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Coastal multi-hazard vulnerability assessment along the Ganges deltaic coast of Bangladesh—A geospatial approach

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A B S T R A C T

It is ironic that countries that are least responsible for or insignificant contributors to global climate change, are in fact, the most susceptible to its harmful impact. The Ganges deltaic coast, one of the largest sediment depocentres with the ~286 km long coastline of Bangladesh, faces potentially multi-hazard threat due to climatic change. This study attempted to develop a coastal vulnerability index (CVI) by using seven physical parameters namely: (a) geomorphology; (b) coastal slope; (c) shoreline change rate; (d) rate of sea level change; (e) mean tide range; (f) bathymetry; and (g) storm surge height. These variables are considered as relative risk parameters and integrated through geospatial techniques (i.e., remote sensing and GIS), and then ranked to estimate the degree of coastline vulnerability to sea level rise. The entire coastline is ranked in accordance with multi-hazard vulnerability and the results reveal that 20.1% of the shoreline (57.9 km of total coastline in the Ganges delta) is very highly vulnerable, whilst 17.5% of shoreline (50.0 km) is estimated to be highly vulnerable. In contrast, 21.5% of the entire shoreline (61.3 km) is moderately vulnerable, whereas approximately 56.6 km (19.7%) and 60.4 km (21.2%) of the total shorelines are in low and very low vulnerability categories, respectively. The results of the CVI are expected to provide a clear picture for predicting future recession of shorelines; hence the outcome of this study can be used as an important tool by coastal managers for developing sustainable resources management practices. Furthermore, this study also offers a framework for prioritizing actions to enhance a community's resilience or to assist in developing appropriate adaptive measures as part of disaster risk reduction initiative.

1. Introduction

Climate change is an inevitable natural phenomenon and is a continuation of the geologic past but the situation is aggravated due to increased anthropogenic activities in the recent past. The issue of climate change is debated far and wide as it directly links to the existence of human civilization. Global warming is an emerging concern in this context, blamable for changes in climate all over the world. As a matter of fact, climate change hampers the natural environment which successively unsettles the human society/system, especially in coastal areas. Generally, coastal regions of the world are vulnerable to natural calamities due to their proximity to the sea, large concentrations of population and economic activity. As a result, these areas are exposed to a wide variety of hazards such as sea water intrusion, coastal flooding due to storm surge, coastline erosion, waterlogging and an increase of sea surface temperature (Torresan et al., 2008).

According to the Intergovernmental Panel on Climate Change 5th Assessment Report (IPCC, 2014), the risk to low lying areas, especially along the coastal belt, is projected to increase significantly throughout the 21st century and beyond. In Asia, accelerated sea level rise and increasing temperatures are apparently affecting marine as well as coastal ecosystems (Woodroffe, 2010). Specifically, South East Asian countries are believed to be at greater risk since large populations are seeking better livelihoods in these low lying fragile coastal plains.

Bangladesh is one of the top fifteen (15) risk hotspots where larger exposure to natural hazards and climate change impacts are

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held responsible for creating a vulnerable society which is again intensified by extreme population pressure, high incidence of poverty, inadequate coping capacity as well as sensitive socioeconomic conditions (Alliance Development Works, 2013). Though the coastal zone of the country is endowed with natural resources, widespread poverty and non-sustainable use of resources together with frequent natural calamities (e.g. cyclones) pose a significant threat to the life and livelihoods of the coastal communities. Further, owing to low lying land and the relatively unstable muddy deltaic plain, Bangladesh's coast is under serious threat of sea level rise which could hinder the country's development activities and, eventually, generate a barrier to achieving sustainable development.

Vulnerability and exposure to climate change are considered to be dynamic and vary within spatial and temporal scales. However, they are also dependent on various factors such as geographic, demographic, economic, social, institutional, governance, and environment (IPCC, 2012). Therefore in the context of disaster risk reduction and mitigation, vulnerability assessment is believed to be a prerequisite task that can enhance resilience of a community, society or of a nation. Vulnerability assessment of coastal regions includes two major areas: the first considers physical variables to evaluate the locational vulnerability of a particular coast (Gornitz, 1990; Gornitz et al., 1994; Shaw et al., 1998; Thieler and Hammar-Klose, 1999; Pendleton et al., 2004; Doukakis, 2005; Hegde and Reju, 2007; Nageswara Rao et al., 2008; Yin et al., 2012; Kumar and Kunte, 2012; Bagdanavičiūtė et al., 2015) whereas the second one includes socioeconomic variables such as population density together with physical parameters to estimate socioeconomic vulnerability of a particular coast (Boruff et al., 2005; Szlafsztein and Sterr, 2007; Devoy, 2008; Murali et al., 2013; Kunte et al., 2014; Mahapatra et al., 2015). However, because of regular variableness and lack of authentic data regarding dwellers and more or less analogous economic conditions, particularly in a data scarce country like Bangladesh, this paper puts particular emphasis on the calculation of physical vulnerability of the Ganges deltaic coast.

A number of techniques have been used to study coastal vulnerability including Coastal Vulnerability Index (hereinafter, CVI), Coastal Sensitivity Index (CSI) and so forth. The major intention of these works is to generate information on the impacts of sea level rise, climate change and non-climatic drivers on a coastline that may be of significant value for community members, coastal managers and other stakeholders for informed decision making. In addition, vulnerability assessment is the first approach used before doing any type of sustainable development work and is found to be highly beneficial in reducing disaster risk (Hinkel and Klein, 2009).

The concept of CVI was first proposed by Gornitz (1990, 1991) to assess coastal vulnerability due to sea level rise on the east coast of the US. It is a numerical approach to rank the segments of a coastline in terms of potential harm caused by global climate change (e.g., sea level rise), and the outcome is normally communicated through maps and statistics to highlight regions where the interaction of various factors influence shoreline vulnerability (Kunte et al., 2014). Specifically, this technique allows a researcher to compute the CVI by taking the key parameters into account so that important drivers influencing vulnerability of a coastal environment can be determined (Gornitz, 1990; Gornitz et al., 1994). In later works, Thieler (2000) and Thieler and Hammar-Klose, (1999) and Pendleton et al. (2004) use the same principle in their CVI calculation to estimate the threat of sea level rise to the Atlantic, Gulf of Mexico, Pacific coasts and Golden gate national recreation area of the US. However, Gornitz's concept continues to be employed by many others (Dwarakish et al., 2008; Gaki-Papanastassiou et al., 2010; Kumar and Kunte, 2012; Mujabar and Chandrasekar, 2013; Kunte et al., 2014) to enumerate coastal vulnerability, of various coasts, in response to sea level rise or with regards to coastal multi-hazard. Despite the wide acceptance and extensive use of Gornitz's algorithm, other approaches have been employed in assessing coastal vulnerability. For example, the CVI approach was modified and employed by Hedge and Raju (2007) in India by considering the sum of the parameters divided by the total number of parameters for the Mangalore Coast, India. Nageswara Rao et al. (2008) work in the Andhra coast using sum of the product techniques, but giving major weight to three variables: geomorphology, coastal slope, and rate of shoreline change. Le Cozannet et al. (2013); Murali et al. (2013); Yin et al. (2012) also use a similar CVI approach to examine coastal vulnerability along the Lithuanian coast, two coastal regions of France, the Puducherry coast of India and along the Chinese coast. Multi-criteria evaluation technique such as analytical hierarchy process (AHP) is adopted by Bagdanavičiūtė et al. (2015) in the estimation of coastal vulnerability.

In lieu of vulnerability, Shaw et al. (1998) introduce the term sensitivity in their Coastal Sensitivity Index (CSI). Abuodha and Woodroffe (2010) conducted a CSI analysis with four iteration techniques using the Gornitz's algorithm to estimate sensitivity of shoreline of an Australian coast. In contrast, many studies appreciated the necessity of the inclusion of socioeconomic parameters to the final CVI calculation as argued by Shaji (2014). In connection with this, Boruff et al. (2005), Reyes and Blanco (2012), Szlafsztein and Sterr (2007), Shaji (2014) and Duriyapong and Nakhapakorn (2011) calculate an index linking both socioeconomic and physical parameters along US coastal counties, the Philippines coast, Brazilian coast, west coast of India and the Thailand coast. However, Boruff et al. (2005), Mujabar and Chandrasekar (2013) and Jana and Bhattacharya (2013) are among the few who considered coastal erosion as a major input variable to assess coastal vulnerability and appraised the use of the Digital Shoreline Analysis System (DSAS).

Although the Bangladesh coastline is believed to be at serious risk of climate change induced sea level rise, study related to coastal vulnerability assessment has received little attention, partly because of the lack of data and restricted access to data. A few studies using single parameter have, so far, been considered to study shoreline change (Sarwar, 2013; Islam et al., 2011), sea level rise (Nishat and Mukherjee, 2013) and coastal flooding (Khan, 1995). Islam et al. (2015) are the first to attempt the CVI approach along the Bhola coast, one of the major offshore islands in the Bay of Bengal, aiming at estimating vulnerability using physical features of the island. However, index based coastal vulnerability assessment, on a regional scale in Bangladesh appears to be rare. Hence, this study aims to fill this gap.

The necessity of disaster risk reduction in the Ganges deltaic coast is said to be a pressing issue owing to the fact that this particular coast of Bangladesh is densely populated and very vulnerable to sea level rise and natural hazards (Bhuiyan and Dutta, 2012). As such, multi-hazard vulnerability assessment could be the first step to supporting sustainable coastal zone planning and management. Keeping this in mind, the objective of the study is to quantify the degree of vulnerability of various coastal segments in a highly dynamic coastal environment by taking seven physical parameters into account within a geospatial domain.

2. Study area

The Ganges deltaic coast is located between 21°40′ to 23°00′ north, and 89°0′ to 91°0′ east. It is a typical example of micro to macro tidal low-lying coastal environment. The coast extends from the Hariabhanga River (along the India-Bangladesh boarder) in the west to the Tetulia River near Bhola Island in the east (Barua, 1991)