SHORT NOTE

Shoreline Change Analysis along the Coast of South Gujarat, India, Using Digital Shoreline Analysis System

Manik Mahapatra · R. Ratheesh · A. S Rajawat

Abstract Shoreline changes along the south Gujarat coast has been analyzed by using USGS Digital Shoreline Analysis System (DSAS) version 4.3. Multi-temporal satellite images pertaining to 1972, 1990, 2001 and 2011 were used to extract the shoreline. The High water line (HTL) is considered as shoreline and visual interpretation of satellite imageries has been carried out to demarcate the HTL based on various geomorphology and land use & land cover features. The present study used the Linear Regression Method (LRR) to calculate shoreline change rate. Based on the rate of shoreline changes, the coastal stretches of study area has been classified in to high erosion, low erosion, stable, low accretion and high accretion coast. The study found that about 69.31 % of the South Gujarat coast is eroding, about 18.40 % of coast is stable and remaining 12.28 % of the coast is accreting in nature. Field investigation was carried out which confirmed the coastal erosion/accretion derived from the analysis. The high erosion area are mostly found along the Umergaon (near Fansa, Maroli, Nargol, Varili river mouth, Umergaon light house) and Pardi (Kolak, Udwara)Taluka in Valsad district. Stable coastal length of the study area is 21.59 km and mostly found in Nani Dandi and near Onjal. High accretion (3.70 %) was only found near Hajira and low accretion (8.58 %) are distributed the study area. The main causes of coastal erosion of the study area were the strong tidal currents accompanied by wave action and reduced the sediment load of the river.

Keywords Shoreline change · DSAS model · HTL · Erosion

M. Mahapatra (✉) · R. Ratheesh · A. S. Rajawat
Geo-Sciences Division, Space Applications Centre (ISRO),
Ahmedabad 380015, India
e-mail: Mahapatra.sac@gmail.com

Introduction

The physical interface of land and water, called shoreline (Dolan et al. 1991) is considered to be one of the most dynamic region in the coastal area and the causes of shoreline changes are mainly attributed to the physical and anthropogenic processes (Chen et al. 2005). These changes occur over both long and short period of time and involve hydrodynamic, geomorphic, tectonic and climatic forces (Scott 2005; Thom and Cowell 2005). Therefore, the study of shoreline position is of utmost importance for management purposes like developmental planning, hazard zonation, academic endeavours, determination of erosion and accretion, estimation of regional scale sediment budgets etc. (Sherman and Bauer 1993; Zuzek et al. 2003). In recent years, satellite remote sensing data in conjunction with Geographic Information System (GIS) is being used in shoreline extraction and mapping [Lee and Jurkevich 1990; White and El Asmar 1999; Bertacchini and Capra 2010]. Synoptic viewing capability, multispectral observations, high resolution, repetitively and its cost effectiveness makes remote sensing data more preferable to the conventional techniques for detecting long-term shoreline changes and to know the evolution of the coastal and near shore areas.

Shoreline-change mapping was carried out for the entire Indian coast for the periods 1967–68, 1985–89 and 1990–92 using LANDSAT MSS/TM and IRS LISS II data on 1 : 250,000 and 1 : 50,000 scale (Shailesh 2002). Shoreline changes study along the different part of Indian coast has been carried out by many researchers by using remote sensing and GIS techniques such as Mani et al. 1997; Thanikachalam and Ramachandran 2003; Navrajan et al. 2005; Sathyanarayan et al. 2009; Pritam and Prasenjit 2010; Mujabar and Chandrasekar 2011;. Abdulla et al. 2011; Abhisek et al. 2011; Saranathan et al. 2011.

In the present study, the shoreline change along the south Gujarat coast was analyzed by using Digital Shoreline Analysis System (DSAS) version 4.3, an extension to ESRI Arc GIS v.10.1 (Thieler et al. 2009). The aim of the study are (a) identify the area where the significant coastal erosion is occurring and (b) quantifying the rates of shoreline changes along the study area, and (c) classification of coastal stretch based on the rates of shoreline change into erosion, accretion and stable. The Digital Shoreline Analysis System (DSAS) is a open source software that works within the Environmental Systems Research Institute (ESRI) Geographic Information System (Arc GIS) software. DSAS computes rate-of-change statistics for a time series of shoreline vector data. The DSAS require the following inputs (a) multiple shoreline positions (b) a user-generated baseline (c) DSAS generates transects that are cast perpendicular to the baseline at a user-specified spacing alongshore. This transects/shoreline intersections along this baseline are then used to calculate the rate-of change statistics. There are various methods to calculate the shoreline change such as Shoreline Change Envelope (SCE) and Net Shoreline Movement (NSM), End Point Rate (EPR), Linear Regression Rate (LRR), Weighted Linear Regression

Rate (WLR), and Least Median of Squares (LMS). The standard error, correlation coefficient, and confidence interval were also computed for the simple and weighted linear-regression methods. The results of all rate calculations are output to a table that can be linked to the transect file by a common attribute field.

The present study uses Linear Regression Rate (LRR) to calculate the shoreline change rate. LRR can be determined by fitting a least-squares regression line to all shoreline points for a particular transects. The regression line is placed 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 main features of LRR method is that: (a) all the data are used, regardless of changes in trend or accuracy, (b) the method is purely computational, (c) calculation is based on accepted statistical concepts, and (d) the method is easy to employ.

Study Area

Coastline of about 117.31 in South Gujarat (three district of Gujarat; Surat, Navsari, Valsad and Daman, Union territory) has been investigated in the present study (Fig. 1). The geographical extends is from 21°05′12.60″N to 21°10′26.16″N latitude and 72°35′48.69″ E to 73°03′29.76″ E longitude. The coast line of the study area is comparatively uniform and broken by few indentions. Narrow sandy beach is present between Mindhola and Purna rivers and extens up to Daman. Mudflats, 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. South Gujarat receives much of its rainfall from the Southwest monsoon during the period between June and September, its maximum intensity being in the months of July and August. The major rivers of the study area are Damanganga, Kolak, Par, Purna, Auranga, Ambica and Mindhola which are comparatively smaller and rise within the boundaries of the state from the eastern trappean highlands.

Material and Methodology

Data Used

In the present study, we used Landsat MSS of January, 1972, TM January, 1990, ETM of January, 2001 and Indian remote sensing satellite IRS P6 (Resourcesat-2), December, 2011 for
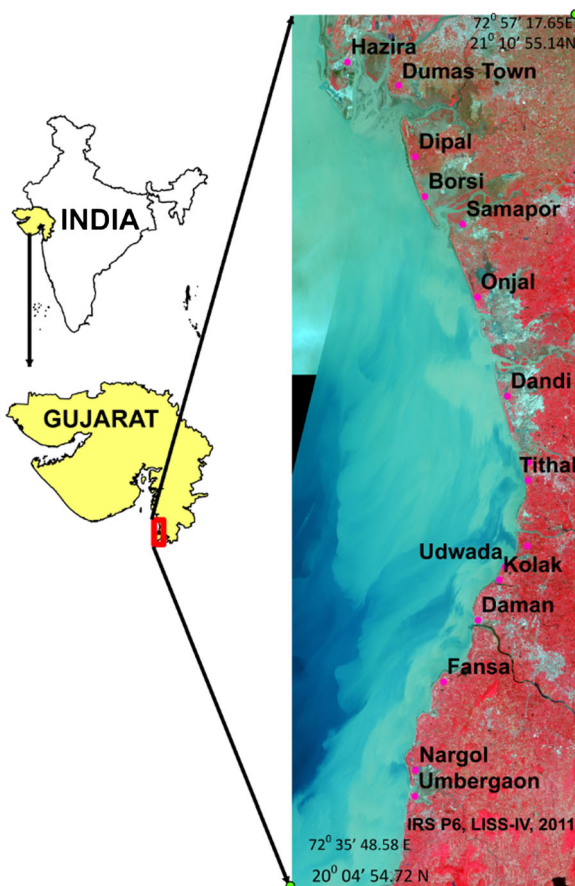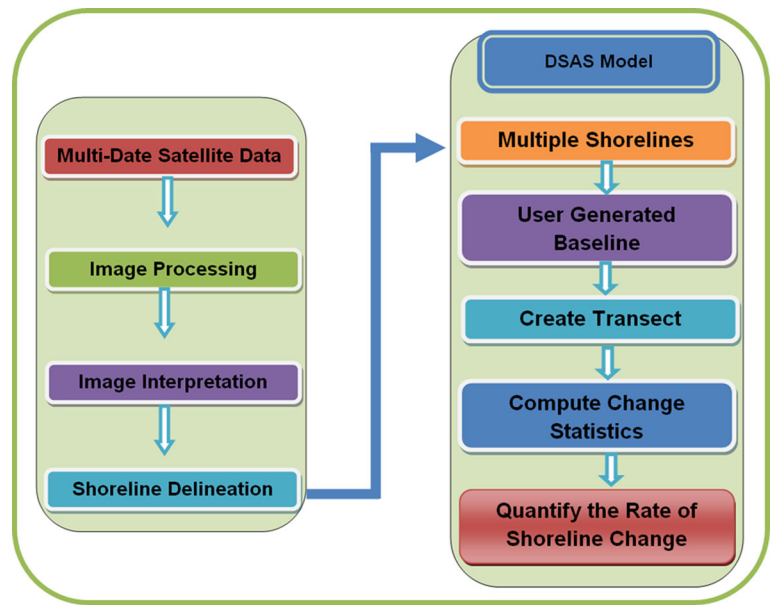

Fig. 1 Study area

Fig. 2 Methodology of the study

monitoring shoreline changes along the south Gujarat coast (Table 1).

Pre-Processing of Satellite Imagery

Four satellite imageries of the years 1972, 1990, 2001 and 2011 have been considered in this study. Landsat MSS and TM data sets have been acquired from USGS [website http://glovis.usgs.gov]. IRS P6 LISS IV data has been procuring from NRSC [www.nrsc.gov.in]. The satellite data has been process in ERDAS IMAGINE s/w. All the data sets are projected in UTM projection with zone no 46 and WGS 84 datum. Satellite imagery of 1990 has been considered as base data and images of 1972, 2001 and 2011 have been co-registered using first order polynomial model with base data with 0.4 pixel (RMSE) accuracy. Normal false colour composites (FCCs) prepared using, bands 2, 3, 4 (Landsat MSS, TM and IRS p6 resourcesat-2, LISS IV) in contrast to black and white (B/W) images yield better discrimination for the wetlands and are, therefore, more suitable for mapping and delineation of shoreline. The satellite data has been enhanced linearly for better visualization and delineation of shoreline.

Shoreline Indictor

There are many shoreline indicators such as high water line, mean high water line, low water line, and mean tide line. The high water line (HWL) is the preferred indicator foe shoreline delineation due to easily photo interpretation, field-located (Crowell et al. 1991). High water line means the line on the land up to which the highest water line reaches during the

spring tide. The horizontal location of the mean high water line on a gentle sloping sandy beach, although precisely defined with respect to elevation, highly variables because the beach and foreshore are dynamic. Thus, the use of the high water line is a practical solution to locating the land/sea boundary in a dynamics environment (Pajak and Leatherman 2002).

Detection of Shoreline

In the present study high tide line (HTL) is considered as shoreline. There are different approaches to demarcate the HTL. They are tidal level projection and using morphological signatures (Thomas 2010). Remotely sensed satellite data are extensively used for detecting shoreline and to know the evolution of the coastal and near shore area because of their synoptic viewing capability, multispectral observations, high resolution, receptivity and its cost

Table 1 Details of satellite data

SATELLITE AND SENSOR	DATE OF ACQUATION	PATH & ROW	BAND USED	SPATIAL RESOLUTION (M)
LANDSAT MSS	11/10/1972	159–45	VNIR	60
	11/10/1972	159–46	VNIR	60
LANDSAT TM	19/10/1990	148_45	VNIR	30
	19/10/1990	148_46	VNIR	30
LANDSAT ETM	10/11/2001	148_45	VNIR	30
	25/10/2001	148_46	VNIR	30
IRS-P6 LISS-IV	02/11/2011	93/57/a	VNIR	5.8
	22/11/2011	93/56/c	VNIR	5.8

effectiveness in comparison to conventional techniques (Shailesh 2002).

In the present study, Satellite data has been interpreted to demarcate HTL based on various geomorphological and land use/land cover features like land-ward berm/dune crest, sea-walls or embankment, permanent vegetation line, landward side of mangroves, beaches, salt pans, high-tidal mud flats and salt marshes. Sea ward side of agricultural/horticulture land etc. are also used. Arc Map s/w was used to delineated the HTL.

Shoreline Change Assessment

The shorelines were carefully digitized and exported to shape-file format. The shorelines extracted were used as input for the DSAS model to calculate the rate of change. Baselines were constructed seaward and parallel to the general trend of all the shorelines. Transects with a spacing of 100 m apart and length 1000 m are used to estimate the different shoreline change rates (Fig. 3). With reference to the baseline, seaward shift of the shoreline along with the transect is considered as a positive

Fig. 3 Historic shoreline and DSAS- generated transect at 100 m spacing with histogram showing rates of shoreline change computed using Linear Regression Rate
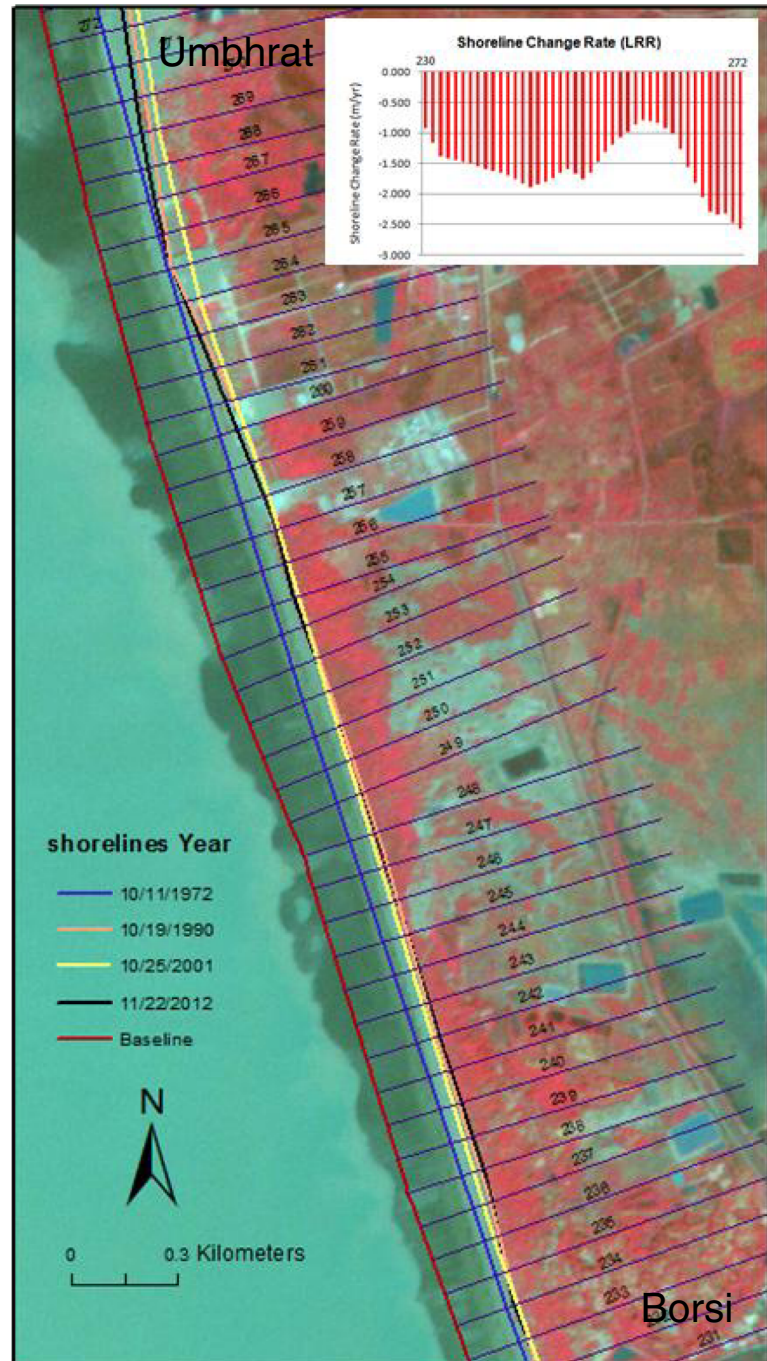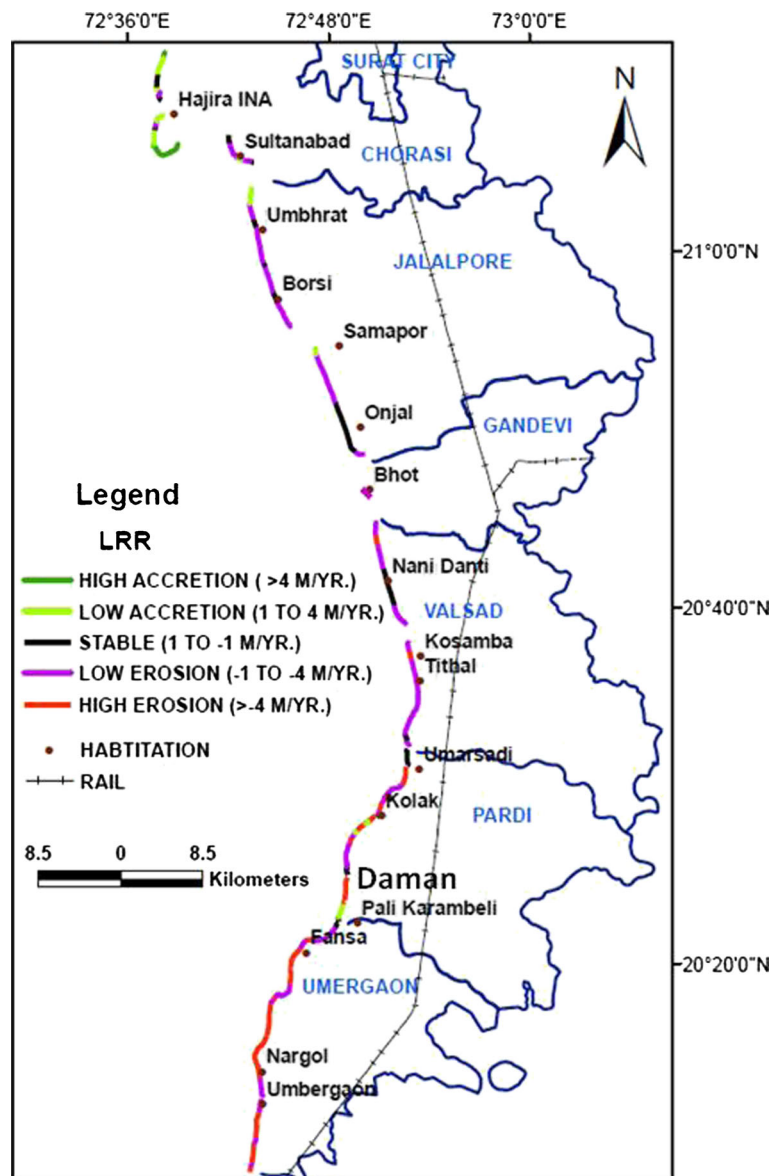
Fig. 4 Classification of coast based on LRR

value, while landward shift is consider a negative value. The rates of shoreline variations were calculated using the LRR method in GIS to \identify erosion, accretion and stable coast along the study area. Based on the rate of shoreline changes, the coastal stretches study area has been classified in to high erosion, low erosion, stable, low accretion and high accretion coast. During the fixation of range of rate of shoreline movement for erosion, accretion and stable coast could minimize the effects of tidal variation, satellite resolution and human error for digitizing shoreline. The methodology adopted for shoreline changes is shown in Fig. 2.

After the shoreline change detection field survey was carried out all along the study area. The aim was to collect more data and information from the field and interview the people from the study area. The people interviewed were asked about the status of the shoreline in relation to previous years. A

number of photographs were also taken of the study site using a digital camera in order to capture the area's current
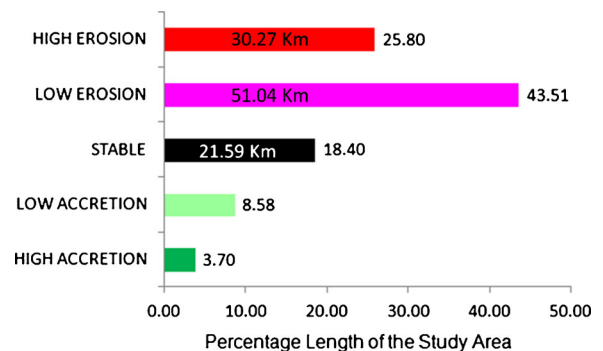

Fig. 5 Classification of coastal stretch of the study area based on LRR. Note that as much as 30.27 km long study area which makes up to 25.80 % of the total length of the coast is at high erosion

Fig. 6 Photos representing the coastal erosion along different sections of study area

Coastal erosion, Dandi

Onjal-Macchiwadd sea wall

Beach berms or terraces, Dandi

Sai Temple beach, Tithal

Kolak-Udwada sea wall

Protected reaches of Maroli

Umargam sea wall

Coastal erosion, Nargol

appearance. The photographs show some vivid examples of shoreline erosion from the ruins of buildings that had collapsed due to shoreline erosion and protection structure of the coast (Fig. 6).

Table 2 Statistics of different categories of coast

CLASSIFICATION OF COAST	SURAT DIST.	NAVSARI DIST.	VALSAD DIST.	DAMAN UT	EXTENT IN KM	PERCENT OF COAST
HIGH ACCRETION	4.34	0.00	0.00	0.00	4.34	3.70
LOW ACCRETION	4.19	3.73	0.15	2.00	10.07	8.58
STABLE	1.68	13.46	4.68	1.77	21.59	18.40
LOW EROSION	1.87	20.74	25.38	6.05	51.04	43.51
HIGH EROSION	0.00	0.00	18.08	9.19	30.27	25.80

Results and Discussion

The shoreline of the study area is about 117.31 km which is distributed in part of three district of Gujarat namely Surat, Navsari, Valsad and Daman, Union territory. Based on the rate of shoreline changes of LRR method, the coastal stretches of the study area has been classified in to five categories. These are high erosion (>− 4 m/yr), low erosion (>− 1 to <− 4 m/yr), stable (− 1 to 1 m/yr), low accretion (>1 to < 4 m/yr), and high accretion (> 4 m/yr) coast (Fig. 4).

The study find that about 25.80 % of the study area over a length of 30.27 km (Fig. 5) is under high erosion categories mostly along the Umergaon (near Fansa, Maroli, Nargol, Varili river mouth, Umergaon light house) and Pardi (Kolak, Udwara)Taluka in Valsad district. About 51.04 km long coastal segment which account for 43.51 % of the total length are under low erosion category mostly along the Jalalpore Taluka (Umbhrat, Borsi) in Navsari district and Valsad Taluka (Pardi, Tithal) in valsad district. Stable coastal length of the study area is 21.59 i.e., 18.40 % of the total length of the study area and mostly found in Nani Dandi and near Onjal. High accretion (3.70 %) is only found near Hajira and low accretion (8.58 %) are distributed within the study area. Analysing the LRR results, the study find that erosion is dominant in the region which is about 69.31 %. The district wise statistic of different categories of coast is shown in Table 2. The coastal length of Valsad district is 48.29 km out of which 43.46 km is eroding. For the 37.93 km length of coast in Navsari district, low erosion is found for 20.74 km and stable length is 13.46 km. Surat district has about 12.08 coastal lengths and is observed to be mostly accreting in nature. Daman coastal length is 19.01 km, out of which 15.24 km length in eroding.

The study found that the coastal erosion is a major problem in the study area. To find out the causes of coastal erosion the study analysed significant wave height, tidal data along the study area. The predicted tide data has been taken from the MICK 21 c map model and the significant wave data has been taken from the spectral wave model in MICK 21 s/w along the south Gujarat coast. The study found that the maximum tidal height and significant wave height increase from northern side i.e. near Hajira to southern side i.e. near Umergaon. The maximum tidal height near Hazira and Valsad are 5.78 m and 7.77 m respectively where as the maximum significant wave height near Hazira is 0.97 and near Valsad is 2.47 m. Based on 20 years of monitoring at various gauging stations, Gupta and Chakrapani 2007, reported that due to the construction of dam and reservoir on Narmada river the suspended sediment flux has significantly decreased. A decrease in suspended sediment load to the river through damming results in an increase in coastal erosion and deterioration of coastal marine ecosystems. So the study found that the Strong tidal currents accompanied by wave action and reduced in sediment input from the river are the possible reasons for the long stretch of eroding shore line in the study area. This large scale erosion in terms of time frame and extent may also be due to sea level rise or tectonic movement. During the field visit it was found the there a large stretch of coastal protection structure in different part of the study area (Fig. 6). The severity of erosion is alarming and draws immediate attention.

Conclusion

Analysis of the results suggest that the use of remote sensing data with the integration of GIS technology and USGS DSAS model are very suitable for extraction of shoreline and monitoring the shoreline change analysis. The present DSAS shoreline change analysis indicated that erosion is predominant in the study area and erosion in Valsad district was more compared to Navsari and Surat district. During the field visit it was found that a lot of construction work is going on to protect the coastal erosion. So it need to recent data of high resolution satellite data to find out the recent coastal erosion and monitoring in details.

References

Abdulla, P. K., Sanma, J., & Joseph Mish, N. K. (2011). Seasonal and medium term changes in the shoreline position at selected stations on Malabar coast, Kerala, ISH. *Journal of Hydraulic Engineering, 17*(1), 1–11.

Abhisek, S., Mitra, D., & Shreyashi, M. (2011). Spatial modelling using high resolution image for future shoreline prediction along Junput Coast, West Bengal, India. *Geo-Spatial Information Science, 14*(3), 157–163.

Bertacchini, E., & Capra, A. (2010). Map updating and coastline control with very high resolution satellite images: application to Molise and Puglia coasts (Italy). *Italian Journal of Remote Sensing*. doi:10.5721/ItJRS20104228.

Chen, S., Chen, L., Liu, Q., Li, X., & Tan, Q. (2005). Remote sensing and GIS based integrated analysis of coastal changes and their environmental impacts in Lingding Bay, Pearl River Estuary, South China. *Ocean &Coastal Management, 48*, 65–83.

Crowell, M., Leatherman, S. P., & Buckley, M. K. (1991). Historical shoreline change: error analysis and mapping accuracy. *Journal of Coastal Research, 7*, 839–852.

Dolan, R., Fenster, M. S., & Holme, S. J. (1991). Temporal analysis of shoreline recession and accretion. *Journal of Coastal Research, 7*, 723–744.

Gupta, H., & Chakrapani, G. J. (2007). Temporal and spatial variations in water flow and sediment load in the Narmada river. *Current Science, 92*(5), 679–684.

Lee, J., & Jurkevich, I. (1990). Coastline detection and tracing in SAR images. *IEEE Transactions in Geosciences and Remote Sensing*. doi:10.1109/TGRS.1990.572976.

Mani, J. S., Murali, K., & Chitra, K. (1997). Prediction of shoreline behaviour for madras, india-a numerical approach. *Ocean Engineering, 24*(10), 967–984.

Mujabar, S., & Chandrasekar. (2011). A shoreline change analysis along the coast between Kanyakumari and Tuticorin, India, using digital shoreline analysis system. *Geo-Spatial Information Science, 14*(4), 282–293.

Navrajan, T., Biradar, R. S., Madhavi, P., & Sunit, C. (2005). A study on shoreline changes of Mumbai coast using remote sensing and GIS. *Journal of the Indian Society of Remote Sensing, 33*(1), 85–91.

Pajak, M. J., & Leatherman, S. (2002). The high water line as shoreline indicator. *Journal of Coastal Research, 18*(2), 329–337.

Pritam, C., & Prasenjit, A. (2010). The Shoreline change and sea level rise along coast of Bhitarkanika wildlife sanctuary, Orissa: an analytical approach of remote sensing and statistical techniques. *International Journal of Geomatics and Geosciences, 1*(3), 436–455.

Saranathan, E., Chandrasekaran, R., Soosai, M. D., & Kannan, M. (2011). Shoreline Changes in Tharangampadi Village, Nagapattinam District, Tamil Nadu, India—A Case Study. *Journal of the Indian Society of Remote Sensing, 39*(1), 107–115.

Sathyanarayan, R. S., Elangovan, K., & Suresh, P. K. (2009). Long term shoreline oscillation and changes of Cauvery delta coastline inferred from satellite imageries. *Journal of the Indian Society of Remote Sensing, 37*(1), 79–88.

Scott, D. B. (2005). Coastal changes, rapid. In M. L. Schwartz (Ed.), *Encyclopedia of coastal sciences* (pp. 253–255). Dordrecht: Springer.

Shailesh, N. (2002). Use of satellite data in coastal mapping. *Indian Cartogrraphy., CMMC-01*, 147–156.

Sherman, D. J., & Bauer, B. O. (1993). Coastal geomorphology through the looking glass. *Geomorphology, 7*, 225–249.

Thanikachalam, M., & Ramachandran, S. (2003). Shoreline and coral reef ecosystem changes in gulf of Mannar, Southeast coast of India. *Journal of the Indian Society of Remote Sensing, 31*(3), 157–173.

Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., & Ergul, A. (2009). Digital Shoreline Analysis System (DSAS) version 4.0— An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Repot.

Thom, B. G., & Cowell, P. J. (2005). Coastal changes, gradual. In M. L. Schwartz (Ed.), *Encyclopedia of coastal sciences* (pp. 251–253). Dordrecht: Springer.

Thomas, K.V. (2010). Setback lines for coastal regulation zone- different approaches and implications, paper presented at the seminar on CRZ −2010 drafts: responses and challenges, organised by ICG, NIO & GCCI.

White, K., & El Asmar, H. (1999). Monitoring changing position of coastlines using Thematic Mapper imagery, an example from the Nile Delta. *Geomorphology*. doi:10.1016/S0169-555X(99)00008-2.

Zuzek, P. J., Robert, B. N., & Scott, J. T. (2003). Spatial and temporal considerations for calculating shoreline change rates in Great Lakes Basin. *Journal of Coastal Research, 38*, 125–146.