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GIS-Based Analysis and Modeling of Coastline Erosion and Accretion along the Coast of Sindh Pakistan

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Abstract

To investigate coastline changes, more research remains to be done on the development and use of innovative and functional geospatial techniques and procedures. This research focused on the integration of remote sensing, Geographic Information Systems (GIS) and modelling techniques to provide meaningful interrelationship on the spatial and temporal dynamics of coastline changes along Keti-Bunder and Kharo-Chann in Indus Delta. Data were extracted from Multi Spectral Scanner (MSS), Thematic Mapper (TM) and (Advanced Space borne Thermal Emission and Reflection Radiometer) ASTER images having the duration of thirty eight years starting from 1973 to 2011. Object based image analysis technique was used to extract the water on the criterion of (Normalized Difference Water Index) NDWI, (Modified Normalized Difference Water Index) MNDWI and threshold level slicing. Topographic maps were also used to extract the topographic information.

Digital Shoreline Analysis System (DSAS) was used to analyse and predict rates of coastline change. The correlation between the calculated values of shoreline using linear regression equation 2011 and the values which was extracted from the remote sensing data of the same year having the average percentage accuracy is almost 92%. It means linear regression can be used to model the coastal erosion and accretion. The linear regression results highlighted temporal changes which are likely to occur along the coastline. Results showed that erosion rate of Keti-Bunder and Kharo-Chann is 16.54 and 63.79 meter per year along the coastline respectively. The areas which can be eroded and accreted in year 2020 will be almost 28.6 square kilometres and 3.6 square kilometres respectively.

Keywords: GIS; Remote sensing; Linear regression; Coastline prediction; Coastal erosion; Accretion; Modelling

Introduction

Shoreline mapping and monitoring plays a very fundamental role to manage coastal resources, environment, navigation and sustainable coastal development and planning as well. Researchers integrate the geospatial techniques with statistical algorithms to better understand the dynamics of coastline changes and predict the trend for future now a day [1]. There are several studies which apply the Geographic Information system based approaches to obtain the better idea for short term and long term changes in coastal and marine environment. GIS is not only useful to test the model but also provide us the visual information regarding the coastline changes (Table 1). This research used GIS to analyze the coastline variation through remote sensing data for investigates the coastal dynamics [2]. DSAS is used to predict the coastline changes. Geo-spatial techniques are very useful and functional for the pointing and management of vulnerable coastal locations susceptible to erosion and rising water levels Figure 1.

Study area

Pakistan coast is the part of sub continental coastal stretch. The total stretch of the coastline of Pakistan is almost 1000 km out of which 250 km lies in the Sindh province. This 250 km stretch mainly comprise on mud flats and creeks. Stretch under consideration in this study is 95 km out of 250 km. administratively, this area belong to the Keti-Bunder and Kharo-Chann tehsil of Thatta district Sindh province Pakistan and geographically it bounds from 67º45″ to 67º17″ longitudes and from 24º46″ to 24º20 (Figure 2). These lie in Indus Delta which is the 5th biggest delta of the world [3-5]. Indus River passing through the area and finally reach the Arabian Sea, it experiences the highest wave energy of any river in the World. There are many warehouses to export the marine food.

Materials and Methods

With the knowledge that remotely sensed satellite data are reliable for monitoring the land cover changes and configuration of coastlines. Procedures which were involved in this study as shown in the flow chart. Landsat images and ASTER image of the study area were used to extract coastlines for various time periods. Coastlines were extracted from Landsat MSS, TM for the time periods 1973, 1977, 1992, 2000 and ASTER image for 2011. MSS and TM imagery acquired from Global Visualization Viewer (GLOVIS) and ASTER image of 2011 was granted by the WWF-Pakistan for the sake of research purpose.

All images were projected in UTM Zone 42N. MSS has four reflectance bands whereas TM has six reflectance bands having a spatial resolution of 60 and 30 meter respectively. ASTER has three reflectance bands having 15 m spatial resolution.

Digital Image Processing Software Earth Resources Data Analysis System (ERDAS) Imagine 9.2 were used to rectify the images geo-metrically and correct the images radio-metrically. Before the coastlines were extracted from the satellite images, the researcher reviewed several coastline extraction and change detection techniques, among them the NDWI, Threshold level slicing, Density slicing, Tasseled

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S. No.	Path / Row	WRS	Satellite	Sensor	Year of Acquisition	Tidal Height (m)	Resolution	
							Spatial Resolution	Spectral Resolution (No. of Bands)
1	152 / 43	2	Terra	ASTER	2011	1.63	15	3
2			Landsat	TM	2000	0.82	30	6
3					1992	1.93		
4	163 / 43	1		MSS	1977	1.85	60	4
5					1973	0.76		

Table 1: Description of satellite images.

Cap Transformation, Morphological segmentation algorithms, Band rationing, MNDWI and Object based image analysis.

The decision was made to use different techniques used for different resolution of the satellite images. So NDWI, MNDWI and threshold level slicing algorithms were selected to extract the water from MSS, TM and ASTER sensors respectively [6-9]. NDWI is the ratio of the difference between green and NIR band to the sum of green and NIR band as shown in equation.

NDWI= Green + NIR/Green - NIR

MNDWI is also the ratio but researcher replaces the NIR to MIR in the to obtain the better extraction of the water from land and the formula of NDWI modified.

MNDWI= Green + MIR/Green - MIR

Object based image analysis (OBIA) technique was used to extract the water on the criterion of NDWI. MNDWI and threshold level slicing of the mean value of the third band of the ASTER imagery. Multi-resolution segmentation algorithm was used to create the segment for the automatic extraction of water. Binary data was converted in to vector line format using the ArcGIS 10.

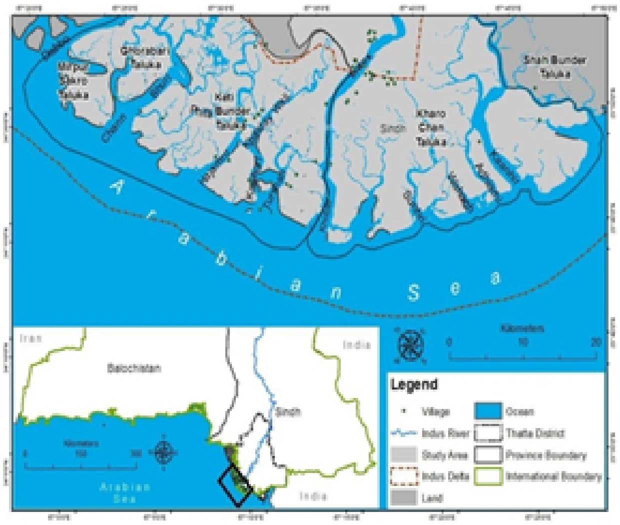

Figure 1: Estimated population of Keti in 2011.

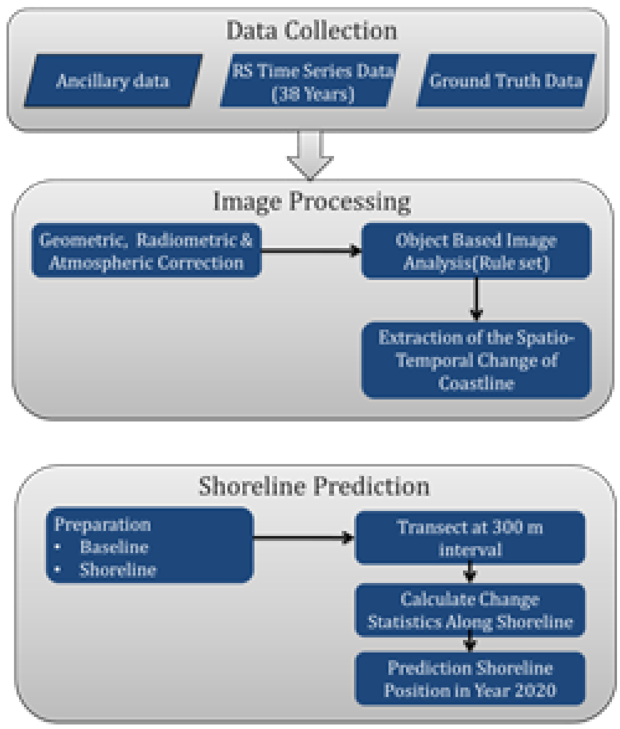

Figure 2: Flow chart.

Digital shoreline analysis system (DSAS)

DSAS version 4.3 was used to calculate the true statistics of the erosion and accretion in the study area This model was a dynamically-segmented linear model with a 4D (four dimensional) system, including x, y, z and t (time). In brief, DSAS is an ArcGIS extension that is used to calculate the statistical details of the coastlines using multiple historic coastline positions. Output contained a distance measurement which was later used to computes a rate of change along each transect. A calculation of shoreline change was done using an estimated distance of shoreline movement and the rate of change. A summary of shoreline movement was undertaken and a prediction of future shoreline positions was carried out [10]. Shorelines were taken from Landsat MSS, TM and Terra ASTER during 1973-2011. An extrapolation of a constant rate of change was applied to predict future shoreline position. Total one hundred and eighty nine transects have been created at the interval of 300 m each to calculate the change in the coastline from the continuous offshore baseline. Coastline of 1973 was used as the baseline [11-13]. For this purpose apply the buffer tool from proximity analysis of ArcGIS 10 to develop the baseline. First 89 transect lie in Keti-Bunder and other are in Kharo-Chann Taluka. The length of each transect is seven kilometre and its starts from the baseline as shown in Figure 3.

Linear Regression Rate (LRR) of coastlines was calculated through the change statistics window in DSAS to predict the new position of coastline in the future. A linear regression rate-of-change statistic can be determined by fitting a least-squares regression line to all shoreline points for a particular transect [14-17]. The regression line is placed

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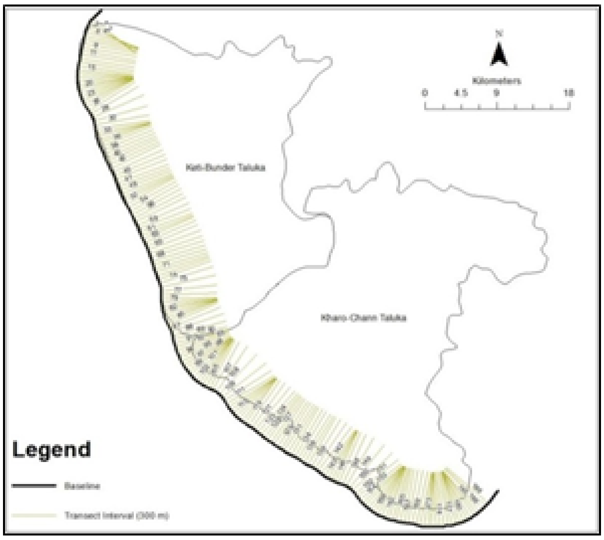

Figure 3: Map of the transect numbers allocated with the specified area along offshore baseline.

so that the sum of the squared residuals (determined by squaring the offset distance of each data point from the regression line and adding the squared residuals together) is minimized. The linear regression rate is the slope of the line. The method of linear regression facilitates the user to identify the trend and this method is purely computation and having the conceptual bases. The linear regression method was selected because in an evaluation of different algorithms (endpoint rate, minimum description length, linear regression, etc.) for coastal management purposes [18-20].

Linear Regression method was typically equal or better than the other techniques. Morton emphasized that the linear regression method was the most statistically robust quantitative method that could be applied for expressing rates of change. The linear regression was used to calculate rate of change at each of the 189 transects [21-24]. A linear model was used to account for the trend in extrapolating historical and future coastline positions.

The linear trend was determined by fitting a regression line to the coastline positional data using the equation.

$$Y = mX+B$$

Where Y denotes the coastline position, m is the rate of coastline movement, X is the date, and B is the intercept. Intercept and rate was the constant quantities, Whereas Y is the dependent variable and X is the independent variables in this linear equation. Position of the coastline depends upon the time so if time X is change the position of the coastline Y change, m and B controlling factors which remains constant for each transect [25]. This expression was applied on all 189 transect to calculate the linear regression for each transect.

Results

Rate of change was calculated from the DSAS but the intercept value was obtained after fitting a linear trend to the data for the 189 transects. LRR for transect 1 as shown in the Figure 4.

The coastline of 1977 was retreat as compared to 1973. From 1977 to 1992 it was sustain but when we move from 1992 to 2000, advancement of the coastline was observed relative to 1992. The coastline of 2011 was again retreat. So, this method provides the trend of the coast at this transect throughout thirty eight year time span.

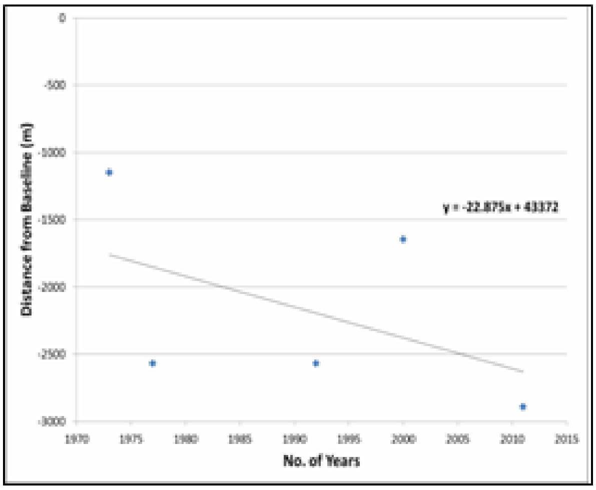

Figure 4: Linear regression rate for transect 1.

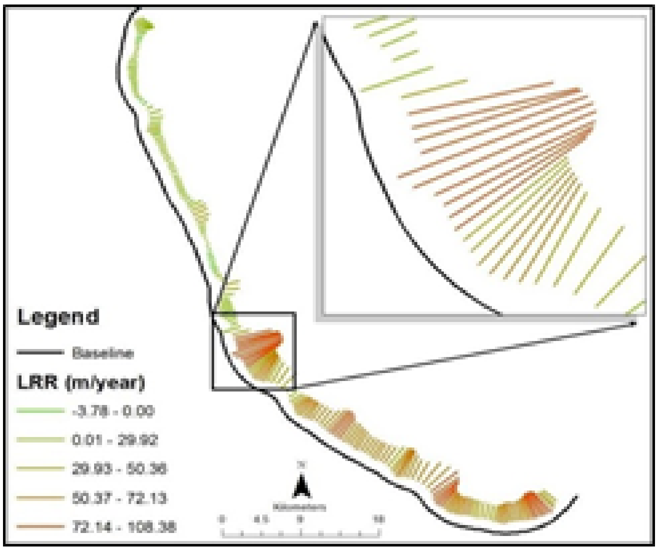

Figure 5: Linear regression rate for the study area.

LRR calculates the value on the basis of cyclic trend. There are only ten transect which show the positive trend and these all are lies in the Keti-Bunder Taluka, therefore it is observed that there are some areas in Keti-Bunder where accretion is taking place. Transects where accretion prevails are 7, 8, 26, 27, 66, 67, 68, 69, 70 and 71 as shown in Figure 4. The maximum value of the accretion is 3.78 m/year and it is observed on the transect 27. The minimum value is 0.29 observed on the transect 7. The results of linear regression show that the maximum erosion in the study area was 108.38 m/year and the maximum accretion is 3.78 m/year as shown in Figure 5. Overall statistical details of LRR of the study area are shown in Table 2.

Accuracy assessment

In the study it is found that the correlation between the predicted values of shoreline 2011 and the values which was extracted from the remote sensing data of the same year having the average percentage accuracy is almost 92%. It means the values which were extracted from

Name of Talukas	Transect			Maximum	Minimum	Mean	Comments
	Start No.	End No.	Total	Erosion (m/year)			Relative Erosion
Keti-Bunder	1	89	89	89.99	-3.78	16.54	Low
Kharo-Chann	90	189	100	108.38	14.9	63.79	High

Table 2: Statistical values of linear regression rate of study area.

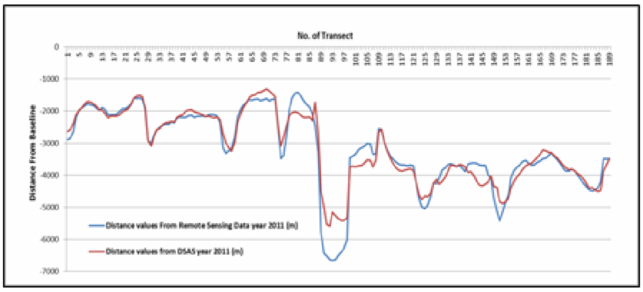

Figure 6: Graphical representation to show the overlapped areas along the study area.

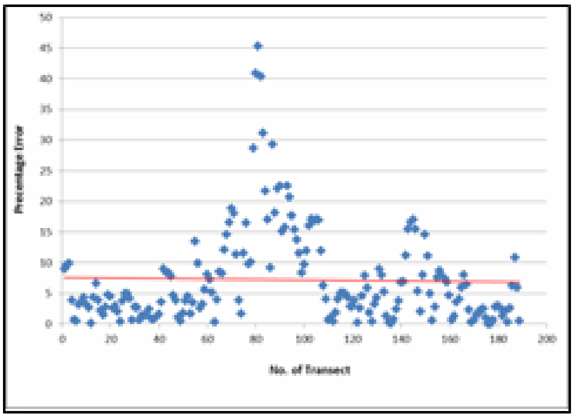

Figure 7: Percentage error along each transect.

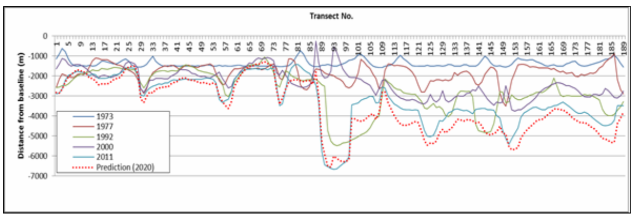

Figure 8: Graphical representation of the predicted coastline 2020.

satellite image and those values which were calculated through the model are in close agreement.

In Figure 6 blue and red lines show the distances determined from remote sensing data sets and the values which have been calculated using DSAS along every transect having interval of three hundred meter respectively.

The average percentage error of the transect shown in the Figure 7, and the average error of the whole data set was almost 7.62% which change the value from one transect to another transect. It means that linear regression is very much suitable for the prediction of the coastline of the study area.

Coastline prédiction for year 2020

Linear regression equations for each transects were processed to calculate the spatial position for the next nine years. Microsoft Excel was used to predict the values from the equation and create the graphs for the graphical representation and shown in Figure 8.

To map the predicted coastline 2020, there was a need to assign it its geographic coordinate on the basis of the distances which was calculated from the model for each transect. This task was done in ArcGIS 10 as shown in Figure 9. Calculation shows that the areas which can be eroded and accreted in year 2020 will be almost 28.6 square kilometre and 3.6 square kilometre respectively. Figure 10 shows the areas where erosion and accretion take place throughout the study area.

Discussion

In the time span of thirty eight years, there had been occurring many changes along the coastline. The position of the coastline may change with respect to the time. Some portions of the coast always retreat but some portions have the cyclic trend and some have sustains their positions. To understand the trend of coastline there is a need to put a glance on satellite images. Divide the whole area in three sets to understand the movements of the coastline briefly (Figure 11).

Set A

This area is under the high pressure of erosion. It is due to the shape of the coastline and there is no source of sediments. Results suggest that concave shoreline-segments experience more erosion than convex and straight ones. Throughout the time span of thirty eight years this area of the land continuously eroded and still on. On the left side the rate of erosion relatively less than on the right side it may be due to the thick mangrove forest which consolidates the land (Figure 12).

Set B

Area under the set B is very much important for the discussion point of view. Mouth of the Indus River changes its position according to time. River mouth moves in the direction of the arrow. From 1973 to 1977, was observed only the erosion. No change observes in the position of the river mouth but when we move from 1977 to 1992 the river divide its mouth in two branches as shown in Figure 13. Movement of the river mouth may be the responsible for the complex trend in the erosion and accretion. There is observed the erosion and accretion phenomena side by side in the set B.

Set C

The phenomena of erosion and accretion are observed but the rate of erosion is less than the area which covers in Set A. In this set accrétion is also take place at different sites but accretion rate is relatively low as compared to erosion rate so, the cumulative effect is the erosion. Accretion take place due to the sediment deposition and the source of it is the Indus River. Usually the huge amount of Indus water fall in Arabian Sea in the season of monsoon and in this season, there is

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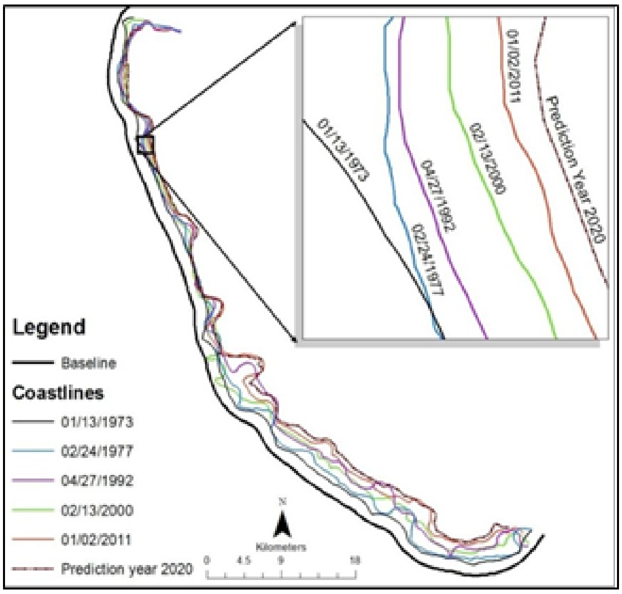

Figure 9: Geographical representation of the predicted coastline 2020.

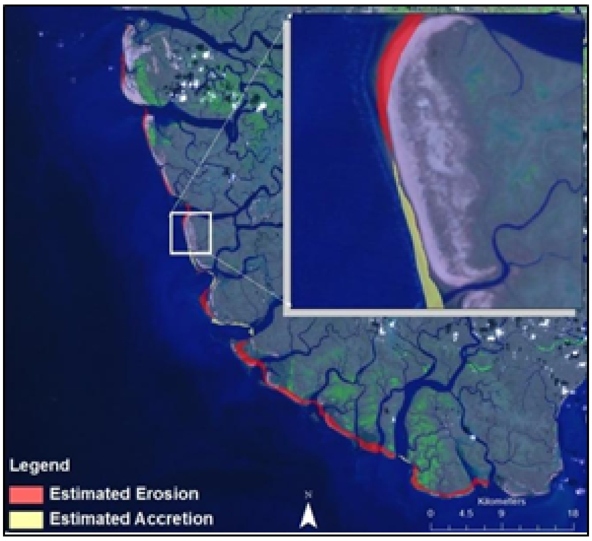

Figure 10: Estimated erosion and accretion up to year 2020.

another current which has the reverse direction of the Somalia current. This current has counter clockwise direction, so all the sediments which fall in sea deposit on the area which cover in Set C and it lies in the Keti-Bunder Taluka. It could be one reason of slow rate of erosion (Figure 14).

There are the statistical values of each set shown in the Table 3 to understand the overall morphological changes in the study area for the sites A, B and C. The pressure of erosion is dominant on the Kharo-Chann as compared to Keti-Bunder as per shown by the Figure 15.

Conclusion

It is very clear from the study that GIS and Remote Sensing techniques along with statistical modelling make it easy to identify, model and predict the changes in the coastline positions by the time.

Figure 11: Locator.

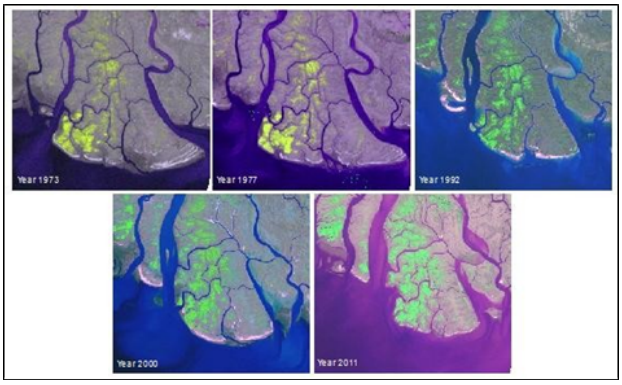

Figure 12: Change plates A (1973-2011).

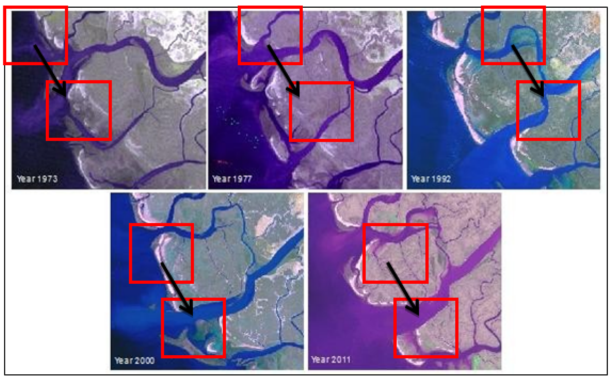

Figure 13: Change plates B (1973-2011).

Linear regression have been used in this study for the prediction of coastline advancement and retreat. This study has shown that the correlation between the predicted values of shoreline 2011 and the values which were extracted from the remote sensing data of the same year are in good agreement, having the average percentage accuracy,

Name of Set	Transect			Maximum	Minimum	Mean	Comments
	Start No.	End No.	Total	Erosion (m/year)			Relative Erosion
A	141	189	49	94.2	34.69	63.9	High
B	67	108	42	108.38	-3.71	41.2	Moderate
C	8	41	34	32.46	-3.78	16.39	Low

Table 3: Max., min. and mean values of LRR for sites A, B and C.

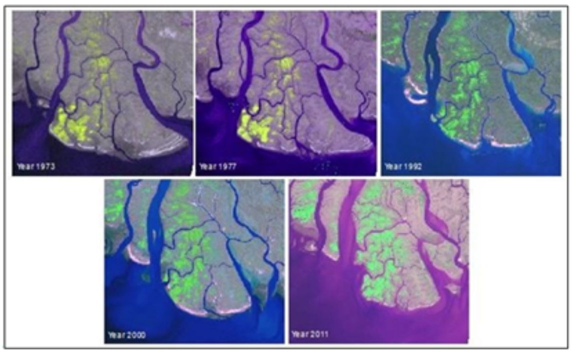

Figure 14: Change plates C (1973-2011).

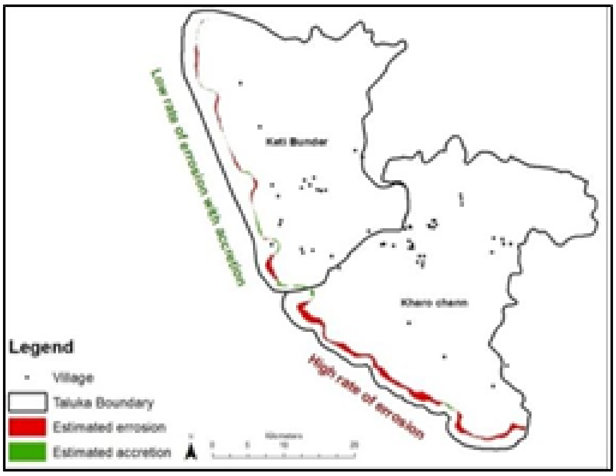

Figure 15: Estimated areas of erosion and accretion along village distribution.

almost 92%.

Mean value of LRR is almost 41.5 meter per year. Mean value of erosion for Keti-Bunder is 16.54 and Kharo-Chann is 63.79 meter per year. Almost 28.6 and 3.6 square kilometre land will be eroded and accreted up to the year 2020, respectively. Reduction in the annual sediment of Indus River may be one reason of the erosion along the study area. More villages are situated in Keti-Bunder as compared to Kharo-Chann, but those villages which are in Kharo-Chann are more vulnerable to erosion due to high erosion rate.

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