Pertanika J. Sci. & Technol. 29 (1): 331 - 348 (2021)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Shoreline Change and its Impact on Land use Pattern and *Vice Versa* – A Critical Analysis in and Around Digha Area between 2000 and 2018 using Geospatial Techniques

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ABSTRACT

The shoreline is a very unpredictable, uncertain, and forever changing landscape for any coastal process. Due to erosional and accretional activities, the shoreline has continuously fluctuated with the continual process of waves and tides. Shore boundaries are determined by the shoreline at its furthest towards the sea (low tide) and extreme towards land (high tide). The present research aimed to identify the temporal alterations of shoreline and changes in land-cover between the areas of Rasulpur to Subarnarekha estuary, east coast of India with 70.04 km length of shoreline. An area amounting to 143sq.km had been selected for showing the land-cover changing and this area had witnessed the rapid growth of population and increasing industrial activities causing an unsurpassable impact on the environment. The present study used three multi dated imageries for land use/ land cover (LULC) map and seven multi-resolution satellite images were applied to estimate the long-term shoreline change rate by dividing the coastal area into three "littoral zones" (LZ). The Digital shoreline analysis system (DSAS) was applied to identify the shoreline change rate of the year 2000 to 2018. Several statistical methods, linear regression rate (LRR), net shoreline movement (NSM), End Point Rate (EPR) were used to find out the erosion and accretion rate. The result showed that maximum erosion had been found in LZ III, rate of -2.22 m/year. Maximum accretion had been identified in

ARTICLE INFO

Article history:
Received: 07 July 2020
Accepted: 28 September 2020
Published: 22 January 2021

DOI: https://doi.org/10.47836/pjst.29.1.19

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ISSN: 0128-7680
e-ISSN: 2231-8526

LZ I, at the rate of 35.5 m/year. The LULC showed that maximum vegetation area had been decreased in the year of 2010 (14.21sq.km) but 38.96sq.km vegetation area had increased in 2018. The prominent increase had been identified in built up and shallow water. Built up had been expanded from 25.59sq.km (2000) to 41.26sq.km (2018). Shallow water was increased from 5.53sq.km (2000) to 18.90sq.km (2018). Sand and soil showed a decreasing pattern from 2000 – 2018. The outcome acquired from the present study will play a significant role to estimate the shoreline migration rate and will be helpful for sustainable land use management. The shoreline change rate will be also useful for coastal planners to adopt mitigation measures.

Keywords: Digital shoreline analysis system, end point rate, land use/land cover, littoral zone, linear regression rate, net shoreline movement

INTRODUCTION

Shoreline is relatively narrow strip of land adjacent to water bodies like sea or lake. Components of shoreline is controlled by the wave dynamics and sediment characteristics, slope, climate, vegetation, tide fluctuation and overall a littoral behavior. Equilibrium shoreline changes its configuration over a time period due to changing behavior of the agent (Pandian et al., 2004). Removal of sediment by erosional process is more vulnerable than accretion and widening of shoreline. Analysis of shoreline change leads to understanding coastal processes operating in a particular area in terms of frequency and magnitude. Anthropogenic factors also influence coastal morphology. Every coastal zone has its specific natural properties like, coastal slope, bathymetry and water density. Shoreline changes are the effects of some coastal processes like, breaking zone, breaker types of wave, breaking energy and so on. The surf zone where wave losses its energy and breaks are called the breaking wave zone. Braking type means the level of unstable movement within the wave (Koloa & Samanta, 2013).

Coastal zones require a huge amount of spatial research to assess and predict the geomorphic changes (Murali & Kumar, 2015). The land use/land cover (LULC) of an area that is a combined output of physical and manmade variable and processes. The present study fulfill the two main objectives, (i) to observe the shoreline changes and calculate the shoreline change rate along the area of Rasulpur river estuary to Subarnarekha river estuary in eastern coast of India, (ii) to identify and quantify the land-cover classes for the bench mark years 2000, 2010 and 2018 by using different GIS tools. The present study area has been subjected to many geo-environmental factors like beach sand loss, lack of sediment transport, shoreline retreat or transgression (erosion), destruction of mangroves, rapid growth of urbanization near shore areas, decreasing soil area and increase of water level which is become significant cause of concern. Identification and estimation of shoreline shifting is an important phenomenon for coastal management and coastal environment monitoring (Van & Bihn, 2008). The output of the present study is the shoreline change and LULC maps that can be useful for coastal authority for coastal zone management plan for the study area.

Various studies can be found in the existing literature for the study of shoreline change and land use/land cover change using geospatial analysis. Present work is based on the scientific approach and methodology of several research details given in Table 1.

Table 1
Scientific approach and methodology of several research details

Scientific approach and methodology	Research
Geospatial analysis of shoreline and LULC changes through remote sensing and GIS techniques.	Samanta & Paul, 2016
Shoreline identification using satellite images	Garcia-Rubio et al., 2009
Study of the land use and land cover changes and CRZ in the coastal area of Ganjam district, Odisha.	Guru et al., 2014
Assessment of shoreline changes along Nagapattinam coast using geospatial techniques.	Mageswaran et al., 2015
Sea level rise and shoreline changes: a geo-informatics appraisal of Chandipur coast, Orissa.	Mukhopadhyay et al., 2011
Long and short-term shoreline changes along mangalore coast, India.	Kumar & Jayappa, 2009
Analysis of land use /land cover using remote sensing techniques –A case study of Karur district, Tamil Nadu, India.	Balachandar et al., 2011
Automatic shoreline detection and future prediction: a case study on Puri Coast, Bay of Bengal, India.	Mukhopadhyay et al., 2012
Coastline change detection using remote sensing.	Alesheikh et al., 2007

STUDY AREA

The length of 70.04 km shoreline in east coast of India, area between Rasulpur to Subarnarekha estuary part of West Bengal and Orissa respectively was selected for the present study (Figure 1). East coast of India along with Bay of Bengal is more inundation prone and various shocked related to ocean than west coast of India (Chatterjee, 1995). The study area is located between latitudes of 21°34′25″ N to 21°47′16″ N and longitudes 87°22′36″ E to 87°52′55″ E. Elevation of is less than 3 m in average above sea level (Umitsu & Sen, 1987; Goodbred & Kuehl, 2000; Khan & Islam, 2008). Beach sand in the study area has been observed as similar to Subarnarekha sand which is mainly quartz and yellowish in color tone. The general conception is contracted that the beach sand has been supplied from Subarnarekha River not from Ganga (River Research Institute, 2009). The entire coastal zone is predominated by south west monsoon with subtropical humid climate and three several climate pattern identified these are (i) per-monsoon (March – June), (ii) monsoon (June – October) and (iii) retreat monsoon (November – February) (Dey et al., 2005). Five important estuary areas have been observed in the study zone.

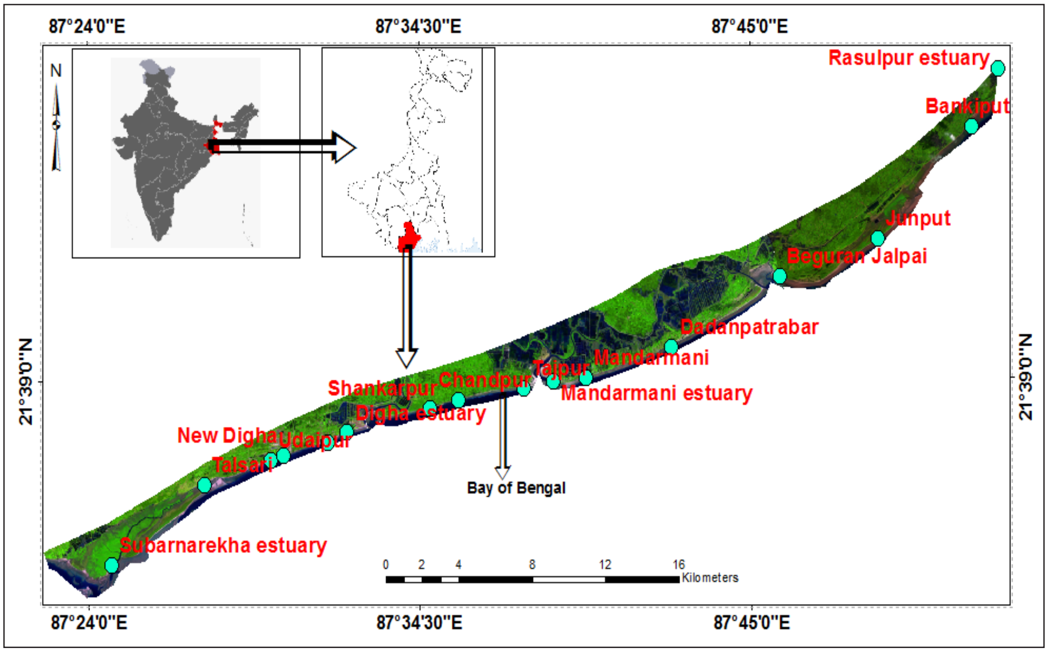

Figure 1. Geographical setting of study area

These are: Subarnarekha estuary (Subarnarekha River), Digha estuary (Digha canal and Champa River), Mandarmani estuary (Balisai canal and Sapua canal), BeguranJalpai (Pichabani canal and Contai canal) and Rasulpur estuary (Rasulpur River). The study area has witnessed rapid growth of urbanization due to development of tourism industry and various commercial activities are found in hinterland of the study area.

METHODS

Various methods of shoreline identification and shoreline retreat measures are available in the existing literature (Jana et al., 2013; Kuleli, 2009; Nguyen et al., 2010; Mujabar & Chandrasekar, 2011; Selvan et al., 2014).The shoreline change detection is primarily based on the actual positioning of tidal datum that is mainly termed as mean high water (MHW) on a map (Everts et al., 1983). In this study, various remote sensing, and GIS methods (explained later) were applied to determine the shoreline position; land use/land cover changes. Different statistical analyses were also performed for estimating the shoreline retreatment rate. The following subsections explain different modules of methodology.

Data Analysis

The study was carried out using three multi-temporal and multi resolution images of Landsat ETM$^+$ (Enhanced thematic Mapper) with a spatial resolution of 30m for bands 1 to 7 and band 8 for 15m and Landsat 8 (Operational Land Imager / OLI) and thermal infrared sensor (TIR) with a spatial resolution of 30m for band 1 to 7 and 9, 15m for band 8, band 10 and 11 are thermal bands with a spatial resolution of 100m. In Landsat 8, band 1 is useful for coastal studies.

Available data over the selected period (2000 – 2018) had differences in their resolutions. Since the images were visually interpreted for mapping purpose, these differences of resolution did influence the accuracy to obtaining the real information about land cover features. Satellite image of 2000 is low resolution image with some atmospheric errors which create some problem in identifying the LULC features. The effect of low resolution has been observed especially in built up area of 2000 image. Landsat data are very much reliable in coastal studies and being used for decades (Munday & Alfodi, 1979; Chand & Acharya, 2010). Use of satellite images also proved its reliability in identifying the shoreline position and coastal changes (Boak & Turner, 2005). The selected satellite images, for the years 2000, 2006, 2007, 2009, 2010, 2015 and 2018 were downloaded from USGS Global visualization viewer (https://glovis.usgs.gov).

Identification and Estimation of Shoreline Change

The shoreline was identified by interpreting the differences in shades of tone between the land and ocean. Brightness, contrast adjustment and histogram stretch techniques were applied on the satellite images for better visual identification. The pixels which represent the shoreline were converted into a polyline vector format in ArcGIS environment. In image of 2000, some errors were observed related to atmospheric disturbances which generate some problem in extracting shoreline; and therefore, correction method was applied for this particular image. The least brightness value in every band was detected and this value was deducted from all pixel values (DN values) in the corresponding band that comport to atmospherically rectified image (Chavez, 1988; Trinh et al., 2020; Emran et al., 2016).

Prerequisite for change detection analysis are precise geometric correction (Saha et al., 2005). All of the satellite images were rectified geometrically in GIS application. Geometrically corrected images were projected by Universal Transverse Mercator (UTM) projection (WGS 84, Zone: 45N) based on nearest-neighbor interpolation technique. Then, standard false color composites (infrared color composites) were created for the satellite images.

To estimate the shoreline shifting rate, the Digital Shoreline Analysis System (DSAS) was most useful system available at USGS earth explorer website that performed with Arc GIS software in collaboration where shoreline change rate had been calculated following the “linear regression” (LR) method (Maiti & Bhattacharya, 2009). The vector layers (.shp) of shoreline for the years 2000 – 2018 were used in DSAS to estimate the rate of shoreline shifting. Transect information were required to estimating the change rate of shoreline and 2682 transects (in the form of shape file) were placed at 50 m interval along the shoreline. The DSAS tool was used to estimate the NSM (Net shoreline movement), EPR (End point rate) and LRR (Linear Regression Rate). The distance between youngest and oldest shorelines was demarcating the estimation of NSM. The LRR was demarcated by compatible least squares regression line to all the relative shoreline points of various years for a single transect. The EPR was estimated from the horizontal change rate of shorelines. The EPR was calculated by dividing the distance of horizontal shoreline change rate by the NSM (Thieler et al., 2009). The negative (-) values indicate the retreat of shoreline and positive (+) values indicate the advance of shoreline or sea ward movement of shoreline. The total area (Subarnarekha estuary to Rasulpur river estuary) was divided into 3 littoral zones (LZ) for prominent identification of erosion and accretion pattern. The littoral zone is very close area to shoreline. This zone is influenced by the process of transportation and sedimentation. The total area was divided into different littoral segment based on important estuaries in the study area that were the main source of sediment supply over the area. First zone was selected Subarnarekha estuary to Digha estuary area (length of 23.04 km) and 932 transects were drawn in this LZ I. Second zone was chosen from Digha estuary to BeguranJalpai (length of 31.15 km) and 1051 number of transect were drawn to calculate the Shoreline change rate. Final zone was BeguranJalpai to Rasulpur river estuary area (length of 16.23km) with 699 number of transects. Three littoral zones were calculated by statistical method and finally a zonation map was prepared with five different zones according to LRR values and classes were defined based on their values in three littoral zones. Two specific classes were obtained: low erosion zone (range -100 to 0) and low accretion (range varies from 0 to 100). The entire study area has been observed by these two classes. The study shows the changes between 2000 – 2018 time periods (18 years) in a long-term method. The analysis was performed based on LRR and EPR method to showing the variation of shoreline change rate. LRR method was more compatible to showing the long-term changes than EPR method because in EPR method could not access more than two shorelines so when additional shorelines were assigned to calculate the change rate extra (more than two) shorelines were neglected. Due to this reason rate of shoreline migration might be overlooked. In case of LRR method, all shoreline data (more than two) were computed in regardless and the accurate rate of shoreline shifting was obtained using acceptable statistical techniques (Dolan et al., 2007). The present study had been applied both methods (EPR and LRR) to calculate the shoreline change rate and variation in both methods.

To justify the location of shoreline a validation method was applied for 2000, 2006, 2007, 2009, 2010, 2015 and 2018 shoreline. These three shorelines were converted into Google earth (.kml) version; and then by the using of Google earth historical imagery system these three shorelines were validated.

Study of Land Use/ Land Cover

Satellite images and field data were used to classify land cover features (Pal et al., 2012). The image classification resulted in the classified land-cover maps for the years 2000, 2010 and 2018. Image classification was performed in Arc GIS software for following land-cover classes: vegetation, soil, shallow water, sand and built-up. To preparing the LULC map approximate 143sq.km area was chosen. The total area was divided into three littoral zones (LZ) for each year. The LULC classification was performed for these three zones of each year to make a comparative study between 2000 – 2018 time periods. The maximum likelihood classification algorithm was used to create this land use/ land cover map. Maximum likelihood classification is a process where known classes are distributed as the maximum for a certain statistic (Scott & Symons, 1971; Mukhopadhyay et al. 2013; Mukhopadhyay et al. 2018). The training samples or signatures were collected from the images by means of visual image interpretation with appropriate ground truthing. From the LULC data, some statistical techniques were adopted to find out the drastic changes between 2000 – 2018 timwere. No classified map has been considered as accurate without performing the accuracy assessment (Bradley, 2009). To assess any classified image, confusion matrix is the most suitable method (Story & Congalton, 1986; Biging et al., 1998; Oumer, 2009; Zhang et al., 2000; Mujabar & Chandrasekar, 2013). Based on this method, similar and dissimilar pixels are assembled to compare the ground truth pixel along the location in classified map. Ground truth data are represented through column and classified pixel data are represented by row (SCGE, 2011). The matrix was performed by calculating user's accuracy, producer's accuracy and overall accuracy measures based on the commission and omission error (Coppin & Bauer, 1996; Boschetti et al., 2004; Carlotto, 2009). Finally, the accuracy assessment was performed to determinethe overall accuracy and Kappa co-efficient accuracy (Rossiter, 2014). The result of accuracy assessment is given in Table 2.

Overall accuracy as in Equation 1:

$$\frac{\sum_{a-1}^{U} C_a}{Q} * 100\% \qquad (1)$$

Where, Q and U is the number of total pixel and classes, respectively. The acceptable overall accuracy has been considered 85% (Congalton & Green, 1999; Lu & Weng, 2007; Li & Zhou, 2009).

Kappa confusion matrix is demarcated as in Equation 2:

$$K=\frac{\sum_{a-1}^{U}\frac{C_a}{Q}\sum_{a-1}^{U}\frac{C_a C_{a\cdot}}{Q^2}}{1-\sum_{a-1}^{U}\frac{C_{a\cdot} C_{a\cdot}}{Q^2}} \qquad (2)$$

Where, $C_{a\cdot}$ =Row sum

Table 2
Showing the accuracy assessment by Kappa Co-efficient

LULC feature name	Producer's accuracy			User's accuracy		
	2000	2010	2018	2000	2010	2018
Built up	100%	100%	71.43%	37.5%	90%	71.43%
Vegetation	100%	90%	100%	87.50%	100%	100%
Soil	66.66%	100%	71.43%	100%	85.71%	100%
Sand	77.77%	90%	100%	100%	100%	90%
Shallow water	100%	100%	100%	100%	100%	89%
	Overall accuracy			85%	95%	90%
	Kappa co-efficient			81.25%	93.67%	87.43%

RESULT AND DISCUSSION

Shoreline Change Analysis

The shoreline change or shoreline recession had been estimated for the area under Subarnarekha to Rasulpur river estuary area using Digital Shoreline Analysis System (DSAS) tool in Arc GIS 10.3 software. In the study area, shoreline length of 70.04 km observed both erosion and accretion (Figure 2, 3, 4). The shorelines of different years were drawn in ArcGIS. From the DSAS analysis, EPR and LRR for every transect length over the shoreline is shown in Figure 5, 6 and 7. From the DSAS transect analysis it was observed that in the LZ I (Figure 2) maximum area was under low erosion to low accretion regime. But near Subarnarekha estuary a prominent accretion zone was found but at the same area also experiences the erosional tendency (Figure 2). The average positive LRR value was found as 35.5 m/year near Subarnarekha estuary and average negative changes of LRR value was -1.5 m/year was observed in the extent part of Subarnarekha estuary to before Talsari area and near Old Digha, New Digha and Digha estuary area which is under low accretion zone. A tetrapod groin was constructed near Digha estuary area for the purpose of sedimentation which protects the beach area from coastal erosion in the year of 2007 by fishery Dept, Govt. of West Bengal (Figure 8). While in the LZ II (Figure 3) it was noticed that maximum area was dominated by low accretional formation and some area near Tajpur and Mandarmani estuary was under low erosional regime. The erosion rate was varying between -0.64 to -1.85 m/year and positive changes rate was 10.15 m/year in LRR value. In the LZ III reflects that the area had experienced low erosional pattern (Figure 4). Junput area was under accretion regime with average 32.33 m/year LRR value whereas Rasulpur river estuary was under low erosional regime with -2.22 m/year LRR value. Bankiput area was under accretion zone but some part of Bankiput shoreline remarked as domination of erosion with rate of -3.23 m/year. Figures 5, 6 and 7 explain the prominence of LRR method to estimating the long-term shoreline migration compare to EPR method in LZ I, II and III. In LRR statistics every change magnitude had been computed which was absence in EPR method and accurate change rate was obtained by LRR method. In case of LZ

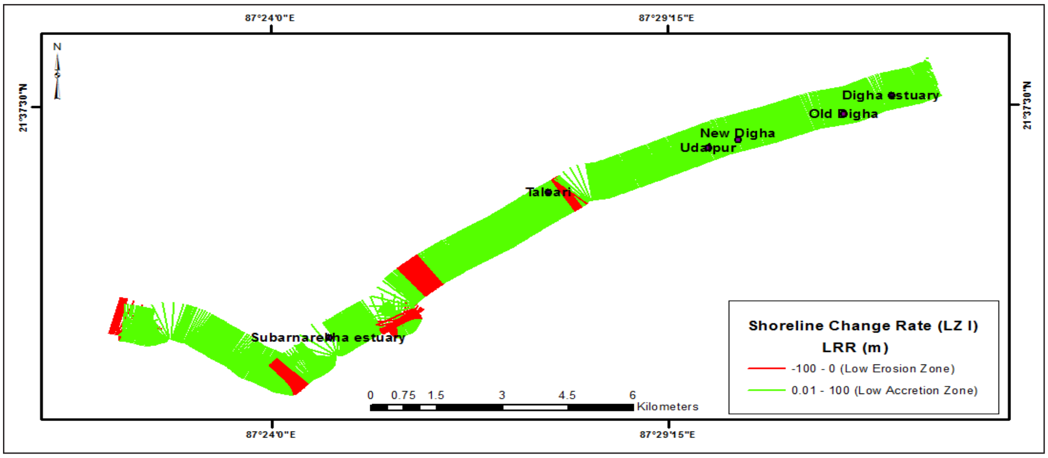

Figure 2. Shoreline change dynamics of LZ 1 (2000-2018)

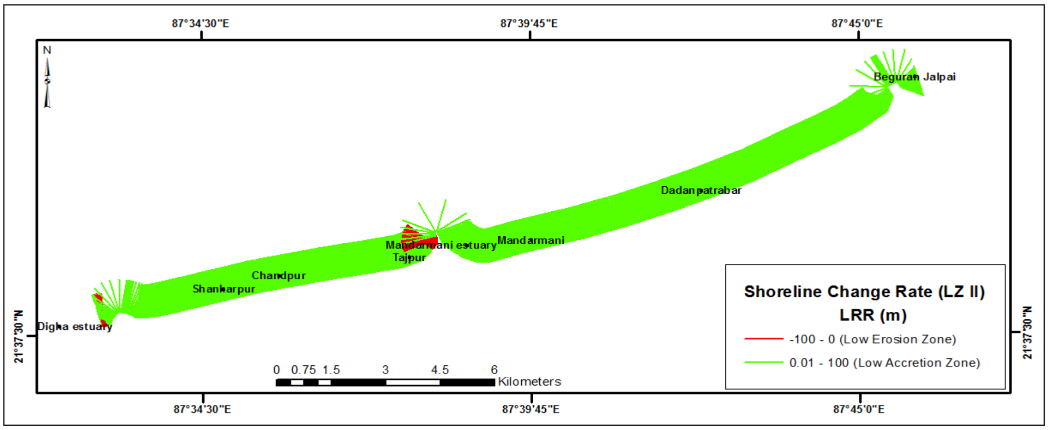

Figure 3. Shoreline change dynamics of LZ 2 (2000-2018)

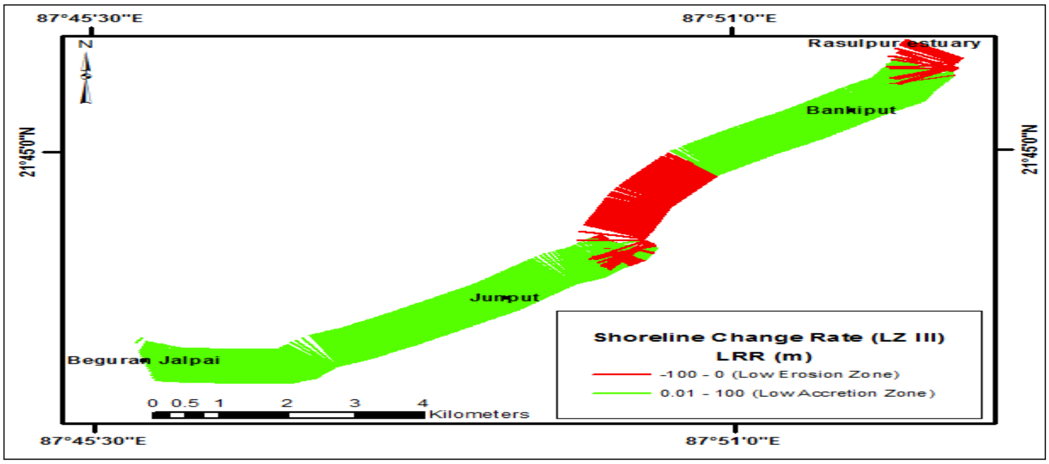

Figure 4. Shoreline change dynamics of LZ 3 (2000-2018)

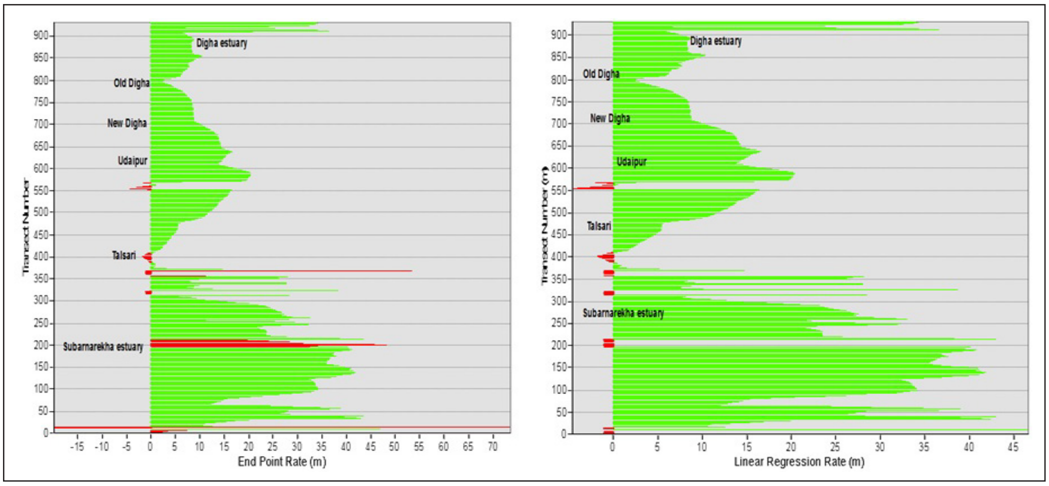

Figure 5. Graphical representation of shoreline changes in LZ I by EPR & LRR (2000 - 18)

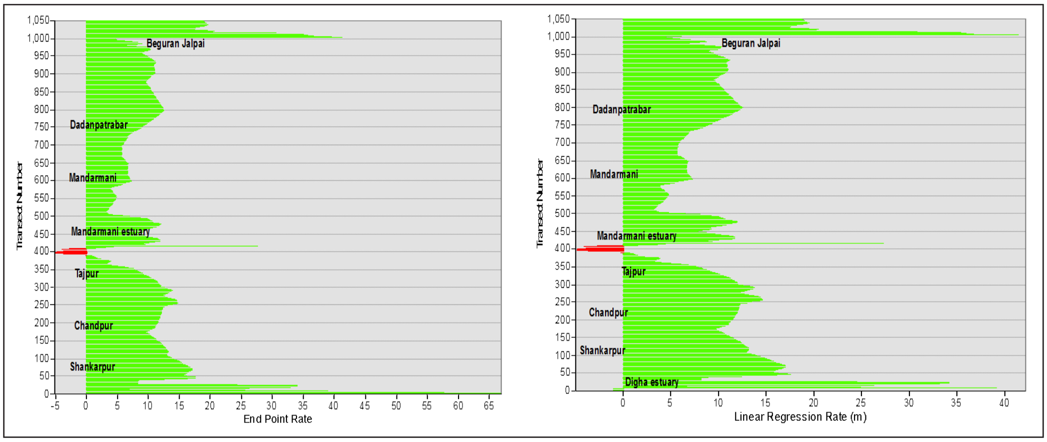

Figure 6. Graphical representation of shoreline changes in LZ II by EPR & LRR (2000 - 18)

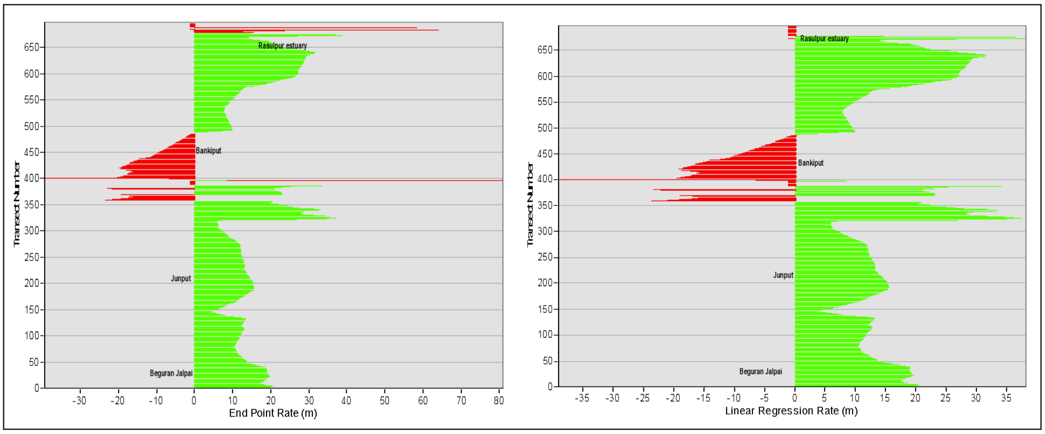

Figure 7. Graphical representation of shoreline changes in LZ III by EPR & LRR (2000-18)

Figure 8. Google earth image of Digha estuary and tetrapod groin

III, the LRR graph showed the prominent erosion in Bankiput and Rasulpur estuary with signified value but in EPR method the values were distracted from erosion to accretion zone due to its adaptation problem in multiple shoreline data. LZ I also experienced the same in Subarnarekha estuary area (Figure 5). Due to this problem, to estimate the long-term shoreline change rate LRR was the most compatible method.

Spatial Changes in Land Use/ Land Cover Mapping

The land use/land cover classification was done for an area of approximate 143sq.km. From this LULC map it was observed that drastic changes occurred from 2000 to 2018 (Figures 9, 10, 11). To identify the prominent change, total area was divided into three littoral zones (LZ) as stated earlier. LZ I (Figure 9) of 2000, 2010, 2018 LULC maps showed that the maximum soil area could be found in the year 2000 but it was reduced rapidly from 2010 to 2018. This zone also showed that how built-up area was enhanced within the time span 2000 to 2018. However, the growth of vegetation was observed after 2010 and it was increased in 2018. It happened because plantation initiative was adopted to protect the shoreline from coastal erosion by West Bengal Govt. after 2010. In the year 2000, shallow water was observed in few areas but from 2010 the increasing trend of water level was found prominently. In LZ II (Figure 10) it was observed that built-up area was low in 2010 but in 2018 LULC map built-up increased again. In this zone, soil area was low in 2000 and 2018, but in the year 2010 maximum soil area was found. Shallow water area was increased from 2010. Maximum sand area was observed in the year 2000. Vegetation was increased after 2010. Most of the built-up area found in Mandarmani to Dadanpatrabar region. The LZ III (Figure 11) was most accreted area where high vegetation cover was found in 2000 and 2018 but in 2010 vegetation cover was reduced. Sand area of higher coverage was observed clearly in 2000 but from 2010 it was decreased. Built-up area was found mostly in 2010and 2018. This zone clearly showed that water level was high in 2010 and 2018 map. Maximum soil area was found in 2010.

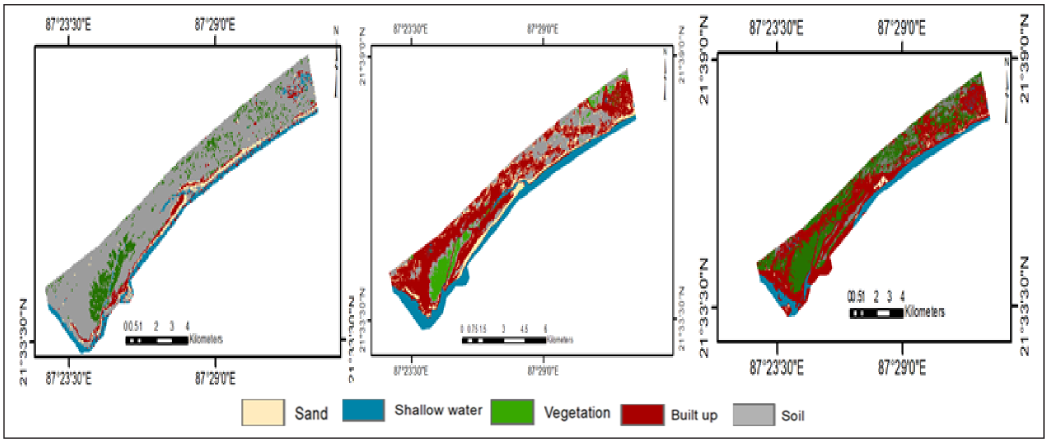

Figure 9. LULC map of LZ I in 2000, 2010, 2018

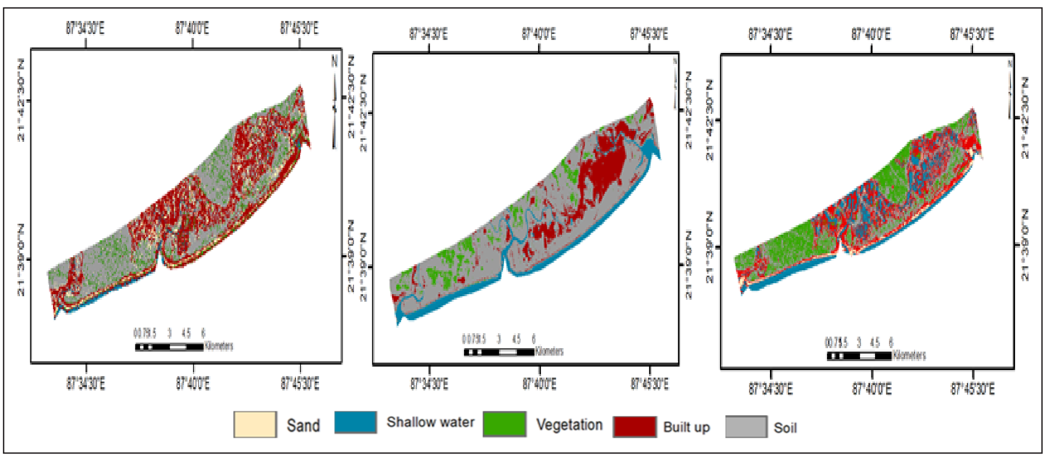

Figure 10. LULC map of LZ II in 2000, 2010, 2018

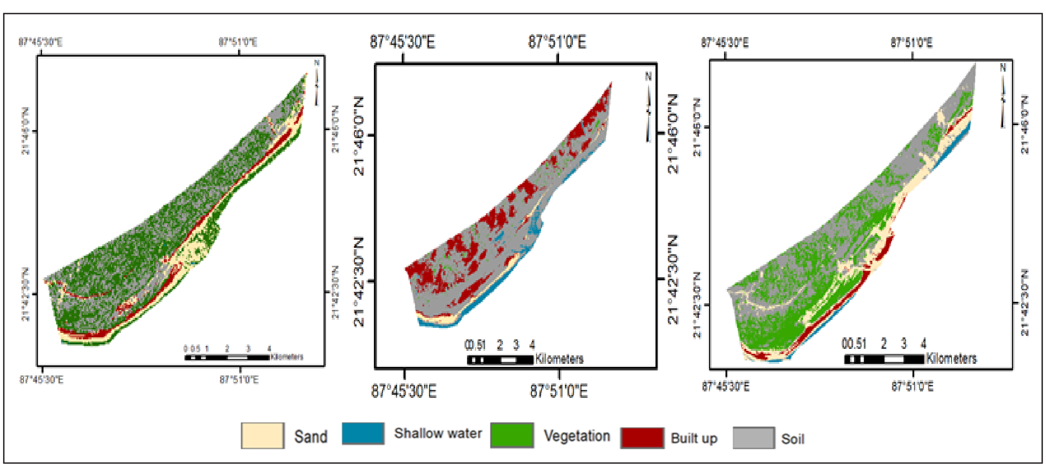

Figure 11. LULC map of LZ III in 2000, 2010, 2018

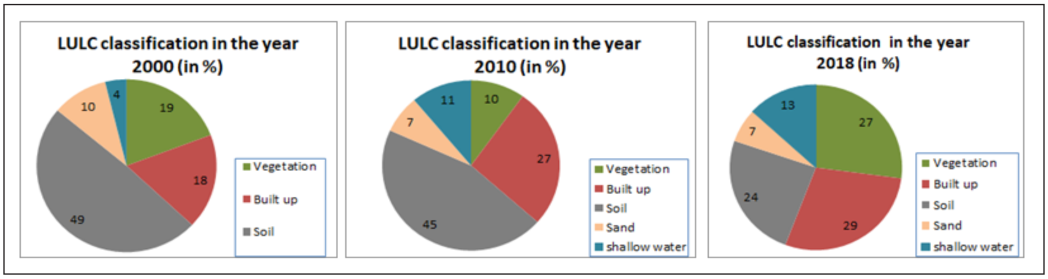

Figure 12. LULC area in percentage (2000 – 2018)

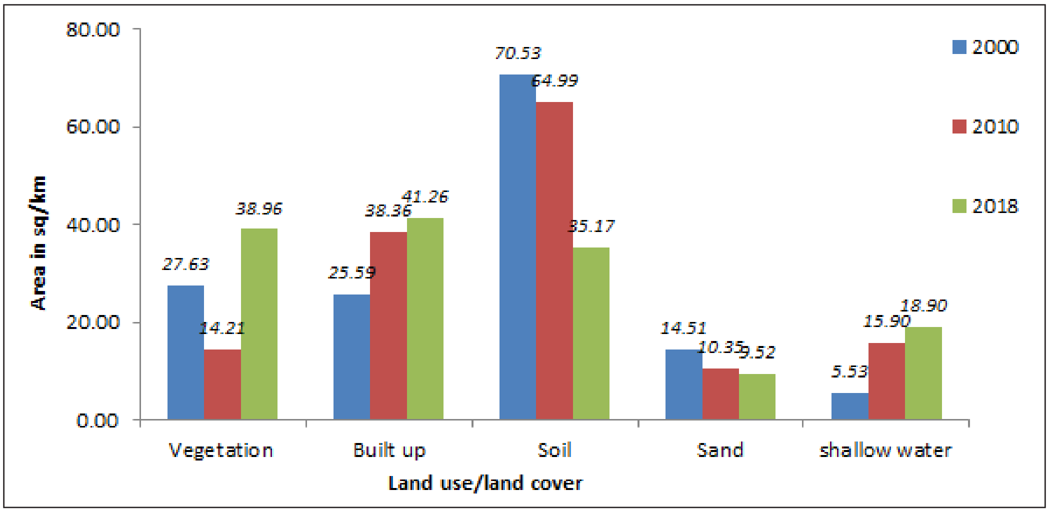

Figure 13. LULC area in sq.km (2000 – 2018)

Figure 12 shows the total changes in percentage. Figure 12 explains the drastic changes that occurred between 2000 – 2018 time span. The built-up area increased in 2000 – 2018 from 18% to 29% where shallow water level also increased in these 18 years from 4% to 13%. But soil area was reduced from 49% in 2000 to 45% in 2010 and 24% in 2018. Sand area was observed 10% in 2000 but decreased 7% in 2018. Vegetation was 19% in 2000 but it decreased to 10% in 2010. Sand area increased again in 2018 to 27%.

Figure 13 shows the LULC area in sq.km from 2000 – 2018 in approx. 143sq.km. This distribution shows that vegetation area was increased from 27.63sq.km to 38.96sq.km. Built-up area was enhanced from 25.69sq.km to 41.26sq.km. Maximum drastic changes were observed in soil area that was decreased rapidly from 70.59sq.km to 35.17sq.km in 18 years. Shallow water was also increased from 5.5sq.km to 18.90sq.km during the same time span.

From the accuracy assessment, it has been observed that maximum producer's accuracy was obtained in built up, vegetation and shallow water, whereas the maximum user's accuracy was obtained in class of soil, sand, and shallow water area (2000, 2010, 2018).

The overall accuracy of 85% and Kappa co-efficient 81.25% has been obtained from the assessment. The built-up area showed the lowest user's accuracy in 2000 map (37.5%) due to the low resolution of the image. In the classified map of 2010, the highest producer's accuracy was found in built up, soil and shallow water area and accurate user's accuracy was reflects in vegetation, sand and shallow water area with 95% overall accuracy and 93.67% Kappa co-efficient. The classified image of 2018 remarked the highest producer's accuracy in vegetation, sand and shallow water area and highest user's accuracy reached in vegetation and soil area where the overall accuracy was 90% and Kappa co-efficient accuracy was 87.43% (Table 2).

CONCLUSION

The use of remote sensing data to find out the erosion – accretion patterns and LULC changes has been presented in this work. The research presented multi-temporal LULC status of the study area with coverage of 143sq.km and it also presented shoreline shifting analysis for a length of 70.04 km. Over the last 18 years the entire area has been facing shoreline advance and retreat related problems, resulting in destructions to the environmental situation of the coastal area. The entire area under observation had been broadly divided into three "littoral zones" (LZ I to LZ III). The LZ I zone shows an average negative LRR value of -0.45 m/year and positive change rate value of 15.5 m/year. The LZ I also showed erosion of -1 m/year LRR and 10.15 m/year positive LRR change values. The LZ III was under accretion and erosional situation. The erosion change rate was found an average of -2.22 m/year and accretion change rate was 32 m/year LRR value. The LULC analysis showed that maximum built-up areas were concentrated in LZ 1 and built-up areashave been enhanced after the year 2000. Subarnarekha estuary to Digha estuary area observed immense pressure of urbanization from 2010. From these three LZ maps it could be observed prominently that shallow water was increased from 2010 to 2018. Finally, the present work shows the shoreline changes and prepares LULC maps that will play a very significant role for decision makers to identify and protect the susceptible zones and invent better mitigation methods for associated coastal problems.

ACKNOWLEDGEMENT

I would like to express my special thanks to Irrigation & Waterways Department and River Research Institute, West Bengal, India for their cooperation in date collection and field survey. I am thankful to Mr. Amiya Bera, Deputy Director (Structure), Irrigation & Waterways Department, West Bengal, Kolkata and Dr. Bibhas Chandra Barman, Deputy Director, River Research Institute, Mohanpur, Nadia, West Bengal, India for their heartfelt contribution. I also thankful to Mr. Bimal Adak, field investigator at Digha, (RRI) West Bengal, India for his support during field visit.

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