Original Research Article

MONITORING COASTLINE CHANGES IN THE COASTAL BELT OF CHITTAGONG USING GIS AND REMOTE SENSING

ABSTRACT

Coastal zones are the most dynamic places in which lithosphere, hydrosphere and atmosphere gets into contact with each other. Such dynamic process should be monitored with great importance as a large portion of the world's population is concentrated along the coastal zones. This paper focuses on delineation of the changes in the coastal land areas of Chittagong in Bangladesh through the shifting of coastline. Chittagong coastal area is around 245 km with an unbroken 125 km gently slopped sandy sea beach in Cox's Bazar. However, due to both the natural phenomenon and human interventions, coastline in these areas has been changing gradually. These changes have occurred in relation to land biomass, erosion and accretion rate. Therefore, shoreline geometry analysis can help understand such dynamic costal process. Several satellite images from Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) were used for the long term coastline change analysis. The Digital Shoreline Analysis System (DSAS) using ArcGIS 10.1, and image rectification, atmospheric correction, edge separation techniques between earth surface and water surface using ENVI software were used in this analysis. DSAS was used as a reliable statistical approach for the rate of coastline change. The result shows that changes in dynamic changes due to erosion and accretion have been impacting the morph-dynamics in the study area. The maximum accession rate was 3.6 km and 1.9 km at different section points and on the contrary the maximum erosion at several section points was 0.37 km and 3.3 km at the time interval of 1989 to 2009 and 2009 to 2014, respectively. Overall, it was found that the area was affected with huge rate of accretion and increase in the landmass of the Chittagong area till the year 2009 but later on till the date of 2014 the erosion rate of the area again increased. The findings of this study can help policy makers to make decisions in delineating new islands emerging at the sea boundary of Bangladesh and planning for better coastal management.

KEY WORDS: Coastal Area, Dynamic Behavior, Shoreline Change, DSAS, Erosion, Accretion.

1. INTRODUCTION

Coastline is the line of connection between land and the water body at one instant in time (Gens, 2010; Naji and Tawfeeq, 2011). It is one of the most important and dynamic linear features on the earth's surface, which is an active indicator for coastal erosion and accretion. Changing climate, frequent events (earthquake, cyclone etc.) and increasing dependence of people on coastal resources is influencing the coastlines both spatially and temporally (Orford et al. 2002; Forbes et al. 2004; Cooper et al. 2004). Nittrouer (1995) revealed in his study that the indulgent of coastal dynamics in the wet tropics have broad scientific interests along with social and economic importance (Addo et al., 2011). Coastal ecosystem health and functions are greatly influenced by shoreline and landscape changes in the coastal belt. Jones et al., (1997) stated that these factors are commonly used to create landscape-based metrics, to assess landscape condition and to monitor the condition and the trends over a specified time interval. Therefore, the study of shoreline change is the utmost importance for management purposes such as developmental planning, hazard mapping, academic endeavors, determination of erosion and accretion, estimation of regional scale sediment budgets etc. An in-depth understanding of regional coastline dynamics (erosion and accretion) is required and necessary for the design of viable land use and protection strategies to reduce potential loss (Blodget et al., 1991; Chu et al., 2006; Jayson-Quashigah et al., 2013; Naji and Tawfeeq, 2011).

The traditional practice to determine the changing nature has been using field measurements, measurement using topographic sheets, comparison with historical data, end point rate (AOR), tracing from aerial photographs etc (Fenster et al. 1993, Kroon et al., 2007; Kumar et al., 2007; Zhang, 2011). Along with traditional methods several studies have been conducted using different innovative methodologies at different parts of the world (Addo et al., 2011; Alesheikh et al., 2007; Boak and Turner, 2005; Chu et al., 2006; Ekercin, 2007; El Banna and Hereher, 2009; Makota et al., 2004; Mujabar and Chandrasekar, 2013; Zhang, 2011). Santra Mitra et al. (2013) applied remote sensing and GIS techniques on the multi-temporal satellite image and topo-sheets, shoreline extraction using water index and subsequent change detection analysis. On the other hand, El-Asmar and Hereher, (2011) used several water indices and on-screen shoreline digitizing to identify the changing shoreline of the coastal areas. However, recent advancements in remote sensing and geospatial assessment techniques it has become possible to semi automate the system to delineate the dynamic nature of shorelines (Choi et al., 2010). Moreover, in Bangladesh, in recent years shows uses of both manual and automated methods. Ghosh et al. (2015) estimated the rate of shoreline changes along the coast of Bangladesh by using semi-automated method.

Moreover, the changes occurred in the past is not necessarily follow the same trends. Later the year of 2009, no study has been conducted to monitor the trend. Recently, Ghosh et al. (2015) utilized integrated techniques of remote sensing and geographic information system (GIS) to monitor coastline changes from 1989 to 2010 at Hatiya Island, Bangladesh. Satellite images from Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) were used to quantify the spatio-temporal changes that took place in the coastal zone of Hatiya Island during the specified period. Besides, Islam et al. (2015) developed a coastal vulnerability index (CVI) using eight parameters namely (a) geomorphology, (b) slope, (c) relative sea level change rate, (d) mean tide range (e) shoreline erosion and accretion, (f) population (g) bathymetry and (h) coastal flooding which were addressed as the relative risk variable for the study area using geospatial techniques i.e., Remote Sensing and GIS.

Bangladesh is supporting an enormous and rapidly growing population (>140 million in 2011) at the confluence of the sediment-laden Ganges, Brahmaputra rivers. As a result, the Bay of Bengal, across low-lying alluvial and delta plains that have accumulated over the past few thousand years (BBS, 2011). But it has been immensely influenced by climate change and sea level rise issues (Begum, 1997) thus although Bangladesh receives a huge portion of sediments due to dynamic nature of the Ganga, Brhmaputra and Meghna basin than elsewhere in the world, some coastal areas are faced with the rapid erosion problem (Gonçalves et al.,2014). Thus accurate demarcation and monitoring of shoreline changes are necessary for understanding and deciphering the coastal processes, coastal zone management planning, hazard zoning, erosion-accretion studies, regional sediment budgets, analysis and modeling the coastal morph dynamics. This study was aimed to determine the changes in the shoreline of Chittagong coast using the semi-automated system. Although it is possible to extract shorelines manually from satellite images (White et al. 1999; Addo et al., 2011; Alesheikh et al., 2007; Tochamnanvita and Muttitanon, 2014), adopting an automated shoreline extraction procedure has several advantages in terms of efficiency and consistency in recognizing former shoreline positions for complex and dynamic coasts like Bangladesh. The study aims to estimate the delineation of the changes in the coastal land areas of Chittagong in Bangladesh through the shifting of coastline by using GIS and remote sensing application.

2. MATERIALS AND METHODS

2.1 Study Area

Coastline of about 245 km in South Bangladesh (two district of Chittagong, and Cox's Bazar) has been investigated in the present study (Fig. 1). It lies between 20º 43' and 21º 56' north latitudes and between 91º 50' and 92º 23' east longitudes. The coast line of the study area is comparatively uniform and broken by few in-dentions. Narrow sandy beach is present between Mindhola and Purna rivers and extends up to Daman. Mud-flats, marsh and mangrove vegetation are found along the estuaries of the Mindhola, the Purna, the Ambica, the Auranga and the Damanganga. Numerous small tidal creeks are also found along the study area. South of Auranga estuary, the coast is observed to be rocky. The study area is in sub-humid climate and receives an annual rainfall more than 2000 mm.

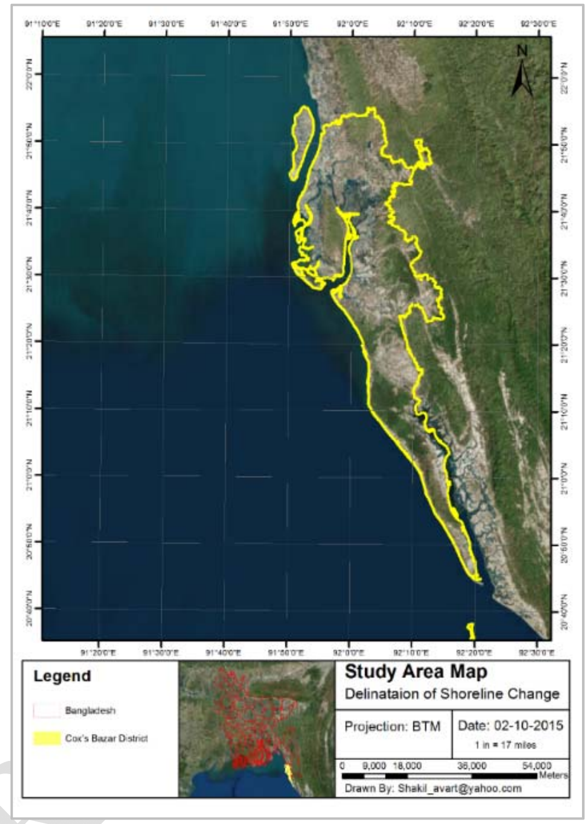


Figure 1: Study Area Map

2.2 Methodology

Data collection

Due to the unavailability of easily accessible data for research purposes, the spectral bands of Landsat 5 TM and Landsat 8 (Table 1) was used to detect the changing coastal process (shoreline change) at the Chittagong coastal area in Bangladesh. The map projection of the satellite images was set as the Bangladesh Transverse Mercator (BTM) within Zone 46 N–Datum World Geodetic System (WGS) 1984. The pixel size of the images was 30 × 30 m. The satellite images were collected from USGS Path 136 and Row 45 covers the whole study area of Chittagong coastal zone (Figure 1). It lies between 20º 43' and 21º 56' north latitudes and between 91º 50' and 92º 23' east longitudes.

Table 1: Data Properties

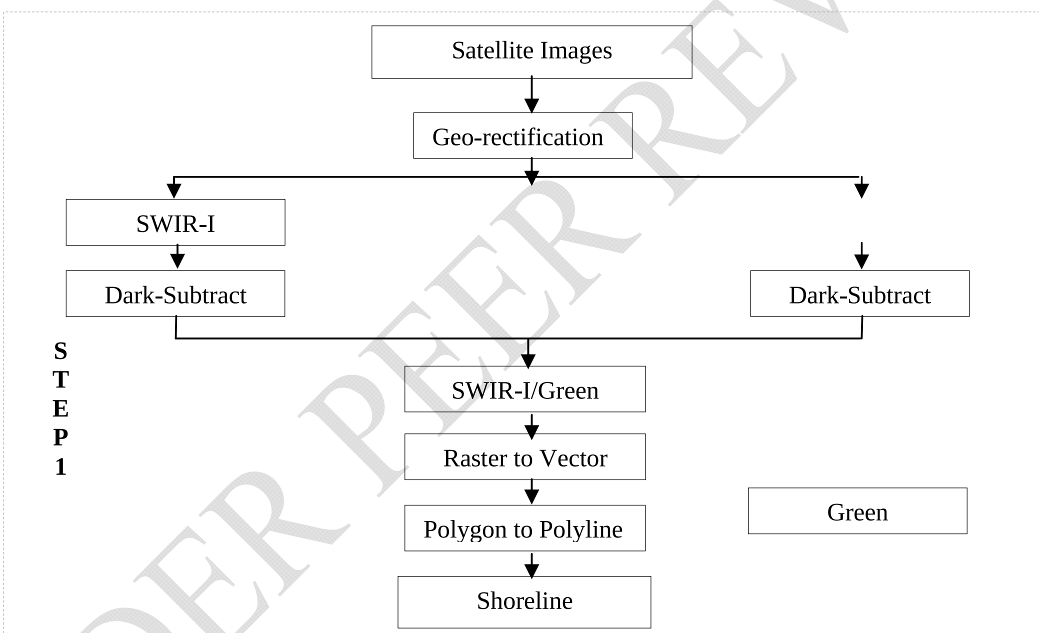
Type	Properties
Landsat 5 TM	20-01-2009, 05-01-1989
Band 5 and Band 2	1.547-1.749 µm and 0.519-0.601 µm
Resolution	30 * 30 m
Cloud cover	0
Landsat 8	24-04-2014
Band 6 and Band 3	1.566-1.651 µm and 0.533 – 0.590 µm
Resolution	30 * 30 m
Cloud Cover	0

Source: (USGS, 2015)

Data processing and analysis

Firstly, the downloaded images from USGS were preprocessed in ENVI software (dark subtract tool) for removing noises (i.e. environmental scattering problem) (Chavez Jr, 1988). While applying this method, the pixel having minimum brightness value in each band of each image was detected and that value was subtracted from the pixel values in the corresponding band. This resulted into the atmospherically corrected images. Furthermore, according to different studies the band ratio approach to delineate shorelines uses Band-5 and Band-2 for Landsat 5 TM images and for Landsat 8 image the considered bands were Band-6 and Band-3 (USGS, 2015; Sarwar, 2013; Alesheikh et al. 2007). The images from Landsat 5 TM were of 1989, 2009 and the images from Landsat 8 image was of the year 2014. So for the band ratio method the bands are selected accordingly. In this method the band-5 was divided by band-2 of Landsat 5TM and band-6 was divided by band-3 of Landsat 8 image in the band-math tool of ENVI. The resulting image was in value of zero (0) and others. The value zero represents the water edge and other values represent reflective land areas (1-127 low reflective land mass, 127-225 highly reflective landmass). Furthermore, the resulted image was inserted in the ArcGIS environment and converted into vector files from raster files. Later on the polygons were converted into polylines. Finally, the mouths of the rivers and tidal creeks were connected by straight lines to generate a single shoreline for the whole coastal zone for each of the assessment year (1989, 2009 and 2014).

Based on the generated shoreline for each of the year a baseline shapefile was created. Based on the baseline shapefile the initially for the year 1989 transects are generated at 100 m intervals the length of each transect was selected as 4000 meters. There were a total of 1925 transects generated by the extension tool of digital shoreline analysis system (DSAS).Finally, based on the implications and reliability, a total of 1470 transects were selected for further assessment and the intersected transects in each shoreline at the measurement points were used to calculate shoreline-change rates.



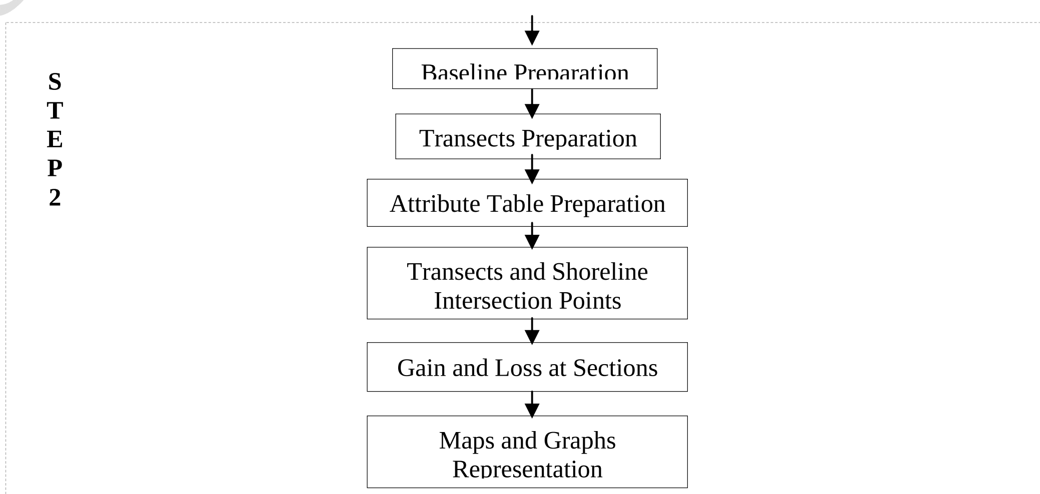


Figure 2: Workflow Diagram

Overall length of the shoreline is about 245 kilometers among that 192 kilometers is selected for analysis. The shoreline was divided into 1925 sections using automatically generated transects based on the baseline drawn inwards the landmass. The length of transects were selected as 4000 meters and the distance from one transact to another was given as 100 meters thus along the baseline a total of 1925 transects are automatically generated by the DSAS extension in the ArcGIS platform. Furthermore, for better analysis some of the transect sections were omitted thus the actual study have been on about 1470 transect points in total. Based on the generated transects the change statistics of the DSAS tool was used and net shoreline movement statistics was implied. Resulted statistics output was exported to an excel sheet containing coordinate value and distance of the intersection points from the baseline to the intersected shoreline. Based on the result the overall gain and loss of the landmass was calculated. The flowchart of the data processing and analysis is shown in figure 2.

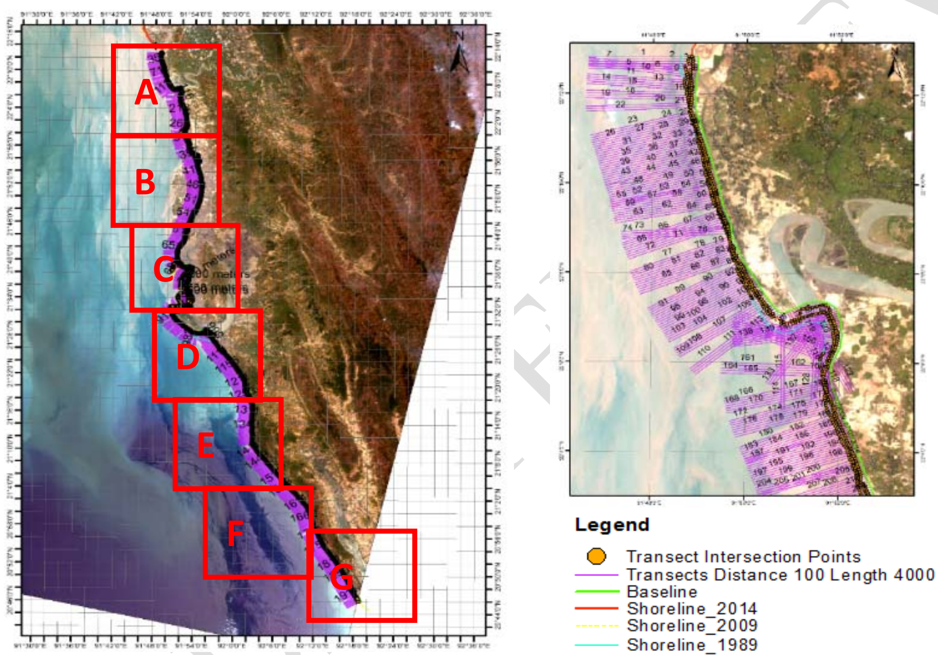
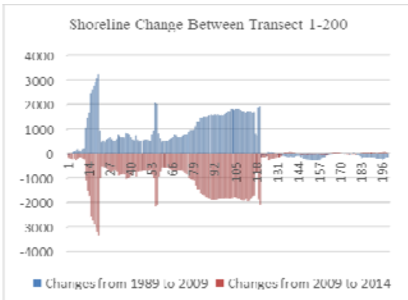


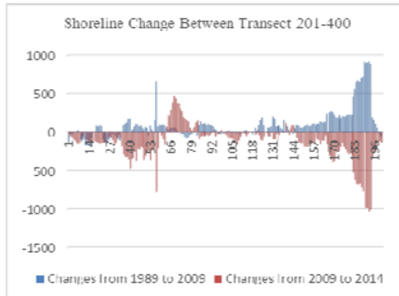
Figure 3: Section wise transects distribution of Chittagong coastline in Bangladesh

3. RESULTS AND DISCUSSION

In this study, we calculated the gain and loss of landmass throughout the coastline of Chittagong, and which significantly varied indifferent locations. The figure 4 shows a specific section profile of gain and loss from the year 1989 to 2014. The portion representing here is the section A. It shows through the mapping representation that the changes occurring from the transect points 1 to 200. It is a simple representation of how the overall profile is calculated to derive the gain and loss of landmass. The figure 3, 4 and 5 shows how the changes took place at different time frame at different locations. Although it is seen that the landmass has increased due to sedimentation or accretion rate from the year 1989 to 2009, but similarly, the rate of erosion increased from 2009 to 2014. A section wise distribution of the profile is done to represent each section separately and analyses the changing profile more deeply. While section profiles A, B and F section shows that the net change in such sections gets balanced as the accretion rate and erosion rate equalizes each other (Figure 4). However, the rate of erosion from 2009 to 2014 was much higher than the accretion rate from 1989 to 2009. On the other hand, for section C, D, E, G and H, the abnormality on the profile is visible. Some of it shows higher erosion rate while some other profile shows higher deposition or accretion rate.



A



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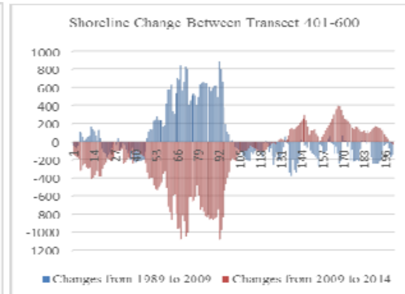

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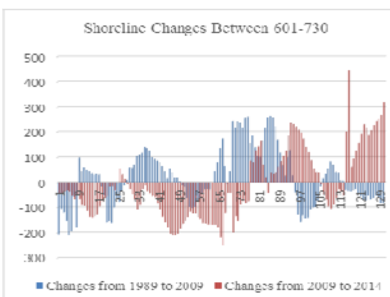

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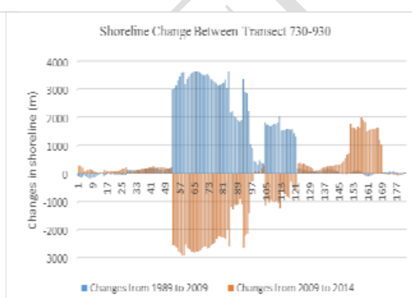

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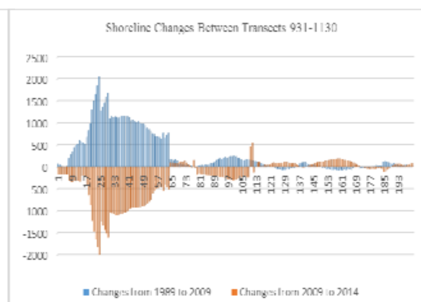

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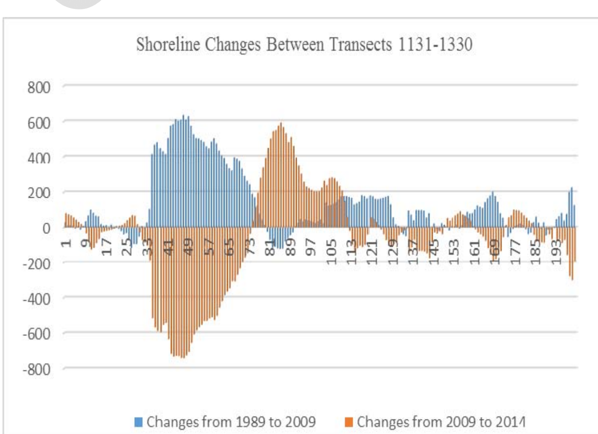

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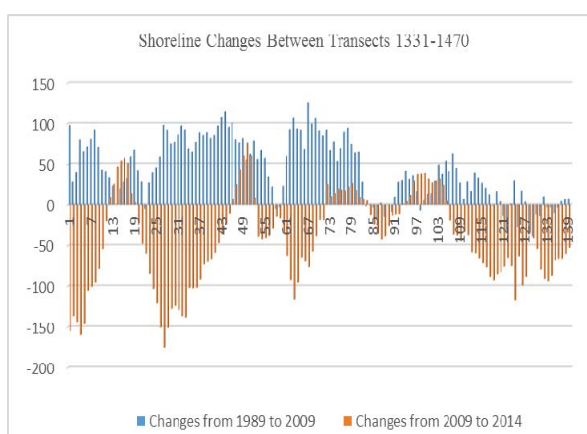

H

Figure 4: Section wise profiling of the study area (1-1470).

Although the rate of deposition and erosion varied significantly at different intersection points, but the highest deposition and erosion was at different time interval. The average rate of deposition since 1989 to 2009 per year was 181.69 m at the maximum deposition point and 18.63 m (- represents erosion) per year was the rate of erosion at maximum erosion intersect points. It is seen that the rate of deposition was higher than the rate of erosion at that time interval and the overall average deposition was14.43 m per year (Table 2). On the other hand, there was a dramatic increase in the rate of erosion for last 5 years in this coastal area. Although the rate of deposition was 337.264 m per year at places but the rate of erosion was about 663.63 m per year resulting in the overall average rate of erosion around 47.45 meters per year.

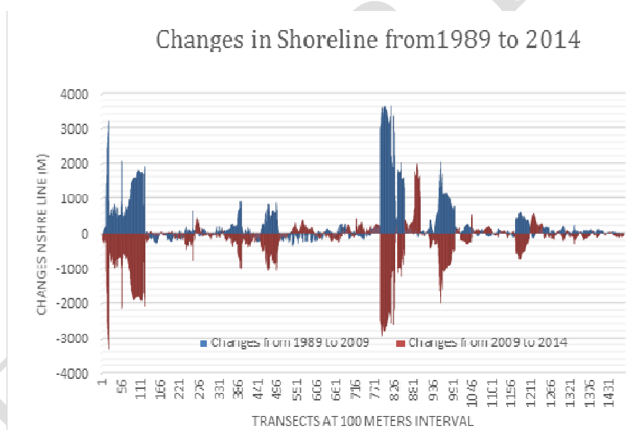

Figure 5: Total Shoreline profile changes from 1989 to 2014

Table 2: Changes in the shoreline of Chittagong coast from 1989 to 2009

	Year 1989 to 2009	**Rate of Change**	**Year 2009 to 2014**	**Rate of Change**
Maximum Deposition	3633.83 m	181.69 m /yr	1986.32 m	337.264 m /yr
Maximum Erosion	-372.45 m	-18.63 m /yr	-3318.16 m	-663.63 m /yr
Average	288.59 m	14.43 m /yr	-237.25 m	-47.45 m /yr

(- sign represents the erosion or land loss)

Moreover, the site investigation at the section intersect points between 730 to 930 represents the shoreline changes are resulting in due to two inverse processes of accretion and erosion. Accretion increases the area of biomass while erosion causes loss of land, threatens human life etc. The analysis result showed the shoreline in the study area has never been constant and a continuous changing pattern (Figure 3). Both the spatial and temporal variations in the deposition and accretion have been observed in the study area. The temporal intervals (from 1989 to 2014) used in the study for assessing the changes have not been uniform. However, the erosion and accretion patterns clearly showed a continuous geomorphic sculpturing over the coastal tract in each temporal gap. Erosion works as a constant factor for the coastline modification in the most of the areas, whereas a small segment near Kutubjom Union and Kutubdia Island inlet shows deposition is varying between 3100 meters to 1000 meters within the year 1989 to 2009. However the area again faced with erosion problem from the year 2009 to 2014 while the shoreline in those same areas varying between 900 to 2600 meters. In the western part of the study area erosion and deposition between 1989 and 2014 was minimal. However, it gets more distinct between the time intervals of the next 20 years. In the following 6 years, the coastline shows a gradual shift towards adjacent land as a consequence mainly of wave erosion. Analysis shows that the proportion of land and water has been continuously changing in the study area (Figure 4 and 5) along the coastline.

The study showed that, based on the baseline measurement, from 1989 to 2009 there was a major deposition of land from intersection point 790 to 800 in compared to those areas faced with erosion problems from 2009 to 2014. Local inhabitants suggest that beach nourishment initiative is required and along with it erosion protection wall might be helpful to reduce such level of erosion in the area.

They also suggest that recent increasing frequencies of cyclones, unplanned developments, encroachments, cutting hills as well as establishment of shrimp hatcheries along the seashore affecting the shore area.

Kutubdia Island Kutubjom Union Cox's Bazar Beach

Figure 6: Field observation of coastal erosion and accretion in Chittagong coast

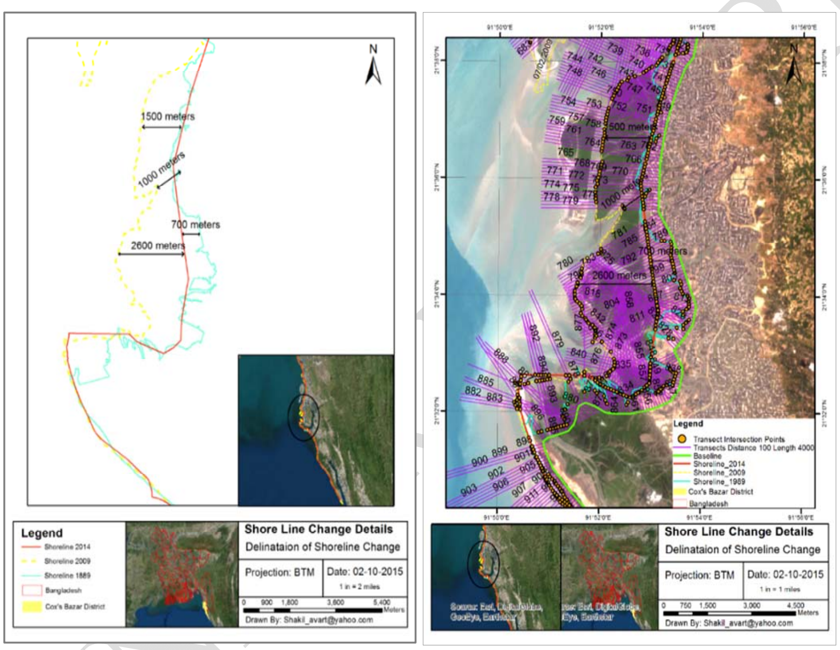

Figure 7: Shoreline change details in Chittagong coast, Bangladesh during 2015

The shifts between the shorelines from 1989 to 2014 were identified. Initially the difference of landmass at two different time interval was accounted from 1989 to 2009 and there was huge deposition along the coast (35.252 sq. km) and the land loss due to erosion was about 14.71 sq. km (Figure 8). On the other hand, from 2009 to 2014 due to increasing human intervention, different natural calamities, deforestation there was huge erosion problem along the coastline of the study area. The landmass of the study area decreased about 41.83 sq. km and at some places the increase of land mass was noticed at that time period though the amount was significantly low (1.47 sq. km) relating to the overall land loss (Figure 9). Field investigation at the local level suggested that several reasons are behind the shifting shoreline at the study area i.e.

- Encroachments at the beach-most of the hotel and resort owners like to build their establishments near the beach to attract more tourists and visitors.
- Hill cutting
- Hatcheries for fish farming-most of the hatcheries located at Kolatali area seemed to be built near the shoreline and the hatcheries are protected by retention walls which hugely deflecting waves of the sea and causing erosion at the opposite sides.
- Shifting human activities from coast to other areas due to increase disaster.
- Extreme water flow in rivers.

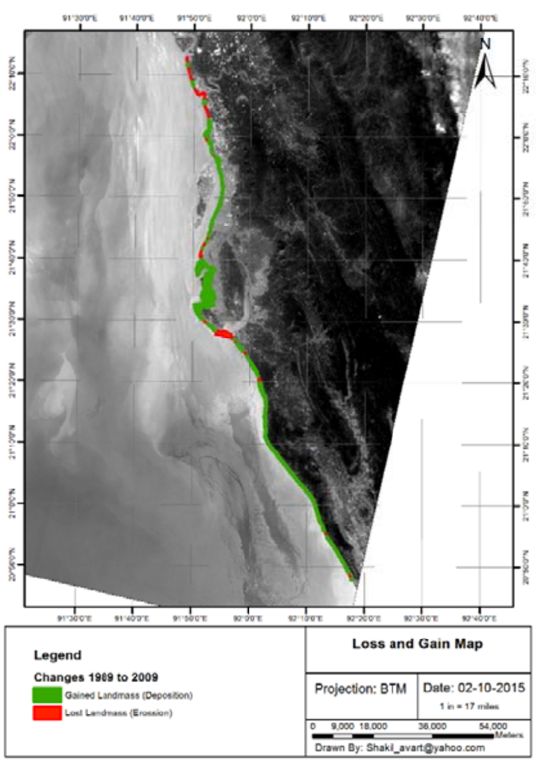

Figure 8: Changes in the Land biomass (1989-2009)

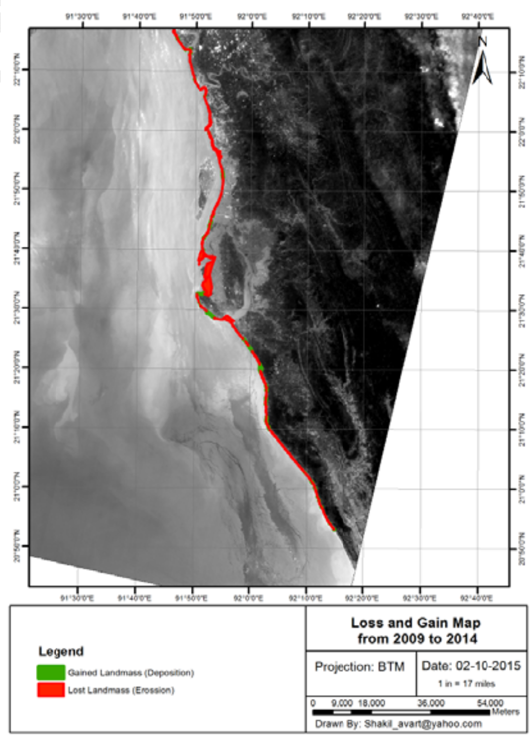

Figure 9: Changes in the Land biomass (2009-2014)

4. CONCLUSION

In this study, approach has been followed to extract the coastline using satellite images, then the role of remote sensing and GIS to support coastal programming as well has been discussed. Erosion and sedimentation are basic factors for the changing of coastline. Due to frequent lack of consistency, sufficient intensity contrast between land and water regions (especially in the Swamp and muddy lands) and the complications of distinguishing coastline from other object boundaries, coastline extraction is a difficult task for most edge detection or segmentation techniques. This study shows that the band ratios of 5/2 (TM) and 6/3 (ETM+) improve the potential of interpretation which can be used to change detection of Chittagong's coastline. Despite the successful applications of satellite images, it could be noted that the quality of the images remains an important factor for coastline extraction. The success of the dissimilar methods still depends upon whether considerable contrast can be achieved between water and land mass and to a lesser degree it also depends on the homogeneity of the water or land mass. The relative accuracy is evaluated in this research based on the comparison between the processing derived coastline and the coastline visually interpreted from the original satellite images. Extensive visual comparison shows that the relative accuracy of the results of the extracted coastlines is within one image pixel compared with the human visual interpretation of the coastline features. In real world applications, the absolute accuracy of the geographical position of the derived coastline is essential. The proposed approach based on integration of the band ratio and histogram thresholding techniques could be applied to Landsat MSS, TM and ETM+ imageries to map changes of coastal land forms such as Chittagong areas shorelines. The technique produces vector files of the coastline which can be analyzed using GIS to estimate rates of change over relatively long time periods or used for modeling long term changes. The synoptic capabilities of remote sensing provide a useful reconnaissance tool to target more detailed field surveys to neighborhoods of change. This study has indicated that modern image processing techniques can provide good information for the change detection and coastline extraction that may be used for any coastal management program.

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