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Assessment of shoreline changes of Alibag coast (Maharashtra, India) using remote sensing and GIS

R. Vidya*, R. S. Biradar[1], A. B. Inamdar[2], Sudha Srivastava[3] and Madhavi Pikle[1]
ICAR - Central Marine Fisheries Research Institute, Ernakulam North P.O., Kochi - 682018, India.
[1]ICAR - Central Institute of Fisheries Education, Fisheries University Road, Versova, Mumbai - 400 061, India.
[2]Centre for Studies in Resources Engineering, Indian Institute of Technology,Mumbai - 400 076, India.
[3]Department of Geography, University of Mumbai, Mumbai - 400 098, India.

*Correspondence e-mail: vidya.panicker@gmail.com

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Original Article

Abstract

The analytical and data integration capability of GIS and the spatial, temporal, spectral and radiometric resolutions of remote sensing help to gain insights into the biophysical systems. These technologies are widely used in geomorphological studies. Remote sensing and GIS technologies were used to study the shoreline changes of Alibag in Raigad district of Maharashtra, India, which lies between 18° 30'N and 18° 45' N latitude, and 72° 45' E and 73° 00'E longitude. IRS-1D LISS III satellite image (2005) and Survey of India (SOI) toposheet (1971) with the map ID 47 B/14 both on the scale 1: 50,000 were used in the change detection study. GIS software GRAM++ and ArcView 3.2 were used for the analysis. Total areas of erosion and accretion along the Alibag coast were found to be 3.81 km^2 and 6.5 km^2 respectively during the last 34 years (1971 to 2005) Ground-truthing validated the findings of the study. Anthropogenic activities like land reclamation, increased human settlements, industrial development, recreational and tourism activities were responsible for the accretion in these areas. Erosion was mainly due to natural forces especially in the eastern side of Korlai where the Kundalika River is flowing. Anthropogenic activities like dredging and deforestation were the causes of erosion in other places of the study area. Shoreline changes resulted in displacement of coastal population, loss of property, salinisation of land and water, as well as decrease in fish landings. The study amply demonstrated the utility of remote sensing and GIS technologies in monitoring and detection of coastal features.

Keywords: *Shoreline changes, remote sensing, GIS, erosion, accretion*

Introduction

The coastal zone contains diverse and unique resources as well as ecosystems that are important for biological and economic productivity, functioning also as an ecotone, a transition protective area between the land and the sea (Clark, 1983). Coastal zones are unique and contain some of the most productive and valuable habitats of the biosphere, including estuaries, lagoons, coastal wetlands, coastal floodplains, marshes, mangroves, tidal flats, beaches, dunes and fringing coral reefs and man-made features such as ports, commercial fisheries and aquaculture operations, industries, tourism and recreational developments, archeological sites and some of the largest and the most densely populated urban areas of the world. Approximately 60% of the world's population lives within 60 km of the coast and this number is increasing rapidly due to the advantages it offers for a variety of human activities such as tourism, transport and fishing (Sorensen and McCreary, 1990).

Coastal zone is a very complex, dynamic and delicate environment, because this area is a transition between land and marine processes (Gunawan, 1998). The coast is a difficult place to manage, involving a dynamic natural system, which has increasingly settled and pressurized by expanding socio-economic systems (Turner, 1999). The coexistence of coastal ecosystems and human activities along the coastline inevitably results in competition for resources and environmental degradation with a negative impact on the economic and social value of the coast (Camhis and Coccossis, 1982).

Shoreline is one of the most rapidly changing landforms of the earth, and geomorphic processes such as erosion, deposition and sedimentation, sediment transport, periodic storms, flooding and sea level changes continuously modify the shoreline and affect coastal ecosystem. Therefore, the accurate demarcation of shoreline is very important for planning and conservation measures. Shoreline position changes can significantly affect human activities (Frihy and Lotfy, 1994). Morton (1979) stated that mapping shoreline changes and predicting future shoreline positions are currently worldwide scientific and coastal management objectives. The accurate measurement of historic shoreline positions and the prediction of future locations are essential for coastal planning and management.

Remote sensing has proved its utility in all fields of geomorphology, which includes the study of coastal processes, detection of changes due to seasons, natural disasters and human activities, because of the rapid, repetitive, synoptic and multi spectral coverage of the satellites. It provides cost-effective multi-spectral and multi-temporal data, and turns them into information valuable for understanding and monitoring land development patterns and processes (Weng, 2002). Remote sensing satellites images have been effectively used for monitoring shoreline changes in different parts of India (Rao *et al.*, 1984; Desai *et al.*, 1991; Nayak *et al.*, 1991; Bhat and Subrahmanya, 1993; Chen and Rau, 1998; Sreekala *et al.*, 1998; De Solan *et al.*, 2001).

GIS is an information system used to manipulate, summarize, query, edit, and visualize information stored in computer databases and referenced to Earth locations (Goodchild, 1997). GIS technology provides a flexible environment for storing, analyzing, and displaying digital data necessary for change detection and database development (Weng, 2002). Satellite imagery has been used to monitor discrete land cover types by spectral classification or to estimate biophysical characteristics of land surfaces via linear relationships with spectral reflectances or indices (Steininger, 1996). Geographical Information Systems have already been used for assessing environmental problems (Golojuch, 1994; Tsakiri-Strati *et al.*, 1994), since they provide a powerful tool for the manipulation and analysis of spatial information (Carver, 1991; Goodchild *et al.*, 1992; Barras *et al.*, 1994; Carlson *et al.*, 1994).

The advent and rapid advance of GIS and RS technologies have advanced the field of geomorphology (Vitek *et al.*, 1996). The analytical power of the system is expanded as a consequence of the integration when remotely sensed data are combined with other landscape variables organized within a GIS environment (Walsh *et al.*, 1998).

This paper attempts to study the shoreline changes in terms of erosion and accretion using remote sensing and GIS for Alibag coast during 1971-2005. A survey was conducted along the coast to know about the shoreline changes, its intensity and also to study the impact of these changes on coastal population.

Material and methods

Study area

Alibag is an idyllic town on the west coast of India, known as the Konkan region. It lies between 18° 30′ N and 18° 45′ N latitude, and 72° 45′ E and 73° 00′ E longitude. Alibag is the headquarters of the erstwhile Kolaba and the present Raigad District of Maharashtra, India and lies in the central portion of the Raigad district (Fig.1). It lies on almost the same

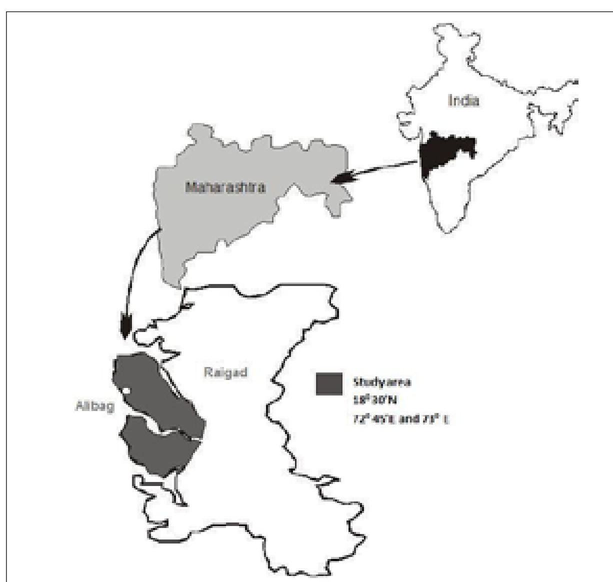

Fig.1. Location of the study area

latitude as the southern tip of Mumbai and is very close to this tip across the narrow strip of the Arabian Sea. It is rapidly developing with flourishing industries and is one of the most important tourist destinations of Maharashtra.

Materials

The remotely sensed satellite image used for this study was IRS-ID, LISS III 2005, (Geocoded) acquired on March 3, 2005 under cloud free conditions, so that the spatial details over the study area were clearly visible. The satellite image was obtained from National Remote sensing Agency (NRSA), Hyderabad that pertains to the Alibag area with the map ID 47 B/14, path 94 and row 59 in the IRS series.

The satellite image covered the area between 18º 30′ N and 18º 45′ N latitude and 72° 45′ E and 73° 00′ E longitude. The image was taken in the visible region having band combination (234) of false color composite (FCC) on 1: 50,000 scale. IRS-1D LISS III imagery was well suited for regulating land/water interfaces because of the strong contrast between land and water in the infrared portion of the electromagnetic spectrum. Further high-resolution data from IRS-1D LISS III satellite was suitable for the study of coastal changes and in identifying areas, which are undergoing rapid changes due to large-scale erosion or accretion. The satellite image was acquired during high tide time.

SOI toposheet map was the reference map, showing the outline of selected man-made and natural features on the Earth. Land, road, railway, rivers, islands and other prominent features were clearly marked on the map. SOI toposheet with map ID 47 B/14 (1: 50,000 scale) was used for the study. It covered the area between 18° 30′ N and 18° 45′ N latitude, and 72° 45′ E and 73° 00′ E longitude.

The GIS software used for the change detection analysis study were GRAM++ (Georeferenced Area Management) which was developed by Center for Studies in Resources Engineering (CSRE), Indian Institute of Technology (IIT), Mumbai. It was developed to handle spatial and attribute data relating to resource management. It has the functionalities for data import/ export, on screen digitization, topology creation, non-spatial data attachment, rasterization, raster analysis, digital remote sensing data analysis and cartographic layout. For the present study, Map edit, raster analysis, raster layout, vector layout, input/output modules were used. ArcView, the world's most popular desktop mapping and GIS software was also used in the present study. ArcView provides data visualization, query, analysis, and integration capabilities along with the ability to create and edit geographic data. ArcView makes it easy to create maps and add data to them. Using ArcView software's powerful visualization tools, records from existing databases can be accessed and they can be displayed on maps. For the present study ArcView 3.2 version was used. Global Positioning System (Garmin Hand held GPS 12XL) was used for locating the various geographical positions during ground truth verification.

Methodology

Visual interpretation of satellite image for generation of thematic layers was carried out using the characters of image called thematic interpretation keys/elements *viz.*, tone/color, shape, size, pattern, texture, association, location etc. An image interpretation key indicating various colors, texture, location etc. was used for identifying different features (Nayak *et al.*, 1991). The IRS-1D LISS III satellite image (2005) and the SOI toposheet with the map ID 47B/14 (1: 50,000) of the study area were geo-registered in GIS environment. The maps were digitized after the geo-registration. The thematic layers digitized were shoreline (high waterline), islands and roads. The ground control points were fixed accurately on the maps. Rasterization of the maps were done since it is easy to overlay the raster file than vector files. Polygons of shoreline (high water line) of different time periods i.e.,1971 and 2005 which were formed from the base map and the satellite image respectively were overlaid using 'unconditional overlay' option in the 'Raster analysis' module of GRAM++. Using the 'unconditional overlay' option, the shoreline layers of SOI toposheet 1971 and the shoreline layers of IRS LISS III image were combined with each other to give the new output image along with Output cross table, from which the change in the total area was ascertained. In the output map, polygons of shoreline of SOI toposheet map 1971, shoreline of IRS LISS III image and the change in the shoreline during this period were represented in different colors. The total changed area was calculated from the cross table which was generated along with the output map after the overlaying of different polygons. The digitized (vector) layers of both the high water line of 1971 and the high water line of 2005 were converted to shape files and exported to ArcView 3.2 using the 'Export' option in the Input/Output module of GRAM++. The changed area was calculated from the 'Attribute table' using the 'Analysis' option in ArcView. Based on changes, labels were assigned to the table as erosion, accretion, unchanged land and sea. The final output map showing areas of erosion, accretion, unchanged land and sea was generated in both GRAM++ and ArcView. Based on the generated output map, the geographical position of the changed area was located. It was followed by field visits to those areas and possible causes for the changes were elucidated.

Results

For the present study area, the analysis was mainly concentrated on detecting the change in shoreline, to quantify the change in area and also to quantify the erosion and accretion if present in the study area.

Accretion

From the comparison of shoreline of two different years i.e., 1971 and 2005, a total accretion of 6.50 km^2 was detected along the Alibag coastline based on cross table generated in GRAM++ (Table 1). Accretion area calculated from attribute table (Table 2) in ArcView was 6.52 km^2, which is very close to the area of 6.50 km^2, arrived at based on cross table of GRAM++. In further discussion, area worked out based on GRAM++ will be used. Accretion was found particularly at Varsoli, Thal, Revdanda and Korlai. Intense accretion was noticed along the east of Revdanda and Korlai. The accretion per year was found to be 0.2 km^2 along the Alibag coast.

Erosion

Erosion was observed to be less when compared to accretion. Erosion was observed in places like Kihim, Alibag beach, south of Nagaon and east of Korlai. Intense erosion was observed along Alibag beach and east of Korlai. Total erosion in these areas were found to be 3.81km^2 (Table 1 and 2). Raster layout showing accretional and erosional sites along Alibag coast in GRAM++ are depicted in Fig. 2. Map showing areas

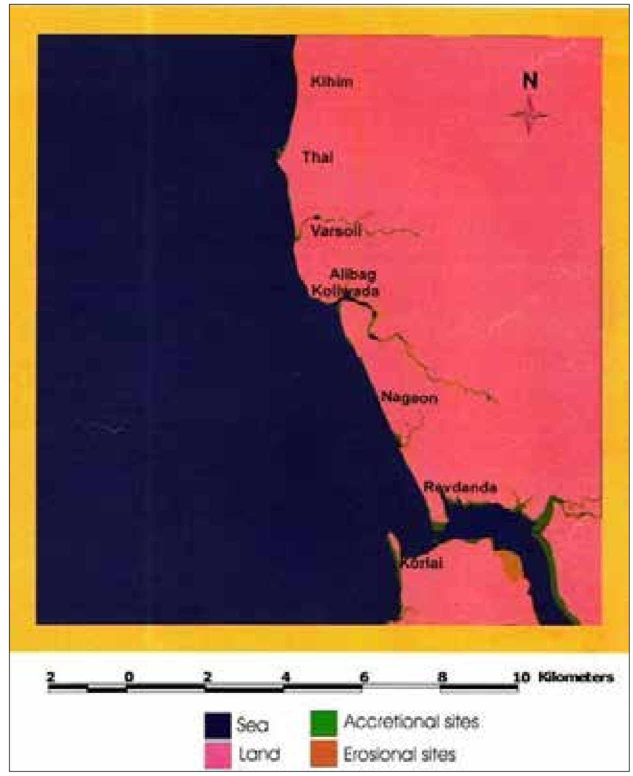

Fig.2. Map showing erosional and accretional sites along Alibag coast (1971-2005) in GRAM++

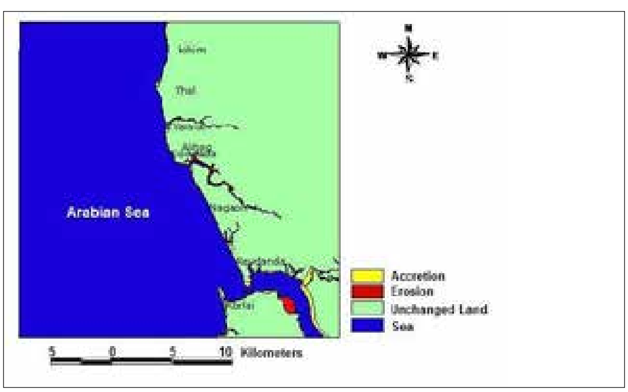

Fig 3. Erosion and accretion along Alibag coast (1971-2005) in ArcView

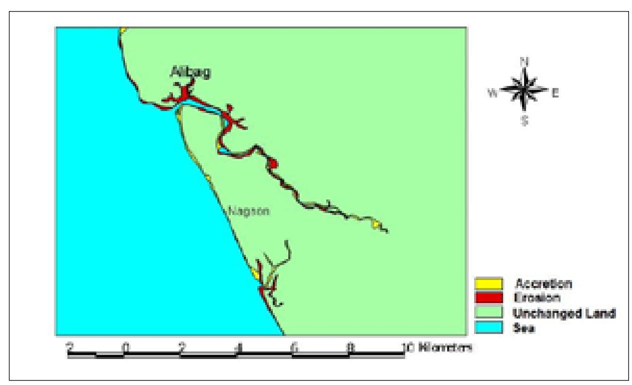

Fig 3b. Erosion and accretion along Alibag-Nagaon (1971-2005)

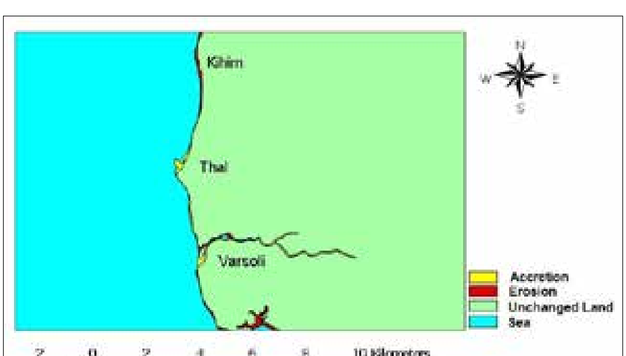

Fig 3a. Erosion and accretion along Kihim-Varsoli (1971-2005)

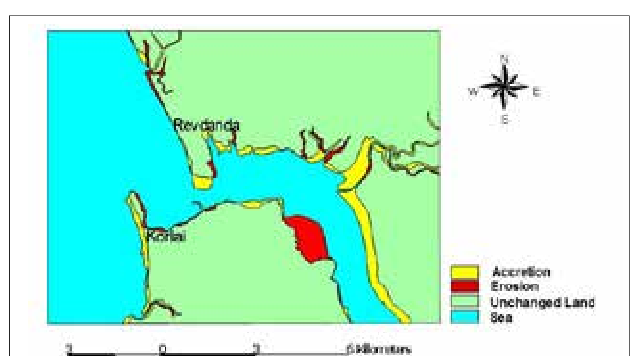

Fig 3c. Erosion and accretion along Revdanda-Korlai (1971-2005)

Table 1. Cross Table generated in GRAM++ after the overlay of the input files

HWL1971 (UID.ras)	HWL2005 (UID.ras)	O/P Class	Total Pixels	Total Area (m^2)	Legend
0	0	1	3181055	380528810.091751	NULL-NULL
2	0	2	4	478.493846	Land71-NULL
0	1	3	8	956.987691	NULL-Sea05
1	1	4	3461499	414076492.108368	Sea71-Sea05
2	1	5	31869	3812280.092238	Land71-Sea05
0	2	6	651	77874.873389	NULL-Land05
1	2	7	54346	6501056.634747	Sea71-Land05

Table 2. Attribute table in Arc View

SID	AREA_ SQ_M_	NO_ OF_SEG	UID	PERM_M	SID	UID	NO_ OF_SEG	PERM_M	AREA_ SQ_M	CHANGE-DE	AREA
6	21888294	3	Land 71	26707.015625	2	Land 05	3	30060.078125	21250564	Unchanged land	20285221.67633
6	21888294	3	Land 71	26707.015625	1	Sea 05	7	180411.46875	418263904	Erosion	1602079.4931
5	10861824	3	Land 71	15524.55664062	4	Land 05	3	16494.50195312	12298240	Unchanged land	10592920.72449
5	10861824	3	Land 71	15524.55664062	3	Land 05	3	126332.796875	278196224	Unchanged land	160112.87094
5	10861824	3	Land 71	15524.55664062	1	Sea 05	7	180411.46875	418263904	Erosion	108951.75272
5	10861824	3	Land 71	15524.55664062	0		0	0	0	Unchanged land	0.00552
4	913408	3	Land 71	5784.134277344	4	Land 05	3	16494.50195312	12298240	Unchanged land	46733.18575
4	913408	3	Land 71	5784.134277344	3	Land 05	3	126332.796875	278196224	Unchanged land	840380.40753
4	913408	3	Land 71	5784.134277344	1	Sea 05	7	180411.46875	418263904	Accretion	26347.78172
3	420894720	9	Sea 71	180742.421875	4	Land 05	3	16494.50195312	12298240	Accretion	1547156.15024
3	420894720	9	Sea 71	180742.421875	3	Land 05	3	126332.796875	278196224	Accretion	4009001.71127
3	420894720	9	Sea 71	180742.421875	2	Land 05	3	30060.078125	21250564	Accretion	907037.40385
3	420894720	9	Sea 71	180742.421875	1	Sea 05	7	180411.46875	418263904	Sea	414317561.30747
3	420894720	9	Sea 71	180742.421875	0		0	0	0	Sea	292.63372
2	275355008	5	Land 71	125851.0546875	3	Land 05	3	126332.796875	278196224	Unchanged land	273144005.02875
2	275355008	5	Land 71	125851.0546875	1	Sea 05	7	180411.46875	418263904	Erosion	2104035.49706
2	275355008	5	Land 71	125851.0546875	0		0	0	0	Unchanged land	5.54547
1	35058	3	Sea 71	1605.165039063	3	Land 05	3	126332.796875	278196224	Accretion	35041.1273
1	35058	3	Sea 71	1605.165039063	0		0	0	0	Sea	0.80775
0	0	0		0	4	Land 05	3	16494.50195312	12298240	Unchanged land	508.94358
0	0	0		0	2	Land 05	3	30060.078125	21250564	Unchanged land	58670.35976
0	0	0		0	1	Sea 05	7	180411.46875	418263904	Sea	2006.47305

of erosion and accretion in ArcView are shown in Fig 3. The enlarged views of erosional and accretional areas are shown in Fig 3a, 3b and 3c. These maps were also generated in ArcView

Discussion

The shoreline changes along the Alibag coast were studied in the present investigation. Coastal areas offer protection to the adjacent areas from the destructive tendencies of marine action. Coastal environments are dynamic, comprising continual, fluxes of mass, energy and transportation of sediments. Coastal managers should be prepared to accept this dynamism and accommodate it within management structures (Carter, 1988). The land use and shoreline change dynamics are controlled by two independent parameters, the sea-level rise induced coastal erosion and growth of population pressure. Within the coastal zones, major long shore movements of sediments shape the coastal profile, producing erosional and depositional landforms (Viles and Spencer, 1995). Due to the increase in population, exploitation of resources in coastal areas resulted in environmental pollution, which in turn, led to imbalance of the sensitive eco-environment. More than 80% of the world's shorelines are eroding at rates varying from centimeters to metres per year (Pilkey and Hume, 2001). Intense shoreline erosion leads to loss of life and property; equally accretion directly affects the influx and mixing processes of saline and freshwaters. Erosion rates are not only used by scientists to study sediment budgets or the role of natural processes in shoreline alteration, they are also used to determine safe construction set backs, settle property ownership disputes, study the effectiveness of shoreline protection structures and to make land use decision (Camfield and Morang, 1996). So the detection of shoreline changes is essential. The advantage of using GIS for integration of thematic information derived from satellite data with other collateral data such as socioeconomic and cultural data are significant in arriving at integrated coastal zone management practices.

The comparison of the shoreline in the topographical map and the imagery showed a large variation in the shoreline at many places of the coast. Accretion was found to be about 6.5 km^2 during the period 1971 to 2005, with accretion rate of 0.2 km^2 per year along the Alibag coast. Anthropogenic activities like land reclamation, human settlements, development of industries, recreational and tourism activities might have led to accretion along the Alibag coast. Severe accretion was noticed along Revdanda and Korlai, which may be due to land reclamation because of the presence of an industrial unit (Vikram Ispath Ltd.).

The total area of erosion was found to be 3.81 km^2 during the period of 1971-2005. Though, erosion was observed in places like Kihim, Alibag beach, south of Nagaon and east of Korlai, its intensity was high along Alibag beach and east of Korlai. In Kihim erosion was found to be mainly due to dredging. The east of Korlai where the Kundalika River is flowing, erosion appears to be mainly because of the natural forces. Owing to a heavy rainfall, river has a tremendous head ward eroding capacity, resulting the river piracy at places. The area is mostly characterized by the dendritic type of drainage pattern in which the streams branch irregularly in all directions and at almost any angle to form a large trunk stream (Wagle, 1987). Evolutions of fluvio-marine environment of Maharashtra are controlled by geologic, geomorphic and tectonic processes and human activities also play significant role in land degradation, land use, marine erosion and accretion (Tandale, 1993). Along Alibag beach, the deforestation especially of mangroves has resulted in erosion in these areas. Mangroves protect and stabilize the coastlines by acting as wave breaks and prevent shoreline erosion. They also act as wind breaks which reduce the force of winds that may destroy and damage property. It was found through interaction with the persons residing in the area that shoreline changes often resulted in displacement of coastal populaion, loss of property, salinisation of land and water, as well as decrease in fish landings

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