

Modelling tropical cyclone hazards under climate change scenario using geospatial techniques

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Abstract. Tropical cyclones are a common and devastating natural disaster in many coastal areas of the world. As the intensity and frequency of cyclones will increase under the most likely future climate change scenarios, appropriate approaches at local scales (1-5 km) are essential for producing sufficiently detailed hazard models. These models are used to develop mitigation plans and strategies for reducing the impacts of cyclones. This study developed and tested a hazard modelling approach for cyclone impacts in Sarankhola upazila, a 151 km² local government area in coastal Bangladesh. The study integrated remote sensing, spatial analysis and field data to model cyclone generated hazards under a climate change scenario at local scales covering < 1000 km². A storm surge model integrating historical cyclone data and Digital Elevation Model (DEM) was used to generate the cyclone hazard maps for different cyclone return periods. Frequency analysis was carried out using historical cyclone data (1960-2015) to calculate the storm surge heights of 5, 10, 20, 50 and 100 year return periods of cyclones. Local sea level rise scenario of 0.34 m for the year 2050 was simulated with 20 and 50 years return periods. Our results showed that cyclone affected areas increased with the increase of return periods. Around 63% of study area was located in the moderate to very high hazard zones for 50 year return period, while it was 70% for 100 year return period. The climate change scenarios increased the cyclone impact area by 6-10 % in every return period. Our findings indicate this approach has potential to model the cyclone hazards for developing mitigation plans and strategies to reduce the future impacts of cyclones.

1. Introduction

Tropical cyclones are devastating natural disasters, typically generating high winds, intense rainfall, terrestrial flooding and storm surges [1]. Globally, many coastal areas are regularly affected by these disasters. By the several studies, it is expected and predicted that under most climate change scenarios, the intensity and frequency of tropical cyclones will increase significantly [2, 3]. The overall impacts of tropical cyclones were very high in many coastal areas of the world. These disasters often cause significant loss of life, large scale property and environmental damage [4]. Cyclone hazard modelling is an effective management process under preparedness stage of cyclone disaster



management which can provide realistic scenarios identifying areas that may be affected in the future [5]. These models could be used by policymakers and administration to develop mitigation plans and strategies. Thus, hazard modelling procedure can reduce the impacts of cyclones on people, property and environment.

There are various advanced mathematical storm surge modelling approaches are available [6, 7, 8]. However, a simple modelling approach at local scales (1-5 km) is essential for producing detailed hazard models. Geospatial techniques using remote sensing and spatial analysis are a potentially effective tool for modelling tropical cyclone hazards in simple manure integrating local knowledge [3, 9]. Moreover, sea level rise scenarios can be simulated easily using geospatial approach to assess the climate change impact on tropical cyclones. Currently, very few studies are available on cyclone hazard modelling using storm surge model under climate change scenario based on geospatial approach at the local scale.

The aim of this study was to develop and test a hazard modelling approach under climate change scenario using geospatial techniques for estimating tropical cyclone impacts at the local scale covering <1000 km² in Sarankhola upazila, Bangladesh.

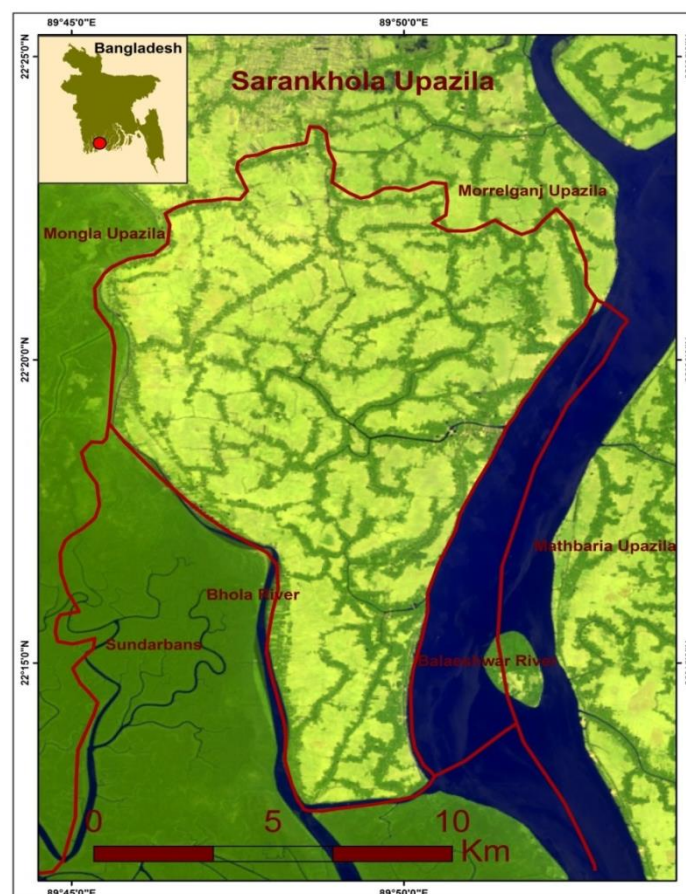


Figure 1. Study area, Sarankhola upazila under Bagerhat district in Bangladesh drawn on Landsat 8 OLI image of 15/04/2014

2. Study area and dataset

The study area is Sarankhola upazila, a local government area (about 151.24 sq. km), under Bagerhat district in Bangladesh (figure 1). The area is geographically located between 22°13' - 22°24' N latitude and 89°46' - 89°54' E longitude in the western coastal area of Bangladesh. The area is open to Bay of Bengal by the coastal Baleshwari and Bhola rivers and is highly vulnerable to tropical cyclones

induced storm surges, strong winds and flooding [10]. This coastal upazila is highly populated and was severely affected by tropical cyclone Sidr in 2007 and Alia in 2009.

The historical cyclone data (1960-2015) of western coastal region of Bangladesh was used in this study for frequency analysis to calculate different return period surge heights. These data were acquired from the Bangladesh Meteorological Department (BMD). The SRTM1 data at 30 m resolution were downloaded from United States Geological Survey (USGS) Earth explorer website and used as a basic input in the storm surge model. We have further processed this SRTM 1 data to remove vegetation artefacts by canopy height estimation model for producing bare earth DEM. The local sea level rise scenario data was acquired from the published study [11]. The study used the local tide gauge data which are closed to our study area for projecting sea level rise scenario.

3. Methods

Geospatial techniques were used to develop the surge models. The local sea level sea rise scenario was integrated with these surge models to assess the climate change impacts. The resultant surge models were used for hazard analysis. The processing flows used in this study are discussed in the following sections and outlined in the figure 2.

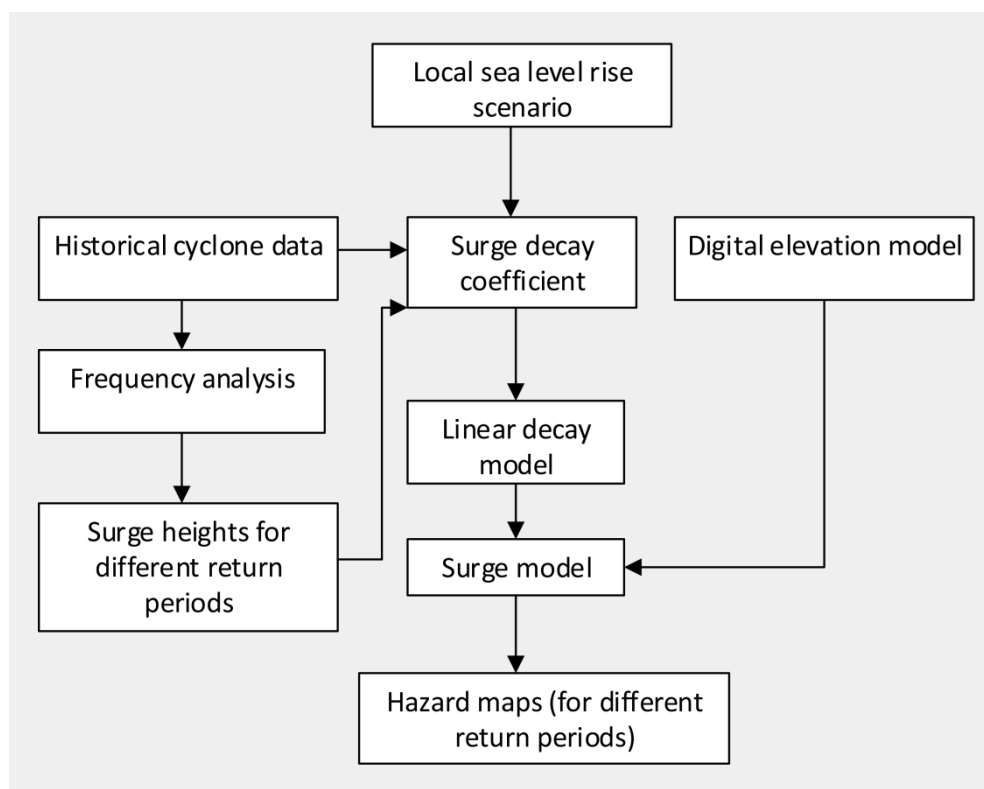


Figure 2. Flowchart of the hazard modelling approach used in this study

3.1 Frequency analysis and surge heights

Historical cyclone data (1960-2015) were used for frequency analysis to calculate different return period surge heights. The coastal area of Bangladesh is divided into three zones. The study area is located in the western coastal zone. Therefore, western coastal region cyclone data were only considered in the frequency analysis. Based on Gumbel Distribution, storm surge heights were

calculated using the frequency analysis for return periods 5, 10, 20, 50 and 100 were 4.65, 5.39, 6.10, 7.01 and 7.70 meters respectively.

3.2 Climate change impact and tropical cyclone

The local sea level rise scenario was used to assess the consequences of global climate change on tropical cyclone storm surges. The local sea level rise scenario of 0.34 m for the year 2050 was projected based on the local gauge station data which are closed to study area [11]. This scenario was simulated with 20 and 50 years return periods surge models.

3.3 Surge model and surge decay coefficient

Storm surge flooding depth is considered as linearly decay towards inland. Based on this concept, the storm surge model was developed in this study. We used the ArcGIS spatial analyst tool for developing the storm surge model. In this process, surge decay coefficient (SDC) was calculated for each surge height. SDC is a function of friction caused by surface forms and land use which helps to find out how the surge depth decreases inland gradually (figure 3). The SDC is calculated using the equation 1 and illustrated in figure 3. SDC values were calculated using field data of tropical cyclone Sidr (2007). Using the SDC values and bare-earth DEM, various raster calculator formulas were used in ArcGIS Software environment to develop storm surge models for different return periods.

$$SDC = \frac{\text{Surge height} - \text{Average elevation at the end of surge}}{\text{Total inundation width} - \text{Width of constant surge}} \quad (1)$$

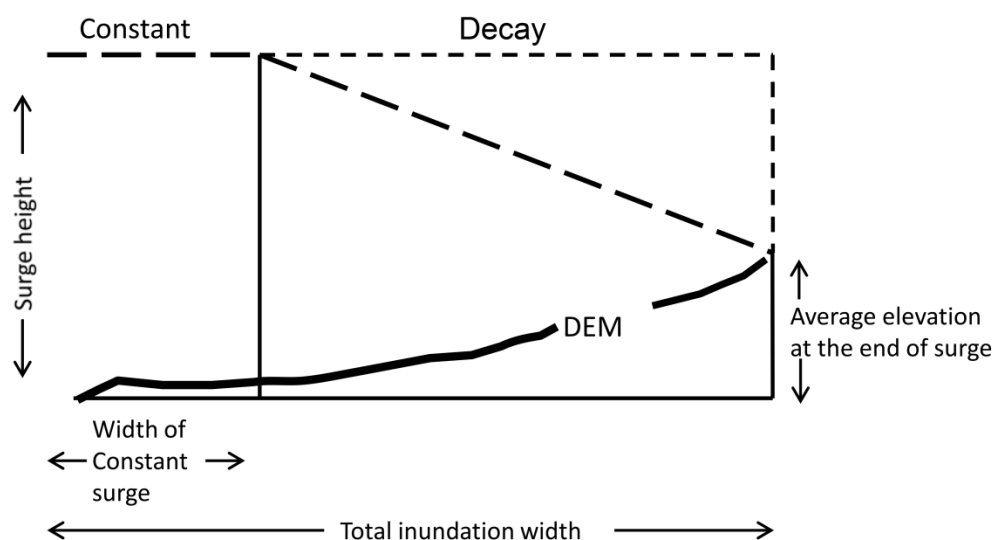


Figure 3. Schematic diagram outlining the linear surge decay model

3.4 Development of hazard map at present and future climate

Hazard maps were produced based on inundation depths derived from surge models for different return periods under present and future climate. Five levels of hazard classes were assigned for every hazard map by inundation depths ranges according to expert opinions. The assigned hazard classes are very low hazard (< 0.5 m), low hazard (0.5-1.5 m), moderate hazard (1.5-2.5 m), high hazard (2.5-3.5 m) and very high hazard (>3.5 m).

4. Results and discussion

4.1 Hazard map at present climate

Hazard maps (figure 4) were prepared by categorizing the inundation depths from storm surge models into five classes under present climatic conditions. The produced hazard maps show that hazard prone areas increase with the increase of return period and surge depth. In 10 years return period, 31% of the study area is located from moderate to very high hazard zone, while it will be 51% in 20 years return period.

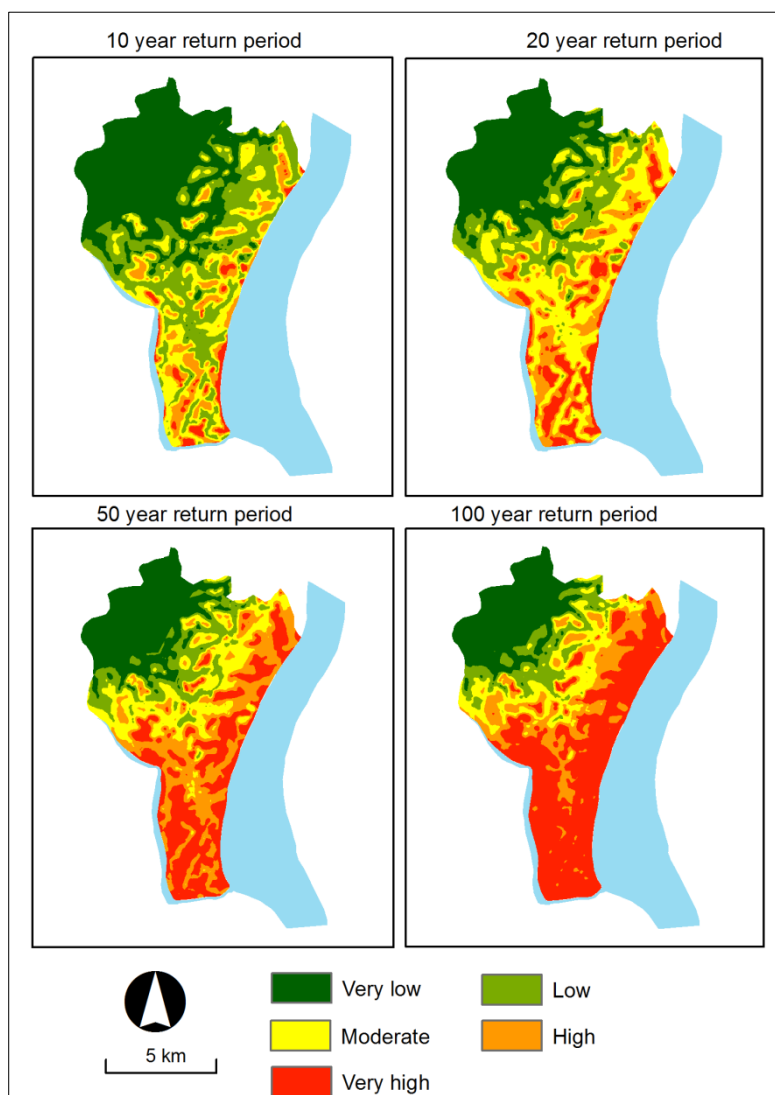


Figure 4. Hazard maps under 10, 20, 50 and 100 year return periods at present climate

On the other hand, for the 50 years return period, 63% of the study area was located from moderate to very high hazard zone, while it will be 70 % in 100 years return period. Moreover, 80% of the area will be inundated above 0.5 surge height in 100 return periods.

4.2 Hazard map under future climate

Hazard maps under future climate change impact were prepared by integrating 0.34 m local sea level rise scenario with existing storm surge models of 20 and 50 years return periods and these models then classified into five hazard classes. Figure 5 presents the hazard maps in both climate change and

normal scenario for the year 2050. The study found that the area in the moderate to high hazard zones will increase by 10% in 2050 for 20 year return period under climate change scenario, while it will be 9% for 50 years return period.

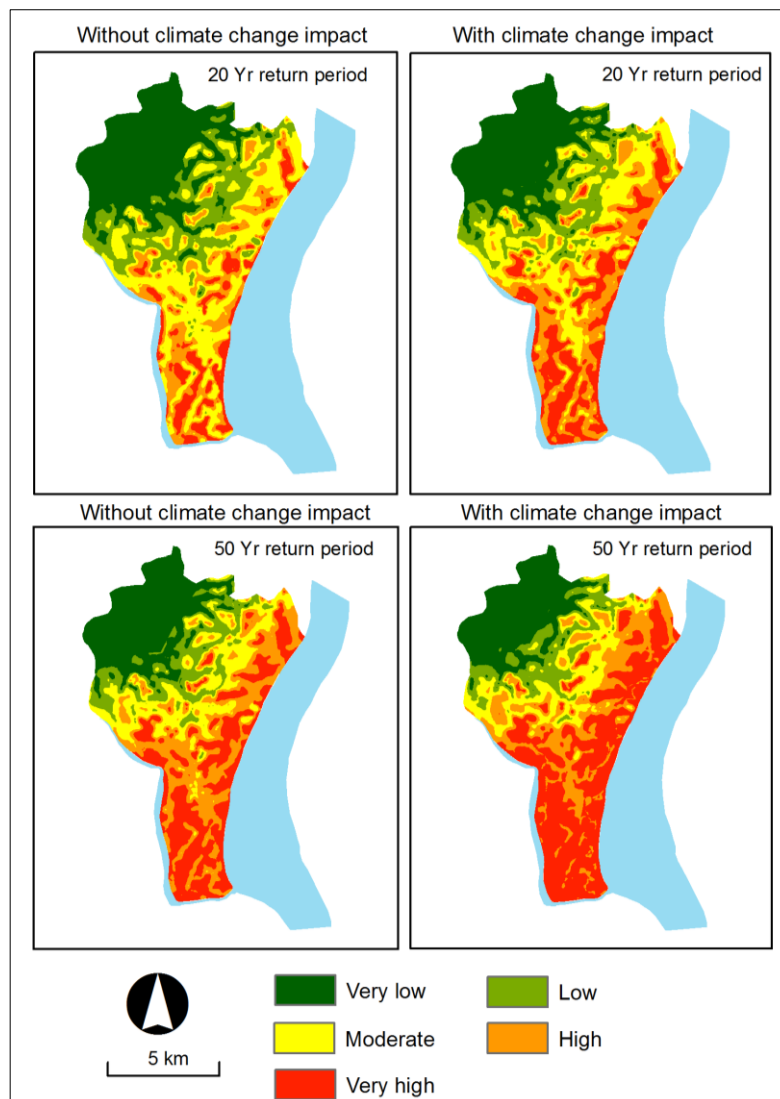


Figure 5. Hazard maps at 0.34 m sea level rise scenario under 20 and 50 year return periods for the year of 2050

5. Conclusions

The study demonstrates the capability of geospatial approach for modelling tropical cyclone hazards by integrating local knowledge with other environmental data representing conditions under climate change scenario at the local scale.

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