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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.

Keywords: accretion; erosion; geomorphology; land dynamics; remote sensing.

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; 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 km² 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 and 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; Sarwar and Woodroffe, 2013; Islam et al., 2016) 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 at., 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 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 emphasised 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 (2007 a, 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/ km²) 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 km², 12,040 km² and 8,010 km² 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 km² (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 km²), and exposed coast (23,935 km²) (PDO-ICZMP, 2006 and 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).

Fig. 1. The selected area of study (coastal area of Bangladesh).

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 downloaded using the USGS Global Visualization Viewer which are freely available in 30m X 30m pixel resolution. The selection of such pixel resolution is essential considering finer spatial resolution and spatial extent of the study area. The TM comprises of seven bands whereas ETM+ contains eight bands (one additional panchromatic band with 15m resolution). Both the bands include the visible (red: 0.63-0.69μm; green: 0.52-0.60μm; blue: 0.45-0.52μm), near infrared (0.76-0.90μm), mid infrared (1.55-1.75μm) regions as well as the thermal infrared (10.4-12.5μm) region of the electromagnetic spectrum (USGS, 2013).

Table 1: Landsat satellite images used for the study.

Year	Sensor	Resolution	Month of Image Acquisition
1985	TM	30x30m	January
1995	TM	30x30m	January
2005	ETM+	30x30m	December
2015	ETM+	30x30m	January

2.3. Policy and management issues

This study makes extensive use of secondary materials to build up and support the objective of identifying policy relevance and management issues of land dynamics in the coastal area of the country. To analyse the policy implications on coastal land dynamics, this study reviewed the available coastal policies along with the relevant plans, strategies and projects of the government. The study also evaluates the impacts of the policies on coastal land dynamics as well as the gaps in formulating policies to address the issues of coastal morphological changes. The management aspects of the dynamic coastal lands are assessed by linking the implementation of existing policies, strategies and projects of the government with the dynamic nature of land found from the results based on GIS and remote sensing analysis.

3. Methods

3.1. Pre-processing of satellite images

For analysing the trends and rates of erosion and accretion in these selected areas, the collected raw satellite images went through some pre-processing works such as atmospheric, radiometric and geometric corrections. These processes will be discussed in turn as follows. First, the images were atmospherically corrected by using Dark Object Subtraction (DOS) method (Chavez, 1996) to cancel-out the presence of dust, smoke and haze in the images. Second, a normalized radiometric correction was performed for the images to achieve the real reflectance values of the images and to remove sensor noise. Next, individual shapefiles were generated for analysis. Finally, all the images were then geo-rectified using the sixteen Ground Control Points (GCPs) with a view to acquire geometrically correct images. By this way, the GCPs yielded an average value of 0.0013054 Root Mean Square Error (RMSE) that demonstrates a good agreement of the selected images with the corresponding locations in the real world.

3.2. Delineation of land-water boundary

The amplitude of tides in the coastal area of Bangladesh is an important factor in detecting land and water that vary substantially for the three coastal zones (Islam et al., 2016). For example, the Ganges deltaic coastal area experiences both micro tidal (<2 m) and meso-tidal (2m to 4m), the Sundarbans area receives only micro tidal amplitudes whereas the coastal areas of Barguna, Patuakhali and Noakhali receive a mix tidal characteristics having both meso and micro tides (Islam et al., 2016). The situation, however, is different for the central (Meghna estuary) and eastern zones of the coast whereby these variations vary from 0.5m to 3.5m (Ghosh et al., 2015). The variations are also visible during monsoon and winter seasons. For this, pre-processed images are further analysed to separate water bodies from landmasses as a pre-requisite to detect land dynamics. Considering the drawbacks pertaining to the delineation of foreshore (between high tide and low tide) associated with tidal variations, spectral signatures from multi-temporal satellite images have been used to demarcate the common boundary between land and water. Band 4 (0.76 to 0.90μm) with Near Infrared (NIR) images have been used to achieve this, as this band is notably suitable for separating landmass from water body (Sarker et al., 2013). These separations have been performed by using the Erdas Imagine software with a simple algorithm (Equation 1). A DN (Digital Number) value 35 obtained from the histograms of the images, is the applied in Eequation (1). This number can vary from 0 to 50 and indicates the threshold value for separating water body from other land covers.

Either (Landsat ETM+) IF (Band 4<36) or 0 otherwise (Equation 1)

3.3. Detection of land dynamics

To determine the dynamic nature of erosion and accretion, the pre-processed images were re-sampled to 30m X 30m pixel size. To do this, the nearest neighbour resampling method was applied by using an algorithm for first order polynomial transformation. To detect the land dynamics, manual digitization was conducted for each image. The digitised shapefiles for each year were then superimposed on the shapefiles for the subsequent years to group the coastal land areas into three categories: eroded, accreted, and unchanged. The results were then quantified and analysed in ArcMap. Next, the rates of these changes were calculated using Equation 2.

$$r = A \div t \qquad \text{(Equation 2)}$$

Here, r= rate of erosion/accretion
A= Area eroded/ accreted
t= time period

3.4. Method of validation

To validate the eroded and accreted landmass obtained for the selected years, category of data obtained has been compared to the referenced data. For reference data, topographical maps ranging from year 1985 and 2005 obtained from Survey of Bangladesh (SoB) were used. The reference map of 1995 was collected from Local Government Engineering Department (LGED) of Bangladesh, while a reference map collected from National Water Resource Database (NWRD) of Water Resources Planning Organization (WRPO), Bangladesh was used to validate the results of 2015. The comparisons were accomplished by using the error matrix (Equation 3). The final assessment was done by calculating overall accuracy (Equation 4) and kappa coefficient (Equation 5). In equations 3, 4, and 5: n indicates the total number of samples, i indicates the number of rows and columns, N indicates the total number of observations and nii indicates the diagonal elements in the error matrix. Likewise, nij indicates the major diagonal element of class i where 'ni' indicates the total number of observations in row i and 'nj' indicates the total number of observations in column j. A total number of 150 sample pixels were selected from each image for validating the results with reference data.

$$\text{Error matrix, } n = \sum_{i=1}^{k} X \sum_{j=1}^{k} nij \qquad \text{(Equation 3)}$$

$$\text{Overall accuracy} = \frac{\sum_{i=1}^{k} nii}{n} \qquad \text{(Equation 4)}$$

$$\text{Kappa coefficient, } K = \frac{n \sum_{i=1}^{k} n_{ii} - \sum_{i=1}^{k} n_{i+} n_{+i}}{n^2 - \sum_{i=1}^{k} n_{i+} n_{+i}} \qquad \text{(Equation 5)}$$

This study uses an in-depth literature survey to identify the relevant causes associated with the dynamic nature of land in different coastal zones of the area studied.

4. Results

4.1. Erosion and accretion (1985 - 1995)

A total 987 km² of eroded lands and 1115 km² of accreted lands were identified for the period from 1985 to 1995. It is observed that the rate of accretion was slightly higher than the rate of erosion during this period, where the rate of accretion was 111.50 km²/year and the rate of erosion was 98.7 km²/year respectively. The net gain of land identified during this period is 128 km². It is important to note that these rates did not vary substantially, only to an extent of 12.8 km² /year. Major erosion and accretion occurred in the central zone of the area for this period (fig. 2). The upper reach (near Chandpur) and the lower reach of the Meghna river exhibited a high rate of erosion and accretion.

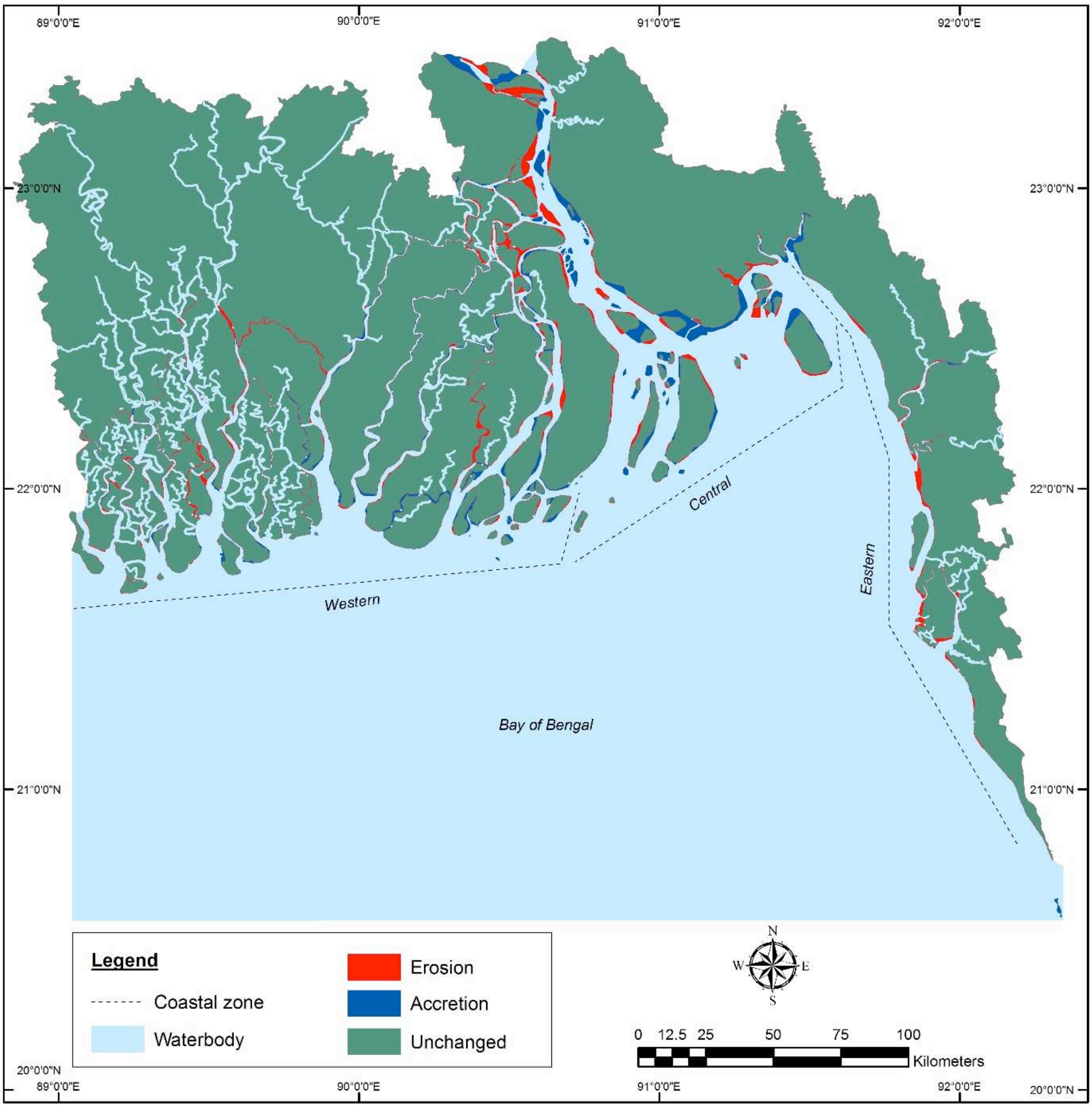

Fig. 2. Areas of erosion and accretion from 1985 to 1995 in the area studied.

4.2. Erosion and accretion (1995 - 2005)

The rate of erosion and accretion did not vary remarkably during the period ranging from 1995 to 2005 in comparision with the previous period. Nevertheless, the results confirmed that the rate of erosion was lower than the rate of accretion during this period. A total of 1183 km² of land has eroded is observed as compared with 1284 km² of land has accreted (Fig. 3). The rate of erosion was 118.3 km²/year whereas the rate of accretion was 128.4 km²/year. The net gain of land for this period was 101 km² of coastal land (10.1 km² per annum) which is slightly 27 km² less than the previous period. Major erosions occured in the areas of Meghna estury and along the coasts of major islands such as the eastern coast of Bhola, the northern coast of Hatiya and the south-western coast of Sandwip whereas, major accretions identified at Noakhali district, Urir Char, Jahajir Char and some small islands in the Meghna estuary.

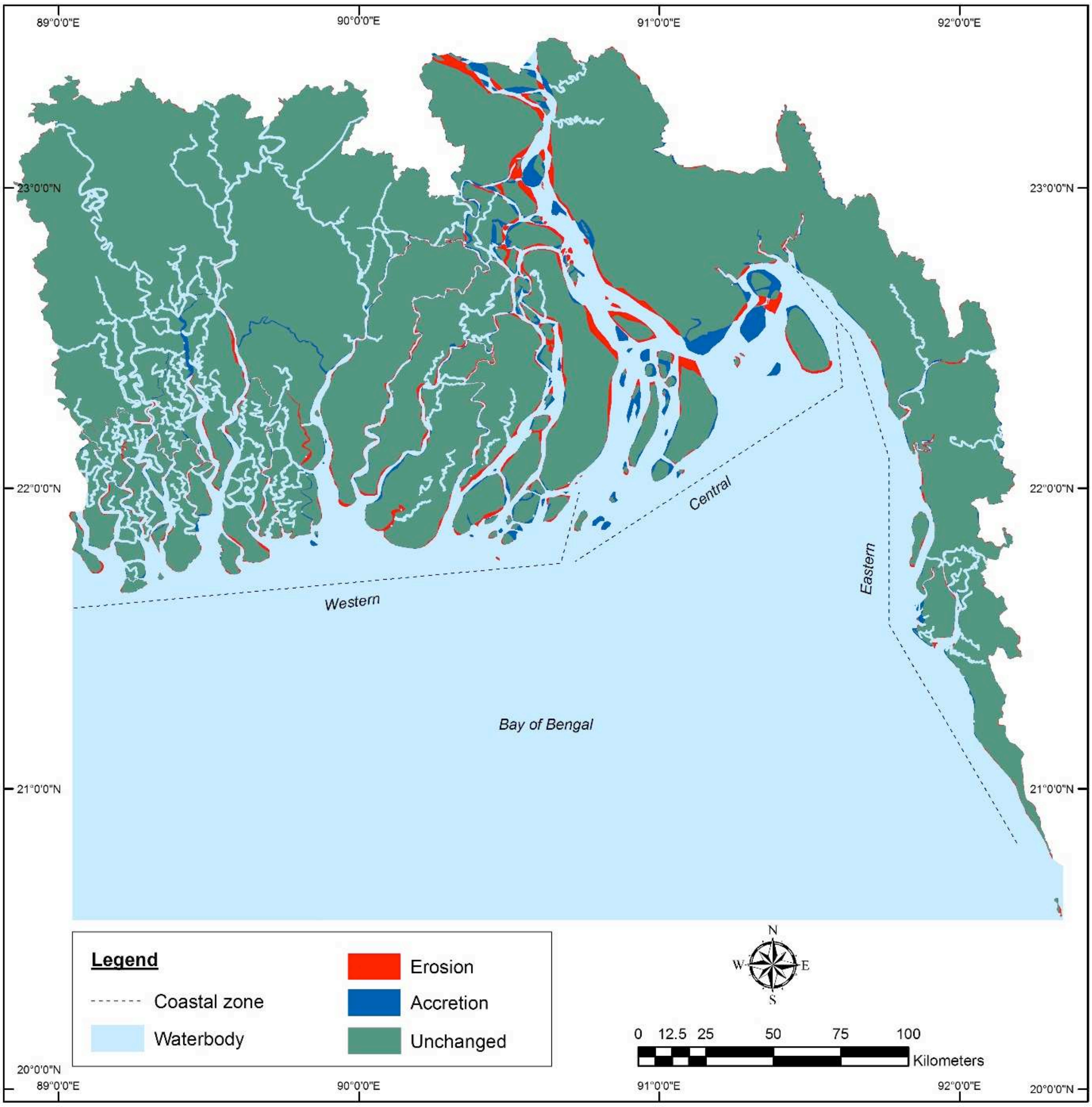

Fig. 3. Areas of erosion and accretion from 1995 to 2005 in the area studied.

4.3. Erosion and accretion (2005 - 2015)

For the period ranging from 2005 to 2015, a higher rate of erosion of land was detected. A total 1194 km² of land has eroded for the period as compared with a total of 1175 km² of land has accreted (Fig. 4). The net balance of land lost is estimated to cover an area of 19 km² (1.9 km² annual average) of coastal land during this period. The probable reason for this could be due to the higher rate of erosion as compared to the rate of accretion during this period. Most of the accretion of land were detected in the Meghna estuary areas, while most of the erosion of land occurred along the coast of Noakhali district.

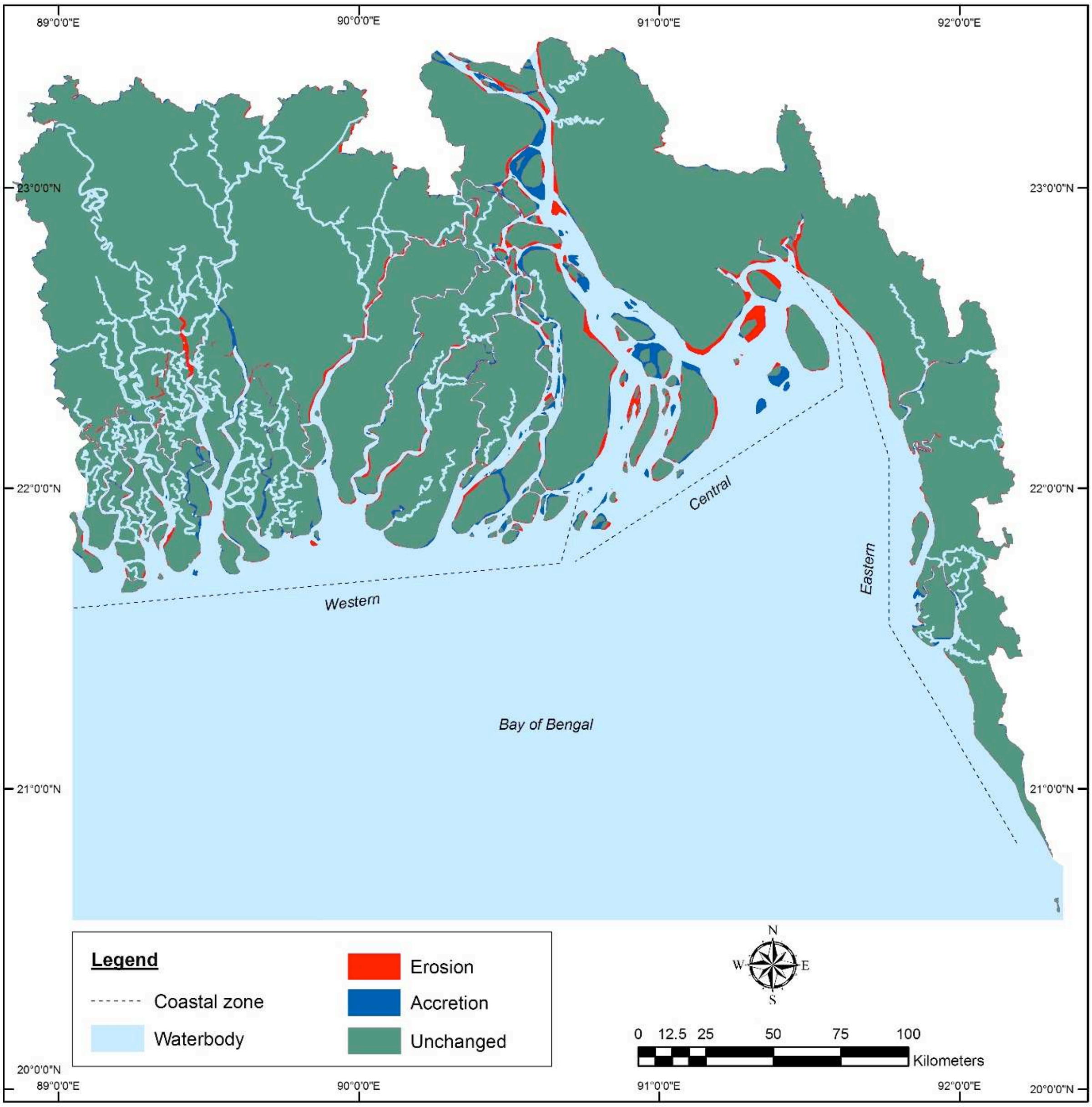

Fig. 4. Areas of erosion and accretion from 2005 to 2015 in the area studied.

4.4. Overall erosion and accretion (1985 – 2015)

Overall, table 2 shows that slightly less erosion took place compared to accretion for the whole period between 1985 and 2015 (Fig. 5 and 6). A total 1576 km² of land has been eroded for the whole period from 1985 to 1995, compared to a total 1813 km² of land accreted for the same period. The rate of erosion observed stood at 52.5 km² as compared with the rate of 60.4 km² accretion annually. The net balance of land demonstrated a gain of 237 km² (7.9 km² annual average) of coastal land for the past thirty years period ranging from 1985 to 2015.

Table 2: The overall area and rate of erosion and accretion for the period from 1985 to 2015.

Duration	Erosion		Accretion		Net Balance	Annual Average
	Total (km²)	Rate (km²/y)	Total (km²)	Rate (km²/y)	Land (km²)	Land (km²)
1985-1995	987	98.7	1115	111.5	(+) 128	(+) 12.8
1995-2005	1183	118.3	1284	128.4	(+) 101	(+) 10.1
2005-2015	1194	119.4	1175	117.5	(-) 19	(-) 1.9
1985-2015	1576	52.5	1813	60.4	(+) 237	(+) 7.9
Note: (+) indicates the gain and (-) indicates the loss of land						

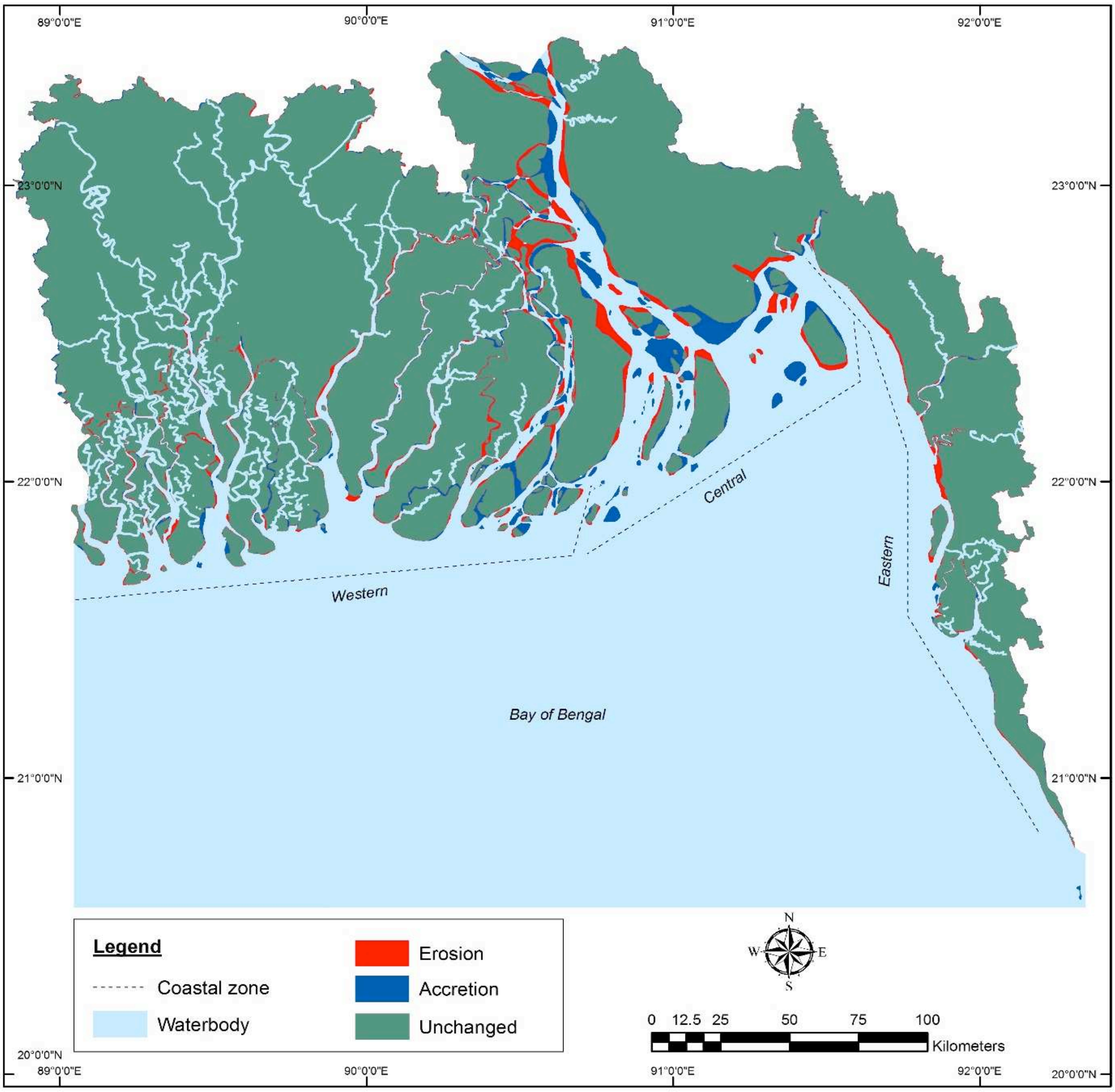

Fig. 5. Areas of erosion and accretion from 1985 to 2015 in the area studied.

4.5. Zone-wise erosion and accretion

This study identified the variations of morphological changes of lands for the three coastal zones. For the period from 1985 to 1995, the analysis exhibited that both erosion and accretion rates were lower in the western zone of the coast, with a reading 36.9 km²/ year and 32.5 km²/year respectively. These rates, however, varied for the remaining periods where rate of erosion increased to 37.6 km²/ year for the period from 1995 to 2005 and 45.2 km²/year for the period from 2005 to 2015. In contrast, the rate of accretion increased slightly to 33.8 km²/year for the period from 1995 to 2005 and 34.6 km²/year for the period from 2005 to 2015. The net balance of land for this coastal zone indicates the losses of 44 km² and 38 km² of land for the periods from 1985 to1995 and 1995 to 2005 respectively. This study shows a loss of 106 km² of land for the period from 2005 to 2015. The significant outcome of the analysis shows a loss of 150 km² of land (5 km² annual average) in this zone for the total period from 1985 to 2015.

The rates of both erosion and accretion were found to be higher for the three periods in the central zone of the coast (Table 3). However, the rates did not vary extensively for the three periods. The variations of the amount of annual average land gained were much lesser, where the records showed 14.7 km², 14.1 km² and 12.3 km² of land lost for these periods: 1985 to 1995, 1995 to 2005 and 2005 to 2015 respectively. This analysis found a net 13.7 km² annual average gain of land in the central zone for the total period from 1985 to 2015.

Table 3: Patterns of erosion and accretion in the central coastal zone.

Duration	Erosion		Accretion		Net Balance	Annual Average
	Total (km²)	Rate (km²/y)	Total (km²)	Rate (km²/y)	Land (km²)	Land (km²)
1985-1995	555	55.5	702	70.2	(+) 147	(+) 14.7
1995-2005	709	70.9	850	85.0	(+) 141	(+) 14.1
2005-2015	623	62.3	746	74.6	(+) 123	(+) 12.3
1985-2015	885	29.5	1296	43.2	(+) 411	(+) 13.7
Note: (+) indicates the gain and (-) indicates the loss of land						

The rate of erosion in the eastern coastal zone was 6.3 km²/year for the period ranging from 1985 to 1995 in comparison with the rate of 8.8 km²/year of accreted area for the same period. That means, the net balance of land was the gain of 25 km² of land (2.5 km² annual average) for the mentioned period. The rate of erosion for the period from 1995 to 2005 was 3.5 km²/year higher than the previous period which was higher than the rate of accretion (9.6 km²/y) for the same period. The results exhibited a sharp margin of 2 km² net loss of land (0.2 km² annual average) for the period ranging from 1995 to 2005. The rate of erosion (11.4 km²/y) was higher for the period ranging from 2005 to 2015 than the previous periods. The ultimate result was the loss of 36 km² of land in this zone of the coast for the same period. The net balance shows a loss of 24 km² of land (0.8 km² annual average) for the total period from 1985 to 2015 in this eastern coastal zone of the country.

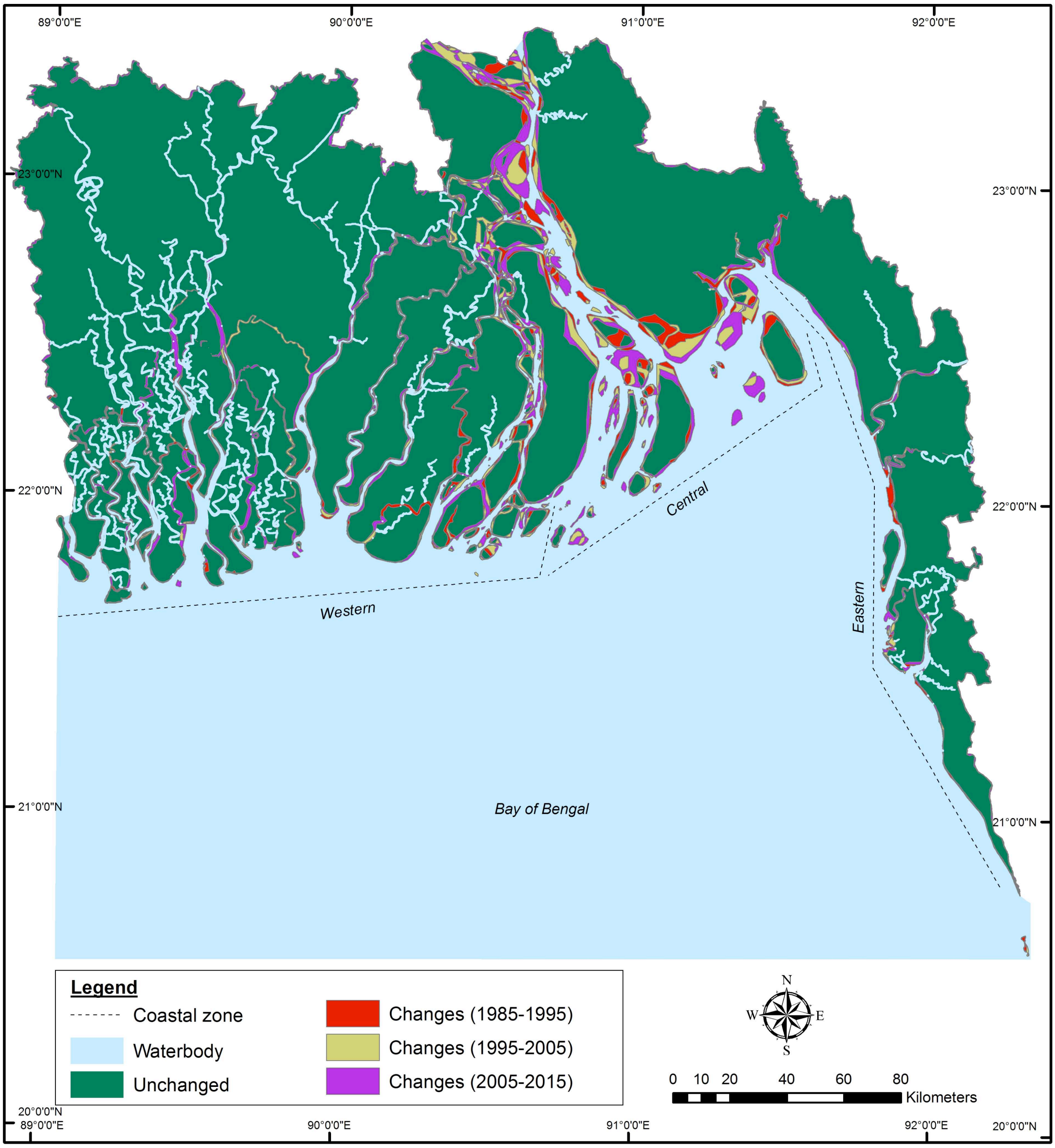

Fig. 6. Periodic changes of lands from 1985- 2015 in the coastal area of the country. The changes in the map indicated both erosion and accretion.

An overall representation of the rates of erosion and accretion for the periods can be found in the Figure 6 and 7, where higher rates of both erosion and accretion in the central zone of the coast were observed in comparison with other zones. Both the rates of erosion and accretion did not consistently exhibited an increase or decrease, instead, they varied over different time periods. This indicates a dynamic nature of land existed in the coastal area of the country.

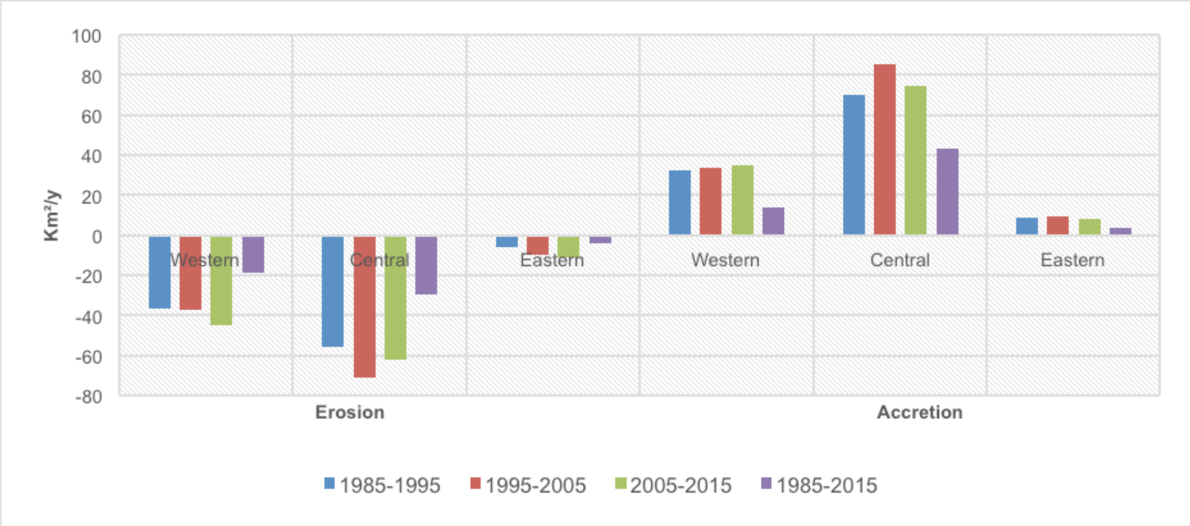

Fig. 7. Zone-wise rates of erosion and accretion.

4.6. Accuracy of satellite images

The identified categories of dynamic landmass such as eroded and accreted lands were matched with the reference data. While matching with the topographical maps collected from Survey of Bangladesh, an overall accuracy of 0.873 (87%) was found for 1985. An almost similar result 0.894 (89%) was obtained for 1995 that matched with the maps collected from the Local Government and Engineering Department (LGED) of Bangladesh. Overall, an accuracy of 0.961 (96%) and 0.982 (98%) were acquired for 2005 and 2015 respectively, both these were much more accurate as compared with those obtained for 1985 and 1995. All the results have met the minimum standard of 85% accuracy as suggested by the U.S. Geological Survey (Anderson, 1976).

4.7. Policy relevance of coastal land dynamics

Since 1970s, the Government of Bangladesh has been very concerned on the issues of coastal land dynamics, and has formulated many policies that are relevant to the management of dynamic coastal land in Bangladesh (Fig. 8). Because of the lack of an integrated coastal policy, a number of area-specific plans and initiatives relevant to coastal land dynamics such as Off-Shore Islands Development Board (1977–1982), UN/ESCAP-GoB Coastal Environment Management Plan for Bangladesh (1987) and National Capacity Building Plan for ICZM (1997) were implemented in different periods. The aforementioned plans and initiatives were acted as the foundation of an Integrated Coastal Zone Management (ICZM) plan initiated in 1999. The principles of ICZM approach has managed to reinforce the coastal development and coastal defense strategy of the Government of Bangladesh (MoWR, 2005; WARPO, 2005). Before the adoption of ICZM in 1999 as a separate policy approach, the Government made several efforts to protect the coastal area from erosion, and to rehabilitate the victims of erosion under the framework of Comprehensive Disaster Management Plan (CDMP) (Iftekhar, 2006).

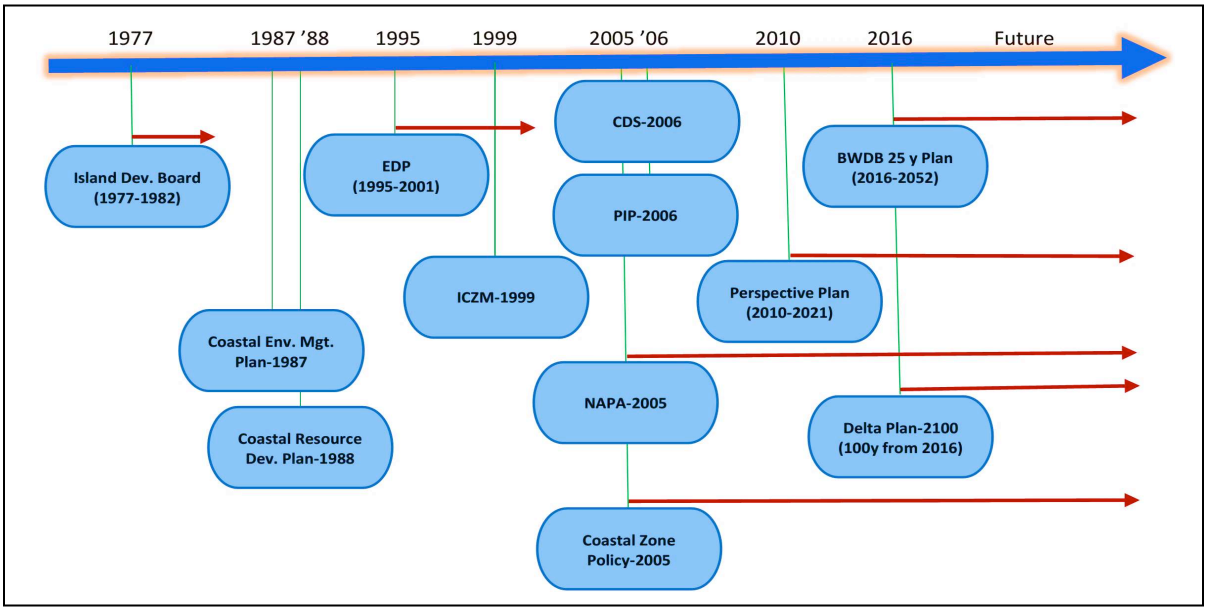

Fig. 8. Development of coastal policy framework in Bangladesh.

The formulation and adoption of Coastal Zone Policy (CZP) in 2005 has been a major step-forward towards the proper implementation of ICZM plan for coastal land dynamics. In the Coastal Zone Policy, coastal erosion is being regarded as a combined natural and human-induced hazard along with other disasters, which has adverse effects on the lives and livelihood of people living in the area. The framework of the coastal zone policy includes different issues under eight broad headings where the issues relevant to coastal land dynamics such as erosion, accretion, land reclamation, rehabilitation, afforestation, land re-distribution etc. have been outlined. Along with the policy, the formulation of Coastal Development Strategies (CDS) in 2006 can be regarded as a linking pin (PDO-ICZM, 2006) between the goals of Coastal Zone Policy and the concrete interventions. The CDS has prioritised different issues of land dynamics in the coastal areas. The optimum use of coastal land, balanced reclamation of new lands and planned and proper distribution of newly emerged lands to the landless and marginal people under existing land use policy have been emphasized in the CDS. However, the issues of land dynamics have also been given priority in the existing 20 concept notes prepared for Priority Investment Program (PIP) of the government.

Along with different coastal policies the issues of coastal land dynamics are being emphasized in different sectoral policies formulated by different ministries of the government. The country's Forest Policy (1994), National Fish Policy (1998), National Water Policy (NWPo) in 1999, National Land Use Policy (NLUPo) in 2001, Draft Shrimp Strategy (2004), Agricultural Strategic Plan (2002-2006), National Agriculture Policy (2013) and resettlement and rehabilitation policy have been prepared for different periods to address the issues related to coastal land dynamics of the country (Mustafa, 2002; Islam and Koudstaal, 2003; Islam, 2006; Mainuddin et al., 2011and Ishtiaque and Chhetri, 2016). The issues of coastal land dynamics have also been reflected in different plans and strategies of the government. Coastal issues are emphasized in the revised 'National Strategy for Accelerated Poverty Reduction' in 2009. Under four strategic goals, the strategic paper identified erosion control, water resource management, land reclamation, *char* (newly formed land) development, afforestation and land zoning for the coastal areas of the country.

Currently, the government is trying to address the issues of coastal land erosion and land management under different long-term strategies and plans. The 'Perspective Plan of Bangladesh' (2010-2021) is prepared for the articulation of development visions of the government where long term strategies relevant to coastal development have been given emphasis. The strategies include coastal water resources management, operation and maintenance of embankments and polders along with the issues of land reclamation. The 'Delta Plan 2100' is a long term plan covering the duration between 50 to 100 years. Special emphasis pertaining to the issues of coastal land erosion, coastal agricultural land use and polder management along with other 16 thematic areas of concern has been placed under this plan.

5. Discussion

The dynamic nature of coastal land identified by this study for different time-period might be the results of a number of causes. These causes can be grouped into two broad headings: natural causes (such as sea level rise, variability in sediment supply to the littoral zone, excessive rainfall, storm waves, long shore sediment transport, prevailing south western monsoon wind), and human-induced causes (such as removal of subsurface resources, interruption of material in transport, reduction of sediment supplies to the littoral zone) (Krantz, 1999). A simplified relationship of the causes of land dynamics for the periods studied is presented in Figure 9.

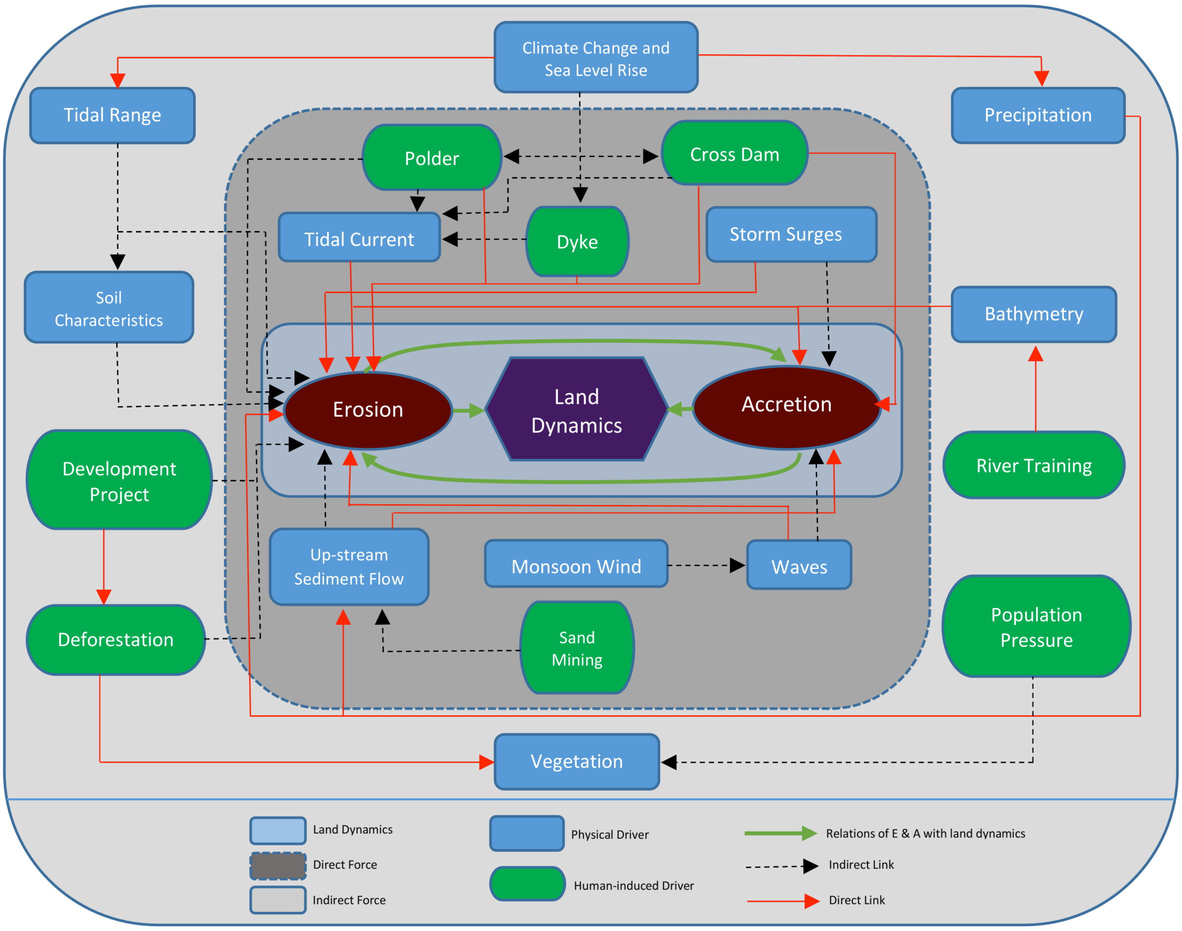

Fig. 9. Influence and relationships of the drivers of coastal land dynamics in Bangladesh.

The variation in magnitude of erosion and accretion in different parts of the coastal area depends on the different grades of vegetation cover, the variation of forces of ebb-tide currents, tidal bores, variation in amount of water discharges from upstream rivers, beach slope gradient, soil compaction and the extent of human interventions (Krantz, 1999). Hence, this study attempted to identify the causes of land dynamics based on the three coastal zones of the area studied (Table 4). This study found very less morphological changes (except some small amounts of local erosion) in the western zone as compared to the estuarine part of the coast (Fig. 5). The reason behind this comparative lower rate of erosion in this zone could be due to the existence of mangrove vegetation that has acted as an active agent of accretion through a strong interrelationship with tide and river flow (Warrick and Ahmad *ed.*, 1996). It has also created barriers to the storm surges originated from tropical cyclones, and these barriers also acted as effective fences against the actions of waves (Umitsu, 1997). The likely causes of lower rates of changes in the western zone during the period from 1985 to 1995 were: the lesser occurances of tropical cyclones in the Bay of Bengal region and consequent lower degree of wave actions in the zone. On the contrary, an explanation on the rising rate of erosion in this coastal zone might be the devastating impact of the tropical cyclone 'Sidr' in 2007 that surpassed the rate of accretion during recent times (Sarwar and Woodroffe, 2013).

The analysis shows that the central coastal area of the country was comparatively more dynamic than other coastal zones. The reason behind this higher rate of erosion and accretion could be the results of high rate of sediment supply, ebb-tide currents, bathymetry, high rate of river water discharges, soft and unconsolidated soils, tropical cyclones and storm surges etc. (Barua, 1997; Ali, 1999; Brammer, 2004; Mikhailov and Dotsenko 2007; Shamsuddoha and Chowdhury, 2007; Parvin et al., 2008; Masatomo, 2009; Hossain, 2012 and Brammer, 2014). The force of ebb-tide currents in estuarine channels was the dominating factor (Brammer, 2014) that affected in higher rate of land dynamics in the central coastal zone. Tidal motions have also greatly influenced the movements of water in this central coastal zone which was affected by the refraction of the incoming tidal wave from the Bay of Bengal (Barua, 1997). The swatch of no ground (submarine canyon) stimulated the refraction which has resulted in high tidal ranges on both sides of the canyon and low tidal ranges at the head of the canyon. In the Sandwip and Hatiya Channel tides, the funneling effect was highly visible. During spring tides, tide current is observed around 3m/sec in Sandwip and Hatiya channels (Barua, 1997) which created tidal bores in areas north of Sandwip Island which ultimately met with Hatiya channel resulting in high rate of erosion in both the islands. With these, the Bay of Bengal drained a combined discharge of the Ganges, Bhramaputra and Meghna rivers amounting an average of up to 35000 m^3/s which accelerated the rate of erosion and accretion in the central coastal area (Krantz, 1999).

A crucial assessment was found in the central coastal zone, whereby gains of land area were observed for these three periods. Brammer (2014) identified a net gain of 451 km^2 of land (19.6 km^2 annual average) for the Meghna estuarine area by comparing two satellite images collected for 1984 and 2007. Similarly, the present study demonstrated a net gain of 411 km^2 of land (13.7 km^2 annual average) in the central Meghna estuarine coast. Although the results of the present study for the central zone are very close to the results found by Brammer (2014), the present study uses multi-temporal satellite images and hence obtained results which are more precise and very much closer to the actual net gain. One of the important reasons contributing to this highly dynamic nature of land can be observed in the central estuarine coastal zone, which could be due to the frequent occurrences of tropical cyclones that hit these islands at the first instance, followed by the mainland. The funnel-shaped Bay of Bengal intensified cyclones and associated storm surges in the coastal area (Rabbani et al., 2010). During the period from 1584 to 2009, the coastal area of Bangladesh experienced 157 recorded cyclones and cyclone induced storm surges (Khan, 2012). The Meghna estuary suffered from most severe tropical cyclones and storm surges (Parvin et al., 2008) which has substantially influenced on the changing shapes of the islands located in the central coastal zone during the periods studied. Another reason behind these high rates of both erosion and accretion found in the central zone could be the action of tidal waves. The tidal waves from the Indian Ocean travel significantly faster through the depth of the Bay of Bengal and the shallow area in front of the delta (Krantz, 1999), which continuously hit the land areas and cause erosion in one place and subsequent accretion in another place of the central coast.

Table 4: Major drivers of land dynamics in the coastal zones (including the islands).

Major Drivers of change		Coastal Zone		
		Western	Central	Eastern
Physical drivers of change	Astronomical tides	No impact	Both erosion & accretion	Erosion
	Wave action	Erosion	Erosion	No impact
	Variation in tidal range	Erosion	Erosion	No impact
	River discharge	Accretion	Erosion	No impact
	Mangrove vegetation	Accretion	No impact	No impact
	Monsoon wind	Erosion	Erosion	No impact
	Bathymetry	Both erosion & accretion	Both erosion & accretion	No impact
	Circulation of residual flow	No impact	Both erosion & accretion	No impact
	Soil characteristics	Both erosion & accretion	Both erosion & accretion	Both erosion & accretion
	Storm surges	Erosion	Erosion	Erosion
	Rainfall	Erosion	Erosion	Erosion
Human induced drivers of change	Polder	Erosion	No impact	No impact
	Destruction of forest	Erosion	Erosion	No impact
	Dykes	No impact	Both erosion & accretion	No impact
	Cross dam	No impact	Both erosion & accretion	No impact
	River training	Erosion	Both erosion & accretion	No impact
	Sand mining	No impact	Both erosion & accretion	No impact
	Development projects	Both erosion & accretion	Both erosion & accretion	No impact

Legend: Erosion (red) Accretion (blue) Both erosion & accretion (yellow) No impact (white)

The islands were found to be extremely dynamic, particularly in the Meghna estuary coastal area. Although there is a significant amount of land gained, there is also a considerable amount of land lost in the islands of the estuary. These could be the results of the dynamic nature of the estuarine and offshore islands of the central coastal zone due to the high rate of water discharge from the rivers and the anti-clockwise circulation of tides in the estuary (Sarwar and Woodroffe, 2013). The present study shows that the existing islands such as Sandwip, Hatiya and Bhola exhibited a significant rate of erosion, which then contributed to the development of new islands such as Urir Char, Jahajir char and other small islands in the estuary. A large mass of land named Jahajir Char has developed during recent times between 2007 and 2013. Rapid and considerable changes in land area were observed for the case of Sandwip, Hatia and Bhola islands. Another dynamic island observed was Hatiya, situated in the Meghna estuary, where the rate of erosion has been reported at 400 meter/year. The reason behind the rapid changes of land areas in the estuarine islands could be the soft and unconsolidated silt and clay sediment (Masatomo, 2009) of the islands.

The present study shows that the eastern coastal zone is comparatively less dynamic than the central and the western coastal zones. The reason could be due to the flat and unbroken coast (Huq et al., 1999), and the northerly transportation of sediments along this coastal zone (Barua et al., 1994). Although the rates of changes were very low in comparison with the other zones, the rates of erosion were higher than the rate of accretion in the zone for all of the periods except from 1985 to 1995. The process of erosion could be accelerated in this coastal zone by the anti-clockwise circulation of tidal current that passes through the Sandwip channel. The excessive amount of rainfall due to rising temperature could also be the probable reason for erosion in this zone whereby the mean annual rainfall ranges between 1750mm in the north-west coast and >3000mm in the south-eastern coast of the country (Krantz, 1999). The net balance of land for this coastal zone showed a loss of 24 km² of land (0.8 km² annual average) during the total period from 1985 to 2015.

To stabilize and protect newly accreted lands in the coastal area, government initiated a number of projects and schemes such as coastal afforestation and polder project (1966), Char Development and Resettlement Project (1994), Coastal Embankment Rehabilitation Project (1995), land reclamation projects, Meghna Estuary Study (1986 to 1994), and Estuary Development Programme (1995 to 2001) (MoWR, 2000; Jakobsen et al., 2002; Islam, 2006; MoWR, 2006; Ali et al., 2007; Parvin et al., 2008). Although the goals of the policies, plans, strategies and projects regarding coastal land dynamics are not fully implemented, the impacts are visible in the coastal area of the country.

The results of this study demonstrate a slightly higher rate of 111.5 km²/year accretion for the period from 1985 to 1995 in comparison with the erosion of 98.7 km²/year for the entire coastal area of the country. The likely cause of this higher rate of accretion colud be the accretion of a considerable portion of landmass at the lower Meghna estuary. This might be the implication of the coastal policy under which a number of cross dams were being built in the Meghna river near Laksmipur, Noakhali and Feni districts by Bangladesh Water Development Board (BWDB). The Meghna-1 cross dam project in 1957 and the Meghna-2 cross dam project in 1964 reclaimed a total 300 km² and 600 km² land areas that have connected Ramgoti island with the mainland of Noakhali district. The Muhuri river cross dam project also yielded a total 500 km² of land near Feni district (Khan, 2008). The polder project initiated by the government during 1970s and 1980s can be also treated as equally important human induced driving force for land dynamics in the coastal area. The northern and eastern coasts of Hatiya island showed a significant rate of erosion during this period. Similarly, the eastern coast of Bhola island showed erosion of land in areas of Borhanuddin and Tazumuddin sub-dirsricts. A sporadic situation observed in the Sandwip island during that period, where a gain of land was identified in the northern front and a loss of land was detected in the southern front. A number of new offshore islands have emerged during that period, namely the Dhal Char, Char Jonak, Nijhum Dwip and Sona Char and some other unnamed small islands. A noticeable portion of land eroded at Bhatiari, Uttar Jaldi and Moheshkhali in the eastern coast during the period from 1985 to 1995. A significant accretion of lands also occured during that period in the eastern coastal zone of the country. In contrast, the changes in land area in the western zone of the coast was very low during that period as compared with the central zone.

The policies and strategies also emphasised on regular maintenance of sea dykes as a first line of defense from storm surges under existing policy framework. This intervention has great implications on the higher rate of accretion from 1995 to 2005 than the rate of erosion identical to the previous period from 1985 to 1995. Like before, the central coastal area experienced more erosion and accretion during the period from 1995 to 2005, yet, the net balance of land yielded 101 km² of land (10.1 km² annual average) during the same period. Additionally, during this period, the policy encouraged the inhabitants to engage in social forestry and other forms of plantation in existing and newly accreted coastal lands (CDSP, 2005). This policy guideline of social forestry could ultimately be beneficial for the protection of coastal lands from erosion and the settlement of newly accreted lands in the coastal area. The coastal afforestation project of the government with a view to protect coastal lands from erosion already brought fruitful results. Forest department has recently been claimed 142,835 hectares of mangroves during the period from 1960 to 2000 through implementing a number of afforestation projects. The pilot mangrove afforestation project afforested 192,395.24 hectares of mangrove, 8689.53 hectares of non-mangrove, 2872.88 hectares Nipa, 10.0 hectares Coconut, 40.0 hectares Arica Palm, 280.0 hectares Bamboo and Cane and 12127.13 km of strip plantations in Chittagong, Cox’s Bazar (south) and Feni areas of the coastal zones.

The coastal zone policy formulated in 2005, but most of the goals still remain incomplete. Although the Coastal Zone Policy (CZP) emphasised the reclamation of new lands in the coastal area, this study found an increasing rate of erosion over accretion for the period covering 2005 to 2015. However, the ultimate result of land reclamation plan has already yielded more than 100,000 hectares of land in the Meghna estuary area during the last half century (GoB, 2006). Currently, the government plans to conduct another major land reclamation project in the Meghna estuary by connecting Sandwip Island and Urir Char with Noakhali mainland. Moreover, Bangladesh Water Development Board (BWDB) aimed at attaining its 25 years future plan from 2016 that includes strategies to reclaim new lands in the coastal area.

Instead of having a sound number of coastal policies, strategies, plans and projects of the government, this research identified some considerable gaps in the existing policies in managing coastal land dynamics (erosion and accretion) of the country. First and foremost, the policies, strategies and plans formulated were made without any detailed and comprehensive study on the dynamic nature of land in the entire coastal area. A study named Meghna Estuary Study (1986-1994) that has been conducted by the government only covers a specific local area and does not include the entire coastal area of the country. Relative to this, the Ggovernment of Bangladesh needs to pay closer attention on the proper implementation of land reclamation projects. For instance, the current study identified that the implementation of Cross Dam 1 and Cross Dam 2 projects by the government has yielded a substantial amount of land near Ramgoti and Noakhali coastal areas, nevertheless the government should also be held responsible for the extensive erosion that has occurred in Hatiya and Bhola islands. This is due to the fact that the two Cross Dams project were conducted by way of shifting the flows of water from the eastern to the western Meghna and Shahbazpur channels (Fig. 2 and 3), which has brought to the massive erosion in the two islands mentioned. Most coastal policies are often regarded as a 'static' system rather than a complex and dynamic interplay between physical and human forces of change. Since the changes of land in one coastal zone could affect the other, land reclamation projects of the government need to be implemented based on a complete feasibility study for the entire coastal area. To address this shift of channels, coastal managers and policymakers need to address the physical behaviour of the coast before implementing any land reclamation projects as well as plan for dredging in major coastal rivers of the country.

Different ministries such as Ministry of Water Resources (MoWR), Ministry of Environment and Forest (MoEF), Ministry of Local Government Rural Development and Cooperatives (MoLGRDC) have identified different issues of coastal land dynamics from different perspectives (Parvin et al., 2008). However, a proper integration of activities among and between ministries is vital for a better management of dynamic coastal land of the country and hence the current research suggests an indicative institutional arrangement which is shown in Figure 10. The current research suggests that the ministries, in particular Ministry of Water Resources, Ministry of Land, Ministry of Environment and Forest and Ministry of Agriculture might implement specific policies through different departments, agencies and NGOs followed by the guidelines of the Ministry of Planning. Constant monitoring on the dynamic nature of land by applying GIS and remote sensing techniques could be a viable management approach for this purpose.

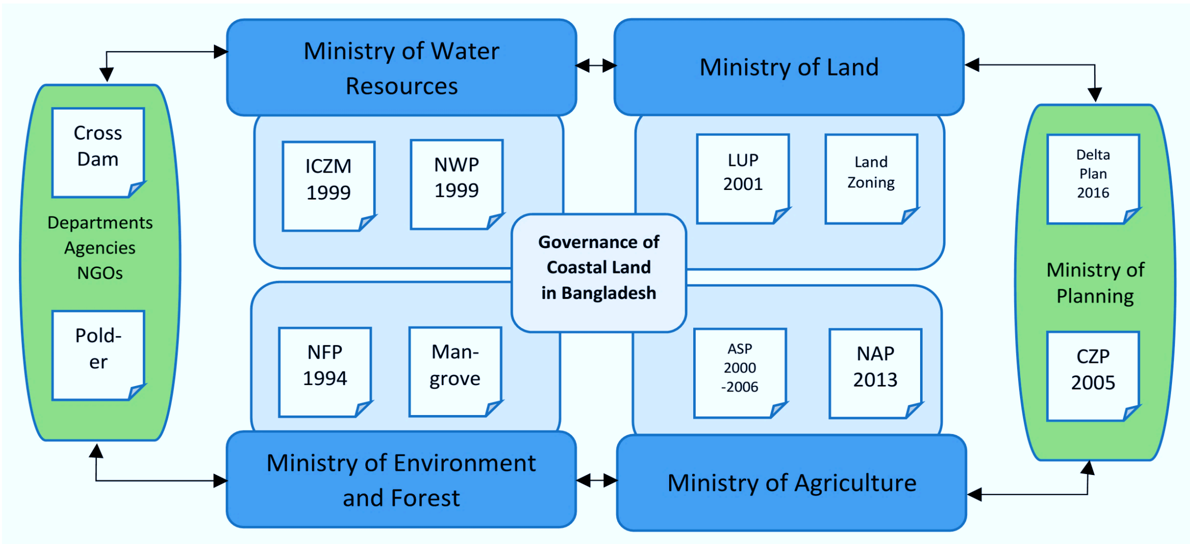

Fig. 10. Indicative institutional arrangement in implementing coastal policies in Bangladesh.

Beside the mentioned issues, the policy lacks proper integration between the probable effects of climate change and associated sea level rise on coastal land dynamics, which overwhelmed the other issues. More importantly, this policy needs to incorporate the future scenario of tidal range, wave dynamics, and cyclone-induced storm surges etc. into its current policy framework to better manage coastal land dynamics. Given that the increase of sea level remain one of the main driving forces of land dynamics in coastal areas of Bangladesh, any increase in sea level could change the horizontal configuration of any coastline through the process of erosion and accretion (Warrick and Ahmad, edt.1996). This may lead to long-term erosion of coastal lands, and a counterbalance to the previous erosion is achieved with the new accretion (Fitzgerald et al., 2008). For instance, a 1.5 metre rise in sea level may affect 22,000 km^2 of coastal land in Bangladesh (Fitzgerald et al., 2008). Moreover, the coastlines and the river mouths have already been pushed in by the rise of relative sea level. This might result in the alteration of flow of discharge and consequent erosion in the coastal areas. Additionally, the frequent occurrence of tropical cyclones as a probable result of climate change in the Bay of Bengal is a common phenomenon which creates storm surges in the coastal area. This phenomenon in the coastal area could further be increased by climate change, global warming and associated sea level rise (Huq et al., 1999). There is a great uncertainty exists in research as to how exactly the drivers of land dynamics are influenced by the rising sea level (Huq et al., 1999). It is also uncertain how the coastal areas of Bangladesh will respond with the future scenario of the rising sea level.

6. Conclusion and recommendations for further work

This study has shed light on the application of GIS and remote sensing techniques for assessing the dynamic nature of land in the coastal area of the country and hence analysed the changing pattern of coastal land in an efficient manner. The current research emphasises on the spatial (three coastal zones) and temporal (past thirty years from 1985 to 2015) patterns of erosion and accretion which evaluates multi-temporal satellite images that cover the entire coastal area of the country. Both the erosion and accretion rates do not produce a consistent increase or decrease, but varied over different time periods which indicates the dynamic nature of land in coastal areas of the country. Annual average net balances of 12.8 km^2 and 10.1 km^2 of land gained for the periods from 1985 to 1995 and 1995 to 2005 respectively. Moreover, an annual average 1.9 km^2 net loss of land identified for the period from 2005 to 2015. However, a number of factors are associated with the dynamic nature of land in the area among which anti-clockwise circulation of tidal current in the Meghna estuary, huge amount of water discharge from the rivers, prevailing monsoon wind and associated actions of waves, storm surges, soft and unconsolidated soils, cross-dams, polders, deforestation are significant physical and human-induced causes. The results demonstrate that both these rates are higher in the central zone of the coast, as compared with the western and the eastern zones.

Because of the changes in natural morphological pattern, coastal planning and coastal land management have received attention by the Government of Bangladesh. A number of policies, strategies and, plans have so far been adopted by the government. The adoption of the Land Use Policy (2001), Coastal Zone Policy (2005), Coastal Development Strategy (2006) and the Delta Plan 2100 (under formulation) are some of the milestone achievements. In recent years, various NGOs have also been engaged in erosion induced vulnerability work. Nonetheless, the policies, strategies, plans and projects have some noticeable shortcomings which needs to be reviewed by the government, that is: both physical and human-induced drivers of coastal land dynamics need to be addressed for a viable policy framework. Both the physical and human-induced drivers of coastal land dynamics need to be addressed for a viable policy framework. The priority, however, needs to be given on understanding the physical behavior of the coast before formulating any further policies. Future scenarios of coastal land dynamics also need to be developed in conjunction with the stakeholders. This will require the proper integration of possible future scenarios into the policies under the condition of changing climate and sea level. Furthermore, the possible reduction of sediment flow from the rivers due to upstream development needs to be addressed in the policies which might be a major future concern for the coastal land dynamics. Population changes, environmental pollution and future infrastructural development are additional factors to be considered when devising new policy on coastal land dynamics of the country.

The results of the study, however, could be a vital input for the implementation of coastal policy and strategy directives which still remain a key issue. This study identified some causes of land dynamics; especially for the three coastal zones which will be helpful for policy makers to decide the nature of interventions needs to be taken for specific coastal zones. This study recommends the consideration of the trends of physical behaviour of coastal lands for taking specific measures options. For instance, the soft defense measures such as polder might be effective for the eastern and the western coastal zones but not highly suitable for the most dynamic central coastal zone of the country. Instead, some hard defense structures, such as embankment, dyke etc. might be suitable for that zone. The results of this study could also be a vital input for the policy on rehabilitation and resettlement of erosion victims. The assessment could be helpful in formulating century-long Delta Plan-2100 as well as updating the existing coastal zone policy formulated by the government in 2005.

In conclusion, this study recommends the integration of future policy issues along with the future scenarios of hydrodynamics, sea levels, coupled with the GIS and remote sensing techniques for further analysis of land dynamics and land management in the area. More importantly, the results of the current study could offer the support and assistance needed by the coastal managers, planners, policy makers, and stakeholders in their decision making process when it comes to coastal land management. The current research offers a comprehensive analysis on the dynamic nature of land for the past thirty years that could be used by the coastal managers and policymakers for taking effective measures to address the issues.

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