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Detection of Shoreline Changes in Ratnagiri Block, Maharashtra, India using Remote Sensing and GIS Techniques

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Abstract

Shoreline of Ratnagiri block, Maharashtra inhabits different species of aquatic flora and fauna and is characterised by different manmade structures supporting various fishery activities. The changes along the shoreline pertaining to erosion and deposition during 1989 to 2009 were studied using remote sensing and Geographic Information System techniques. Temporal and multispectral satellite images of the year 1989, 1999, 2004 and 2009 taken from different satellite sensors were processed through ERDAS Imagine 9.1 image processing software for mapping of shoreline and associated changes pertaining to erosion and deposition. The study revealed an average accuracy of 97.33% for shoreline mapping with Root Mean Square error in the range of 0.1910 to 0.3255 pixels. The study revealed addition of 160 ha area during 1989 to 2009 pertaining to the deposition of 233 ha and erosion of 73 ha. Dhamankhol Bay, Kachare, Varvade, Ganpatipule, Areware, Kalbadevi, Mandovi, Bhatye, Ranpar and Gaonkhadi were the major areas of deposition whereas, erosion was prominent along Nandivade, Kachare, Ganpatipule, Mirya and Mandovi beach areas. Navigational difficulties were seen at Mirkarwada fishing harbour due to deposition of sand material eroded from Mirya beach during 1989 to 2009 whereas Dhamankhol Bay showed accretion during 2004 to 2009 due to land filling activity carried out for port construction.

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Introduction

Shoreline characterised by variety of natural resources like beaches, mangrove forests, estuaries, sand dunes, sand bars and coastal vegetation provide natural habitat for variety of species. In addition to this, different manmade structures like harbours, landing centres, jetties and breakwater walls have been erected along the shoreline to serve different human purposes. All these natural resources along with manmade structures were found prone to natural calamities or else victim of anthropogenic activities during recent past. Sea level rise due to global warming may also guzzle potential shoreline area in near future (Unnikrishnan et al., 2006).

Variety of aquatic plants such as seaweed and mangroves, crustaceans, molluscs and finfishes inhabit different shore substrates such as sand, mud, rock as well as water pools. Many other aquatic species rely on shore substrate for spawning, larval rearing, feeding and foraging. Alteration in the physical aspects of the shores causes significant changes in the biodiversity of aquatic flora and fauna.

Thus, it is necessary to implement appropriate management action plan for conservation of coastal resources and biodiversity as well as to ensure sustainable development of coastal areas with respect to industries, agriculture, aquaculture, human settlements and infrastructure. Planning and implementation of such management action plans requires detailed and timely information about coastal processes, habitats, hazards, shoreline conditions, exploration and sediment dynamics. Remote sensing and geographic information system (GIS) are valuable tools available for collection, analysis and interpretation of multiple coastal data required for above needs.

Shoreline along Ratnagiri block of Maharashtra with 57 km stretch, is characterised by pocket beaches, rocky shores, ridges, coastal vegetation, sandbars, mangrove forests, estuaries and sand dunes along with manmade structures like harbours, landing centres, jetties and breakwater walls. Shores along the study area shoreline are enriched with a variety of aquatic organisms such as plants, mangrove, crustaceans, molluscs and finfishes. An attempt is made to estimate spatial and temporal changes along the shoreline of Ratnagiri block during 1989 to 2009 using remote sensing and GIS techniques.

Materials and Methods

The study was employed along the 57 km stretch of Ratnagiri block extended from 17°18′50.89" N and 73°11′15.90" E to 16°45′37.70" N and 73°18′20.00" E (Fig. 1). Digital satellite images of study area acquired by various satellite sensors with different spectral and spatial resolutions were used for the present study (Table 1). Digital satellite images were processed through ERDAS Imagine 9.1 digital image processing software.

Different errors associated with the digital satellite image acquisition were removed by application of different pre-processing techniques. Satellite images were corrected for geometric errors using Ground Control Points (GCPs) and were then rectified to (Zone 43) map projection with Root Mean Square (RMS) error threshold of 0.5 pixels. Digital Number (DN) values of geometrically corrected images were then converted to Top-of-Atmosphere (TOA) reflectance. This facilitated the curtailing of radiometric errors associated with seasonal variations and atmosphere. In addition to this, TOA reflectance values provided a standardized measure for direct comparison of digital images acquired by different sensors onboard different satellites. Multi-spectral satellite images with different spatial resolutions were then transformed to the equal spatial resolution of 15 m through resolution merge with high resolution imagery. Subsets of areas of interest were then drawn from the corrected images for further processing.

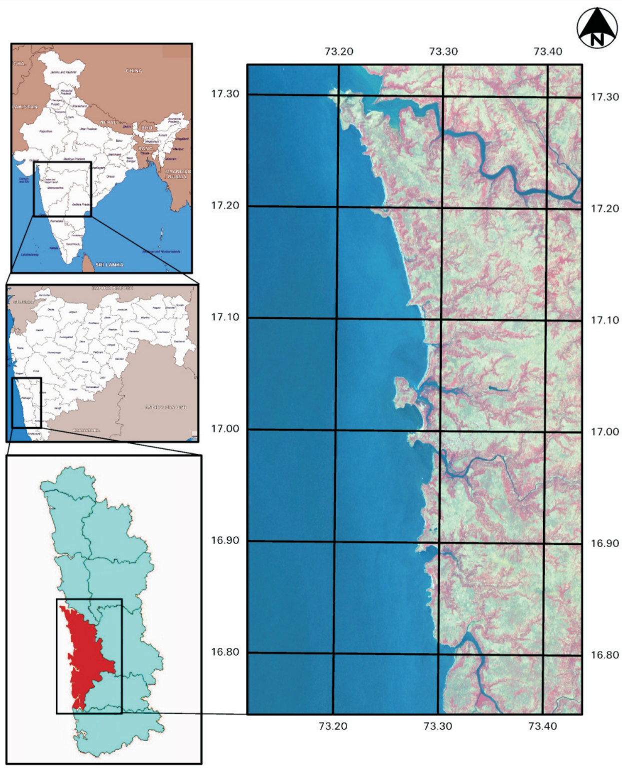

Fig. 1. Study area

Different digital image processing techniques (Deekshatulu & Rajan, 1984; Reddy, 2001; Lillesand et al., 2004) were applied to the corrected imageries for mapping of shoreline as well as for quantification of areas of erosion and accretion along the shoreline. As infrared band produces superior contrast between land and water areas showing higher pixel values for land areas and lower pixel values for water areas, land and water areas in infrared band images were separated by using threshold value from transition zone. The pixels with value above threshold were classified as land and those with lesser values were classified as water areas. The binary image thus produced was then multiplied with band ratio images of GREEN/NIR and GREEN/MIR so as to increase the accuracy of shoreline mapping (Van & Binh, 2008). Shoreline positions for year 1989, 1999, 2004 and 2009 were extracted from respective date binary images. Unsupervised classification of multi-spectral satellite images was performed using ISODATA clustering technique to classify image pixels into several clusters. Clusters belonging to land area in the images were assigned with pixel value of one and those belonging to water areas were assigned with pixel value of zero, so as to produce binary images with land and water classes only. Binary images were produced for respective year and used for mapping the shoreline positions of year 1989, 1999, 2004 and 2009. Multi-spectral satellite images were transformed into principal components and first three principal components were classified unsupervisely into several clusters.

For accuracy assessment of different image processing techniques, 1000 pixels belonging to land water interface were selected randomly and selected pixels were then tested against ground truth data. Chi square test was applied to the number of correctly classified pixels for testing the level of significance in the accuracy of shoreline mapping by different image processing techniques.

Sequential shoreline changes were estimated for time intervals between 1989 to 1999, 1999 to 2004, 2004 to 2009 and 1989 to 2009 by subtraction of respective date binary images derived by different image processing methods. Subtraction of TOA reflectance MIR bands of temporal images was also performed for analysis of shoreline changes for the same time intervals. The pixels with zero values represented the areas of no change while, pixels with positive values belonged to the areas of shore accretion and the areas of shore erosion were represented by pixels with negative values. The temporal shoreline change estimates, analyzed by different image processing techniques, were tested by ANOVA (Snedecor & Cochran, 1967) for significance.

Results and Discussion

RMS error estimates of temporal satellite images used in the present study ranged from 0.1910 to 0.3255 pixels which was much lower than those reported by Frihy et al. (1998), El-Raey et al. (1999), Wu (2007) as well as Van & Binh (2008) during their shoreline studies ensuring the preciseness of shoreline estimates of the present study. The average accuracy of shoreline mapping by different digital image processing methods used for present study was 97.33%. Shreedhar et al. (1997), Tikekar et al. (1997) and Chen & Rau (1998) encountered different errors in the studies carried out by manual methods using different tools on printed maps. Ma et al. (2007) achieved overall accuracy of 91.4% in change detection studies by digital image processing techniques. Moreover, the shorelines mapped using different digital image processing techniques during present study showed precise overlapping as reported by Guariglia et al. (2006) during shore studies along Bassilicata region. The temporal shoreline changes estimated by different methods during present study did not show much variation as reported by the El-Raey et al. (1999).

The shoreline study showed net increase of 160 ha shore area with an average annual addition of 8 ha area that resulted due to temporal patterns of erosion and deposition along shoreline during 1989 to 2009 (Fig. 2, Table 2). Shoreline accretion of 233 ha area was observed at an average rate of 11.65 ha year^{-1} due to deposition along Dhamankhol bay, Kachare, Varvade, Ganpatipule, Areware, Kalbadevi, Mandovi, Bhatye, Ranpar and Gaonkhadi whereas, altogether 73 ha shore area was lost at an average rate of 3.65 ha year^{-1} mainly along Nandivade, Kachare, Bhatye, Ganpatipule, Kalbadevi, Varvade, Mirya and Mandovi beach areas during the study period. Shoreline accretion reported by Tikekar et al. (1997) as well as Kunte et al. (2000) along the Maharashtra coast comprising the shoreline stretch of Ratnagiri block supports the findings of present study.

Major changes observed during the present study were sand bar formation at river mouths, changes in beach sedimentation in the harbour vicinity and land filling. Deposition of material in the mouth region of rivers along the beach areas of Varvade, Areware, Kalbadevi, Bhatye and Ranpar results in formation of sandbars, their structural changes, narrowing of river mouth and extensions of levees causing navigational difficulties for the fishing vessels. Gujar (1995) also reported development of

Table 1. Details of digital satellite images

Satellite and Sensor	Acquisition Date	Spatial Resolution (m)
Landsat- Thematic Mapper	25th October 1989	30120
Landsat- Enhanced Thematic Mapper+	14th November 1999	153060
TERRA-ASTER	29th February 2004	153090
IRS-P6-LISS III	22nd January 2009	23.5

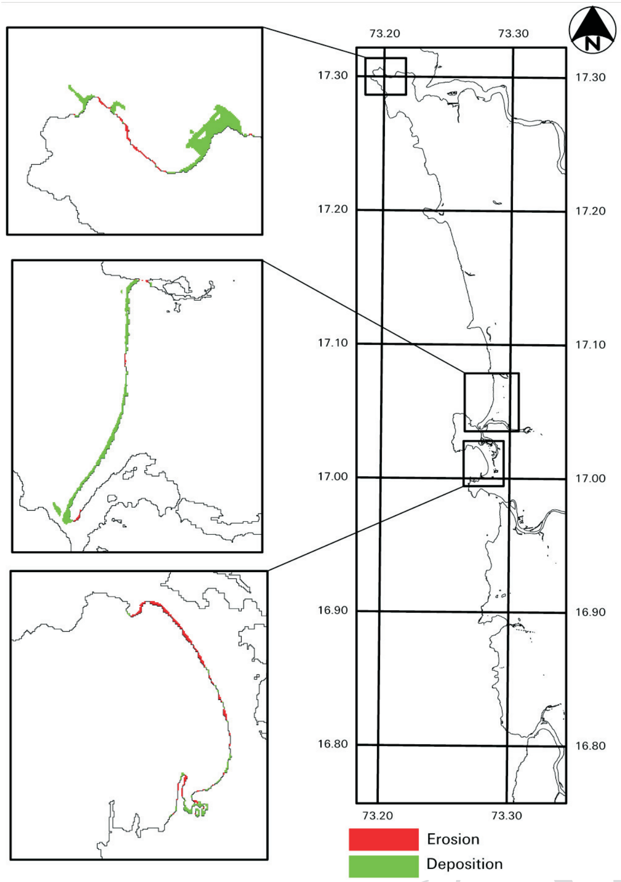

Fig. 2. Shoreline changes along Ratnagiri block

sandbars along the river mouth areas of Areware, Kalbadevi and Bhatye. Mirya bay showed severe erosion along the Mirya beach, transportation of eroded material towards the Mirkarwada minor fishing harbour with alongshore water currents and accumulation of sand at the embayment as well as navigational channel of the harbour. The sand bar was observed at the entrance of the harbour resulting in navigational difficulties to the fishing fleets. Erosion along Mirya beach was also recorded by Iyer (2004) whereas, Tikekar et al. (1997)

Table 2. Shoreline changes along the Ratnagiri block

Time interval	Shoreline change (ha)		
	Erosion	Deposition	Net change
1989-1999	69	198	129
1999-2004	87	161	74
2004-2009	137	94	-43
1989-2009	73	233	160

predicted navigational hindrances in the Mirkarwada harbour due to deposition. The change pattern observed in the Mirya bay may be attributed to alteration of water currents due to construction of breakwater and formation of eddy flow pattern in the bay. The formation of eddies and associated shoreline changes due to construction of breakwater walls was also reported by Rajawat et al. (2004) in different regions of Kerala. The deposition in the Mirkarwada harbour reduced the accessibility and workability of the harbour resulting in decrease of harbour life. But the dredging and extraction of sediments from basin as well as entrance channel was undertaken, which resulted in reduction of navigational hindrances as well as sandbar at the entrance during 1985 to 2009 increasing the life of the harbour (Personal communication). Construction of port and breakwater in Dhamankhol bay constructions may alter the water current pattern in the region and may alter the morphology of the shore features in the vicinity in recent future as seen in the case of Mirya bay.

Ganpatipule beach showed dominant deposition during 1989 to 2009. The accretion of the beach may be attributed to the activities undertaken for the tourism development in the areas along the Hurghada coast (Vanderstraete et al. 2006). The findings of the present study are supportive to the reports of accretion by Tikekar et al. (1997) and Kunte et al. (2000). Dominant accretion was also reported along the beach areas of Varvade, Gaonkhadi, Mandovi, Bhatye as well as Areware from 1989 to 2009. Kalbadevi beach showed accretion during 1989 to 2009 followed by severe erosion between 2004 to 2009 as reported by Ganesan (2004) during Kalbadevi beach profile studies. These changes were mainly attributed to natural processes as no major anthropogenic activity was observed along these regions during the study period.

Deposition was prominent along most of the regions of Ratnagiri coast during 1989 to 2009 with some areas under the threat of erosion. Sand bar formed due to deposition caused navigational difficulties in the estuaries as well as Mirkarwada fishing harbour. Severe erosion was found along the Mirya beach and eroded material was deposited in the Mirkarwada fishing harbour. The study revealed that remote sensing and GIS were efficient tools for shore mapping and change detection studies, which will be vital in preparation of coastal management plans.

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