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Monitoring long-term morphological changes of Narmada estuary using remote sensing and GIS techniques

M. Mahapatra, R. Ramakrishnan and A.S. Rajawat
Space Applications Centre (ISRO), Jodhpur Tekra, Ambadi Vistar P.O., Ahmedabad – 380 015
Email: mahapatra.sac@gmail.com; ratheeshr@sac.isro.gov.in; rajawat@sac.isro.gov.in

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Abstract: Long term monitoring of morphological changes in river estuaries is useful for understanding the evolution of river mouth geomorphology. . In the present study the morphological changes in the estuary of the Narmada river are monitored and analyzed by means of remote sensing satellite images. Analysis of multi-date maps and satellite images spread over a 37-year period was carried out. It revealed significant changes in the land use/land cover and morphological features. The Alia Bet area which appeared as an island in the toposheets from 1974 has been progressively welded to the left bank of the Narmada estuary due to the closure of the southern branch of the estuary channel by accretion as can be seen in the Landsat TM image from 1990 and IRS Resourcesat-2 LISS IV from 2011. The shoreline of Alia Bet in the estuary has retreated landward by almost 4 km in certain sections. The Kim river, which is located to the south of the Narmada estuary, has shifted further south. The study also revealed that the region has transformed from a natural to an industrial-urban dominated landscape. Human activity in the form of salt pans, industrial and settlement built up has consistently increased during past three to four decades.

Keywords: Estuary, Morphological change, Monitoring, Satellite remote sensing, Land use/land cover, Narmada river

1. Introduction

The mixing of both seawater and freshwater provide high levels of nutrients in both the water column and sediment, making estuaries the most productive natural habitats in the world (Pritchard, 1967). Estuaries are essential for the survival of many species such as fish, bird and shellfish etc. The wetland associated with estuary may also perform other valuable functions such as to protect the land from storm and flood damages. Water draining from the uplands carries sediments, nutrients and other pollutants. When such water flows through salt marshes, much of the sediments and pollutants are filtered out (Tanaka, 2006). The morphology of estuaries are most dynamic due to the influence of tides, waves and the influx of saline water from the sea and riverine influences including flows of fresh water and sediment.

A number of natural and anthropogenic factors control the water and suspended sediment flux of a river basin along its pathway such as drainage basin area, topography, geology of basin, vegetation cover, tectonics activity, land-use patterns and climate including rainfall intensity and run-off (Gupta and Chakrapani, 2007). The important factor which influences water discharge and suspended sediment load is the presence of a number of reservoirs/dams along the river course, constructed for irrigation, hydroelectric or flood control purposes (Gupta and Chakrapani, 2007). According to Vorosmarty et al. (1997; 2003), construction of dams for flood control, water consumption, and power generation have resulted in significant reduction of water and sediment discharged to coastal regions by rivers. Over 40% of the river water discharge and close to 30% of the sediment discharge on a global scale are intercepted by large man-made impoundments. A decrease in suspended sediment load to the river through damming results in an increase in coastal erosion and deterioration of coastal marine ecosystems. A number of dams such as Bargi, Barna, Indra Sagar, Kolar, Omakareshwar, Maheshwar, Bhagwant Sagar, Tawa dam and Sardar Sarovar have been constructed on the Narmada river and its tributaries during the recent decades. At present three large dams are in operation on the Narmada mainstream namely, Bargi (upper), Indra Sagar (middle) and Sardar Sarovar dam (lower). With the retention of water and sediment at the burgeoning of dams in the Narmada river basin, it is likely that the coastal tracts of the Narmada estuary are under stress. Therefore, it is important to assess the morphological change of Narmada estuary. In the present study the morphological changes in the estuary of the Narmada river are monitored and analyzed by means of remote sensing satellite images, which with the advantage of repetitive, multi-spectral and synoptic nature provide accurate information on various coastal features and land use/land cover (LULC) changes of the study area. Several studies have also demonstrated the utility of satellite remote sensing data and GIS techniques for examining and monitoring the morphology change at the river mouth (Siddiqui and Maajid, 2004; Liviu et al., 2006; Tanaka, 2006; Kawamura and Tanaka, 2003).

2. Study area

The study area is Narmada river mouth, which is located in the gulf of Khambhat (Arabian Sea) of Bharuch district, Gujarat, India (Figure 1). The geographical location of the study area is 21^0 24' 46.25''N to 21^0 43' 25.95''N and 72^0 30' 10.36'' E to 72^0 52' 12.25'' E. At the estuarine mouth of the river Narmada, the alluvium gets deposited creating deltaic island, Alia Bet. Narmada estuary is macro-tidal in nature with a mean tidal range of 5.67 m (at Dahej

Bandar) and the significant wave height of 0.21 m (at Dahej Bandar). The Kim river is flowing in the southern side of the Narmada river. The important industrial area of the study area is Dahej, located in the north-western side of the Narmada estuary.

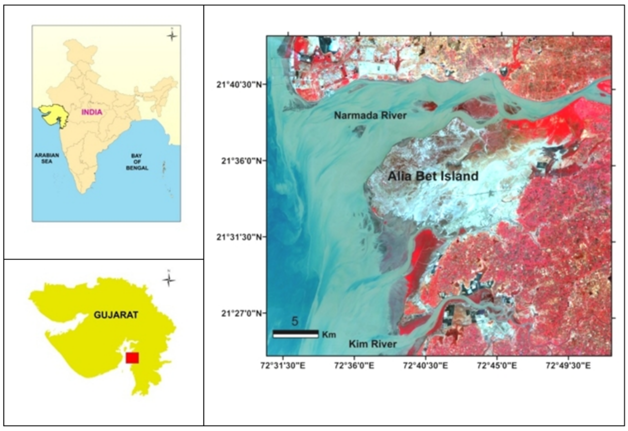

Figure 1: Location map of the study area and IRS Resourcesat-2 LISS IV data of 2011 covering it

3. Methodology

In this study, multi-temporal and different resolution satellite remote sensing digital data i.e., 30 m Landsat TM data of 19 October 1990, and 5.8m Indian Remote Sensing Satellite Resourcesat-2, (IRS P6) LISS IV data of 10 November 2011, besides Survey of India (SOI) topographical maps from 1974 (46C10, 46C11, 46C14 AND 46C15) at 1:50,000 scale, have been used for monitoring geomorphological and land use/land cover changes of the Narmada estuarine region. These data sets have been geometrically rectified and registered based on the SOI toposheets. Image processing S/W (ERDAS Imagine) and GIS S/W (Arc Map) were used to prepare the database of land use/land cover map. Low waterline has been considered as shoreline. The shoreline changes of the study area of have been carried out (Figure 2). The land use/land cover map of the study area (Figure 3, a, b, c) were prepared and the geomorphological change of the Alia Bet island (Figure 4) have been generated using on screen digitization.

4. Result and discussion

The area of different land use/land cover categories are shown in Table 1. The agricultural area, which was the largest component of the land use/land cover of the region, has gradually decreased from 35.17% in 1974 to 34.23 % in 1990 and 31.24% in 2011 due to urban and industrial growth. It is also observed that the forest area which occupied about 0.35% of area in 1974 has decreased to 0.18% by 1990 but increased to 0.25% by 2011. Scrub land covering an area about 1.19% in 1974, 1.34% in 1990 has increased to 3.25% in 2011, because of the draining of mudflats and waterlogged areas into scrub land. It is observed that salt pan activity, covering 0.89% in 1990, is increased to 3.18% in 2011. In 1974 and 1990 there was no industry and in 2011 it is observed that the area under industry covered about 30.54 km^2 (2.29%). Mangroves area significantly decreased from 7.90% in 1974 to 0.06% in 1990, but increased to 1.85% in 2011 due to plantation activity in the inter-tidal area. It is observed that settlement area gradually increased from 0.53% in 1974 to 0.71% in 1990 and 1.18% in 2011. During 1974 - 2011, the area occupied by the river channels and tidal creeks decreased because of siltation. It is observed that the river covered about 12.18% of area in 1974 but decreased to 10.73% by 2011. Similarly, creek area decreased from 1.45% in 1974 to 0.37% in 1990 and further to 0.10% by 2011.

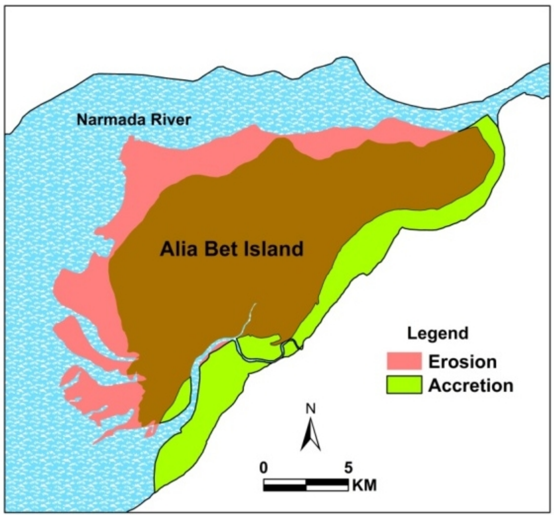

Figure 2: Shoreline changes in the Narmada estuarine region during the 37-year period between 1974 - 2011

The study revealed that nearly 237.21 km^2 area of Alia Bet island in 1974 SOI Toposheet, has merged to the mainland as observed from Landsat TM (1990) and IRS P6 LISS IV (2011) images. The study also found that the seaward extent of the Alia Bet has gradually shifted towards the eastern side or mainland due to erosion. Shoals and sand bar are the most dynamic features of an estuary. The shoal has been reduced from the 1974 to 2011. The land erosion and accretion of the study area reveal the geomorphological changes during the 37 years period (i.e., between 1974 and 2011). As shown in Figure 2, the northern portion of the Alia Bet island has eroded and the northern branch of the estuarine channel widened whereas the southern branch of the estuary has closed leading to the merger of Alia Bet with the mainland. It has been also observed that the direction of the Kim river mouth has also shifted toward southeast. The study revealed the changes Alia Bet island during the 37-year period between 1974 and 2011 (Fig. 4) resulted in a net loss of 18.04 km^2 with erosion claiming 66.22 km^2 area and offsetting the accretion of 48.18 km^2 (Table 2).

At present, there are 4818 completed large dams and 375 more large dams are under construction in India and Gujarat state has 666 dams under national register of large dams (http://www.cwc.nic.in). A large number of dams have been constructed on the Narmada river and its tributaries. 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 the 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. The morphological changes of Narmada river can be attributed to the reduction of sediment discharge and the action of wave and tide.

Table 2: Statistics of erosion and accretion of Alia Bet island (area in km^2)

Sl. No.	Area/Year	16 years (1974-1990)	21 years (1990-2011)	37 years (1974-2011)
1	EROSION	25.42	62.92	66.22
2	ACCRETION	57.14	24.33	48.18

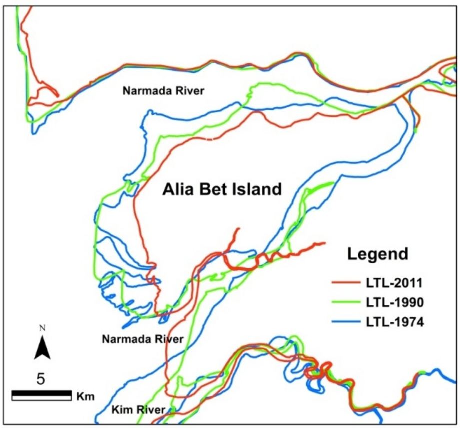

Figure 4: The erosion and accretion area of Alia Bet Island

5. Conclusion

Satellite remote sensing data along with SOI toposheet used in this study are found very useful for mapping and monitoring of land use/land cover and geomorphological changes in the Narmada estuarine region. Significant changes have been observed in the Alia Bet Island as a result of which it is now attached to the mainland due to the aggradations of the southern branch of the Narmada estuary. Some of the probable causes of such change are decreasing sediment load of the river due to the dam construction on the Narmada river and its tributaries along with the effect of large tidal current and wave action. The study further revealed that the region has transformed into an industrial-urban dominated landscape and the area under salt pans, industry and settlements has considerably increased during the 37-year period between 1974-2011.

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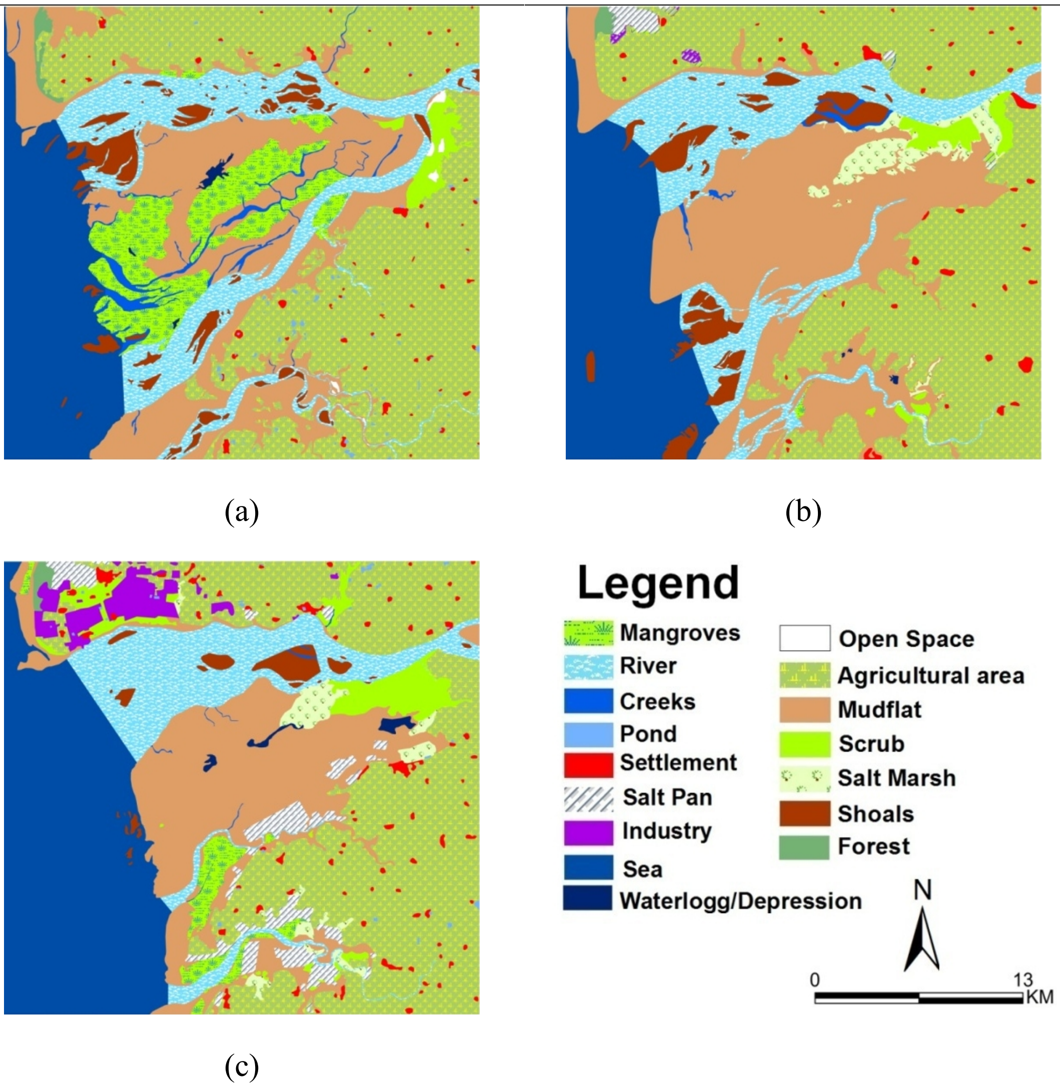

Figure 3: Land use/ land cover maps of the Narmada Estuary zone in (a) 1974, (b) 1990 and (c) 2011

Table 1: Area (km^2) of land use / land cover (LULC) classes in 1974, 1990 and 2011

LULC classes	1974	% of area	1990	% of area	2011	% of area
Agricultural land	467.07	35.18	454.52	34.23	414.83	31.24
Reserved forest	4.65	0.35	2.48	0.19	3.40	0.26
Scrub	15.87	1.20	17.86	1.35	44.55	3.36
Salt marsh	0.00	0.00	28.93	2.18	22.40	1.69
Mangroves	104.95	7.90	0.81	0.06	24.58	1.85
Mudflat	272.10	20.49	339.98	25.61	237.07	17.86
Shoals	44.58	3.36	49.18	3.70	17.60	1.33
River	161.82	12.19	159.31	12.00	142.56	10.74
Creeks	19.35	1.46	4.96	0.37	1.33	0.10
Pond	3.75	0.28	1.85	0.14	2.24	0.17
Waterlogged/depression	2.41	0.18	0.48	0.04	4.30	0.32
Open space	2.63	0.20	0.00	0.00	0.00	0.00
Settlement	7.09	0.53	9.53	0.72	15.73	1.18
Salt pan	0.00	0.00	11.90	0.90	42.33	3.19
Industry	0.00	0.00	0.00	0.00	30.45	2.29
Sea	221.43	16.68	245.93	18.52	324.34	24.43
Total	1327.71	100.00	1327.71	100.00	1327.71	100.00