flooded area was estimated after subtracting the normal water area (river, lake, pond, etc.) from total inundated area; it was then converted to percentage of land area (non-water area in dry season) of the whole country. The more occurring number indicates more frequency that is expressed by multiplier for a particular risk area for a particular hazard.

4.6 RELATIVE PRIORITY SCORING SYSTEM FOR NATURAL HAZARD

For a particular area, scores are calculated as follows:

Risk Score (for particular hazard e.g. Cyclone(c)/ Flood (f)/ Tornado (t)/ Earthquake (e)) = Weighting factor (WT (fr)) × Risk (Potential Damage Magnitude).

$$TR\ (c/\ f/\ t/\ e) = WT\ (WT = f\ (fr)) \times R \quad \text{.......................(4.1)}$$

For Cyclone:

$Rci = f\ (w, h, Cp)$

Where i= 0, 1, 2, 3, 4, 5.

w= Wind speed, h= Storm Surge, Cp= Central Pressure.

$WTcj = f\ (fr)$

fr = Frequency.

Where j= 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

$$TRc = Rci \times 0.1WTcj \quad \text{.......................................(4.2)}$$

For Tornado:

$Rti = f\ (w)$

Where i= 0 and 5.

w= Wind speed.

$WTtj = f\ (fr)$

fr = Frequency.

Where j= 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

$$TRti = Rti \times 0.1WTtj \quad \text{.................................... (4.3)}$$

For Flood:

$Rfi = f\ (hw)$

Where i= 1, 2, 3, 4, 5.

hw= Water level.

$WTfj = f\ (fr)$

f_r = Frequency.

Where j= 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

$$TRti = Rti \times 0.1WTfj \quad \text{....................................(4.4)}$$

For Earthquake:

$Rei = f\ (m, p)$

Where i= 2, 3, 4.

m = Magnitude, p= Peak Ground Acceleration.

$WTej = f\ (fr)$

fr = Frequency.

Where j= 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

$$TRei = Rei \times 0.1WTej \quad \text{..(4.5)}$$

Total Risk Score:

$$TR = \sum_{k=1}^{n} TR_k \quad \text{...} \quad (4.6)$$

where

k= 1 is for Cyclone.

k=2 is for Tornado.

k=3 is for Earthquake

k=4 is for flood

k=n disaster.

In these equations, two of the hazards have locations with a risk score of 0 (Cyclone and Tornado). In case of Cyclone, the maximum extent of the hazard risk does not realistically include the entire county and is limited to proximity to coastal waters. Tornado may always have high risk, i.e score 5 for all the tornado prone area. For the locations with no consideration of risk for Tornado was given a score of 0. Again earthquake hazard of Bangladesh was expressed as minimum by 2 and as maximum by 4.

The minimum risk score for each of the remaining hazards is 1 since there is some potential that each of these hazards could occur anywhere throughout each county. This scoring system has been used according to our district-based database. For particular district of Bangladesh the hazard for Earthquake, Tornado, Cyclone and Flood is calculated. Then adding those scores, total risk score for each of the 64 districts was found.

4.7 LOCATING THE HAZARD

4.7.1 Tornado

The existing tornado map of DMB, GoB (DMB, 1993), is shown in Figure 2.30 in Literature chapter. In the map the areas affected by Tornadoes are identified. The basis of this map is not clear. For this study a new tornado map is digitised based on frequency or number of occurrence from the compiled database, which contains Tornado data from 1875-2007. From the database, the frequency of the tornado is calculated by the occurrence of Tornado.

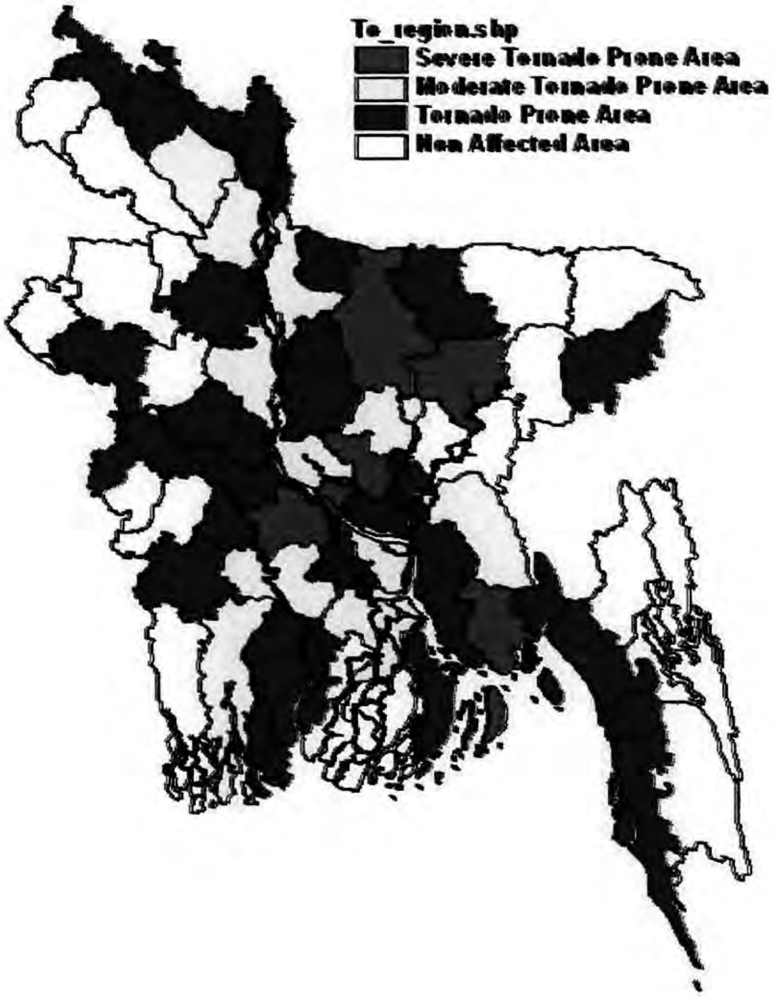


Figure 4.2 Proposed Tornado Hazard Maps of Bangladesh

The proposed digitized district wise Tornado map is also shown in Figure 4.2. Bangladesh is divided into four zones as shown in Figure 4.2 and Table 4.1.

Table 4.1 Risk vulnerability Table for Tornado

SL. No.	Area	No. of Occurrence/ Frequency	Risk Score
1.	Severe Tornado Prone Area	> 4	5
2.	Moderate Tornado Prone Area	3-2	
3.	Tornado Prone Area	1	
4.	Non Affected Area	0	0

The vulnerability table is proposed based on the Fujita-Pearson Tornado scale as below:

Table 4.2 Tornado Vulnerability Table

Scale Value	Wind Speed (mph)	Intensity	Vulnerability	
F0	40-72	Light Damage	Very Low	VL
F1	73-112	Moderate Damage	Low	L
F2	113-157	Considerable Damage	Moderately Low	ML
F3	158-206	Severe Damage	Moderate	M
F4	207-260	Devastating Damage	Moderately High	MH
F5	261-318	Incredible Damage	High	H
F6	>318	Inconceivable Damage	Very High	VH

In the existing tornado map of Bangladesh (DMB, 1993), the areas affected by Tornadoes are identified. The basis of the map can not be found. So a new tornado map has been developed based on frequency or no of occurrence in the period of 1875-2007 (Appendix 6 and 7).

The hazard area of Tornado is identified on the basis of the database and digitized according to the occurrence or frequency of the Tornado. The area is divided into by four zones as given in Table 4.3. High Risk, i.e 5 scores for all the tornado prone area. Because there will have possibility of occur any tornado of any scale value or wind speed. For the locations with no consideration of risk has been given a score of 0. The number of values that fall in to a particular class is known as frequency. Table 4.4 is the table of Weighting Factor based on frequency or occurrence of events, i.e if the number of occurrence of a tornado is 6 then the Weighting Factor will be 1.6. Calculating by equation 4.3 Tornado risk table for all districts of Bangladesh has been shown in Table 4.5.

Table 4.3 Tornado Risk Score Table

SL. No.	Area	No. of Occurrence/ Frequency	Risk Score
1.	Severe Tornado Prone Area	> 4	5
2.	Moderate Tornado Prone Area	3-2	
3.	Tornado Prone Area	1	
4.	Non Affected Area	0	0(1)

Table 4.4 Tornado Weighting Factor Table

SL. No.	Risk Area	No of Occurence/ Frequency	Weighting Factor
1.	Tornado Prone Area	1	1.1
2.	Moderate Tornado Prone Area	2	1.2
		3	1.3
3.	Severe Tornado Prone Area	4	1.4
		5	1.5
		6	1.6
		7	1.7
		8	1.8
		9	1.9
		10	2.0

Table 4.5 Tornado Risk Table for all Districts of Bangladesh

SL. No.	District Name	Frequency	Weighting Factor	Risk	Total Risk
1.	Dhaka	8	1.8	5	9.0
2.	Narayanganj	1	1.1	5	5.5
3.	Munshiganj	2	1.2	5	6.0
4.	Narsingdi	0	1.0	1	1.0
5.	Manikganj	4	1.4	5	7.0
6.	Gazipur	4	1.4	5	7.0
7.	Mymensingh	8	1.8	5	9.0
8.	Kishoreganj	5	1.5	5	7.5
9.	Jamalpur	4	1.4	5	7.0
10.	Sherpur	1	1.1	5	5.5
11.	Netrokona	1	1.1	5	5.5
12.	Tangail	2	1.2	5	6.0
13.	Faridpur	5	1.5	5	7.5
14.	Madaripur	1	1.1	5	5.5
15.	Shariatpur	3	1.3	5	6.5
16.	Rajbari	1	1.1	5	5.5
17.	Gopalganj	3	1.3	5	6.5
18.	Chittagong	1	1.1	5	5.5
19.	Rangmati	0	1.0	1	1.0
20.	Cox's bazar	1	1.1	5	5.5
21.	Bandaban	0	1.0	1	1.0
22.	Khgrachari	0	1.0	1	1.0
23.	Noakhali	6	1.6	5	8.0
24.	Lakshmipur	1	1.1	5	5.5
25.	Feni	1	1.1	5	5.5
26.	Comilla	4	1.4	5	7.0
27.	Chandpur	1	1.1	5	5.5
28.	Brahmanbaria	0	1.0	1	1.0
29.	Rajshahi	1	1.1	5	5.5
30.	Nawabganj	0	1.0	1	1.0
31.	Natore	0	1.0	1	1.0
32.	Naogaon	0	1.0	1	1.0
33.	Pabana	2	1.2	5	6.0
34.	Sirajganj	4	1.4	5	7.0
35.	Bogra	1	1.1	5	5.5
36.	Joypurhat	0	1.0	1	1.0
37.	Rangpur	4	1.4	5	6.0
38.	Kurigram	1	1.1	5	5.5
39.	Nilphamari	2	1.2	5	6.0
40.	Lalmonirhat	2	1.2	5	6.0
41.	Gaibandha	4	1.4	5	7.0
42.	Dinajpur	0	1.0	1	1.0
43.	Thakurgoan	0	1.0	1	1.0
44.	Panchagarh	1	1.1	5	5.5
45.	Khulna	3	1.3	5	6.5
46.	Bagerhat	2	1.2	5	6.0
47.	Satkhira	0	1.0	1	1.0
48.	Jessore	2	1.2	5	6.0
49.	Magura	2	1.2	5	6.0
50.	Jhenaidah	0	1.0	1	1.0
51.	Narail	4	1.4	5	7.0
52.	kushtia	2	1.2	5	6.0
53.	Meherpur	1	1.1	5	5.5
54.	Chuadanga	0	1.0	1	1.0

SL. No.	District Name	Frequency	Weighting Factor	Risk	Total Risk
55.	Barishal	3	1.3	5	6.5
56.	Jhalkati	0	1.0	1	1.0
57.	Pirojpur	1	1.1	5	5.5
58.	Potualkali	0	1.0	1	1.0
59.	Barguna	0	1.0	1	1.0
60.	Bhola	2	1.2	5	6.0
61.	Sylhet	0	1.0	1	1.0
62.	Sunamganj	0	1.0	1	1.0
63.	Habiganj	0	1.0	1	1.0
64.	Moulvibazar	1	1.1	5	5.5

4.7.2 Earthquake

The peak ground acceleration (PGA), i.e., maximum acceleration experienced by the ground during shaking, is one way of quantifying the severity of the ground shaking. Approximate empirical correlations are available between the MM intensities and the PGA that may be experienced as Table 4.6 (Bolt, 1993).

Table 4.6 PGAs during shaking of different intensities

MMI	V	VI	VII	VIII	IX	X
PGA(g)	0.03-0.04	0.06-0.07	0.10-0.15	0.25-0.30	0.50-0.55	>0.60

The proposed Seismic-zoning map of Bangladesh proposed by Ansary and Sharfuddin (2001) is shown in the Figure 4.3.

Comparing the Table 4.6 and the seismic zoning map with different Earthquake intensity, a Vulnerability Table for Earthquakes of Bangladesh has been proposed in Table 4.7.

Table 4.7 Proposed Vulnerability Table of Earthquake for Bangladesh

SL. No.	Zone	PGA	Intensity EMS	Risk Score
1.	Zone-1	0.075g	VI	2
2.	Zone-2	0.15g	VII	3
3.	Zone-3	0.25g	VIII	4

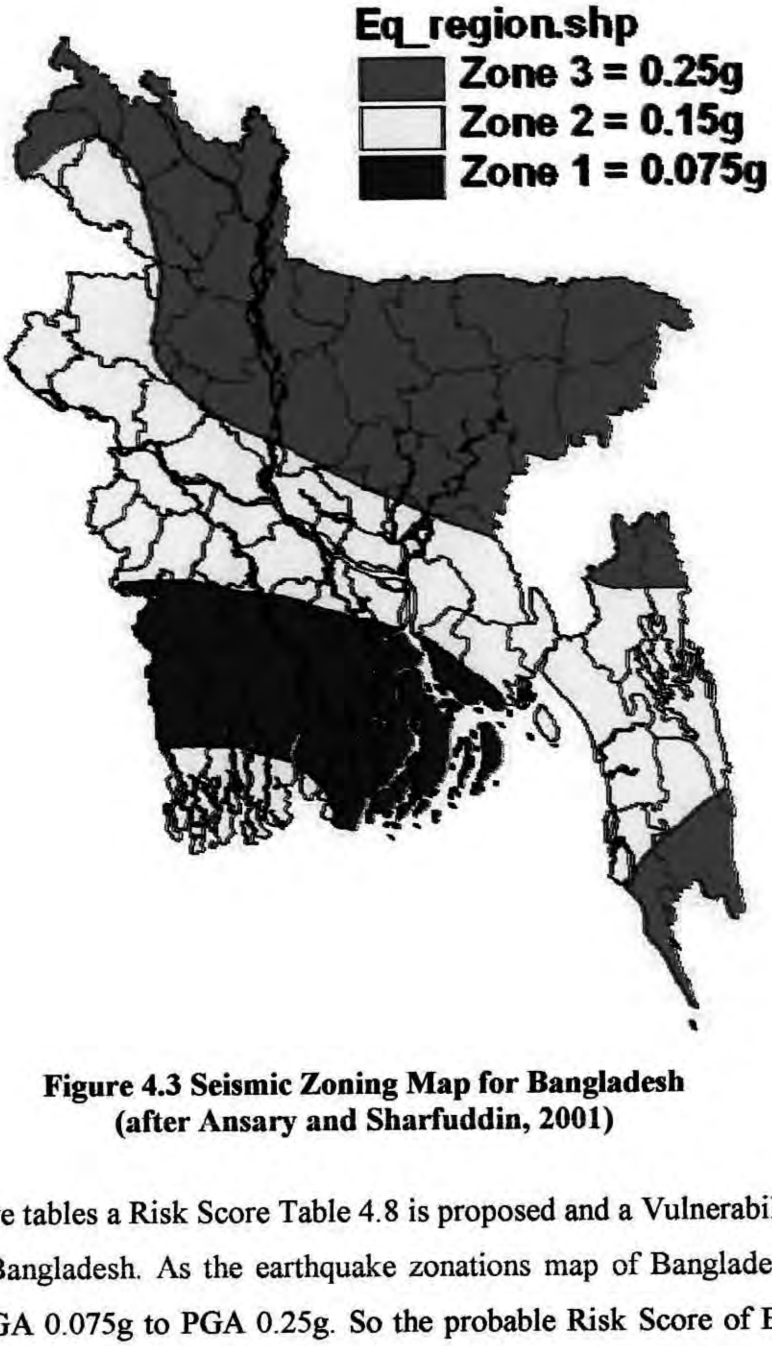


Figure 4.3 Seismic Zoning Map for Bangladesh (after Ansary and Sharfuddin, 2001)

Comparing the above tables a Risk Score Table 4.8 is proposed and a Vulnerability Table 4.9 for Earthquake of Bangladesh. As the earthquake zonations map of Bangladesh the whole Bangladesh is in PGA 0.075g to PGA 0.25g. So the probable Risk Score of Bangladesh is from 2 to 4 as in Table 4.9.

Table 4.8 Proposed Risk Score Table of Earthquake

SL. No.	Intensity EMS	Intensity MMI	Vulnerability		Risk Score
1.	5	V	Very Low	VL	1
2.	6	VI	Low	L	2
3.	7	VII	Moderate	M	3
4.	8	VIII	High	H	4
5.	9	IX	Very High	VH	5

Table 4.9 Proposed Vulnerability Table of Earthquake for Bangladesh

SL. No.	Zone	Intensity MMI	Intensity EMS	Magnitude M	PGA	Risk Score
1.	Zone-1	VI	6	5	0.075g	2
2.	Zone-2	VII	7	6	0.15g	3
3.	Zone-3	VIII	8	7	0.25g	4

Based on the Earthquake data from 1869-2006, the frequency of the magnitude of Earthquake M>5 the weighting factors are classified as shown in Table 4.10. Table 4.11 shows the district wise zoning occurrence/ frequency of earthquake M>5 of Bangladesh and the categories of vulnerability with earthquake risk score.

Table 4.10 Earthquake Weighting Factor Table

SL. No.	Frequency/ No. of Occurence	Weighting Factor
1.	1-3	1.1
2.	3-5	1.2
3.	6-8	1.3
4.	9-12	1.4
5.	13-15	1.5
6.	16-18	1.6
7.	19-21	1.7
8.	22-24	1.8
9.	25-27	1.9
10.	28-30	2.0

Based on the Earthquake data from 1869-2006 (Eartthquake Magnitude >5) the frequency is calculated and the weighting factor is classifies then from the proposed risk table of earthquake the total risk of earthquake for all districts of Bangladesh is calculated by the equation 4.5. The tabular form of the risk for all districts of Bangladesh is shown in Table 4.12.

Table 4.11 Zone and District wise No. of Occurrence/ Frequency

SL. No.	Zone	District Name	Frequency (M>=5)	Risk Score	Vulnerability
1.	Zone-1	Jessore	2	2	Moderate (M)
		Gopalganj	3		
		Khulna	3		
		Pirojpur	3		
		Barguna	3		
		Jhalkati	3		
		Narail	4		
		Barishal	3		
		Bhola	3		
		Potualkali	3		
		Satkhira	3		
		Bagerhat	3		

SL. No.	Zone	District Name	Frequency (M>=5)	Risk Score	Vulnerability
2.	Zone-2	Narayanganj	3	3	High (H)
		Munshiganj	4		
		Manikganj	6		
		Faridpur	4		
		Madaripur	3		
		Shariatpur	3		
		Rajbari	7		
		Chittagong	6		
		Noakhali	2		
		Lakshmipur	1		
		Feni	3		
		Comilla	4		
		Chandpur	4		
		Rajshahi	4		
		Nawabganj	2		
		Natore	6		
		Naogaon	4		
		Pabana	8		
		Dhaka	4		
		Magura	4		
		Jhenaidah	2		
		kushtia	5		
		Meherpur	4		
		Chuadanga	3		
		Dinajpur	3		
3.	Zone-3	Narsingdi	5	4	Very High (VH)
		Gazipur	8		
		Mymensingh	11		
		Kishoreganj	10		
		Jamalpur	19		
		Sherpur	21		
		Netrokona	19		
		Tangail	9		
		Rangmati	6		
		Cox's bazar	6		
		Bandaban	8		
		Khgrachari	5		
		Brahmanbaria	5		
		Sylhet	16		
		Sunamganj	18		
		Habiganj	12		
		Moulvibazar	17		
		Sirajganj	8		
		Bogra	10		
		Joypurhat	8		
		Lalmonirhat	9		
		Gaibandha	13		
		Kurigram	16		
		Rangpur	7		
		Nilphamari	3		
		Thakurgoan	3		
		Panchagarh	3		

Table 4.12 Earthquake Risk Table for all Districts of Bangladesh

SL No	District Name	Frequency	Weighting Factor	Risk	Total Risk
1.	Dhaka	4	1.2	4	4.8
2.	Narayanganj	3	1.1	4	4.4
3.	Munshiganj	4	1.2	4	4.8
4.	Narsingdi	5	1.2	5	6.0
5.	Manikganj	6	1.3	4	5.2
6.	Gazipur	8	1.3	5	6.5
7.	Mymensingh	11	1.4	5	7.0
8.	Kishoreganj	10	1.4	5	7.0
9.	Jamalpur	19	1.7	5	8.5
10.	Sherpur	21	1.7	5	8.5
11.	Netrokona	19	1.7	5	8.5
12.	Tangail	9	1.4	5	7.0
13.	Faridpur	4	1.2	4	4.8
14.	Madaripur	3	1.1	4	4.4
15.	Shariatpur	3	1.1	4	4.4
16.	Rajbari	7	1.3	4	5.2
17.	Gopalganj	3	1.1	3	3.3
18.	Chittagong	6	1.3	4	5.2
19.	Rangmati	6	1.3	5	6.5
20.	Cox's bazar	6	1.3	5	6.5
21.	Bandaban	8	1.3	5	6.5
22.	Khgrachari	5	1.2	5	6.0
23.	Noakhali	2	1.1	4	4.4
24.	Lakshmipur	1	1.1	4	4.4
25.	Feni	3	1.1	4	4.4
26.	Comilla	4	1.2	4	4.8
27.	Chandpur	4	1.2	4	4.8
28.	Brahmanbaria	5	1.2	5	6.0
29.	Rajshahi	4	1.2	4	4.8
30.	Nawabganj	2	1.1	4	4.4
31.	Natore	6	1.3	4	5.2
32.	Naogaon	4	1.2	4	4.8
33.	Pabana	8	1.3	4	5.2
34.	Sirajganj	8	1.3	5	6.5
35.	Bogra	10	1.4	5	7.0
36.	Joypurhat	8	1.3	5	6.5
37.	Rangpur	7	1.3	5	6.5
38.	Kurigram	16	1.6	5	8.0
39.	Nilphamari	3	1.1	5	5.5
40.	Lalmonirhat	9	1.4	5	7.0
41.	Gaibandha	13	1.5	5	7.5
42.	Dinajpur	3	1.1	4	4.4
43.	Thakurgoan	3	1.1	5	5.5
44.	Panchagarh	3	1.1	5	5.5
45.	Khulna	3	1.1	3	3.3
46.	Bagerhat	3	1.1	3	3.3
47.	Satkhira	3	1.1	3	3.3
48.	Jessore	2	1.1	3	3.3
49.	Magura	4	1.2	4	4.8
50.	Jhenaidah	2	1.1	4	4.4
51.	Narail	4	1.2	3	3.6
52.	kushtia	5	1.2	4	4.8
53.	Meherpur	4	1.2	4	4.8

SL No	District Name	Frequency	Weighting Factor	Risk	Total Risk
54.	Chuadanga	3	1.1	4	4.4
55.	Barishal	3	1.1	3	3.3
56.	Jhalkati	3	1.1	3	3.3
57.	Pirojpur	3	1.1	3	3.3
58.	Potualkali	3	1.1	3	3.3
59.	Barguna	3	1.1	3	3.3
60.	Bhola	3	1.1	3	3.3
61.	Sylhet	16	1.6	5	8.0
62.	Sunamganj	18	1.6	5	8.0
63.	Habiganj	12	1.4	5	7.0
64.	Moulvibazar	17	1.6	5	8.0

4.7.3 Cyclone

From the cyclone affected area map of Bangladesh prepared by SPARRSO, a cyclone risk map of Bangladesh was developed in 1993 which is shown in Figure 4.4.

Comparing with the Saffir-Simpson Hurricane Intensity Scale with the damage database of Bangladesh (LGEB, 1991), a cyclone risk area table for Bangladesh was proposed as shown in Table 4.13. The area of Bangladesh categorizes in four areas and the risk score for those area types is shown in table 4.13. Both the cyclone surge high risk and risk area are in risk score of 5 and the high wind area is in low risk area scored 1. And none affected area is scored 0 for cyclone.

Table 4.13 Cyclone Risk Area of Bangladesh

SL No	Risk Area	Category with storm surge		Risk Score	Vulnerability
		Storm surge	Category		
1.	High Risk Area	Above 1m	Category 4 and 5	5	Very High
			Category 3	4	Very High
			Category 2&1	3	Very High
2.	Risk Area	Below 1m	-	2	Very High
3.	High Wind Area	Storm Surge buffer		1	Low
4.	Non Affected Area	-		0	None

Based on the Cyclone data from 1584-2004 considering the frequency of cyclone the weighting factor table is shown in Figure 4.14. The more number of frequencies the more number of weighting factor.

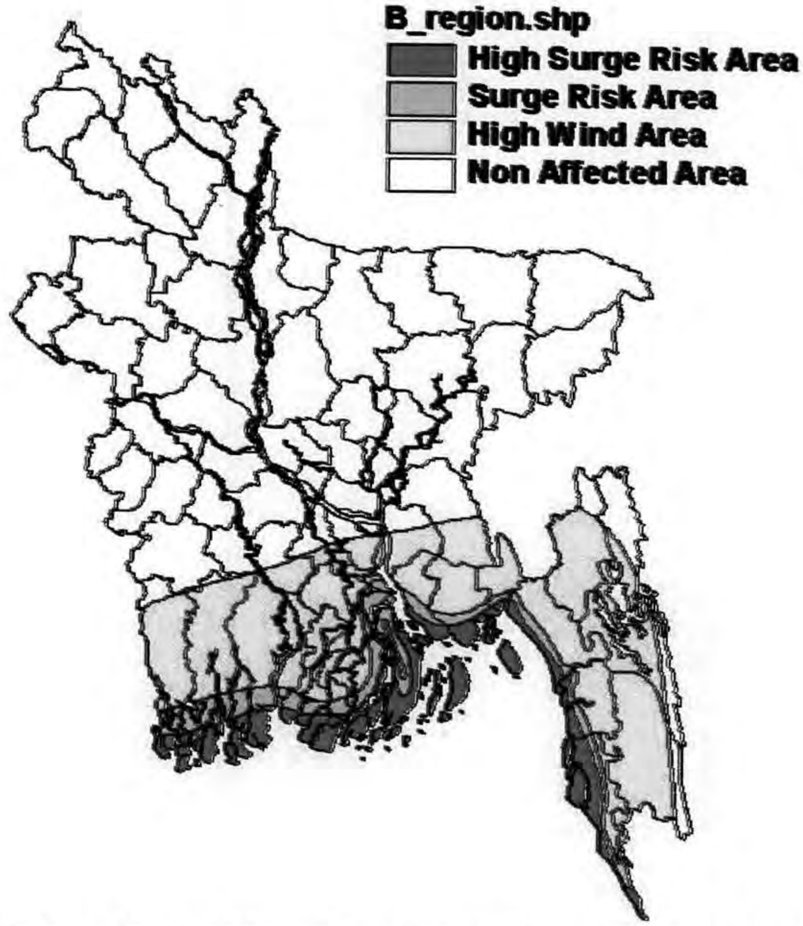


Figure 4.4 Cyclone Hazard Map of Bangladesh (after SPARSSO, 1993)

Table 4.14 Cyclone Weighting Factor Table

SL. No.	No. of Occurence/ Frequency	Weighting Factor
1.	1-4	1.1
2.	5-8	1.2
3.	9-12	1.3
4.	13-16	1.4
5.	17-20	1.5
6.	21-24	1.6
7.	25-28	1.7
8.	29-32	1.8
9.	33-36	1.9
10.	37-40	2.0

Based on the Cyclone data from 1584-2004 & focused the 1991 cyclone the risk score for individual districts of Bangladesh are given in Table 4.15.

From Table 4.13, 4.14 and 4.15 a risk table for Cyclone of Bangladesh has been proposed. The district consider under high risk area which is under both the high risk area and risk area of cyclone. From the equation 4.2 the total risk of cyclone is calculated and shown in the table 4.16.

Table 4.15 Cyclone Risk Score for indivisual Districts of Bangladesh

SL. No.	Zone	District Name	Frequency	Risk Score
1.	High Risk Area	Chittagong	32	5
		Cox's bazar	25	5
		Khulna	19	5
		Barishal	21	5
		Noakhali	18	5
		Potualkali	12	5
		Bagerhat	6	5
		Feni	1	5
		Barguna	1	5
		Bhola	5	5
		Satkhira	5	5
		Lakshmipur	-	5
2.	Risk Area	Chittagong	32	5
		Cox's bazar	25	5
		Khulna	19	5
		Barisha	21	5
		Noakhali	18	5
		Potualkal	12	5
		Bagerhat	6	5
		Feni	1	5
		Barguna	1	5
		Bhola	5	5
		Satkhira	5	5
		Lakshmipur	0	5
3.	High Wind Area	Chittagong	32	1
		Cox's bazar	25	1
		Khulna	19	1
		Barisha	21	1
		Noakhali	18	1
		Potualkal	12	1
		Bagerhat	6	1
		Feni	1	1
		Lakshmipur	0	1
		Barguna	1	1
		Satkhira	5	1
		Pirojpur	0	1
		Comilla	1	1
		Chandpur	0	1
		Gopalganj	0	1
		Jhalkati	0	1
		Madaripur	0	1
		Shariatpur	0	1
		Rangmati	0	1
		Bandaban	0	1
		Khagrachari	0	1

SL. No.	Zone	District Name	Frequency	Risk Score
4.	Non affected Area	Magura	0	0
		Jhenaidah	0	0
		kushtia	0	0
		Meherpur	0	0
		Habiganj	0	0
		Moulvibazar	0	0
		Sirajganj	0	0
		Bogra	0	0
		Joypurhat	0	0
		Lalmonirhat	0	0
		Gaibandha	0	0
		Kurigram	0	0
		Rangpur	0	0
		Nilphamari	0	0
		Thakurgoan	0	0
		Panchagarh	0	0
		Narayanganj	0	0
		Natore	0	0
		Nawabganj	0	0
		Rajshahi	0	0
		Narail	0	0
		Jessore	0	0
		Rajbari	0	0
		Faridpur	0	0
		Manikganj	0	0
		Munshiganj	0	0
		Tangail	0	0
		Netrokona	0	0
		Sherpur	0	0
		Jamalpur	0	0
		Kishoreganj	0	0
		Chuadanga	0	0
		Mymensingh	0	0
		Naogaon	0	0
		Pabana	0	0
		Dhaka	0	0
		Gazipur	0	0
		Narsingdi	0	0
		Dinajpur	0	0

Table 4.16 Cyclone Risk Table for all Districts of Bangladesh

SL No	District Name	Frequency	Weighting Factor	Risk	Total Risk
1.	Dhaka	0	1.0	0	0.0
2.	Narayanganj	0	1.0	0	0.0
3.	Munshiganj	0	1.0	0	0.0
4.	Narsingdi	0	1.0	0	0.0
5.	Manikganj	0	1.0	0	0.0
6.	Gazipur	0	1.0	0	0.0
7.	Mymensingh	0	1.0	0	0.0
8.	Kishoreganj	0	1.0	0	0.0
9.	Jamalpur	0	1.0	0	0.0
10.	Sherpur	0	1.0	0	0.0
11.	Netrokona	0	1.0	0	0.0
12.	Tangail	0	1.0	0	0.0

SL No	District Name	Frequency	Weighting Factor	Risk	Total Risk
13.	Faridpur	0	1.0	0	0.0
14.	Madaripur	0	1.0	1	1.0
15.	Shariatpur	0	1.0	1	1.0
16.	Rajbari	0	1.0	0	0.0
17.	Gopalganj	0	1.0	1	1.0
18.	Chittagong	32	1.8	5	9.0
19.	Rangmati	0	1.0	1	1.0
20.	Cox's bazar	25	1.7	5	8.5
21.	Bandaban	0	1.0	1	1.0
22.	Khgrachari	0	1.0	1	1.0
23.	Noakhali	18	1.5	5	7.5
24.	Lakshmipur	0	1.0	5	5.0
25.	Feni	1	1.1	5	5.5
26.	Comilla	1	1.1	1	1.1
27.	Chandpur	2	1.1	1	1.1
28.	Brahmanbaria	0	1.0	0	0.0
29.	Rajshahi	0	1.0	0	0.0
30.	Nawabganj	0	1.0	0	0.0
31.	Natore	0	1.0	0	0.0
32.	Naogaon	0	1.0	0	0.0
33.	Pabana	0	1.0	0	0.0
34.	Sirajganj	0	1.0	0	0.0
35.	Bogra	0	1.0	0	0.0
36.	Joypurhat	0	1.0	0	0.0
37.	Rangpur	0	1.0	0	0.0
38.	Kurigram	0	1.0	0	0.0
39.	Nilphamari	0	1.0	0	0.0
40.	Lalmonirhat	0	1.0	0	0.0
41.	Gaibandha	0	1.0	0	0.0
42.	Dinajpur	0	1.0	0	0.0
43.	Thakurgoan	0	1.0	0	0.0
44.	Panchagarh	0	1.0	0	0.0
45.	Khulna	19	1.5	5	7.5
46.	Bagerhat	6	1.2	5	6.0
47.	Satkhira	5	1.2	5	6.0
48.	Jessore	0	1.0	0	0.0
49.	Magura	0	1.0	0	0.0
50.	Jhenaidah	0	1.0	0	0.0
51.	Narail	0	1.0	0	0.0
52.	kushtia	0	1.0	0	0.0
53.	Meherpur	0	1.0	0	0.0
54.	Chuadanga	0	1.0	0	0.0
55.	Barishal	21	1.6	5	8.0
56.	Jhalkati	0	1.0	1	1.0
57.	Pirojpur	0	1.0	1	1.0
58.	Potualkali	12	1.3	5	6.5
59.	Barguna	1	1.1	5	5.5
60.	Bhola	5	1.2	5	6.0
61.	Sylhet	0	1.0	0	0.0
62.	Sunamganj	0	1.0	0	0.0
63.	Habiganj	0	1.0	0	0.0
64.	Moulvibazar	0	1.0	0	0.0

4.7.4 Flood

Model-GIS interface and Digital Elevation Models (DEM) are widely used to assess risk and development of floodplain zoning maps all over the world. The main constraint to developing such maps in Bangladesh 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 the flood prone areas (Hossain, 2004).

1998 flood is the extreme flooding of Bangladesh. The 1998 flood hazard map prepared by FFWC, BWDB Dhaka, has been used as a reference. According to the hazard map the whole area is divided in four zones based on water level. The map is shown in Figure 4.5. Table 4.17 shows different flood level of Bangladesh. The damage risks for flooding have been developed by the Vulnerability Atlas of India (BMTPC, 1997) based on material behavior under submergence. Comparing with flood water level of Bangladesh with the Vulnerability Atlas of India, a flood risk table for Bangladesh was proposed as shown in Table 4.18.

Table 4.17 Flood Water level of Bangladesh

SL. No.	Area	Water Level
1.	Severe Flooding Area	Above 50cm DL
2.	Moderate Flooding Area	Up to 50cm above DL
3.	Normal Flooding Area	Within 50cm DL
4.	Non Flooding Area	Below 50cm DL

Table 4.18 Flood Risk Table for Bangladesh

SL.No.	Area Type	Water Level	Damage Type	Risk Score
1.	Severe Flooding Area	Above 50cm D.L	Very High Damage Risk (>3m above D.L)	5
			High Damage Risk (<3m above 50cm D.L)	4
2.	Moderate Flooding Area	Up to 50cm Above DL	Moderate Damage Risk	3
3.	Normal Flooding Area	Within 50cm DL	Low Damage Risk	2
4.	No Flooding Area	Below 50cm DL	Very Low Damage Risk	1

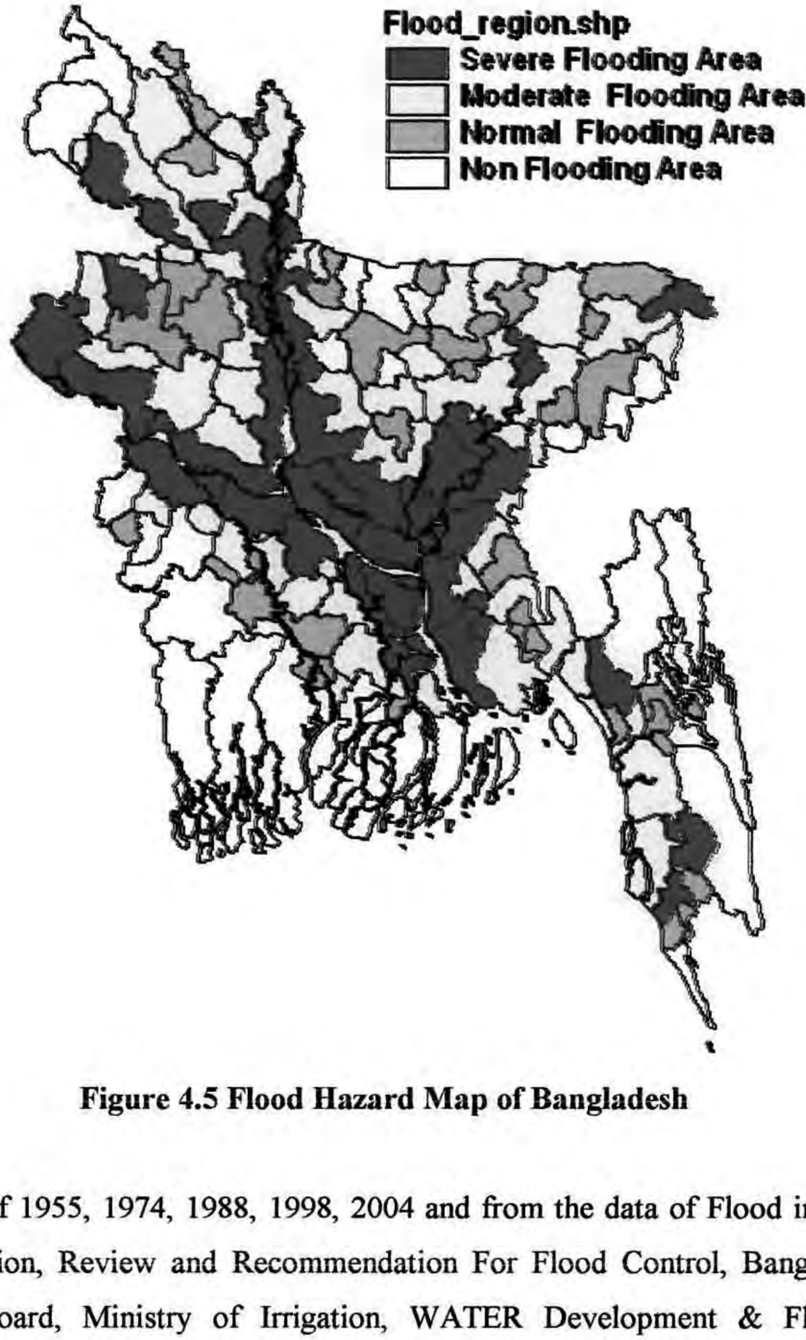


Figure 4.5 Flood Hazard Map of Bangladesh

From the Map of 1955, 1974, 1988, 1998, 2004 and from the data of Flood in Bangladesh, 1987, Investigation, Review and Recommendation For Flood Control, Bangladesh Water Development Board, Ministry of Irrigation, WATER Development & Flood Control, December, 1987 and Annual Flood Report 1991, Flood Forecasting and warning Division, Surface Water Hydrology-2, BWDB, Dhaka, UNDP/WMO- BGD/88/013, 29th February 1991, Dhaka. (BWDB 1987, 1991), the flood affected area of different districts of Bangladesh of different flood year has been calculated. Then from the above maps the author proposes the District frequency/ occurence Table 4.19.

The flood type in different districts are classified from the table 4.18 are also shown in Table 4.19.

Table 4.19 District wise Flood Frequency/ Occurrence in different Flood Year of Bangladesh

SL. No.	District Name	Type of Flood	1955 (34%)	1974 (36%)	1987 (39%)	1988 (61%)	1991 (19%)	1998 (68%)	2004 (24%)
1.	Dhaka	Severe	√	√	√	√	×	√	√
2.	Narayanganj	Severe	√	√	√	√	×	√	√
3.	Munshiganj	Severe	√	√	×	√	×	√	√
4.	Narsingdi	Severe	√	√	√	√	×	√	√
5.	Manikganj	Severe	√	√	√	√	×	√	√
6.	Gazipur	Moderate	√	√	√	√	×	√	√
7.	Mymensingh	Moderate	√	√	√	√	√	√	√
8.	Kishoreganj	Severe	√	√	√	√	√	√	√
9.	Jamalpur	Severe	√	√	√	√	√	√	√
10.	Sherpur	Moderate	√	√	√	√	×	√	√
11.	Netrokona	Moderate	√	√	√	√	×	√	√
12.	Tangail	Severe	√	√	√	√	√	√	√
13.	Faridpur	Severe	√	√	√	√	×	√	√
14.	Madaripur	Severe	√	√	√	√	×	√	√
15.	Shariatpur	Severe	√	√	√	√	×	√	√
16.	Rajbari	Severe	√	√	√	√	×	√	√
17.	Gopalganj	Moderate	√	√	√	√	×	√	√
18.	Chittagong	Severe	√	√	√	×	√	√	×
19.	Rangmati	Very Low	×	×	×	×	×	√	×
20.	Cox's bazar	Severe	×	√	√	×	×	√	×
21.	Bandaban	Severe	×	×	√	×	×	√	×
22.	Khgrachari	Very Low	×	×	×	×	×	×	×
23.	Noakhali	Moderate	√	√	√	×	×	√	×
24.	Lakshmipur	Severe	√	√	√	√	×	√	×
25.	Feni	Moderate	√	√	√	×	×	√	×
26.	Comilla	Severe	√	√	√	×	×	√	√
27.	Chandpur	Severe	√	√	√	√	√	√	√
28.	Brahmanbaria	Severe	√	√	√	√	×	√	√
29.	Rajshahi	Severe	√	×	√	√	×	√	√
30.	Nawabganj	Severe	×	×	√	√	√	√	√
31.	Natore	Severe	√	√	√	√	×	√	√
32.	Naogaon	Severe	√	×	√	√	√	√	√
33.	Pabana	Severe	√	√	√	√	×	√	√
34.	Sirajganj	Severe	√	√	√	√	×	√	√
35.	Bogra	Severe	√	√	√	√	×	√	√
36.	Joypurhat	Moderate	×	√	√	×	×	√	×
37.	Rangpur	Severe	√	√	√	√	√	√	×
38.	Kurigram	Severe	√	√	√	√	√	√	√
39.	Nilphamari	Moderate	√	√	√	×	√	√	×
40.	Lalmonirhat	Moderate	×	√	√	√	×	√	×
41.	Gaibandha	Severe	√	√	√	√	×	√	√
42.	Dinajpur	Severe	×	√	√	×	√	×	×
43.	Thakurgoan	Very Low	×	×	√	×	×	×	×
44.	Panchagarh	Very Low	×	×	√	×	√	×	×
45.	Khulna	Very Low	×	×	×	×	×	×	×
46.	Bagerhat	Very Low	×	√	√	×	×	√	×
47.	Satkhira	Very Low	×	×	√	×	×	×	×
48.	Jessore	Very Low	×	×	√	×	×	×	×
49.	Magura	Moderate	√	√	×	√	×	√	√
50.	Jhenaidah	Very Low	×	×	×	×	×	×	×
51.	Narail	Low	√	√	√	√	×	√	√
52.	kushtia	Severe	×	×	√	×	×	√	×

SL. No.	District Name	Type of Flood	1955 (34%)	1974 (36%)	1987 (39%)	1988 (61%)	1991 (19%)	1998 (68%)	2004 (24%)
53.	Meherpur	Very Low	×	×	√	×	×	×	×
54.	Chuadanga	Moderate	×	×	×	×	×	√	×
55.	Barishal	Severe	√	√	√	√	×	√	√
56.	Jhalkati	Very Low	×	×	√	×	×	×	×
57.	Pirojpur	Low	×	√	×	×	×	√	×
58.	Potualkali	Very Low	×	×	×	×	×	×	×
59.	Barguna	Very Low	√	×	√	×	×	×	×
60.	Bhola	Moderate	√	√	×	×	×	√	√
61.	Sylhet	Severe	√	√	√	√	√	√	√
62.	Sunamganj	Severe	√	√	√	√	√	√	√
63.	Habiganj	Severe	√	√	√	√	√	√	√
64.	Moulvibazar	Moderate	√	√	√	√	√	√	√

From the above 7 flood year data assume as 10 flood year data the occurrence/ Frequency of flood calculate and shown the weighting factor in the Table 4.20.

Table 4.20 Flood Weighting Factor Table

SL. No.	Frequency/ No. of Occurence	Existing Frequency	Weighting Factor
1.	1	-	1.1
2.	2	-	1.2
3.	3	-	1.3
4.	4	1	1.4
5.	5	2	1.5
6.	6	3	1.6
7.	7	4	1.7
8.	8	5	1.8
9.	9	6	1.9
10.	10	7	2.0

From the Table 4.18, Table 4.20 and calculating the total risk of flood by equation 4.4 for all districts of Bangladesh are shown in the Table 4.21.

Table 4.21 Flood Risk Table for all Districts of Bangladesh

SL. No.	District Name	Frequency	Risk	Weighting Factor	Total Risk
1.	Dhaka	6	4	1.9	7.6
2.	Narayanganj	6	4	1.9	7.6
3.	Munshiganj	5	4	1.8	7.2
4.	Narsingdi	6	4	1.9	7.6
5.	Manikganj	6	4	1.9	7.6
6.	Gazipur	6	3	1.9	5.7
7.	Mymensingh	7	3	2.0	6.0
8.	Kishoreganj	7	4	2.0	8.0
9.	Jamalpur	7	4	2.0	8.0
10.	Sherpur	6	3	1.9	5.7

SL. No.	District Name	Frequency	Risk	Weighting Factor	Total Risk
11.	Netrokona	6	3	1.9	5.7
12.	Tangail	7	4	2.0	8.0
13.	Faridpur	6	4	1.9	7.6
14.	Madaripur	6	4	1.9	7.6
15.	Shariatpur	6	4	1.9	7.6
16.	Rajbari	6	4	1.9	7.6
17.	Gopalganj	6	3	1.9	5.7
18.	Chittagong	5	4	1.8	7.2
19.	Rangmati	1	1	1.4	1.4
20.	Cox's bazar	3	4	1.6	6.4
21.	Bandaban	2	4	1.5	6.0
22.	Khgrachari	0	1	1.0	1.0
23.	Noakhali	4	3	1.7	5.1
24.	Lakshmipur	5	4	1.8	7.2
25.	Feni	4	3	1.7	5.1
26.	Comilla	5	4	1.8	7.2
27.	Chandpur	7	4	2.0	8.0
28.	Brahmanbaria	6	4	1.9	7.6
29.	Rajshahi	5	4	1.8	7.2
30.	Nawabganj	5	4	1.8	7.2
31.	Natore	6	4	1.9	7.6
32.	Naogaon	6	4	1.9	7.6
33.	Pabana	6	4	1.9	7.6
34.	Sirajganj	6	4	1.9	7.6
35.	Bogra	6	4	1.9	7.6
36.	Joypurhat	3	3	1.6	4.8
37.	Rangpur	6	4	1.9	7.6
38.	Kurigram	7	4	2.0	8.0
39.	Nilphamari	5	3	1.8	7.2
40.	Lalmonirhat	4	3	1.7	5.1
41.	Gaibandha	6	4	1.9	7.6
42.	Dinajpur	3	4	1.6	6.4
43.	Thakurgoan	1	1	1.4	1.4
44.	Panchagarh	2	1	1.5	1.5
45.	Khulna	0	1	1.0	1.0
46.	Bagerhat	3	1	1.6	1.6
47.	Satkhira	1	1	1.4	1.4
48.	Jessore	1	1	1.4	1.4
49.	Magura	5	3	1.8	5.4
50.	Jhenaidah	0	1	1.0	1.0
51.	Narail	6	2	1.9	3.8
52.	kushtia	2	4	1.5	6.0
53.	Meherpur	1	1	1.4	1.4
54.	Chuadanga	1	3	1.4	4.2
55.	Barishal	6	4	1.9	7.6
56.	Jhalkati	1	1	1.4	1.4
57.	Pirojpur	2	2	1.5	3.0
58.	Potualkali	0	1	1.0	1.0
59.	Barguna	2	1	1.5	1.5
60.	Bhola	4	3	1.7	5.1
61.	Sylhet	7	4	2.0	8.0
62.	Sunamganj	7	4	2.0	8.0
63.	Habiganj	7	4	2.0	8.0
64.	Moulvibazar	7	3	2.0	6.0

4.8 DISTRICT WISE RISK SCORES

Total Risk Scores for four individual hazards (Tornado, Earthquake, Cyclone and Flood) for each of 64 districts were estimated following the above methods. Table 4.22 summarizes the total risk scores for individual Districts of Bangladesh. This table is calculated by the summation of four individual hazard score from the Table 4.5, 4.12, 4.16 and 4.21. For Dhaka district Total Score for Tornado, Earthquake, Cyclone and Flood are respectively 9.0, 4.8, 0.0 and 7.6. So the total risk score for Dhaka district is 21.4.

From the Proposed Risk Score Table a district risk-ranking map for Bangladesh is proposed which is shown in Figure 4.6. This map indicates the risky districts of Bangladesh for multi hazard (Cyclone, Flood, Tornado and Earthquake). This Figure shows risk scenario of Bangladesh at a glance.

The risk areas were combined and the scores were added together to create summary scores for every location in the county. These summary scores were used to develop a summary risk area map. The summary scores also provide the foundation for ranking high-risk areas in the remainder of the assessment. The ranking of the risk scores are categoried in the Table 4.23. From the table 4.22 and 4.23 the hazard index for all districts of Bangladesh categorized by total risk score of different districts of Bangladesh for different hazards like tornado, flood, cyclone and earthquake shown in the Table 4.24.

Table 4.22 Proposed Risk Score Table

SL. No.	District Name	Risk Score/Disaster Type				Total Risk Score
		Tornado	Earthquake	Cyclone	Flood	
1.	Dhaka	9.0	4.8	0.0	7.6	21.4
2.	Narayanganj	5.5	4.4	0.0	7.6	17.5
3.	Munshiganj	6.0	4.8	0.0	7.2	18
4.	Narsingdi	1.0	6.0	0.0	7.6	14.6
5.	Manikganj	7.0	5.2	0.0	7.6	19.8
6.	Gazipur	7.0	6.5	0.0	5.7	19.2
7.	Mymensingh	9.0	7.0	0.0	6.0	22
8.	Kishoreganj	7.5	7.0	0.0	8.0	22.5
9.	Jamalpur	7.0	8.5	0.0	8.0	23.5
10.	Sherpur	5.5	8.5	0.0	5.7	19.7
11.	Netrokona	5.5	8.5	0.0	5.7	19.7
12.	Tangail	6.0	7.0	0.0	8.0	21
13.	Faridpur	7.5	4.8	0.0	7.6	19.9
14.	Madaripur	5.5	4.4	1.0	7.6	18.5
15.	Shariatpur	6.5	4.4	1.0	7.6	19.5
16.	Rajbari	5.5	5.2	0.0	7.6	18.3
17.	Gopalganj	6.5	3.3	1.0	5.7	16.5

SL. No.	District Name	Risk Score/Disaster Type				Total Risk Score
		Tornado	Earthquake	Cyclone	Flood	
18.	Chittagong	5.5	5.2	9.0	7.2	26.9
19.	Rangmati	1.0	6.5	1.0	1.4	9.9
20.	Cox's bazar	5.5	6.5	8.5	6.4	26.9
21.	Bandaban	1.0	6.5	1.0	6.0	14.5
22.	Khgrachari	1.0	6.0	1.0	1.0	9.0
23.	Noakhali	8.0	4.4	7.5	5.1	25
24.	Lakshmipur	5.5	4.4	5.0	7.2	22.1
25.	Feni	5.5	4.4	5.5	5.1	20.5
26.	Comilla	7.0	4.8	1.1	7.2	20.1
27.	Chandpur	5.5	4.8	1.1	8.0	19.4
28.	Brahmanbaria	1.0	6.0	0.0	7.6	14.6
29.	Rajshahi	5.5	4.8	0.0	7.2	17.5
30.	Nawabganj	1.0	4.4	0.0	7.2	12.6
31.	Natore	1.0	5.2	0.0	7.6	13.8
32.	Naogaon	1.0	4.8	0.0	7.6	13.4
33.	Pabana	6.0	5.2	0.0	7.6	18.8
34.	Sirajganj	7.0	6.5	0.0	7.6	21.1
35.	Bogra	5.5	7.0	0.0	7.6	20.1
36.	Joypurhat	1.0	6.5	0.0	4.8	12.3
37.	Rangpur	6.0	6.5	0.0	7.6	20.1
38.	Kurigram	5.5	8.0	0.0	8.0	21.5
39.	Nilphamari	6.0	5.5	0.0	7.2	18.7
40.	Lalmonirhat	6.0	7.0	0.0	5.1	18.1
41.	Gaibandha	7.0	7.5	0.0	7.6	22.1
42.	Dinajpur	1.0	4.4	0.0	6.4	11.8
43.	Thakurgoan	1.0	5.5	0.0	1.4	7.9
44.	Panchagarh	5.5	5.5	0.0	1.5	12.5
45.	Khulna	6.5	3.3	7.5	1.0	18.3
46.	Bagerhat	6.0	3.3	6.0	1.6	16.9
47.	Satkhira	1	3.3	6.0	1.4	11.7
48.	Jessore	6.0	3.3	0.0	1.4	10.7
49.	Magura	6.0	4.8	0.0	5.4	16.2
50.	Jhenaidah	1	4.4	0.0	1.0	6.4
51.	Narail	7.0	3.6	0.0	3.8	14.4
52.	kushtia	6.0	4.8	0.0	6.0	16.8
53.	Meherpur	5.5	4.8	0.0	1.4	11.7
54.	Chuadanga	1	4.4	0.0	4.2	9.6
55.	Barishal	6.5	3.3	8.0	7.6	25.4
56.	Jhalkati	1	3.3	1.0	1.4	6.7
57.	Pirojpur	5.5	3.3	1.0	3.0	12.8
58.	Potualkali	1	3.3	6.5	1.0	11.8
59.	Barguna	1	3.3	5.5	1.5	11.3
60.	Bhola	6.0	3.3	6.0	5.1	20.4
61.	Sylhet	1	8.0	0.0	8.0	17
62.	Sunamganj	1	8.0	0.0	8.0	17
63.	Habiganj	1	7.0	0.0	8.0	16
64.	Moulvibazar	5.5	8.0	0.0	6.0	19.5

Table 4.23 Ranking High Risk Areas

SL. NO.	HAZARD INDEX	RISK SCORE
1.	HIGH	20-30
2.	MODERATE	10-20
3.	LOW	1-10

Table 4.24 Hazard Index and Risk Score

Sl. No.	Hazard Index	Total Risk Score	Hazardous Districts
1.	High	20-30	Dhaka, Bogra, Sirajganj, Feni, Comilla, Cox's bazaar, Lakshmipur, Noakhali, Chittagong, Tangail, Mymensingh, Kishoreganj, Jamalpur, Rangpur, Bhola, Barishal, Kurigram, Gaibandha
2.	Moderate	10-20	Sylhet, Gazipur, Manikganj, Narsingdi, Narayanganj, Munshiganj, Netrokona, Sherpur, Gopalganj, Rajbari, Shariatpur, Madaripur, Sunamganj, Pabana, Bandaban, Faridpur, Naogaon, Natore, Nawabganj, Rajshahi, Brahmanbaria, Joypurhat, Chandpur, Lalmonirhat, Nilphamari, Dinajpur, Magura, Khulna, Satkhira, Bagerhat, Jessore, Panchagarh, Meherpur, kushtia, Habiganj, Narail, Moulvibazar, Potualkali, Pirojpur, Borguna.
3.	Low	1-10	Jhalkati, Chuadanga, Rangmati, Thakurgoan, Khgrachari, Jhenaidah

4.9. PROPOSED MULTIHAZARD MAP OF BANGLADESH

Again from the individual digitized maps of Bangladesh for different hazard (Cyclone, Flood, Tornado and Earthquake) and superimposing those, a multi hazard zonation map for Bangladesh is prepared as shown in Figure 4.7. From this map one can easily identify the hazard area with the hazard type and intensity. This map will be easily comprehensible to everybody.

For identifying multihazard in a district more clearly, the multihazard map of Chittagong District is shown in Figure 4.8. Table 4.27 provides explanation for Figure 4.8. This chapter proposes a multihazard Map of Bangladesh based on a recently compiled disaster database. For this purpose initially Tornado, Earthquake, Flood and Cyclone zonation maps were reviewed and updated. This multihazard maps will be used for policy makers to take decision for disaster management and preparedness.

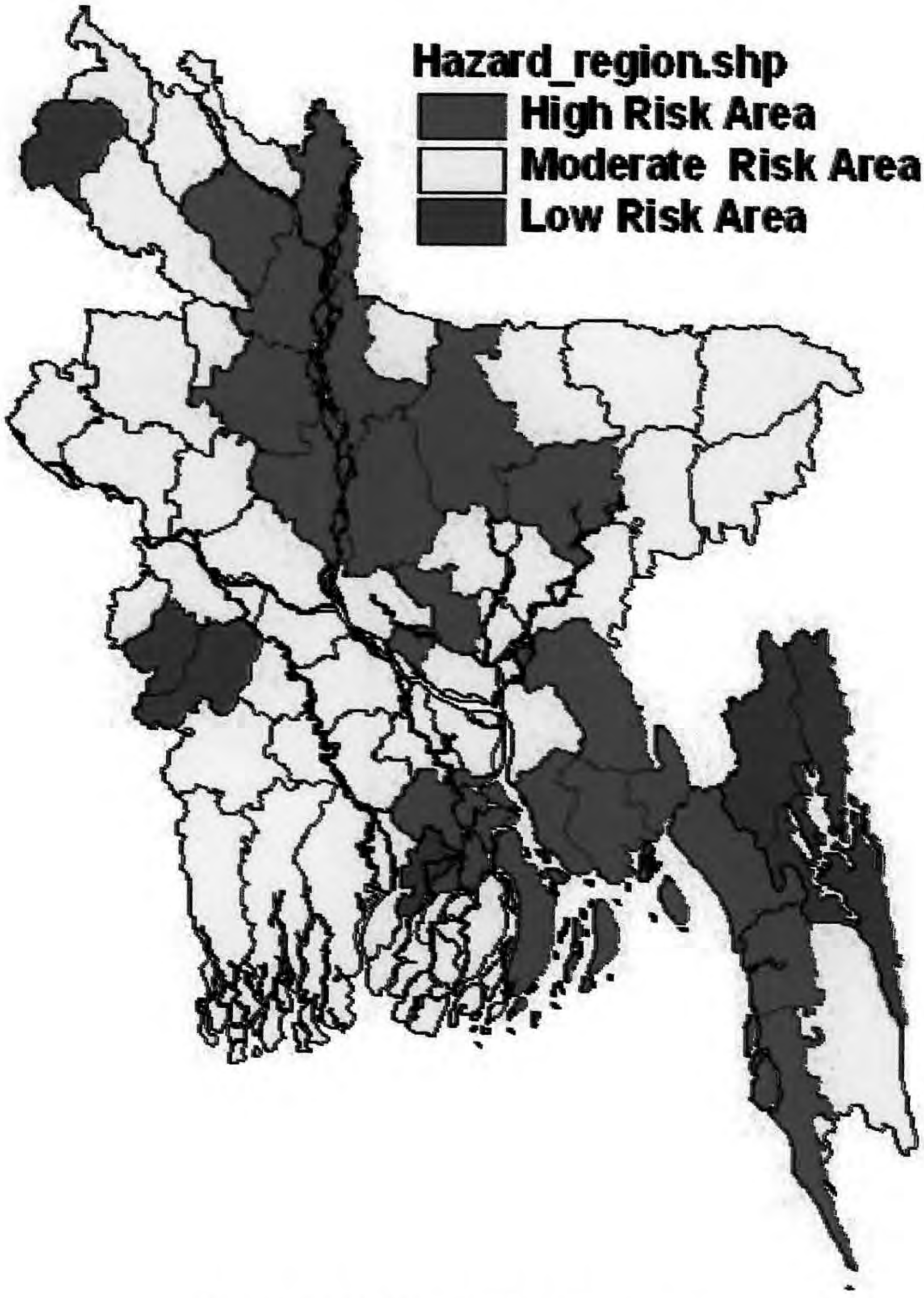


Figure 4.6 Risk Hazard Map of Bangladesh

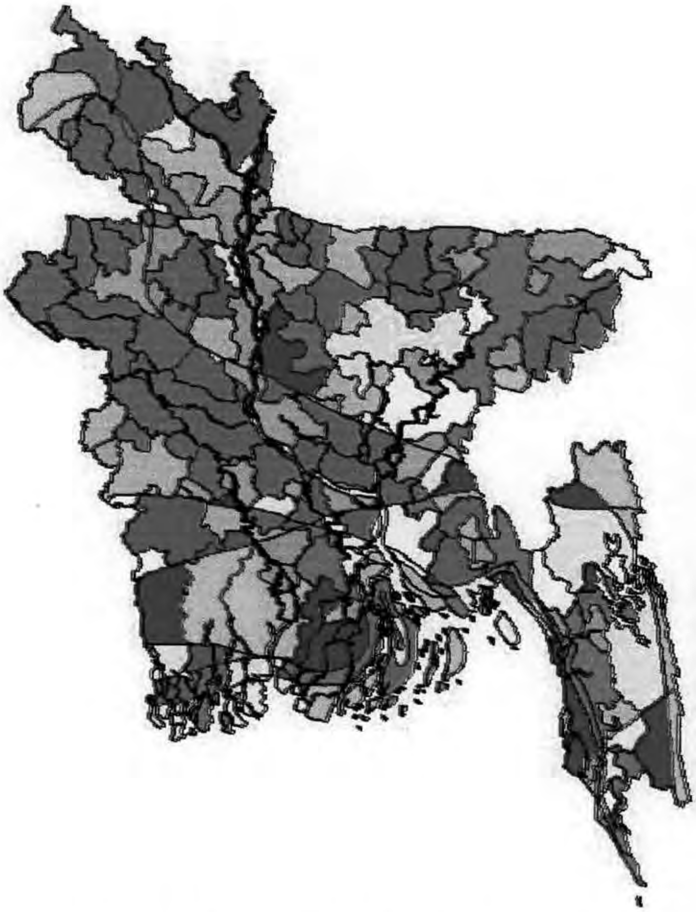


Figure 4.7 Proposed Multi Hazard Zonation Map of Bangladesh

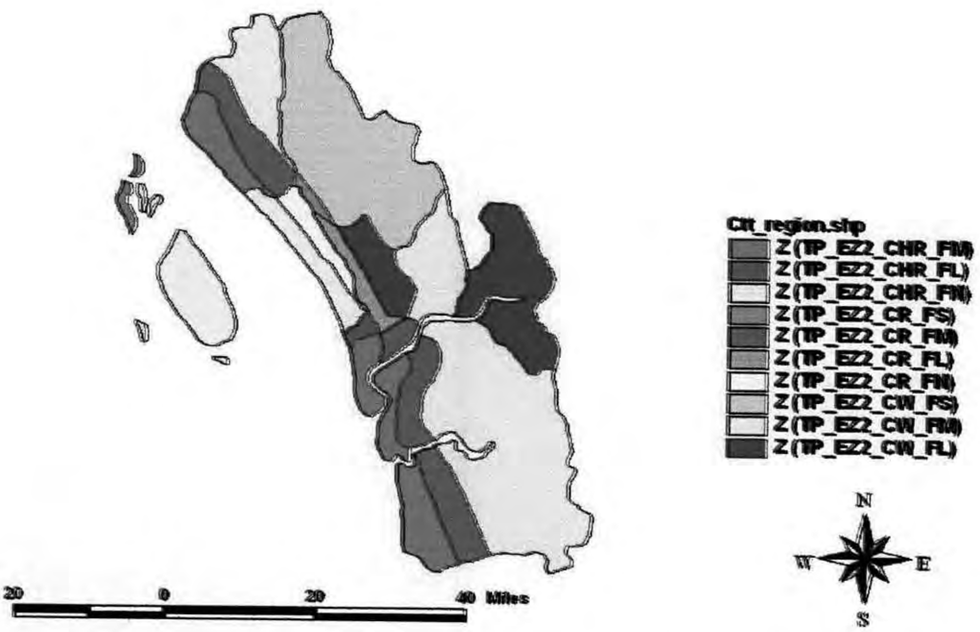


Figure 4.8 Proposed Multi Hazard Zonation Map of Chittagong

Table 4.25 Explanation of the multi hazard zonation map of Chittagong

SL. NO.	CODE	Explanation
1.	Z(TP_EZ2_CHR_FM)	Zone: Tornado Prone Area Earthquake Zone 2=0.15g Cyclone High Risk Area Moderate Flooding Area
2.	Z(TP_EZ2_CHR_FL)	Zone: Tornado Prone Area Earthquake Zone 2=0.15g Cyclone High Risk Area Low Flooding Area
3.	Z(TP_EZ2_CHR_FN)	Zone: Tornado Prone Area Earthquake Zone 2=0.15g Cyclone High Risk Area Non Flood Affected Area
4.	Z(TP_EZ2_CR_FS)	Zone: Tornado Prone Area Earthquake Zone 2=0.15g Cyclone Risk Area Severe Flooding Area
5.	Z(TP_EZ2_CR_FM)	Zone: Tornado Prone Area Earthquake Zone 2=0.15g Cyclone Risk Area Moderate Flooding Area
6.	Z(TP_EZ2_CR_FL)	Zone: Tornado Prone Area Earthquake Zone 2=0.15g Cyclone Risk Area Low Flooding Area
7.	Z(TP_EZ2_CR_FN)	Zone: Tornado Prone Area Earthquake Zone 2=0.15g Cyclone Risk Area Non Flood Affected Area
8.	Z(TP_EZ2_CW_FS)	Zone: Tornado Prone Area Earthquake Zone 2=0.15g High Wind Area Severe Flooding Area
9.	Z(TP_EZ2_CW_FM)	Zone: Tornado Prone Area Earthquake Zone 2=0.15g High Wind Area Moderate Flooding Area
10.	Z(TP_EZ2_CW_FL)	Zone: Tornado Prone Area Earthquake Zone 2=0.15g High Wind Area Low Flooding Area

CHAPTER 5

HOUSING VULNERABILITY TABLES

5.1 GENERAL

The census of houses (BBS, 1991), provides details of houses based on materials of construction for walls and roofs. Table 5.1 summarized the building types in different category based on Census of BBS, (1991). This grouping for the whole Bangladesh can be identified by collecting the whole district wise census report of Bangladesh. The census reports generally show the dwelling households by material of wall and material of roof of the main structure. The wall and roof combinations are categorized as sloping (Straw/Bamboo/Polythene, Tiles/C.I/Metal Sheet) and Flat (Cement). The vulnerability of different categories of houses can be described according to the intensity scales described in chapter three.

5.2 HOUSING SITUATION IN BANGLADESH

The housing situation in Bangladesh is extremely poor. According to the 1991 housing census, the backlog in housing was 3.1 million units, composed of 2.15 million units in rural areas and 0.95 million units in urban areas. By the year 2000, the housing shortage is likely to exceed 5 million. If we take into account the replacement needs of the rudimentary thatched houses, the target will be much more. About 90% of dwellings in rural areas and 60% in urban areas are non-durable which implies that even if they are not subjected to extreme natural hazards, they would have to be replaced.

5.3 IMPACTS OF HAZARDS ON HOUSING

The effects and consequences of some of the major natural hazards on housing are shown in Table 5.1.

Table 5.1 Effects of Major Natural Hazards on Housing

Hazard	Effects	Impact on Housing
Flood (can be caused by unusually intense rainfall or by changes to earth's surface, such as deforestation upstream)	Inundation	Damage to human settlements: walls may collapse, foundations may fail. Forces evacuation.
Tropical Cyclone, Tornado, Thunderstorm	High winds	Damages to buildings and other man-made structures: roofs blown away, collapse of walls & frames.
Storm Surge	Inundation and wave action	Collapse of walls due to inundation: foundation failure; collapse of walls and roof due to wave action
Earthquake	Tremors(ground shaking) Liquefaction Ground failure (horizontal displacement)	Damage to buildings, particularly unreinforced brick masonry and mud-walled housing. Buildings on surface sink into soil Damage buildings on the rupture lines
River erosion	Loss of ground support	Collapse of foundation

5.4 TYPES OF HOUSING IN BANGLADESH

The latest data about the housing of Bangladesh is required for the study. The 2001 census report of Bangladesh did not consider the housing data. So 1991 Census report was used. The census of houses (1991) gives the following details of houses based on materials of construction for walls and roofs.

Table 5.2 House Types of Bangladesh

SL. NO.	TYPE	MATERIAL	
1.	TYPE OF ROOF/ MATERIALS OF ROOF	i)	Straw/Bamboo/Polythene
		ii)	Tiles/ C.I./Metal Sheet
		iii)	Cement
2.	TYPE OF WALL/ MATERIALS OF WALL	i)	Straw/Bamboo
		ii)	Mud/ Unburnt Brick
		iii)	C.I./Metal Sheet
		iv)	Wood
		v)	Cement/ Brick
3.	TYPES OF FLOORING	Various types like mud, stone, concrete etc.	

The distribution of houses based on Predominant materials of roof and wall over different district of Bangladesh according to 1991 was presented in Table 5.2. Dwelling households by material of wall and material of roof of the main structure for Chittagong district is presented in Table 5.2. From the point of view of vulnerability to the earthquake, cyclone, tornado and flood hazards, it was seen that the type of flooring had hardly any significance, hence it was omitted.

Table 5.3 Dwelling Households by Material of Wall and Material of Roof of the Main Structure of Chittagong District

Type of Material	Material of Roof		
	Straw/Bamboo/Polythene	**Tiles/C.I/Metal Sheet**	**Cement**
Material of Wall	Straw/Bamboo	Straw/Bamboo	Straw/Bamboo
	Mud/ Unburnt Brick	Mud/ Unburnt Brick	Mud/ Unburnt Brick
	C.I/Metal Sheet	C.I/Metal Sheet	C.I/Metal Sheet
	Wood	Wood	Wood
	Cement-Brick	Cement-Brick	Cement-Brick

According to Table 5.3, the building types in different category can be summarized. This grouping for the whole Bangladesh can be identified by collecting the whole districtwise 1991 census report of Bangladesh. Table 5.4 shows the categories of roof's mentioned as sloping (Straw/Bamboo/Polythene, Tiles/C.I/Metal Sheet) and Flat (Cement) with the reference to Vulnerability Atlas of India (1997).

Table 5.4 Categories of Housing (after Vulnerability Atlas of India, 1997)

Category A	A1.	Mud wall with all roofs sloping.
	A2.	Unburnt Brick wall with all roofs sloping.
Category B	B1.(a) B1.(b)	Burnt Brick wall with sloping roof Burnt Brick wall with flat roof
Category C	C1.(a) C1.(b)	Cement Wall with sloping roof Cement Wall with flat roof
	C2.	Wood wall with all roof sloping
Category X	X1.	C.I/Metal Sheet with all roofs sloping
	X2.	Straw/Bamboo with all roofs sloping

The census report of Chittagong district shown in Annexure 15: H02 Dwelling Households by Material of Wall and Material of Roof of the Main Structure, wherein the wall and roof combinations are categorized in three types "Type A", "Type B" and "Type X" shown in Table 5.5. The burnt brick wall and the cement concrete wall are not categorized in 1991 census. So according to census report the categories of housing types of Bangladesh are shown in Table 5.5.

Table 5.5 Categories of Housing of Bangladesh as per 1991 Census

Category A	A1.	Mud wall with all roofs sloping.
	A2.	Unburnt Brick wall with all roofs sloping.
Category B	B1.(a)	Burnt Brick wall with sloping roof
	B1.(b)	Burnt Brick wall with flat roof
	B2.(a)	Cement-Brick Wall with sloping roof
	B2.(b)	Cement-Brick Wall with flat roof
	B3.	Wood wall with all roof sloping
Category X	X1.	C.I/Metal Sheet with all roofs sloping
	X2.	Straw/Bamboo with all roofs sloping

5.5 DAMAGE RISK OF HOUSE TYPES

The damage risk to various house types is based on their average performance observed during past occurrences of damaging events. In view of numerous variations in the architectural planning, structural detailing, quality of construction and care taken in maintenance, the performance of each category of houses in a given event could vary substantially from the average observed. The intensity scales as given in Annexure or Table represent average observations. For example, under seismic occurrence, the following observations have been made in many cases.

5.5.1 All Masonry Houses (Categories A and B)

- Quality of construction comes out as a major factor in the seismic performance particularly under intensities EMS IX and lower. Good quality constructions perform much better than poor quality constructions in any category. Appropriate maintenance increases durability and maintains original strength.

- Number of storeys in the house and the storey height are other factors. Higher the storey and more the number of storeys, greater are the observed damage.

- Size, location and number of door and window openings in the walls also determine seismic performance, since the opening have weakening effect of the walls. Smaller and fewer openings and located more centrally in the walls are better from seismic performance viewpoint.

- Architectural layout, particularly in large buildings, that is, shape of building in plan and elevation, presence of offsets and extended wings, also play important role in initiation of damage at certain points and its propagation as well. More symmetrical plans and elevations reduce damage and unsymmetrical ones lead to greater damage.

- Where clay/mud mortar is used in wall construction, its wetness at the time of earthquake is very important factor in the seismic performance since the strength of fully saturated mortar can be as low as 15% of its dry strength.

5.5.2 Wooden Houses

- Quality of construction, that is seasoning of wood and joinery are important in seismic and cyclonic wind performance and flood also. Better the quality better the performance.

- Wood decays with time due to dry rot, insect and rodent attack, etc., therefore the joints tend to become loose and weak. The state of the wooden building will determine its performance during earthquake, high wind as well as flooding.

5.5.3 Reinforced Concrete Houses

- In reinforced concrete construction, good structural design and detailing and good quality contruction only could ensure excellent performance.Carelessness in any of these can lead to poor behaviour both under earthquake, cyclone, tornado and flood.

Now the average risk levels to various categories of houses for various hazards and their intensities are defined below for use in the housing vulnerability tables.

5.6 DAMAGE RISK LEVELS FOR DIFFERENT DISASTERS

5.6.1 Damage Risk Levels for Tornado

Basic Tornado Zones

The tornado hazard map contains the following information. Disaster Management Bureau (1993) prepared Tornado hazard map of Bangladesh which is divided into Tornado prone area, severe storm area and non affected area. The basis of this map can not be found. So a new Tornado Map according to the already complied database (Appendix 6 and 7) proposed in the chapter four divided total Bangladesh into four zones. Those are shown in Table 5.6.

Table 5.6 Tornado Prone Zones

SL. No.	Area Type	No. of Tornado Occurrence
1.	Most severe Tornado Prone Area	Area affected tornado by more than three times
2.	Severe Tornado Prone Area	Area affected tornado by less than three & more than two times.
3.	Tornado Prone Area	Area affected tornado by at least one time
4.	Unaffected Area	Never affected Area

The tornado prone area cannot be divided into vulnerability scale as it is difficult to ensure the wind speed. So it can be said that the whole tornado prone area has to maintain the same scale of Intensity.

In Bangladesh no tornado scale exists. But according to database Bangladesh need an individual tornado scale. Here Fujita Scale (F-Scale) is used. According to the Fujita Scale and previous tornado database, it can be said that the largest tornado wind speed in our country is 360 kph (224mph) which is F4 category of F-Scale (Appendix 10). A scale to use in housing vulnerability table has been developed based on Fujita Scale is shown in Table 5.7. For damage risk to buildings from wind storms, there appears no universally accepted scale like the seismic intensity scale.

Table 5.7 Damage Risk Levels for Tornado

Risk Damage Level	Scale Value	Wind Speed (mph)	Intensity	Type of Damage	Vulnerability	
Very Low Damage Risk (VL)	F0	40-72	Light Damage	Some damage to chimneys; tree branches broken off, shallow-rooted trees pushed over, sign boards damaged.	Very Low	VL
Low Damage Risk (L)	F1	73-112	Moderate Damage	Roof surfaces peeled off; mobile homes pushed off foundations or overturned; moving automobiles pushed off roads.	Low	L

Risk Damage Level	Scale Value	Wind Speed (mph)	Intensity	Type of Damage	Vulnerability	
Moderate Damage Risk (M)	F2	113-157	Considerable Damage	Roofs torn from houses, mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light-object missiles generated.	Moderately Low	ML
	F3	158-206	Severe Damage	Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.	Moderate	M
High Damage Risk (H)	F4	207-260	Devastating Damage	Well-constructed houses levelled; structures with weak foundations blown off some distance; cars thrown; large missiles generated.	Moderately High	MH
Very High Damage Risk (VH)	F5	261-318	Incredible Damage	Strong frame homes lifted off foundations and carried considerable distances to disintegrate; automobiles-size missiles fly through the air in excess of 100 yards; trees debarked.	High	H
	F6	>318	Inconceivable Damage	These wind speeds have rarely been recorded. The area of damage would be completely obliterated and unrecognizable. Large missiles would be thrown in excess of 100 yards.	Very High	VH

5.6.2 Damage Risk Levels for Earthquake

The damage risk to various house types is defined under various seismic intensities on EMS scale (Appendix 4). Table 5.8 shows the damage risks defined based on this intensity Scale.

Table 5.8 Damage risks based on intensity Scale for Earthquake

Damage Risk Levels	Classification of Damage to Building	Description
Very Low Damage Risk(VL)	Grade 1	Fine cracks in plaster; fall of small pieces of plaster.
Low Damage Risk(L)	Grade 2	Small cracks in walls; fall of fairly large pieces of plaster, pantiles slip off; cracks in chimneys, part may fall down.
Moderate Damage Risk(M)	Grade 3	Large and deep cracks in walls fall of chimneys on roofs.
High Damage Risk(H)	Grade 4	Gaps in walls, parts of buildings may collapse, separate parts of the building lose their cohesion; and inner walls collapse.
Very High Damage Risk(VH)	Grade 5	Total collapse of buildings

The EMS intensity scale describes the generally observed grades of damage to buildings and structures in various intensity levels or convenience of reference, the damage vulnerability of the various building types in EMS seismic intensities VII, VIII, and IX is presented in Table 5.9.

Table: 5.9 Seismic Intensity vs Damage to Buildings

Building Type	**Intensity VI**	**Intensity VII**	**Intensity VIII**	**Intensity IX**
A. Mud and Adobe houses, random-stone constructions	**Many** buildings sustain slight damage and **Few** may even have moderate damage like small cracks in walls and fall of large pieces of plaster.	**Most** have large deep cracks **Few** suffer partial collapse	**Most** suffer partial collapse	**Most** suffer complete collapse
B. Ordinary brick building of large blocks and prefab type, poor half timbered houses	Free of damage except occasional fine cracks.	**Many** have small cracks in walls	**Most** have large and deep cracks	**Many** show partial collapse **Few** completely collapse
C. Reinforced buildings , well built wooden buildings	Free of damage	**Many** have fine plaster cracks	**Most** may have small cracks in walls. **Few** may have large deep cracks	**Many** may have large deep cracks **Few** may have partial collapses.

Most=About 75%, **Many**=About 50%, **Few**=About 5%

5.6.3 Damage Risk Levels for wind storms

For damage risk to buildings from wind storms, there appears no universally accepted scale like the seismic intensity scale.The damage risk scale shown in Table 5.10 has been proposed by the expert group of Vulnerability Atlas of India (1997), for developing the house vulnerability tables.

Table 5.10 Damage Risk Levels for Wind Storms

Damage Risk Levels	**Description**
Very Low Damage Risk (VL)	Generally similar to "Low Risk" but expected to be very limited in extent.
Low Damage Risk (L)	Loose metal or fibre cement sheets fly; a few lighting and telephone poles go out of alignment;sign boards and hoardings partially damaged;well detail non-engineered/semi-engineered buildings suffer very little damage.
Moderate Damage Risk (M)	Loose tiles of clay fly, roofs sheets fixed to buttens fly; moderate damage to telephone and lighting poles; moderate damage to non-engineered/semi-engineered buildings.
High Damage Risk (H)	Boundary walls overturn, walls in houses and industrial structures fail; roofing sheets and tiles or whole roofs fly; large scale destruction of life-line structures such as lighting and telephone poles, a few transmission line towers/communication towers may suffer damage; and non-engineered/semi-engineered constructions suffer heavy damage.
Very High Damage Risk (VH)	Generally similar to "High Risk" but damage is expected to be more widespread as in the case of cyclonic stroms.

In the above table there is no consideration of storm surge. Storm surge needs to have a damage risk level table from previous damage study. But for the limited data this study couldnot identify the actual damage risk level. In this study, details Cyclone Intensity Scale for Bangladesh for the damage risk level table was used with some modification.

Basic Wind Speed:

The Basic Wind Speed Map is shown in Figure 5.1.This map shows the basic wind speeds in km/h for any location in Bangladesh. The minimum value of the basic wind speed set in the map is 130 km/h. Basic wind speeds for selected locations are also provided in Appendix 16 (BNBC, 1993). From this wind speed map the zones of wind can be categorized as shown in Table 5.11.

Table 5.11 Wind Speed Zone

SL. No.	Wind Speed	Zone
1.	260 km/hr	Very high damage risk zone
2.	220 km/hr	High damage risk zone
3.	190 km/hr	Moderate damage risk zone
4.	160 km/hr	Low damage risk zone
5.	130 km/hr	Very Low damage risk zone

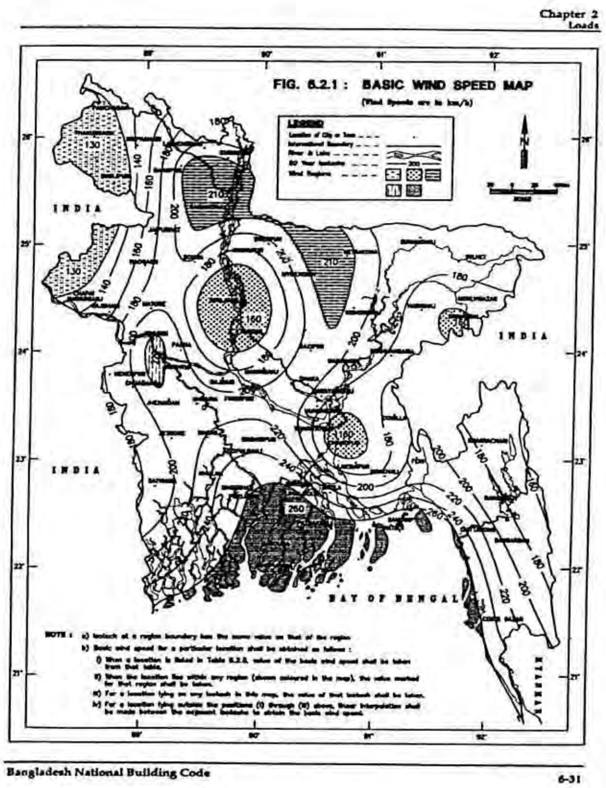


Figure 5.1 Basic Wind Speed Map (BNBC, 1993)

In general, wind speed in the atmospheric boundary layer increases with height from zero at ground level to a maximum at a height called gradient height. The variation with height depends primarily on the terrain conditions. However, the wind speed at any height never remains constant and it has been found convenient to resolve its instantaneous magnitude into an average or mean value and a fluctuating component around this average value. The average value depends on the averaging time employed in analyzing the meteorological data and this averaging time varies from a few seconds to several minutes. The magnitude of fluctuating component of the wind speed which is called gust depends on the averaging time. In general smaller the averaging interval, greater is the magnitude of the gust speed.

5.6.4 Damage Risk Levels for Cyclone

The cyclone hazard map contains the following information:

Basic Cyclone Zones

The whole Bangladesh is divided based on area and surge height/high wind speed area into four zones are shown in Table 5.12. (SPARRSO, 1993)

Table 5.12 Basic Cyclone Zones

SL. No.	Area	Surge Height
1.	High Risk Area	Above 1m
2.	Risk Area	Less than 1 m
3.	High wind area	None
4.	None affected area	No affect

Storm Surge

The coastal areas suffer from the onslaught of sea water over the coast due to storm surge generated by cyclones.A storm surge is the sudden abnormal rise in sea level caused by cyclone.The surge is generated due to interaction of air,sea and land.The cyclone provides the driving force in the form of very high horizontal atmospheric pressure gradient and very strong surface winds.The sea water flows across the coast as well as inland and then recedes back to the sea.Great life and loss of the property takes place in the process. From the Table 5.13 the damage risk levels for cyclone can categorized and from the Cyclone hazard map the area or zone can be identified:

Table 5.13 Damage Risk Levels for Cyclone

Damage Risk Level	Storm surge	Description
Very Low Damage Risk (VL)	Category 1	Winds 74-95 mph (64-82 knots or 119-153 km/hr) - maximum below 12 ft above normal. No real damage to building structures. Damage primarily to fishing boats, trees near coastal. Some damage to poorly constructed signs. Also, some coastal road flooding and minor pier damage.
Low Damage Risk (L)	Category 2	Winds 96-110 mph (83-95 knots or 154-177 km/hr) - Storm surge may maximum 12-18 feet above normal. Some roofing material, door, and window damage of buildings. Considerable damage to trees with some trees blown down. Somefishing boats missing. Considerable damage to poorly constructed signs, and piers. Small craft in unprotected anchorages break moorings.
Moderate Damage Risk (M)	Category 3	Winds 111-130 mph (96-113 knots or 178-209 km/hr) - Storm surge may reach maximum 16-18 ft above normal. Tin roof, wooden supports blown off. Tin shed cottage industry totally damage. Crack in wall and beam and floor settled of some godown. Some structural damage to small residences and utility buildings with RCC roof and wall crack. Extensive damage to doors and windows of one storey buildings and General damage of doors-windows of some two storey residential buildings. Some damage of boundary wall and steel gate. Some retaining wall washed away and some damage to toe of wall. Wooden jetty totally damage. Some electrical works damage. Major damage to lower floors of structures near the shore.
High Damage Risk (H)	Category 4	Winds 131-155 mph (114-135 knots or 210-249 km/hr) - Storm surge may reach maximum within 18-25 ft above normal. More extensive curtain wall failures with some complete roof structure failures on small residences. Semi pucca tin roof totally destroyed. Roofs blown away and windows-doors damaged of dormitory and community centre. Single storey buildings totally collapse. General damage to interior of cyclone shelter. RCC pillars crack. Doors and windows of two storey cyclone shelter destroy. Complete roof failure of many residential and industrial buildings. Trees and all signs are blown down. Major damage to lower floors of structures near the shore.
Very High Damage Risk (VH)	Category 5	Winds greater than 155 mph (135 knots or 249 km/hr) - Storm surge may maximum greater than 25 ft above normal. Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All trees and signs blown down. Severe and extensive window and door damage. Stairs, auditorium and toilet block severely damage. Some one storey buildings and boundary walls collapse. Some two storey buildings destroy.

5.6.5 Damage Risk Levels for Flood

No Detailed building damage reports under flooding appear to have been worked out as yet. Also flood intensities in terms of depth of water velocity of flow or time duration of inundation are not yet defined. In the absence of such data, no definate recommendation about damage risk levels could be made. The damage risks have been drafted by the Group based on understanding of material behaviour under submergence are shown in Table 5.14. (BMTPC, 1997)

Table 5.14 Damage Risk Levels for Flood

Damage Risk Level	Description
Very High Damage Risk (VH)	Total collapse of buildings; roof and some walls collapse; floating away of sheets, thatch, etc; erosion of foundation; severe damage to life line structures and systems.
High Damage Risk (H)	Gaps in walls;punching of holes through wall by flowing water; parts of buildings may collapse; light roofs float away; erosion of foundation, sinking or tilting; undercutting of floors, partial roof collapse.
Moderate Damage Risk (M)	Large and deep cracks in walls; bulging of walls; loss of belongings; damage to electric fittings.
Low Damage Risk (L)	Small cracks in walls; fall of fairly large pieces of plaster.
Very Low Damage Risk (VL)	Fine cracks in plaster; fall of small pieces of plaster.

5.7 THE HOUSING VULNERIBILITY TABLES

Now correlating the house types, the hazard intensities on the maps and the damage risk levels, the housing damage risk levels have been generated, for the country as a whole. For each district an overall risk table has been developed.

Each table provides hazard intensities, the percentage of total area of the country, or district covered by the Table, laying under the various intensities as shown in Table 5.15. The table provides the maximum possible damage risk of different categories of dewelling, according to intensity scale for tornado, earthquake, cyclone and flood. Thus the concerned administrative or professional authority can visualize the extent of damage risk of existing houses to any hazard at one time.

Table 5.15 Damage Risk to Housing under various Hazard Intensities

Category	Type of Wall and Roof	Tornado Intensity					Earthquake Intensity					Cyclone Intensity					Flood Intensity				
		F6-F5	F4	F2 –F3	F1	F0	≥IX	VIII	VII	VI	≤V	Category 5	Category 4	Category 3	Category 2	Category 1	>3m above D.L	<3m above 50cm D.L	Upto 50cm Above D.L	Within 50cm D.L	Below 50 cm D.L
A1	Mud wall with all roofs sloping.				**VH**	**H**			**VH**	**H**	**M**				**VH**	**H**	**VH**	**H**	**M**	**L**	**VL**
A2	Unburnt Brick wall with all roofs sloping.				**VH**	**H**			**VH**	**H**	**M**				**VH**	**H**	**VH**	**H**	**M**	**L**	**VL**
B1.(a)	Burnt Brick wall with sloping roof			**VH**	**H**	**M**		**VH**	**H**	**M**	**L**			**VH**	**H**	**M**	**M**	**L**	**VL**		
B1.(b)	Burnt Brick wall with flat roof			**VH**	**H**	**M**		**VH**	**H**	**M**	**L**			**VH**	**H**	**M**	**M**	**L**	**VL**		
B2.(a)	Cement-Brick Wall with sloping roof		**VH**	**H**	**M**	**L**	**VH**	**H**	**M**	**L**	**VL**		**VH**	**H**	**M**	**L**	**L**	**VL**			
B2.(b)	Cement-Brick Wall with flat roof	**VH**	**H**	**M**	**L**	**VL**	**VH**	**H**	**M**	**L**	**VL**	**VH**	**H**	**M**	**L**	**VL**	**L**	**VL**			
B3	Wood wall with all roof sloping			**VH**	**H**	**M**	**VH**	**H**	**M**	**L**	**VL**			**VH**	**H**	**M**	**H**	**M**	**L**	**VL**	
X1	C.I/Metal Sheet with all roofs sloping.				**VH**	**H**	**VH**	**H**	**M**	**L**	**VL**			**VH**	**H**	**M**	**H**	**M**	**L**	**VL**	
X2	Straw/Bamboo with all roofs sloping				**VH**	**H**	**VH**	**H**	**M**	**L**	**VL**			**VH**	**H**	**M**	**VH**	**H**	**M**	**L**	**VL**

5.7.1 Housing Vulnerability for Example district 'XY'

As an example, let us refer to a district 'XY'. From Table 5.16 it can be seen that 100% area of the district 'XY'lies in seismic intensity VII zone. The 100% area is in cyclone risk zone i.e, 25% is under cyclone high risk zone, 15% is under cyclone risk zone and 60% is under high wind area. The area is under 100% Tornado zone. Also 25% is severe flood prone zone and 55% area has been moderate flood zone. According to 1991 census, there are 12,098 housing units in the district, 21.09% of which are of category A (weak type) and 52.54% of category B (moderate/ strong types). The risk of damage from earthquake to Category A houses is 'very high', and to Category B it is 'moderate'.

In Table 5.16, level of risk for tornado are severe tornado (ST), moderate tornado (MT), tornado prone (TP) and none (N). For earthquake level of risk are earthquake zone 1(VI), zone-2 (VII) and zone-3 (VIII). For Level of risk for cyclone high risk area (HRA), risk area (RA), high wind area (HWA) and none (N). For flood severe flooding area (SFA), moderate flooding area (MFA), normal flooding area (NFA) and none (N) are the levels of risk.

Table 5.16 Distribution of Houses by Predominant Materials of Roof and wall and level of Damage Risk (XY District)

Wall and roof combination		Census Houses		Level of Risk Under															
		No. of Houses	%	Tornado				Earthquake				Cyclone				Flood			
				ST	MT	TP	N	VI	VII	VIII	N	HRA	RA	HWA	N	SFA	MFA	NFA	N
				Area in %				Area in %				Area in %				Area in %			
						100 %			100 %			25 %	15 %	60 %	0 %	25 %	55 %	10%	10 %
CATEGORY-A				-	-		-	-		-	-								
A. Mud/ Unburnt Brick wall with all roofs sloping	Urban	242																	
	Rural	324				VH			VH			VH	H	M	-	VH	VH	VH	-
	Total	566																	
Total Category-A		**815**	**21.09**																
CATEGORY-B																			
B2. (a) Cement-Brick wall with sloping roof	Urban	562		-	-	M	-	-	M	-	-	M	L	VL	-	M	M	M	-
	Rural	238																	
	Total	800																	
B2. (b) Cement-Brick wall with flat roof	Urban	234		-	-	L	-	-	M	-	-	L	VL		-	L	L	L	-
	Rural	612																	
	Total	846																	
B3. Wood wall with all roof sloping	Urban	133		-	-	H	-	-	M	-	-	H	M	L	-	M	M	M	-
	Rural	251																	
	Total	384																	
Total Category-B		**2030**	**52.54**																
CATEGORY-X																			
X1. C.I/Metal Sheet wall with all roofs sloping	Urban	506		-	-	VH	-	-	M	-	-	H	M	L	-	M	M	M	-
	Rural	124																	
	Total	630																	
X2. Straw/Bamboo wall with all roofs sloping	Urban	154		-	-	VH	-	-	M	-	-	H	M	L	-	H	H	H	-
	Rural	235																	
	Total	389																	
Total Category-X		**1019**	**26.37**																
GRAND TOTAL		**3864**	**100**																

5.7.2 Housing Vulnerability for Chittagong District

According to the Population and Housing Census, 1991, total number of households enumerated in the Zilla was 919,677. In Chittagong 33.18% of households have cement as the material of wall and roof both and another 67.09% of the households have their wall of the main structure made of cement. The main houses in rest of the households are semipucca, tin shed, tiles or any other combination of construction materials.

The total number of wall type of main house and roof material of main house with percentage according to census 1991 are shown in Table 5.17.

Table 5.17 Household Situation of Chittagong District (BBS, 1991)

SL.No.	ITEMS	1991	
		Number	**Percent**
1.	**HOUSEHOLD TYPE**	**919, 677**	**100.00**
	General	854, 450	92.91
	Institutional	8, 268	0.90
	Other	56, 959	6.19
2.	**WALL MATERIAL OF MAIN HOUSE**	**919, 677**	**100.00**
	Straw-Bamboo/ Jute stick	436, 172	47.43
	Mud/ Unburnt Brick	283, 506	30.83
	Corrugated Iron Sheet	27, 423	2.98
	Wood	7, 081	0.77
	Cement-Brick	165, 495	17.99
3.	**ROOF MATERIAL OF MAIN HOUSE**	**919, 677**	**100.00**
	Straw/Bamboo/ Jute stick/Polythene	456, 977	49.69
	Metalled/ Corrugated Iron Sheet	354, 394	38.53
	Cemet	108, 306	11.78

The example the district of Chittagong the distribution of houses by predominant materials of roof and wall and level of damage risk is given in Table 5.18. Total numbers of dwelling household of Chittagong district are 854, 450.

Dwelling households by material of wall and material of roof are shown in Appendix 15. According to 1991 census, there are 854, 450 housing units in the district, 32.66%

of which are of category A (weak type) and 16.17% of category B (moderate/ strong types). The risk of damage from earthquake to Category A houses is 'very high', and to Category B it is 'moderate'.

Chittagong lays in the zone II of Earthquake, hence the life and the property of 100% living population area is in at high seismic risk. This district is located in tornado prone area. 25% of this district is under cyclone high risk zone, 15% is under risk zone and 60% is under high wind area for cyclone. Almost the whole district is also under flood threat. 25% area of this district is under severe flooding area, 60% is under moderate flooding area, 10% of the whole district is under normal flooding and only 10% area is non flooding.

From the Table 5.18 it is also visually clear that the housing of this district is how much vulnerable for the natural hazards. Hence serious attention has to be paid to the district from earthquake, tornado, cyclone and flood disaster prevention, and mitigation and preparedness points of view. The whole scenario of vulnerability of housing for different disaster of any particular district of Bangladesh can be identified with this similar type of table 5.18.

Table 5.18 Distribution of Houses by Predominant Materials of Roof and wall and level of Damage Risk (Chittagong District)

Wall and roof combination		**Census Houses**		**Level of Risk Under**															
		No. of Houses	**%**	**Tornado**				**Earthquake**				**Cyclone**				**Flood**			
				ST	**MT**	**TP**	**N**	**VI**	**VII**	**VIII**	**N**	**HRA**	**RA**	**HWA**	**N**	**SFA**	**MFA**	**NFA**	**N**
				Area in %				**Area in %**				**Area in %**				**Area in %**			
						100 %			**100 %**			**25 %**	**15 %**	**60 %**	**0 %**	**25 %**	**55 %**	**10%**	**10 %**
CATEGORY-A																			
A. Mud/ Unburnt Brick wall with all roofs sloping	Urban	63336				VH			VH			VH	H	M		VH	VH	VH	VH
	Rural	215749																	
	Total	279085																	
Total Category-A		**279085**	**32.66**																
CATEGORY-B																			
B2. (a) Cement-Brick wall with sloping roof	Urban	34745				M			M			M	L	VL		M	M	M	M
	Rural	8974																	
	Total	43719																	
B2. (b) Cement-Brick wall with flat roof	Urban	77355				L			M			L	VL			L	L	L	L
	Rural	11762																	
	Total	89117																	
B3. Wood wall with all roof sloping	Urban	2626				H			M			H	M	L		M	M	M	M
	Rural	2692																	
	Total	5318																	
Total Category-B		**138154**	**16.17**																
CATEGORY-X																			
X1. C.I/Metal Sheet wall with all roofs sloping	Urban	7846				VH			M			H	M	L		M	M	M	M
	Rural	15614																	
	Total	23460																	
X2. Straw/Bamboo wall with all roofs sloping	Urban	183973				VH			M			H	M	L		H	H	H	H
	Rural	229778																	
	Total	413751																	
Total Category-X		**437211**	**51.17**																
GRAND TOTAL		**854450**	**100**																

5.5.3 Use of Housing Vulnerability Tables

The Table provides some ready information for use of the authorities involved in the task of disaster mitigation, preparedness and preventive actions. At a glance at the hazard maps will bring to the notice of the district authorities, the location and percent areas of the districts most susceptible to hazard occurrence, the probable maximum hazard intensities, the type of housing and its vulnerability and risk to the hazards. It must be realized that most of the human problems arise due to loss of the houses; deathes mostly occur in collapsed houses; rescue, evacuation, relief and rehabilitation become more acute when houses get lost. Knowing the extent problem of future disasters with the vulnerability atlas, the district authorities can formulate development plans for:

(a) Preventive actions like hazard resistant construction,retrofitting and upgrading of existing buildings,
(b) Mitigation the intensity and extent of the disaster,
(c) Warning system installation drills for its use,
(d) Training of manpower in various tasks in the emergency
(e) Implementation of land zoning regulations in flood plains and coastal and building byelaws with disaster resistant features in various towns and cities, etc.

The District authorities can create the necessary awareness leading to self help. The hazard zoning can be improved at local levels by specific studies carried out in the district particularly for minimizing the flood havoc by measures such as suitable vulnerability analysis, hazard reduction measures, and risk mapping, and improved resistance of buildings wherein the local technical institutions and professionals could also be involved. The Vulnerability Atlas can be used to identify areas in each district of the country which are prone to high risk from more than one hazard. This information will be useful in establishing the need of developing housing designs to resist the combination of such hazards.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The prime objective of this theis was identification of vulnerable areas with reference to natural hazards causing damage to the housing stock for earthquakes, cyclones, tornadoes and floods. As a basic requirement in this regard a complete database of those natural hazards of Bangladesh was prepared. Different intensity scales for these disasters were also reviewed. The collected damage data, damage scenario and models were used to develop and propose intensity scales for earthquake, flood, cyclone and tornado for Bangladesh.

The digitized maps of earthquake, cyclone, tornado and flood hazards was presented in this study as Vulnerability Risk Areas of Bangladesh, wherein the risk score was tabulated for different districts of Bangladesh. The district of Bangladesh was subdivided in to three risk areas based on risk score. Also a multihazard map of Bangladesh was proposed. This multihazard map may be used by policy makers to take decision for disaster management and preparedness.

The housing types of Bangladesh were categorized based on Bureau of Statistics data. The housing vulnerability table for each district was prepared based on risk of damage for different housing types. At a glance the tables will show the percent areas of the district most susceptible to earthquake, cyclone, tornado and flood hazards for different housing categories.

The research findings are crucial and an important aspect for management strategy for planning and disaster mitigation, preparedness and preventive actions. The information will assist the environmental management, different field of sciences such as engineering and policy making and planning of Bangladesh and should be an integral part of the whole process of economic and social development in Bangladesh.

6.2 LIMITATIONS

Following constrains are recognized in doing of this thesis work.

1. Lack of information and damage data of past hazard occuences, physical structures etc.
2. Unavilability of Contour maps in flood prone areas including areas prone to storm surge.
3. Lacks of damage data for all hazards are more barriers for the intensity identification.
4. The propability of occurance of different disaster were not considered in the risk score assessment. The propability of occurance of different disaster of same time duration make this risk score assessment more reliable.
5. Consideration of flood duration data can make the calculation of flood risk score more accurate.
6. Model-GIS interface and Digital Elevation Models (DEM) are widely used to assess risk and development of floodplain zoning maps all over the world. The main constraint to developing such maps in Bangladesh is the 50 year-old topographic maps and land elevation data.

6.3 RECOMMENDATIONS

It is seen that a large number of studies and actions are needed in different disciplines which will involve a number of government agencies, institutions, departments and working levels ranging from districts and the central government. Specific recommendations are as follows:

- Microzonation mapping of multihazard for Thana level areas is to be initiated and risk mapping suitable to Bangladesh conditions needs to be developed, so that local government disaster prepared planning could be evolved.
- To develop methodology for rapid assessment of damage caused by earthquake hazard, cyclone hazard and flood hazard considering more variables like same time duration, probability.
- A set of vulnerability functions have been developed for earthquake hazards using the EMS intensity scale representing average conditions. These need to be refined for Bangladesh conditions. Similar functions still need to be developed for cyclones, tornadoes and floods.

- Implementation of building codes and construction act, land use planning for the root level of Bangladesh to protect natural hazard.
- Standarization and quality control of building materials and construction processes.
- Ensure all new constructions are natural hazard resistant according to their hazard area.
- Undertake retrofitting of critical structures aspect of multihazard contest.
- Raising awareness in administrative level about multihazard zonation area.
- Education curricula of engineering and architectural colleges and polytechnics should be modified to include various aspects of disaster resistant buildings, structures and systems.
- As well as to carry out vulnerability analysis of buildings, when subjected to one of the four hazards, by research studies using the damage data, scientific analysis of the buildings and structures, testing of models etc.

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Appendix 1: The Mercalli Scale

The original scale for measuring the severity of earthquakes was compiled by the Italian Seismologist, Guiseppe Mercalli, in 1902. It has gone through a number of revisions since then. The Mercalli Scale relies on how much damage is caused by an earthquake. Currently it runs as follows:

I	Only felt by instruments.	**VII**	Most people run outdoors. Damage to weakly constructed buildings. Felt by people in moving vehicles.
II	Felt by people at rest, especially on upper floors. Suspended objects may swing.	**VIII**	Considerable damage to most buildings. Heavy furniture overturned. Some sand fluidised.
III	Felt indoors. Vibrations like passing traffic.	**IX**	Even well-designed and sturdy buildings badly damaged, moved from their foundations. Ground cracks. Pipes break.
IV	Many people feel it indoors, a few outdoors. Crockery and windows rattle. Standing cars rock. Some sleepers awake.	**X**	Most masonry destroyed. Landslides occur. Water slops from reservoirs and lakes. Railway lines bend.
V	Felt by nearly everyone. Tall objects rock. Plaster cracks.	**XI**	Few structures remain upright. Bridges fall. Extensive fissures in the ground. Underground pipes totally out of action.
VI	Most people run outdoors. Damage to weakly constructed buildings. Felt by people in moving vehicles.	**XII**	Total destruction. Ground thrown into waves. Objects flung into the air. You would be lucky to survive this one.

JMA seismic intensity scale		Reference items
Scale	Explanation	
0	No feeling. Shocks too weak to be felt by humans, registered only by seismographs.	Not felt unless shaking is felt by the body, even when a hanging object is seen to be slightly swinging or some rattling is heard.
I	Slight. Extremely weak shocks felt only by persons at rest or by those who are very sensitive to earthquakes.	Shaking is slightly felt when a person is quiet, but the duration is not long. The shaking is not frequently felt when a person is standing.
II	Weak. Shocks felt by most persons, slight shaking of doors and Japanese sliding doors (shoji).	Hanging objects are seen to move, and slight shaking is felt even when a person is standing, but it is generally not felt when a person is moving. Occasionally a person can be awakened.
III	Rather strong. Slight shaking of houses and buildings, rattling of doors and Japanese sliding doors (shoji). The water surface of a vessel can be seen to ripple.	Felt to be slightly surprising, and sleeping persons wake up, but they do not run outside or feel afraid. Many people outside feel it, but some pedestrians may not.
IV	Strong. Strong shaking of houses and buildings, overturning of unstable objects, and spilling of liquids out of vessel. Felt by walking people outdoors, and many people inside rush outdoors. Considerable swinging of hanging objects such as light bulbs.	Sleeping people jump out of bed, and feel afraid. Electric poles and trees are seen to shake. Some roofing tiles of general houses may slip out of place, but serious damage does not occur yet. Slight dizziness is felt.
V	Very strong. Cracks in the walls, overturning of gravestones, stone lanterns etc., damage to chimneys and stone fences.	It is considerably difficult to remain standing. In houses, slight damage is generally sustained. A soft ground can split or break. Unstable furniture falls over.
VI	Disastrous. Collapse of less than 30% of all houses, landslide, and fissures in the ground. Most people cannot stand.	It is difficult to walk, and one has to crawl to move.
VII	Very disastrous. Collapse of more than 30% of all houses, intense landslide, large fissures in the ground, and faults.	

EMS	DEFINITION	DESCRIPTION
1	Not felt	Not felt, even under the most favourable circumstances.
2	Scarcely felt	Vibration is felt only by individual people at rest in houses, especially on upper floors of buildings.
3	Weak	The vibration is weak and is felt indoors by a few people. People at rest feel a swaying or light trembling.
4	Largely observed	The earthquake is felt indoors by many people, outdoors by very few. A few people are awakened. The level of vibration is not frightening. Windows, doors and dishes rattle. Hanging objects swing.
5	Strong	The earthquake is felt indoors by most, outdoors by few. Many sleeping people awake. A few run outdoors. Buildings tremble throughout. Hanging objects swing considerably. China and glasses clatter together. The vibration is strong. Top heavy objects topple over. Doors and windows swing open or shut.
6	Slightly damaging	Felt by most indoors and by many outdoors. Many people in buildings are frightened and run outdoors. Small objects fall. Slight damage to many ordinary buildings e.g.; fine cracks in plaster and small pieces of plaster fall.
7	Damaging	Most people are frightened and run outdoors. Furniture is shifted and objects fall from shelves in large numbers. Many ordinary buildings suffer moderate damage: small cracks in walls; partial collapse of chimneys.
8	Heavily damaging	Furniture may be overturned. Many ordinary buildings suffer damage: chimneys fall; large cracks appear in walls and a few buildings may partially collapse.
9	Destructive	Monuments and columns fall or are twisted. Many ordinary buildings partially collapse and a few collapse completely.
10	Very destructive	Many ordinary buildings collapse.
11	Devastating	Most ordinary buildings collapse.
12	Completely devastating	Practically all structures above and below ground are heavily damaged or destroyed.

Appendix 4: THE EUROPEAN MACROSEISMIC (EMS 98) intensity scale

The EMS 98 intensity scale is more comprehensive and describes the intensity of earthquake more precisely:

Table 1: vulnerability classes

	Type of Structure	A	B	C	D	E	F
MASONRY	rubble stone, fieldstone	O					
	adobe (earth brick)	O	—				
	simple stone	---	O				
	massive stone		—	O	---		
	unreinforced, with manufactured stone units	---	O	---			
	unreinforced, with RC floors		—	O	---		
	reinforced or confined			—	O	—	
REINFORCED CONCRETE (RC)	frame without earthquake-resistant design (ERD)	---	—	O	---		
	frame with moderate level of ERD		---	—	O	—	
	frame with high level of ERD			---	—	O	—
	walls without ERD		—	O	—		
	walls with moderate level of ERD			—	O	—	
	walls with high level of ERD				—	O	—
STEEL	steel structures			---	—	O	—
WOOD	timber structures		---	—	O	—	

O most likely vulnerability class; — probable range;
--- range of less probable, exceptional cases

The masonry types of structures are to be read as, e.g., simple stone masonry, whereas the reinforced concrete (RC) structure types are to be read as, e.g., RC frame or RC wall.

1.1 Classification of damage

The way in which a building deforms under earthquake loading depends on the building type. As a broad categorization one can group together types of masonry buildings as well as buildings of reinforced concrete as shown in Table 2 and Table 3.

Table 2: Classification of damage to masonry buildings	
	**Grade 1: Negligible to slight damage** **(no structural damage, slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	**Grade 2: Moderate damage** **(slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.

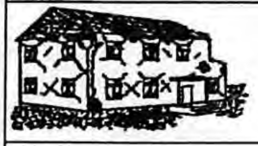
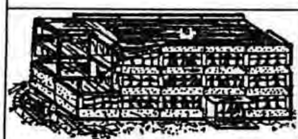
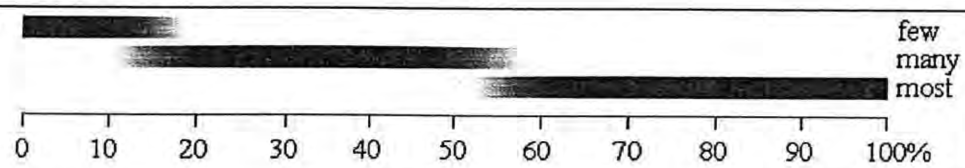
	**Grade 3: Substantial to heavy damage** **(moderate structural damage, heavy non-structural damage)** Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	**Grade 4: Very heavy damage** **(heavy structural damage, very heavy non-structural damage)** Serious failure of walls; partial structural failure of roofs and floors.
	**Grade 5: Destruction** **(very heavy structural damage)** Total or near total collapse.

Table 3: Classification of damage to buildings of reinforced concrete

	**Grade 1: Negligible to slight damage** **(no structural damage, slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	**Grade 2: Moderate damage** **(slight structural damage, moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	**Grade 3: Substantial to heavy damage** **(moderate structural damage, heavy non-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	**Grade 4: Very heavy damage** **(heavy structural damage, very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	**Grade 5: Destruction** **(very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings.

Definitions of quantity



1.2 Definitions of intensity degrees

Arrangement of the scale:

a) Effects on humans, b) Effects on objects and on nature and c) Damage to buildings

The single intensity degrees can include the effects of shaking of the respective lower intensity degree(s) also, when these effects are not mentioned explicitly.

I. Not felt

a) Not felt, even under the most favourable circumstances. b) No effect. c) No damage.

II. Scarcely felt

a) The tremor is felt only at isolated instances (<1%) of individuals at rest and in a specially receptive position indoors.

b) No effect. c) No damage.

III. Weak

a) The earthquake is felt indoors by a few. People at rest feel a swaying or light trembling.

b) Hanging objects swing slightly. c) No damage.

IV. Largely observed

a) The earthquake is felt indoors by many and felt outdoors only by very few. A few people are awakened. The level of vibration is not frightening. The vibration is moderate. Observers feel a slight trembling or swaying of the building, room or bed, chair etc.

b) China, glasses, windows and doors rattle. Hanging objects swing. Light furniture shakes visibly in a few cases. Woodwork creaks in a few cases.

c) No damage.

V. Strong

a) The earthquake is felt indoors by most, outdoors by few. A few people are frightened and run outdoors. Many sleeping people awake. Observers feel a strong shaking or rocking of the whole building, room or furniture.

b) Hanging objects swing considerably. China and glasses clatter together. Small, top-heavy and/or precariously supported objects may be shifted or fall down. Doors and windows swing open or shut. Infew cases windowpanes break. Liquids oscillate and may spill from well-filled containers. Animals indoors may become uneasy.

c) Damage of grade 1 to a few buildings of vulnerability class A and B.

VI. Slightly damaging

a) Felt by most indoors and by many outdoors. A few persons lose their balance. Many people are frightened and run outdoors.

b) Small objects of ordinary stability may fall and furniture may be shifted. In few instances dishes and glassware may break. Farm animals (even outdoors) may be frightened.

c) Damage of grade 1 is sustained by many buildings of vulnerability class A and B; a few of class A and B suffer damage of grade 2; a few of class C suffer damage of grade1.

VII. Damaging

a) Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors.

b) Furniture is shifted and top-heavy furniture may be overturned. Objects fall from shelves in large numbers. Water splashes from containers, tanks and pools.

c) Many buildings of vulnerability class A suffer damage of grade 3; a few of grade 4. Many buildings of vulnerability class B suffer damage of grade 2; a few of grade 3. A few buildings of vulnerability class C sustain damage of grade 2. A few buildings of vulnerability class D sustain damage of grade 1.

VIII. Heavily damaging

a) Many people find it difficult to stand, even outdoors.

b) Furniture may be overturned. Objects like TV sets, typewriters etc. fall to the ground. Tombstones may occasionally be displaced, twisted or overturned. Waves may be seen on very soft ground.

c) Many buildings of vulnerability class A suffer damage of grade 4; a few of grade 5. Many buildings of vulnerability class B suffer damage of grade 3; a few of grade 4. Many buildings of vulnerability class C suffer damage of grade 2; a few of grade 3. A few buildings of vulnerability class D sustain damage of grade 2.

IX. Destructive

a) General panic. People may be forcibly thrown to the ground.

b) Many monuments and columns fall or are twisted. Waves are seen on soft ground.

c) Many buildings of vulnerability class A sustain damage of grade 5. Many buildings of vulnerability class B suffer damage of grade 4; a few of grade 5. Many buildings of vulnerability class C suffer damage of grade 3; a few of grade 4. Many buildings of vulnerability class D suffer damage of grade 2; a few of grade 3. A few buildings of vulnerability class E sustain damage of grade 2.

X. Very destructive

c) Most buildings of vulnerability class A sustain damage of grade 5. Many buildings of vulnerability class B sustain damage of grade 5. Many buildings of vulnerability class C suffer damage of grade 4; a few of grade 5. Many buildings of vulnerability class D suffer damage of grade 3; a few of grade 4. Many buildings of vulnerability class E suffer damage of grade 2; a few of grade 3. A few buildings of vulnerability class F sustain damage of grade 2.

XI. Devastating

c) Most buildings of vulnerability class B sustain damage of grade 5. Most buildings of vulnerability class C suffer damage of grade 4; many of grade 5. Many buildings of vulnerability class D suffer damage of grade 4; a few of grade 5. Many buildings of vulnerability class E suffer damage of grade 3; a few of grade 4. Many buildings of vulnerability class F suffer damage of grade 2; a few of grade 3.

XII. Completely devastating

c) All buildings of vulnerability class A, B and practically all of vulnerability class C are destroyed. Most buildings of vulnerability class D, E and F are destroyed. The earthquake effects have reached the maximum conceivable effects.

Appendix5: Chronology of big floods of Bangladesh

1781	Serious flood, which was more pronounced in the western part of SYLHET district. The CATTLE suffered much from the loss of fodder.
1786	Floods in the Meghna wrought havoc to the crops and immense destruction of the VILLAGES on the banks. It was followed by a FAMINE, which caused great loss of life at BAKERGANJ. At Tippera the embankment along the GUMTI gave way. At Sylhet the PARGANAS were entirely under water, the greater part of the cattle drowned and those surviving were kept on BAMBOO rafts.
1794	The Gumti embankment burst again, causing much damage around Tippera.
1822	Bakerganj division and Patuakhali subdivision were seriously affected, 39,940 people died and 19,000 cattle perished and properties worth more than 130 million taka were destroyed. BARISAL, Bhola and MANPURA were severely affected.
1825	Destructive floods occurred at Bakerganj and adjoining regions. There were no important embankments or other protective works against inundation in the district.
1838	Heavy rainfall caused extensive inundation at RAJSHAHI and a number of other districts. The cattle suffered much from loss of fodder and the people were greatly inconvenienced when driven to seek shelter on high places and when the water subsided CHOLERA broke out in an epidemic form.
1853	Annual inundation was more pronounced than usual in the west of Sylhet district, partly the result of very heavy local rainfall and partly caused by the overflow of the Meghna.
1864	Serious inundation when the embankment was breached and the water of the Ganges flooded the greater part of Rajshahi town. There was much suffering among the people who took shelter with their cattle on the embankment.
1865	Extensive inundation caused by the annual rising of the Ganges flooded Rajshahi district. Excessive rainfall seriously affected Rajshahi town.
1867	Destructive flood also affected Bakerganj. Crop was partially destroyed. But no general distress resulted.
1871	Extensive inundation in Rajshahi and a few other districts. Crops, cattle and valuable properties were damaged. This was the highest flood on record in the district. Cholera broke out in an epidemic form.
1876	Barisal and PATUAKHALI were severely affected. Meghna overflowed by about 6.71m from the SEA LEVEL. Galachipa and Bauphal were damaged seriously. A total of about 215,000 people died. Cholera broke out immediately after flood.
1879	Flooding of the Tista when the change in the course of the Brahmaputra began.
1885	Serious floods occurred due to the bursting of an embankment along the Bhagirathi, affected areas of Satkhira subdivision of KHULNA district.
1890	Serious flood at SATKHIRA caused enormous damage to cattle and people.
1900	Due to the bursting of an embankment along the Bhagirathi, Satkhira was affected.
1902	At Sylhet the general level of the river went so high that there was terrible flood. Crops and valuable properties were damaged.
1904	The crops in some parts of COX'S BAZAR subdivision and KUTUBDIA island were damaged due to an abnormally high tide. This flood was exceptional in severity in MYMENSINGH. The distress caused on this occasion is probably the nearest parallel to that which resulted from the flooding of the Tista in 1879, when the change in the course of Brahmaputra began.
1954	On August 2, Dhaka district went under water. On August 1 flood peak of the JAMUNA river at Sirajganj was 14.22m and on August 30 flood peak of the Ganges river at HARDINGE BRIDGE was 14.91m. Affected 55% of country.
1955	More than 30% of Dhaka district was flooded. The flood level of the BURIGANGA exceeded the highest level of 1954.
1962	The flood occurred twice, once in July and again in August and September. Many people were

	affected and crops and valuable properties were damaged.
1966	One of the most serious floods that ever visited Dhaka occurred on 8 June 1966. The flood level was almost the highest in the history of Sylhet district too. A storm on the morning of 12 June 1966 made the situation grave. About 25% of houses were badly damaged, 39 people died and 10,000 cattle were lost, and about 1,200,000 people were affected. On September 15 Dhaka city became stagnant due to continuous rainfall for 52 hours, which resulted in pools of water 1.83m deep for about 12 hours.
1968	Severe flood in Sylhet district and about 700,000 people were badly affected.
1969	Chittagong district fell in the grip of flood caused by heavy rainfall. Crops and valuable property were damaged
1974	In Mymensingh about 10,360 sq km area was flooded. People and cattle were severely affected and more than 100,000 houses were destroyed. Moderately severe, over 2,000 deaths, affected 58% of country, followed by famine with over 30,000 deaths.
1984	Inundated 52,520 sq-km, cost estimated at US$ 378 million
1987	Catastrophic flood occurred in July-August. Affected 57,300 sq km (about 40% of the total area of the country) and estimated to be a once in 30-70 year event. Excessive rainfall both inside and outside of the country was the main cause of the flood. The seriously affected regions were on the western side of the Brahmaputra, the area below the confluence of the Ganges and the Brahmaputra, considerable areas north of Khulna and finally some areas adjacent to the Meghalaya hills.
1988	Catastrophic flood occurred in August-September. Inundated about 82,000 sq km (about 60% of the area) and its return period is estimated to be 50-100 years. Rainfall together with synchronisation of very high flows of all the three major rivers of the country in only three days aggravated the flood. Dhaka, the capital of Bangladesh, was severely affected. The flood lasted 15 to 20 days. Inundated 61% of country, estimated damage US$ 1.2 billion, more than 45 million homeless, between 2,000-6,500 deaths.
1989	Flooded Sylhet, SIRAJGANJ and MAULVI BAZAR and 600,000 people were trapped by water.
1993	Severe rains all over the country, thousands of hectares of crops went under water. Twenty-eight districts were flooded.
1998	Over two-thirds of the total area of the country was flooded. It compares with the catastrophic flood of 1988 so far as the extent of flooding is concerned. A combination of heavy rainfall within and outside the country, synchronisation of peak flows of the major rivers and a very strong backwater effect coalesced into a mix that resulted in the worst flood in recorded history. The flood lasted for more than two months. 1,100 deaths, inundated nearly 100,000 sq-km, rendered 30 million people homeless, damaged 500,000 homes, heavy loss to infrastructure, estimated damage US$ 2.8 billion.
2000	Five southwestern districts of Bangladesh bordering India were devastated by flood rendering nearly 3 million people homeless. The flood was caused due to the outcome of the failure of small river dykes in West Bengal that were overtopped by excessive water collected through heavy downpour. Inundation 38%, damage US$ 6.6 billion, deaths 700, affected people nearly 3.8 million

Appendix 6: List of 86 tornados in Bengal for 1838-2001

	Date	Time Local	Location	Lon., Lat.	# killed	d	I	w
1	04-08-1838	1330	Eastern side of Calcutta, IN	22.6, 88.4	215	330	16	.5
2	05-01-1865	1800	Pundooah in Hooghly dist. IN	23.1, 88.2	20	230	4	.004
3	04-15-1872		Satkhira in 24-Paraganas dist. IN	22.8, 89.0	3			
4	03-26-1875	dusk	Uladah, Mymensingh dist. BD	24.3,90.6	?	230	2	.15
5	03-31-1875		Mymensingh dist. BD	24.3, 90.6	many			
6	03-27-1888	sunset	Jessore dist. Hit 2 miles sse of Magura,BD	23.4, 89.4	4	340	7	1
7	03-27-1888		Pabna dist., BD	24.1, 89.8	>20			
8	04-07-1888	1900	Dhaka, BD	23.7, 90.4	118	320	7	.15
9	04-07-1888	1930	Rajbari, BD	23.4, 90.6	70	330	4	.15
10	04-27-1888	2000	16 miles north of Calcutta, IN	22.9, 88.3	>7	340	2	.15
11	04-29-1895	1530	Manikganj, BD	23.9, 90.1	24			
12	04-12-1902		Dhaka, BD	23.7, 90.4	88			.1-.4
13	03-28-1903		Rangpur, BD	25.8, 89.3	many			.1
14	04-29-1904		Pabna, BD	24.1, 89.3	7		.6	.1
15	04-04-1927	1630	Noakhali, BD	22.9, 91.1	many		13	.1
16	03-20-1951	1215	Diamond Harbour in Midnapore dist. of West Bengal, IN	22.3, 88.3				
17	05-02-1951		Gopalganj	23.0, 90.0	19			
18	05-02-1951		Narail, BD	23.2, 89.6	25			
19	05-12-1951		Faridpur dist., BD	23.6, 89.8	200			
20	03-13-1953		Meherpur in Kustia dist., BD	23.8, 88.5	19		16	.25
21	05-05-1954	1200	Bhairab Bazaar, BD	24.1, 91.1	17			
22	05-21-1959	1750	Alipore in the south suburbs of Calcutta,IN	23.3, 88.2	11			
23	03-18-1961		along Jamuna river near Mymensingh-Rangpur border, BD	25.3, 89.8	32			
24	03-19-1961	1600	Jhaukandi in Faridpur, Dohar and Nawabganj in Dacca dist. BD	23.6, 90.2	210	270	15	1.5
25	04-03-1961		hit south of Comilla between Zangalia and Lalmia, BD	23.5, 91.1	62		4	
26	04-15-1962	1350	Kalibari and Kishorganj, BD	24.4, 90.7	none			
27	03-10-1963		Atpara and Barghata in Mymensingh dist., BD	24.9, 90.8	20			
28	04-19-1963	1650	Formed north of Cooch Behar, IN	26.3, 89.7	300	300	20	.10
29	04-11-1964	1630	Magura and Narail dists. including Mohammadpur, BD	23.3, 89.6	500+	360		
30	03-23-1965		Kustia dist., BD	23.8, 89.0	15			
31	03-21-1967		Karimganj, BD	24.5, 90.9	2			
32	04-16-1967		Naria and Bhederganj unions, BD	23.2, 90.5	77		10	
33	04-17-1967		Sonamura in Tripura dist., IN	23.4,91.3	25+			
34	04-19-1967		Sudharam, BD	22.8, 91.0	12			
35	05-01-1967	1630	Laksham in Comilla dist. and	23.2, 91.1	30+			

			Munshiganj in Dhaka dist. BD						
36	04-03-1968	1500	Noakhali dist. Hit Raipur, Lumxipur & Begumganj, BD	22.8, 91.1	42	280	10		
37	04-11-1968		Naria, Zajira and Bhederganj under Sariatpur zila, BD	23.2, 90.4	141	320			
38	03-21-1969	0530	Diamond Harbour in Midnapore dist. of West Bengal, IN	22.3, 88.3	0	270	8	.003	
39	04-14-1969	1645	NE suburbs of Dhaka BD	23.8, 90.4	660	320			
40	04-14-1969	1715	Homna P.S. under Comilla dist. BD	23.6, 90.8	263	320			
41	04-17-1969		Kharmakhali and Khoksa in Kustia dist., BD	23.9, 89.3	15				
42	04-17-1969		Rajshahi dist. Moved from Gustompur to Manda unions, BD	24.9, 88.4	37				
43	04-17-1969	1540	Tangail and Sirajganj in Mymensingh dist., BD	24.5, 90.0	32				
44	04-28-1969		Katiadi in Mymensingh dist., BD	24.2, 90.8	8				
45	04-13-1970	1600	Joydepur and Sreepur of Gazipur dist., BD	24.1, 90.4	37	350			
46	04-01-1972	1830	14 miles southwest of Mymensingh, BD	24.6, 90.2	200+		15	1	
47	04-05-1972	1650	Keraniganj and Baliaghata in south Dhaka suburbs, BD	23.6, 90.4	75				
48	04-29-1972		Bhakua and Haripur unions of Barishal P.S., BD	24.3, 90.7	300				
49	04-12-1973	1500	Baliakandi in Faridpur dist., BD	23.6, 89.6	200				
50	04-14-1973		Alipur Duar subdiv. of Jalpaiguri, WB, IN	26.5, 89.6	15				
51	04-17-1973	1445	Manikganj, Singair and Nawabganj in Dhaka dist., BD	23.6, 90.1	681	320			
52	04-11-1974		11 miles W of Bogra, BD	25.0, 89.3	100				
53	04-10-1976	1730	Naria and Bhederganj under Sariatpur zila, BD	23.2, 90.5	46				
54	05-08-1976		Hatiya Island, BD	22.3, 91.2	2				
55	05-09-1976		S. suburbs of Dacca, BD	23.6, 90.5	1				
56	03-31-1977		Lahund and Dangargaon villages in Katiadi, BD	24.2, 90.8	17				
57	04-01-1977	1600	Madaripur & Shibchar, BD	23.2, 90.2	500				
58	04-02-1977		Mokshedpur, Bhanga and Tungipara unions of Gopalganj, BD	23.3, 90.0	111				
59	04-07-1977		Gholapara and Fakiradanga villages of Nadia dist., IN	24.0, 88.2	2				
60	04-15-1977	1530	13 km north of Contai in Midnapore dist., IN	21.9, 87.8	10				
61	04-16-1978	1630	Jaipur and Keonjhar dist. of Orissa, IN	21.1, 86.1	173	340	9		
62	04-18-1978	1400	Karimpur in Murshidibad of Nadia dist., West Bengal state, IN	24.0, 88.6	128	300	8	.25	
63	05-07-1979		Jamalpur, BD	25.1, 90.1	5				
64	03-01-1981	2100	Itna, BD	24.5, 91.1	15				
65	04-12-1981	midday	Parshuram to Fulgazi to Somarpur to Sonagazi in Feni dist., BD	23.2, 91.4	200	360			

66	04-17-1981	1430	Moved along Baitarani river, BD. Hit villages of Kapundi, Erandi, Dhanbeni and Rengalbeda.	21.6, 85.8	120	360	10	.62
67	04-12-1982		Rangpur and Gaibandha, BD	25.6, 89.4	23			
68	04-09-1983		Jessore, BD	23.1, 89.3	16			
69	04-12-1983	noon	40 km northeast of Calcutta. Galahata under Bangaon, IN	23.0, 88.9	50			
70	04-23-1983		Raghunathpur village of Kutubpur union in Fatullah, BD	23.6, 90.5	2			
71	04-24-1983		Rupsha under Khulna dist., BD	22.7,89.7	25			
72	04-14-1986	evening	Borni of Tongiapara, BD	22.9, 89.8	120			
73	04-26-1989	1830	Daultipur and Salturia, BD	24.0, 89.9	1300	270	8	1
74	04-28-1989		Missile launch site, IN		10			
75	04-20-1990		Taras, Ullahpara and Shahazadpur in Sirajganj, BD	24.3, 89.6	76			
76	04-29-1990		Sirajganj, BD	24.7, 89.7	19			
77	03-31-1991	evening	Champak in Comilla, BD		18			
78	05-07-1991	aftern.	Between Tongi, Joydevpur and Gazipur, BD	24.0, 90.5	45+		5	.30
79	05-18-1991		Gournadi in Barisal, BD	23.0, 90.3	50			
80	04-22-1992		Naogaon in Assam, IN		25			
81	04-09-1993	1530	Kandi, Murshidibad dist., IN	24.1, 88.2	145	250	8	.18
82	05-13-1993	1645	Begumganj, Noakhali dist., BD	22.8, 91.1	50			
83	04-08-1995		Lohaganj, Serajdikhan and Srinigar in Munshiganj dist., BD	23.5, 90.4	40+			
84	05-13-1996	1630	Madarganj, Gopalpur, Kallhati, Basail, Shakipur and Mrizapur in Jamalpur and Tangail districts, BD	24.7, 90.0	700+	330		
85	03-24-1998	1500	Dantan along border between Orissa and West Bengal, IN	22.1, 87.2	250			
86	04-08-1998	0800	Nilphimari, BD	26.0, 88.9	21			

Appendix 7: Description of some historical Tornadoes in Bangladesh

• *April 7, 1888*

The Times of London reported that a 500-foot wide tornado killed 118 people and injured 1200 more on the west edge of Dhaka. Soon afterwards, another 66 died in the Murchagunja area. There were unsubstantiated rumors that 150 people were killed by hail stones weighing up to two pounds each.

• *April 11, 1964(then called East Pakistan)*

The Bangladesh Observer reported that as many as 500 people may have died as a tornado destroyed villages in the Narail and Magura regions of Jessore. Bangladesh newspapers that use the words "cyclone," "tornado," and "Nor'wester" interchangeably make it difficult to determine the exact nature of the storm. The presence of bodies in trees and cooking utensils imbedded in trees left little doubt that this was a true tornado. What was probably another tornado killed 4 people in Narail just nine days earlier, on April 2nd.

• *April 26, 1989*

What may have been the world's deadliest tornado took place on this day. As many as 1300 people were initially reported killed and 12,000 injured as a tornado cut a long track, up to a mile wide, about 50 miles northwest and north of Dhaka, striking 5 districts. The towns of Saturia and Manikgank sadar were leveled and about 80,000 people were made homeless. There were at least 600 deaths in the tornado, along with 992 dead on April 14, 1969, 500 dead on April 1, 1977, and 800 dead on May 26, 1989.

• *January 9, 1993*

Nearly 50 people were killed and thousands made homeless when a tornado battered villages in northeast Bangladesh. The tornado, which lasted five minutes, struck early on Saturday, a day after another tornado further north killed at least 26 people.

• *May 14, 1993*

A tornado ripped through several villages in southern Bangladesh. The winds destroyed 350 mud-and-straw houses and left at least 50 people dead. More than 4,000 people were made homeless.

• *September 28, 1995*

Five people were killed in northern Bangladesh when a tornado pushed a passenger train off the tracks. The train derailed in the northern district of Jamalpur.

• *May 13, 1996*

On Monday afternoon, May 13, massive thunderstorms (probably supercells) formed along a dryline in western Bangladesh. Dew points in the northeast Indian desert were in the low 40's. Dew points in Bangladesh were in the low 80's. The resulting windstorms killed between 500 and 1,000, injured more than 30,000, and left 100,000 homeless. More than 80 villages with 10,000 homes were destroyed. Some people were buried alive in their collapsing dwellings. "The whole village has diminished into a vast grave" observed a police officer in the village of Barabhita. At Bashial, nearly 120 people were killed, many who were students at a boarding school that was toppled. As many as 22 people died in one family. "Some families have no one left to mourn." More than 2000 people were brought to one hospital that had a capacity of 35. The appearance of the trees seems to indicate that at least a portion of these windstorms were tornadic. There were also press reports that people and animals were carried "long distances." The area near Tangail is about 50 miles NNW of Dhaka and about 30 miles north of the Manikganj area, where an estimated 1300 died in a tornado on April 26th, 1989. A rough plot of the villages that were destroyed indicates that there were at least two separate tracks, about 10 miles north and south of Tangail. The northern track must have been at least 50 miles long. "Buses and trucks frantically ferried the injured to hospitals in Tangail and the nearby town of Mymensingh; others were carried on shoulders or carts" witnesses said. The extraordinary death and injury total may have been enhanced by a recent increase in "prosperity." The growth in the textile industry had allowed the people in this region to move out of homes of mud and straw and into frail sheet metal structures. It tossed homes, buildings and trees as if they were feathers." The air became filled with the loose sheet metal, literally acting like an enormous blender. Hundreds of paramedics and volunteers rushed to the affected areas, but their efforts were hindered by poor weather. Of the patients visiting one of the clinics set up to care for the injured, 99% had multiple injuries due to flying corrugated iron sheets that had been used as roofs and walls. In 84%, the wounds were infected and needed not only debridement but also antibiotics for infection control." Head injury was the cause of death in a majority of cases. "Seven per cent of the hospital deaths due to the tornado in Tangail district result from sepsis after wound infections." The horrendous death and injury total seems likely to be repeated. An east-west corridor lying north of the capital (Dhaka) of this impoverished country has a long history of killer tornadoes. On April 14, 1969, estimates of the death toll from another tornado range as high as 922. The official death toll will be about 700, but at the time this number was quoted, there were still 9000 people in critical condition, and many hundreds had probably been buried by survivors without ever reporting the deaths with officials.

- *October 12, 1997*

At least 15 and as many as 25 people were killed in Tongi, a town about 10-20 miles north of Dhaka in Bangladesh, when a tornado tracked through the town. The World Congregation of Muslim Devotees was conducting a 5 day seminar on the banks of the Turag River, in a massive but frail tin-shed "pandal". The Dhaka paper reported that there were 80,000-100,000 people attending the seminar, but that it had just ended, and they were preparing to return to their homes. At least 1000, and as many as 5000 were injured--depending on whether you go by a government source or rescue workers at the scene. All the dead were clerics, many if not all quite elderly. The major cause of death was by flying debris, as corrugated iron roofing, bamboo stakes and other materials became airborne. ``Tin was flying like pieces of paper tossed into the air," said Baker Ali, a preacher who survived the tornado. Torn pieces of metal, iron rods, wood, cooking utensils, shoes and water pots littered the muddy field where the Islamic clerics had gathered. Nine trucks full of dead or dying people were rushed to different hospitals. The Tongi Hospital was described as a "war clinic", with blood stained floors and corridors jammed with people wrapped in blankets, awaiting attention.

- *July 19, 1998*

A tornado moved through villages flooded by heavy monsoon rains in northern Bangladesh, injuring at least 25 people. It struck the Sirajganj district, 65 miles north of Dhaka, destroying dozens of mud-and-thatch houses already weakened by flooding. Flooding contaminates the drinking water supply, causing dysentery, diarrhea, and sometimes death.

- *March 26, 1999*

A tornado tore through scores of villages in northern Bangladesh, killing at least two people and leaving thousands of villagers homeless. It blew down thousands of mud huts, uprooted trees and knocked down telephone and electricity poles in the Panchagarh district, 215 miles north of Dhaka. The bodies of a man and woman were recovered from the debris of their collapsed home in Satmora, a village near the Indian border. About 60 other people received serious injuries.

- *September 19, 2000*

Two people were killed and 5 others severely injured as a violent tornado tracked through five villages in the Savar and Gazipur districts near Dhaka. Many others received lesser injuries. A tornado also struck an industrial township in the Savar subdistrict, collapsing three factories, including a textile mill. About 500 homes, many of bamboo and tin, were destroyed and electric power and telephone services were cut off. Incessant rain for two days also caused flash flooding and many injuries and much damage was caused by that.

- *May 2004*

A tornado moved through Haluaghat Netrokona killing 70, injuring 1200.

- *26 July 2007*

Parts of central and northern Bangladesh have been lashed by a series of tornados. Hundreds of homes have been damaged or destroyed by the storm and 500 people have been injured. In addition, an eight-year-old boy was killed when the storm forced a wall to collapse. Three districts were affected by the tornadoes, which also caused widespread damage to the local infrastructure. Conditions were also bad at sea as a cargo vessel sank in the Bay of Bengal.

The Beaufort scale is an empirical measure for describing wind velocity based mainly on observed sea conditions. Its full name is the Beaufort wind force scale. Wind speed on the 1946 Beaufort scale is based on the empirical formula:

$$v = 0.836\ B3/2\ m/s$$

where v is the equivalent wind speed at 10 metres above the surface and B is Beaufort scale number.

Beaufort number	Wind speed				Mean wind speed (kn / km/h / mph)	Description	Wave height		Sea conditions	Land conditions	Sea state photo
	kn	km/h	mph	m/s			m	ft			
0	0	0	0	0-0.2	0 / 0 / 0	Calm	0	0	Flat.	Calm. Smoke rises vertically.	
1	1-3	1-6	1-3	0.3-1.5	2 / 4 / 2	Light air	0.1	0.33	Ripples without crests.	Wind motion visible in smoke.	
2	4-6	7-11	4-7	1.6-3.3	5 / 9 / 6	Light breeze	0.2	0.66	Small wavelets. Crests of glassy appearance, not breaking	Wind felt on exposed skin. Leaves rustle.	
3	7-10	12-19	8-12	3.4-5.4	9 / 17 / 11	Gentle breeze	0.6	2	Large wavelets. Crests begin to break; scattered whitecaps	Leaves and smaller twigs in constant motion.	
4	11-15	20-29	13-18	5.5-7.9	13 / 24 / 15	Moderate breeze	1	3.3	Small waves.	Dust and loose paper raised. Small branches begin to move.	
5	16-21	30-39	19-24	8.0-10.7	19 / 35 / 22	Fresh breeze	2	6.6	Moderate (1.2 m) longer waves. Some foam and spray.	Smaller trees sway.	

6	22-27	40-50	25-31	10.8-13.8	24 / 44 / 27	Strong breeze	3	9.9	Large waves with foam crests and some spray.	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult.	
7	28-33	51-62	32-38	13.9-17.1	30 / 56 / 35	Near Gale/Moderate gale	4	13.1	Sea heaps up and foam begins to streak.	Whole trees in motion. Effort needed to walk against the wind.	
8	34-40	63-75	39-46	17.2-20.7	37 / 68 / 42	Fresh Gale	5.5	18	Moderately high waves with breaking crests forming spindrift. Streaks of foam.	Twigs broken from trees. Cars veer on road.	
9	41-47	76-87	47-54	20.8-24.4	44 / 81 / 50	Strong Gale	7	23	High waves (6-7 m) with dense foam. Wave crests start to roll over. Considerable spray.	Light structure damage.	
10	48-55	88-102	55-63	24.5-28.4	52 / 96 / 60	Whole Gale/Storm	9	29.5	Very high waves. The sea surface is white and there is considerable tumbling. Visibility is reduced.	Trees uprooted. Considerable structural damage.	
11	56-63	103-119	64-73	28.5-32.6	60 / 112 / 70	Violent storm	11.5	37.7	Exceptionally high waves.	Widespread structural damage.	
12	64-80	120	74-95	32.7-40.8	73 / 148 / 90	Hurricane	14+	46+	Huge waves. Air filled with foam and spray. Sea completely white with driving spray. Visibility greatly reduced.	Considerable and widespread damage to structures.	

The TORRO tornado intensity scale (or T-Scale) is a scale measuring tornado intensity between T0 and T11. It was developed by Terence Meaden of the Tornado and Storm Research Organisation (TORRO), a meteorological organisation in the United Kingdom, as an extension of the Beaufort scale.

T-Scale formula may be expressed as:

v = 0.837 (2T+8)3/2 m/s

where, v is wind speed and T is TORRO intensity number.

Tornado Intensity	Description Of Tornado & Windspeeds	Description Of Damage (for guidance only)
T0	Light Tornado 17 - 24 m s-1 (39 - 54 mi h-1)	o Loose light litter raised from ground level in spirals. o Tents, marquees, awnings seriously disturbed. o Some exposed tiles, slates on roofs dislodged. Twigs snapped; trail visible through crops. o Wheelie bins tipped and rolled. o Garden furniture & pots disturbed.
T1	Mild Tornado 25 - 32 m s-1 (55 - 72 mi h-1)	o Deck chairs, small plants, heavy litter becomes airborne. o Minor damage to sheds. o More serious dislodging of tiles, slates. o Chimney pots dislodged. Wooden fences flattened. o Slight damage to hedges and trees. o Some windows already ajar blown open breaking latches.
T2	Moderate Tornado 33 - 41 m s-1 (73 - 92 mi h-1)	o Heavy mobile homes displaced. Light caravans blown over. o Garden sheds destroyed. Garage roofs torn away and doors imploded. o Much damage to tiled roofs and chimneys. Ridge tiles missing. o General damage to trees, some big branches twisted or snapped off, small trees uprooted. o Bonnets blown open on cars. o Weak or old brick walls toppled. o Windows blown open or glazing sucked out of frames.
T3	Strong Tornado 42 - 51 m s-1 (93 - 114 mi h-1)	o Mobile homes overturned / badly damaged. Light caravans destroyed. Garages and weak outbuildings destroyed. o House roof timbers considerably exposed. Some of the bigger trees snapped or uprooted. o Some heavier debris becomes airborne causing secondary damage breaking windows and impaling softer objects. o Debris carried considerable distances. Garden walls blown over. o Eyewitness reports of buildings physically shaking. o Mud sprayed up the side of buildings
T4	Severe Tornado 52 - 61 m s-1 (115 - 136 mi h-1)	o Motorcars levitated. Mobile homes airborne / destroyed. o Sheds airborne for considerable distances. Entire roofs removed from some houses. o Roof timbers of stronger brick or stone houses completely exposed. Gable ends torn away. o Numerous trees uprooted or snapped. Traffic Signs folded or twisted.

Tornado Intensity	Description Of Tornado & Windspeeds	Description Of Damage (for guidance only)
		o Some large trees uprooted and carried several yards. o Debris carried up to 2km leaving an obvious trail.
T5	Intense Tornado 62 - 72 m s-1 (137 - 160 mi h-1)	o Heavier motor vehicles (4x4, 4 Tonne Trucks) levitated. o Wall plates, entire roofs and several rows of bricks on top floors removed. o Items sucked out from inside house including partition walls and furniture. o Older, weaker buildings collapse completely. o Utility poles snapped.
T6	Moderately-Devastating Tornado 73 - 83 m s-1 (161 - 186 mi h-1)	o Strongly built houses suffer major damage or are demolished completely. o Bricks and blocks etc. become dangerous airborne debris. o National grid pylons are damaged or twisted. o Exceptional or unusual damage found, e.g. objects embedded in walls or small structures elevated and landed with no obvious damage.
T7	Strongly-Devastating Tornado 84 - 95 m s-1 (187 - 212 mi h-1)	o Brick and Wooden-frame houses wholly demolished. o Steel-framed warehouse-type constructions destroyed or seriously damaged. o Locomotives thrown over. o Noticeable de-barking of trees by flying debris.
T8	Severely-Devastating Tornado 96 - 107 m s-1 (213 - 240 mi h-1)	o Motorcars carried great distances. o Some steel framed factory units severely damaged or destroyed. o Steel and other heavy debris strewn over a great distances. o A high level of damage within the periphery of the damage path.
T9	Intensely-Devastating Tornado 108 - 120 m s-1 (241 - 269 mi h-1)	o Many steel-framed buildings demolished o Locomotives or trains hurled some distances. o Complete debarking of any standing tree-trunks. o Inhabitants survival reliant on shelter below ground level.
T10	Super Tornado 121 - 134 m s-1 (270 - 299 mi h-1)	o Entire frame houses and similar buildings lifted bodily from foundations and carried some distances. o Destruction of a severe nature, rendering a broad linear track largely devoid of vegetation, trees and man made structures.

Tornadoes of strength T0, T1, T2, T3 are termed weak tornadoes.
Those reaching T4, T5, T6, T7 are strong tornadoes.
T8, T9, T10, T11 are violent tornadoes.

Appendix 10: The Fujita tornado intensity scale (F-Scale)

The Fujita scale (F-Scale), or Fujita-Pearson scale, is a scale for rating tornado intensity, based on the damage tornadoes inflict on human-built structures and vegetation. The official Fujita scale category is determined by meteorologists (and engineers) after a ground and/or aerial damage survey; and depending on the circumstances, ground-swirl patterns (cycloidal marks), radar tracking, eyewitness testimonies, media reports and damage imagery, as well as photogrammetry/videogrammetry if video is available.

F-Scale Number	Intensity Phrase	Wind Speed	Type of Damage Done
F0	Gale tornado	40-72 mph	Some damage to chimneys; breaks branches off trees; pushes over shallow-rooted trees; damages sign boards.
F1	Moderate tornado	73-112 mph	The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.
F2	Significant tornado	113-157 mph	Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light object missiles generated.
F3	Severe tornado	158-206 mph	Roof and some walls torn off well constructed houses; trains overturned; most trees in fores uprooted
F4	Devastating tornado	207-260 mph	Well-constructed houses leveled; structures with weak foundations blown off some distance; cars thrown and large missiles generated.
F5	Incredible tornado	261-318 mph	Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air in excess of 100 meters; trees debarked; steel re-inforced concrete structures badly damaged.
F6	Inconceivable tornado	319-379 mph	These winds are very unlikely. The small area of damage they might produce would probably not be recognizable along with the mess produced by F4 and F5 wind that would surround the F6 winds. Missiles, such as cars and refrigerators would do serious secondary damage that could not be directly identified as F6 damage. If this level is ever achieved, evidence for it might only be found in some manner of ground swirl pattern, for it may never be identifiable through engineering studies

The Enhanced Fujita Scale, or EF Scale, is the scale for rating the strength of tornadoes in the United States estimated via the damage they cause.

Category EF0	Wind speed	65–85 mph	105–137 km/h	
	Potential damage	EF0 damage example Light damage. Peels surface off some roofs; some damage to gutters or siding; branches broken off trees; shallow-rooted trees pushed over. Confirmed tornadoes with no reported damage (i.e. those that remain in open fields) are always rated EF0. 		
Category EF1	Wind speed	86–110 mph	138–178 km/h	
	Potential damage	EF1 damage example Moderate damage. Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken. 		
Category EF2	Wind speed	111–135 mph	179–218 km/h	
	Potential damage	EF2 damage example Considerable damage. Roofs torn off well-constructed houses; foundations of frame homes shifted; mobile homes completely destroyed; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground. 		

1584 Bakerganj (presently Barisal) and Patuakhali; hurricane with thunder and lightening continued for five hours; the houses and boats were swallowed up, leaving only Hindu temples on a height; about 2,000,000 living creatures perished.

1585 Mouth of the Meghna estuary; severe storm wave swept up the eastern side of Bakerganj; number of living creatures perished, standing crops destroyed.

1797 (November) Chittagong; severe cyclonic storm; every hut levelled to the ground and 2 vessels sunk in chittagong port.

1822 (May) Barisal, Hatiya Island and Noakhali district; severe cyclonic storm with storm wave; Collectorate records swept away, 40,000 people killed and 100,000 cattle lost.

1831 (October) Barisal; storm-wave; many lives lost and cattle destroyed (exact figures not available).

1872 (October) Cox's Bazar; cyclonic storm; exact figures of the loss of lives and cattle are not available.

1876 (31 October) Meghna estuary and coasts of Chittagong, Barisal, Noakhali; most severe storm-surge of about 12.2m (40 ft) height; about 200,000 people died during the storm, but perhaps more people died from the after-effects of the storm, such as epidemic and famine, and enormous properties destroyed by tidal bore. Considering the population at that time, a death figure of 200,000 was indeed too heavy. The inundation extended inland to a distance of from 3 to 6 miles except where the mouths of rivers and creeks afforded the storm-wave an easy entrance and there the flood passed much further up and spread over the country for miles.

1897 (24 October) Chittagong; hurricane reached maximum intensity with series of storm-waves; Kutubdia Island and coastal villages were swept over, 14,000 people killed and 18,000 died in epidemics (cholera) that followed.

1898 (May) Teknaf;cyclonic storm-waves; exact figures of damage not available.

1904 (November) Sonadia; cyclonic storm; 143 killed and fishing fleet wrecked.

1909 (16 October) Khulna; cyclonic storm-waves; killed 698 people and 70,654 cattle.

1913 (October) Muktagachha upazila (Mymensingh); cyclonic storm; demolished many villages killing about 500 persons.

1917 (24 September) Khulna; hurricane; 432 persons killed and 28,029 cattle lost.

1941 (May) Eastern Meghna estuary; cyclonic storm with storm-wave; exact figures of the loss of lives and cattle aer not available.

1942 (October) sundarbans; severe cyclonic storm; number of human lives, exact figures of the loss of wildlife and boats are not available.

1948 (17-19 May) Between Chittagong and Noakhali; cyclonic storm; about 1,200 persons killed and 20,000 cattle lost.

1958 (16-19 May) East and west Meghna estuary, east of Barisal, Noakhali; cyclonic storm along with surge; 870 persons killed, 14,500 cattle lost and standing crops destroyed.

1958 (21-24 October) Chittagong coast; cyclonic storm; about 100,000 families lost their homes and government had to provide house-building loans.

1960 (9-10 October) Eastern Meghna estuary (Noakhali, Bakerganj, Faridpur and Patuakhali); severe cyclonic storm, maximum wind speed 201 km/hr, maximum storm wave 3.05m; considerable damage to Char Jabbar, Char Amina, Char Bhatia, Ramgati, Hatiya and Noakhali; 3,000 lives lost, 62,725 houses damaged, crops on 94,000 acres of land were fully damaged and thousands of cattle perished.

1960 (30-31 October) Chittagong, Noakhali, Bakerganj, Faridpur, Patuakhali and eastern Meghna estuary; severe cyclonic storm, maximum wind speed 210 km/hr, surge height 4.5-6.1m; about 10,000 persons killed, 27,793 cattle lost and 568,161 houses destroyed (especially 70% of houses in Hatiya blown off), two large ocean liners washed ashore, 5-7 vessels capsized in Karnafuli river.

1961 (9 May) Bagerhat and Khulna; severe cyclonic storm with a wind speed of 161 km/hr, surge 2.44-3.05m; rail track between Noakhali and Harinarayanpur damaged, heavy loss of life in Char Alexander, 11,468 people killed and about 25,000 cattlehead destroyed.

1962 (26-30 October) Feni; severe cyclonic storm with a wind speed of 161 km/hr, surge 2.5-3.0m; heavy loss of life; about 1,000 people died and many domestic cattle perished.

1963 (28-29 May) Chittagong, Noakhali, Cox's Bazar and the offshore islands of Sandwip, Kutubdia, Hatiya and Maheshkhali were badly affected; severe cyclonic storm with storm-wave rising 4.3-5.2m in Chittagong, maximum wind speed 203 km/hr and at Cox's Bazar 164 km/hr; more than 11,520 people killed, 32,617 cattle lost, 376,332 houses, 4,787 boats and standing crops destroyed.

1965 (11-12 May) Barisal and Bakerganj; most severe cyclonic storm, maximum speed 162 km/hr with storm-wave rising 3.7m; total loss of life 19,279; in Barisal alone 16,456 people killed.

1965 (14-15 December) Cox's Bazar along with adjacent coastal area and Patuakhali; severe cyclonic storm with storm-wave rising 4.7-6.1m; maximum speed 210 km/hr in Cox's Bazar, hoisted danger signal #10 at Cox's Bazar and along the coast of Sonadia, Rangadia and Hamidia islands, and Patuakhali; 40,000 salt beds in Cox's Bazar inundated and 873 people killed.

1966 (1 October) Sandwip, Bakerganj, Khulna, Chittagong, Noakhali and Comilla; severe cyclonic storm with storm-waves of 4.7-9.1m, maximum wind speed 146 km/hr; affected 1.5 million people, loss of human life and livestock were 850 and 65,000 respectively in Noakhali and Bakerganj.

1969 (14 April) Demra (Dhaka district); tornado locally known as Kalbaishakhi with wind speed of 643 km/hr; 922 people killed and 16,511 injured; estimated loss Tk 40 to 50 million.

1970 (12-13 November) The most deadly and devastating cyclonic storm that caused the highest casualty in the history of Bangladesh. Chittagong was battered by hurricane winds. It also hit Barguna, Khepupara, Patuakhali, north of Char Burhanuddin, Char Tazumuddin and south of Maijdi, Haringhata and caused heavy loss of lives and damage to crops and property. Officially the death figure was put at 500,000 but it could be more. A total of 38,000 marine and 77,000 inland fishermen were affected by the cyclone. It was estimated that some 46,000 inland fishermen operating in the cyclone affected region lost their lives. More than 20,000 fishing boats were destroyed; the damage to property and crops was colossal. Over one million cattlehead were reported lost. More than 400,000 houses and 3,500 educational institutions were damaged. The maximum recorded wind speed of the 1970 cyclone was about 222 km/hr and the maximum storm surge height was about 10.6m and the cyclone occurred during high-tide.

1971 (5-6 November) Chittagong coast; severe cyclonic storm; exact figures of the loss of lives and cattle are not available

1971 (28-30 November) Sundarban coast; cyclonic storm with a wind speed of 97-113 km/hr and storm surge of less than 1m; Khulna district experienced stormy weather and low lying areas of Khulna town inundated.

1973 (6-9 December) Sundarban coast; severe cyclonic storm accompanied by storm surge; low-lying coastal areas of Patuakhali and adjoining offshore islands inundated.

1974 (13-15 August) Khulna; cyclonic storm with a wind speed of 80.5 km/hr; about 600 lives lost and number of cattlehead destroyed.

1974 (24-28 November) Coastal belt from Cox's Bazar to Chittagong and offshore islands; severe cyclonic storm with a wind speed of 161 km/hr and storm surge of 2.8-5.2 m; 200 people killed, 1000 cattle lost and 2,300 houses perished.

1975 (9-12 May) Bhola, Cox's Bazar and Khulna; severe cyclonic storm with a wind speed of 96.5 to 112.6 km/hr; 5 persons killed and a number of fishermen missing.

1977 (9-12 May) Khulna, Noakhali, Patuakhali, Barisal, Chittagong and offshore islands; cyclonic storm with a wind speed of 112.63 km/hr; exact figures of the loss of lives and cattle are not available.

1983 (14-15 October) Offshore islands and chars of Chittagong and Noakhali; severe cyclonic storm with a wind speed of 122 km/hr; 43 persons killed, 6 fishing boats and a trawler lost, more than 150 fishermen and 100 fishing boats missing and 20% aman crops destroyed.

1983 (5-9 November) Chittagong, Cox's Bazar coast near Kutubdia and the low lying areas of St Martin's Island, Teknaf, Ukhia, Moipong, Sonadia, Barisal, Patuakhali and Noakhali; severe cyclonic storm (hurricane) with a wind speed of 136 km/hr and a storm surge of 1.52m height; 300 fishermen with 50 boats missing and 2,000 houses destroyed.

1985 (24-25 May) Chittagong, Cox's Bazar, Noakhali and their offshore islands (Sandwip, Hatiya, and Urirchar); severe cyclonic storm, wind speed Chittagong 154 km/hr, Sandwip 140 km/hr, Cox's Bazar 100 km/hr and storm surge of 3.0-4.6m; about 11,069 persons killed, 94,379 houses damaged, livestock lost 135,033 and road damaged 74 km, embankments damaged.

1986 (8-9 November) Offshore island and chars of Chittagong, Barisal, Patuakhali and Noakhali; cyclonic storm hit 110 km/hr at Chittagong and 90/hr at Khulna; 14 persons killed, damaged 97,200 ha of paddy fields, damage to schools, mosques, warehouses, hospitals, houses and buildings at Amtali upazila in Barguna.

1988 (24-30 November) Jessore, Kushtia, Faridpur, offshore islands and chars of Barisal and Khulna; severe cyclonic storm with core wind speed 162 km/hr, storm surge of 4.5m at Mongla point; killed 5,708 persons and lot of wild animals - deer 15,000, Royal Bengal Tiger 9, cattle 65,000 and crops damaged worth about Tk 9.41 billion.

1991 (29 April) The Great Cyclone of 1991, crossed the Bangladesh coast during the night. It originated in the Pacific about 6,000 km away and took 20 days to reach the coast of Bangladesh. It had a dimension of more than the size of Bangladesh. The central overcast cloud had a diameter exceeding 600 km. The maximum wind speed observed at Sandwip was 225 km/hr. The wind speeds recorded at different places were as follows: Chittagong 160 km/hr, Khepupara (Kalapara) 180 km/hr, Kutubdia 180 km/hr, Cox's Bazar 185 km/hr, and Bhola 178 km/hr. The maximum wind speed estimated from NOAA-11 satellite picture obtained at 13:38 hours on 29 April was about 240 km/hr. The cyclone was detected as a depression (wind speed not exceeding 62 km/hr) on the 23rd April first in the satellite picture taken at SPARRSO from NOAA-11 and GMS-4 satellites. It turned into a cyclonic storm on 25 April. The cyclone in its initial stage moved slightly northwest and then north. From 28 April it started moving in a north-easterly direction and crossed the Bangladesh coast north of Chittagong port during the night of the 29th April. The cyclone started affecting the coastal islands like Nijhum Dwip, Manpura, Bhola and Sandwip from the evening of that day. The maximum storm surge height during this cyclone was estimated to be about 5 to 8m. The loss of life and property was colossal. The loss of property was estimated at about Tk 60 billion. The death toll was estimated at 150,000; cattlehead killed 70,000.

1991 (31 May to 2 June) Offshore islands and chars of Patuakhali, Barisal, Noakhali and Chittagong; cyclonic storm, maximum wind speed 110 km/hr and surge height of 1.9m; people killed, cattlehead perished, boats lost and standing crops destroyed.

1994 (29 April 3 May) Offshore island and chars of Cox's Bazar; severe cyclonic storm with maximum wind speed of 210 km/hr; people killed about 400, cattle lost about 8,000.

1995 (21-25 November) Offshore island and chars of Cox's Bazar; severe cyclonic storm with maximum wind speed of 210 km/hr; about 650 people killed, 17,000 cattlehead perished.

1997 (16-19 May) Offshore islands and chars of Chittagong, Cox's Bazar, Noakhali and Bhola; severe cyclonic storm (hurricane) with a wind speed of 225 km/hr, storm surge of 3.05m (similar strength to that of 1970 cyclone); only 126 people killed because of better disaster management measures taken by the government and the people.

1997 (25-27 September) Offshore islands and chars of Chittagong, Cox's Bazar, Noakhali and Bhola; severe cyclonic storm (hurricane) with a wind speed of 150 km/hr, storm surge of 1.83 to 3.05m.

1998 (16-20 May) Offshore islands and chars of Chittagong, Cox's Bazar and Noakhali; severe cyclonic storm (hurricane) with a wind speed of 150 km/hr, storm surge of 1.83 to 2.44m.

1998 (19-22 November) Offshore islands and chars of Khulna, Barisal and Patuakhali; cyclonic storm with maximum wind speed of 90 km/hr, storm surge of 1.22 to 2.44m.

A 1-5 rating based on a hurricane's present intensity, used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf in the landfall region.

Intensity	**Description**
Category 1  Gaston at landfall	**Winds 74-95 mph** (64-82 knots or 119-153 km/hr) - Storm surge generally 4-5 ft above normal. No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Some damage to poorly constructed signs. Also, some coastal road flooding and minor pier damage.
Category 2  Diana approaching land	**Winds 96-110 mph** (83-95 knots or 154-177 km/hr) - Storm surge generally 6-8 feet above normal. Some roofing material, door, and window damage of buildings. Considerable damage to shrubbery and trees with some trees blown down. Considerable damage to mobile homes, poorly constructed signs, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of the hurricane center. Small craft in unprotected anchorages break moorings.
Category 3  Alicia approaching Texas	**Winds 111-130 mph** (96-113 knots or 178-209 km/hr) - Storm surge generally 9-12 ft above normal. Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures. Damage to shrubbery and trees with foliage blown off trees and large tress blown down. Mobile homes and poorly constructed signs are destroyed. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the hurricane center. Flooding near the coast destroys smaller structures with larger structures damaged by battering of floating debris. Terrain continuously lower than 5 ft above mean sea level may be flooded inland 8 miles (13 km) or more. Evacuation of low-lying residences with several blocks of the shoreline may be required.
Category 4  Iniki over the Hawaiian Islands	**Winds 131-155 mph** (114-135 knots or 210-249 km/hr) - Storm surge generally 13-18 ft above normal. More extensive curtainwall failures with some complete roof structure failures on small residences. Shrubs, trees, and all signs are blown down. Complete destruction of mobile homes. Extensive damage to doors and windows. Low-lying escape routes may be cut by rising water 3-5 hours before arrival of the hurricane center. Major damage to lower floors of structures near the shore. Terrain lower than 10 ft above sea level may be flooded requiring massive evacuation of residential areas as far inland as 6 miles (10 km).
Category 5  Gilbert near peak intensity	**Winds greater than 155 mph** (135 knots or 249 km/hr) - Storm surge generally greater than 18 ft above normal. Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All shrubs, trees, and signs blown down. Complete destruction of mobile homes. Severe and extensive window and door damage. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the hurricane center. Major damage to lower floors of all structures located less than 15 ft above sea level and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5-10 miles (8-16 km) of the shoreline may be required.

Appendix 14: Table of Maximum Water Level

River	Station	Recorded Maximum Water Level(m)	Danger Level (m)	Maxm.Water Above D.L	Peak of the Year (m)			Days above Danger Level	
					1998	Recorded Maximum	1988	1998	1988
Dhalia	Kurigram	27.50	26.50	1.00	27.22	27.50	27.25	30	16
Teesta	Dalia	52.97	52.25	0.72	52.20	52.97	52.89	NA	8
Teesta	Kaunia	30.52	30.00	0.52	29.91	30.52	30.43	NA	38
Brahmaputra	Noonkhawa	28.10	27.89	0.21	27.35	28.10	NA-	NA	2
Brahmaputra	Chilmari	25.06	24.00	1.06	24.77	25.06	25.04	22	15
Jamuna	Bahadurabad	20.62	19.50	1.12	20.37	20.62	20.62	66	27
Jamuna	Serajganj	15.12	13.75	1.37	14.76	15.12	15.12	48	44
Jamuna	Aricha	10.76	9.14	1.62	10.76	10.58	10.58	68	31
Old Brahmaputra	Jamalpur	18.00	17.00	1.00	17.47	18.00	17.83	31	8
Old Brahmaputra	Mymensingh	14.02	12.50	1.52	13.04	14.02	13.69	33	10
Buriganga	Dhaka	7.58	6.00	1.58	7.24	7.58	7.58	57	23
Lakhya	Narayanganj	6.93	5.50	1.43	6.93	6.71	6.71	71	36
Turag	Mirpur	8.35	5.94	2.41	7.97	8.35	NA	70	NA
Turag	Tongi	7.84	6.08	1.76	7.54	7.84	NA	66	NA
Kaliganga	Taraghat	10.39	8.38	2.01	10.21	10.39	10.39	66	65
Karatoa	Panchagarh	72.65	70.75	1.90	71.08	72.65	70.95	3	1
Punarbhaba	Dinajpur	34.40	33.50	0.90	34.09	34.40	34.25	3	4
Mahananda	Chapai Nawabganj	23.01	21.00	2.01	23.01	22.25	21.98	60	32
Little Jamuna	Naogaon	15.63	15.24	0.39	15.48	15.63	NA	17	NA
Padma	Pankha	24.14	21.50	2.64	24.14	22.97	NA	66	NA
Padma	Rajshahi	20.00	18.50	1.50	19.68	20.00	19.18	28	24
Padma	Hardinge Bridge	15.19	14.25	0.94	15.19	15.04	14.87	27	23
Padma	Goalundo	10.21	9.83	0.38	10.21	9.83	9.83	68	41
Padma	Bhagyakul	7.58	7.58	0.00	7.50	7.58	7.43	72	47
Gorai	Gorai Rly Br	13.65	13.65	0.00	13.45	13.65	13.65	25	25

Surma	Kanaighat	15.26	13.20	2.06	15.00	15.26	15.10	73	75
Surma	Sylhet	11.95	11.25	0.70	11.72	11.95	11.95	14	21
Surma	Sunamganj	9.46	8.25	1.21	8.90	9.46	9.30	56	62
Kushiyara	Amalshid	18.28	15.85	2.43	17.61	18.28	17.50	54	65
Kushiyara	Sheola	14.33	13.50	0.83	14.14	14.33	14.09	37	80
Manu	Manu Rly Br	19.39	17.07	2.32	18.63	19.39	18.95	6	66
Manu	Moulvi Bazar	13.25	11.75	1.50	11.68	13.25	13.01	NA	25
Khowai	Habiganj	11.55	9.50	2.05	11.44	11.55	11.00	8	14
Someswari	Durgapur	15.15	13.00	2.15	13.92	15.15	14.31	7	30
Upper Meghna	Bhairab Bazar	7.66	6.25	1.41	7.33	7.66	7.66	68	68
Gumti	Comilla	13.56	11.75	1.81	12.90	13.56	12.79	11	17
Muhuri	Parshuram	14.85	13.00	1.85	14.60	14.85	12.42	9	48
Halda	Narayangat	18.25	14.63	3.62	16.57	18.25	NA	21	NA
Halda	Panchpukuria	11.55	9.50	2.05	10.44	11.55	10.05	4	6
Sangu	Bandarban	20.38	15.25	5.13	15.25	20.38	16.8	1	3
Sangu	Dohazari	9.05	7.00	2.05	7.42	9.05	NA	2	NA
Matamuhuri	Lama	15.45	12.25	3.20	13.05	15.45	12.18	2	NA
Feni	Ramgarh	21.41	17.37	4.04	17.50	21.41	NA	1	NA

Appendix 15: Table HO2 Dwelling Households by Material of Wall and Material of Roof of the Main Structure

Locality and Wall Material	Material of Roof			
	Total Household	Straw/Bamboo/Polythene	Tiles/C.I/Metal Sheet	Cement
Chittagong Zila				
Total Households	**854450**	**439387**	**325946**	**89117**
Straw/Bamboo	413751	283531	130220	-
Mud/ Unburnt Brick	279085	147573	131512	-
C.I/Metal Sheet	23460	4234	19226	-
Wood	5318	896	4422	-
Cement/Brick	132836	3153	40566	89117
Rural Area				
Total Households	**484569**	**285830**	**186977**	**11762**
Straw/Bamboo	229778	162138	67640	-
Mud/ Unburnt Brick	215749	119445	96304	-
C.I/Metal Sheet	15614	3064	12550	-
Wood	2692	562	2130	-
Cement/Brick	20736	621	8353	11762
Municipality Area				
Total Households	**214456**	**75476**	**72850**	
Straw/Bamboo	96021	65499	30522	
Mud/ Unburnt Brick	18436	7085	11351	
C.I/Metal Sheet	4079	562	3517	
Wood	1426	171	1255	
Cement/Brick	94494	2159	26205	
Other Urban Area				
Total Households	**155425**	**78081**	**66119**	**11225**
Straw/Bamboo	87952	55894	32058	-
Mud/ Unburnt Brick	44900	21043	23857	-
C.I/Metal Sheet	3767	608	3159	-
Wood	1200	163	1037	-
Cement/Brick	17606	373	6008	11225

Appendix 16: Basic Wind Speeds for Selected Locations in Bangladesh

Location	Basic Wind Speed (km/hr)	Location	Basic Wind Speed (km/hr)
Angarpota	150	Lalmonirhat	204
Bagerhat	252	Madaripur	220
Bandarban	200	Magura	208
Barguna	260	Manikganj	185
Barisal	256	Meherpur	185
Bhola	225	Moheshkhali	260
Bogura	198	Moulvibazar	168
Brahmanbaria	180	Munshiganj	184
Chandpur	160	Mymensingh	217
Chapai Nawabganj	130	Naogaon	175
Chittagong	260	Narail	222
Chuadhanga	198	Narayanganj	195
Comilla	196	Narsinghdi	190
Cox's Bazar	260	Natore	198
Dahagram	150	Netrokona	210
Dhaka	210	Nilphamari	140
Dinajpur	130	Noakhali	184
Faridpur	202	Pabna	202
Feni	205	Panchagarh	130
Gaibandha	210	Patuakhali	260
Gazipur	215	Pirojpur	260
Gopalganj	242	Rajbari	188
Habiganj	172	Rajshahi	155
Hatiya	260	Rangamati	180
Ishurdi	225	Rangpur	209
Joypurhat	180	Sathkhira	183
Jamalpur	180	Shariatpur	198
Jessore	205	Sherpur	200
Jhalakati	260	Sirajgonj	160
Jhenaidah	208	Srimangal	160
Khagrachhari	180	St. Martin's Island	260
Khulna	238	Sunamganj	195
Kutubdia	260	Sylhet	195
Kisoregang	207	Sandwip	260
Kurigram	210	Tangail	160
Kushtia	215	Teknaf	260
Lakshmipur	162	Thakurgaon	130

ID	DIS	YR	MN	D	TM	LAT/LON	LO	MAG	AFF A(sq km)	WIND SPEED	TIDAL HT	DEATH	No.AFF P	HOUSES DSTRD	REFERENCES
1	CYL	1584					Bakerganj (presently Barisal) and Patuakhali					200000			BNR,HA,PRSP,BBS,PR ,GoB.
2	CYL	1585					Eastern side of Bakerganj(presently Barisal)								BNR,HA,PRSP,BBS,PR ,GoB.
3	CYL	1797	Nov				Chittagong								BNR,HA,PRSP,BBS,PR ,GoB.
4	CYL	1822	May				Barisal, Hatiya Island and Noakhali					40000			BNR,HA,PRSP,BBS,PR ,GoB.
5	CYL	1831	Oct				Barisal								BNR,HA,PRSP,BBS,PR ,GoB.
6	CYL	1869	May				Khulna					250			BNR,HA,PRSP,BBS,PR ,GoB.
7	CYL	1872	Oct				Cox's Bazar								BNR,HA,PRSP,BBS,PR ,GoB.
8	CYL	1876	Oct	31			Chittagong, Barisal, Noakhali				12.2m	200000			BNR,HA,PRSP,BBS,PR ,GoB.
9	CYL	1895	Oct				Bagerhat/Sunderban								BNR,HA,PRSP,BBS,PR ,GoB.
10	CYL	1897	Oct	24			Chittagong in Kutubdia Island					32000			BNR,HA,PRSP,BBS,PR ,GoB.
11	CYL	1898	May				Cox's Bazar; Teknaf								BNR,HA,PRSP,BBS,PR,GoB,DMB
12	CYL	1901	Nov				Sunderban								BNR,HA,PRSP,BBS,PR ,GoB.
13	CYL	1904	Nov				Sonadia					143			BNR,HA,PRSP,BBS,PR ,GoB.
14	CYL	1909	Oct				Khulna					698			BNR,HA,PRSP,BBS,PR ,GoB.
15	CYL	1909	Oct				Chittagong								BNR,HA,PRSP,BBS,PR ,GoB.
16	CYL	1909	Dec				Cox's Bazar								BNR,HA,PRSP,BBS,PR ,GoB.
17	CYL	1911	Apr				Teknaf								BNR,HA,PRSP,BBS,PR ,GoB.
18	CYL	1912					....					40000			BNR,HA,PRSP,BBS,PR ,GoB.
19	CYL	1913	Oct				MuktagachhMymensingh					500			BNR,HA,PRSP,BBS,PR ,GoB.
20	CYL	1917	May				Sundarban								BNR,HA,PRSP,BBS,PR ,GoB.
21	CYL	1917	Sep	24			Khulna					432			BNR,HA,PRSP,BBS,PR ,GoB.
22	CYL	1919	Sep				Barisal					40000			BNR,HA,PRSP,BBS,PR ,GoB.
23	CYL	1926	May				Cox's Bazar								BNR,HA,PRSP,BBS,PR ,GoB.
24	CYL	1941	May				Barisal/Noakhali				4m	7500			BNR,HA,PRSP,BBS,PR ,GoB.
25	CYL	1942	Oct				Sundarbans								BNR,HA,PRSP,BBS,PR ,GoB.
26	CYL	1948	May	17			Chittagong, Noakhali					1200			BNR,HA,PRSP,BBS,PR ,GoB.
27	CYL	1950	Nov				Patuakhali								DMB
28	CYL	1958	May	16-19			East& west Meghna estuary, east Barisal, Noakhali					870			BNR,HA,PRSP,BBS,PR ,GoB.
29	CYL	1958	Oct	21-24			Chittagong coast						100000		BNR,HA,PRSP,BBS,PR ,GoB.
30	CYL	1960	Oct	9-10			Noakhali, Bakerganj, Faridpur and Patuakhali		94,000 acores	201(km/hr)	3.05m	3000		62725	BNR,HA,PRSP,BBS,PR ,GoB.
31	CYL	1960	Oct	30-31			Chittagong,Noakhali,Barisal,Faridpur,Patuakhali			210(km/hr)	4.5- 6.1m	10000		568161	BNR,HA,PRSP,BBS,PR ,GoB.
32	CYL	1961	May	9			Bagerhat and Khulna			161(km/hr)	2.44-3.05m	11468			BNR,HA,PRSP,BBS,PR ,GoB.
33	CYL	1962	Oct	26-30			Feni			161(km/hr)	2.5- 3.0m	1000			BNR,HA,PRSP,BBS,PR ,GoB.

ID	DIS	YR	MN	D	TM	LAT/LON	LO	MAG	AFF A(sq km)	WIND SPEED	TIDAL HT	DEATH	No.AFF P	HOUSES DSTRD	REFERENCES
34	CYL	1963	May	28-29			Chtgong,Noa,Cox'sB,Mshkhali,Hatiya,Kutbdia,Sandwip			Ctg203Cox's164	4.3-5.2m	11520		376332	BNR,HA,PRSP,BBS,PR ,GoB.
35	CYL	1965	May	11-12			Barisal			162(km/hr)	3.7m;	19279			BNR,HA,PRSP,BBS,PR ,GoB.
36	CYL	1965	Dec	14-15			Cox's Bazar coastal area,Patuakhali			Cox's210 km/hr	4.7-6.1m;	873			BNR,HA,PRSP,BBS,PR ,GoB.
37	CYL	1966	Oct	1			Sandwip, Barisal, Khulna, Chtgong,Noakhali,Comilla		2,727(sq km)	146(km/hr)	of 4.7-9.1m	850			BNR,HA,PRSP,BBS,PR,GoB,DMB
38	CYL	1967	Oct	11/14			Cox's Bazar				7.6m				BNR,HA,PRSP,BBS,PR,GoB,TS
39	CYL	1969	Apr	14			Demra (Dhaka district)			643 km/hr		922	16511		BNR,HA,PRSP,BBS,PR ,GoB.
40	CYL	1970	May	7			Cox's Bazar				5m				BNR,HA,PRSP,BBS,PR,GoB,TS
41	CYL	1970	Oct	23			Chandpur				4.7m	300			BNR,HA,PRSP,BBS,PR,GoB,TS
42	CYL	1970	Nov	12-13			Chittagong, Barguna, Khepupara, Patuakhali			about 222 km/hr	10.6m	500000		403500	BNR,HA,PRSP,BBS,PR ,GoB.
43	CYL	1971	Sep	30			Chandpur				5m				BNR,HA,PRSP,BBS,PR,GoB,TS
44	CYL	1971	Nov	5-6			Chittagong coast.								BNR,HA,PRSP,BBS,PR,GoB,TS
45	CYL	1971	Nov	28-30			Sundarban coast			97-113 km/hr	<1m;				BNR,HA,PRSP,BBS,PR ,GoB.
46	CYL	1973	Dec	6-9			Sudarban Coast Patuakhali / Island			34m/s	4.5m	83			BNR,HA,PRSP,BBS,PR GoB,DMB,Ts
47	CYL	1974	Aug	13-15			Khulna			80.5 km/hr	6.7m	600			BNR,HA,PRSP,BBS,PR ,GoB.
48	CYL	1974	Nov	24-28			Cox's Bazar,Chittagong coast			161 km/hr	2.8-5.2 m	200		2300	BNR,HA,PRSP,BBS,PR ,GoB.
49	CYL	1975	May	9-12			Bhola, Cox's Bazar and Khulna			96.5-112.6 km/hr		5			BNR,HA,PRSP,BBS,PR ,GoB.
50	CYL	1975	Nov				Barisal/Noakhali				3.1m				BNR,HA,PRSP,BBS,PR ,GoB.
51	CYL	1977	May	9-12			Khulna, Noakhali, Patuakhali, Barisal, Chittagong			112.63 km/hr					BNR,HA,PRSP,BBS,PR ,GoB.
52	CYL	1983	Oct	14-15			Offshore islands,chars of Chittagong and Noakhali			122 km/hr		43			BNR,HA,PRSP,BBS,PR ,GoB.
53	CYL	1983	Nov	5			Chtgng, Cox'sB, Kutbdia, Teknf,Ptkali,Brsal,Ukhia			136 km/hr a	1.52m				DMB.
54	CYL	1985	May	24			Chtgong,Cox'sB,Nkhali,Sandwip, Hatiya,Urichar			154 km/hr	3.0-4.6 m	11069	167500	94379	DMB
55	CYL	1986	Nov	8			Chittagong, Barisal, Patuakhali and Noakhali			ctg110&Khu90km/hr		14	238600	1116	DMB
56	CYL	1988	Nov	24			Jessore, Kushtia, Faridpur, Char of Barisal,Khulna			162 km/hr,	4.5m	5708	1006536	788715	DMB
57	CYL	1990	Oct				Barisal					150	1015866	75085	BNR,HA,PRSP,BBS,PR,GoB,DMB
58	CYL	1991	April	29			Sandip, Chtgong, Kepupara,Cox'sB,Kutubdia,Bhola		19 dis,102t & 9u	Maximum 225 km/hr	5-8m/6-8m	138822	13798275	0	BNR,HA,PRSP,BBS,PR,GoB,DMB,Ts
59	CYL	1991	My-Jun	31M-2Jun			Patukali, Barsal, Nokhali,Chtgng,Offshore islands			110 km/hr	1.9m	76	121229	34791	BNR,HA,PRSP,BBS,PR,GoB,DMB
60	CYL	1994	Ap-My	29Apr-3M			Offshore island and chars of Cox's Bazar			210 km/hr;		400	422020	52057	BNR,HA,PRSP,BBS,PR,GoB,DMB
61	CYL	1995	Nov	21-25			Offshore island and chars of Cox's Bazar					650	305953	1838	BNR,HA,PRSP,BBS,PR,GoB,DMB
62	CYL	1997	May	16-19			Chittagong,Cox's Bazar, Noakhali and Bhola			225 km/hr	3.05m	126	2015669	3196	BNR,HA,PRSP,BBS,PR,GoB,DMB
63	CYL	1997	Sep	25-27			Chittagong,Cox's Bazar, Noakhali and Bhola			150 km/hr	1.83 to 3.05m.	127	3784916	7960	BNR,HA,PRSP,BBS,PR ,GoB.
64	CYL	1998	May	16-20			Offshore island ofChittagong,Cox's Bazar, Noakhali			150 km/hr	1.83 to 2.44m.				BNR,HA,PRSP,BBS,PR ,GoB.
65	CYL	1998	Nov	19-22			Offshore island of Khulna, Barisal and Patuakhali			90 km/hr	1.22 to 2.44m.				BNR,HA,PRSP,BBS,PR ,GoB.
66	CYL	1961	May	30			Chittagong(near Feni)			41m/s\160kph	6-9m\1.8-4.5m				Takahashi,1991,BMD1991
67	CYL	1964	Apr	11			....					196			Takahashi,1991

ID	DIS	YR	MN	D	TM	LAT/LON	LO	MAG	AFF A(sq km)	WIND SPEED	TIDAL HT	DEATH	No.AFF P	HOUSES DSTRD	REFERENCES
68	CYL	1968	May	10			....				3-5m				Takahashi,1991
69	CYL	1969	Oct	10			....				2-7m				Takahashi,1991
70	CYL	1971	May	05							2-4m				Takahashi,1991
71	CYL	1973	Nov	18							2-4m				Takahashi,1991
72	CYL	1976	Oct	28						29m/s	2-5m				Takahashi,1991
73	CYL	1981	Dec	10						27m/s	2m	2			Takahashi,1991
74	CYL	1983	Jun	03						25m/s					Takahashi,1991
75	CYL	1965	Nov				Chittagang			160kph	2.4-3.0m				BMD,1991
76	CYL	1966	Nov	01			Chittagang			120kph	6.1-6.7m				BMD,1991
77	CYL	1981	Dec				Khulna			120kph	2.1-4.6m				BMD,1991
78	CYL	1990	Dec				Cox's Bazar Coast			115kph	1.5-2.1m				BMD,1991
79	TOR	1888	Apr	07			Dhaka,Murchagunja					118/88	1200		EIA Volume 2 ,The TPUSA TP,USA
80	TOR	1951	May	12		23.6, 89.8	Faridpur					200			EIA Volume 2 (2004)
81	TOR	1961	Mar	19	1600	23.6, 90.2	Jhaukandi in Faridpur and Dohar and NawabganjDhaka			270		210			EIA Volume 2 (2004)
82	TOR	1964	Apr	11	1630	23.3, 89.6	Magura,Narail including Mohammadpur			360		500+			EIA Volume 2 (2004)
83	TOR	1969	Apr	14			Dhaka,Demra			Demra 640kph		922	16511		TOB,Mr. Rezaul Hasan
84	TOR	1972	Apr	29		24.3, 90.7	Bhakua and Haripur unions of Barishal P.S					300			EIA Volume 2 (2004)
85	TOR	1973	Apr	17	1445	23.6, 90.1	Singair,Manikganj,Nawabganj in Dhaka			320kph		681	1000		EIA, Volume 2 ,TOB,Hasan
86	TOR	1974	Apr	11		25.0, 89.3	11 miles W of Bogra			240kph		28/100	75		TOB,Mr. Rezaul Hasan
87	TOR	1976	Apr	10	1730	23.2, 90.5	Faridpur/Naria and Bhederganj under Sariatpur zila			240kph		36/46			TOB,Mr. Rezaul Hasan
88	TOR	1977	Apr	01	1600	23.2, 90.2	Madaripur,Shibchar(Faridpur)			320kph		500	6000		EIA, Volume 2 TOB,Hasan
89	TOR	1989	Apr	26	1830	24.0, 89.9	Daulatpur and Saturia ,Manikganj			270(km/hr)		1300	12000		EIA, Volume 2 ,The TP USATP,USA
90	TOR	1989	May	26			....					800			The TP,USA
91	TOR	1993	Jan	09	Early		northeast Bangladesh					50			The TP,USA
92	TOR	1993	May	14/13	1645	22.8, 91.1	southern Bangladesh,Begumganj-Noakhali					50			The TP,USA
93	TOR	1995	Sep	28			northern Bangladesh,Jamalpur					5			The TP,USA
94	TOR	1996	May	13	1630	24.7, 90.0	TAN,JAM(BasailMadrganjGoplpurKalhatiSakipurMirjapr			330(km/hr)		1000	30000		EIA, Volume 2 ,The TP,USA
95	TOR	1997	Oct	12			Tongi,Gazipur					50	5000		The TP,USA
96	TOR	1998	Jul	19			Sirajganj						25		The TP,USA
97	TOR	1999	Mar	26			Panchagarh					2	60		The TP,USA
98	TOR	2000	Sep	19			Savar-Dhaka and Gazipur					2	5		The TP,USA
99	TOR	2006	Mar	4			Bagerhat,Khulna					4	100		NIRAPAD
100	FLD	1954							36,800(25%)						FFWC
101	FLD	1955							50,500(34%)						FFWC

ID	DIS	YR	MN	D	TM	LAT/LON	LO	MAG	AFF A(sq km)	WIND SPEED	TIDAL HT	DEATH	No.AFF P	HOUSES DSTRD	REFERENCES
102	FLD	1956							35,400(24%)						FFWC
103	FLD	1960							28,400(19%)						FFWC
104	FLD	1961							28,800(20%)						FFWC
105	FLD	1962							37,200(25%)						FFWC
106	FLD	1963							43,100(29%)						FFWC,PASCHE1990
107	FLD	1964							31,000(21%)						FFWC,PASCHE1990
108	FLD	1965							28,400(19%)						FFWC
109	FLD	1966							33,400(23%)						FFWC
110	FLD	1967							25,700(17%)						FFWC
111	FLD	1968							37,200(25%)						FFWC,PASCHE1990
112	FLD	1969							41,400(28%)						FFWC
113	FLD	1970							42,400(29%)						FFWC,PASCHE1990
114	FLD	1971							36,300(25%)						FFWC,PASCHE1990
115	FLD	1972							20,800(14%)						FFWC,PASCHE1990
116	FLD	1973							29,800(20%)						FFWC,PASCHE1990
117	FLD	1974							52,600(36%)				3000000		Elahi,DMB,FFWC,PASCHE
118	FLD	1975							16,600(11%)						FFWC
119	FLD	1976							28,300(19%)						FFWC,PASCHE1990
120	FLD	1977							12,500(8%)						FFWC
121	FLD	1978							10,800(7%)						FFWC
122	FLD	1980							33,000(22%)				2000000		Elahi,DMB,FFWC,PASCHE
123	FLD	1982							3,140(2%)						FFWC
124	FLD	1983							11,100(7.5%)						FFWC
125	FLD	1984							28,200(19%)				2000000		Elahi,DMB,FFWC,PASCHE
126	FLD	1985							11,400(8%)						FFWC
127	FLD	1986							6,600(4%)			57	6715734	196803	DMB,FFWC
128	FLD	1987							57,300(39%)			1470	24823376	71572	FFWC,DMB,PASCHE1990
129	FLD	1988							89,970(61%)			1517	35732336	1030659	FFWC,DMB,PASCHE1990
130	FLD	1989							6,100(4%)			23	1848389	3203	FFWC,DMB
131	FLD	1990							3,500(2.4%)			41	1383360	14101	FFWC,DMB
132	FLD	1991							28,600(19%)			697	5582355	232633	FFWC,DMB
133	FLD	1992							2,000(1.4%)						FFWC
134	FLD	1993							28,742(20%)			162	11559586	234393	FFWC,DMB
135	FLD	1994							419(0.2%)			10	553467	19177	FFWC,DMB
136	FLD	1995							32,000(22%)			137	16382922	344276	FFWC,DMB

ID	DIS	YR	MN	D	TM	LAT/LON	LO	MAG	AFF A(sq km)	WIND SPEED	TIDAL HT	DEATH	No.AFF P	HOUSES DSTRD	REFERENCES
137	FLD	1996							35,800(24%)			76	8106988	218275	FFWC,DMB
138	FLD	1997										125	5008868	13252	DMB
139	FLD	1998							1,00,250(68%)			918	30916351	980571	FFWC,DMB
140	FLD	2002										23	9637475	0	DMB
141	FLD	2004							35000(24%)			247	36337944	894954	FFWC,DMB
142	FLD	1991										697	5582355	0	DMB
143	FLD	1991										91	2293445	0	DMB
144	FLD	1995										53	4007310	79725	DMB
145	FLD	1995										56	5806950	474707	DMB
146	FLD	1988										104	8937724	120530	DMB
147	CYL	1989										573	346087	12173	DMB
148	CYL	1996										245	81162	15868	DMB
149	TOR	1875	Mar	26	Dust	24.3, 90.6	Uladah, Mymensingh dist.			230(km/hr)					
150	TOR	1875	Mar	31		24.3, 90.6	Mymensingh dist.								
151	TOR	1888	Mar	27	sunset	23.4, 89.4	Jessore dist. Hit 2 miles sse of Magura			340(km/hr)		4			
152	TOR	1888	Mar	27		24.1, 89.8	Pabna dist.					>20			
153	TOR	1888	Apr	07	1900	23.7, 90.4	Dhaka			320(km/hr)		118			
154	TOR	1888	Apr	07	1930	23.4, 90.6	Rajbari			330(km/hr)		70			
155	TOR	1895	Apr	29	1530	23.9, 90.1	Manikganj					24			
156	TOR	1902	Apr	12		23.7, 90.4	Dhaka					88			
157	TOR	1903	Mar	28		25.8, 89.3	Rangpur					many			
158	TOR	1904	Apr	29		24.1, 89.3	Pabna					7			
159	TOR	1927	Apr	04	1630	22.9, 91.1	Noakhali					many			
160	TOR	1951	May	02		23.0, 90.0	Gopalganj					19			
161	TOR	1951	May	02		23.2, 89.6	Narail					25			
162	TOR	1953	Mar	13		23.8, 88.5	Meherpur(Past is Under Kustia dist)					19			
163	TOR	1954	May	05	1200	24.1, 91.1	Bhairab Bazaar,Kishoreganj					17			
164	TOR	1961	Mar	18		25.3, 89.8	along Jamuna river near Mymensingh-Rangpur border					32			
165	TOR	1961	Apr	03		23.5, 91.1	hit south of Comilla between Zangalia and Lalmia					62			
166	TOR	1962	Apr	15	1350	24.4, 90.7	Kalibari and Kishorganj					none			
167	TOR	1963	Mar	10		24.9, 90.8	Atpara and Barghata in Mymensingh dist					20			
168	TOR	1965	Mar	23		23.8, 89.0	Kustia					15			
169	TOR	1967	Mar	21		24.5, 90.9	Karimganj,Kishoreganj					2			
170	TOR	1967	Apr	16		23.2, 90.5	Naria and Bhederganj unions in Sariatpur					77			

ID	DIS	YR	MN	D	TM	LAT/LON	LO	MAG	AFF A(sq km)	WIND SPEED	TIDAL HT	DEATH	No.AFF P	HOUSES DSTRD	REFERENCES
171	TOR	1967	Apr	19		22.8, 91.0	Sudharam in Noakhali					12			
172	TOR	1967	May	01	1630	23.2, 91.1	Laksham in Comilla dist. and Munshiganj in Dhaka					30+			
173	TOR	1968	Apr	03	1500	22.8, 91.1	Noakhali dist. Hit Raipur Lumxipur & Begumganj			280(km/hr)		42			
174	TOR	1968	Apr	11		23.2, 90.4	Naria, Zajira and Bhederganj under Sariatpur zila			320(km/hr)		141			
175	TOR	1969	Apr	14	1645	23.8, 90.4	NE suburbs of Dhaka			320(km/hr)		660			
176	TOR	1969	Apr	14	1715	23.6, 90.8	Homna P.S. under Comilla dist			320(km/hr)		263			
177	TOR	1969	Apr	17		23.9, 89.3	Khumarkhali and Khoksa in Kustia dist					15			
178	TOR	1969	Apr	17		24.9, 88.4	Rajshahi dist. Moved fromGustompur to Manda unions					37			
179	TOR	1969	Apr	17	1540	24.5, 90.0	Tangail and Sirajganj, Mymensingh					32			
180	TOR	1969	Apr	28		24.2, 90.8	Katiadi in Mymensingh					8			
181	TOR	1970	Apr	13	1600	24.1, 90.4	Joydepur and Sreepur of Gazipur			350(km/hr)		37			
182	TOR	1972	Apr	01	1830	24.6, 90.2	14 miles southwest of Mymensingh					200+			
183	TOR	1972	Apr	05	1650	23.6, 90.4	Keraniganj and Baliaghata in south Dhaka suburbs					75			
184	TOR	1973	Apr	12	1500	23.6, 89.6	Baliakandi in Faridpur					200			
185	TOR	1976	May	08		22.3, 91.2	Hatiya Island,Noakhali					2			
186	TOR	1976	May	09		23.6, 90.5	S. suburbs of Dacca/Dhaka					1			
187	TOR	1977	Mar	31		24.2, 90.8	Lahund-Dangargaon villages in Katiadi inMymensingh					17			
188	TOR	1977	Apr	02		23.3, 90.0	Mokshedpur,Bhanga&Tungipara unions of Gopalganj					111			
189	TOR	1979	May	07		25.1, 90.1	Jamalpur					5			
190	TOR	1981	Mar	01	2100	24.5, 91.1	Itna,Kishoreganj					15			
191	TOR	1981	Apr	12	midday	23.2, 91.4	Parshuram-Fulgazi-Somarpur-Sonagazi in Feni			360(km/hr)		200			
192	TOR	1981	Apr	17	1430	21.6, 85.8	along Baitarani river-Kapndi,Erndi,Dnbeni Rnglbeda			360(km/hr)		120			
193	TOR	1982	Apr	12		25.6, 89.4	Rangpur and Gaibandha					23			
194	TOR	1983	Apr	09		23.1, 89.3	Jessore					16			
195	TOR	1983	Apr	23		23.6, 90.5	Raghunathpur vill-Kutubpur union-Fatullah-Narayang					2			
196	TOR	1983	Apr	24		22.7, 89.7	Rupsha under Khulna					25			
197	TOR	1986	Apr	14	evening	22.9, 89.8	Borni of Tongiapara-Gopalganj					120			
198	TOR	1990	Apr	20		24.3, 89.6	Taras, Ullahpara and Shahazadpur in Sirajganj					76			
199	TOR	1990	Apr	29		24.7, 89.7	Sirajganj					19			
200	TOR	1991	Mar	31	evening		Champak in Comilla					18			
201	TOR	1991	May	07	aftrn.	24.0, 90.5	Between Tongi, Joydevpur and Gazipur					45+			
202	TOR	1991	May	18		23.0, 90.3	Goumadi in Barisal					50			
203	TOR	1995	Apr	08		23.5, 90.4	Lohaganj, Serajdikhan and Srinigar in Munshiganj					40+			
204	TOR	1998	Apr	08	800	26.0, 88.9	Nilphimari					21			

ID	DIS	YR	MN	D	TM	LAT/LON	LO	MAG	AFF A(sq km)	WIND SPEED	TIDAL HT	DEATH	No.AFF P	HOUSES DSTRD	REFERENCES
205	TOR	1969	Apr	14			Saturia and Manikganj Sadar					992			The TP,USA
206	TOR	2001	Oct	05	1:00- 6:00pm		Nilphamary,Lalmonirhat,Gaibandha,Rangpur district					11	463		Nirapad
207	TOR	2004	Apr	13	4pm		Moulvi Bazar						60	450	Nirapad
208	TOR	2004	Apr	14	7:30pm		Haluaghat of Mymensingh,Netrokona,Purbadhala			120kmph		69	1200	4000	Nirapad
209	TOR	2005	Mar	20	Evening		Gaibandha,Rangpur					46	5223	6000	Care,Nirapad
210	TOR	1964	Apr	02			Narail					4			The TP,USA
211	CYL	1960	Oct	11			Chittagong			160kmph	15ft				BMD
212	CYL	1960	Oct	31			Chittagong			193kmph	20ft				BMD
213	CYL	1961	May	09			Chittagong			160kmph	8-10ft				BMD
214	CYL	1961	May	30			Chittagong(Near Feni)			160kmph	6-15ft				BMD
215	CYL	1963	May	28			Chittagong- Cox's Bazar			209kmph	8-12ft				BMD
216	CYL	1965	May	11			Chittagong-Barisal Coast			160kmph	12ft				BMD
217	CYL	1965	Nov	05			Chittagong			160(km/hr)	8-12ft				BMD
218	CYL	1965	Dec	15			Cox's Bazar			210(km/hr)	8-10ft				BMD
219	CYL	1966	Nov	01			Chittagong			120(km/hr)	20-22ft				BMD
220	CYL	1970	Oct	23			Khulna-Barisal			163(km/hr)	Moderate				BMD
221	CYL	1970	Nov	12			Chittagong			224(km/hr)	10-33ft				BMD
222	CYL	1974	Nov	28			Cox's Bazar			163(km/hr)	9-17ft				BMD
223	CYL	1981	Dec	10			Khulna			120(km/hr)	7-15ft				BMD
224	CYL	1983	Oct	15			Chittagong			93(km/hr)	-				BMD
225	CYL	1983	Nov	09			Cox's Bazar			136(km/hr)	5ft				BMD
226	CYL	1985	May	24			Chittagong			154(km/hr)	15ft				BMD
227	CYL	1988	Nov	29			Khulna			160(km/hr)	2-14.5ft				BMD
228	CYL	1990	Dec	18			Cox's Bazar Coast			115(km/hr)	5-7ft				BMD
229	CYL	1991	Apr	29			Chittagong			225(km/hr)	12-22ft				BMD
230	CYL	1994	May	02			Cox's Bazar-Teknaf Coast			278(km/hr)	5-6ft				BMD
231	CYL	1995	Nov	25			Cox's Bazar			140(km/hr)	10ft				BMD
232	CYL	1997	May	19			Sitakundu			232(km/hr)	15ft				BMD
233	CYL	1997	Sep	27			Sitakundu			150(km/hr)	10-15ft				BMD
234	CYL	1998	May	20			Chittagong Coast near Sita Kundu			173	3ft				BMD
235	CYL	1999	Oct	17			Orissa Coast			-	-				BMD
236	CYL	1999	Oct	25			Orissa Coast			-	-				BMD
237	CYL	2000	Oct	28			Sundarban coast near Mongla			50-60(km/hr)	2-4ft				BMD
238	CYL	2001	Oct	16			Andhra coast			65-85(km/hr)	-				BMD
239	CYL	2002	Nov	12			Sundarban coast near Raimangal river			65-85(km/hr)	5-7ft				BMD

ID	DIS	YR	MN	D	TM	LAT/LON	LO	MAG	AFF A(sq km)	WIND SPEED	TIDAL HT	DEATH	No.AFF P	HOUSES DSTRD	REFERENCES
240	CYL	2003	May	20			Myanmar coast			65-85(km/hr)	3-5ft				BMD
241	CYL	2003	Dec	16			Andhra coast			98-115(km/hr)	-				BMD
242	CYL	2004	May	19			Cox's Bazar – Akyab Coast			65-90(km/hr)	2-4ft				BMD
243	TOR	2006	Sep	19			South-west part,Cox,Sat,Cht,Bol,Bag,Noa,Piroj,Mong					3476			PRDI
244	ERK	1866	Jan	6		91.70,22.30	Chittagong,BD								OLD
245	ERK	1868	jun	30		94.50,24.50	Sylhet,BD	5							OLD,TS
246	ERK	1870	Apr	22		90.40,23.70	Dhaka,BD	0							MIL
247	ERK	1897	Aug	18		89.80,24.40	Serjgonj,BD	0							SR
248	ERK	1897	Aug	29		89.80,24.40	Serjgonj,BD	0							SR
249	ERK	1897	Sep	2		89.9,24.20	Tangail,BD	0							SR
250	ERK	1897	Oct			88.60,25.70	Dinjpore,BD	0							SR
251	ERK	1918	Jul	8	10:22:07	91.73,24.22	Balisera Valley,BD	0							GR,ISS,MST,TS
252	ERK	1920	Aug	15	6:59:8	93.20,22.20	Chittagong,BD	6							TS,HKG
253	ERK	1924	Jan	30	0:5:24	93.00,25.00	Sylhet,BD	6							ISS,TS,ISETR
254	ERK	1926	Oct	23	14:30:18	93.00,25.00	Sylhet,BD	5.5							GR,ISS,TS
255	ERK	1927	Aug	25	22:56:38	90.00,22.00	Offshore,BD								ISS,ISETR
256	ERK	1930	Jul	11	7:6:34	93.80,25.00	Sylhet,BD	5.5							TS,ISS,ISETR
257	ERK	1964	Oct	13	10:36:56	91.20,24.00	ID-BD								ISC,NDI,ISETR
258	ERK	1965	Aug	4	15:27:1	88.30,23.50	ID-BD								NDI
259	ERK	1991	Feb	2	0:15:40	91.17,25.51	ID-BD								ISC,MOS,BJI(4.5b,4.3s),NEIC
260	ERK	1991	Feb	3	13:22:10	91.67,25.50	ID-BD								ISC,NEIC
261	ERK	1991	Apr	26	9:15:52	89.67,20.81	Bay of Bengal								ISC,NEIC,BJI
262	ERK	1991	May	8	11:41:20	93.00,23.20	ID-BD								ISC
263	ERK	1991	Jul	13	4:26:12	92.20,23.90	ID-BD								ISC
264	ERK	1991	Aug	7	11:36:29	88.66,25.27	ID-BD								ISC,NEIC,BJI
265	ERK	1991	Aug	10	13:0:15	90.51,24.40	BD								ISC,NEIC
266	ERK	1991	Aug	22	3:53:44	91.18,25.29	ID-BD(Shillong)								ISC,BJI(4.5b),NEIC
267	ERK	1991	Sep	2	17:20:37	90.47,24.50	BD								ISC,NEIC
268	ERK	1991	Sep	25	19:26:50	88.40,26.70	ID-BD								ISC,NEIC
269	ERK	1866	May	23		87.00,2400	Darjeeling.ID	5.5							OLD, MIL,TS
270	ERK	1869	Jan	10		92.70,24.70	Cachar.ID	7.5	250000sq km						OLD,MIL,TS,MS
271	ERK	1897	Jun	12	11:05	91.00,26.00	Shillong.ID	8.7	1750000sqm						MIL,HKG,TS,MS
272	ERK	1906	Sept	29	14:58	88.50,23.30	Calcutta.ID		50000sqm						MDS
273	CYL	2007	Nov	15			Piroj, Bargu, Patua, Baris, Jhal, Bho, Bagerhat, Dublar			215km/h		10,000			RCS
274	TOR	2007	Mar	22			Bhola					10			24march,Jugantar

A List of terms, considered important for this study and procedural purposes in disaster-related activities:

- DISASTER: a serious disruption of the functioning of a society, causing widespread human, material, or environmental losses which exceed the ability of the affected society to cope using only its own resources. Disasters are often classified according to their sped of onset (sudden or slow) or according to their cause (natural or man-made).

- HAZARD: a threatening event, or the probability of occurrence of a potentially damaging phenomenon (e.g.an earthquake, a cyclonic storm, tornadoes, tunami or a large flood) within a given time period and area.

- RISK: the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural phenomenon, and consequently the product of specific risk and elements at risk.

- VULNERABILITY: the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon (or man made event) of a given magnitude and expressed on a scale from 0.0 (no damage or loss) to 1.0(total loss).

- MITIGATION: measures taken in advance of a disaster aimed at decreasing or eliminating its impact on society on environment.

- PREPAREDNESS: activities design to minimize loss of life and damage, to organize the temporary removal of people and property from a threatened location and facilitate timely and effective rescue, relief and rehabilitation.

- PREVENTION: encompasses activities designed to provide permanent protection from disasters. It includes engineering and other physical protective measures, and also legislative measures controlling land-use and urban planning.