

MULTI-HAZARD DISASTER REDUCTION IN THE COASTAL REGION OF BANGLADESH

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ABSTRACT: The coastal region of Bangladesh facing the Bay of Bengal is prone to a variety of natural hazards. It has witnessed the havoc of some of the worst natural disasters of the world due to tropical cyclones and storm surges. Floods and local seasonal storms are annual events which cause loss of lives and damage to housing, agriculture and economy. The coastal region is also exposed to the risk of earthquakes and possibly tsunami too. A major earthquake in 1762 in the southeastern coastal region caused severe flooding and landmass changes, the chances of a damaging local tsunami cannot therefore be ruled out. Most of the housings are non-engineered. Housing patterns among the common people typically consist of thatched huts, mud-walled houses, bamboo/wood framed houses and unreinforced masonry buildings. There are also many reinforced concrete frame buildings for residential and official/business purposes particularly in the urban areas. Bangladesh has achieved remarkable success in disaster management (early warning and post disaster management) related to floods and tropical cyclones. The management structure includes the country's top leadership continuing to the grass roots level. Bangladesh Meteorological Department (BMD) is playing a key role in this process and is principally involved in weather forecasting and issuing warnings for cyclone, storm surge and local storms. BMD's existing capabilities will be expanded to include modern seismic observatories for digital earthquake recording and for issuing early tsunami warnings. There are other natural hazard concerns such as coastal erosion and sea level rise due to global warming, which also need to be dealt on a long term basis. An integrated multi-hazard disaster reduction scheme may be taken using the country's existing disaster management structure but with its capability enhanced and in cooperation with other organizations including academic and research institutions.

1. INTRODUCTION

Bangladesh with an area of 147,570 km² and a population of about 140 million, is bounded by India to the west, north and north-east and by Myanmar to the south east and by the Bay of Bengal to the south. The country has a very flat and low topography except in the northeast and southeast regions. Bangladesh is basically a deltaic plain of three mighty rivers, namely the Padma (Ganges), the Jamuna (Brahmaputra) and the Meghna which form one of the largest river systems in the world. These rivers have large number of distributaries and tributaries. The country has about 24,140 km. of rivers which carry huge amount of water and sediments to the Bay of Bengal in the south where they are subjected to dynamic actions by the conditions in the Bay.

Bangladesh has a 700 km long coastline in the south. The coastal zone of Bangladesh forms the lowest landmass and is part of the delta of the extended 'Himalayan Drainage Ecosystem'. The enormous rainfall associated with monsoon climate and snowmelt in the Himalayan ranges constitute the main sources of water, flowing down through a myriad of rivers into the Bay of Bengal. Similarly the tidewater intrudes through these drainage channels inward in the countryside. The coastal belt may be divided into three distinct coastal regions, namely the western, central and eastern regions. The western and central zones are very flat and low. The land here is criss-crossed by numerous rivers and channels with a large number of islands in between them. The western

zone of Satkhira, Khulna, Bagerhat, Perojpur is home to the famous mangrove forest called the Sundarbans. A submarine canyon named Swatch of No Ground runs NE-SW up to about 24 km south of the western coast. The central region of Barguna, Patuakhali, Bhola, Barisal, Lakshmipur, Noakhali, Feni is geomorphologically most active where continuous process of land accretion and erosion is going on. The main Meghna river estuary which discharges about 90% of the total river inflow to the sea and the largest islands are located in this region. Geomorphologically the eastern coast is quite stable. The eastern coastal region of Chittagong and Cox's Bazar contains hilly areas and has nice long beaches. The population is concentrated in the central and eastern zones.

Economically, the coastal area plays a very important role in Bangladesh, with further development it can play much greater role. The coastal waters are a big source of marine fisheries as well as inland and marine transport. Shrimp farming has been a very lucrative business. There are two sea ports located in the coastal area, namely Chittagong in the eastern zone and Mongla in the western zone. While Mongla port is located on a river away from the coastline, Chittagong port is located right on the coast line at the mouth of Karnafuli river. Chittagong is the main port and second largest city of the country and handles most of the country's exports and imports. A number of industrial complexes are situated in Chittagong. Chittagong plays a vital role in the nation's economy. The Sundarban mangrove forest area is home to a rich wildlife including the Royal Bengal tiger and a very important eco-system of the region. It has been declared a world heritage site. The newsprint mill established there is based on the basic raw materials drawn from the Sundarbans. The country has also a big prospect of oil and gas in the coastal area. Gas is produced from Sanghu gas field in the Bay of Bengal. The eastern zone boasts the beautiful tourist spot of Cox's Bazar, which is world famous for its large beaches.

The coastal region of Bangladesh is susceptible to a variety of natural hazards which includes flood, cyclone, storm surge, tornado, earthquake, sea-level rise, coastal erosion and landslides. Some of the greatest natural disasters of the world have taken place in this region. The death toll in the hundreds of thousands due to tropical cyclones and storm surge in 1970 and 1991 bears testimony to this fact. Bangladesh has gained international appreciation for its success in disaster management related to floods and tropical cyclones. Such disaster management issues include early warning as well as post disaster relief and rehabilitation. This paper deals with the different kinds of natural hazards affecting the coastal region and important aspects of a multi-hazard approach to deal with the problem, with a major emphasis on earthquake, tsunami, tropical cyclones and storm surges which can be very destructive.

2. NATURAL HAZARDS

The different natural hazards that may strike the coastal regions of Bangladesh are described separately in the following sub-sections.

2.1 Tropical Cyclone & Storm Surge

Because of the funnel shaped coast of the Bay of Bengal, Bangladesh very often becomes the landing ground of cyclones formed in the Bay of Bengal. The Bay cyclones also move towards the eastern coast of India, towards Myanmar and occasionally into Sri Lanka. But they cause the maximum damage when they come into Bangladesh and north-eastern coast of India. This is because of the low flat terrain, high density of [population](#) and poorly built houses. Most of the damage occurs in the coastal regions of Khulna, Patuakhali, Barisal, Noakhali and Chittagong and the offshore islands of Bhola, Hatiya, Sandwip, Manpura, Kutubdia, Maheshkhali, Nijhum Dwip, Urir Char and other newly formed islands. Severe Cyclones cause extensive damage to exposed thatched huts and bamboo/wood framed houses that are not designed to withstand the strong winds.

Storm surges accompanying cyclones hitting Bangladesh have been noted to be several metres high. The 1970 cyclone (12-13 November) with a cyclonic surge of 6 to 10m and a wind speed of 222 km/h occurred during high tide causing an appalling natural disaster in the Central Coastal Zone claiming 500,000 human lives. The cyclone of 29 April 1991 hit Chittagong, Cox's Bazar, Barisal, Noakhali, Patuakhali, Barguna and Khulna along with storm surge of 5 to 8 m, killing 140,000 people. Table 1 provides information [1] on major cyclones and storm surges.

As-Salek and Yasuda [2] have developed a numerical model that takes into account how coastal winds, the shape of the estuary, and the ebb and flow of the local tides affect a storm surge. A surge that coincides with a high tide, for example, is much more destructive. The estuary can also have a funnelling effect that accentuates flooding. The funnelling effect is the amplification of the surge due to concentration of the surge energy confined by the triangularly shaped bay in the central and eastern coastal zone. As a result, the estuary of the Meghna River is generally hit hardest by storm surges.

Table 1: Historical information on major cyclonic storms and storm surges [1]

Year	Coastal Zone	Wind Speed (km/hr)	Storm Surge (m)	Deaths
1822	Central	---	Yes	40,000
1876	Central, Eastern	---	12.2	200,000
1897	Eastern	---	Yes	14,000
1960	Central, Eastern	210	4.5-6.1	10,000
1961	Western	161	2.4-3.1	11,468
1963	Eastern	164-203	4.3-5.2	11,520
1965	Central	162	3.7	19,279
1970	Central	222	10.6	500,000
1985	Eastern, Central	154	3.0-4.6	11,069
1988	Western	162	4.5	5,708 wild animals
1991	Eastern, Central	178-225	5-8	140,000
1997	Eastern, Central	225	3.05	126

2.2 Local Severe Storms/tornadoes.

Local thunderstorms including severe tornadoes occur throughout the country. These storms normally occur during the monsoons. These storms particularly tornadoes can cause severe damage to traditional rural housing lacking wind resistant design and result in significant casualties in localized areas.

2.3 Flood

Every year, Bangladesh experiences major floods that inundate about one-third of the country. Most of the flood water comes from the neighbouring countries. Islam [3] gives a good detail of major aspects of the causes of the flood. The combined catchment basin of the major rivers is more than 12 times the size of Bangladesh. Under average conditions, from June to September, 775 billion cubic meter of water flow into Bangladesh from other countries through the main rivers and an additional 184 billion cubic meter of streamflow is generated by rainfall in Bangladesh. The river system carries annually about two billion tons of sediments. In addition to this, there is large fluctuation of water flow between lean and peak seasons, 85% of the precipitation occurring in only about one-third of the year. All these aspects in combination with the low elevation of the country result in flooding of large areas of the country.

The flood situation in the country may turn worse due to back water effect (BWE) created in the Bay of Bengal. BWE means the retardation of a river outflow by a rise in the sea water level at the river mouth. BWE is very pronounced [4] particularly in the Meghna river estuary through which about 90% of the river water in Bangladesh discharges into the Bay of Bengal. As a result of BWE, flood water inside the country continues to accumulate, bringing more areas under inundation and increasing the length and depth of flooding in areas already inundated. BWE may arise in the Bay of Bengal due to (i) south-west monsoon wind (ii) astronomical tides and (iii) storm surges. Ali and Hoque [5] using a numerical model found that for a discharge rate corresponding to the 1988 flood in Bangladesh, a 2 m/s rise in wind speed nearly doubles the amount of water held up inside the country.

2.4 Earthquake

Bangladesh is located in a tectonically active region close to the plate boundaries of the north moving Indian plate and the Eurasian plate to its north and east. As a result, there are several seismic sources (fault zones) in and around Bangladesh. Several large earthquakes of magnitude 7 to more than 8 have affected Bangladesh during the last 150 years, these earthquakes have occurred to the north and in the northern parts of Bangladesh. It should be noted that large earthquakes in the region have not been occurring for quite a long time (around 75 years) and hence, the possibility of a major earthquake occurring soon is quite high. As part of an ongoing study on assessment of seismic hazard for Bangladesh, an earthquake catalogue [6] for the region has been formed for the period 1845-Feb.2005. Fig.1 shows the earthquake epicentres during this period (Bangladesh is in the middle). Both eastern and western coastal region has been source to earthquakes of magnitude greater than 5. While the western coastal region has seen 5.7 magnitude earthquake, the eastern coastal region has seen much larger earthquake as described in the next paragraph.

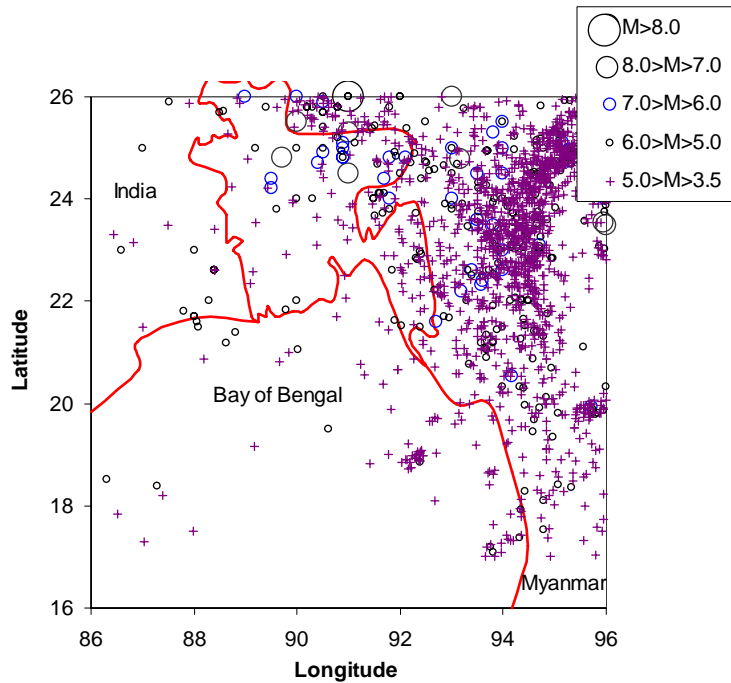


Fig.1: Earthquake epicentres around the coastal region of Bangladesh [6]

The largest earthquake in the Chittagong/Cox's Bazar area has a magnitude of 6.5. Moreover, historical documents mention the occurrence of a large earthquake on April 2, 1762 (not shown in Fig.1) near Chittagong in the south-east which caused sea flooding, river waves inland, land mass changes etc. It is among the earliest known large earthquakes in South Asia. The earthquake, a major one (possibly $M > 7.0$), was centred 40 km SE of Chittagong and 257 km SE of Dhaka, 61 km north of Cox's Bazaar district. Chittagong suffered very severely; great explosion heard at first; earth opened in many places; quantities of water gushed out, great chasms remained unclosed and filled with water. Water spouted out like a fountain together with fine sand or mud, evidence of liquefaction. The great earthquake of April 2, raised the coast of some islands by several metres and also caused a permanent submergence of 155.40 sq km near Chittagong. At Dollazari houses fell. Near Luckipore, a circuit of land, about 15 miles in circumference, was swallowed up, and all the inhabitants and cattle perished. The earthquake also agitated the rivers and lakes of the country causing deaths inside the country.

During the last seven or eight years, the occurrence and damage caused by some earthquakes (magnitude between 4 and 6) in the south-eastern part of the country inside the country or near the country's border, has raised the level of awareness among the general people and the government as well. The damage has been mainly restricted to rural areas or towns near the epicentre, but there has been some instances of damage in urban areas 50 to 100 km away. An under-construction reinforced concrete frame building of faulty design and construction collapsed (Fig.2a) and killed several people in the port city of Chittagong due to the Nov. 21, 1997 magnitude 6.0 earthquake at the Bangladesh-Myanmar border 100 km away. This earthquake also caused some cracks in some buildings and walls in the Chittagong and Bandarban region, and collapse of a portion of an under-construction earthen dam. The July 22, 1999 magnitude 5.1 earthquake with its epicenter very near the island of Moheshkhali, off the coast of Cox's Bazar, caused extensive damage and collapse of rural mud-walled houses (Fig.2b). This earthquake exposed the vulnerability of mud-walled houses, which is quite common in the rural areas. Concrete column of a multipurpose cyclone shelter (Fig.2c) was also severely damaged. The July 27, 2003 magnitude 5.6 Barkal-Rangamati earthquake which caused serious damage to masonry and mud-walled buildings in Barkal, also caused concern about the safety of the Kaptai dam at the country's only hydro-electric power plant. Any failure of the dam/spillway will cause sudden onrush of huge mass of water through the Karnaphuli river which could damage parts of the port city of Chittagong. Minor earthquakes have been frequently occurring in the Chittagong area. It is apparent that the eastern coastal zone is quite vulnerable to earthquakes. The western zone is also vulnerable but to a lower extent as pointed out earlier.



Fig.2: (a) Collapsed RC Frame building in Chittagong city (Nov.1997 M=6.0 earthquake 100 km away)
 (b) Partially collapsed mudwalled house in Moheshkhali Island (July 1999 M=5.1 earthquake)
 (c) Multipurpose Cyclone Shelter in Moheshkhali Island that sustained damage in its column (July 1999)

2.5 Tsunami

Tsunami may be caused by major earthquakes with sudden vertical displacement of sea-floor or by sudden submarine slope failure which may be triggered by an earthquake. Volcanic sources are not present in the region. The only mention of something like tsunami is the sea water movement due to the 1762 earthquake just south of Chittagong. The great earthquake raised the coast of Foul island by 2.74m and the northwest coast of Chedua island by 6.71m above sea level and also caused a permanent submergence of 155.40 sq km near Chittagong. To this severe earthquake is attributed an elevation, of varying amount, of the coast of Arakan, stated to extend over more than 100 miles in length. The rivers and tanks throughout the country were strongly affected- the waters rushing with violence and rising in some places ten feet perpendicularly, and continuing in agitation for a quarter of an hour at a time. The rise in the water level at Dhaka was so sudden that hundreds of boats capsized in Burigonga River and 500 people were drowned. The rivers and jheels were agitated and rose high above their usual levels and when they receded their banks were strewn with dead fish. A large river dried up, a tract of land sank and 200 people with all their cattle were lost. The water in the Hoogly river in Kolkata rose by two metres. Water in tanks rose 6 feet; direction said to have been north and south; lasted ten minutes. At Ghitotty, 18 miles above Calcutta, river rose more than 6 feet perpendicularly.

The 1881 Car Nicobar Island 7.9 magnitude earthquake spawned a tsunami in the Bay of Bengal, which was recorded in Sri Lanka and India including the Andaman & Nicobar Islands. Nothing significant happened in Bangladesh. The recent December 26 2004 Great Sumatra earthquake with a magnitude of 9.3 devastated several countries bordering the Indian Ocean killing nearly 300,000 people. Most of the casualties and devastation occurred in Indonesia, Sri Lanka, India and Thailand. Fortunately, this tsunami struck Bangladesh mildly. Two deaths were reported in Bangladesh as a result of the tsunami waves that caused the capsizing of boat in the coastal area. The earthquake/tsunami effect was sensed all over Bangladesh, coastal district in particular. Waves were created in all rivers in the coastal area and the sea with a wave height of 5/6ft. It has been reported from different places inland that the quake lasted for six to 30 seconds and surged the water in the rivers, canals and ponds by a few feet for much longer time. Waves created in standing water bodies such as ponds and lakes, also known as seiches, were reported to be observed all over Bangladesh including Dhaka the capital.

2.6 Sea Level Rise

In the foreseeable future, Bangladesh is likely to be affected by the long lasting and global scale human-induced disaster-the climate change (global warming due to green-house gas emissions) and sea level rise (SLR). The low topography of Bangladesh has made it one of the most vulnerable countries of the world. The low lying coastal regions will be affected first by SLR. Two estimates of potential future SLR for Bangladesh are 0.30-1.5m and 0.30-0.50m for 2050 [7]. A very recent study by Singh, et al. [8] shows that mean tidal level at Hiron Point (21048' N, 89028' E), Char Changa (22008' N, 91006' E) and Cox's Bazar (21026' N, 91059' E) is showing an increase of 4.0 mm/yr, 6.0 mm/yr and 7.8 mm/yr respectively, which is much higher than the global rate. The higher rate may be attributed to tectonic subsidence of land. An increasing tendency in SLR from west to east along the coast has been found. About 2,500, 8,000 and 14,000 km² of land (representing 2%, 5% and 10% of the total land area of the country) will be lost due to SLR of 0.1m, 0.3m and 1.0m respectively. About one-fourth of the population lives in the coastal area. As a result, SLR may cause migration of a lot of people inland, raising the population density there and causing socio-economic problems.

Sea level rise will bring more coastal area under inundation. This coupled with reduced flows from upland during winters will accelerate the saline water intrusion inland. Not only that, even the ground water aquifers will bear the brunt of salinity intrusion. Agriculture, forestry and fisheries sectors will be severely affected by increased water and soil salinity. The mangrove forest of Sundarbans and its bio-diversity may face extinction. It will also increase the risk of flood disasters and accelerate coastal erosion. SLR may cause damage to port facilities and coastal embankments/ structures and result in loss of recreational beaches.

2.7 Coastal Erosion

Coastal erosion in Bangladesh are caused by a number of factors, such as high monsoon wind waves and currents, high river discharge currents, strong tidal actions and storm surges. Superimposed on these will be the SLR which can cause considerable erosion directly and through modification of these factors. It has been predicted that the average recession of the eastern coastline of Bangladesh would be about 87 times the SLR. Using above-mentioned figure of shoreline recession (i.e.87 times the SLR), it has been found that about 626, 1879 and 6264 ha of land will be lost through erosion by SLR of 0.1m, 0.3m and 1.0m respectively. These losses will be in addition to what has been given in section 2.6. Land loss will have severe consequences in an overpopulated country like Bangladesh.

3. DISASTER MANAGEMENT SYSTEM IN BANGLADESH

The Ministry of Food and Disaster Management (formerly the Ministry of Disaster Management and Relief) of the Government of Bangladesh has responsibility for coordinating the government disaster management efforts. Government Standing Orders [9] have been developed that describe in detail the preparedness, response and recovery mechanisms of key stakeholder agencies in responding to an immediate crisis. Responsibilities of different personnel during a disaster event are described. A detailed description of the country's disaster management system and activities has been given in a recent publication [10].

The Draft National Policy on Disaster Management has emphasized a group of broad-based strategies:

- Management of both risks and consequences of disasters that would include prevention, emergency response and post-disaster recovery. The goal is to minimize the loss of lives and properties.
- Strengthen national institutions for disaster management with emphasis on preparation of action plans and guidelines. Enhance professional skills and knowledge of key personnel of the MFDM on risk reduction, preparedness, warning and forecasting system and post-disaster activities.
- Non-structural mitigation measures such as community disaster preparedness, training, advocacy and public awareness with the involvement of local government bodies. Promote measures to create employment opportunities in the disaster prone areas and develop self-reliance.
- Structural mitigation measures including construction of rural infrastructure, shelter and communication facilities in the high-risk areas.

There are three bodies for multi-sectoral coordination and collaboration at the national level:

- The National Disaster Management Council (NDMC) is headed by the Prime Minister and has 30 members including Ministers and permanent Secretaries of ten concerned ministries (Water Resources, Finance and Planning, Health and Family Welfare, Agriculture, Home Affairs, Defense, Local Government and Cooperatives, Roads and Railways, Shipping, and Food and Disaster Management) and the Chiefs of Staff of the defense services. Its responsibilities include both policy direction and the highest level of national coordination.
- The Minister in charge of the Ministry of Food and Disaster Management (MFDM) chairs the Inter Ministerial Disaster Management Coordination Committee (IMDMCC). The committee has 30 members including Secretaries of twenty ministries concerned with disaster management and risk reduction. The committee has specific responsibilities to be performed before, during and after disasters.
- A National Disaster Management Advisory Committee (NDMAC) with memberships drawn from both public and private sectors. Disaster Management Specialist nominated by Prime Minister, Members of Parliament elected from disaster prone areas, experienced person from Government agencies, University, NGOs, donor organizations and other agencies in the field of water resources, meteorology, seismographic engineering, physical infrastructure planning, social anthropology, education, disaster management.

The government has several programmes related to disaster reduction:

- Comprehensive Disaster Management Programme (CDMP) encompassing different natural hazards including earthquakes has recently started as an initiative of the Ministry of Food and Disaster Management.

The objectives are to develop and strengthen human and institutional capacities, increase public participation in risk reduction activities and educate policy makers. The goal is to create a holistic and comprehensive risk reduction culture within national policies and strategies for disaster risk reduction.

- National Water Management Plan to reduce the impact of floods and erosion, drought induced famine and effectively manage water resources
- Integrated Coastal Zone Management (ICZM) program has built-in components to address risk reduction in the coastal regions.
- National Environment Management Action Plan (NEMAP) for protection and improvement of environment.
- The National Adaptation Plan of Action (NAPA) is in the process of development by representatives of the scientific community under the leadership of the Ministry of Environment and Forest. The NAPA will focus attention on three impacts associated with climate change: increasing sea-level rise, changing rainfall patterns, and increases in the frequency and intensity of extreme events.

The different key government organizations involved in disaster management includes: Food and Disaster Management Ministry, Disaster Management Bureau (DMB), Bangladesh Meteorological Department (BMD), Flood Forecasting and Warning Center (FFWC), Space Research and Remote Sensing Organization (SPARRSO), Directorate for Relief and Rehabilitation (DRR), Water Development Board (WDB) (Coastal Embankment), Forest Department (Coastal Green Belt program), Local Government Administration Officials, City Corporations, Armed Forces, Police, Fire Service, Utility Services, Bangladesh Radio/ Television (Weather Forecasts)

Disaster risk reduction is incorporated into the intervention strategies of many NGOs and civil society institutions addressing developmental problems. Disaster management courses are taught at the university level and in the curricula of government training institutions. The Disaster Management Bureau (DMB) has introduced disaster management and awareness programmes into primary and secondary school curricula in order to inculcate disaster preparedness into a new generation of citizens. The government media has also developed products that draw attention to the plight of vulnerable groups living daily in hazard-prone areas. The Bangladesh Red Crescent Society (BDRCS) is particularly active in all areas of the country to mobilize risk reduction initiatives.

Hazard mapping/assessments have been undertaken by several disaster management stakeholder agencies to examine the potential risk facing urban and rural populations to specific hazards i.e. cyclone, flood, drought, riverbank erosion, landslides, tornado and earthquakes. A flood hazard map and land development priority map were developed in 2000 using National Oceanographic and Atmospheric Administration (NOAA) Satellite, Advanced Very High Resolution Radiometer (AVHRR) and Geographical Information System (GIS) data. The GIS data maintained by Local Government Engineering Department (LGED) and Bangladesh Agriculture Research Council (BARC) are also consulted for vulnerability mapping. DMB developed a detailed hazard map of the country showing zones affected by flood, cyclone, earthquake and drought. The results of the hazard mapping is being used by a plethora of government, nongovernment and donor agencies to design, implement and assess the risk reduction impact achieved through development intervention strategies. Agencies such as the Flood Forecasting and Warning Centers (FFWC), the Bangladesh Meteorological Department (BMD), Centre for Environmental and Geographic Information Services (CEGIS), Institute of Water Modeling (IWM) and the Space Research and Remote Sensing Organization (SPARRSO) have particular interest in this information as per responsibilities for early warning dissemination and collaborative linkages with regional and international organizations.

The Ministry of Disaster Management and Relief and the Red Crescent Society are jointly operating the Cyclone Preparedness Program (CPP) with a volunteer force of more than 27000 trained men and 5000 women to disseminate cyclone information, and carry out rescue operations if a cyclone strikes the coast. Bangladesh Radio and Television at frequent intervals transmit warning messages for the events. As a part of structural mitigation measures the Government of Bangladesh with its own and external resources has constructed more than 1800 multipurpose cyclone shelters, and 200 flood shelters for evacuation of people threatened by cyclone or flood. These multipurpose cyclone shelters are used for other activities such as school, community programs etc. In addition, coastal embankments around 3931 km long have been made to protect coastal land from inundation by tidal waves and storm surges, and drainage channels of total length 4774 km have been constructed. Coastal Green Belt Program of Forest department (FD) is a participatory reforestation program aimed to reduce the impact of natural hazards on the coastal areas.

The present role of two important institutions in the nations' disaster management activities are given in the following two sub-sections:

3.1 Bangladesh Meteorological Department (BMD)

Bangladesh Meteorological Department (BMD) is playing a key role issuing early warning for cyclones and storms. The warnings are relayed to the country's population through radio and TV broadcasting. An effective communication system also exists in BMD for exchanging information both at national and international levels. The following are the summarized activities of BMD:

- Gives advanced warning for tropical cyclones, storm surges, thunderstorms, and tornadoes.
- Gives weather forecasts which are important for predicting flood responses.
- Operates a network of four radar stations at Dhaka, Rangpur, Cox's Bazar and Khepupara as well as satellite ground receiving stations to receive imageries from NOAA, GMS and InSAT to monitor cyclones as soon as they form in the Bay of Bengal.
- Operates an old seismic observatory (not fully operational) in Chittagong and will soon be operating four digital seismic observatories in Bangladesh and additional short period seismometer stations.
- Receive and issue tsunami warning messages with international assistance. It will also link itself with the international tsunami early warning system that is being developed for the Indian Ocean Region and will upgrade itself so that it can operate as the regional tsunami warning centre.

3.2 Bangladesh University of Engineering and Technology (BUET)

BUET is the nation's leading institution for teaching, research and consultancy in civil, water resources and environmental engineering as well as urban and regional planning. Faculty members of BUET are involved in various activities that are related to disaster reduction, such as:

- Development of 1993 National Building Code with new seismic zoning map & earthquake resistant design provisions.
- Consultants for Multipurpose Cyclone Shelter Project in the coastal areas, initiated by the Government after the devastating 1991 cyclone.
- Research studies on storm surge predictions, flood impact assessments, seismic hazard and risk assessments, environmental pollution problems including arsenic contamination, wind and flood resistant rural housings etc .
- Training programs for professionals.
- Activities in national professional bodies such as Institution of Engineers Bangladesh, Bangladesh Earthquake Society,
- Involved as technical experts in national committees

4. INTEGRATED MULTI-HAZARD DISASTER MITIGATION SYSTEM

Bangladesh has an effective disaster management system that issues early warning for cyclones to the coastal region which is transmitted to the coastal population through local administration and volunteers. This system may be expanded and strengthened [11] to include warning capability for tsunami also, where the response time will be very limited. The government is also considering a multi-hazard approach through its Comprehensive Disaster Mitigation Program (CDMP). Disaster management structure available for one hazard may be effectively used for other hazards with some upgrading.

Although post-disaster rescue, relief and rehabilitation is important, the major emphasis of an integrated disaster mitigation system should be on pre-disaster measures. For each natural hazard, such pre-disaster measures include four components:

- (i) **Risk Assessment:** It is a technical activity which involves prediction of future disaster scenarios and its impact. The success of such studies depends on installation of appropriate scientific instruments, collection of accurate data, use of state of the art scientific procedures and consideration of local variations.
- (ii) **Preparedness:** It involves taking necessary measures, both structural and non-structural, where both technical and social experts as well as community leaders have to contribute. Community awareness and training is part of this component. Women and children who are the most vulnerable group needs to be given proper attention. These measures will depend on results obtained from component (i).
- (iii) **Warning:** It involves rapid assessment of local data obtained from scientific instruments and evaluation of warning messages from foreign sources and taking decision if warning needs to be issued.
- (iv) **Communication:** It depends on the existing machinery of the disaster management system of the country. Warning will be issued centrally from a designated organization such as BMD to selected stations (offices) in the coastal region, which will in turn take necessary action to communicate with disaster management personnel at local levels. Telecommunication to local levels can be done by mobile phone, walkie-talkies

and two-way radios. At local level, warning to the local population can be issued by sirens, drum beats, using loudspeakers (of mosques), mobilizing volunteers going door to door (if time permits) etc.

A multi-hazard disaster mitigation system should ensure participation and interaction of different academic and research institutions and professionals from different disciplines. There are some examples for recent cooperation between organizations. BMD will be installing modern seismic observatories whose data will be available for transfer and analysis by BUET, Dhaka University, Bangladesh Geological Survey etc. There are some organizations such as Bangladesh Earthquake Society which is a platform of professionals from various disciplines with a common goal of disaster mitigation. It is very much hoped that its activities will promote understanding between different groups of people and as a professional body will deliver required message to the government authorities.

Research Centres of excellence for disaster reduction need to be supported at BUET as well as other academic and research institutions. At BUET, there is already an Institute for water and flood management (IWFM), centre for environmental resource management (CERM), proposed (by the first author) [12] national centre for earthquake engineering (NCEE) operating on a project basis. An ultimate objective may be to establish an institute for disaster reduction which will be able to consider any particular hazard as component of an integrated multiple hazard mitigation scheme.

Scientific studies on impact assessment of future cyclones, storm surge, tsunami, sea level rise will need accurate data of the local bathymetry and topography which also changes with time. Available data is not sufficiently detailed or accurate, so measurement of this data and preparation of detailed bathymetric and topographic maps in the coastal regions is one of the top priorities. Bangladesh government has associated itself with future IOC (International Oceanographic Organization) activities in the region which is expected to result in improved maps.

Coastal engineering relies on estimates of the 'design cyclone': the hypothetical hurricane that generates the flood wave with the largest water volume at a particular point. Current defences in Bangladesh are scattered and inadequate since they were not based on scientific predictions. Numerical models such as that of As-Salek and Yasuda [2] can help make these calculations, putting sea defences on a rational footing. This would help in planning permanent sea defences.

Sea level rise is not getting the desired attention and should be addressed by related professionals as how to deal with this problem in the long term. The approach will obviously be long-term, and needs to be started without delay, otherwise the long term consequences will be disastrous.

Tsunami may be generated by distant or local submarine earthquakes. Although there are local submarine earthquake sources, whether they are capable of producing significant vertical uplift of the sea-floor resulting in tsunami that needs carefully studies. It must be noted here that tsunami may also be generated by local submarine landslides which again may be triggered by earthquakes.

Considering the existing and planned infrastructure and instrumental setup of BMD, it is quite obvious that BMD with appropriate upgrading could develop itself to be the country's centre for issuing warning messages for multiple hazards. The following considerations are important:

- Existing capacity of BMD in terms of qualified manpower and instrumental setup needs to be enhanced so that it is capable for the analysis of data and issuance of early warnings to the community levels for multiple hazards including floods, storms, cyclones, storm surge and tsunami.
- An effective communication system on real time basis is required to allow sharing of earthquake data and tsunami monitoring information with national and international organizations.
- Early warning systems does not work for earthquakes, but once there is such an event, rapid analysis of earthquake data by BMD will give valuable information on earthquake magnitude, earthquake location, areas likely to be affected, extent of damage etc.
- BMD will also need the assistance of other academic and research institutions for the analysis and interpretation of its data. Collaboration and cooperation between different organizations needs to be improved.

5. CONCLUDING REMARKS

The coastal region of Bangladesh is vulnerable to various natural hazards: flood, cyclone, storm surge, tornado, earthquake, sea-level rise, coastal erosion, landslide etc. An Integrated multi-hazard disaster reduction is the

nation's top priority. The Bangladesh government is planning about it through a comprehensive disaster management program (CDMP). To make it successful, it is necessary to improve co-ordination among different organizations and programmes. Considering existing infrastructure, current operations, future plans, it appears that Bangladesh Meteorological Department may be upgraded to be the national warning centre that will assess and issue warnings on a 24 hour basis for major natural hazards such as cyclone, storm surge, tornado, floods, tsunami etc. Technical experts from home and abroad should be given wider scope to conduct research and contribute with their academic expertise and research findings. The nation's existing defences against coastal hazards are not based so much on scientific predictions, they are rather based more on past occurrences. Detailed scientific studies are necessary to predict possible coastal disaster scenarios that may be different from previous occurrences and to prepare refined coastal vulnerability and hazard maps. Such maps will guide the authorities concerned to undertake preparedness activities. Technical experts in the country's leading academic and research institutions should have open access to data from BMD or other organizations for conducting research activities that would lead to improved hazard and vulnerability assessment. BMD has recently set an example by its decision to provide direct access of data from its seismic observatories to BUET and some other organizations. Sustainable research and information centres of excellence should be developed, supported and promoted by the Government at academic and research institutions. The nation's existing national cyclone and flood disaster warning and response plan, proven to be successful, need to be continued, supplemented and strengthened to include pre-disaster measures and other hazards. Sea-level rise is not getting the required attention, but immediate long term scientific planning and activities is essential to cope with this foreseeable situation.

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