Report on use of Satellite data for detection of violation of land use along the Coastal Regulation Zone and Impact of Port structures on Shoreline changes

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Ministry of Environment and Forests

Ministry of Earth Sciences
ICMAM Project Directorate, Chennai and
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The Ministry of Environment and Forests (MoEF) have requested the Ministry of Earth Sciences (MoES) to explore the possibility of use of satellite data for detection of construction of structures along the Coastal Regulation Zone (CRZ) so that it would help the MoEF to check the violations of CRZ norms especially on construction of residential and commercial structures in the non-permitted zones. MoEF has also stated that there are reports on adverse impact of coastal structures especially the breakwaters of Ports and Harbours causing erosion of beaches of adjoining areas ultimately leading to loss of land for local inhabitants especially the fishermen who use the beaches for landing their boats. It has also sought advise on use of satellite and other data for determining shoreline changes before commencement and after completion of construction of breakwater including the long-term changes.

A meeting among MoES institutions such as Integrated Coastal and Marine Area Management (ICMAM) Project Directorate (ICMAM PD), Indian National Centre for Ocean Information Service (INCOIS) and MoEF was held on 16th September 2009 to discuss the issue and it was felt that use of satellite data would be possible to accomplish the above tasks. The main tasks to be carried out in this regard were defined as follows:

1. Two pilot areas namely Cuddalore and Kutch can be used to study the violations beyond 1991 based on available satellite data to demonstrate use of satellite data for this purpose. While ICMAM PD will study the Cuddalore, Space Application Centre, Ahmedabad can be requested to provide necessary maps with HTL or data for Kutch. If the HTL data for Puri available from the State Authorities, IOM can document violations along Puri using the Satellite data.

2. Use of mangrove areas for reclamation or aquaculture beyond 1991 can also be documented from the satellite observations.

3. Since only low resolution satellite data is available for 1991 and high resolution from 1997 onwards, a cautious approach is necessary while using data of two different resolutions for arriving at details of violation. Details of error on account of each source of satellite data need to be documented. The interpretations on violations using satellite data are merely indicative and would be valid only after appropriate ground truth.

4. The shoreline changes caused by manmade activities such as construction of shore protection measures and breakwaters for ports shall be documented based on field observations and model studies for Ennore, Gopalpur, Ullal and Kayankulam by ICMAM PD and for Bavanpadu and Krishnapatnam by INCOIS. Further, detection of shoreline changes through satellite data with a minimum error of 10m is possible only through high resolution data and such data are available only from 1997, the meeting recommended to use the satellite data from 1997 to document shoreline changes caused by manmade structures.

5. The regional level shoreline changes for Tamilnadu and Andhra as studied by INCOIS through satellite data can also be used to obtain a broad picture on eroding areas along the coasts of the two states.

Based on the above guidelines, a report on application of satellite data for land use and critical habitats and use of field data in case of Port structures along with satellite data has been prepared and details are given below. The information on shoreline changes is based on field data collected, satellite imageries and information provided by the State Governments thro' Ministry of Water Resources at the end of 10th plan. Several details require updation and due to short of time, the available information has been provided. Due to non-availability of information on Gulf of Kutch and Puri, the report deals with Cuddalore in case of CRZ violations. The entire aspects as suggested by the meeting with regard to Ports have been carried out.

1. Applications of Remote Sensing in Coastal Zone Management especially to study Critical Habitats, Landuse and Landcover

1.1. Introduction

Coastal zone is an area of interaction between land and sea and thus both terrestrial and marine environments influence this zone. The interaction between various natural processes and human activities is an important factor. Coastal zone in India assumes its importance because of high productivity of its ecosystems, development of industries, concentration of population, exploration of living and non-living resources, discharge of industrial waste effluents and municipal sewage, and spurt in recreational activities. Thus, there is a need to protect coastal environment while ensuring continuing production and development. In view of this, the Govt. of India has declared coastal stretches of bays, estuaries, backwaters, seas, creeks, etc. which are influenced by tidal action up to 500 m from High Tide Line (HTL) and land between Low Tide Line (LTL) and HTL as coastal regulation zone (CRZ) during 1991. Restrictions were imposed on setting up and expansion of industries, operations and processes in CRZ to manage development in coastal areas. In order to regulate these activities in coastal areas, it is necessary to have knowledge about present land use conditions and precise delineation of HTL and LTL.

Remote sensing data, especially Indian Remote Sensing (IRS) data have been used to generate database on various components of coastal environment of the entire country. Applications of remote sensing in the coastal environment include

I. Preparation of Coastal area maps for implementation of CRZ. Each of these maps have information on
    - Ecological sensitive areas or critical habitats (mangroves, coral reef, mudflats, beach) between HTL and LTL,
    - land use (agriculture, forest, barren land, built up land) up to 500 m from HTL
    - Delineation of HTL and LTL on 1:25,000-scale.

II. Monitoring and management of coastal critical habitats

III. Identify unauthorized developmental activities in the coastal regulation zone.

1.2. Role of Remote Sensing in Coastal Zone Management

In India, satellite data is widely used to study many aspects of coastal zone. During last thirty years, availability of remote sensing data has ensured synoptic and repetitive coverage for the entire Earth. This information has been extremely useful in generation of spatial information on coastal environment at various scales and with reasonable classification and control accuracy. In India, coastal wetland, land use and landform and shoreline-change maps have been produced on 1:250,000, 1:50,000 and 1:25,000 scale using IRS LISS I, II and III, LANDSAT MSS/TM and SPOT data.

Remote Sensing data is also being used to study the status of the critical habitats to see that changes that have occurred on coral reefs and mangroves over the decades. The classification accuracy achieved is 85 - 90 per cent confidence level. A control accuracy of 20-m has been achieved. The major advantage of remote sensing data is monitoring of changes that occur in the area periodically. This has helped to resolve some of the disputes related to implementation regulations in the coastal zone. The important achievement has been the acceptability of satellite-based information on CRZ by both the executive and judicial authorities. It is now almost essential for all industries, governmental as well as non-governmental agencies to use satellite-derived information for the coastal regulation zone activities. Realising the value of the remote-sensing derived information, the state and central agencies responsible for the implementation of CRZ are increasingly adopting remote sensing data for their routine use. The availability of 1-5 m high-resolution and stereo data from IKONOS, RESOURCESAT-I and CARTOSAT greatly facilitate preparation of local level maps at 1:5,000 scale and larger. The easy access to high spatial resolution data along with multi-spectral characteristics, repetitive coverage and development of geographic information system has provided new impetus to coastal mapping.

1.3.Classification of Coastal Zone in India

To regulate all the developmental activities in the coastal zone, the Government of India has, vide a Notification issued in February 1991 under the Environment Protection Rules 1986, created the Coastal Regulation Zone (CRZ) which includes the coastal stretches of seas, bays, estuaries, creeks, rivers and backwaters which are influenced by tidal action (in the landward side) upto 500 m from the High Tide Line (HTL) and the land between the Low Tide Line (LTL) and High Tide Line (HTL), and has imposed restrictions on the construction activities, setting up of new industries, expansion of existing ones, operations or processes. For regulating the development activities, the CRZ has been classified into 4 categories. The important features of this Notification are as follows:

Category I (CRZ-1): Where no new construction is permitted within 500 m of the HTL and between HTL and LTL:

- Area between the LTL and HTL
- Areas that are ecologically sensitive and important such as National Parks, Marine Parks, Sanctuaries, Reserve Forests, Wild Life Habitats, Mangroves, Corals/Coral Reefs, etc.,

Category II (CRZ-II): Where, buildings are permitted only on the landward side of the existing road or on the landward side of the existing authorized structure. This mostly includes areas already developed up to or close to the shoreline.

Category III (CRZ-III): Where the area up to 200 m from the HTL is to be earmarked as "No Development Zone". Between 200 m and 500 m from the HTL development of vacant plots are permitted for construction of hotels, beach resorts subject to certain conditions. Constructions of dwelling houses are also permitted so long as they are within the ambit of traditional rights or customary uses such as existing fishing villages.

Category IV (CRZ-IV): Where:

- No new construction of buildings is permitted within 200 m of HTL.
- Between 200 m and 500 m from HTL buildings will not have more than 2 floors (ground and 1st floor):Andaman and Nicobar Islands, Lakshadweep and small islands, except those designated as CRZ-I, CRZ-II and CRZ-III.

1.4. Applications of Remote Sensing for preparation of Coastal maps used for CRZ implementation

The increasing pressure on the coastal zone due to migration of population, spurt in development of industries and resultant increase in discharge of waste effluents and municipal sewage and booming recreational activities, have adversely affected the coastal environment. The population of coastal districts is currently about 15 per cent of the total population of India. The Govt. of India had issued a notification to use satellite data for preparation of 1:25,000 scale maps for implementation of coastal regulations. Based on this, maps showing wetland features between HTL and LTL and coastal land use features up to 500 m from HTL on 1:25,000 scales for the entire Indian coast, using IRS LISS II and SPOT and recently with IRS LISS III and PAN merged data, were prepared. The accurate demarcation of HTL and LTL is important as they control boundaries of regulation zones.

These maps provided condition of land use and wetlands during 1990-91, just before the notification of CRZ issued by the Govt. of India.. The information on mangroves, coral reef, protected areas, etc. were used to identify ecologically sensitive areas, CRZ I. Separate maps on coral reefs and mangroves were prepared to assess condition of such areas. The maps showing areas under erosion and deposition were also prepared to assess vulnerability of coast. CRZ II areas are essentially built up lands. The remaining areas have been identified as CRZ III and all islands as CRZ IV.

These maps have about 85 per cent classification accuracy at 90 per cent confidence level. The planimetric accuracy is about 60-75 m. The use of IRS 1C/1D data has improved the planimetric accuracy to 15-20 m. CRZ maps are being used by the State Governments to prepare coastal zone management plans (Fig.1).

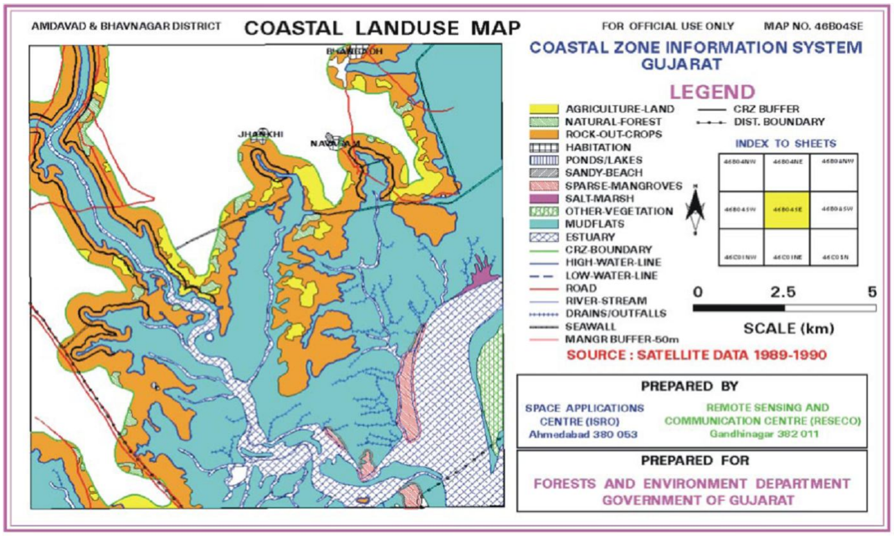


Fig.1. CRZ map for a part of Gujarat

1.5. Applications of Remote sensing to monitor and manage ecologically sensitive zones

Ecologically sensitive zones or Critical habitats are identified as areas, which are vital to the survival of the species at some phase of its life cycle or to the survival of the community, because of the ecological processes, which occur within it (IUCN, 1976). Critical habitats include feeding, nesting, breeding and nursery areas of estuarine and marine animals; major sources of food and nutrients for feeding areas elsewhere (e.g. mangroves); or areas that are particularly rich in species (e.g. coral reef); or highly productive areas (e.g. seagrass); or areas of special scientific interest. The mangrove forests, tidal flats, beaches, lagoons/estuaries seagrass or kelp beds and coral reefs are termed as the critical areas/habitats. These critical habitats are under threat due to both natural and anthropogenic activities and hence need to be focused for management and conservation. The management strategy of these critical habitats should be based on the detailed knowledge of resource vulnerabilities and a candid examination of conservation issues. Applications of Satellite data to study the features of mangrove ecosystem which is relevant to CRZ notification, is described below.

1.5.1. Mangrove Ecosystems

Mangroves are the tidal forests of coastal wetlands, existing in the intertidal zones of sheltered shores, estuarine tidal creeks, backwaters, lagoons, marshes and mudflats of the tropical and sub-tropical region of the world (Fig.2). The total area of mangroves in India is estimated at 6740 sq. km. This covers about 7% of the world's mangroves.

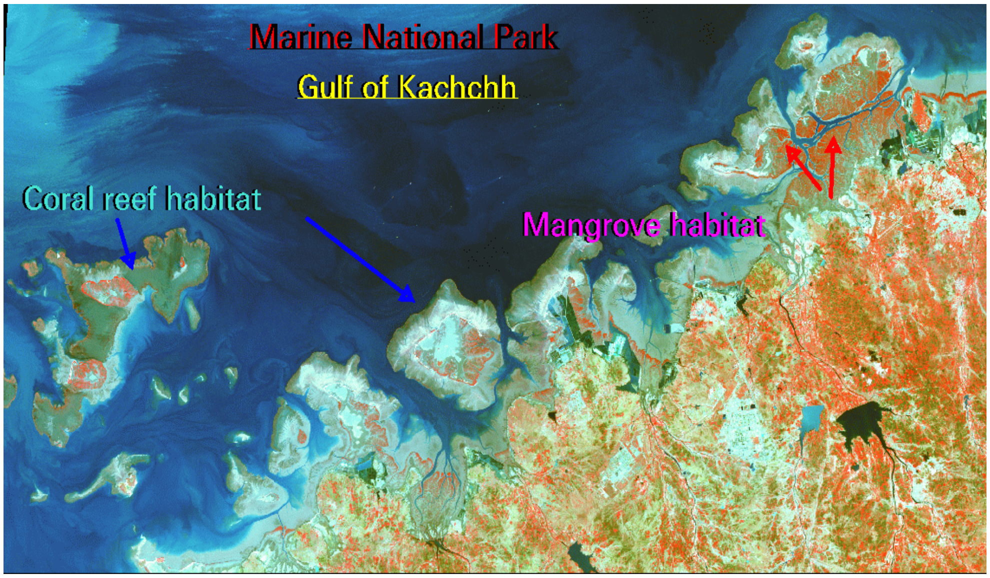


Fig.2. Mangroves in Gulf of Kachchh

The decadal changes that have occurred in two mangroves ecosystems namely Pichavaram in Tamil Nadu, Coringa in Andhra Pradesh were studied using remote sensing data. Landsat TM data with a spatial resolution of 30m was used to study the state of the ecosystem in the late eighties. IRS LISS III data was then used to study the state ecosystem at nineties. By analyzing multi-temporal data over a period of ten years, it was found that there was a gain in the mangrove area in Pichavaram while a loss of mangrove area in Coringa (Fig.3,5).

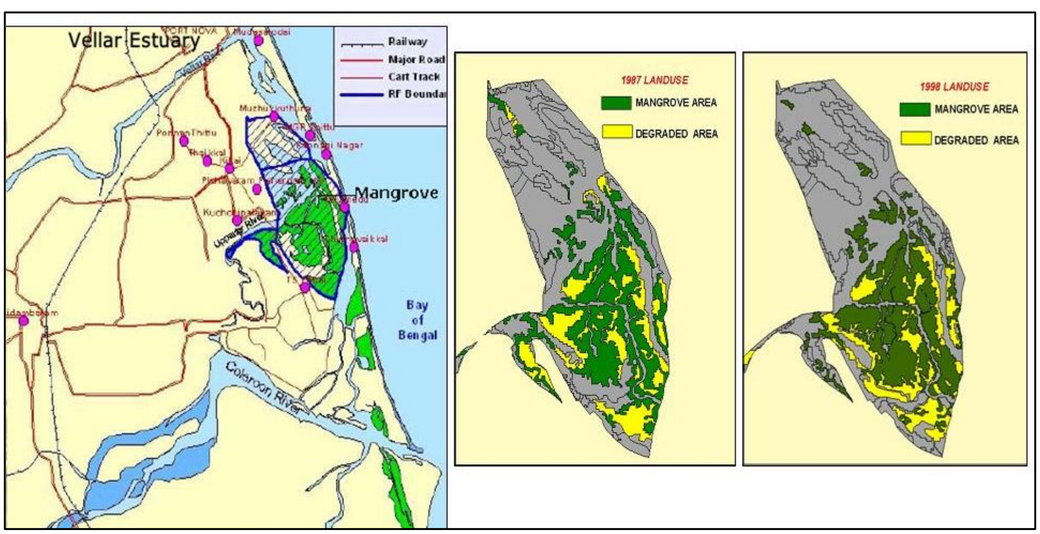


Fig 3. Decadal Changes in the Landcover within Pichavaram Reserve Forest

Remote sensing data is an invaluable tool to study natural or anthropogenic changes that that have occurred in reserve forest areas. The changes that have taken place in the in the Pichavaram reserve forest were studied using toposheet and multi-temporal satellite data. Comparison of 1987 and 1998 land use/cover maps revealed that conversion of mangroves have occurred in both ways viz., (1) healthy mangroves to degraded and mudflats, and (2) degraded and mudflats to healthy mangroves (Fig.4). This means that both degradation and rejuvenation have taken place during these years.

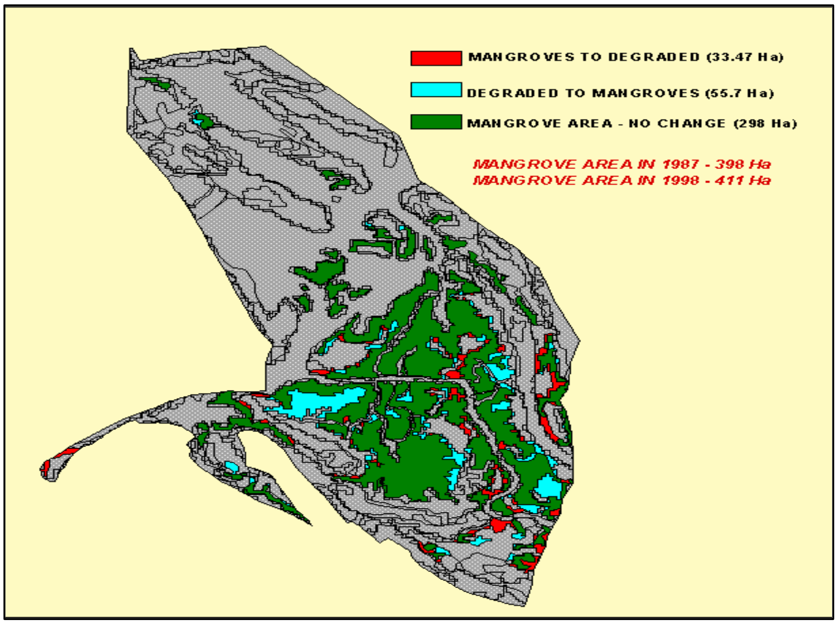


Fig.4 Decadal changes (1987-1998) in the mangrove cover in Pichavaram Reserve Forest

Degraded mangrove areas are less in 1998 than in 1987 indicating an increase in mangrove area. Some of the major changes that have occurred from 1987 to 198 are given in Table 1.

Table 1. Changes in Landuse/Landcover in Pichavaram Reserve forest area

(1987-1998)

Landuse/Landcover	Area in ha
Mangrove to degraded mangrove	33
Degraded area to mangrove	58
Mangrove to mudflat	29
Mudflat to Mangroves	24

It was found that the gain in mangrove area was mainly due to afforestation measures and degradation mainly due to insufficient tidal flushing and anthropogenic pressure exerted by the local population.

Within Coringa Reserve Forest limits, in 10 years, mangrove area has decreased from 9623 to 9320 ha, while degraded mangrove area has increased from 685 to 874 ha (Fig.5). Analysis of 1988 and 1998 landuse maps overlaid in GIS revealed that changes have occurred from mangrove to other categories (such as aquaculture, degraded area, mudflat, etc) and vice versa and some areas remained unchanged. This information is useful in taking conservation/remedial measures to rejuvenate lost mangroves and to minimize non-beneficial landuse changes like conversion of mudflat ecosystems to prawn farming etc.

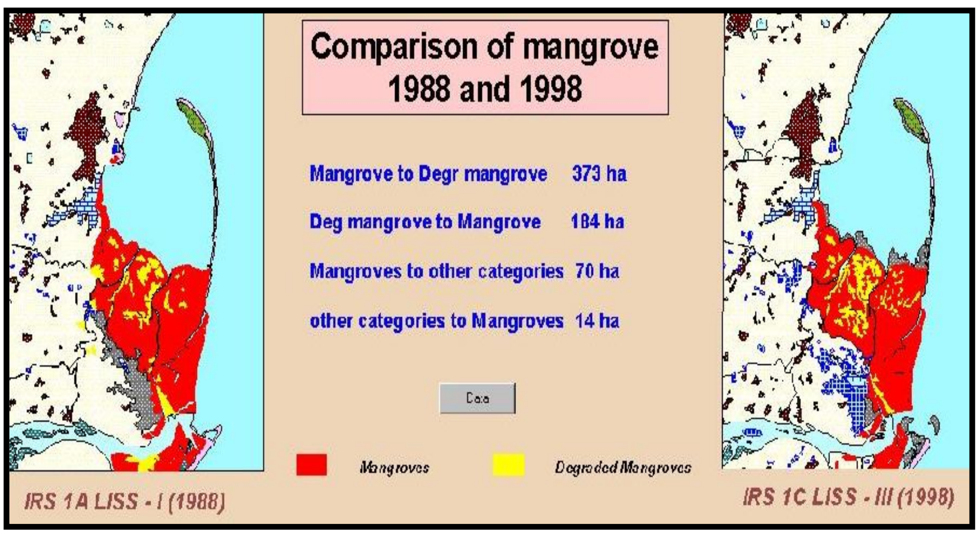


Fig.5 Decadal changes in mangrove cover over Coringa, Kakinada.

1.6. Applications of remote sensing data in monitoring the developmental activities in the CRZ

1.6.1 Landuse changes in Coastal Goa

Due to the phenomenal growth of the coastal tourism industry, the state has been witnessing distinct changes in its landuse which are responsible for the environmental stress in the coastal landscapes of the state (Fig.6). The landuse and landcover changes in coastal Goa have been studied using remote sensing and GIS techniques. The total land area of Goa comprising of two districts namely North Goa and South Goa is 3317 km² of which only 18% is considered to be coastal areas.

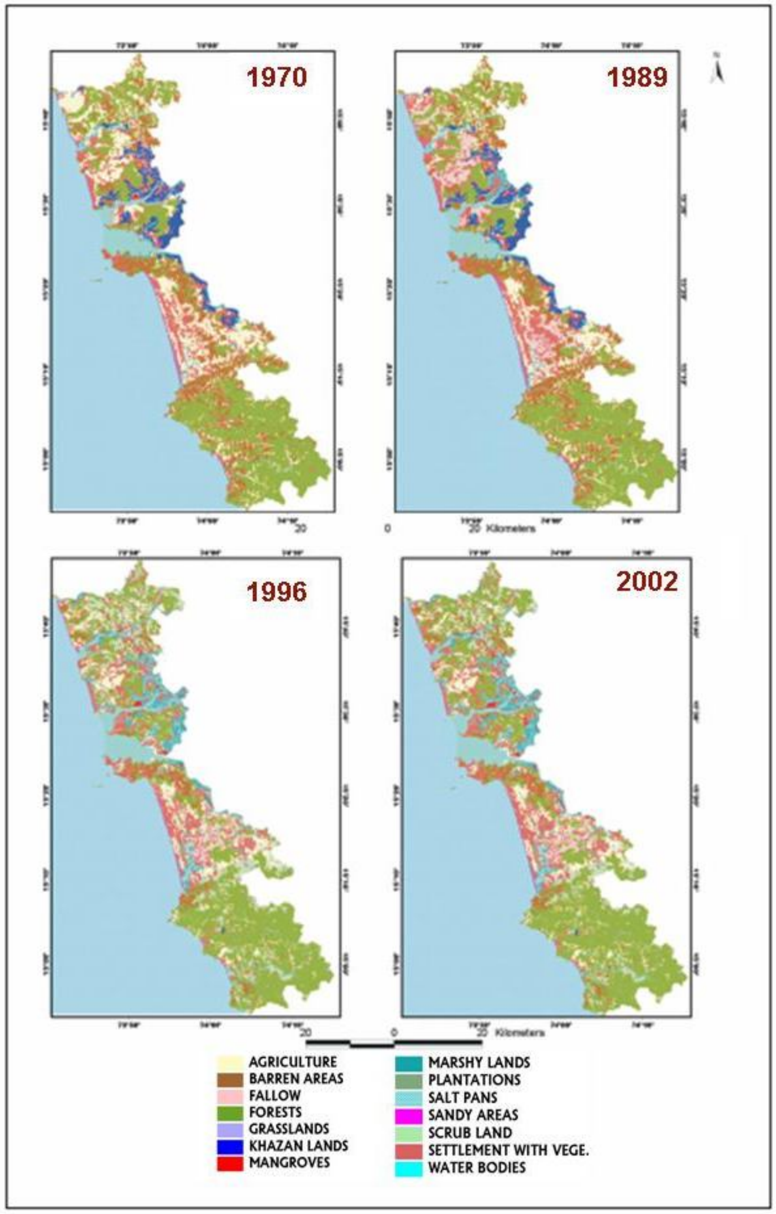


Fig.6: Changes in the Coastal areas of Goa over the decades

Survey of India toposheets (1970) provides the earliest documentation on the landuse of coastal Goa. Toposheets were used to prepare the landuse and landcover of Goa for the year 1970. Remote sensing data pertaining to April 1989, April 1996, March 2002 were analysed to prepare the landuse/ landcover map of Goa pertaining to the corresponding years . The major changes in the Landuse / Landcover observed in Goa between 1989 and 2002 are decline in area under agriculture and Khazans and an increase in area under mangroves and settlement.

1.6.2. Use of Satellite data in identifying CRZ Violations

Remote sensing data can be used to identify coastal zone violations. By comparing satellite data pertaining to 1990 and the latest available imagery it is possible to identify the changes that have taken place in an area. However, it should be noted that the satellite data pertaining to early 1990s had poor spatial resolution compared to the data available today. Landsat TM data with a spatial resolution of 30m can be used to identify the landuse/landcover in the coastal areas during 1990. This data when compared with the presents LISS III data (23m) would help identify major changes such as conversion of vegetation, wetlands, loss of green cover, growth of settlements in the coastal areas(Fig.7).

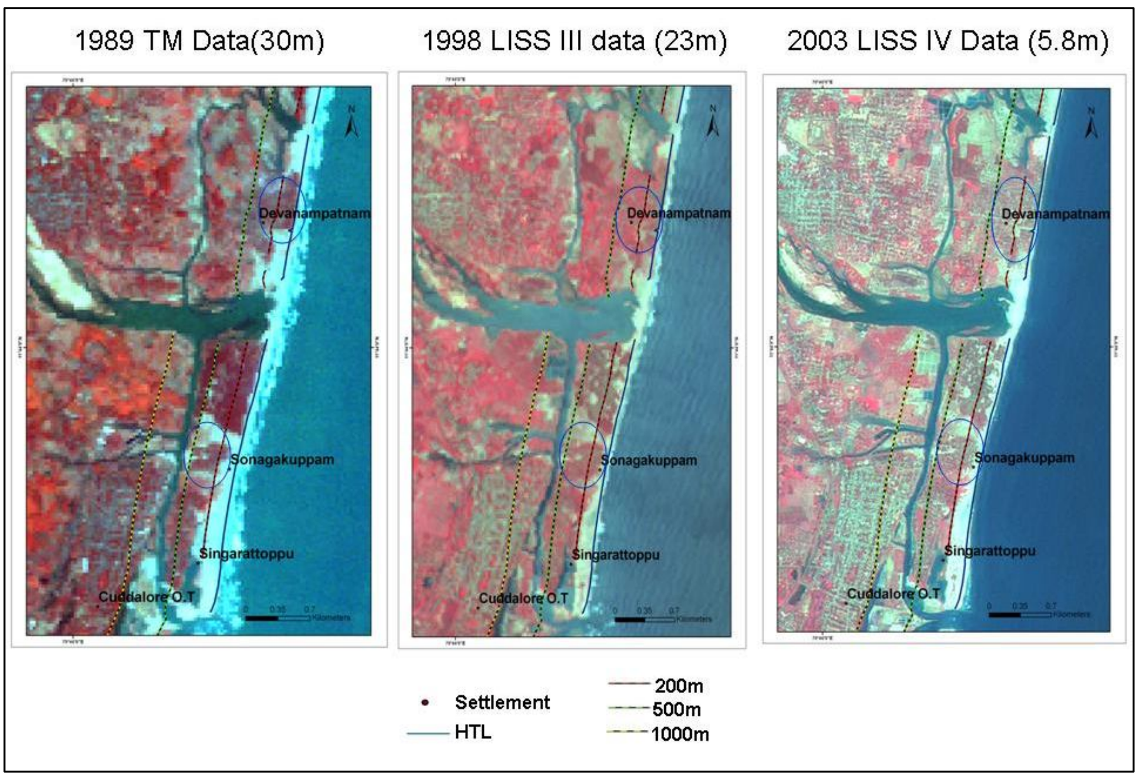


Fig:7 Changes in the Coastal areas of Devanampattinam, Cuddalore over the decades

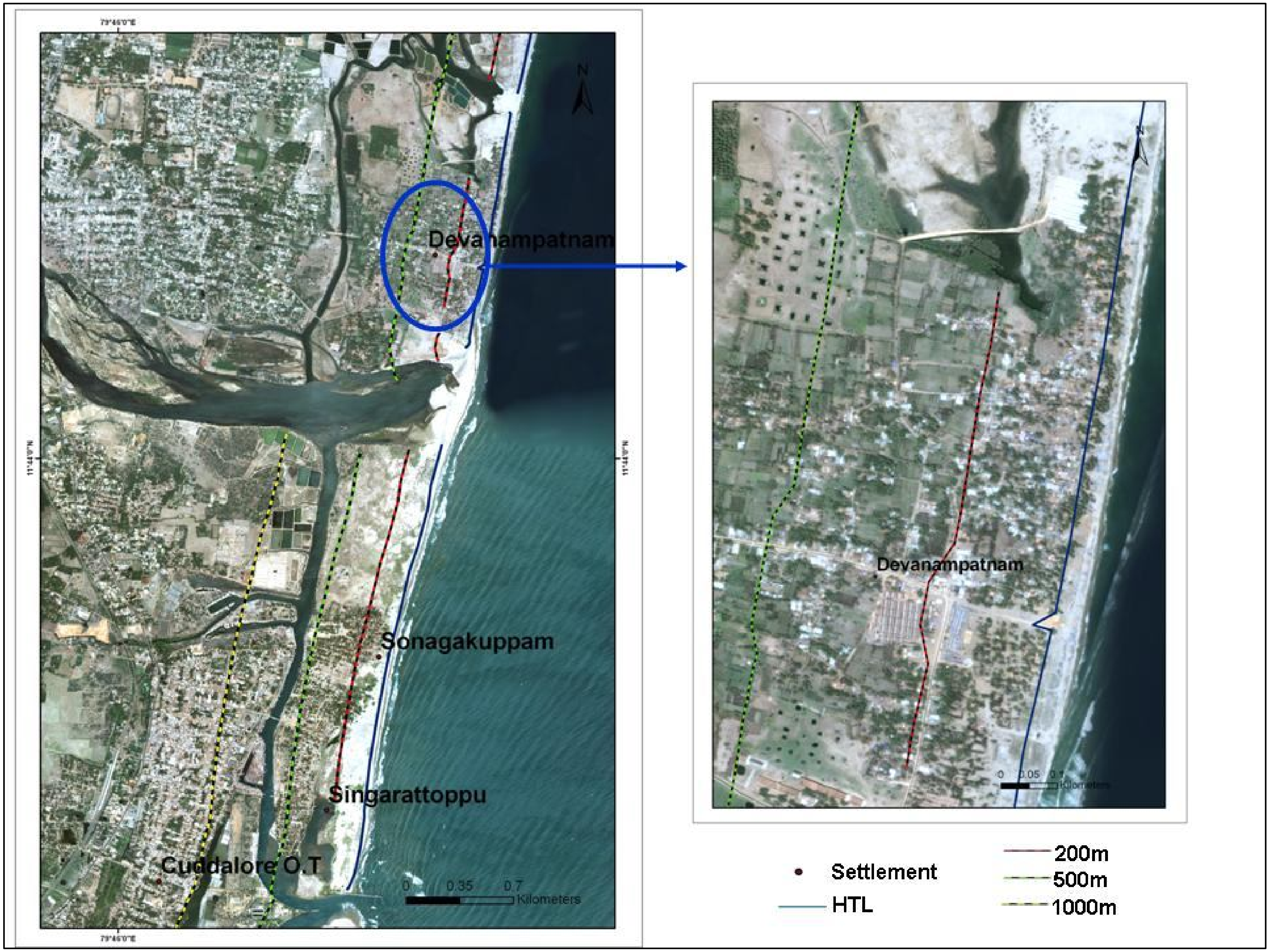


Fig.8. Buildings that fall in the CRZ area in Devenampattinam

By using high resolution data such as Cartosat, IKONOS and Quickbird it is now possible to identify all the coastal structure that fall within the CRZ area (Fig.8). However, field verification is required to ascertain whether it is a CRZ violation or not.

The following aspects have to be taken into consideration while using Satellite data to identify violations.

- As there were no high resolution satellite data before 1990, information on structures present before February 1991 (i.e, date of CRZ notification)can be obtained only from local authorities.
- Tidal conditions at the time of acquisition of satellite data must be taken into account and appropriately indicated in the map as the seawater line and the HTL may not match.
- Buildings beneath thick canopy cannot be studied even using high resolution data and so collection of field data becomes mandatory to ascertain existence of structures in these areas.
- The type of structure for e.g commercial or residential, cannot be identified using satellite data. Ground truthing will only ascertain the type of structure in the area.
- As the availability of high resolution satellite data is limited to weekly or monthly intervals, it may not be possible to use satellite data to pinpoint the exact date/week during which construction was commenced.

Therefore, a combination of examination of records from Local authorities and comparison of Satellite data between 1991 and 1998 will grossly indicate the extent of violation in the coastal area. A similar comparison with high resolution data obtained after 1997 will clearly indicate the actual extent of violation.

1.7 Accuracy of CRZ maps

The ultimate quality of map depends upon type of satellite data, its resolution, scale of mapping, size of minimum area to be mapped, analysis procedure, amount of ground information collected, skill of interpreter, method of digitisation, etc. The specification for input satellite data (bands, season, etc.), scale, classification system, interpretation key, minimum mapping unit, etc. should be taken into consideration based on the application. Moreover quality checks are to be carried at each stage of work as follows.

i) Preliminary interpretation checks
ii) Final Interpretation checks
iii) Digitisation checks
iv) Estimation of classification and control accuracy

CRZ maps presently available in the country have a horizontal accuracy (other than harbours, berthing areas, approach channels, etc.) of 20 m in case of 1:25,000-scale as per the International Hydrographic Survey.

1.8 Conclusion

Realising the value of the remote-sensing derived information, the state and central agencies are increasingly adopting remote sensing data for their routine use. Availability of temporal satellite data provides information on changes that have occurred in the coastal areas over a period of time. It has been proved beyond doubt that critical habitats, landuse/landcover, developmental activities, growth of settlements etc in the coastal regulation zone can be mapped, monitored and managed using remote sensing data. The combination of moderate and high-resolution data provided detailed coastal land use maps at a classification accuracy of 85% on the 1:25,000-scale for implementing coastal regulation measures. Remote Sensing data were used to classify Mangrove areas up to community level through contextual editing. High spatial resolution satellite data plays an important role in updating and monitoring the developmental activities in the Coastal regulation zone at low cost, manpower and time. High resolution Remote sensing data adequately supplemented with field data would be an invaluable tool to quantify the violations in the coastal zone.

2. Shoreline changes – caused by natural and anthropogenic activities especially by Ports and Harbours and use of Satellite data for identification

2.1. Introduction

The evolution of shorelines and coastlines is of major concern for coastal communities. The shoreline retreat leads to the loss of the beach and consequently to a setback of the coastline that threatens the coastal communities. The basic cause of most shoreline changes is a gradient in the littoral transport over a coastal stretch. For example less sediment is transported into a given section of the coastal area than is transported out of the same section, will lead to either erosion of the seabed or coastal erosion, i.e. shoreline setback and possibly coastline setback.

Shorelines are generally more or less in dynamic equilibrium. Their evolution due to changes in winds, waves, currents, and sediment transport, is rather seasonal, characterized by alternate erosion and accretion. Additional changes occur when perturbations are introduced by anthropogenic factors/activities such as construction of structures in coastal waters. Shoreline change is a natural process of evolution of coastal areas. The shoreline evolution at a given site depends on the interaction of these processes with the geological setting and may result in a great variety of shoreline forms and features on different scales of time, from a single tidal event, to decades or centuries. However, three time scales of shoreline change evolution can be distinguished:

i) Geological evolution. Takes place over centuries and affects a large area
ii) Long-term evolution. Annual to decadal shoreline changes affecting a limited stretch of the shoreline
iii) Short-term evolution. Seasonal variations of shoreline at the local scale

The understating the cause and pattern of erosion/accretion is very essential and attracts added importance in the case of Indian coast which is thickly populated and where a lot of developmental activities are undertaken along the coast. As coastal populations continue to grow, and community infrastructures are threatened by erosion, there is an increased demand for accurate information regarding past and present trend in the shoreline changes. This information is also needed to draw a setback line for regulating the developments near the coast. This report provides information about shoreline changes along the Andhra Pradesh and Tamil Nadu coastline during the period of 1972 to 2000 and with some site specific information about the changes in shoreline due to structures at local scales.

2.2. Causes of Coastal Erosion

While the effects of waves, currents, tides and wind are primary natural factors that influence the coast the other aspects eroding the coastline include: the sand sources and sinks, changes in relative sea level, geomorphologic characteristics of the shore and sand, etc. Other anthropological effects that trigger beach erosion are: construction of artificial structures, mining of beach sand, offshore dredging, and reduction in sediment supply from the rivers.

2.2.1 Major anthropogenic cause of shoreline erosion

Coastal structures constructed for port operations and coastal protection works interfere with the littoral transport are found the most common cause of coastal erosion. The presence of the structure in surf zone has a series of effects such as accretion on the upstream side of the structure, erosion on downstream, large structures may also cause initial erosion on the upstream side, loss of sand to deep water, trapping of sand in entrance channels and in fore harbours.

i) Groyne or shore perpendicular structures

Groynes are normally built perpendicular to the shoreline with the purpose of protecting a section of the shoreline by blocking (part) of the littoral transport, whereby sand is accumulated on the upstream side of the groyne. However, the trapping of the sand causes a deficit in the littoral drift budget, and this kind of coast protection is always associated with corresponding erosion on the lee side of the structure. In other words, a groyne just shifts the erosion problem to the downstream area. This is the reason that groynes are often built in long series along the shoreline, a so-called groyne field. The more efficient the groyne field is protecting the shoreline within the groyne field, the more lee side erosion will be experienced downstream. These effects of groynes were not fully understood and realized at the beginning of the last century when most major groyne fields were constructed. Nowadays, this mechanism is understood and can be modelled and therefore groynes can be designed to fulfill their purpose in an optimal way to prevent erosion in the lee side.

ii) Breakwaters for Ports

The primary purpose of port breakwaters is to provide tranquility required for safe mooring, cargo handling and navigation for the calling vessels. But when built on the shoreline it interferes with the littoral drift budget and the results are sedimentation and shoreline impact. Like a groyne, the breakwater acts as a blockage of the littoral transport, whereby it causes trapping of sand on the upstream side in the form of an accumulating sand filet, and the possible bypass causes sedimentation in the entrance. The sedimentation requires maintenance dredging and deposition of the dredged sand. The result is a deficit in the littoral drift budget which causes lee side erosion along the adjacent shoreline.

2.3. Status of Coastal Erosion in India

The India has about 7517 km long coastline spreading about 5423 km along the mainland and 2094 km the Andaman and Nicobar, and Lakshadweep Islands. The mainland coastline consists of nearly 43% sandy beaches, 11% rocky coast with cliffs and 46% mud flats and marshy coast (Table 2). At present, about 23% of shoreline along the Indian main land is affected by various degree of erosion varying from minor, moderate to severe. As much as 1248 km of the shoreline is getting eroded all along the coast.

The erosion problems are reported for all coastal states. Along Gujarat coast, shoreline erosion is observed at Ghoga, Bhagwa, Dumas, Kaniar, Kolak and Umbergaon, and sediment deposition leading to the formation of sand spits at the estuarine mouths of the Tapi, Narmada, Dhadar, Mahe, Sabarmati, Kim, Purna and Ambika. Erosion has been observed at Versova, Mumbai; near Kelva fishing port, north of Mumbai and at Rajapuri, Vashi and Malvan along the Maharashtra coast spreading 263 km of the 652.6 km shoreline. Along Goa coast, erosion is noticed at Anjuna, Talpona and Betalbatim. The Andaman and Nicobar consists of about 265 islands, most of which are composed of rocks like fossiliferous marine petroliferous beds, conglomerates, sandstone and limestone. Land subsidence of 0.8 metre to 1.3 metre has occurred at the Andaman and Nicobar islands due to December 26, 2004 tsunami and has resulted in shoreline erosion in some of the islands. Coastal erosion and submergence of land have been reported at Ankola, Bhatkal, Malpe, Mulur, Mangalore, Honnavar, Maravante and Gokarn in Karnataka influencing 249.6 km out of the state's total coastline of 280 km. The problem is relatively more severe in Dakshina Kannada and Udupi coasts, where about 28% of the total stretch is critical. In Uttara Kannada region, about 8% of the coast is subjected to severe erosion. Erosion is noticed at Gopalpur, Puri, Paradip and Satbhaya in Orissa. Growth of long sand spits at Chilka lake indicates the movement of littoral sediment and subsequent deposition. 480 km of the 569 km shoreline of Kerala is being affected by the phenomenon.

It may be noted that the rate of erosion varies over time and site to site, due to many factors such as longshore current regime, erodibility of beach material and its composition, nearshore seabed shoals and slopes, storm wave energy and duration, shoreline orientation, shore protection structures etc. Oscillation of the shoreline along the Indian coast is seasonal. Some of the beaches regain their original profiles by March/April indicating seasonal fluctuations. However other beaches that do not regain their original shape over an annual cycle undergo net erosion. Along east coast, the wave activity is significant both during southwest and northeast monsoons. Extreme wave conditions occur under severe tropical cyclones which are frequent in the Bay of Bengal during the northeast monsoon period. Shoreline erosion along the east coast is experienced in the northern regions of Chennai, Ennore, Visakhapatnam Paradip and Gopalpur ports due to construction of breakwaters /groins of the respective port . These structures have altered the sediment transport pattern causing erosion on the northern sides of the structures. However, the west coast nearshore current regime experiences high wave activity during the southwest monsoon with relatively calm sea conditions prevailing during the rest of the year. Further, it has been reported that sea level rise of 1 mm per year could cause a maximum recession of shoreline in the order of about 0.5 m per year.

Table 2: State wise coastline and Status of coastal erosion

	Name of State	Length of Coastline (km)	Sandy beach (%)	Rocky Coast (%)	Muddy Coast (%)	Marshy Coast (%)	coastline subject to erosion	coastline protected (km)
1)	Gujarat	1214.7	28	21	29	22	36.4	4.0
2)	Maharashtra	652.6	17	37	46	-	263.0	127.0
3)	Goa	160.5	44	21	35	-	10.5	3.0
4)	Karnataka	280.0	75	11	14	-	249.6	56.0
5)	Kerala	569.7	80	5	15	-	480.0	369.0
6)	Tamilnadu	906.9	57	5	38	-	36.2	14.0
7)	Andhra Pradesh	973.7	38	3	52	7	9.2	0.5
8)	Orissa	476.4	57	-	33	10	107.5	10.0
9)	West Bengal	157.5	-	-	51	6	49.0	14.0
10)	Daman and Diu	9.5					-	
11)	Pondicherry	30.6					6.4	
12)	Andaman & Nicobar	1962					-	--
13)	Lakshadweep	132.0					132.0	44.0
Total length of Indian coastline with Islands		7526.1					1379.8	641.5
Total length of Indian coastline without Island		5432.1	396	103	313	45	1247.8	597.5

As shoreline is one of the rapidly changing landform. The accurate demarcation and monitoring of shoreline (long-term, seasonal and short-term changes) are necessary for understanding of coastal processes. Remote sending data provides valuable information about the changes & rate of changes of shoreline. Here some case studies are illustrated where site specific field measurements and multi-date satellite data have been used to study shoreline changes and coastal landforms to understand the coastal processes.

2.3.1 Shoreline changes along the Tamilnadu coast

Tamilnadu has about 906 km long coastline The shoreline changes along Tamilnadu coast was studied using remote sensing data for past 28 years i.e. Year 1972's, to 2000. Considering the Maximum and Minimum values of the shoreline change rate, the shoreline is divided in to three categories as accretion, low erosion and high erosion. The study reveals that the area experiences both erosion and accretion. The dominant class is the low erosion with rate up to 5m/y observed with a length of 500km. The coastlines along Chennai-Ennore, Devipattinam and Kanyakumari are experiencing the high erosion with a rate more than 5 m/yr with total length of coastline 70km. whereas the remaining 375km coastline is under accretion (Figs.9 & 10).

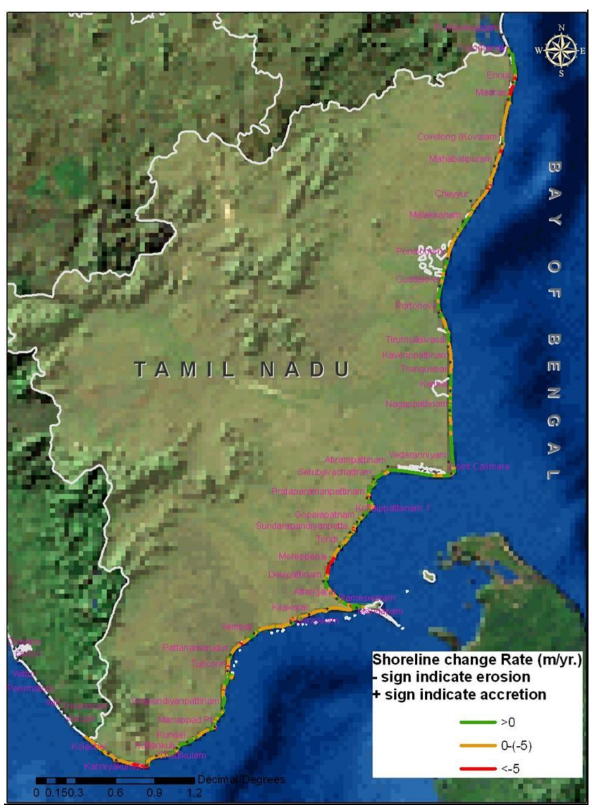


Fig.9. Monitoring locations for shoreline changes along Tamilnadu coast.

The study provides overall information about the coastal erosion at regional scale.The beach width of 30 sites covering about 77 km long coastline spreading along Tamilnadu coast were monitored at monthly intervals during 1978 to 1988 by IHH, Pondi, Govt of Tamilnadu to estimate the erosion and accretion rates It was reported that on an average 0.419 m/m run of beach length/ year is taking place along the Tamilnadu coast, which is an alarming figure. Erosion was reported along Pulicat, Royapuram, Eliot, Kovalam, etc with while Ennore, Cuddalore, Rameshwaram, Muttom etc locations were reported accreting zones coast. The erosion rate observed at Poompuhar, Tarangampadi, Nagapattinam, Mandapam, Manapadu, Ovari, Kanyakumari, Pallam, Manavalakurichi and Kolachel is about 0.15, 0.65, 1.8, 0.11, 0.25, 1.1,0.86, 1.74, 0.60 and 1.2 m/yr respectively. The maximum rate of erosion along Tamil Nadu coast is about 6.6 m/yr near Royapuram, between Chennai and Ennore port (Table 3 and Fig.11). The accretion rate at Cuddalore, Point Calimere, Ammapattinam, Kilakarai, Rameswaram, Tiruchendur, Manakudi and Muttam is observed to be about 2.98, 3.4, 0.72, 0.29, 0.06, 0.33, 0.57 and 0.17 m/yr respectively. The Table 3 below indicates rate of erosion/ deposition at some important places Tamilnadu coast.

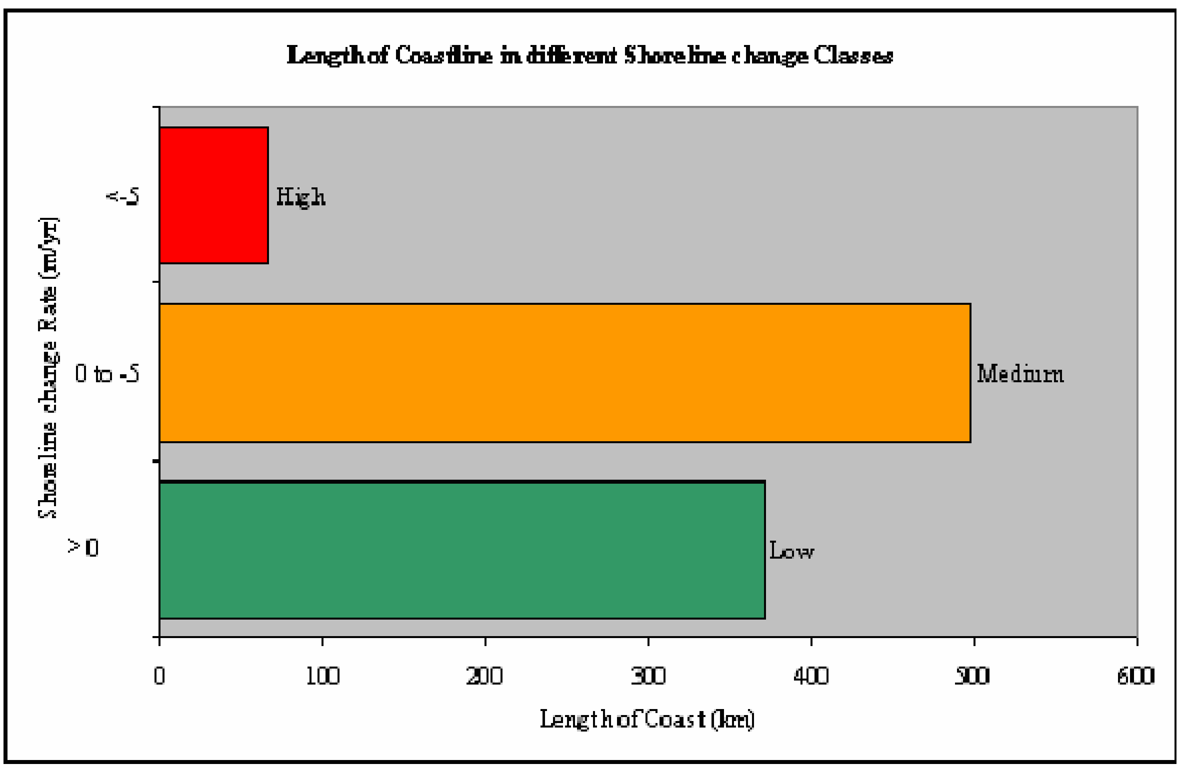


Fig.10. Length of Coastline in different Shoreline change classes along the Tamil Nadu coast

Table 3 : Accretion and erosion zone along Chennai coast

Sl. No.	***Locations***	***Length (m)***	***Accretion/ Erosion***	***Rate m/year***
1	*Pulicat*	*710*	*E*	*3.20*
2	*Ennore*	*3265*	*A*	*1.30*
3	*Royapuram*	*5380*	*E*	*6.60*
4	*Marina*	*2968*	*A*	*1.70*
5	*Foreshore*	*2300*	*A*	*1.09*
6	*Elliot*	*2080*	*E*	*1.28*
7	*Kovalam*	*3150*	*E*	*0.81*
8	*Mahabalipuram*	*5450*	*A*	*0.25*
9	*Pondicherry*	*1190*	*E*	*0.15*
10	*Cuddalore (North)*	*1538*	*A*	*8.00*
11	*Cuddalore (South)*	*483*	*A*	*2.98*
12	*Poompuhar*	*1905*	*E*	*0.65*
13	*Nagapattinam*	*4270*	*E*	*0.11*
14	*Mandapam*	*2194*	*E*	*0.25*
15	*Rameswaram*	*3295*	*A*	*0.06*
16	*Manappadu*	*1600*	*E*	*1.10*
17	*Uvari*	*2600*	*E*	*0.86*
18	*Kanyakumari*	*700*	*E*	*1.74*
19	*Manakkudi*	*3650*	*A*	*0.57*
20	*Pallam*	*2600*	*E*	*0.93*
21	*Muttom*	*3000*	*A*	*0.17*
22	*Manavalakurichi*	*3500*	*E*	*0.60*
23	*Colachel*	*1750*	*E*	*1.20*
24	*Midalam*	*2500*	*E*	*0.84*

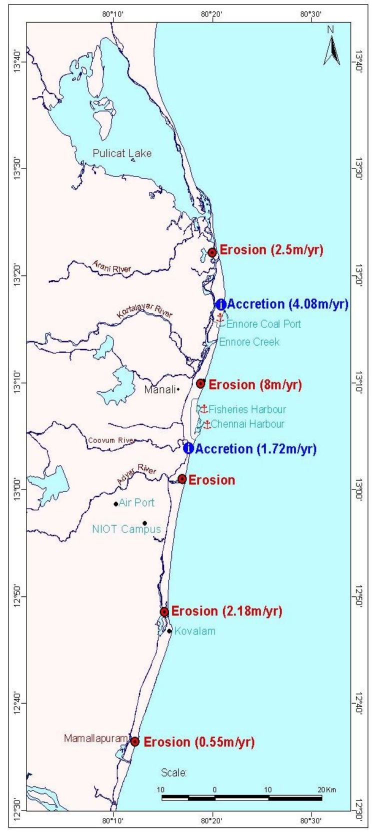


Fig 11: Accretion and erosion zone along Chennai coast (Mahabalipuram to Pulicat lake)

2. 3.1.1 Shoreline Changes due to Chennai Port

Chennai port has undergone several changes since its inception in 1861 as a single pier of 335 m, mainly to counteract the adverse problems associated with the sediment finding its way to port approach channel till developed full-fledged port. The present layout of Chennai port and its effect on adjacent shoreline is shown as pictorial representation in Figure 12. The outer harbour was commissioned in year 1972. The Chennai coastline was in dynamic equilibrium prior to the development of Chennai harbour. However, the 11 km length of the coast extending from fishing harbour to Ennore creek is under enormous stress due to an increased industrial growth combined with harbour facilities and has resulted changes in coastal dynamics. The coast north of the harbour has been experiencing erosion at the rate of about 8 meters per year since the Chennai harbour was constructed. The rate of sediment transport is towards the north from March to October and towards the south from November to February. The net drift towards north is in the order of 0.3 x 10^6 m^3 per year. It is estimated that 500 meters of beach has been lost between 1876 and 1975 and another 200 meters between 1978 and 1995. Schematic diagram (Fig. 12) shows the present day configuration of the Chennai port and the growth of the beach on the southern side over the years. Marina Beach has been formed as a result of arresting the littoral drift by the

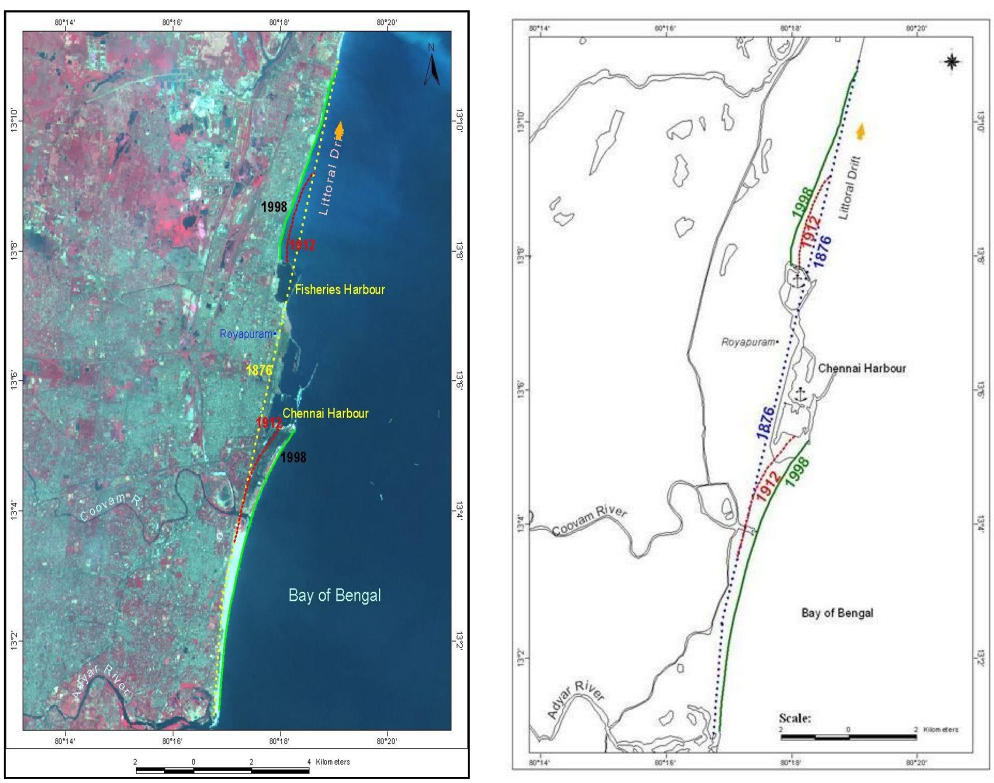


Fig.12 – Configuration of Chennai Port and shoreline changes

breakwater. The north Chennai coast, extending from the fisheries harbour is fragile and is very sensitive for change in the environmental conditions. One of the main reasons for this delicate response of the coastal stretch is the disruption in sediment supply induced by the Chennai port causing extensive erosion over the years. This has been aggravated by the rough sea conditions during the northeast monsoon.

A View of surf zone and accreted shore opposite Marina, Chennai Harbour is seen in background (Apr-1980)

A View of erosion north of Chennai Harbour Break water is seen in back ground (June 1978

Fig. 13: impact of Chennai port a) Positive Impact b) Negative Impact

Wave overtopping and undermining of the coast due to unprecedented wave actually has caused substantial damage to the coastal region. The consequences of the construction of Chennai port and Fishing harbour on the North Chennai coast is a classic example to understand the long term impact of port on shoreline changes for coastal area management. The shoreline has recessed by about 1000 m with respect to the original shoreline in 1876. (Fig.13). The villages, hutment and the Royapuram-Ennore express highway connecting the Manali Refineries and Thermal Power Station to Chennai are subjected to sea erosion during both Southwest and Northeast monsoons every year. The erosion in the coast which became very pronounced affected the coastline up to the 13/150 KM stone near Bharathi Nagar and necessitated constant attention and protective works in response to the

Fig. 14 - Sea wall along Rayapuram

cry of the fishermen living in this stretch. The southern side of port, Marina Beach has been formed as a result of arresting the littoral drift by the breakwater. (Fig.13).

In order to protect the coastline, the State authorities resorted to construction of short-term protective structures i.e. Rubble Mound Stone wall and groins as short-term measures. Part of this protected coastal stretch experiences undermining of the seabed due to large-scale wave action. Though the short-term measures taken up by authorities gave temporary solution to the villages in protected areas, the problem is not resolved completely. Due to the construction of stone wall (**Fig. 14**), the natural beach available is lost and the down drift villages, north of protected areas started experiencing erosion. The village Chinnakuppam near Ennore fly ash outfall is experiencing severe erosion.

2.3.1.2 Ennore port

Ennore port is located 17 km north of Chennai port, between two tidal inlets viz., Pulicat on north and Ennore creek on south, has distinct morphological characteristics such as Narrow barrier spit, shoals and coastal orientation form a complex nearshore system. The port was constructed in the year 2000, became operational from 2001 with coal as a major cargo. It has a water-spread area of 240 ha with southeastern entrance,

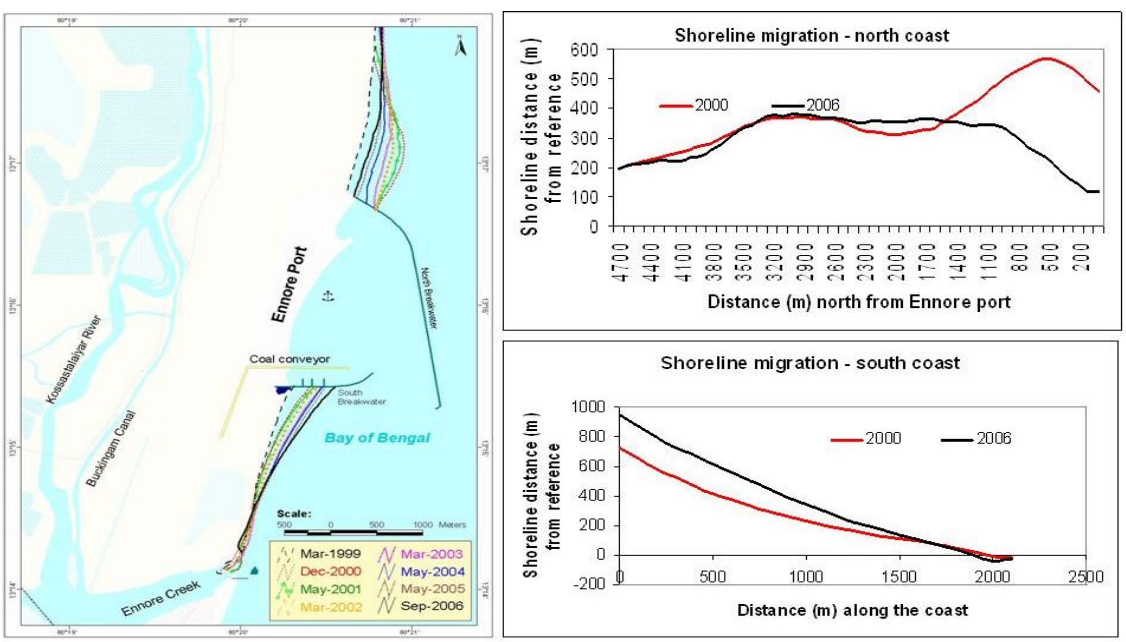


Fig.15. Observed shoreline at Ennore Port (1999 to 2006)

sheltered by breakwaters of 1.1 km long on its south and 3.2 km long on north (Figure 15). The construction of breakwater has arrested the movement of longshore sediment transport resulting accretion in south side and erosion on north side. As erosion was expected north side, the port authorities have artificially nourished the northern part of shoreline. At the time of port construction in the year 2000 by placing $3.5x10^6$ m^3 of sand dredged from the harbour basin and the approach channel through capital dredging to prevent down drift erosion. The shoreline around the Ennore port was monitored since 1999 to 2006 regularly as understand the impact of port on coastline. The study revealed that severe erosion took place in 1.5km stretch, north coast of Ennore port and the erosion rate was of 50m/yr. The beach fill carried out by port in year 2002 as anti erosion work lasted in year 2007. Further the impact of coastal erosion due to breakwater was seen upto Kattupalli village 3 km north from port where shoreline underwent readjustment over the period with moderate erosion of 50 m. The village is about 15 km south of Pulicat lake.

As the sediment moves south to north and breakwater stopped the free movement of sediment in along the coast, the shore, south of the Ennore port has accreted at a rate of 45m per annum, extended offshore 300m to 400m (during 2000-2006) The zone of accretion extended south upto 2.6 km alongshore where 90 m wide beach has developed that eventually lead to rapid silting of Ennore Creek used to draw cooling water by power plants mentioned earlier. The long-term analysis of wave climate and coastal profile revealed that if no intervention is planned, northern areas of port will have erosion at rate of 20 m per year.

In order to prevent the erosion in north coast, a submerged reef with sand bypassing is suggested for protection of Ennore coast since it not only reduced the wave energy but also provides wave rotation which reduces convergence of energy on lee side of the reef. The reefs will reduce wave energy upto 20 to 40% on near coast, thereby helps in accumulation of sediments due to reduction in wave intensity (Figure 16). The cross impacts of these reefs is also minimum when compared to other options.

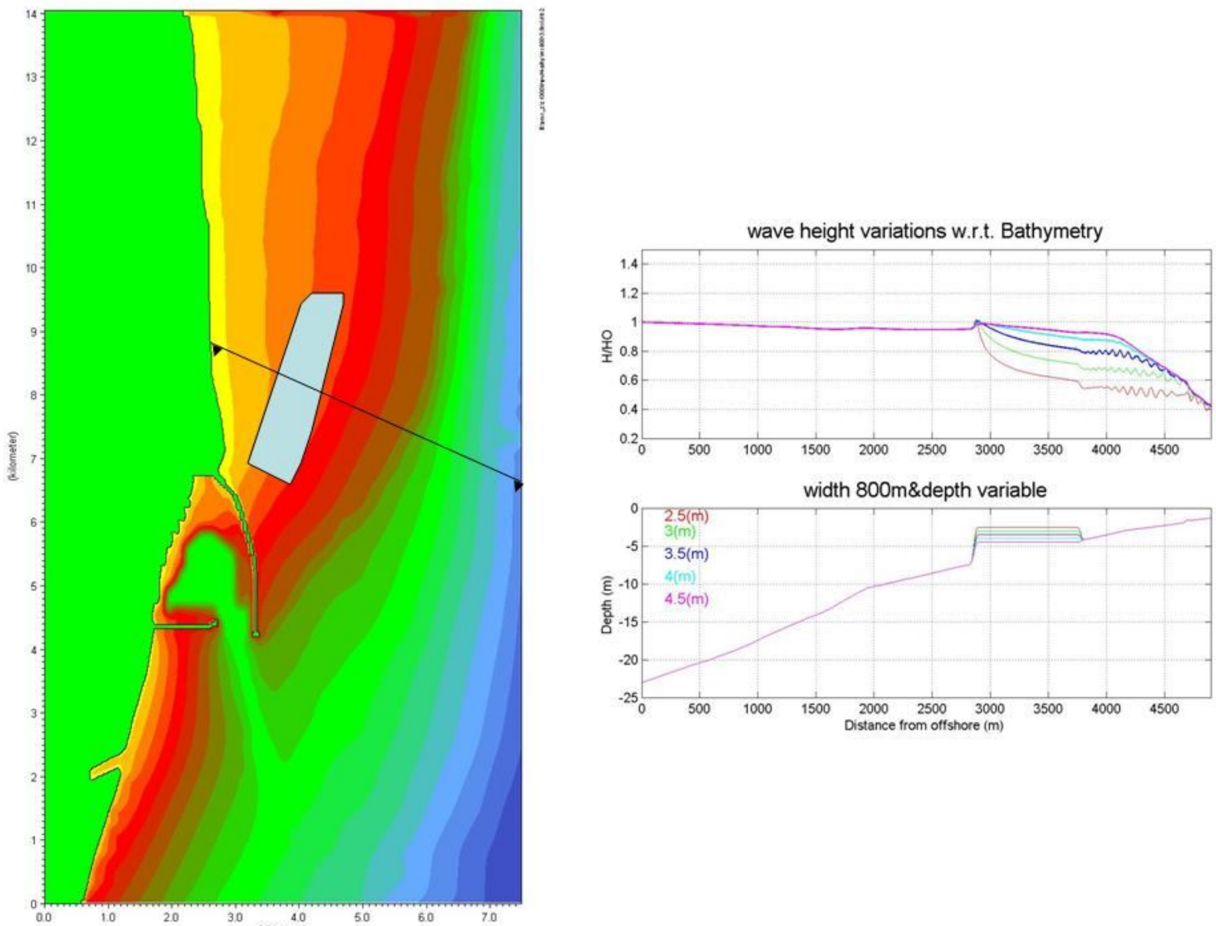
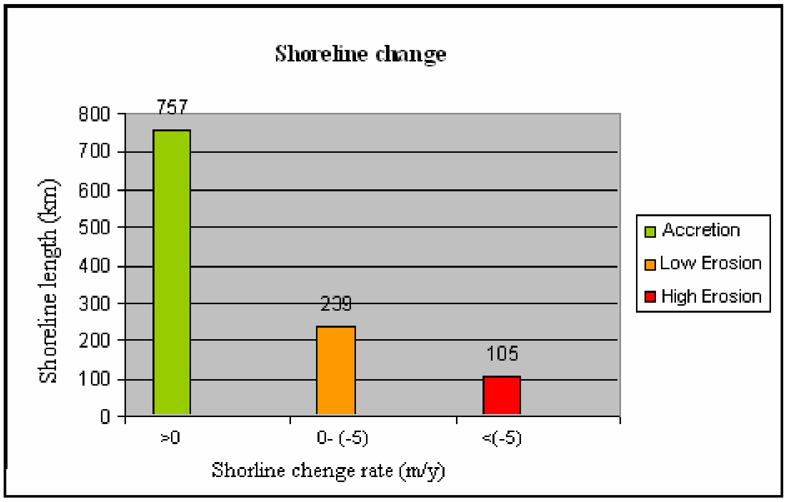


Figure 16. Configuration of reef breakwater and wave height distribution along the transect taken across the reef

2.3.2 Shoreline-change along Andhra Pradesh coast

Andhra Pradesh coast has frequently been affected by cyclones and inundated by storm surges. Erosion is noticed in certain areas such as Uppada, Visakhapatnam and Bhimunipatnam. The present study reveals that the major part of Andhra Pradesh coastline is experienced accretion. In the districts of Srikakulam and Vizianagaram, accretion is dominant and low rate of erosion is seen in Vishakapatnam. Whereas major parts of Krishna and East Godavari districts shoreline are subjected to high rate of erosion. Total of 757km coastline of AP is under accretion and out of 344 km of coastline is under erosion, 239km is under low erosion and 105 km of the coastline under high erosion (Figs. 17 &18).



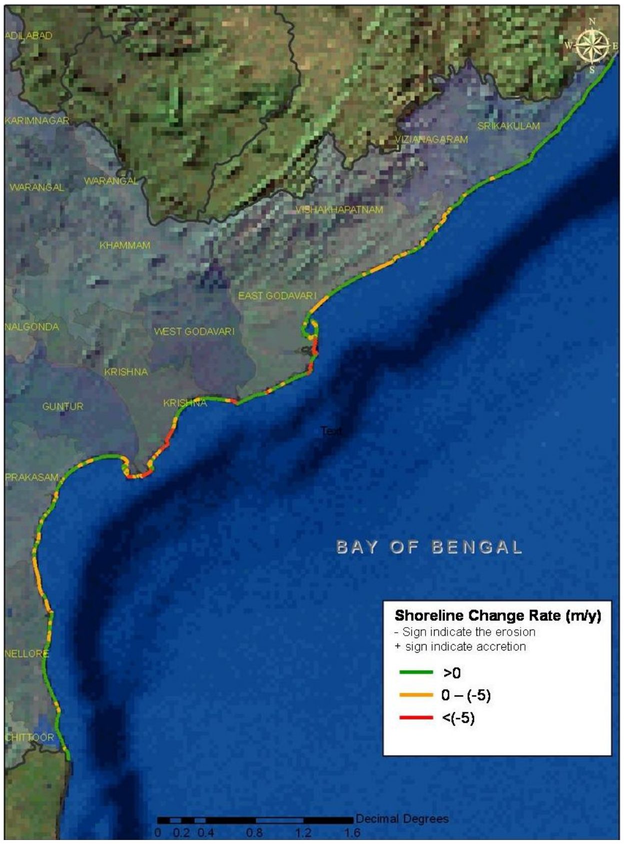


Fig 17. Bar chart representing length coastline under different shoreline change classes along Andhra Pradesh coast, total 757 km of coastline under accretion (green), 239 km of coastline is under low erosion (orange) and 105 km of shoreline is under high erosion (red).

Fig 18. Map depicting the shoreline change rate along the Andhra Pradesh coast.

2.3.2.1 Shoreline change around Bhavanapadu Harbor

Bhavanapadu fishing harbor was constructed during 1983-88 with breakwater structures on the northern and southern side of the mouth of the creek. (Figure 19) in the confluence of the Tekkali Creek for the fishing activity, in the Srikakulam district of North Andhra Pradesh, East Coast of India. The geographical coordinates of the study area are 84°20'13" to 84°23'58" E longitudes, 18°32'09" to 18°37'14" N latitudes. Fishing harbour at Bhavanapadu was constructed.

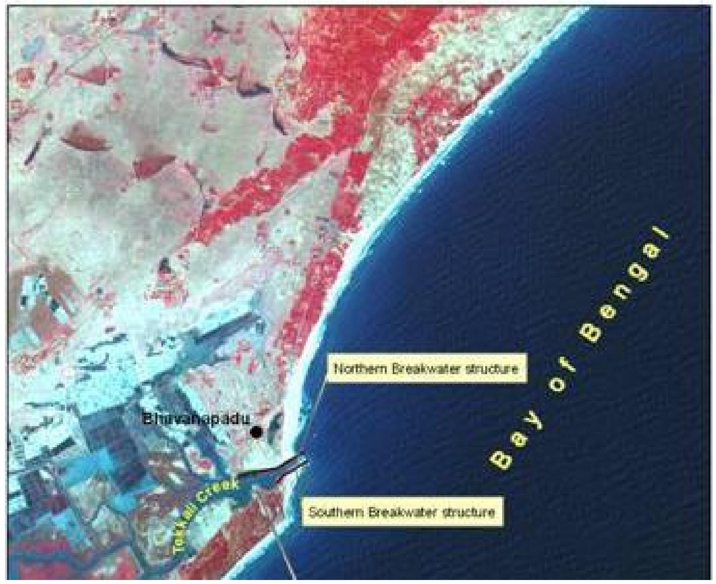


Fig. 19: Study area for coastal processes: Bhavanapadu

The thirty-two-year analysis of the Bhavanapadu shoreline shows that the shoreline is primarily dominated by erosion. The shoreline on either side of the mouth of the creek was in the process of erosion before construction of the breakwaters. The construction of breakwater accelerated the rate of erosion starting from a distance of 1.3 km north of the northern breakwater.

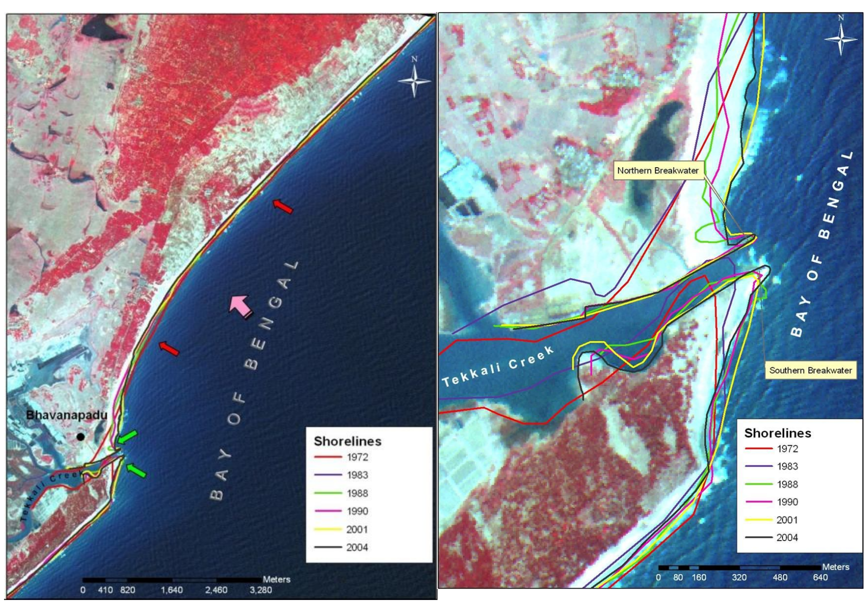


Figure 20 Erosion and accretion zones around Bhavanpadu and change in shoreline around inlet

Maximum erosion was observed in two stretches along the shoreline to the north of the creek shown by red arrows in Figure 20 with shoreline changes took place around inlet.

The only areas of considerable deposition in the study area are observed in and very near the creek mouth as well as in the channel. Shoreline-change rates for 1972-2004 indicated that most of the area has experienced erosion, which can be clearly seen in Figure 13. The maximum erosion rate is up to 4.7 m per year which is observed in the northern part and the maximum accretion rate is up to 10.4 meters per year which is observed in seaward side of both the walls. Further, the deposition of the sediment was observed also in the navigation channel as seen from the satellite data of 2004.

The setting of Bhavanapadu Coast is complex in terms of coastline changes and sedimentation. The net littoral drift is quite large and is reported to be about 0.7 million cubic meter per year and is mainly from south to north (Shankar, 1998). A study of the wave climatology (pink arrow in Figure 21) of the area indicates that waves predominantly approach this part of the coast from the south-east direction. These sets off a littoral drift facilitating net movement of the sediment northwards. The sediment supply has to be either from the southern part of the coast or from within the creek. The construction of

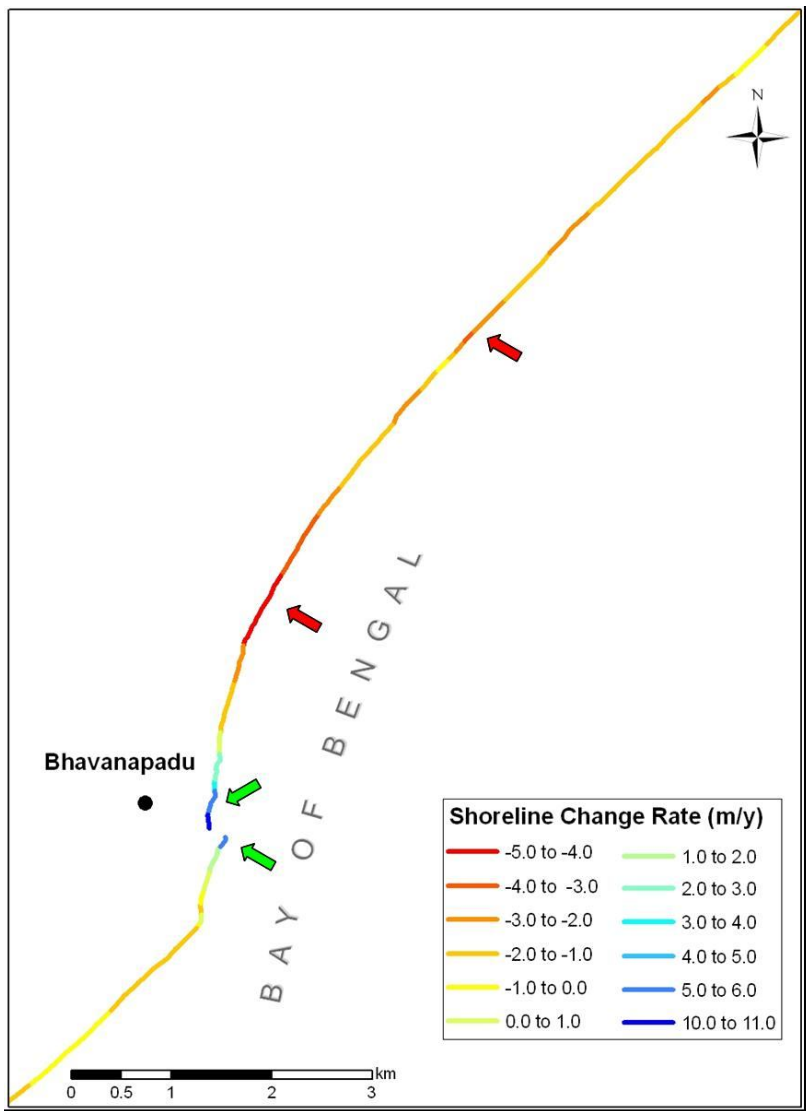


Figure 21: Shoreline Change Rate (+ ve: accretion and – ve: erosion, Red/Green arrows indicate areas of severe erosion/accretion)

breakwater has considerably altered the sediment budget within the study area. While accelerating erosion on the northern part of the creek mouth, it has accelerated deposition at the creek mouth. The construction of breakwaters altered the sediment supply from the south; with much of the sediment getting deposited near the mouth and less of it being able to move northwards. This was aggravated by the reduction in sediment supply from within the creek due to development of saltpans and aquaculture activity in the catchment.

2.3.2.2 Krishnapatnam Port (Nellore)

The Krishnapatnam Port is located in Kandaleru creek in Nellore District of Andhra Pradesh. The shoreline changes around the port were studied using the satellite data consecutive month for the one year of the period (June 2007 to May 2008). Results showed that there was slight erosion in the northern parts upto 2 km beyond that there was slight accretion and more or less no change in the southern parts observed. The shorelines extracted during June 2007 to May 2008 were overlaid in the ArcGIS for the change analysis as shown in Fig. 22.

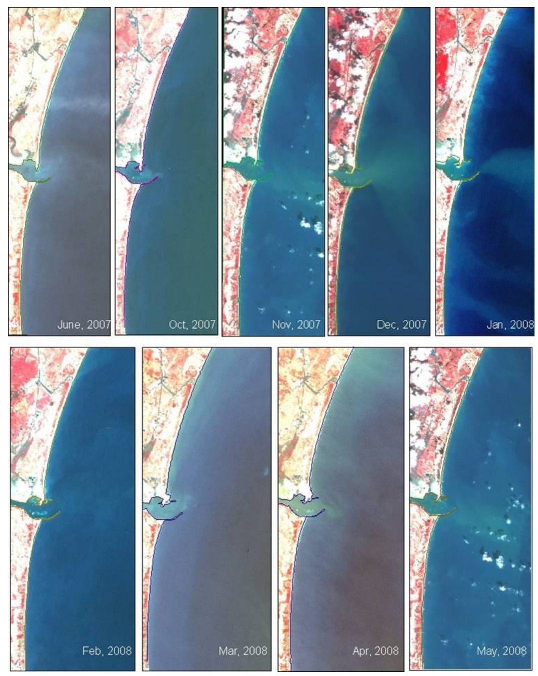


Figure 22: Monthly Shoreline Changes depicted from remote sensing data

Shoreline change rate has been calculated by drawing shore normal transects for one kilometer interval. The results of the shoreline change rates indicate that the severe erosion areas depicted with the erosion rate about 30-35 m/y red arrows shown in the Fig 23. The maximum accretion observed immediate north of the northern breakwater. The sediment will be trapped on either side of the breakwaters in the normal case however, there is no sediment trap observed in the south of the southern

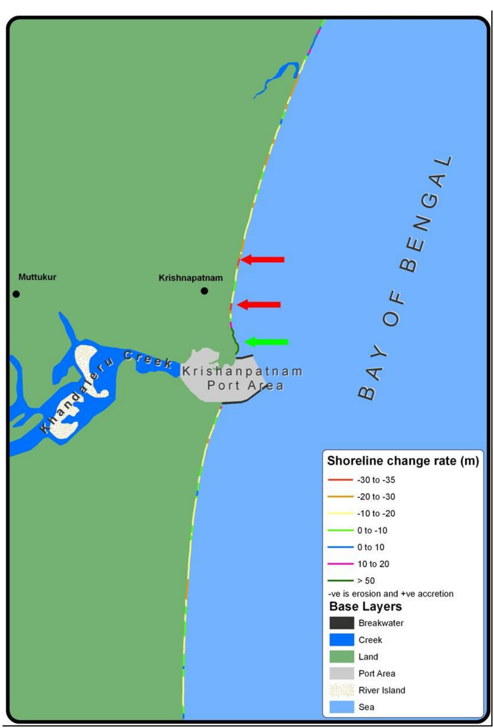


Figure 23: Shoreline Change Rate (+ ve: accretion and – ve: erosion, Red/Green arrows indicate areas of severe erosion/accretion)

breakwater. The net shoreline change calculated for the study area depicting the erosion in the both northern and southern parts. The extreme northern parts again showing the accretion, this is probably due to the one more creek supplying the sediment in the north. Results show that most of the northern part experiencing dominantly erosion and southern parts shown minor erosion (Figure 23).

2. 3.3 Orissa coast

2.3.3.1 Gahirmatha coast:

It is recently realized that construction of dam on rivers significantly alters coastal environment at least for some time. The analysis of multi-date satellite imagery and field measurements indicated significant shoreline changes in the Gahirmatha area between 1972, 1988 and 2004 (Fig 24). These changes were attributed to construction of dams on the Mahanadi river in upstream regions during 1975. In May 1998, a cyclonic storm swept across the Gahirmatha coast and fragmented the mass nesting beach. However, currently due to the heavy erosion of this region, the width of the beach has reduced. Seasonal beach profile measurements and shoreline mapping carried out during 2004- 2005 reveals that the beaches of Gahirmatha are in most cases narrow except the beaches near the river mouth. The beach elevation between high water and low watermark ranges from 2.35 to 4.65 meters. The average width of the beaches is 50 meters. The beach width in Gahirmatha coast (1972: SOI toposheet and 1998 and 2004 –IRS-1D LISS-III) along with field data (2004, Collected using Real time –KGPS) are given below.

Name of the place	1972	1998	2004
Satabhaya	375 m	198 m	90 m
Gahirmatha	405 m	101 m	65 m
Habalikhati	756 m	159 m	60 m
Ekakula	70 m	123 m	105 m

Fig. 24. Shoreline changes in coast Gahirmatha and eroding beaches

2.3.3.2 Gopalpur Coast

The Gopalpur-on-Sea (19° 16' N and 84° 55 E) is a semi-urban town and an important tourist site along the south Orissa coast. Two Semi-perennial Rivers discharge into the bay near Gopalpur, the river Bhauda about 10km to south and the river Rushikulya about 23km to the north. Between these river mouths, the coastline is completely sandy stretch with wide backshore of 100-150m.Well-developed sand dunes with continuous ridges running parallel to the shore are conspicuously present along the entire coast. Dunes are 8 to 10m high. An open coast seasonal port was constructed in 1987 by excavating the basin on the backshore. At present, various structures are under constructions with an intention to convert the port into an all weather full-fledged port by 2010. Measurement made in February 2007 indicates that Gopalpur on-sea settlement is located nearly 6.0 m above mean sea level (MSL). The beaches at Gopalpur tourist beach of 600m lengths are nearly 50 – 60 m wide and the inter-tidal region is about 20 m (Fig.25) were experiencing active erosion during 2007 southwest monsoon period. Major erosion took place on the southern side beaches of Gopalpur town. At some places, the vertical cut was about 3m or more. Some of the hotels are located right on the edge of the High Tide Line (Fig/photo.25). During cyclonic events, sometimes, the wave effect is strongly felt and some of the Hotels existing on seafront usually take safety measures by constructing stonewalls as a part of precautionary measures, which is more or less regular activity every year.

Fig. 25: Hotels right on the High Tide Line along Gopalpur Coast (photo: 22/11/2007)

This unusual erosion might be attributed due to persistence of localized high waves attributed to continuous weather disturbances and low-pressure system in the Bay of Bengal that has created a sea level surge. This caused scouring of sand from the bottom of the concrete structures of the existing Hotels and causing a void space under the structures and dislocating it, ultimately eroding it. This gets normalized once the waves and weather conditions become normal and consolidation of berm takes place in the fair seasons. This is a cyclic behavior.

As per the available records, in the last two decades, the shoreline almost remains at the same position without any major erosion landward infers that as such the erosion event along the coast is more seasonal and cyclonic dependent and site specific. The observation made by ICMAM-PD indicates that with the construction of two groins at the entrance channel near the Gopalpur port, the southern beaches are depositing and the beaches have accreted to the extent of nearly 200m. On the other hand, the northern beaches are continually on eroding phase and there is loss of about 120m of the beach (Fig-26). At present, the major changes are restricted to 1.5-2 km along the shore on each side of the groin. The proposed expansion of the Port with breakwaters on southern side will aggravate erosion. Unless remedial measures are taken the beaches of the fishing villages located 2 to 3 km from the port will face erosion depriving facilities for landing crafts to fishermen.

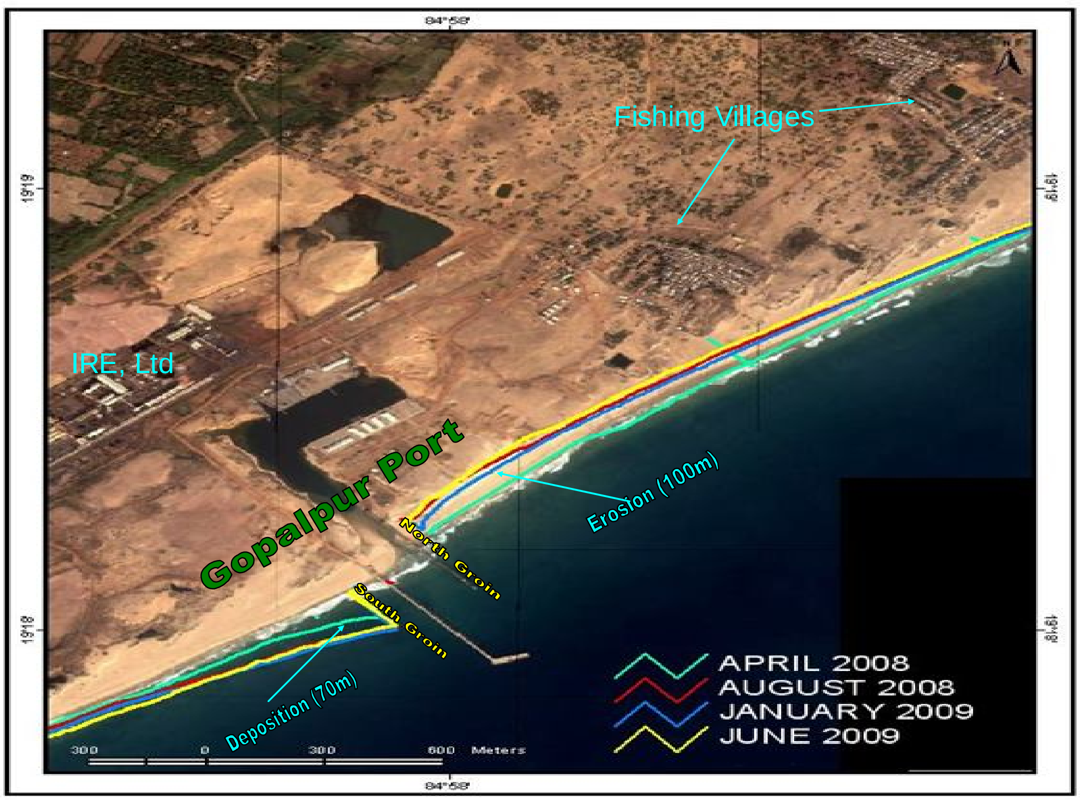


Figure-26: Temporal changes of the shoreline showing beach buildup and erosion

2.3.4 Erosion along Mangalore (Ullal-Bengre) coast

The Mangalore inlet was of migrating nature leading to navigational hazards to fishing community and old Mangalore port since several decades. Two rubble mound breakwaters (river training jetties) were built during 1994 to guide the flow for safe navigability of fishing boats. Due to breakwaters, the migration of river mouth has stalled. But, it leaded to severe coastal erosion at the south of southern breakwater since 1996 during the monsoon months. However, the major part of beach regains again during non monsoon months. The site of erosion is a barrier spit over a length of 1.4 Km connected to main land at southern end. The northern end of this spit is free to migrate as a part of changes in shoreline around the mouth of River Netravathi. Similarly, the northern spit, known as Bengre spit exists running parallel to the mainland with northern end connected to land and the southern end is free to migrate as a part of river mouth. Gurupur River also joins this mouth running from north adjacent to Bengre Spit. This erosion has potential threat during monsoon to open another mouth to which will lead to operational hazards for fishing community and old Mangalore port (Fig 27).

Figure 27: Location of Mangalore Inlet and status of erosion and temporary protection work being carried out every monsoon since past one decade

The shoreline changes were studied at monthly, seasonal and annual scale using remote sensing (1997-2002) and field data (2004-2006). The 21 Beach profiles and shoreline position was monitored at fortnightly interval for the 2 years data to estimate the seasonal pattern of accretion/erosion and movement of sediment around the mouth (Fig.28).

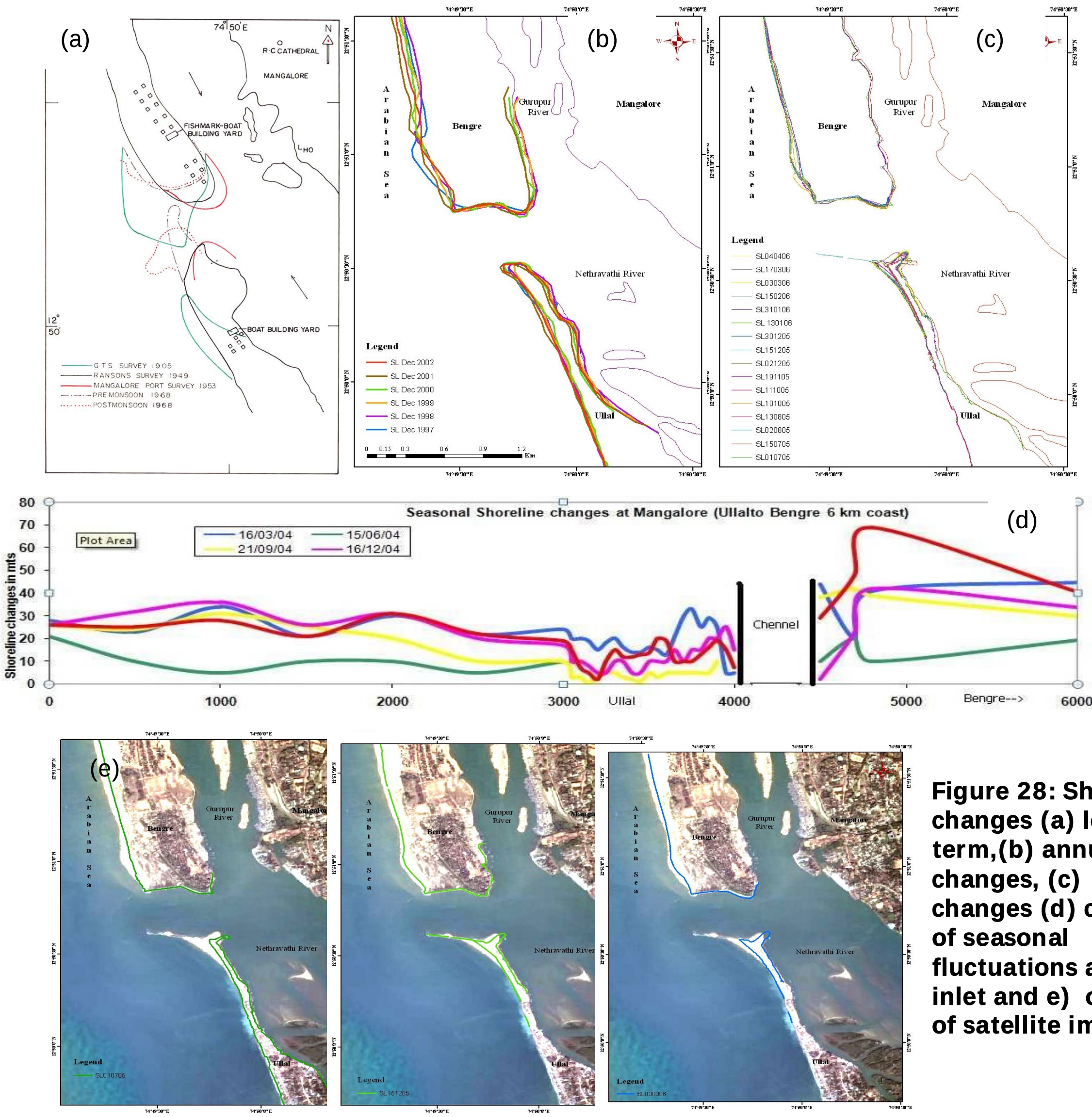


Figure 28: Shoreline changes (a) long term,(b) annual changes, (c) monthly changes (d) close view of seasonal fluctuations around inlet and e) overlaid of satellite image

The study showed the occurrence of contrast accretion and erosion pattern around the inlet i.e. north (Bengre) and south (Ullal) spits of inlet. Ullal beach faces severe erosion during monsoon months and regained the 90% of sediment during fair season. The Bengre (Northern) area was accreted during monsoon months due to sand supply from rivers and erosion during fair weather. Minimum beach width was observed in the month of July and the beach recovery starts in the month of November as the monsoon recedes and maximum beach width is observed during March. However, Southern side, the minimum beach width was observed in the month of June to September and the beach recovery starts in the month of October - November and maximum beach width is observed during December-January. The net erosion was 0.06 mm3 along Ullal and 0.25 mm3 accretion along Bengre during March 2004- March 05. The analysis of remote sensing data revealed that wide fluctuation in shoreline (35-60 m) at seasonal scale due to monsoon conditions, however net annual changes are indicate marginal erosion (0-10m) at Ullal and accretion (0-20m) at Bengre.

The problem of erosion at Ullal occurs during monsoon months due to sever wave conditions, to arrest the erosion, a conceptual solution was devised based upon the mathematical model studies by providing submerged reef/ emerging breakwaters to reduce the wave energy in sea itself, prior to reaching the wave at coast.

2.3.5 A Case study for Arattupuzha coast along Kerala coast

The Arattupuzha coast just north of the Kayamkulam inlet is undergoing severe erosion which has already encroached into many settlement areas and many parts of the main road. The need to provide protection to already threatened property, establishments and infrastructure due to coastal erosion is the major concern. The width of the land between the sea and the backwater is considerably low in the Arattupuzha. From the long term shoreline change maps, it can be summarized that during the 15 year period 1985-2000, erosion was dominant in the Thottapally - Alleppey sector while accretion was overwhelmingly dominant in the zone north of the Cochin inlet as shown in Fig . 29 with red colour. Both the sides of the Kayamkulam inlet show erosion. Further south, towards the Kayamkulam inlet, erosion picks up. Two breakwaters were constructed for safe navigation to support fisheries sector in year 2000.

From field visits made to the site, it is seen that this scenario is changed considerably since 2000 along with the progress in the construction of the break water at the inlet. The breakwaters constructed at the inlet to facilitate a fishing harbour has resulted in accretion towards south of the inlet and increased erosion in the northern side. The record accretion at Puthuvype region gives rise to a spectacular accretion of 396 ha in the Vypin – Munambam zone. It is important that at least the present line of shoreline has to be maintained in Arattupuzha. Hence the option of giving buffer zone for the forces of the sea to act upon cannot hold in the Arattupuzha sector which has already lost beach and coast more than an affordable level. Then, CRZ as a protection tool becomes impractical. Seawall can hold the present shoreline. But the experience here shows that it is slumping and it cannot sustain or

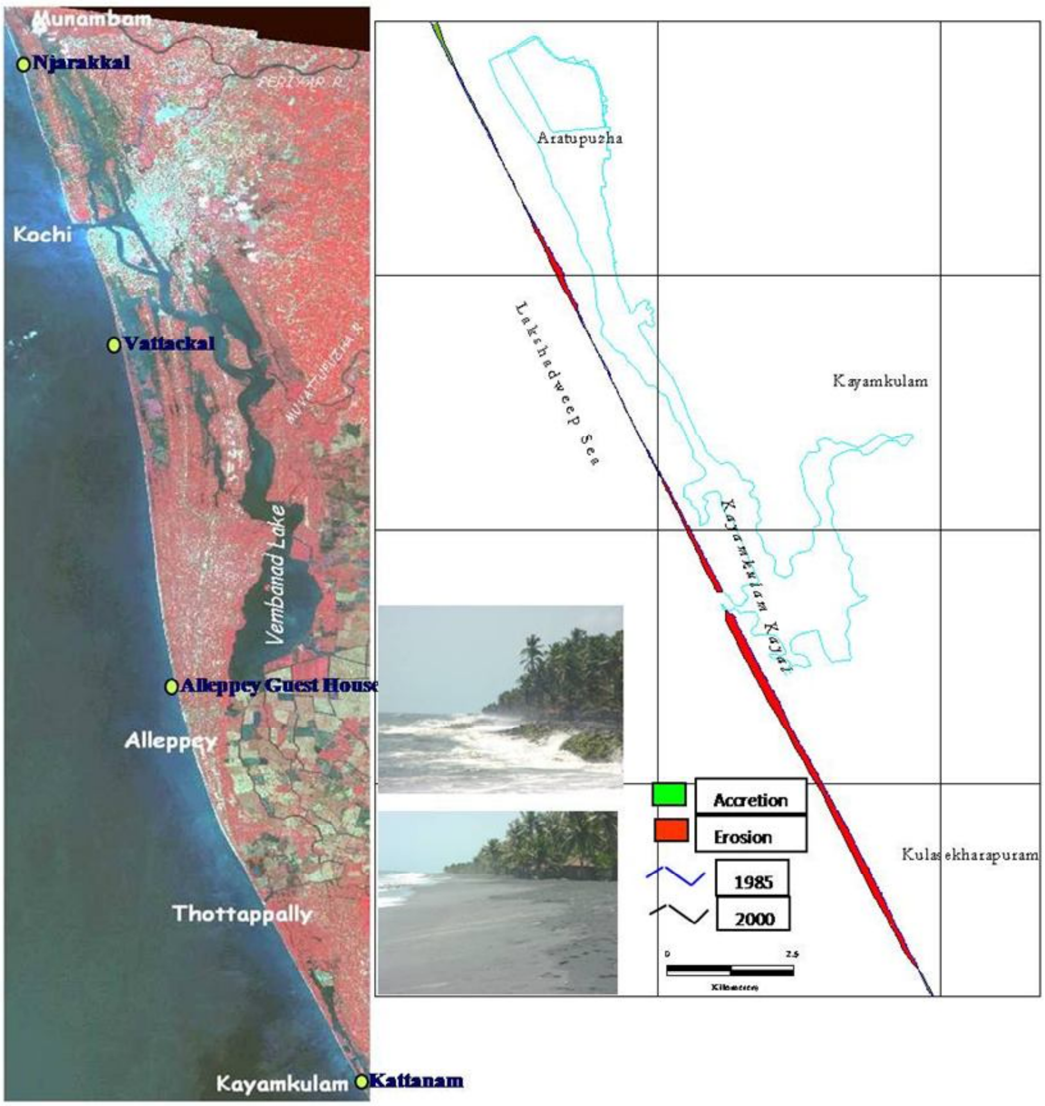


Figure 29: Location of Arattupuzha and observed accretion & erosion areas (1985 - 2000)

generate a beach which is essential for the community. Beach nourishment, groins, offshore submerged breakwater and artificial offshore reefs are the options which can sustain and trigger development of beach.

Shoreline evolution with the proposed groin field is presented in Fig.30. An increase in beach width of the order of 40 to 50m is seen for the first 2km where equal length groins are provided. Further down, the increase in beach width gradually reduces as expected due to the presence of shorter groins provided at the end, to allow smooth transition, however high rate of erosion is seen at the down drift side just immediately after the termination point of the groin field. Beach nourishment is recommended at the down drift end to prevent this end erosion. Further improvement in performance can be attained by artificially filling sand between groins during the initial years.

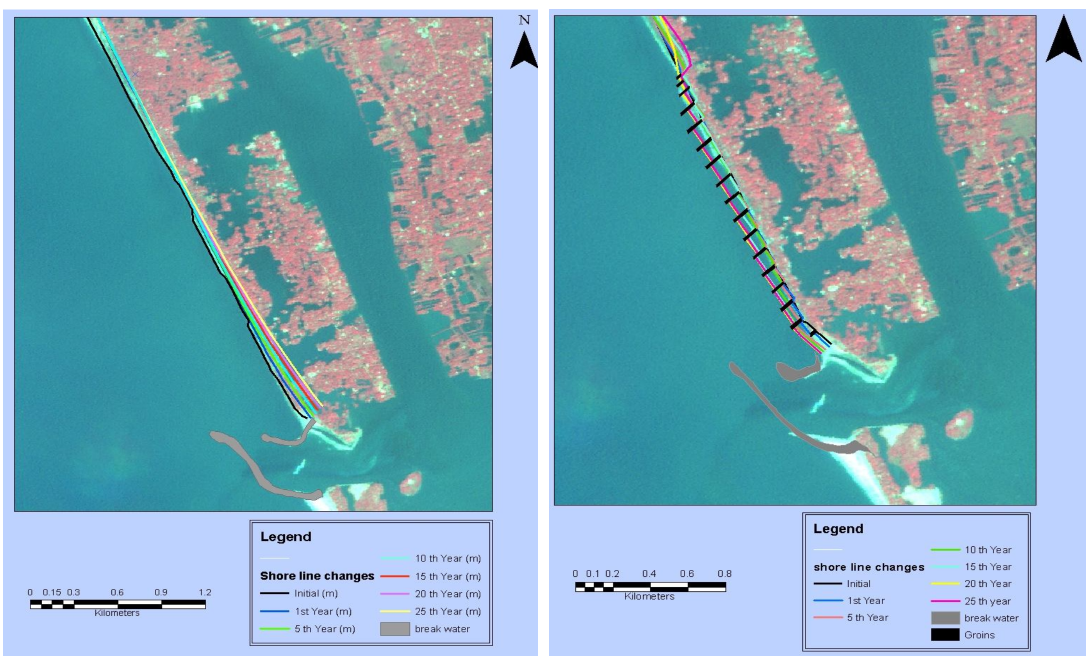


Figure 30: Long term shoreline evolution for existing scenario and with proposed groin field

The above details of erosion are based upon the earlier works carried out by ICMAM and its associated institutions and INCOIS at selected locations along the coast to provide the baseline information about the erosion and to understand the impacts of port on coastal erosion and effectiveness of remedial measures. It is suggested to MoEF that while permitting the Ports and Harbours, the Port authorities be instructed that if the construction of breakwaters etc likely to lead to erosion, appropriate remedial measures be done. The measure should have a component of beach nourishment, as it has been found that in most of the cases of remedial measures carried out in the form of construction groins etc., the terminal part of the remedial measure always face minor erosion, which can be arrested only with the beach nourishment.

2.4. Activities and Interventions leading to Shoreline Changes and Morphological Impact

It is evidenced from these sites specific studies of Indian coast that the shoreline is always susceptible to changes due to natural processes and manmade interventions. However, the rates of shoreline changes vary place to place due to nature of coast, wave conditions and sediment characteristics of the coast. Further the physical interventions also lead to morphological impacts, which could be in form of either coastal erosion or accumulation at coastline. The morphological impacts can be occurred within the littoral zone or outside away from coastline.

The major interventions which lead to morphological impact are listed as:

- Coastal structures of any kind, which by their occupation directly impact the transport processes and thereby the coastal morphology. Such structures are typically the Ports and marinas, active coastal protection structures (groynes, breakwaters and all other structures occupying part of the foreshore and/or the shoreface), passive coastal protection structures (revetments, seawalls etc which fix the coastline), reclamations and dikes, inlet jetties at tidal inlets and sea works at river mouths, embankments for bridges /runways, intake / outlet structures crossing the littoral zone

- Structures outside the littoral zone, which, by their impact on the hydraulic conditions, may impose coastal impacts or impacts off the littoral zone. Such structures are typically Offshore breakwaters, Island ports, Artificial reefs and Artificial islands, Bridge piers etc

- Interventions in rivers and in the backland such as sand mining, deepening for navigation, construction of dams, drainage and irrigation schemes, construction of river dikes, logging of forested areas, discharge of silty spill water from sand and gravel mining

- Extraction from the underground causing subsidence such as water, oil or gas

- Others such as changed storm surge or tidal conditions due to regulations of lagoons, Sea level rise

2.5. Locations of beach erosion identified by State Governments:

Besides, the above locations studied, the information provided by various state governments about the status of erosion to Central government during X plan period at the end of the 10^{th} Plan period has been compiled and the details are given in table 2, which shows the severity of problem. It is seen from the table 2 that almost all the maritime States/UTs are facing coastal erosion problem in various magnitudes covering 23% of mainland coastline. About 1380 km of coastline has been reported to be affected by sea erosion, out of which about 700 km of coastline has been reasonably protected by construction of seawalls, groins, etc, and 780 km is yet to be protected. The name of locations and extent of erosion is given the state wise Annexure 1. It may be noted that there are other locations also, but not reported in the report. Most of the eroding locations are facing open coast with high wave conditions or/and around the coastal structures. The developmental activities in coastal zone further aggravate the erosion. Shoreline erosion in the northern regions of Chennai, Ennore, Visakhapatnam and Paradip ports has resulted due to construction of breakwaters of the respective port. There are 12 major and about 186 intermediate and minor port and harbour rimed all along the coastline. The information about the location of minor, and intermediate ports and harbor and jetties along the Indian coast is given in Annexure 2. The major highlights of the available data/information are as:

- Available information about erosion sites are indicative and about 5-10 years old based upon state govt. inputs to seeking funds to facilitate the coastal protection work for priority areas. There are other locations which are not indicated in the list. However, it is evident from the list that the location specific erosion is spreading in small pockets i.e. 200 m to 2 km spreading all along the coast. The causes of erosion are not specified i.e. natural or anthropologic. This need to be updated. MoEF may convene a meeting with States in this regard.

- The minor and intermediate Ports and Harbors and jetties (Annexure 2) are located all along the coast i.e. open coast, protected coast, bays, Gulfs and creeks in different wave energy environment

Table 2 : Status of Coastal Erosion along Indian Coast

	Name of State	Length of Coastline (km)#	coastline subject to erosion $	Coastline protected (km)$	Length(km) of coast / open beaches under severe erosion		Districts / Division / locations of critical erosion (km.)
					New$	Repair$	
1)	Gujarat	1214.7	36.4	4.0	45.19	--	Valsad(13.5), Navsari (20.39), Surat(10.3) Bharuch (1.0)
2)	Maharashtra	652.6	263.0	127.0	72.36	--	Mumbai, Suburban, Thane, Raigad, Ratanagiri, Sindhudurg
3)	Goa	160.5	10.5	3.0	7.5	1.5	South Goa (3.25) North Goa(4.25)
4)	Karnataka	280.0	249.6	55.8	49.875	17.605	Mangalore, Udupi, Kundapur, Bhaktal, Honnavar, Kumta, Ankola, Karwar
5)	Kerala	569.7	480.0	369.0	52.065	59.448	Trv(2.315), Alappuzha(12.45), Thale(2.1), Manjeri(11.25), Kozhi(6.786), Kasargode(16.465)
6)	Tamilnadu	906.9	36.2	14.0	13.824	--	Chennai north, Kovalam, Devanampattinam, Poomuhar, Tharangambadi, Kanyakiumari
7)	Andhra Pradesh	973.7	9.2	0.5	2.615	--	Uppada, Chinnagollapalem
8)	Orissa	476.4	107.5	10.0	66.2	--	Gopalpur, Rushikulya, Puri, Satbhaya, Chandabali
9)	West Bengal	157.5	49.0	14.0	10.75	--	Digha, Shridarnagar, Buraburirttat, Gobardhanpur Frezerganj, Shibpur, Beguakhali, Kusumtala
11)	Pondicherry	30.6	6.4	6.4	--	6.4	
12)	Andaman & Nicobar	1962	-	--	--	--	
13)	Lakshadweep	132.0	132.0	44.0	72.57		Agatti, Amini, Androth, Bitra, Chetlat, Kadmat, Kiltan, Kalpeni, Kavratti, Minicoy
Total length of Indian coastline with Islands		7516.6	1379.8	647.7	392.95	84.95	

As per Naval Hydrodgraphic office Dehradun, $ Information collected from States by CWC for NCPP during X plan (Data source: CWC letter No. 3(5)/2005/CED/993 dated 08 Dec 2005)

- Normally, the coastal structures which obstruct the littoral drift have significant erosion problems in down drift side particularly in high sediment regions and impact could be felt up to 2-5 km along coast and 100 m to 500 m landward depending upon the length and types of structure.

2.6. Tools to monitor the long term Shoreline Changes

As discussed the human intervention in surf zone leads to changes in shoreline. Remote Sensing and GIS have been found to be extremely useful for understanding the shoreline changes at various scales i.e. monthly, seasonal to decadal changes. The availability of high resolution data provides the better representation of shoreline. India has number of remote sensing satellites to provide the data at different resolution and repeatability. The details and resolution of various data sets available in India are given in table 3.

Table 3: Major specifications of present IRS series of satellites

Satellites (year)	Sensor	Spectral bands (μm)	Spatial res. (m)	Swath (km)	Radiometric res. (bits)	Repeat cycle (days)
IRS-1A/1B (1988, 1991)	LISS I	0.45–0.52 (B) 0.52–0.59 (G) 0.62–0.68 (R) 0.77–0.86 (NIR)	72.5	148	7	22
	LISS-II	Same as LISS-I	36.25	74	7	22
IRS-P2(1994)	LISS-II	Same as LISS-I	36.25	74	7	24
IRS 1C/1D (1995, 1997)	LISS III	0.52–0.59 (G) 0.62–0.68 (R) 0.77–0.86 (NIR) 1.55 -1.60 (SWIR)	23.5 70.5(SWIR)	141 148	7	24
	WiFS	0.62–0.68 (R) 0.77–0.86 (NIR)	188	810	7	24(5)
	PAN	0.50–0.75	5.8	70	6	24(5)
IRS-P3 (1996)	MOS-A	0.755–0.768 (4 bands)	1570 × 1400	195	16	24
	MOS-B	0.408–1.010 (13 bands)	520 × 520	200	16	24
	MOS-C	1.6 (1 band)	520 × 640	192	16	24
	WiFS	0.62–0.68 (R) 0.77–0.86 (NIR) 1.55–1.70 (SWIR)	188	810	7	5

Satellites (year)	Sensor	Spectral bands (μm)	Spatial res. (m)	Swath (km)	Radiometric res. (bits)	Repeat cycle (days)
IRS-P4(1999)	OCM	0.402–0.885 (8 bands)	360 × 236	1420	2	2
	MSMR	6.6, 10.65, 18, 21 GHz(V & H)	150, 75, 50 and 50 km	1360	–	2
IRS-P6 (2003)	LISS-IV	0.52–0.59 (G) 0.62–0.68 (R) 0.77–0.86 (NIR)	5.8	70	10(7)	24(5)
	LISS-III	0.52–0.59 (G), 0.62–0.68 (R) 0.77–0.86 (NIR) 1.55–1.70 (SWIR)	23.5	141	7	24
	AWiFS	0.52–0.59 (G), 0.62–0.68 (R) 0.77–0.86 (NIR) 1.55–1.70 (SWIR)	56	737	10	24(5)
IRS-P5 (Cartosat-1) 2005	PAN (Fore (+26°) & Aft (−5°)	0.50–0.85	2.5	30	10	5
Cartosat-2 (2007)	PAN	0.50–0.85	0.8	9.6	10	5

The advantage of the data is that it provides the historical information however with medium resolution especially prior to the availability of high resolution data in 2000. The normal error in remote sensing data may be about 1-2 pixels (~10 m- 75m) depending upon coastal land use and satellite data. Therefore, it is vary essential to collect the field data to validate the remote sensing data. However, the use of remote sensing data has to be validated form field information and its limited application for macro tidal coast with gentle coastal slope. The episodic erosion during high wave condition in monsoon or storm contributes significantly. One of the major limitation to get cloud free data especially during the monsoon months and therefore, it is always required to have field data and shoreline monitoring programme using GPS based equipments to understand the local changes and lower temporal scale (monthly).

2. 7. Suggested approach to monitor Shoreline Changes around a project site like Ports using field and satellite data

- In any open coast, when manmade structures such as groin or breakwaters interfere with the littoral currents shoreline changes drastically. During the low tide condition, maximum land is exposed and even low water line / land water boundary and high water line are distinctly visible. However, fixed land-water interfaces line namely the berm-line is appropriate to monitor as shoreline. This shoreline information can be concurrently analysed through remote sensing and GIS techniques. The berm line should be mapped using sub meter accuracy GPS based equipment prior to construction of any structure within 4 km either side of the project site. The same line should be monitored at monthly interval preferable at new-moon or full-moon day and mapped in 1:10000 scales to record the monthly changes. This will provide the database to enable seasonal mapping of the shoreline and their time series monitoring. The demarcation and the areal extent of the sites of erosion and accretion are queried and estimated through GIS package.

- Remote sensing data can also be used effectively to monitor the shoreline changes along the coast with reasonable accuracy to compliment the field monitoring program. Remote sensing data helps and / or replaces the conventional survey by its repetitive, spatial coverage and less cost-effectiveness. Standard guidelines to determine the berm line on a satellite imagery should be followed. Neverthless, high resolution satellite data(<1m) should be used to map the shoreline changes as only from such a resolution the berm can be identified. A geocoded map should be prepared in GIS environment with sufficient ground control points and the initial berm-line determined from field data should be plotted on the map. Thereafter, at periodical intervals, say every 4 months, the satellite data can be obtained and the position of berm determined and overlaid on the map containing initial berm line. This will help in determining accurate shoreline change analysis.

- In case of shoreline changes to be determined for the years, before the availability of high resolution satellite data, especially when the shoreline changes have to be compared between 1990s and 1997, the only option is to use IRS LISS type of data having a resolution of 23 m. It is often difficult to determine the berm line using such a resolution especially on a coast that has a gentle slope. Therefore, while using satellite data of such resolutions to determine the shoreline changes, the tide at the time acquisition of data from satellite need to be obtained from tide tables and only images with similar tide condition of future years should be used for comparison.

- This comprehensive approach to monitoring the shoreline provides data that can document changes to the shoreline over time and provides important information to decision-makers when beach replenishment efforts are contemplated

2.8. Suggestions to MoEF on Moratorium on New Ports and Harbours

1. Avoid port structures etc at least 5 km on either side of eroding locations, as indicated in the report . Further, location of Ports should be avoided around 10 km on either of ecologically sensitive areas, estuaries and lagoons of biodiversity importance as accretion/erosion may lead to changes in morphodynamics of the inlets causing reduction in tidal water flow in the water body. Reduction in tidal exchange will adversely affect the biodiversity.
2. For other locations especially for the locations selected to construct Ports and Harbours, (the locations do not figure in the report), the status of erosion should be verified in consultation with the State government. If found to be eroding areas, construction of ports and harbours at these locations should be avoided.
3. As an immediate measure, Ports & Harbours may be permitted in non eroding locations confirmed by State Government. If the predictive models indicate that the impact of Ports' structures may cause erosion/accretion, remedial measures must be part of EMP to deal with the likely eroded and accreted areas.

As a long term strategy, there is a need to have the basic information and long term database for shoreline changes and rate of erosion for Indian coastline which would to precisely identify areas of erosion and accretion. To obtain such an information, a proposal has been prepared and the details are as follows:

Proposal to study Land use, Land cover, violations in CRZ and Shoreline changes along the Indian coast

1.0. Introduction

Coastal zone in India assumes its importance because of high productivity of its ecosystems, development of industries, concentration of population, exploration of living and non-living resources, discharge of industrial waste effluents and municipal sewage, and spurt in recreational activities. Thus, there is a need to protect coastal environment while ensuring continuing production and development. In view of this, the Govt. of India has declared coastal stretches of bays, estuaries, backwaters, seas, creeks, etc. which are influenced by tidal action up to 500 m from High Tide Line (HTL) and land between Low Tide Line (LTL) and HTL as coastal regulation zone (CRZ) during 1991. Restrictions were imposed on setting up and expansion of industries, operations and processes in CRZ to manage development in coastal areas. However, rampant violations in the coastal zones have been observed and satellite remote sensing with its synoptic view of the earth's features, regular repetitive coverage over large areas, and digital mode of data capture would be an ideal tool to monitor and map the coastal areas and shoreline changes for monthly, annual and decadal scale.

2.0. Objective

The objective of the project would be to study the temporal and spatial changes (from 1991 onwards) in the different coastal regulation zones with reference to landuse, land cover to identify CRZ violations and critical habitats and shoreline changes along the Indian coastline using remote sensing data adequately supplemented by field verifications.

The project would have the following major components:

- To study the major changes in landuse. Landcover especially the CRZ violations and critical habitats along the Indian coastline during the last two decades using a multi-temporal remote sensing dataset i.e., 1991, 1997 to 1999, 2000 and 2008) with special reference to the different Coastal Regulation Zones (CRZ)

- To identify land use and land cover violations in the CRZ based on satellite data of various resolutions and mapping of such violations in 1:25000 and where need in 1:5000 scales
- Mapping of Shoreline changes and erosion rates based upon 1972 topo sheet, 1991, 1997, 2000 and 2008 remote sensing data and to estimate the rate of erosion around port and other location to develop the setback line to guide the development along the coast

3.0. Methodology and Approach

3.1. Land use, land cover violations in CRZ

Satellite data of various resolutions available from 1991 onwards, supported land records from local authorities would also be essential to identify and quantify the exact violations in the coastal zone.

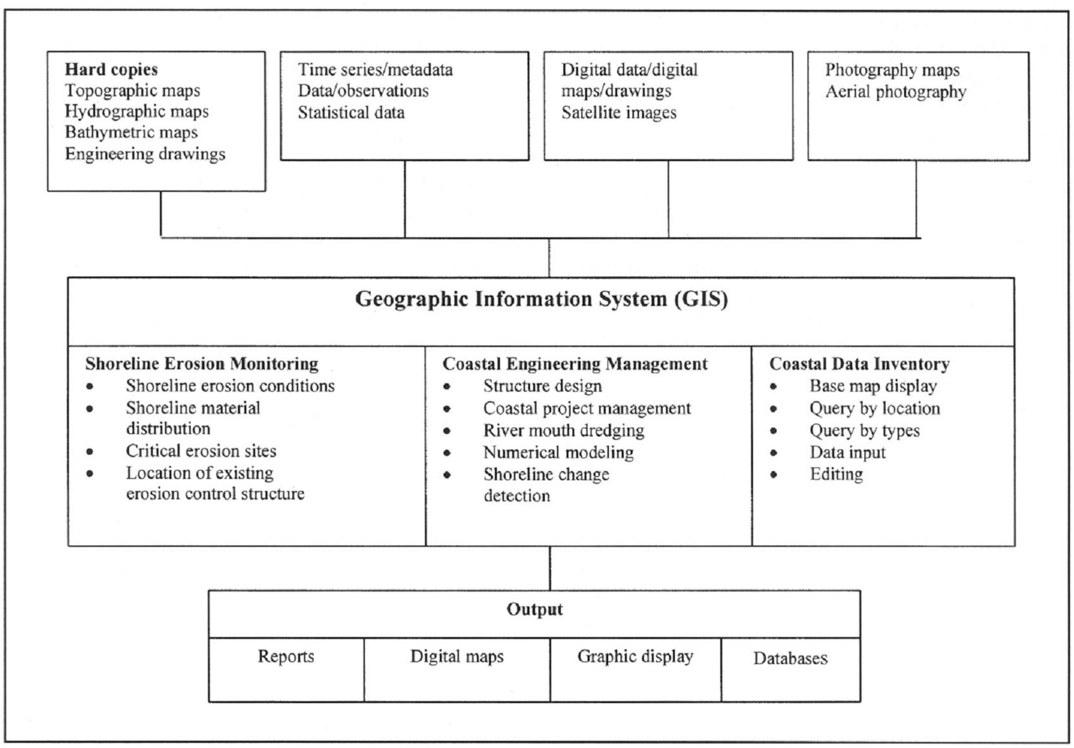
The land use and land cover as it existed in 1991 when the CRZ came into force would be studied using Landsat TM data. Since IRS satellites were hitherto not available, Landsat TM with a spatial resolution of 30m would be used for this purpose. Using the TM data a base map of land use and land cover in CRZ will be prepared and validated with land records from the local authorities. This map will be updated using 1997 LISS III data and to check annual violations LISS data from 1998 to 1999 will be used. Updated information will be checked for their accuracy from the land records.

In order to exactly identify CRZ violations it is imperative to have high resolution data such as IKONOS, Quickbird, Cartosat etc. pertaining to 2000. After validation with land records, this will be used as Updated Base map and prepared in 1:5000 scale. Annual violations where necessary will be checked using yearly high resolution data subject to their availability. Generally high resolution data of 1m resolution is not available for a particular location throughout the year or every year.

Two areas namely Cuddalore in Tamil Nadu and Dwarka or Porbandar in Gujarat will be taken up as pilot project areas to test the effectiveness of the methodology for the study. Based on the outcome from the pilot areas, the work is proposed to be extended to the entire coastline.

3.2. Monitoring the Shoreline Changes around port at short and long term

For a construction location, it is necessary to have background information about shoreline changes along the coast. Remote Sensing and GIS supported by ground truth are extremely useful for understanding the shoreline changes at seasonal, annual and decadal changes. Remote Sensing Satellite Data from Landsat and IRS will be used for the study with the available data sets within the periods of 1972 – 2008. High resolution data (<=1.0 m) will be used to detect the shoreline changes around the priority site. The shoreline will be digitized from the available satellite data sets using standard digitization technique along with other secondary information such as bathymetry, infrastructure etc. While digitizing, near infrared band of the satellite data set will be used for the demarcation of the land-water boundary. The digitized shoreline for the study period will be used as the input to analytical Shoreline analysis and modeling tools, to calculate the rate of shoreline change. Considering the Maximum and Minimum values of the shoreline change rate, the shoreline is divided in to three categories as accretion, low erosion and high erosion. The functional design of GIS for shoreline monitoring and management is shown in the chart below:



A shoreline base map using 1972 toposheet will be prepared and updated with 1991 TM data. Similar to land use, periodical shoreline changes of locations of interest will be carried out using 1997-1999 LISS III data and further high resolution data of 2000. 1:25000 scale shoreline map for the entire coastline using LISS III data and 1:5000 scale maps for areas of high erosion will be prepared. The areas will be selected based on assessment of erosion, locations identified for Ports and other developmental activities, the information on which will be provided by MoEF time to time.

4.0. Data Required

- High resolution Digital topographical maps from SOI for the base layers generation
- High resolution elevation data for the entire Indian coast including the islands from ALTM to be provided by NRSC / SOI
- Remote sensing TM, LISS/PAN etc data for entire coastline for 1991 and 1997
- High-resolution Satellite Data (IKNOIS, QUICKBIRD, CARTOSAT etc for 2000 - 2008
- Field Survey Data for Shoreline Mapping and ground trouthing / verification of results using remote sensing data

5.0. Deliverables

- A GIS based spatial database on the changes that have occurred in the Indian coast line with special reference to the CRZ area.
- A GIS based spatial database on the "violations" identified since 1991 in the Coastal zone.
- Hard copy CRZ land use and land cover violation maps at 1:25000 for the CRZ of entire country for different years and 1:5000 scale for selected locations for required years
- A GIS based database for coastal erosion and shoreline change maps at 1:25000 for the CRZ of entire country and 1:5000 scale for selected locations
-
- Shoreline mapping for entire coastline

6.0. Responsibility of Institutions

It is proposed that the work will be coordinated and carried out by MoES institutions with the help of participating institutions, one each for respective state. It is proposed that MoES will procure the required data and provide to respective state institutions for ground truthing, field data collection and preparing the base maps.

No.	Work Package	Lead Institutions	Collaborating Institutions
1	Overall coordination	ICMAM & INCOIS	
2	Shoreline changes Mapping	ICMAM & INCOIS	State institutions
3	Identification of CRZ violation	ICMAM & INCOIS	State institutions

7.0. Schedules

No	Activity	I Year	II Year	III Year
1.	Project Organisation including selection of institutions, manpower recruitment etc	---------------- --------------------	--------------------	-------
2.	Satellite data Procurement and field investigations, data processing and interaction with State Govts		------------	------------
3.	Preparation of maps, reports etc	--------------		

8.0 Budget

COST ESTIMATES: Total Cost: Rs 28.95 Crores

The details of the cost estimates are given below.

Task	Budget requirement (Rs. in Lakh)
ICMAM, INCOIS, Data and Surveys (ALTM, Remote sensing)	1875
Funds to institutions for manpower, Data Preparation and Map Generation,	1020
Total	**2895**

Break up details:

A. Tamilnadu & Pondicherry, Andhra Pradesh, Maharashtra, Gujarat and Andaman: 495.2 lakhs

Sl.	Head of Expenditure	I year	II year	II year
1	Manpower: JRF-3; SRF-2, RA/PS-1	13.68	13.68	13.68
2	Travel	2.00	2.00	1.00
3	Data and Maps	2.00	2.00	--
4	Consumables	2.00	2.00	1.00
5	Contingency	2.00	2.00	1.00
6	Vehicle hiring	2.00	2.00	2.00
7	Equipment: Trimble GPS-1, Workstation , PC-1, Laptop, spares	30.00	--	--
8	Overheads	1.00	1.00	1.00
	Total	54.68	24.68	18.68
	The funds for each state institution (Rs in Lakhs)			99.04

B. For Karnataka, Kerala and Orissa---------------Rs 272.34 lakhs

Sl.	Head of Expenditure	I year	II year	II year
1	Manpower: JRF-2; SRF-2, RA/PS-1	11.76	11.76	11.76
2	Travel	2.00	2.00	1.00
3	Data and Maps	2.00	2.00	--
4	Consumables	2.00	2.00	1.00
5	Contingency	2.00	2.00	1.00
6	Vehicle hiring	1.50	1.50	2.00
7	Equipment: Trimble GPS-1, Workstation , PC-1, Laptop, spares	30.00	--	--
8	Overheads	1.00	1.00	1.00
Total		52.26	22.26	17.26
The funds for each state institution (Rs in Lakhs)				91.78

C. Goa, Lakshadweep, West Bengal --------------------Rs 252.24lakhs

Sl.	Head of Expenditure	I year	II year	II year
1	Manpower: JRF-3; RA/PS-1	9.36	9.36	9.36
2	Travel	2.00	2.00	1.00
3	Data and Maps	2.00	2.00	--
4	Consumables	2.00	2.00	1.00
5	Contingency	2.00	2.00	1.00
6	Vehicle hiring	1.00	1.00	2.00
7	Equipment: Trimble GPS-1, Workstation , PC-1, Laptop, spares	30.00	--	--
8	Overheads	1.00	1.00	1.00
Total		49.36	19.36	15.36
The funds for each state institution (Rs in Lakhs)				84.08

D. Requirement of ICMAM and INCOIS, including data procurement --------------Rs 1874.16 lakhs

Sl.	Head of Expenditure	I year		
1	Manpower: RA/PS-1, Field Asst-2, SRF - 2	10.40	10.40	10.40
2	Equipment: and computes, accessories	150.00	-	-
Total		160.40	10.40	10.40
The funds for each state institution (Rs in Lakhs)				181.08

E. Data procurement from NRSC and SOI etc- -----------------1000 lakhs

Sl.	Head of Expenditure	I year
1	LANDSAT TM (1991), IRS LISS III (1997 to 2000,), IKONOS / QUICKBIRD (2000, 2008), (roughly 30$ per sq.km) -for entire coastline including island	1500

Table: Locations of erosion based on information provided by State Governments to Ministry of Water Resources at end of 10th plan. Annexure 1.

Locations of Erosion in in GUJARAT: Critical erosion: 45.19 km

District / Division	Location	Extent of Erosion (m)
Valsad 13.5 km	Umbergaon	850
	Nargol	1000
	Maroli	900
	Fansa	800
	Kalai	1000
	Kolak	1200
	Udwada	1500
	Umarsadi Machhiwad	2000
	Kosamba	1200
	Moti Danti, Nani Danti	3050
Navsari 20.39 km	Mendhar	1000
	Onjal Machhiwad	1590
	Dandi Tl. Navsari	1300
	Borsi Machhiwad	2500
	Sampur	900
	Danti Tal. Jlalpore	600
	Movasa	2000
	Dholai	3000
	Bhat	3000
	Wagrech	3000
	Goyandi-Bhatla	1500
Surat 19.3 km	Bhimpor Sultanabad Dumas	2500
	Suvali Damka	1100
	Bhandut Lavachha	1500
	Dandi Tal. Olpad	900
	Mora Bhagua Kudiana	2500
	Neshpardi	1200
	Budia Tal. Choryasi	600
Bharuch 1.0 km	Nahar	1000

Locations in Goa: 7.5 km

District / Div.	Location	Extent of Erosion (m)
North Goa 4.25 km	Pernem-Morjim	1000
	Bardez – Anjuna	500
	Bardez – Siolim	800
	Tiswadi – Carmallim	1000
	Tiswadi – Siridao	1000
	Tiswadi – Britona	250
	Tiswadi – Dona Paula	500
	Tiswadi – Miramar and Campal	700
South Goa 3.25 km	Salcete – Varca	250
	Salcete – Majorda	500
	Salcete – Colva	1000
	Canacona – Agonda	500
	Canacona – Patne Colomb	1000

Orissa : 66.2 km

District / Div	Location	Extent of Erosion (m)
Ganjam 2.5 km	Gopalpur	1000
	Rushikulya	1500
Puri 59.0 km	Samanag cut	5000
	Nuanai mouth	30000
	Belanga	10000
	Nuagarh jetty	4000
	Sahab to Balabhadrapur	4000
	Keutajanga	2000
	Tendahara Singiripal	2000
	Chhotipada Badraula	100
	Serei	1000
Kendrapara 1.0km	Satabhaya	1000
Balasore 3.7 km	Chandabali	1500
	Chandipur	1200
	Chudamani	400
	Chandinipal	600

Kerala :52.065 km

District / Div.	Location	Extent of Erosion (m)
Thiruvananthapuram 2.315 km	Valiyathura – Reach II	600
	South of Valiyathura	765
	Puthukurichib-Marianadu	950
Kasargode 16.465 km	Moosadi	1250
	Beraka	780
	Koyipady	2000
	Kavugoli beach	1000
	Cherangai Kadapuram	750
	Adkathbail	500
	Ajanoor Kadapuram	750
	Bella Kadapuram	1000
	Hosdurg Kadapuram	1000
	Thai Kadapuram	1500
	Thai Kadapuram II	1000
	Thai Kadapuram III	1000
	Pedanna Kadapuram	685
	Kannu Veedu	800
	Kannu Veedu II	1000
	Kannu Veedu Kadapuram	1000
	Keezhu	450
Thalassery 2.1 km	Pachakara	500
	Kadalay	700
	Puthiyangadi	400
	Meenkunnu	500
Manjeri 11.25 km	Kadappuram	1500
	Ariyalur	1000
	Koottayi	1750
	Padinjarekkara	2000
	Vakkad	1000
	Thevar Kadappuram	2000
	Vettom Pt	2000

District	Location	Extent of Erosion (m)
Thrissur 0.7 km	Vadanampilly	700
Kozhikode 6.785 km	Bangladesh Colony	3000
	Moodadi beach	400
	Kothi beach	900
	Kappad beach	1000
	Puthiyakadavu beach	750
	Modadi beach II	340
	Marat beach	205
	Puthiyangadi beach	1000
	Kollam	140
	Ayanikadu	500
	South beach	300
	Kottakal kadapuram	950
Alappuzha 12.45 km	Thumboli	900
	Chethy	1000
	Chennaveli	1750
	Arthungal	2000
	Kakkazham	1800
	Kattoor	2000
	Thykal – Ottamassery	1500
	Thykal – Ottamassery Part II	1500
Ernakulam	Chellanam island	--
	Vypeen island	--
	Cherai	--

Lakshadweep-72.57 km

District / Division	Location	Extent of Erosion (m)
Lakshadweep 72.57 km	Agatti	8246
	Amini	6500
	Andrott	8113
	Bitra	564
	Chetlat	4273
	Kadmat	13137
	Kalpeni	5958
	Kavaratti	5552
	Kiltan	4883
	Minicoy	15344

West Bengal : 10.75 km

District / Division	Location	Extent of Erosion (m)
24 Parganas (South) 9.1 km	Kusumtala	600
	Beguakhali	1500
	Shibpur	500
	Frezerganj	1000
	Gobardhanpur	2000
	Buraburirttat	1500
	Shridharnagar	2000
Midnapore 1.646 km	Digha	1646

Tamil Nadu : 13.824 km

District / Division	Location	Extent of Erosion (m)
Chennai	Periyakuppam	1000
	Chinnakuppam	250
	Ernavoorkuppam	300
	Annai Sivakami Nagar Kuppam	400
	Indira Gandhi Nagar Kuppam	350
Kancheepuram	Kovalam Kuppam	600
	Oyyalikuppam	600
	Chinnakuppam, Periyakuppam & Alikuppam	1800
Cuddalore	Devanampattinam	1000
Nagapattinam	Poompuhar	650
	Tharangambadi	1050
	Ariyanattu Theru	400
Thoothukudi	Periathalai	400
	Alanthalai	453
Thirunelveli	Koothankuzhi	300
	Kootapuli	300
	Uvari	400
	Idinthakarai	275
	Kooduthalai	290
	Kootapanai	250
	Thomayapuram	250
	Perumanal	250
Kanyakumari	Ratchakar Street	350
	Kodimunai	500
	Kodimunai II	300
	Keezhmidalam	300
	Chinnathurai	290
	Marthandamthurai	290

Karnataka : 48.875 km

District / Division	Location	Extent of Erosion (m)
Uttar Kannada	Gorte	200
	Belke	200
Bhakatal Taluk (5.85 km)	Mundalli	300
	Bhatkal Port	300
	Jali	750
	Honnagadde	500
	Tengtinagudi	500
	Shirali Port	750
	Kalkini	300
	Mavalli	300
	Bailur Mavalli	1750
Honnavar (5.85 km)	Doddagunda	1000
	Manki	100
	Apsarakonda	750
	Tonka	200
	Pavinkurvs	200
Kumta taluk (7.0 km)	Dhareshwar	1000
	Alvekode	1000
	Bada	2000
	Holanagadde	2000
	Jestapura	1000
Ankola Taluk (3.3 km)	Belambar	1200
	Bhavikere	900
	Belekeri	600
	Hawade	600
Karwar (4.0 km)	Amadalli	1500
	Devbhag	1250
	Dhandabhag	1250

District / Division	Location	Extent of Erosion (m)
Mangalore (3.69 km)	Ullal	1550
	Kulai	300
	Hosabettu	400
	Guddakopla	630
	Doddakopla	110
	Mukka	300
	Sasihithlu	400
Udipi (13.35 km)	Hejamadikodi	1340
	Kadipatna	1850
	Tenka Yermal	900
	Bada Yermal	1025
	Uchila	300
	Muloor	300
	Polipu Padu	620
	Uliargoli Padukere	1450
	Hoode Kemannu	9450
	Kodibengre	150
	Hosa Bengre	800
	Kodi Kanyana	850
	Paramapalli	700
	Kotathattu	1270
	Mannur Padukere	850
Kundapura (6.835 km)	Beejadi	450
	Kasabakodi	440
	Maravanthe	1050
	Navunda	400
	Adragoli	600
	Hosahithlu	850
	Gangebailu	100
	Uppunda –Amma.ppalu	975
	Alivekodi	1370
	Kalihithlu	600

Maharashtra : 72.36 km

District /Division	Location	Extent of Erosion (m)
Mumbai - 8900 mts.	Nariman Point to Chowpati	3000
	Raj Bhavan	200
	Nepean Sea Road to Priyadarshan Park	400
	Chaitya Bhumi, Dadar	1000
	Worli Koliwada to RBI Colony	500
	Mahim Fort	200
	NCPA of Nariman Point	100
	Geeta Nagar	300
	Cuffe Parade - World Trade Centre	300
	Haji Ali	2900
Mumbai Suburban 3100 mts.	Bandra Khadi near Bandra	300
	Band Stand Bandra	200
	Khardanda near Ram Temple	500
	Chimbai Khardanda	500
	Versova	200
	Versova opp. side of creek	200
	Madh	200
	Patgaon	200
	Manori	400
	Gorai	400
Thane	Baindar	500
	Pachu Bunder	800
	Vasai	500
	Naigaon	300
	Kochiwade	200
	Satpale-Rajodi	1000
	Bhuigaon	1700
	Rangaon	1200
	Kalamb	2250
	Arnala	880
	Arnala (Fort)	300
	Kore	660
	Datiware	600

District	Location	Extent of Erosion (m)
Thane 28740 mts	Edvan	650
	Mathane	750
	Kelwa	1000
	Mahim	300
	Wadrai	500
	Satpati	1200
	Navapur	700
	Dandi	650
	Tarapur	420
	Ghiwali	1000
	Tadiyale	500
	Dhakti Dahanu Khadi	600
	Dahanu (Khadi)	300
	Dahanu, (seaside)	1000
	Narpad	400
	Bordi	650
	Zai	600
	Ghod Bunder	1000
	Belapur	500
	Vashi	500
	Vashi	500
	Kalyan	500
	Kalwa	500
	Dahanu	200
	Dhakti Dahanu	120
	Gungwada	100
	Chikhala	100
	Kamboda	100
	Waroor	150
	Kelwa Danda	60
	Chinchani	300
	Murbe	250
	Nandgaon	250
	Vaitarana	2000

District / Division	Location	Extent of Erosion (m)
Raigad 8662 mts	Bagdanda	427
	Navedar Navgaon	200
	Mandwa	900
	Sakar (Akshi)	250
	Ranjankhar Morapada	405
	Nagaon	975
	Ramraj	200
	Mohalla Part II	200
	Smashan Bhumi Part I & II	450
	Barshiv (Near Smashanbhumi)	200
	Barshiv	400
	Murud (Near Khora Bunder)	75
	Vihur at Pail Mohalla Part II	385
	Salav to Korlai Part III	500
	Salav Part II	1000
	Rajpuri Muslim Mohalla	145
	Kashid Part II	375
	Agardanda	210
	Rajpuri Navenagar	145
	Adgaon Part II	200
	Diveagar Muslim Mohalla Part III	300
	Barshiv Smashanbhumi Part II	150
	Jeevana Part II	570

District / Division	Location	Extent of Erosion (m)
Ratnagiri 17548 mts	Kolthare	100
	Ansure	100
	Velas Dandawadi	120
	Jakimirya	400
	Bhatimirya	1100
	Rajiwada, Jetty to Bhatye Bridge	1400
	Karanjgaon	240
	Burondi	70
	Adaye	150
	Palshet, Amboshi	78
	Varavade	200
	Avare Jaitapur	300
	Borya	150
	Velas	2500
	Bankot	440
	Kelshi	2500
	Anjarla	1000
	Rammandir to Harne	1500
	Harne	500
	Palande	1000
	Saldure	200
	Ladghar	200
	Ladghar Rammandir	500
	Bhikhmandir	200
	Velneshwar	200
	Tavsal	100
	Bhatkarwada	500
	Bhandarpule	200
	Palshet	500
	Ansure	600
	Bhaterwadi	300
	Varavade	200

Statewise details of Ports and Harbours (intermediate/minor/jetty) Annexure 2

GUJARAT
1 Mandvi
2 Navilakhi
3 Bedi
4 Sikka
5 Jafarabad
6 Okha
7 Porbandar
8 Veraval
9 Bhavanagar
10 Bharuch
11 Madallaa
12 Koteshwar
13 Mundra
(i)GAPL
(ii)Old
14 Jakhau
15 Jodia
16 Salaya
17 Pindhara
18 Beyt
19 Rupen
20 Mangrol
21 Kotda
22 Madhwad
23 Navabandar
24 Rajapara
25 GPPL(Pipavav)
26 Mahuva
27 Talaja
28 Ghogha
29 Khambhat
30 Dahoj
31 Bhagwa
32 Onjal
33 Vansi-Borsi
34 Billimora
35 Valsad
36 Umarsadi
37 Kolak
38 Maroli
39 Umergaon
40 Mul-Dwarka

DAMAN & DIU
1 Daman
2. Diu

GOA
1. Panaji
2. Chapora
3. Betul
4. Talpona
5. Tiracol

MAHARASHTRA
1 Dahanu
2 Tarapur
3 Nawapur
4 Satpati
5 Kelwa-Mahim
6 Arnala
7 Datiware
8 Uttan
9 Bassein
10 Bhiwandi
11 Manori
12 Kalyan
13 Thane
14 Versova
15 Bandra
16 Trombay
17 Ulwa-Belapur
18 Panvel
19 Mora
20 Mandwa
21 Karaja
22 Thal
23 Rewas
24 Alibag
25 Dharamtar
26 Revdanda
27 Borli/Mandla
28 Nandgaon
29 Murud-Janjira
30 Rajpuri
31 Mandad
32 Kumbharu
33 Sriwardhan
34 Bankot
35 Kelshi
36 Harnai
37 Dabhol
38 Palshet
39 Borya
40 Jaigad
41 Tiwri-Varoda
42 Purnagad
43 Jaitapur
44 Vijaydurg
45 Deogad
46 Achara
47 Malvan
48 Niwti
49 Vengurla
50 Redi
51 Kiranpani
52 Ratnagiri
53 Dighi

KARNATAKA
1 Mangalore
2 Mal pe
3 Hangarkatta
4 Kundapur
5 Bhatkal
6 Honavar
7 Tadri
8 Belekeri
9 Karwar
10 Padubidri

KERALA
1 Alappuzha
2 Vadakara
3 Kannur
4 Kasargode
5 Kodungallore
6 Ponnani
7 Thalassery
8 Thiruvananthapuram
9 Qullon
10 Kozhikode/Beypore
11 Needakara
12 Azhikkal
13 Koavalam/Vizhijam

LAKSHADWEEP
1 Agatti
2 Amini
3 Andrott
4 Bitra
5 Chetlat
6 Kavaratti
7 Kadmat
8 Kiltan
9 Kalpeni
10 Minicoy

TAMILNADU
1 Cuddalore
2 Nagapattinam
3 Rameshwaram
4 Pamban
5 Colachel
6 Valinokkam
7 Kanyakumari
8 Punnakayal (C)
9 Thirukkadaiyur (C)
10 PY-3 (Oil Field) (C)
11 Kattupalli (C)
12 Thiruchopuram (C)
13 Manappad (C)
14 Kudankulam
* (C) : Captive Ports

PONDICHERRY
1. Pondicherry

ANDHRA PRADESH

1 Bhavanapadu
2 Calingapatnam
3 Bheemunipatnam
4 Kakinada
(i) Anchorage
(ii) Deep Water
5 Narsapur
6 Machilipatnam
7 Vadarevu
8 Nizampatnam
9 Kirshnapatnam
10 Gangavaram
11 Mutyalam mapalem
12 Ravva

ORISSA
1. Gopalpur
2. Behrabalpur (Balasore)

WEST BENGAL
1. Kulpi

ANDAMAN & NICOBAR

1 Port Blair
2 Mus
3 Car Nicobar
4 Havelock
5 Mayabunder
6 Diglipur
7 Rangat
8 Hut Bay
9 Katchal
10 Campbell Bay
11 Neil Havlock
12 Dugong Creek
13 Nancowry
14 Chowra
15 Teressa
16 Kondul
17 Pillow Millow
18 East Island
19 Clnque Island
20 Jolly Bouy Island
21 Tillonchong
22 Castle Bay
23 South Bay

(Source: Compilation from secondary information, Association of ports, other records,2005). List under updation