APPLICATION OF REMOTE SENSING AND GIS FOR CYCLONE DISASTER MANAGEMENT IN COASTAL AREA: A CASE STUDY AT BARGUNA DISTRICT, BANGLADESH

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ABSTRACT

Bangladesh is one of the top vulnerable countries to the climate change and the adverse impact on the country will be catastrophic because of convergence of climate change, poverty and large population. The frequency of natural disasters like floods, cyclones etc have increased significantly over the last decade particularly in the coastal line of Bangladesh which is asserted as the impact of climate change. The consequences of these disasters are a huge loss of lives and properties that implicates the economy of the country. So disaster management is now an important concern to minimize all those losses. Disaster management of an event like Cyclone, Flood or Earthquake etc. requires some ingredients, such as, response, incident mapping, establishing priorities, developing action plans and implementing the plan to protect lives, property and the environment. GIS in combination with Remote Sensing (RS), can be used very effectively to identify hazards and risk for cyclone. In Bangladesh, cyclone and tidal surge are considered as the most catastrophic phenomena for coastal regions. From the historical data, it is seen that during the years 1797 to 2009, Bangladesh has been hit by 65 severe cyclones, 35 of which were accompanied by storm surges. Some cases the surge height was more than 6 meters which created devastating situation for the people and for the country as well. The main focus of the study is to develop a model that could be used for disaster planning and management. A storm surge model has been developed integrating historical cyclone data with Digital Elevation Model (DEM), which generates the cyclone hazard maps for different return periods. Satellite images and field survey data are used in GIS and RS platform to assess the vulnerability of lives and infrastructures. Cyclone risk in terms of casualty is assessed considering the hazard and vulnerability analysis for the study area which can be implied to give a signal of awareness to the local community and the decision makers to provide advance planning for cyclone disaster management.

INTRODUCTION

Most of the coastal areas of the world are at risk from natural hazards resulting from geological or meteorological disturbances. In Bangladesh cyclone and tidal surge are considered as the most catastrophic phenomena of coastal regions. The coastal region of Bangladesh which is formed out of the process of sedimentation (of salts) by the mighty river systems of the Ganges, the Brahmaputra, and the Meghna, particularly vulnerable to cyclonic storm surge floods due to its location in the path of tropical cyclones, wide and shallow continental shelf and the funneling shape of the coast (Das, 1972). Cyclone-induced storm surges in this region typically originate in the central and southern parts of the Bay of Bengal or in the Andaman Sea. Due to the shallow continental shelf, the surge amplifies to a considerable extent as it approaches land and causes disastrous floods along the coast (Murty et al., 1986). In the northern Bay of Bengal, a unique combination of high tides, a funneling coastal configuration, the low flat coastal terrain and a high population density have produced some of the highest mortality figures associated with storm surges (Flierl and Robinson, 1972). All the ingredients for a major cyclone disaster are present and such disasters have occurred several times in the past and claimed hundreds of thousands of lives notably in 1970 and 1991 (Haque,1997). Rather, Bangladesh is one of the top vulnerable countries to the climate change. Due to climate change and sea-level rise, the country is likely to be affected by more intense cyclonic events in the foreseeable future. The consequences of climate change lead to an increase in the cyclone-prone area and put a large number of people at risk.

During the years 1797 to 2009, Bangladesh has been hit by 65 severe cyclones, 35 of which were accompanied by storm surges. A tropical cyclone forming in the Bay of Bengal has a lifetime of one week or longer. The height of the surges is limited to a maximum of 10 meters in the bay. When propagating into the shallower inland, coastal areas, the heights of these waves are further reduced. The frequency of a wave (surge plus tide) with a height of about 8 m is approximately once per 20 years. A storm surge of approximately once in 5 years has a height of about 5 m (surge plus tide). Besides these exceptional surges, wind waves occur, the dimensions of which depend on wind speed and direction, fetch, water depth and duration. Waves of 3 m height may occur under unfavorable conditions in the coastal regions (French Engineering Consortium and Bangladesh Water Development Board, 1989).

More recently, advances in computer, GIS and RS technology have increased the accessibility and mobility of GIS tools. As a consequence, GIS has now become a fundamental component of community-based methodologies. Thus, integrating local knowledge with GIS and RS techniques in the disaster identification stage in order to develop map and assess the hazard prone areas is an excellent tool for cyclone disaster

management and regional planning development. Cyclone storm surge mapping through modeling with RS and GIS tools, which help analyze a variety of possible scenarios, has been the focus of this study. Barguna District was selected for this study and detail study was carried out in three unions of that district. The main objective of this study is to develop cyclone hazard map and to figure out the vulnerability assessment of the study area which could be an efficient and important tool in cyclone disaster management for decision makers to provide advance planning.

STUDY AREA

Barguna district is situated at the south-western part of Bangladesh, on the south bounded by the Bay of Bengal with the total area of approximately 1831.31 Sq. Km. It is located within $21^0 29'$ to $22^0 51'$ N and in- between $89^0 53'$ to $90^0 22'$ E (Figure 1).
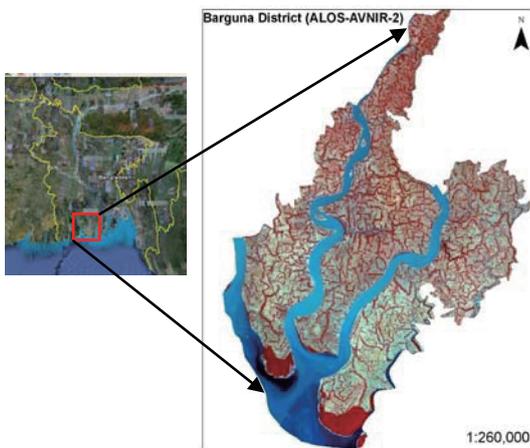

Figure 1: Study Area (Barguna)

According to the Population census of 2001, the population size of this area is 9,02,465, where females constitute a majority of the population with a percentage of 50.12% while males constitute 49.88%. However, due to the position in coastal areas and adjacent to the Bay of Bengal the district was severely affected by cyclone like Sidr in 2007 and Aila 2009.

METHODOLOGY

Development of Surge Model

For better prediction of cyclone hazards, especially in low land areas like Bangladesh, historical data such as cyclone wind speed and storm surge height, inundation of surge water, landuse and other data of the study area are essential. The frequency of cyclonic events and other statistical aspects of the tropical cyclones that stuck the Bangladesh during the period 1960 to 2009 have been considered in the study. The wind speed data which are found identical in the most of the articles and documents on Bangladesh cyclones (Khan, 1995; MCSP, 1992 and Karim, 2008) and Bangladesh Meteorological Department historical data are taken into consideration for frequency analysis and result show that the corresponding wind speed for 5, 10, 20, 50 and 100 are of 166, 205, 243, 291 and 327 km/h respectively. Based on the bay configuration, tidal amplitudes and bathymetry, the entire coastal belt is divided

into three zones and our study area falls in to zone-1 (Khan, 1995). Historical cyclone wind speeds and surge heights of zone-1 are used in the regression analysis and it is linearly correlated. Based on the regression analysis result, storm surge heights are calculated using the frequency analysis result for 5, 10, 20, 50 and 100 are of 3.1, 3.9, 4.7, 5.7 and 6.5 meters respectively.

To develop the storm surge model ILWIS Program (Integrated Land and Water Information system) is used. To develop the surge model, Surge Decay Coefficient (SDC), has been calculated for each surge height. The SDC is a function of the friction caused by surface forms (morphology, embankments and elevated roads) and land cover (houses, rice fields, homestead gardens with trees, etc.). The contribution to the friction of all the terrain elements to the SDC is not fully understood and is still being investigated. However, from historical records we know that in areas with low or no dikes along the coast the surge depth will be more or less constant; after this it will decrease until a certain distance inland.

The SDC is calculated as:

$$\frac{\text{Surge height - Average elevation at end of surge}}{\text{Total inundation width - Width of constant surge}}$$

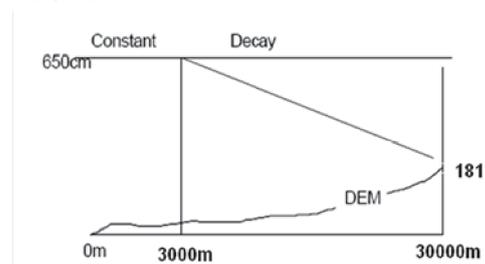The figure 2 shows an example for a surge height of 650cm at the coast line.

Figure 2: Surge Decay Coefficient

The data from the total limit to inundation from the coastline for different storm surge has been assumed based on 2007 cyclone (SIDR) case field data. Using the Surge Decay Coefficient and various MapCalc formulas are used in ILWIS program to develop the storm surge model for different periods.

Development of Hazard Map

To develop the different return period hazard map of surge water depth, two models have been used:
  (i)   surge model based on historical records of cyclone flooding in Bangladesh
  (ii) Digital Elevation model (DEM) of the area

Elevation data of the coastal area in digital format is a primary input for cyclone hazard mapping. From the spot height data of FAP-19 of Bangladesh Water Development Board, 30 meter resolution DEM has been generated using GIS analysis. Using the calculated SDC, DEM and various MapCal formulas are used in ILWIS for storm surge modeling which result the surge hazard maps for different return period.

The figure 3 shows the 100 year return period hazard map for surge inundation depth. It shows that for 100 year return

period; almost 70% area of the district will be inundated. It is also illustrated that the southern part of the district will be inundated above 600 cm.
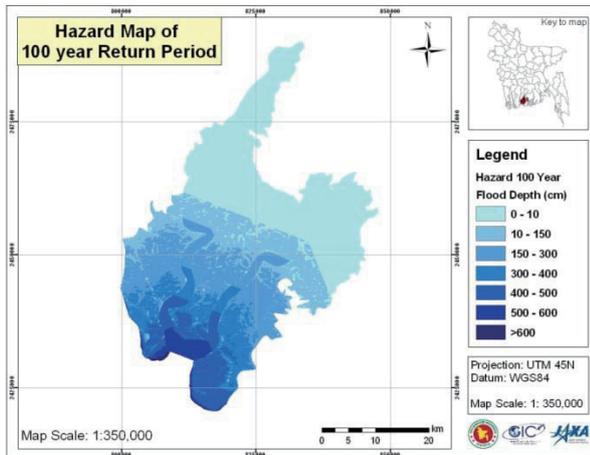

Figure 3: Hazard Map of 100 year return period

Vulnerability Analysis

To calculate the population density of village level, village boundary is essential. Pan sharpened ALOS/AVNIR-2 images by ALOS/PRISM and Participatory GIS approach are used for developing the village boundary maps. Three unions (Barabagi of Amtali Upazila, Naltona of Barguna Sadar Upazial and patharrgata union of Pathargata Upazila) of Barguna District's village boundary maps are prepared for detail study. A village boundary map is shown as figure 4.

Figure 4: Village Boundary Map of Amtali union of Barguna District.

The vulnerability of the people to flooding is the degree of loss to the total population, or particular categories, resulting from flooding with a certain depth. It is expressed on a scale from 0 to 1. Based on "Cyclone 91 – An environmental and perceptional study 1991, Bangladesh Center for Advanced Studies" the following assumptions are made for vulnerability analysis:
It is considered that 16 percent of the population moved to safer place for early warning system. The casualty rates for the different categories are: Children: 50%, Women: 25%, Elderly: 15% and Men: 10%

The relationship between the flood depth and vulnerability is derived from following assumptions:
Near the coast (=8000m) the vulnerability is 0.7
At some distance from the coast (in this case 20000m) the vulnerability is 0.3. The vulnerability of 1.0 at an arbitrary depth of 500 cm

Based on the above assumptions and using different MapCal in ILWIS, different return period vulnerability maps of district and union level have been developed. The figure 5 shows the vulnerability map of 100 year return period of Barguna District where red color shows the most vulnerable areas.
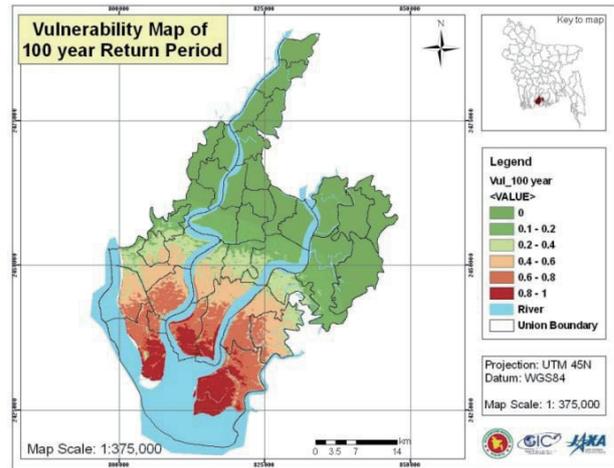

Figure 5: Vulnerability Map of 100 year return period

Development of Casualty Map

Union level population densities as well as village level population density for the three studied union are calculated. For calculating the population density it has been considered that 16% of the population will flee to safer places and are thus assumed unaffected. Densities are also calculated for different categories of the population: children, elderly, men and women. Using the MapCal in ILWIS different categories population density maps have been developed.

For every surge height, the number of casualties per union and village for three unions are calculated by multiplying the population density maps with the vulnerability maps. The casualty maps are expressed in number of people per skm per union that will be died as a result of a certain surge height flooding. A casualty map for 100 year return period has been shown as figure 6.

The total loss of population, as well as population losses in the different population categories (children, women, elderly and men) have been calculated for casualty map. For population categories losses, extra multiplication factors are used representing the susceptibility of a category to drown as a result of flooding: for children: 50% ; for women: 25% ; for elderly: 15% ; for men: 10%. In figure 6, the values indicate the number of casualty of total population per square km for 100 year cyclone storm surge return period.
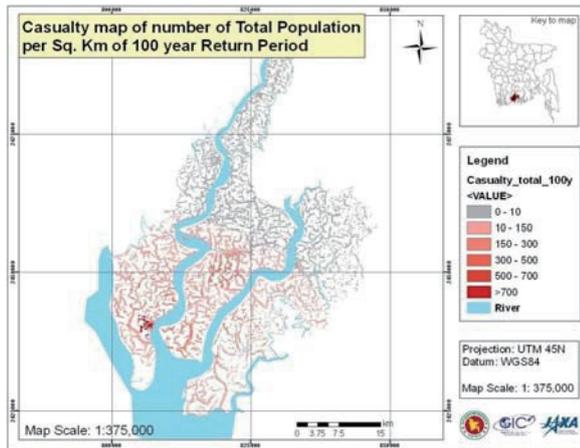
Figure 6: Casualty Map of 100 year return period

Risk Assessment

The flood risk for a certain return interval is the statistical chance that people drown due to the surge event. It is the product of the probability of occurrence of the event in years, the vulnerability and the number of people living in the area. To make some predictions on risks during next 100 years, risk map is calculated as: (Probability of occurrence in 100 y * Vulnerability * Population density).

The calculation of risk is carried out separately for the total population, for the population categories and for surge heights expected every 100 years, 50 years, 20 years, 10 years and 5 years. Population growth does not take into account for calculating the risk. A 100 year return period risk map is shown as figure 7. In general, it can be concluded that small surge heights result in higher risks and within the population categories, the children's category has the highest risk and the elderly category is the lowest. The risks within population categories however are entirely dependent on the category densities. Risk may change due to the frequency of the cyclones in the future, the population growth and, for instance, the building of dikes, cyclone shelters, etc.
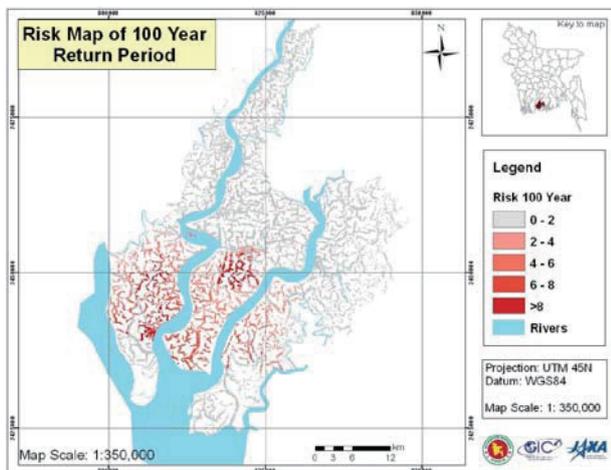

Figure 7: Risk Map of 100 year return period

IMPROVEMENT OF CYCLONE DISASTER MANAGEMENT

Emergency disaster management requires response, incident mapping, establishing priorities, developing action plans and implementing the plan to protect lives, property and the environment. GIS and RS allow disaster managers to quickly Access and visually display critical information by location. This information facilitates the development of action plans that are printed or transmitted to disaster response personnel for the co-ordination and implementation of emergency efforts.

In this study several hazard, vulnerability and risk maps of different return period have been developed. Using those maps, disaster management planner can acquire information about the future cyclone hazard and risk. From the figure 8, it is seen that there is no cyclone shelter at some vulnerable area (encircle areas) for storm surge flooding. Priority basis those locations should be considered for construction of new cyclone shelter to reduce the damage of lives and property due to cyclone.
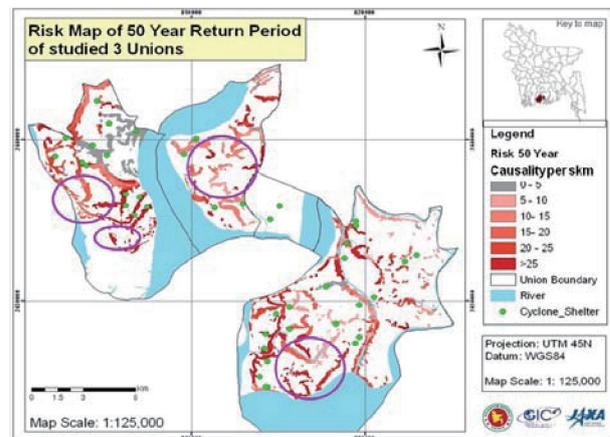

Figure 8: Locations for new cyclone shelter for 50 year return period of cyclone storm surge

From this study the following features can be taken into account for improvement of cyclone disaster management:

- o Prioritize the construction of cyclone shelters according to the study
- o Travel distance, population density and categories should be incorporated when deciding the location of cyclone shelters
- o Using the result of the study, planners can prioritize the construction & reconstruction the embankments
- o Awareness programs about the early warning in village level
- o Highlight the importance of forestation along the coastal belt
- o Mobile voice message can be use as a early warning tool

CONCLUSIONS

This study analysis is one example of the application of Remote Sensing and GIS in Disaster Management. Studies have been carried out on storm surge modeling for hazard and risk analysis. The main conclusion can be summarized as follows:

o Using the RS and GIS techniques, the results of the storm surge model show the hazard for different return period

o The model developed in this study considering the actual inundation data of Cyclone SIDR, 2007, as a basis for analysis

o The model shows that for 100 year return period (wind speed more than 320 km/h and surge height 6.5 m) more than 70% area of the district will be inundated

o Southern part of Barguna district (Amtali, Phatargata and Sadar upazila) are more vulnerable for storm surge flooding

o Casualty maps for different category people show that, it is directly related to the density of population and vulnerability of that area

o Risk may change due to the frequency of the cyclones in future, the population growth and, for construction of embankments, dikes, cyclone shelters etc.

ACKNOWLEDGEMENTS

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