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Where is the coast? Monitoring coastal land dynamics in Bangladesh: An integrated management approach using GIS and remote sensing techniques

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ABSTRACT

This paper draws upon the application of GIS and remote sensing techniques to investigate the dynamic nature and management aspects of land in the coastal areas of Bangladesh. The geomorphological characteristic of the coastal areas is highly dynamic where land erosion and accretion with different rates remain a constant phenomenon. This study focuses on three coastal zones: western, central and eastern that comprise the entire coastal area of the country. At its core, this study uses the past 30 year Landsat satellite images. This research reveals that the rate of accretion in the study area is slightly higher than the rate of erosion. Overall land dynamics indicate a net gain of 237 km^2 (7.9 km^2 annual average) of land in the area for the whole period from 1985 to 2015. The results also demonstrate that the rates of both erosion and accretion are higher in the central zone compared to the western and the eastern zones of the coastal area. This is the first time that the entire coastal areas of Bangladesh have been considered for assessment. This study also recommends that coastal managers, planners and policymakers to consider the identified dynamic trends of coastal land before opting for any specific measure. Constant monitoring using the GIS and remote sensing techniques would be a viable management for this purpose. This study has identified some causes of land dynamics, particularly for the three coastal zones, that might be helpful for policymakers in identifying the nature of interventions needs to be taken for specific coastal zones.

1. Introduction

The coasts of the world are dynamic systems (Balica et al., 2012), since coastal areas exhibit constant morpho-dynamic processes as a result of the geomorphological and oceanographic factors (Cowell et al., 2003a,b). They are also prone to a large number of hazards (Torresan et al., 2008). Coastal land dynamics, particularly coastal erosions are seen to pose serious morpho-dynamic hazards in coastal areas around the world (Addo et al., 2008). Morpho-dynamic processes are active in about 70 percent of world's beaches in different forms (Ghosh et al., 2015). Coastal land dynamics includes the process of erosion (removal of materials from shoreline) that results in the loss of coastal land and the retreat of coastline. The deposition of materials removed through the process of erosion leads to the accretion of land in another place (Gibb, 1978).

Instant and reliable techniques are keys to addressing the dynamic nature of coastal lands (Ghosh et al., 2015). Although empirical field studies and aerial photos are generally used to address the issue, the techniques are not cost-effective and take a long time to accomplish. However, remote sensing and GIS techniques provide the opportunity to monitor the dynamic nature of coastal land in a cost effective manner (Ghosh et al., 2015). The monitoring of coastal land dynamics around the world through using GIS and remote sensing techniques is not new. In fact, there are numerous studies (Dolan et al., 1980; Saha and Singh, 1991; White and El-Asmar, 1999; Shifeng et al., 2002; Azab and Noor, 2003; Potdar et al., 2003; Wang, 2003; Zoran and Anderson, 2006; Jimmy, 2010; Prabaharan et al., 2010; Iqubal and Ali, 2011; Shibly and Takewaka, 2012; Alam and Uddin, 2013; Chowdhury and Tripathi, 2013; Islam et al., 2013; Sarwar and Woodroffe, 2013) conducted for different coastal areas using aerial photographs, GIS and remote sensing techniques. Depending on the behavior of the coasts, a number of approaches based on numerical models (Ferreira et al., 2006; Zoran and Anderson, 2006) have been used where dynamic stability, erosion, and accretion of the shores have been assessed. Empirical field studies (Prabaharan et al., 2010; Duc et al., 2012) have also been conducted for assessing coastal erosion. Along with empirical field studies, approaches based on Decision Support Systems (DSS) and Dynamic Computer Modelling (DCM) have been used (Shifeng et al., 2002;

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Brown et al., 2005) to study coastal land dynamics that are devoted to the detection of coastal morphological changes, measuring both the rates of coastal erosion and accretion and estimating land losses and shoreline changes.

From geomorphological point of view, the coastal area of Bangladesh is highly dynamic where land erosion and accretion are taking place at different rates (Brammer, 2014). The Bengal delta encompasses a large part of the coastal area and is the second largest delta in the world (Goodbred et al., 2003; Hori and Saito, 2007) which covers approximately 100,000 km^2 in area. The Bengal delta is driven by the hydrologic discharges of the Ganges-Brahmaputra-Meghna (GBM) river system which carries sediments from upstream (Sarker et al., 2015; Fergusson, 1863; Williams, 1919; Umitsu, 1993; Goodbred and Kuehl, 2000a, 2000b; Allison and Kepple, 2001). These three rivers, via the lower Meghna river channel (Sarker et al., 2015) carry close to one trillion m^3 of water and one billion tons of sediment annually. For the past 100 years, significant changes have been observed in the courses of major rivers in Ganges-Brahmaputra-Meghna (GBM) basin. The changes of the river courses together with the tidal influence from the Bay of Bengal were the major driving forces in shaping the coastal area of Bangladesh (Sarker et al., 2015) and are still considered as the active agents of changes in the coastal area of the country.

In-depth regional study on coastal land dynamics is crucial for effective management of coastal lands (Naji and Tawfeeq, 2011; Jayson-Quashigah et al., 2013). This is especially true for the coastal area of Bangladesh where a comprehensive and detailed study is essential to address the potential loss of land and to take effective measures to minimize that loss. The changes in lands are very rapid in the coastal area of the country which is home to 44.8 million people (28% of the total population in Bangladesh) (Ahmed, 2011). Monitoring dynamic nature of coastal land, particularly in the coastal area of Bangladesh is important because it affects the livelihoods of the people living in that area. Although a number of studies (de Wilde, 2011 (ed.); Shibly and Takewaka, 2012; Islam et al., 2013, 2016; Sarwar and Woodroffe, 2013) have been conducted using GIS and remote sensing techniques on morphological changes in the coastal areas of Bangladesh, the studies were limited to deal with the retreat of shorelines. Some studies (Krantz, 1999; BWDB, 2001; Morner, 2010; Rahman et al., 2011; Rahman, 2012; Alam and Uddin, 2013; Ali et al., 2013; Sarker et al., 2013; Taguchi et al., 2013; Brammer, 2014; Hussain et al., 2014a,b; Ghosh et al., 2015; Uddin, 2015; Emran et al., 2016; Hossain et al., 2016) have identified the dynamic nature of coastal lands but these studies have been conducted only for specific coastal islands, sections and zones. For instance, the notable work of Brammer (2014) identified the dynamic nature of land from the perspectives of past records of rising sea levels, and analysed the general picture of erosion and accretion in the Meghna estuary area with lesser details for the western coastal zone and no analysis for the eastern coastal zone of the country. The work was primarily based on topographical survey maps and empirical field tests, where Landsat satellite images were employed for two years only (1984 and 2007) to compare the rate of erosion and accretion between the mentioned years.

This research contributes significant new knowledge to the study on land dynamics of the coastal area of Bangladesh in a number of ways. The previous studies identified the coastal land dynamics of the country that were mainly conducted for selected small sections of the coast. In contrast, the current study attempts to identify the long-term trend (past thirty years from 1985 to 2015) of the dynamic nature of land for the entire coastal area of the country. Some previous studies (Sarwar and Woodroffe, 2013; Islam et al., 2016) identified the rates of erosion and accretion along the coastline by way of analyzing the changes of shoreline. However, this study considers the total land area of the coast which has the threshold limit of tidal movement and has both direct and indirect influences of the Bay of Bengal. As such, this research aims to offer a more comprehensive and complete picture on the dynamic nature of lands for the entire coastal area of the country. As far as the authors are aware, there is no complete study on the comparison of the dynamic nature of land among and between the three coastal zones. Hence, the present study emphasized on the identification and comparison of rates of erosion and accretion among the three coastal zones. This study identified the underlying causes of the variations of rates of erosion and accretion among the zones. The study also carries essence from the methodological point of view. This study used multi-temporal satellite images in the assessment where the uses of multi-temporal satellite images are more advantageous to delineate land areas from existing water bodies more accurately. More specifically, this study attempted to analyse the past and present conditions of land dynamics (total area of erosion and accretion for the three selected periods), compared and analysed the rates of erosion and accretion along with the associated causes that are significant in attaining a complete understanding of the dynamic nature of land for the entire coastal area of the country. Nevertheless, this study also addressed the existing policy relevance and management aspects of the dynamic nature of land and suggested some measures options for the coastal managers and policymakers to deal with the issues.

2. Study area and data

2.1. The study area

The reason for choosing the study area lies on its dynamic nature along with multifarious coastal characteristics as identified by IPCC (2007a,b) that brings in most of the natural coastal systems, namely the beaches, deltas, estuaries, lagoons and mangroves. Another important reason behind the selection of the study area is the rapid and dynamic nature of changes in densely populated coastal lands (about 949 persons/km^2) and the tale of survival for the people living in the area. On the basis of geomorphological characteristics, Pramanik (1988) first divided the coastal area of Bangladesh into three zones: western, central and eastern that covers approximately 27,150 km^2, 12,040 km^2 and 8010 km^2 of coastal land area respectively (Fig. 1). These have been used in this study. The total area of the identified coastal zones is 47,200 km^2 (MoEF, 2007) which covers the land area (including islands), internal rivers, estuary and near shore water bodies. This study groups the land areas into three different categories: eroded, accreted, and unchanged lands. The assessment of land dynamics for this research considers the dynamic land areas only that found from 1985 to 2015, while the total areas for water bodies have been excluded from the analysis. The inland boundary of the coast area from the coastline has been fixed to the threshold limit of tidal movement that has both direct and indirect influences of the Bay. Based on the exposure to the Bay of Bengal, the coastal area can also be marked as interior coast (23,265 km^2), and exposed coast (23,935 km^2) (PDO-ICZMP, 2006; Islam et al., 2006). The exposed coast meets directly with the Bay and lower estuary (MoWR, 2005), of which this has met the maximum limit of tidal movement, salinity, cyclone risk etc. (PDO-ICZMP, 2006).

2.2. Satellite images

The study analysed multi-temporal Landsat satellite images (Table 1) to acquire current and past rates of erosion and accretion in order to assess the dynamic nature of coastal land in the area selected. Hence, this study used multiple images of the same scene acquired at different times of selected months for specific years. In discussing the temporal changes of land dynamics, the past 30 years images is split into four periods, hence images of 1985, 1995, 2005 and 2015 have been gathered for analysis. Landsat Thematic Mapper (TM) images that have been used for the years 1985 and 1995 which are multispectral data obtained from Landsat 4 and 5 missions. Landsat Enhanced Thematic Mapper Plus (ETM+) images have been used for the years 2005 and 2015 which are high resolution multispectral data obtained from Landsat 7 mission. The images acquired during those periods have been