SHORELINE CHANGE MONITORING IN TUTICORIN COAST USING REMOTE SENSING AND GIS TOOLS

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Abstract

Erosion and accretion along the Tuticorin coast were identified using Landsat 5 TM May 1993, IRS P2 LISS II May 1996 and IRS 1C LISS III May 2002 data in comparison with Survey of India toposheet no L1 & L5 (1969) as baseline data. Erosion during the period 1969 to 1993 was 9 ha, 1993 to 1996 was 14 ha and 1996 to 2002 was 18 ha respectively. The accretion during the period 1969 to 1993 was 138 ha, 1993 to 1996 was 18 ha and 1996 to 2002 was 24 ha respectively. Erosion and accretion were also observed in specific geographical areas such as sand spits, Hare Island, below south harbour breakwater and urban coast. In all these areas the accretion dominates, suggesting the coast as prograding coast. To substantiate the change, wave pattern and its dynamics were also studied using IRS P2 May 1996 and IRS 1C May 2002 data. Image enhancement technique for infrared band of IRS P2 and IRS 1C were carried out using ERDAS IMAGINE image processing software. Coastal processes such as wave diffraction, wave refraction and shadow zone formation were identified. Because of wave action there is erosion at the tip of the Hare Island and the Vann Island during 1969 to 2002. Slope analysis from the 3-dimensional bathymetry model showed that near the urban coastal area as well as above and below the harbour breakwater the slope is less than 4°, but from the vicinity of the harbour towards the offshore the slope becomes steeper. Sediment transport and the slope variations observed from urban coastal and harbour environment showed that chances are less for sediments to enter into harbour area and hence the Tuticorin harbour is free from sedimentation problem. Geomorphic study of Tuticorin coast showed that the entire coastline is prograding and the coastal process that has been taking place is similar as noticed from IRS P2 1996, IRS 1C 2001 and IRS 1C 2002 satellite imageries.

Introduction

Shoreline or coastline, the boundary between land and sea keeps changing its shape and position continuously due to dynamic environmental conditions. The change in shoreline is mainly associated with waves, tides, winds, periodic storms, sealevel change, the geomorphic processes of erosion and accretion and human activities. Shoreline also depicts the recent formations and destructions that have happened along the shore. Waves change the coastline morphology and forms the distinctive coastal landforms. The loose granular sediments continuously respond to the ever-changing waves and currents. The beach profile is important, in that it can be viewed as an effective natural mechanism, which causes waves to break and dissipate their energy. When breakwaters are constructed, they upset the natural equilibrium between the sources of beach sediment and the littoral drift pattern. In response, shoreline changes its configuration in attempt to reach a new equilibrium (Ramesh and Ramachandran 2001). Monitoring changes in shoreline helps to identify the nature and processes that caused these changes in any specific area, to assess the human impact and to plan management strategies. Remote sensing data could be used effectively to monitor the changes along the coastal zone including shoreline with reasonable accuracy. Remote sensing data helps and / or replaces the conventional survey by its repetitive and less cost-effectiveness. Hence, in order to study the coastal processes in Tuticorin coastal area, the shoreline change, wave action, bathymetry and coastal geomorphology were analyzed using Remote Sensing and GIS tools.

Study area

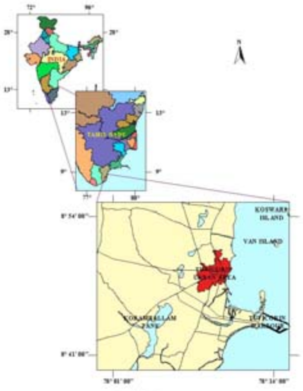

Figure 1. Study area map

Tuticorin coast has a major port and it is a rapidly developing area. The study area falls in the latitudinal and longitudinal extensions of 8° 40’ – 8° 55’ N and 78° 0’ – 78° 15’ E on the Tamil Nadu, East Coast of India (fig 1). Major Industries such as Southern Petrochemical Industrial Corporation, Thermal Power Plant, Tuticorin Alkali Chemicals and Heavy Water Plant are also present in this area. Due to the accelerated development activities the coastal area experience significant changes.

Tuticorin was a centre of maritime trade and pearl fishery for more than 2000 years. To cope with increasing trade through Tuticorin, the government of India sanctioned the construction of an all weather port at Tuticorin. On 11-7-1974, the newly constructed Tuticorin port was declared as the tenth major port. On 1-4-1979, the erstwhile Tuticorin minor port and the newly constructed Tuticorin major port were merged and the Tuticorin Port Trust was constituted under the major port trusts act, 1963.

Methodology

Geomorphology

Geocoded IRS LISS III May 2002 imagery was used to prepare coastal geomorphology map adopting visual interpretation technique. In the present study, the classification system developed by the Space Application Center, Ahmedabad for the nation wide coastal geomorphic mapping was adopted for the study (SAC 1991).

Shoreline change

Survey of India toposheets No. L1 & L5 of (1969) (lat: 8° 40 '- 8° 55', long: 78° 0' - 78° 15'; Scale 1:50,000) were used as a base map. They was digitized, edited, geometrically projected and transformed through ARC INFO to maintain real world coordinates. To eliminate the effect of tidal influence in shoreline change study, low tide satellite data were used. SOI toposheets 1969, Landsat 5 TM May 1993, IRS P2 LISS II May 1996 and IRS 1C LISS III May 2002 satellite data were used to assess the changes in shoreline for 33 years period from 1969 to 2002. Raster data procured through satellites were geometrically corrected using the Survey of India toposheet as a base. More than 25 ground control points were taken and the Root Mean Square (RMS) error for geometric correction is 0.002. Band 1 of IRS P2 LISS II 1996, band 5 of LANDSAT 5 TM 1993 and band 3 of IRS 1C LISS III 2002 were used. These different bands were used based on their contrast between land and ocean. In these bands the information content is more in land as compared to water. The Landsat 5 TM 1993, IRS P2 1996 and IRS 1C LISS III 2002 data were vectorised by adopting onscreen digitization technique with single pixel zoom level using ERDAS imagine 8.4 software. The vector layers of the shoreline got through on screen digitization in ERDAS imagine and vectorisation through ArcInfo were imported as Arc coverage for the above four data sets. Each of the data sets had a polygon ID 1 for Land area and 2 for Ocean. The shoreline obtained from Survey of India toposheet of 1969 and the shoreline demarcated through the satellite data of Landsat 5 TM 1993, IRS P2 1996, and IRS 1C 2002 were kept in different coverage in the same projection and map coordinates. These four coverages were overlaid through Arc info GIS. Shoreline change map of 1969 to 1993, 1993 to 1996 and 1996 to 2002 were generated. The resolution differs for different satellite data products. For LANDSAT 5 TM, IRS P2 and IRS 1C resolutions were 30m, 73.5m and 23.5m respectively. Though there is resolution difference, edge detection technique gives a clear demarcation of land and water boundary. The shoreline features were brought to Arcview GIS for further querying and analysis.

Wave pattern recognition

Remote Sensing is becoming a major tool in identifying the coastal processes spatially. Infrared band gives the maximum information on ocean parameters, so band 3 of IRS P2 1996, band 2 of IRS 1C of 2001 and band 2 of IRS 1C 2002 were used for the identification of wave patterns. Noise reduction technique is applied to the IRS P2 May 1996, IRS 1C May 2001 and IRS 1C May 2002 data for enhancing the image. Convolution filtering technique with 3*3 kernel edge detect is applied to IRS P2 May 1996, IRS 1C May 2001 and IRS 1C May 2002 for enhancing the wave characteristics for interpretation.

Coastal bathymetry

For coastal bathymetry studies Naval Hydrographic Organisation (NHO) chart 1999 is interpolated, interpreted and analysed using Arcinfo and Arcview GIS. The NHO chart number is 2075, scale is 1:50000 and the density of spot soundings is 4 per sq.km. This chart was surveyed in 1975-1976, in transverse mercator projection, updated in 1999 and the tidal levels referred to datum of soundings is Lat 8° 48' and Long 78° 10' and the heights in meters above datum is MHWS 1.0, MHWN 0.7, MLWN 05, MLWS 03 and MSL 0.6 respectively. TIN interpolation technique is adopted for spatial interpolation and DEM generation. Zero is defined as datum or the reference to which the depth is measured. Representation of the seabed in this model is in the form of elevation matrix formed by overlaying a square grid mesh over the surface and recording the elevation value for each grid cell. The cell values are organized in matrix form where the row and column numbers imply the x-y co-ordinate of the cell respectively. The elevation matrix is produced by interpolation from irregularly spaced bathymetric data points over a contour map. The three dimensional view and the slope of bathymetry is derived by applying TIN spatial analysis model using Arc View 3.2a software.

Results and discussion

Coastal geomorphology

Sandy beach

Sandy beaches are the product of waves interacting with a sandy beach at the shoreline. The sandy beaches are extensively developed along the entire coast of study area except at some places. Tuticorin is covered by long and extensive sandy beach. It trends in north-south direction. Well developed sandy beach is identified below south harbour breakwater. This beach is dominated by an admixture of quartz, feldspars and mica minerals. The beach is found as thick white patch at south of south harbour breakwater in satellite imagery (fig.2).

Spits

A spit is a small point of low tongue or narrow bankment, commonly consisting of sand or gravel deposited by a long-shore drifting and having one end attached to the mainland and other terminating in the open sea. It is identified in white patch in satellite imagery (fig.2). Two spit formations have been observed in south of the urban coast. Normally the formation of spit has been attributed to the movement and deposition of materials by long shore current (Thornbury 1969). Spit indicates seaward progradation (Loveson and Rajamanickam 1987). The spit near Tuticorin is 0.75 to 2 km long and tongue shaped. Tuticorin spit has resulted by long shore currents during monsoon and the sediments discharged by Tamiraparani River.

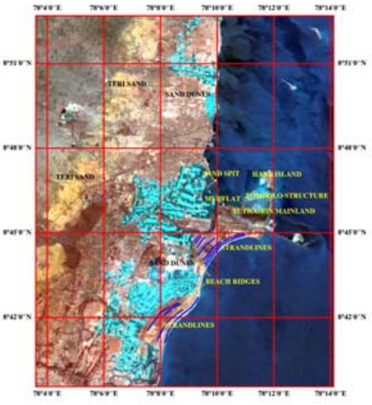

Figure 2. Geomorphology map using IRS 1C LISS III 2002 satellite imagery

Beach ridges

Beach ridges are moderately undulating terrain features of marine depositional type, formed during pliestocene to recent age, in the plains of the study area. They are low, essentially continuous beach or beach dune materials (sand, gravel and shingle) heaped up by the action of wave and currents on the backshore of a beach beyond the present limit of storm waves or the reach of ordinary tides, and occurring as a single or as one of a series of approximately parallel deposits (Chockalingam 1993). The beach ridges have been recognized as representing successive still-stand position of sea of an advancing shoreline from satellite imagery (fig.2). Beach ridges of Tuticorin are highly reworked.

Mudflat

Mudflat is a flat area containing a fluid to plastic mixture of finely derived particles of solid material mainly silt and clay water. They are always associated with silted environments like lagoons, estuaries and other embankments. Mudflats are formed by the deposition of fine inorganic material and organic debris in particulate form. Mud flats are wide expense of deposit of clay, silt, ooze, etc (Davies 1972). Mudflats are well developed at the river mouth of Koramballam Oodai, an estuarine environment. They appear as dark black tone in satellite imagery (fig.2).

Dune complex

Dune complex is an important geomorphic unit comprising of active and loose sediment heaps with negligible amount of vegetation. In this zone, the aeolian activity is reportedly high resulting in migration without a major change in their shapes. It indicates the age of late Pliestocene to Recent (Loveson 1993). Tuticorin is situated in dune complex (fig.2).

Teri dune complex

Teri dune complex is an undulating terrain having loose heaps of red color sand and silt dust of aeolian origin. They represent Pliestocene to Recent age of formation (Loveson 1993; Loveson et. al. 1990). They appeared as round to oval shaped mounts with dense vegetation. It is assumed that the fierce and continuous winds of south west monsoon by sweeping up vast clouds of dust from the dry surface of the red loam, exposed at the base of the hills must have brought and deposited their load of sediments near the coast over the plain to form Teri dune complex (Ahmad 1972). All dune complexes in this area are trending in the northeast to southeast direction. In recent years, these Teri dune complexes are being utilized for cultivation also. It is identified in greenish yellow color in satellite imagery (fig.2).

Shoreline change

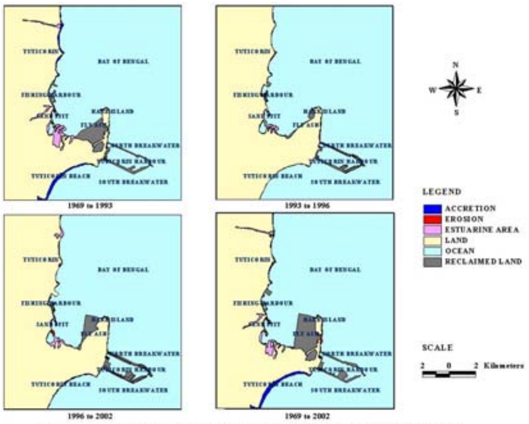

Figure 3. Erosion and Accretion observed in Tuticorin using SOI (1969), Landsat 5 TM 1993, IRS P2 1996 & IRS 1C 2002 Satellite imageries.

Shoreline is one of the important dynamic coastal features where the land, air and sea meet. In any open coast, when manmade structures such as harbour or breakwaters interfere with the littoral currents shoreline changes drastically. Chauhan and Nayak (1995) have studied the shoreline changes using the satellite data covering low tide period. During the low tide condition, maximum land is exposed and even low water line / land water boundary and high water line are distinctly visible. This enables better mapping of the shoreline. The demarcation and the areal extent of the sites of erosion and accretion are queried and estimated through Arc View GIS package (fig. 3). The total areas of erosion during the periods 1969 to 1993, 1993 to 1996 and 1996 to 2002 are given in table 1. It was observed that during 1969 to 1993 the erosion along the coastline of Tuticorin area was 9 ha. During the period of 1993 to 1996 it was 14 ha and in the period 1996 to 2002 it was 18 ha. Most of the erosion was observed in sand spit, Hare Island and at urban coast (fig. 3). The total areas of accretion during the periods 1969 to 1993, 1993 to 1996 and 1996 to 2002 are given in table 2. The accretion during the different periods were 138 ha (1969 to 1993), 18 ha (1993 to 1996) and 23 ha (1996 to 2002) (fig. 3). Since accretion was more than the erosion, the entire shoreline could be considered as the shore of progradation. Rajamanickam (1991) observed the features of emergence and submergence respectively along the southern parts of Tamilnadu. He also suggested upwarping along Tuticorin area.

For analyzing the shoreline change in the study area, specific sites such as south harbour breakwater, Hare Island, sand spit and urban coast were studied for erosion and accretion. Urban coast is the coastline of the urban area. It is demarcated and shown in the figure 3. The areal extent of erosion and accretion observed in the abovesaid areas are presented in Table 3 and 4. Both erosion and accretion factors were avoided in estuarine environment since demarcation of shoreline is not accurately possible in estuarine environment because this area is highly dynamic.

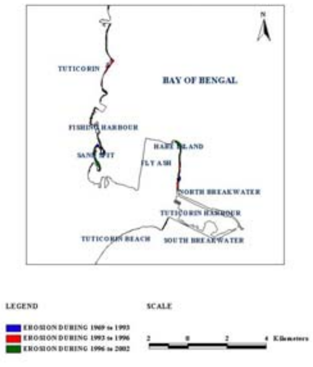

Figure 4. Erosion in Tuticorin using SOI (1969), LANDSAT 5 TM (1993), IRS P2 (1996) and IRS 1C LISS III (2003) satellite imageries

In sand spit (fig. 4 & 5), during 1969 to 1993 erosion was 4 ha and the accretion was 7 ha, during 1993 to 1996 erosion was 4 ha and accretion was 3 ha and during 1996 to 2002 erosion was 5 ha. and accretion was 2 ha (Table 3 & 4). In sand spit the erosion is noticed at wave exposed side and accretion is noticed at leeward side of the spit. This may be due to the transport of eroded sediments from the wave exposed side to the leeward side of the spit.

Tombalo structure formation is noticed in between Tuticorin mainland and Hare Island (fig. 2). This is due to longshore sedimentation from south to north resulting in the Hare Island and the mainland to link. It took geological years to link the mainland and Hare Island. In Hare Island (fig. 4 & 5), during the period of 1969 to 1993 erosion was 4 ha, during 1993 to 1996 erosion was 6 ha and during 1996 to 2002 erosion was 6 ha (Table 3). There is no accretion activity observed in Hare Island.

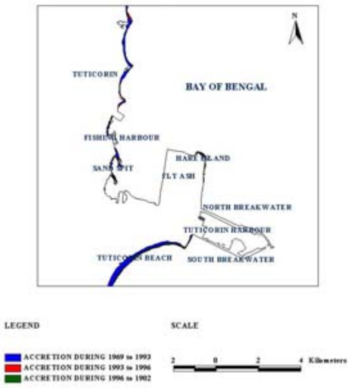

Figure 5. Accretion in Tuticorin using SOI (1969), Landsat 5 TM (1993), IRS P2 (1996) and IRS 1C LISS III (2003) satellite imageries

In South harbour breakwater (fig. 4 & 5), during the period of 1969 to 1993 accretion was 81 ha, during 1993 to 1996 accretion was 8 ha and during 1996 to 2002 accretion was 18 ha. There is no erosion observed (Table 4). The accretion here takes place in curvilinear manner. Accretion in curvilinear manner along the shoreline results in a formation of beach and similar paleo beach ridges were noticed besides the beach. The curvilinear formation of this paleo beach ridges is termed geomorphologically as strandlines.

At urban coast (Fig. 4 & 5), erosion was 1 ha and accretion was 15 ha during 1969 to 1993, erosion was 3 ha and accretion was 6 ha from 1993 to 1996, and the erosion was 3 ha and accretion was 3 ha for the period 1996 to 2002. The observation shows that the erosion is lower and accretion is higher in this site (Table 3 & 4). It is also observed that there is not much shoreline change in the urban environment. Loveson and Rajamanickam (1987 and 1988a) and Loveson et al (1990) have also reported the changes in shoreline of south Indian coast based on deposition of landforms like beach ridges, occurrence of backwater zone etc., through remote sensing based geomorphological interpretation. Loveson and Rajamanickam (1988b) have also pointed out the possible fall of sea level in Tuticorin coast due to neotectonic emerging of the seafloor. The prevailing winds noticed at Tuticorin area were maximum at North West, North East and North directions respectively. Prevailing winds were also noticed at South West, South and South East directions but the majority of the months experience NW, NE and N winds only. The wind speed ranges from 9-16 km/hr.

Table 1: Erosion observed at Tuticorin coast during 1969, 1993, 1996 and 2002

Year	Erosion
1969-1993	9 ha.
1993-1996	14 ha.
1996-2002	18 ha.

Table 2: Accretion observed at Tuticorin coast during 1969, 1993, 1996 and 2002

Year	Accretion
1969-1993	138 ha.
1993-1996	18 ha.
1996-2002	24 ha.

Table 3: Erosion observed at specific sites in Tuticorin coast during 1969, 1993, 1996 and 2002

Year	Spit	Hare Island	Urban Coast
1969-1993	4 ha.	4 ha.	1 ha.
1993-1996	4 ha.	6 ha.	3 ha.
1996-2002	5 ha.	6 ha.	3 ha.
1969-2002	13 ha.	16 ha.	7 ha.

Table 4: Accretion observed at specific sites in Tuticorin coast during 1969, 1993, 1996 and 2002

Year	Spit	Below South harbour breakwater	Urban Coast
1969-1993	7 ha.	81 ha.	15 ha.
1993-1996	3 ha.	8 ha.	6 ha.
1996-2002	2 ha.	18 ha.	3 ha.
1969-2002	12 ha.	107 ha.	24 ha.

Wave pattern

Depending on the wave pattern, which was present in imagery, various features such as refracted waves, diffracted waves and shadow zone were identified. These features play a major role in shaping the shoreline, which also depends on the geographic features that exist along the coast.

Wave refraction

In the study area wave refraction is observed in the tip of the northern harbour breakwater. Wave propagation and its refraction pattern is clearly identified in IRS P2 May 1996 and IRS 1C LISS III May 2001 and IRS 1C LISS III May 2002 satellite imageries (fig. 6, 7 & 8). The linear progressive wave from the offshore area is almost progressing with an angle of 115° with respect to the mainland. The angularity of the wave propagation is measured through Arc View GIS 3.2 software. They propagate in SW to NE, towards mainland. The north breakwater is exactly perpendicular (90°) to the direction of the wave (fig. 6, 7 & 8). When the wave touches the north breakwater the wave breaks running along the breakwater. The refracted wave passes along with harbour breakwater, almost two kilometers in distance and dissipates its energy (fig. 6, 7 & 8). In the south break water a shoal is present and this shoal hinders the refracted waves and dissipates its energy. This refracted wave doesn't cause any coastal geomorphic change to the headland because it doesn't touch it.

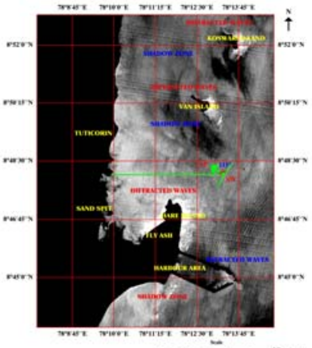

Figure 6. Coastal wave action map using IRS P2 LISS II 1996 satellite imagery

Wave diffraction

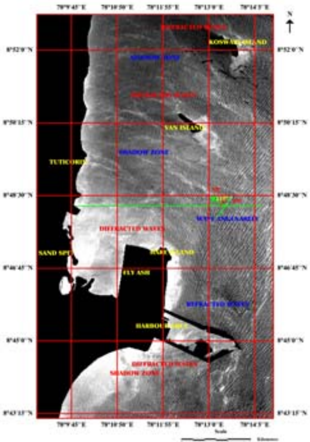

Figure 7. Coastal wave action map using IRS 1C LISS III satellite imagery

Diffraction of water waves is a process by which energy flow laterally along wave crest. Most obvious example is when waves are intercepted by an impervious structure such as breakwater. Presence of an obstruction scatters wave disturbance and give rise to fanning of wave trains on the lee or shadow of the obstruction. Diffraction is a common phenomenon around islands and can create substantial disturbance to the coastal region which adds further to the dynamic nature of the coast. IRS P2 May 1996, IRS LISS III 2001 and IRS LISS III 2002 data gives a clear representation of diffracted waves in the study area. Diffraction of wave is observed in the Vann Island and as well as the Hare Island. Since these islands were the major source of obstruction for the ocean waves, they give rise to fanning of wave trains (fig. 6, 7 & 8). Wave diffracts around with face of Hare Island and dissipates energy. Change in shoreline is clearly shown in fig. 3. The erosion that has been identified in sand spit and Hare Island are only due to wave diffraction. This is interpreted through IRS P2 1996, IRS 1C 2001 and IRS 1C 2002 coastal processes study and 1969 to 2002 shoreline change study. Erosion / accretion problem in the study area is not due to harbour location and its activity. Accretion observed at the leeward side of sand spit is due to this diffraction (Fig. 5). The deposition of sediments is also due to the convergence of the diffracted wave in the windward side of the sand spit.

Shadow zone

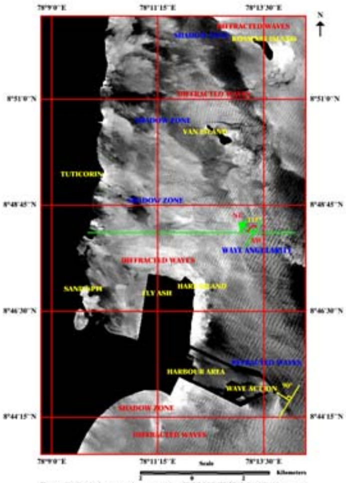

Figure 8. Coastal wave action map using IRS LISS III 2002 Satellite imagery

When two waves converge with one another, the energy at the place of convergence becomes negligible and the waves become calm. The point at which the two waves get converged is known as point of convergence and the area at which this phenomena occurs is known as the shadow zone. Shadow zone is very well identified from IRS P2 1996, IRS 1C LISS III 2001 and IRS 1C LISS III 2002 imageries. In the study area the shadow zone is observed in between Hare island and Vann island and also below the south harbour breakwater. When the diffracted wave from both the Hare Island and Vann Island converges, shadow zone is formed. The point of convergence and the shadow zone is clearly shown in the figure 6. The same phenomenon was observed below the southern breakwater. Here when the linear progressive wave touches the south of harbour breakwater the wave breaks. Since the hinterland is curvilinear the waves from the south breakwater’s mainland converges with the linear progressive waves and forms a shadow zone (fig. 6, 7 & 8). There is not much problem because of this shadow zone formation in the study area.

Bathymetry

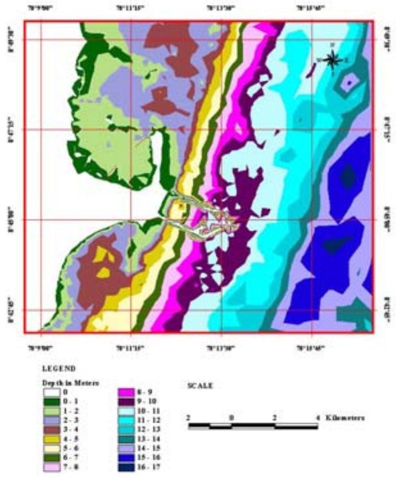

Figure 9. Bathymetry map of Tuticorin area using NHO chart 1999

Monitoring of coastal bathymetry is vital for designing of ports and coastal structures. It is also important for the exploration and exploitation of non-living and living resources, to understand the dynamics of ocean processes in the continental shelves, for ship mooring and assessment of marine living habitats. In a GIS, the modeling of the Z-axis has become an important element. When the 3-D model is specifically applied to represent terrain, then this digital representation of the elevation is termed as a Digital Elevation Model (DEM). The 3D Tuticorin Bathymetry Elevation Model derived from Naval Hydrographic Chart is shown in figure 9. The slope analysis of Tuticorin port and its environment inferred from the 3-dimensional bathymetry model reveals that the slope is gradually declining in the direction of NW to SE. Gentle slope (1 - 4 °) is observed adjacent to the urban coast as well as above and below the harbour area (fig. 9). Attenuation of waves is more when it reaches the nearshore area and where the depth is minimum and the different wave patterns observed because of this attenuation is clearly seen using satellite remote sensing (fig. 8).

Waves observed from the satellite imagery and shoreline change were integrated and the effect of wave over the erosion / accretion site gives the reason for the site to be eroding or accreting. Moreover bathymetry also supports this. The analysis of wave action from 1996 – 2002 provides the information that the wave action is similar from the geologic past. Moreover the study area has also specific pattern of accretion as observed through strandlines present in south of Tuticorin harbour. So this wave data gives a clear idea about the shoreline change in the present study. From the vicinity of the harbour, in the direction of NW to SE, steep slopes were observed further offshore (fig. 9). The net sediment transport is from south to north. Delta sedimentation is also observed near Koramballam Odai and this river mouth is sheltered with depth value less than 2m. This is very well identified through satellite imagery. Sediment transport and the slope variations inferred from the urban coastal and harbour environment clearly show that the chances are less for sediments to enter into harbour breakwater (fig. 9). Hence not much dredging activity is required in Tuticorin harbour area.

Conclusion

The coastal processes in Tuticorin coastal area, the shoreline change, wave action, bathymetry and coastal geomorphology were analysed using Remote Sensing and GIS tools. The erosion and accretion observed at Tuticorin using temporal satellite imageries show that the shoreline dynamics is natural and this is not due to human interference. Coastal processes play a major role in shaping the coastal configuration of this area. The integrative approach using Remote Sensing and GIS tools clearly illustrates both the cause and reasons for the shoreline change. The results of this study will be more useful for shoreline management.

ACKNOWLEDGEMENT

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