COASTAL PROCESSES ALONG THE INDIAN COAST – CASE STUDIES BASED ON SYNERGISTIC USE OF IRS-P4 OCM AND IRS-1C/1D DATA

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ABSTRACT:

The sequential Suspended Sediment Concentration (SSC) maps were generated using IRS-P4 OCM data for selected tide dominated, wave dominated and deltaic coasts around the Indian subcontinent. Patterns of SSC were studied to understand the sediment dynamics, circulation patterns, fronts and consequent impact on coastal processes. Hitherto unknown sediment plumes extending for large distance into deep offshore areas could be identified from the major deltaic regions. The high temporal capability of OCM data was extremely useful to understand sediment dynamics in tide dominated regions of the Gulf of Khambhat, Gulf of Kachchh and the Hoogli estuary. SSC maps in conjunction with corresponding tide and bathymetry data could be sequenced as per flooding and ebb cycles. Development, formation shifting nature of shoals and sediment curls during a tide cycle could be studied. It is observed that during the NE monsoon suspended sediment influx of the Ganga- Brahmaputra system influences the coastal processes along the continental margins of Orissa and Northern Andhra Pradesh along east coast of India. The occurrence of cyclone aids in entrapment of fluvial discharge into the coastal waters, leading to a reduced offshore influx into deeper regions of the Bay of Bengal and high sedimentation near to the coast. Seasonal changes along wave-dominated west coast showed net sediment transport from north to south in the pre-monsoon season and south to north in post-monsoon season. Significant onshore - offshore transport along west coast was also observed. The impact of the regional sediment dynamics on the site specific local coastal environment was studied by integrating observations derived from OCM and IRS-1C/1D data.

1. INTRODUCTION

India has a coastline of around 7, 500 km and rational development of coastal areas, which form the habitat of over 25% of the country's population, living within 60 km of the shore line, can only be achieved by understanding the various interactive processes that are operative in the coastal environment. Protection of human life, property and the natural environment in the coastal zone are major causes of concern. One of the major requirement of planning coastal protection work is to understand coastal processes of erosion, deposition and transport of sediments which occur due to natural processes, anthropogenic activities as well episodic events like cyclones, storm surges, floods etc.

It has been possible to utilise data from Landsat MSS, Landsat TM, IRS-1C & 1D for monitoring coastal environment of the country since last three decades (Nayak 1983, 94, 96, 97; Nayak and Sahai, 1983, 85; Nayak and Manikiam, 1992; Chauhan and Nayak, 1995; Chauhan et al., 1996; Desai et al., 1991: Nayak et al. 1985, 91, 92, 96; Shaikh et al., 1989). These data sets have been extremely useful for understanding the net impact on the coastal landforms in terms of net gain or loss. However, the poor temporal resolution of remote sensing data provided constraints for understanding sediment transport. Monitoring and understanding of sediment transport is required due to the adverse affects like siltation of harbours, accumulation of sand bars to create navigational hazards, seasonal blockage of estuaries or degradation of coastal environment. Regular monitoring of sediment dynamics is essential and the ways and means by conventional point measurements using ships or boats are limited due to extremely poor spatial coverage that too of a particular time and high costs of conducting such surveys. Ocean colour sensors onboard satellites provide synoptic view, high repetivity and are excellent tools to map and monitor sediment patterns, estimate relative changes in sediment concentrations and retrieve sea surface velocities using sediments as a tracer in sequential images (IOCCG, 2000; Garcia and Robinson, 1989).

The Indian Remote Sensing Satellite (IRS - P4) also known as the OCEANSAT-1 was launched on May 26, 1999 by the Indian Space Research Organisation (ISRO). The satellite carried two oceanographic payloads i.e., the Ocean Colour Monitor (OCM) and the Microwave Scanning Multi-frequency Radiometer (MSMR). The first payload OCM is designed to measure ocean colour, the spectral variation of water leaving radiance that can be related to concentration of phytoplankton pigments, suspended sediments, coloured dissolved organic matter i.e., yellow substance or gelbstoff and aerosols. OCM collects data in eight spectral channels (402-422, 433-453, 480-500, 500-520, 545-565, 660-680, 745-785, 845-885 nm) with spatial resolution of 360 m, every alternate day for the same region at local time around 12 noon with radiometric resolution of 12 bits. Each OCM scene covers 1420 km by 1420 km ground area.

The present paper reports case studies carried out to study sediment dynamics for tide dominated, wave dominated as well as deltaic coasts around the Indian subcontinent using sequential IRS-P4 OCM and IRS-1C/1D LISS-III and PAN data.

2. MATERIALS AND METHODS

Sequential OCM data since October, 1999 (cloud free dates) was analysed for two paths i.e., path 09 and row 13 & 14 for the Arabian sea and path 10 and row 13 & 14 for the Bay of Bengal using atmospheric correction and bio-optical algorithms developed at Space Applications Centre (ISRO), Ahmedabad (Chauhan, 2002; Mohan et al., 1998). The sequential Suspended Sediment Concentration (SSC) maps were generated and studied. IRS-1C/1D LISS-III and PAN data has been analysed using ERDAS IMAGINE s/w and Unix based SGI Workstation. The coastal landforms, geology, landcover and shoreline changes were studied. Multitemporal analysis was carried out and results of recent satellite data were compared with information shown on old maps of 1929-30, 1967-68 and 1972-73. The impact of the regional sediment dynamics on the site specific local coastal environment was studied by integrating observations derived from OCM and IRS-1C/1D data.

3. OBSERVATIONS AND DISCUSSIONS

3.1 Gulf of Khambhat

The Gulf of Khambhat is part of the widest continental shelf on the west coast of India located in the state of Gujarat. The Gulf is a strongly converging channel experiencing tides with large amplitudes. The tidal range is between 8 and 11 m. Current velocities are very high and could be as high as 10 m/s. Mumbai is located in the southeastern and Veraval in the southwestern corner of the region and the entire coastline around the Gulf has large industrial and urban growth. Several major rivers like the Narmada, Tapi, Mahi, Sabarmati, Shutrunji pour their discharges into the Gulf. Several major and minor ports add to the economic importance of the region. There is a need to understand the sedimentation and circulation processes occurring in the region in view of several developmental activities taking place in the region as well the proposed activities like the Kalpasar project which aims to create a freshwater reservoir by closing off the Gulf itself and use the large tidal range to generate power.

It is extremely difficult to get the information on sediments using ships/boats due to strong tidal currents, moreover the information obtained is also only point measurements, which may provide accurate concentration measurements but provide extremely poor spatial coverage that too of a specific time. In addition, the costs of conducting such surveys are very high.

Tides play an important role in the movement of suspended sediments and fronts. In the Gulf of Khambhat, large tidal range gives rise to strong tidal currents and provides mechanism for transport of suspended sediments. The net transport of sediments is towards land, evidenced by extensive mudflats. The observation of suspended sediments suggests that during the monsoon sediments brought in by various river systems remain in suspension and start settling down with onset of winter season (Nayak and Sahai, 1985). These observations are based on the analysis of Landsat MSS data, which could bring out only seasonal changes. However, OCM derived SSC maps in conjunction with corresponding tide and bathymetry data could be sequenced as per flooding and ebb cycles for the Gulf of Khambhat to understand sediment dynamics within a tidal cycle (Fig. 1). Different sediment dispersal path ways could be identified. It was possible to get a high tide as well a low tide image and bring out changes in SSC through the transects drawn. (Fig. 2). These pathways provided information on the development, formation and shifting nature of shoals during a tide cycle, where as IRS-1C/1D data could provide seasonal changes of shoals.

It was observed that a distinct front appears between 30 and 50 m depth contour separating the Gulf of Khambhat waters from the open ocean waters in all the SSC maps derived from OCM as well LISS-III images of different seasons and years. It was observed that there is no exchange of gulf waters and the open ocean waters. The sediments as well pollutants under the influence of strong tidal currents are getting dispersed and settled within the Gulf of Khambhat. The study suggests that the Gulf of Khambhat is getting silted at a rapid rate.

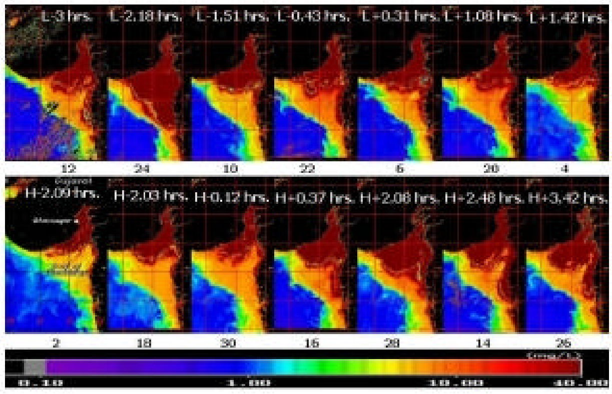

Figure 1: Sequential SSC maps as per tide cycle (low to high tide) over the Gulf of Khambhat derived from IRS-P4 OCM data.

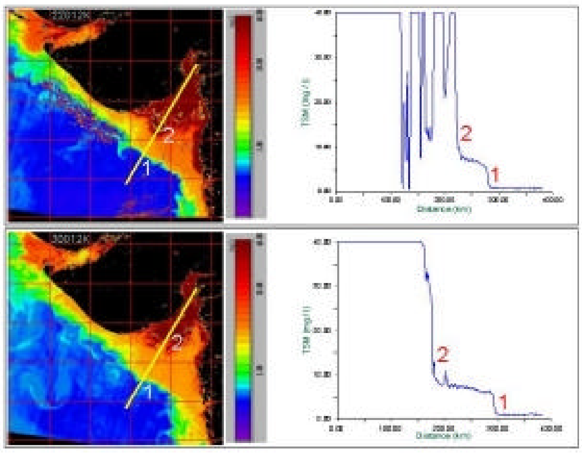

Figure 2: SSC maps for low tide (upper) and high tide (lower) along with corresponding transects showing changes in SSC over the Gulf of Khambhat derived from IRS-P4 OCM data.

3.2 Northern Bay of Bengal – Hughli & Mahanadi deltaic regions

The Bay of Bengal is one of the largest fresh water & sediment input sites of the World Ocean (Emmel and Curray, 1984). The annual fresh water discharge into the bay exceeds $1.5x10^{12}$ m^3, which reduces mean salinity by about 7‰ in the northernmost bay (Laviolette, 1967). The bay receives about 2000 million-tons of sediments annually, mostly contributed through the Himalayan Rivers, the Ganga & the Brahmaputra (G-B) from the north, the Indian Peninsular Rivers the Mahanadi, the Godavari, the Krishna, etc. (from the west), and the Irrawady and the Salveen (from the eastern bay). The OCM data provided opportunity to decipher and understand source to sink mechanism of fluvial sources - from the sequential, regional dispersal patterns of the numerous fluvial plumes debouching the bay during rather short events (for two days), influenced by short meteorological phenomena such as depression - cyclone or high pulses of fluvial plumes due to torrential rains.

It has been observed that the two day repitivity of IRS-P4 OCM data has been extremely useful to understand circulation and dispersal patterns of sediments in the Bay of Bengal. Fig. 3 shows sequential IRS-P4 OCM derived TSM maps (parts of the full scene) covering the region off Ganga-Brahmaputra-Hoogli deltaic region during Nov. 08-14, 1999. Note the formation, development and dissipation of sediment curl showing dynamic nature of sediment dispersal. Sediment curls of short duration i.e., forming, developing and dissipating within a period of eight days could be brought out using sequential OCM data. A very distinct eddy SE of Sagar island around the same region could be detected using IRS-1D LISS-III data of January 31, 1999 but could not be monitored due to its 24 day repitivity.

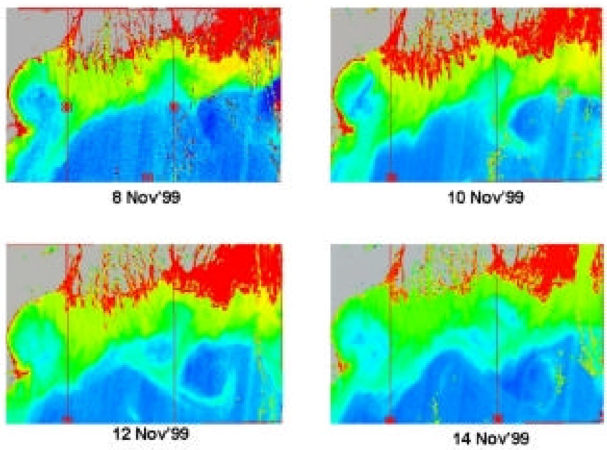

Figure 3 : Sequential IRS-P4 OCM derived TSM maps covering the region off Ganga-Brahmaputra-Hoogli deltaic region during Nov. 08-14, 1999. Note the formation, development and dissipation of sediment curl showing dynamic nature of sediment dispersal

Figure 4 shows comparison of sediment dispersal in the Northern Bay of Bengal during transition period (March 18, 2001) and NE monsoon (November 10 & 12, 2000). Much reduced equatorwards dispersal is observed during the March, whereas extensive sediment dispersal from the Ganga-Brahamaputra systems extending upto the northern parts of Andhra Pradesh is distinctly observed in the images of November period. In addition, the region off the Chilika lagoon depicts circulation as distinct gyre (digitally enlarged in offset). This feature is typically dominant in the month of November during the period of observation (1999-2001) and suggests convergence of two opposite currents. This is indicative of higher rate of sedimentation off Chilika lagoon.

The analysis of sequential IRS-P4 OCM data (January, 2000) brought out extensive sediment plumes (Fig. 5) off the Dhamra river (part of Mahanadi Delta, Orissa). These indicate sediment transport for around 100-200 km into the Bay of Bengal. A pattern matching method based on maximum cross-correlation was developed using sequential OCM derived SSC maps to retrieve advective velocities using sediments as a tracer (Prasad et al. 2002). The dispersal pattern of plumes in sequential images could be studied.

Analysis of sequential OCM data for the northern Bay of Bengal showed that during the NE monsoon suspended sediment influx of the Ganga- Brahmaputra system influences the coastal processes along the continental margins of Orissa and Northern Andhra Pradesh (Anuradha et al., 2000). There exists a strong teleconnection between discharge of Ganga- Brahamaputra and coastal turbidity in southern Orissa and Northern AP. Comparison with salinity data validates these fresh water plumes.

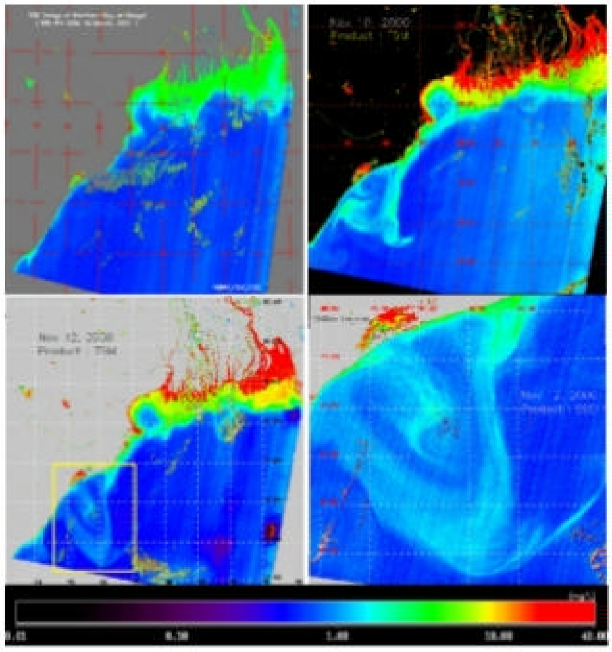

Figure 4: SSC maps during pre-monsoon and post-monsoon show depletion in pre-monsoon and large transport of SSC from the discharge of Ganga-Brhmaputra-Hugli upto northern part of coastal Andhra Pradesh (upper). Sequential SSC maps show distinct circulation patterns like formation of gyre off Chilika lagoon (lower).

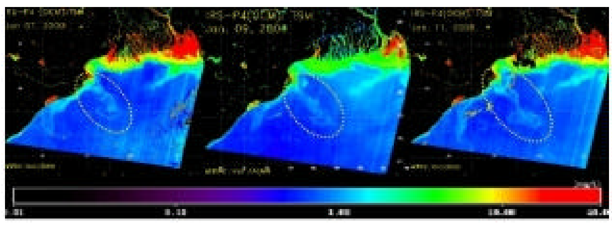

Figure 5: SSC maps (January 07, 09 & 11, 2000) covering the northern Bay of Bengal show sediment plumes of large magnitude extending from the Dhamra (part of Mahandi delta) into the offshore region..

The occurrence of cyclone aids in entrapment of fluvial discharge into the coastal waters, leading to a reduced offshore influx into deeper regions of the bay and high sedimentation near to the coast (Nayak et al., 2001). The analysis of IRS-1C/1D LISS-III and PAN data also show that coastal landforms of the Mahanadi delta are strongly influenced by the storm surge induced rapid changes apart from natural marine as well terrestrial processes. Anthropogenic activities accelerate these processes. The shoreline changes along the Mahanadi deltaic coast brought out using shoreline of 1928-29, 1972-73 and recent satellite data of IRS-1D LISS-III of 2001 suggest that although Mahanadi delta is prograding in general but there are critical areas affected by severe erosion. The region south of Dhhamra is one such critical area (Fig. 6 a & b). It has been observed that for a total area of 12, 772 ha, 2133 ha area is the net erosion and 243 ha area is net accretion. (Table-1).

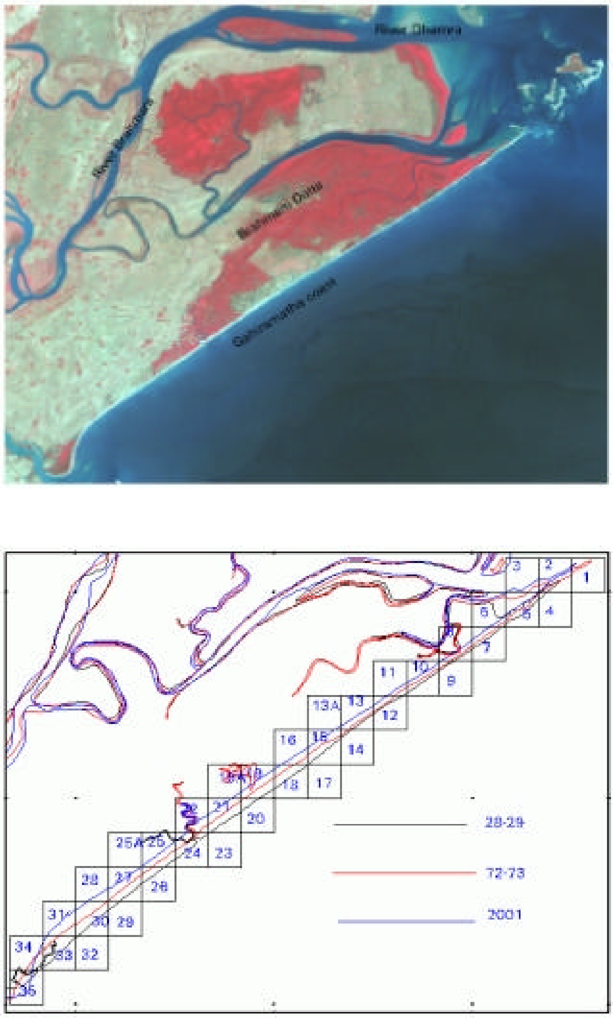

Figure 6: (a) IRS-1C LISS-III FCC showing parts of the Orissa coast, under severe erosion (b) Shoreline change map show comparison with respect to 1928-29, 1972-73 shoreline and shoreline derived from IRS-1C LISS-III data of March 19, 2001 covering parts of the Orissa coast, India.

Table – 1: Shoreline change computed for each grid cell of Fig. 6 (b).

Grid No.	1928-1972 (ha)	Average rate (ha/yr)	1972-2001 (ha)	Average rate (ha/yr)	1928-2001 (ha)	Average rate (ha/yr)
1	12.40	0.28	-11.74	-0.40	0.65	0.01
2	29.22	0.66	-6.79	-0.23	22.47	0.31
3	13.75	0.31	-30.58	-1.05	44.33	0.61
4	7.47	0.17	-0.60	-0.02	-8.07	-0.11
5	60.10	1.37	-9.91	-0.34	39.18	0.54
6	65.13	1.48	41.42	1.43	71.39	0.98
7	-30.58	-0.70	-35.30	-1.22	-65.88	-0.90
8	-17.98	-0.41	-41.11	-1.42	-58.06	-0.80
9	-8.32	-0.19	-10.01	-0.35	-18.34	-0.25
10	-37.38	-0.85	-47.38	-1.63	-84.76	-1.16
11	-12.43	-0.28	-20.88	-0.72	-33.31	-0.46
12	-20.00	-0.45	-35.69	-1.23	-55.69	-0.76
13	-17.07	-0.39	-65.11	-2.25	-82.24	-1.13
13A	0.00	0.00	-2.66	-0.09	-2.66	-0.04
14	-6.54	-0.15	-6.18	-0.21	-12.70	-0.17
15	-62.81	-1.43	-72.49	-2.50	-135.31	-1.85
16	-13.78	-0.31	-46.58	-1.61	-60.36	-0.83
17	-0.10	0.00	0.00	0.00	-0.10	0.00
18	-83.02	-1.89	-31.92	-1.10	-114.94	-1.57
19	-67.83	-1.54	-73.84	-2.55	-152.40	-2.09
19A	0.00	0.00	-10.40	-0.36	-10.40	-0.14
20	-32.19	-0.73	-0.90	-0.03	-33.09	-0.45
21	-90.63	-2.06	-79.84	-2.75	-170.47	-2.34
22	-13.10	-0.30	-48.51	-1.67	-65.51	-0.90
23	-0.17	0.00	0.00	0.00	-0.17	0.00
24	-60.86	-1.38	-47.37	-1.63	-101.85	-1.40
25	-42.43	-0.96	-68.60	-2.37	-111.03	-1.52
25A	0.00	0.00	-0.40	-0.01	-0.40	-0.01
26	-40.89	-0.93	-11.15	-0.38	-52.03	-0.71
27	-76.81	-1.75	-89.26	-3.08	-166.06	-2.27
28	-0.30	-0.01	-40.61	-1.40	-40.91	-0.56
29	-11.86	-0.27	0.00	0.00	-11.86	-0.16
30	-95.51	-2.17	-92.00	-3.17	-187.51	-2.57
31	-28.97	-0.66	-90.61	-3.12	-119.58	-1.64
32	-0.20	0.00	0.00	0.00	-0.20	0.00
33	-123.55	-2.81	-28.48	-0.98	-140.28	-1.92
34	-42.13	-0.96	5.48	0.19	-36.65	-0.50
35	-14.65	-0.33	79.46	2.74	64.81	0.89
Total						
(+)	188.07	2.16	126.36	2.84	242.83	2.14
(-)	-1052.09	-20.70	-1156.90	-37.86	-2132.82	-24.37

Note: Grid size=336.11 ha and total area=12,772.18 ha

3.3 Central part of west coast and south-west coast

Seasonal changes along Mumbai-Goa-Mangalore-Kerala coast , which is in general wave-dominated coast showed net sediment transport from north to south in the pre-monsoon season and south to north in post-monsoon season on SSC maps derived using OCM data. However, there is also a significant contribution of onshore - offshore transport which varies with seasons (Figure 7).

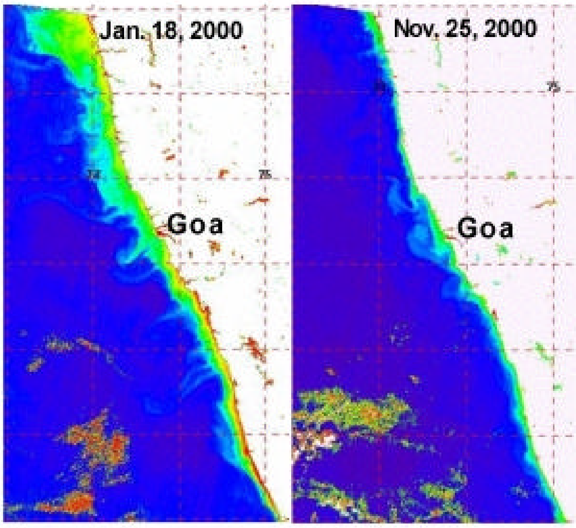

Figure 7: Seasonal changes (January 18, 2000 & November 25, 2000) in suspended sediment pattern on wave dominated central parts of west coast of India.

The human intervention to the coast like construction of breakwaters, jetties, fishing harbours etc. has also contributed to changes in circulation patterns, erosion and accretion areas. These could be studied using IRS-1C/1D LISS-III and PAN data. As an example two breakwaters parallel to each other were constructed (northern 950 m and southern 800 m with a gap of 340 m) around Beypore estuary in Kerala. This has resulted in the increased velocity of river and tidal flows. The currents from south to north against this obstruction have resulted in formation of eddy-flow-pattern seen distinctly on the satellite imagery (Figure 8). This has caused incidences of capsizing of boats of fishermen. The analysis of multitemporal LISS-III and PAN data covering the coast of Kerala showed many other interesting features like well developed eddy south of Ezhimala due to a natural land protrusion, migration of coastal inlet near Badagara, well developed sediment plume near Cochin outlet, changes in shoreline around Munambam inlet due to construction of breakwater, dispersion pattern of effluent discharge of the Travancore titanium products factory near Thiruvananthapuram as distinct plume etc.

It has been difficult to get sequential cloud free OCM data for south coast of India, however, seasonal changes in suspended sediment pattern could be brought out distinctly (Figure 9). Large sediment plumes are observed along Kerala coast during August, September, and January months. Less suspended sediments are seen in April and November images. It is observed that Gulf of Manar (south-eastern area) is devoid of suspended sediments throughout the year whereas Palk Bay (area north-east of Gulf of Manar) is under high suspended sediment concentration throughout the year and is under heavy siltation.

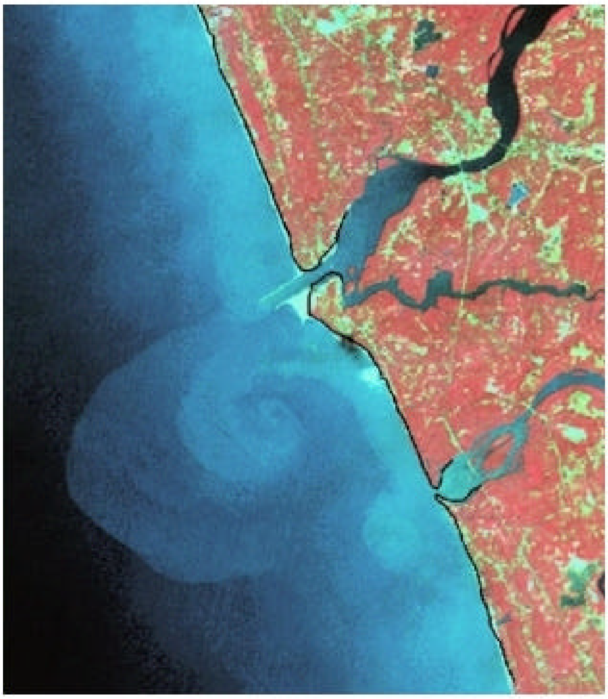

Figure 8: Impact of breakwaters constructed around Beypore estuary on circulation patterns, sediment dynamics and erosion and accretion seen on IRS-1D-LISS-III imagery.

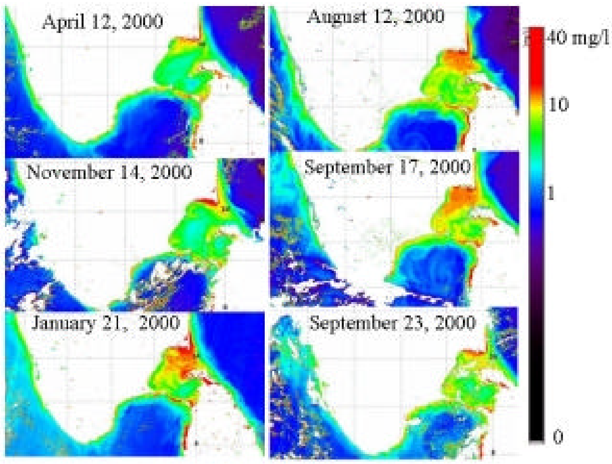

Figure 9: SSC maps covering the southern coast of Kerala and Tamilnadu during pre-monsoon (April 12, 2000), post-monsoon (November 14, January 21, 2000) and during monsoon (August 12, September 17 & 23, 2000) show seasonal changes in suspended sediment patterns.

4. CONCLUSIONS

It is concluded that understanding of coastal processes needs synergistic use of ocean colour data related to regional sediment dynamics provided by sensors like IRS-P4 OCM with information extracted from high spatial resolution data like the one from IRS-1C/1D related to changes in coastal landforms, landuse, shoreline and neotectonics for developing efficient shoreline management plans.

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