Chapter 16
Advancement of Technology for Detecting Shoreline Changes in East Coast of India and Comparison with Prototype Behavior

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Abstract Developments in the coastal area have significant impact on the adjacent shorelines. Mathematical modeling provides a useful tool for predicting such changes in shorelines in advance. Processing and analysis of satellite imageries of coastal area enables us to estimate and monitor the shoreline changes, which is otherwise extremely difficult, time consuming and costly by field surveying. In this paper the shoreline changes obtained by mathematical modelling and by image processing technique are compared by applying these techniques to shoreline adjacent to Ennore region. The study indicated that the cross-shore and longshore impact predicted by mathematical model and satellite information match satisfactorily. Thus the satellite information is useful for calibrating the mathematical model which can be further used for predictive purposes.

16.1 Introduction

The coastline is an interface between the land and sea where winds, waves, tides and currents attack the land. The land responds to this attack by dissipating the energy of the sea and changing the shape and alignment of the coastline continuously. Waves play a prominent role in the nearshore processes. The action of waves is the principal cause for changes in the shorelines.

Human interventions into the natural processes taking place in the coastal zone have an impact on the shorelines. These are construction of ports and coastal structures, dredging, mining etc. In order to anticipate the impact and suggest remedial measures to minimize the adverse effects, it is desirable to predict the

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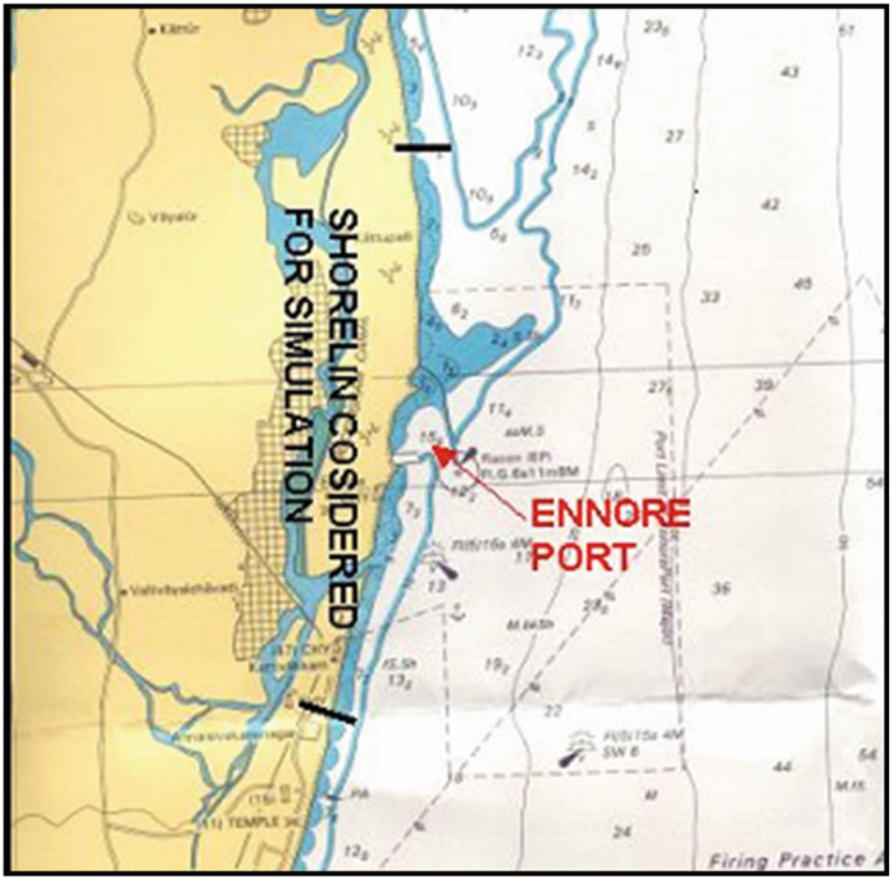

Fig. 16.1 Location of Ennore region

changes in the shorelines before undertaking the developments. Mathematical modeling provides a useful tool for predicting such changes in the shorelines.

Satellite remote sensing technique is a very useful tool for studies regarding coastline changes. It can provide synoptic view in the form of satellite imageries of coastal area at different time instants. Processing and analysis of these imageries enables us to estimate, monitor and understand the shoreline changes, which is otherwise extremely difficult, time consuming and costly by field surveying.

This study is carried out to demonstrate the usefulness of the satellite derived information for mathematical modelling of the shoreline changes. The coastal site around Ennore region is considered for this study (Fig. 16.1). Shoreline changes due to the development of the port are simulated by mathematical modelling techniques and compared with the shoreline changes derived from remote sensing/image processing techniques. The methodology and findings of this study is described below.

16.2 Development of Port at Ennore

It is located on the east coast of India about 20 km north of Chennai port. It was constructed in 1999 to meet the increasing demand of cargo. It is in operation since 2001 with coal as major cargo. The port is sheltered by northern breakwaters of 3.2 km length and southern breakwaters of 1.1 km length with entrance from southeast direction. Since the region is located in highly sensitive zone of littoral drift, the development of the port was expected to cause significant impact on the coastline. After the construction of the port, the southern shoreline has witnessed accretion due to the southern breakwater and also due to presence of Ennore creek while the northern coastline has experienced severe erosion.

16.3 Site Conditions

For simulation of littoral drift and shoreline changes, data on bathymetry, tidal levels, currents, waves and sediments at the site are required. The site at Ennore is near Chennai where the tidal levels MHWS, MHWN, MSL, MLWN and MLWS are 1.1 m, 0.8 m, 0.6 m, 0.4 m and 0.1 m respectively. Tidal currents are unidirectional, northward during SW and non-monsoon period and southward during NE monsoon period with average magnitude of the order of 0.1–0.2 m/s. The major data required for simulation of shoreline changes is the nearshore wave climate at the site.

Instrumentally observed wave data at the site over a period of several years, if available, are best suited for design purposes. As such data were not available, the ship observed deep water wave data reported by India Meteorological Department (IMD) covering a period of about 30 years for quadrant between latitude 10–150°N and longitude 80–85°E were analysed to obtain seasonal and annual wave climates in the offshore region of Ennore. It is seen from the annual wave climate (Fig. 16.2a) that the predominant wave direction is from SW and NW quadrants with maximum wave height of the order of 4.5 m. This wave climate in the deep sea was transformed to get the nearshore wave climate at Ennore using a mathematical model which is described subsequently. The orientation of the coastline in this region of Ennore is approximately in North-South direction.

Littoral drift rates near the site at Ennore were computed by various researchers. Chandramohan et al. (1990) estimated northward drift of 1.027×10^6 m^3 and southward drift of 0.683×10^6 m^3 with net drift towards north to be 0.344×10^6 m^3 along Madras coast. Natesan and Subramanian (1994) indicated that along the coastal stretches of Grid I (Lat. 9–12 N, Long. 80–83 E) and Grid II (12–15 N, 81–84 E), a net transport of 0.35–0.4 million m^3 of sand towards north occurs. Indomer (2005) estimated northward drift of 0.977313×10^6 m^3 and southward drift of 0.512757×10^6 m^3 with net drift towards north to be 0.464556×10^6 m^3 along Minjur coast. Shoreline studies were carried out by ICMAM (2007) in which the net transport towards north at Ennore coast was assumed to be 0.35×10^6 m^3.

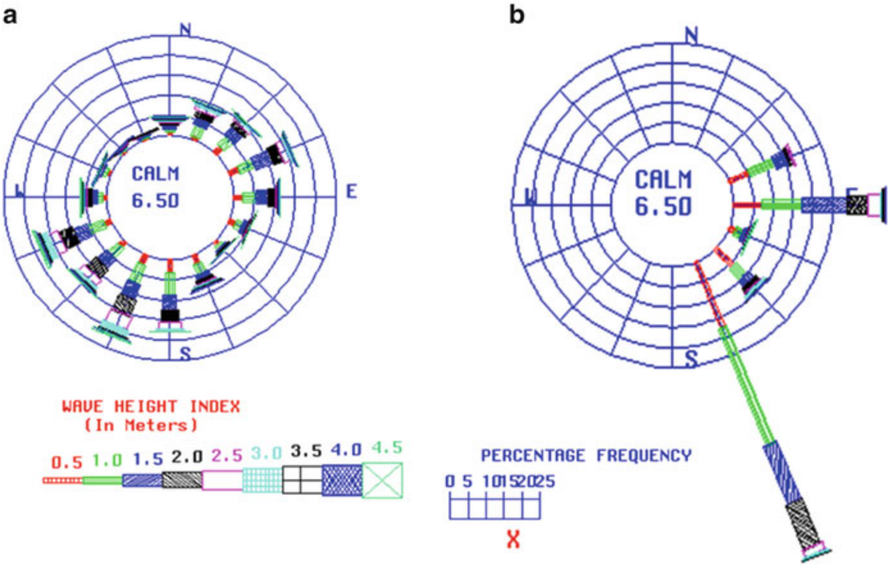

Fig. 16.2 Rose diagram for wave heights for annual period. (**a**) Offshore. (**b**) Inshore

From the above discussions it is seen that there is considerable variation in the estimation of littoral drift in the region due to the uncertainties involved. However, in general, the annual rate of northward and southward transport at the Chennai coastline are of the order of 0.6 and 0.1 million m^3 respectively. Hence the average northward and southward transports for Ennore coastline are considered to be 0.60 and 0.1 million m^3 so that net and gross transports are 0.5 and 0.7 million m^3.

16.4 Transformation of Waves

The wave climate prevailing at the site is one of the important parameters for estimating littoral drift and shoreline changes which is derived by wave transformation from deep to shallow waters using OUTRAY (1989) model. This model takes the deep water wave height, period and direction as input and computes the wave height, period and direction at the inshore point of interest. The wave height and period are input to the model by specifying the spectral distribution of wave energy at the offshore boundary. The offshore wave climate described earlier was transformed to the inshore location near Ennore in 12 m contour to obtain the seasonal and annual inshore wave climates. It is seen that during SW monsoon (June–Sept.), the waves approach predominantly from SSE direction with 90 % occurrence. During NE monsoon (Oct.–Jan) the predominant wave directions are East, and SSE at the nearshore location with percentages 48 % and 29 % respectively. In non-monsoon period (Feb. to May), the predominant wave directions are East, ESE, SE and SSE with percentages 23 %, 17 %, 15 % and 40 % respectively. The maximum wave

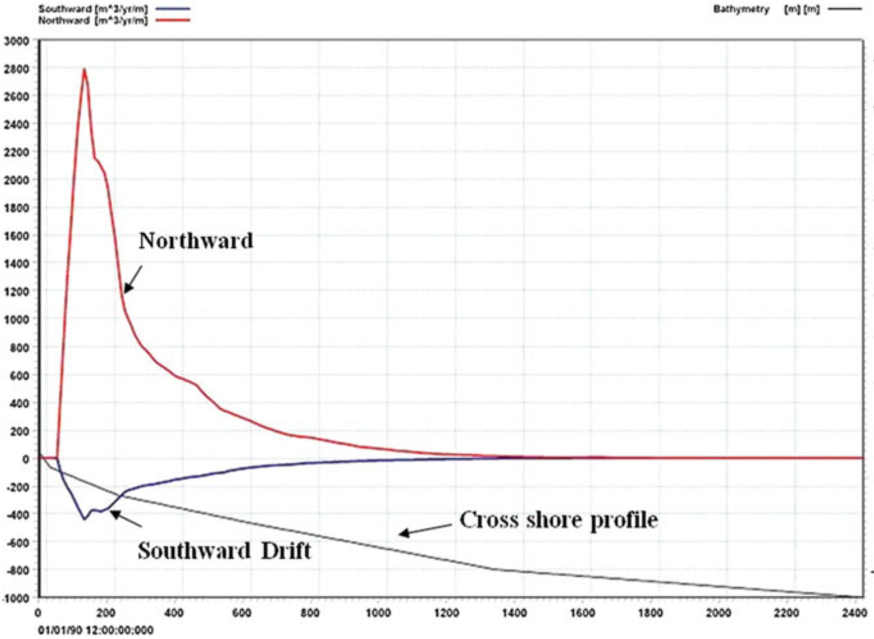

Fig. 16.3 Distribution of littoral drift during annual period

height of 3.5 m is seen to occur. The annual frequency distribution of waves at the inshore location near Ennore is shown as rose diagram in Fig. 16.3b which indicates that the waves approach predominantly from East and SSE directions with percentages 25 % and 48 % respectively and waves up to 4.0 m are seen.

16.5 Simulation of Littoral Drift and Shoreline Changes

For these studies, LITPACK (2000) software was used to simulate the longshore transport and impact of the construction of Ennore port. Computation of longshore sediment transport is based on the local wave, current and sediment characteristics. The sediment transport model takes into account time-varying distribution of both suspended load and bed load in combined wave and current motion including the effect of wave breaking, when relevant. The model gives a deterministic description of cross-shore distribution of longshore sediment transport for an arbitrary, non-uniform bathymetry and sediment profile. The seasonal/annual sediment budget is found by the contribution of transport from each of the wave incidents occurring during the season/year. For simulation of shoreline evolution, the following continuity equation for sediment volumes is numerically solved.

$$\frac{\partial y_c}{\partial t} = -\frac{1}{h_{act}(x)}\frac{\partial Q(x)}{\partial x} + \frac{Q_{sou}(x)}{h_{act}(x)\Delta x} \tag{16.1}$$

Table 16.1 Seasonal and annual transport rates (million cu m)

Profile	Season	Northward	Southward	Net	Gross
South profile	SW monsoon	−0.34	0.00	−0.34	0.34
	NE monsoon	−0.11	0.07	−0.04	0.18
	Non-monsoon	−0.16	0.02	−0.14	0.18
	Annual	−0.61	0.09	−0.52	0.70
North profile	SW monsoon	−0.29	0.00	−0.29	0.29
	NE monsoon	−0.13	0.08	−0.05	0.21
	Non-monsoon	−0.15	0.02	−0.13	0.17
	Annual	−0.57	0.10	−0.47	0.67

Note : +ve sign indicates southward transport, −ve sign indicates northward transport

where, $y_c =$ distance from the base line to the coastline, $h_{act} =$ height of the active cross-shore profile, $Q =$ longshore transport of sediment expressed in volume, $x =$ longshore position, $\Delta x =$ longshore discretisation step, $Q_{sou} =$ source/sink term expressed in volume. Thus the term Q_{sou} can be conveniently used to include sand bypassing arrangement.

16.5.1 Littoral Drift Distribution

The LITPACK (2000) model assumes the depth contours parallel to the coast and longshore transport is computed along a representative cross-shore profile. The longshore transport was computed for 2.5 km long bed profiles normal to shore with depth varying from +2.9 m to −15 m. The profiles were divided into 250 grid points with grid size of 10 m. For these studies, besides the inshore wave climate and bathymetry along the cross-shore profile, grain size distribution over the profiles is also required. At the site grain size was observed to be of the order of 0.2 mm Hence grain size D50 over the profiles was assumed to be 0.2 mm.

Since the general orientation of the coastline at Ennore is North-South, depending on the wave direction with respect to the shoreline, the littoral drift will be directed towards north or south along the shoreline. The model was run for the two cross-shore profiles for seasonal and annual inshore wave climates. The model was calibrated for the net and gross annual transport of 0.70 million cum and 0.50 million cum and the seasonal/annual northward, southward, net and gross transport quantities computed are given in Table 16.1.

The distributions of seasonal and annual transports over the profile are shown in Fig. 16.3 which indicate that the transport is mainly confined within 400 m from the shore. The maximum transport occurs at about 50–70 m from the shore.

16.5.2 Shoreline Changes

For the shoreline evolution model, shoreline of 14.4 km length extending 6 km towards north and 6 km on the south of Ennore region was considered. This was

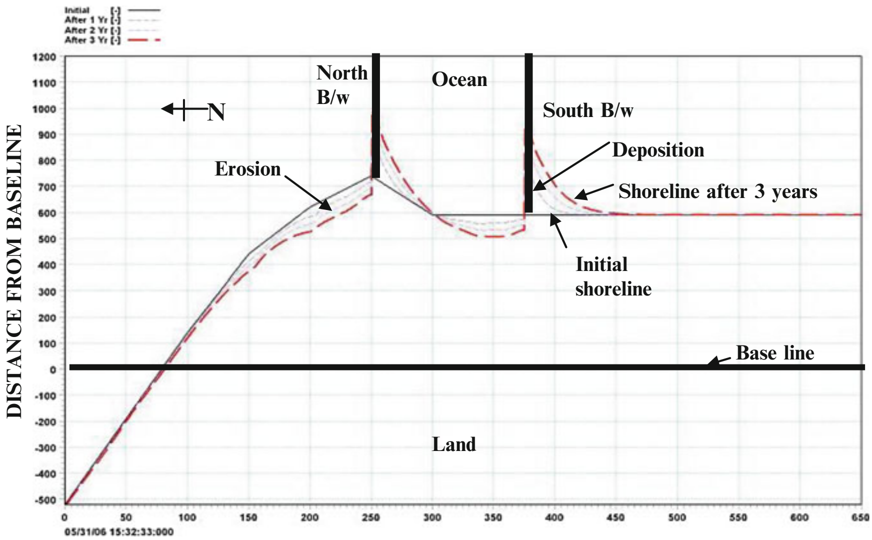

Fig. 16.4 Shoreline changes after 1, 2, 3 years

divided into 721 grid points with grid size of 20 m. The port with 3.2 km long north breakwater and 1.1 km long south breakwater was considered in the model. The effective blocking lengths normal to shoreline of the north and south breakwaters are considered to be 1,500 m and 1,000 m. With these conditions the shoreline evolution model is run with the schematic layout of the breakwaters for 3 years period. The shorelines evolved after each year is shown in Fig. 16.4.

As the net transport is towards north, the coastline on the south side of the south breakwater has advanced and the coastline on the north side of the north breakwater has receded. The maximum cross-shore advancement on the south side is about 300 m after 3 years and its longshore accretion effect on south side of south breakwater is felt for about 1.5–2 km. The maximum cross-shore recession on the north side is about 100 m after 3 years and its longshore erosion effect on north side of north breakwater is felt for about 2 km.

16.6 Shoreline Changes by Image Processing

Remote sensing satellite records the features of earth's environment in the form of spectral response without physically coming in contact with the earth's surface. The electro-magnetic energy in the discrete bands of different wavelengths of electro-magnetic spectrum reflected or radiated by different objects enables identification of different objects, their locations, spatial distribution and helps in obtaining their properties. The advantage of remote sensing satellites is their capability to map regions including coastal, oceanic and land features like wetlands, intertidal zones etc., at regular interval of time. The temporal data obtained from remote sensing satellite can effectively be used to assess the dynamic changes in the shorelines by delineation of water and land. The infrared band in the spectral range of 0.77–0.86 μm is found to be suitable for demarcation of shoreline as the contrast between land and water is very sharp. Multi-date digital satellite images can be compared to detect any changes in the shoreline using digital satellite image processing software. While comparing two imageries of different dates, it is important to ensure that both the imageries are at similar tidal condition.

In order to evaluate the shoreline, satellite data sets of two dates covering a period of 3 years were selected. The details of the imageries selected for this study are listed in the following table.

Sl. No.	Satellite	Sensor	Date	Path	Row	Spatial resolution (m)
1.	IRS-1D	LISS-III	12.02.2001	102	064	23.8
2.	IRS-1D	LISS-III	17.04.2004	102	064	23.8

The imageries are in digital form having visible and infrared spectral bands. Subset imageries bounded by latitude 13.2795 and longitude 80.3574 were used for the analysis of shoreline changes. The images of shorelines of 2001 and 2004 near Ennore region as viewed by LISS-III sensor of IRS-1D satellite are compared.

16.7 Comparison of Shoreline Changes Obtained by Mathematical Model and Image Processing

The shoreline changes obtained by mathematical modelling and image processing are shown in Fig. 16.5 for comparison. It can be seen that the cross-shore and longshore shoreline changes obtained by the model and image processing match

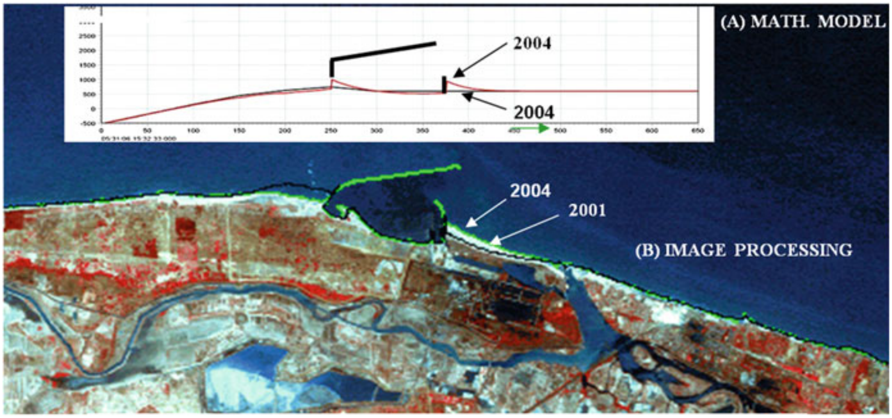

Fig. 16.5 Comparison of shoreline changes obtained by mathematical model

satisfactorily. With further refinement in the model results by tuning model parameters and analysis of additional imageries, the matching of the two results can be improved.

16.8 Conclusion

Human interventions into the natural processes taking place in the coastal zone such as construction of ports has significant impact on the shorelines. In order to assess the effect of such developments and suggest remedial measures in anticipation, it is desirable to predict the shoreline changes in advance. Mathematical modeling provides a useful tool for predicting such changes in advance. Processing and analysis of satellite imageries of coastal area enables us to estimate and monitor the shoreline changes, which is otherwise extremely difficult, time consuming and costly by field surveying. Satellite remote sensing is a very useful technique for studies regarding coastline changes. Processing and analysis of satellite imageries of coastal area enables us to estimate and monitor the shoreline changes, which is otherwise extremely difficult, time consuming and costly by field surveying.

Shoreline changes due to the development of Ennore port are simulated by mathematical modelling technique and compared with the shoreline changes derived from remote sensing/image processing technique. The study indicated that the cross-shore and longshore impacts predicted by mathematical model and satellite information match satisfactorily. Thus the satellite information is useful for calibrating the mathematical model which can be further used for predictive purposes. With further refinement in the model results by tuning model parameters and analysis of additional imageries, the model could be improved.

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