

Assessment of shoreline changes along Karnataka coast, India using GIS & Remote sensing techniques

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Present analysis revealed that about 70% of the coastline was either stable or accreting in nature, whereas remaining 30% region was experiencing varying magnitude of erosion. Change rate was classified in three categories indicating the accretion, low erosion and high erosion locations. High rate of erosion was observed all along the river mouth of northern side of northern Karnataka Rivers i.e. Kalinadi, Haladi, Sharavati, Swarna etc. While the southern side of the Kalinadi River is noticed with high accretion. Erosion and accretion pattern observed along the coast is influenced mainly by the coastal process and riverine inputs. Short term analysis was also carried out along the Karnataka coast. In Karwar region, the south of Kalinadi River shows accretion during the period of 1989-2000; whereas, the same area shows erosion pattern during the period of 2000-2006. This may be due to variation in coastal processes, land runoff and geomorphologic units influencing the coast. About 168 km of coastline was found to be accreting in nature with an average rate of 1.5 m/yr followed by 71km coastal stretch with mild erosion of an average rate of 1.0 m/yr. It was also observed that the erosion was found in isolated pockets throughout the coast. The variation in river mouth morphology was quite significant. The present study demonstrates that combined use of satellite imagery and statistical method such as weighted linear regression can be a reliable method for shoreline change analysis.

[Keywords: Satellite images, Erosion and Accretion, Weighted Linear Regression Rate and End Point Rate]

Introduction

A shoreline is idealistically defined as the interface of land and water^{1,2}. Shoreline change is considered as one of the most dynamic processes in the coastal area³⁻⁵. The evolution of coastal systems is controlled by various factors viz., morphology and geology of the catchment, the size of the catchment area, nature of sedimentation basin, climate leading to rainfall and river discharge at coastal zone, freshwater input and coastal hydrodynamics - waves, tides and currents⁶. Wind, waves and currents are natural driving forces that easily move the unconsolidated sand and soils in the coastal area, resulting in rapid changes in the position of the shoreline. The coastal systems have also been affected by several developmental activities such as ports, industries, aquaculture farming and other human intervention in the form of coastal defences. Thus, it is not possible to ascertain the complex morpho-dynamic pattern of any coast by hydrodynamic modeling alone.

Remote Sensing and Geographical Information System (GIS) techniques⁷ have been widely employed in various coastal morphodynamic studies as they are cost effective, reduce manual error and are useful in

the absence of field surveys. The applications of remote sensing and GIS have proved particularly effective in delineation of coastal morphology and coastal landforms, detection of shoreline positions⁸⁻¹⁵. The location of the shoreline and its historical rate of change can provide important information for the design of coastal protection, plans for coastal development, and the calibration and verification of numerical models, etc¹⁶.

The main purpose of the work is to provide systematic historical information on shoreline change along the Karnataka coast using multi-resolution satellite data (Landsat (MSS, TM & ETM+)) and Geographic Information System (GIS). Digital Shoreline Analysis System (DSAS) version 4.2¹⁷, an extension of ESRI ArcGIS software was used to calculate shoreline rate of change statistics from a time series of multiple shoreline positions. Both long term period and short term period shorelines were analyzed. For long term shoreline analyses, LRR and WLR were selected as they are most statistically robust quantitative methods when a limited number of shorelines are available¹⁸. In the present study, WLR statistical method is used for long term change

analysis because it takes uncertainty field into account to calculate the long-term rates of shoreline change. For short term, EPR method is adopted.

Materials and Methods

The coastline of Karnataka stretches about 280 km between Mangalore in Dakshina district and Karwar in Uttara Kannada district. Karnataka lies within 11°30' North and 18°30' North latitudes and 74° East and 78°30' East longitude as shown in Fig. 1. The coastline of Karnataka has been along the eastern shore of Arabian Sea. The coast has one major and ten minor ports in their coastal belt. It is one of the most indented coasts with numerous river mouths, lagoons, bays, creeks, cliffs, spits sand dunes and long beaches. Sea erosion, migration of river mouths, siltation of ports and harbours are the prominent problems along this coast. Fourteen rivers drain into the Arabian Sea. The important estuaries include Netravati-Gurpur, Gangolli, Hangarkatta, Sharavthi, Aganashini, Gangavali and Kalinadi.

Multi-resolution satellite data such as Landsat MSS, Landsat TM and Landsat ETM+ of different dates have been acquired, as same resolution data is not available over the chosen period (Table 1). Estimation of the rates of erosion and accretion along the Karnataka coast was performed for the studied periods.

Remote sensing satellites images have been used effectively for coastal shoreline change monitoring along the coast. Interpretation of shoreline position is a difficult task due to the fact that coastal environment are dynamic in nature and many other distortions associated with the images are to be rectified.

Rectification Process

Remote sensing data obtained by different satellites are usually geometrically distorted due to the acquisition system and the movement of the platform. A geometric correction of the image is required to compare an image with other existing maps or images. The images used here for analysis are of different satellite type with different sensors and spatial resolution. It is most important that all spatial

data are located with respect to a common frame of reference. For this, the satellite images were georeferenced with the aid of Global Positioning System (GPS) coordinates recorded from the selected known locations so that the images are corrected brought into a standard coordinate system. All the images were rectified using ERDAS IMAGINE geographic imaging software by placing at least ten well-spaced Ground Control Points (GCPs). Total root mean square error (RMSE) for the rectification process was maintained below 1 pixel. All the satellite images were converted to the Universal Transverse Mercator (UTM) projection on the World Geodetic Datum of 1984 (WGS 84).

Shoreline Extraction and Delineation

Recent advancements in remote sensing and Geographical Information System (GIS) techniques have led to improvements in coastal Geomorphological studies such as, semi-automatic determination of shorelines^{14,15}. These techniques are attractive, due to their cost-effectiveness, time consuming etc.



Fig. 1. Study Area

Table 1—Data used

List of Image	Pixel Size (m)	Date	Source
Landsat 1 MSS	60	03/01/1973	USGS
Landsat 5 TM	30	11/19/1989	USGS
Landsat 5 TM	30	04/01/1992	USGS
Landsat 7 ETM+	30	03/11/2000	USGS
Landsat 7 ETM+	30	11/07/2005	USGS
Landsat 7 ETM+	30	02/11/2006	USGS

Automatic shoreline delineation is a complex process due to the presence of water saturated zone at the land-water boundary^{8,14}. The shorelines were identified and delineated by processing the NIR bands of Landsat TM using 'Gray Level Thresholding' and by 'Edge Enhancement Technique'¹⁹. In the present study, the exact land-water boundary was obtained by using a nonlinear edge-enhancement technique with Sobel operator (3×3 kernel matrix). These operations were applied to the image data to produce an enhanced image output for subsequent visual interpretations. The enhancement techniques improve the feature exhibition and increases visual distinctions between features contained in a scene.

Geographical Information System (GIS)

Continuous shoreline positions were extracted automatically and digitized manually for six different periods i.e. 1973, 1989, 1992, 2000, 2005 and 2006. Digital Shoreline Analysis System (DSAS) version 4.2¹⁷, an extension of ESRI ArcGIS software was used to calculate shoreline rate-of-change statistics from a time series of multiple shoreline positions. The shoreline positions were compiled in ArcGIS with 5 attribute fields that included ObjectID (a unique number assigned to each transect), shape, shape length, ID, date (original survey year) and uncertainty values. All different shoreline features were then merged within a single line on the attribute table, which enabled the multiple coastline files to be appended together into a single shape file. The Shoreline change rate was calculated by End Point Rate (EPR) for short term and Weighted Linear Regression (WLR) for long term period. DSAS is purely a statistical approach. A baseline was digitized onshore by closely digitizing the direction and shape of the outer shoreline, which was used as the starting point for all transects cast.

Uncertainties and Errors

Several sources of error impact the accuracy of historical shoreline position. It is necessary to accurately estimate the errors and uncertainties associated with each shoreline. Here in the present study two statistical methods are adopted for shoreline analysis. To calculate Weighted Linear Regression Rate (WLR) it is necessary to estimate the errors of each shoreline separately. Three positional and four measurement errors were recently described²⁰⁻²⁴; for the historical shoreline positions digitized from aerial photographs and topographic maps. In the present study, 5 (Rectification error (E_r), Pixel error (E_p),

Seasonal error (E_s), Tidal error (E_{td}) and Digitizing error (E_d)) different errors were taken in to account for shoreline analyze. The 5 different sources of errors are summed in quadrature (the square root of the sum of the squares) to get a total positional uncertainty (Ut) associated with each shoreline. Finally, overall uncertainty value, was estimated for each shoreline by accounting for both positional and measurement uncertainties as given equation below:

$$Et = \pm \sqrt{E_s^2 + E_{td}^2 + E_r^2 + E_p^2 + E_d^2}$$

Two approaches were applied: a long-term analysis using six shorelines and a short-term analysis using two periods i.e. 1989-2000 and 2000-2006^{18,25,26}.

Results and Discussion

Long-term rates of shoreline change were calculated for entire study area at each transect for past 33 years i.e. 1989 to 2006 using EPR for (short-term) and WLR (long-term) methods.

The study area is divided into three region based on the district boundary. Totally 5600 transects were generated with 50 m spacing and the length of transects was 250 m. Long-term rates of shoreline change for 1973 to 2006 were calculated at each transect considering all six shoreline positions using Weighted Linear Regression (WLR) methods. In a weighted linear regression, more reliable data are given greater emphasis or weight towards determining a best-fit line. Karwar region shows low erosion to moderate accretion all along the region. Along the Kalinadi River, accretion was noticed on either side of the river. Along the Malpe region, accretion is seen on both side of the river mouth. The Northern side of the Sharavathi River mouth is shows erosion and the southern side shows accretion. High erosion was noticed at the northern side of the Sharavathi River²⁷. At the northern side of the Haladi River (Kundapur), accretion was noticed. Whereas, southern side of the river low erosion was observed²⁸.

Overall an average of 1.5 m/yr accretion was noticed all along the coast and about 1.0 m/yr moderate erosion along the Karnataka coast. The erosion and accretion pattern observed along the coast is influenced mainly by coastal process and riverine inputs. The variation in river mouth morphology was quite significant and changes in rate were more all along the river mouth. Figs. 2, 3 and 5 shows the shoreline change map of three coastal districts (Uttar Kannada, Udupi and Dakshina Kannada) of Karnataka.



Fig. 2—Shoreline change along Uttar Kannada district.



Fig. 3—Shoreline change for Udupi district

Further short term analysis was carried for all the three districts separately from 1989-2000 and from 2000-2006. Along Karwar region, south of Kalinadi River shows accretion during the period of 1989-2000 as shown in Fig. 4; whereas, the area shows erosion pattern during the period of 2000-2006 as shown in Fig. 4.

In Udupi district, the maximum trend of accretion was observed from the Thannirbhavi to Bengre which is clearly noticed from the graph in Fig. 6. From

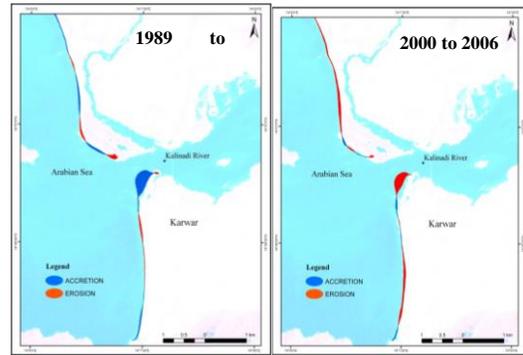


Fig. 4— Shoreline change over time, for Karwar region (1989 – 2000) and (2000 – 2006)

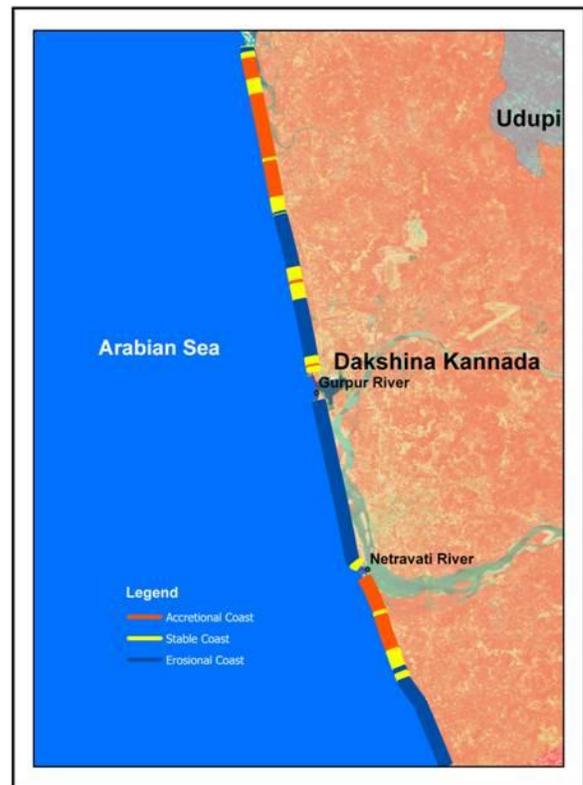


Fig. 5—Shoreline change for Dakshina Kannada district

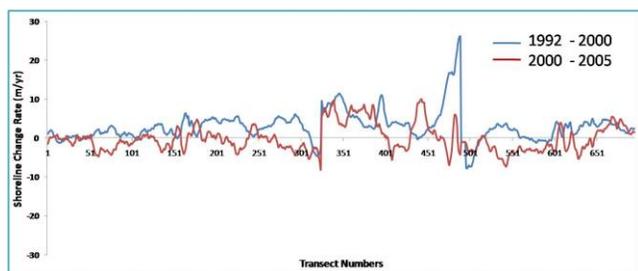


Fig. 6—Shoreline change over time, for Udipi district (1992 – 2000) and (2000 – 2006)

1992-2000, accretion was noticed between Kotepura to Ullal. Whereas, the same region was noticed with erosion after 2000. The region between Mulki River to Gurpur River is seen with low accretion between 1992-2000. But from 2000-2005, the region is observed with low erosion. Overall, most of the Udipi district was noticed with low erosion between 2000-2005.

Conclusions

The main purpose of the study was to investigate the application of Remote Sensing data to understand the behaviour of shoreline change along the Karnataka coast. The study observes both erosion and accretion in isolated pockets all along the coast. The analysis revealed that about 70% of the coastline were under stable or accretion, whereas remaining 30% region was experiencing varying magnitude of erosion. High rate of erosion was observed all along the river mouth of northern side of Sharavati Rivers. While the Southern side of the Kalinadi River is noticed with high accretion. The erosion and accretion pattern observed along the coast is influenced mainly by coastal process and riverine inputs. The variation in river mouth morphology was quite significant. Hence the study reveals that shoreline change is mainly due to variation in coastal process, land runoff and geomorphologic units influencing the coast.

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References

- 1 R Dolan, B P Hayden., P May., and S May., *he Reliability of Shoreline Change Measurements from Aerial Photographs*. Shore and Beach, 1980. 48: p. 22-29.
- 2 K Horikawa, *Nearshore dynamics and coastal processes: Theory, measurement, and predictive models*. 1988: University of Tokyo press.
- 3 S Bagli. and P Soille., *Morphological automatic extraction of coastline from pan-European Landsat TM images*, in *Fifth International Symposium on GIS and Computer Cartography for Coastal Zone Management*. 2003: Genova. p. 58-59.
- 4 Sunarto., *Geomorphic changes in coastal area surround Muria Volcano*. 2004, Gadjah Mada University: Indonesia.
- 5 J Mills, S Buckley, H Mitchell, P Clarke, and S Edwards, *A geomatics data integration technique for coastal change monitoring*. *Earth Surface Processes and Landforms*, 2005. 30 (6): p. 651-664.
- 6 P Albert and G Jorge, *Coastal changes in the Ebro delta: Natural and human factors*. *Journal of Coastal Conservation*, 1998. 4 (1): p. 17-26.
- 7 J R Jensen, *Introductory Digital Image Processing: A Remote Sensing Perspective*. 1995: Prentice Hall PTR. 318.
- 8 S Maiti and A K Bhattacharya, *Shoreline change analysis and its application to prediction: A remote sensing and statistics based approach*. *Marine Geology*, 2009. 257 (1-4): p. 11-23.
- 9 H Jantunen and J Raitala, *Locating shoreline changes in the Porttipahta (Finland) water reservoir by using multitemporal Landsat data*. *Photogrammetria*, 1984. 39 (1): p. 1-12.
- 10 A Singh, *Review Article Digital change detection techniques using remotely-sensed data*. *International Journal of Remote Sensing*, 1989. 10(6): p. 989-1003.
- 11 K White and H M El Asmar, *Monitoring changing position of coastlines using Thematic Mapper imagery, an example from the Nile Delta*. *Geomorphology*, 1999. 29 (1): p. 93-105.
- 12 V Lafon, J Froidefond, F Lahet, and P Castaing, *SPOT shallow water bathymetry of a moderately turbid tidal inlet based on field measurements*. *Remote Sensing of Environment*, 2002. 81 (1): p. 136-148.
- 13 M Siddiqui and S Maajid, *Monitoring of geomorphological changes for planning reclamation work in coastal area of Karachi, Pakistan*. *Advances in Space Research*, 2004. 33(7): p. 1200-1205.
- 14 J-H Ryu, J-S Won, and K D Min, *Waterline extraction from Landsat TM data in a tidal flat: a case study in Gomso Bay, Korea*. *Remote Sensing of Environment*, 2002. 83 (3): p. 442-456.
- 15 H Yamano, H Shimazaki, T Matsunaga, A Ishoda, C McClennen, H Yokoki, K Fujita, Y Osawa, and H Kayanne, *Evaluation of various satellite sensors for waterline extraction in a coral reef environment: Majuro Atoll, Marshall Islands*. *Geomorphology*, 2006. 82 (3): p. 398-411.
- 16 Hanson., H G M B., and K N C., *Prototype applications of a generalized shoreline change numerical model*. Twenty-first Coastal Engineering Conference, proceedings of the International Conference, Vol. 2, June 20-25, 1988, Costa del Sol-Malaga, Spain, Ch. 94, 1988: p. 1265-1279.
- 17 E R Thieler., E A Himmelstoss., J L Zichichi, and A Ergul., *The Digital Shoreline Analysis System (DSAS) version 4.0 an ArcGIS extension for calculating shoreline change*. 2009: U.S. Geological Survey.
- 18 M Crowell, S P Leatherman, and M K Buckley, *Historical Shoreline Change: Error Analysis and Mapping Accuracy*. *Journal of Coastal Research*, 1991. 7(3): p. 839-852.
- 19 J-S Lee. and I Jurkevich. *Coast line detection and tracing in SAR images*. in *IEEE Transactions on Geo-Science and Remote Sensing*. 1999.

- 20 C Fletcher, J Rooney, M Barbee, and S-C Lim, *Mapping Shoreline Change Using Digital Orthophotogrammetry on Maui, Hawaii*, J.o.C. Research, Editor. 2003.
- 21 C H Fletcher, B M Romine, A S Genz, M M Barbee, M Dyer, T R Anderson, S C Lim, S Vitousek, C Bochicchio, and B M Richmond, *National assessment of shoreline change: Historical shoreline change in the Hawaiian Islands*. 2012: US Department of the Interior, US Geological Survey.
- 22 A S Genz, C H Fletcher, R A Dunn, L N Frazer, and J J Rooney, *The Predictive Accuracy of Shoreline Change Rate Methods and Alongshore Beach Variation on Maui, Hawaii*. Journal of Coastal Research, 2007: p. 87-105.
- 23 B M Romine, C H Fletcher, L N Frazer, A S Genz, M M Barbee, and S-C Lim, *Historical Shoreline Change, Southeast Oahu, Hawaii; Applying Polynomial Models to Calculate Shoreline Change Rates*. Journal of Coastal Research, 2009: p. 1236-1253.
- 24 C J Hapke, E A Himmelstoss, M G Kratzmann, J H List, and E Thieler, *National assessment of shoreline change; historical shoreline change along the New England and Mid-Atlantic coasts*. 2010, U. S. Geological Survey.
- 25 E R Thieler and W W Danforth, *Historical Shoreline Mapping (I): Improving Techniques and Reducing Positioning Errors*. Journal of Coastal Research, 1994. 10 (3): p. 549-563.
- 26 B C Douglas and M Crowell, *Long-term shoreline position prediction and error propagation*. Journal of Coastal Research, 2000: p. 145-152.
- 27 P Vinayaraj, G Johnson, G U Dora, C S Philip, V SanilKumar, and R Gowthaman, *Quantitative Estimation of Coastal Changes along Selected Locations of Karnataka, India: A GIS and Remote Sensing Approach*. International Journal of Geosciences, 2011. 2: p. 385-593.
- 28 V K Jayappa. and A Kumar., *Evolution of Coastal Landforms, Southern Karnataka—A Remote Sensing Approach*, in K. S. Jayappa and A. C. Narayana, Eds., *Coastal Environmental Problems and Perspectives*. 2009, I.K. international Publishing House Pvt. Ltd.: New Delhi. p. 79-96.