Mapping the coastal geomorphological landforms through Aster DEM and Landsat data – a case study from Tuticorin-Vembar coastal stretch, southeast coast of India

N.S. Magesh*, N. Chandrasekar, S. Kaliraj
Centre for Geotechnology, Manonmaniam Sundaranar University, Tirunelveli, Tamil Nadu 627 012, India

ABSTRACT

The present study highlights the importance of digital elevation model and satellite imageries for mapping the coastal geomorphological landforms in Tuticorin-Vembar coastal stretch, southeast coast of India. Aster DEM 30 meter resolution data and Landsat 2006 image (30 meter resolution) of the study area were overlaid together with 30 and 70 percent transparency ratio respectively in ArcGIS platform. Further, a hillshade layer derived from Aster DEM has been included to visualize the surface morphology of the study area. Visual interpretation technique was used for identifying the various coastal geomorphological landforms in the study area. The results were cross validated through a GPS based field check. Based on the analysis, we have found that the study area has a wide variety of geomorphological landforms such as beach ridges, alluvial plains, deltaic plains, channel deposits, sand dunes, linear ridges, mud flats, plain lands, salt marsh, sand sheets, sand bars, beaches and backwater channels. The dominant landform features like the beach ridges and alluvial plains are found near to Vembar and Vaippar river systems. Salt pans are other dominant features, which have been evolved from scraping the mud flats and salt marsh lands by human induced activities. The concept used in this paper provides a cost effective and time saving technique for mapping the coastal geomorphological landforms at a resolution of 30 meters. However, micro scale mapping at 1-meter resolution using LiDAR datasets needs to be explored in future.

1. Introduction

The study of coastal landforms is one of the fascinating areas of geomorphological research and it is indispensable for understanding the morphology at all dimensions. The study is important as the tides, waves and currents provide energy, which is working constantly to alter the landforms in short span of time. The coastal processes of erosion, deposition, sediment transport, flooding and sea level changes are incessantly modifying the shoreline configuration. Depending upon the interactive processes the morphology undergoes change and problems for developmental activities. The study of coastal landforms bestows intimation to the processes operating in an area. Therefore, it is imperative to understand the coastal landforms and allied features.

The coastal zones are often influenced by terrestrial and marine components, thus forming unique landforms and ecosystems. These components include coastal plains, river deltas, wetlands, beaches and dunes, reefs, mangrove forest, and lagoons. Coastal landforms are controlled by physical, chemical and biological factors and they continuously modify the geomorphology of the area.

The coastal landform features such as coastal dunes, mangrove, salt marshes and wetlands are not only act as a resource producers but also safeguarding the environment of the coastal zones. Application of remote sensing and Geographical Information System (GIS) is found to be useful for mapping the morphology of earth surface (Verstappen 1977; Smith et al. 2006). Moreover, land surface delineation and interpretation of various features from satellite data are well documented for effective management of natural resources (Servenay and Prat 2003; Sallun Filho and Karmann 2007).

Researchers around the world have used Digital Elevation Models (DEMs) and satellite imagery for detecting geomorphological and associated landforms (Bolch et al. 2005; Bubenzer and Bolten 2008; Demirkesen 2008). Integration of remote sensing data and DEM has been extensively studied by various researchers. They require systematic hierarchical approaches for delineating landforms at different scales and sizes (Hung et al. 2002; Bolten and Bubenzer 2006; Mesev and Walrath 2007).

The coastal geomorphology between Tuticorin and Vembar is known for its distinct geomorphological features. However, mapping such morphological features require intense field visit and data processing. Such kind of mapping is possible by integrating satellite imageries and DEM. So far such concept has not been applied in the coastal stretch of southern Tamil Nadu. Therefore, the objective of the paper is to map the coastal geomorphological landforms using integrated Aster DEM and Landsat imagery.
2. Study area

The present study area is located in the southeastern coastal tract of southern Tamil Nadu (Fig. 1). The coastal stretch extends from Tuticorin to Vembar (78°10′ E and 8°47′ N to 78°22′ E and 9°04′ N) with distance of about 40 km in length. This coastal stretch is classified as sandy beach with a beach width ranges from 20 to 40 meters from berm to low tide line. Between Tuticorin and Sippikulam, the beach is flat and narrow. Islands such as Vaan Tivu, Kaasuvar Tivu, Karaichalli Tivu are present within 5 km distance from the coastline and offer protection from wave action and erosion. The backshores of this coastal segment comprises of saltpans. The Vaippar river joins Gulf of Mannar near Sippikulam. The coastal segment between Sippikulam and Vembar is open without any offshore islands or submerged coral banks and is exposed to direct wave action. The backshore of Kallar, Veppalodai and Tuticorin segment largely consists of saltpans. Dune complexes of medium to fine sand with heavy minerals are present in Vembar and Tuticorin areas. The study area experiences humid tropical climate with the temperature ranges from 25 to 40° C and the relative humidity lies between 52 to 80%. The average annual rainfall in the study area has 662.2 mm. The general coastline configuration is governed by the influence of northeast and southwest trade winds. Apart from that, the coast is controlled by various coastal processes like long-shore current, littoral drift, and wave height.

3. Methodology

3.1. DEM processing

The coastal landforms in the study area have been extracted using ASTER DEM and Landsat image (2006) of 30 m resolution. The raw DEM data has been rectified and then projected to WGS 1984 UTM Zone 44N coordinate system. The projected DEM is processed by a fill tool in ArcGIS 10, which removes the errors such as sinks and eliminates discontinuities. The filled DEM is further used for creating a hill-shade layer. This layer will highlight the overall surface landforms in the study area. A 30% hill-shade and 70% landsat layer was merged together to get the final landform map. A ground truth survey was also carried out to confirm the geomorphological features in the study area.

3.2. Image processing and classification

The coastal geomorphology between Tuticorin and Vembar has been prepared based on visual as well as digital interpretation of landsat false colour composite (FCC). An unsupervised classification was performed on the Landsat image for estimating the geomorphological features in the study area. The multispectral data was registered to the universal Transverse Mercator (UTM) map projection-zone 43 and scaled to planetary reflectance. The Landsat data was processed into a six channel data stack of the visible, near infrared, and shortwave infrared reflectance bands. Erdas imagine software was used to compute each geomorphic features of the study area. Extensive ground survey has been made on field parameters such as topography, relief, surface cover, soil and vegetation. The coastal geomorphological classification system developed by Nayak et al. (1996) is used for the present study. They include image elements like tone, texture, shape, size and association (Table 1).

4. Results and discussion

The study area comprises of sandy beaches, which is frequently observed in Vembar, Vaippar and Tuticorin coastal areas. The beach width ranges from 20 to 40 m and normally gentle (Fig. 2). A well
developed beach ridge system is observed in Vembar, Vaippar and Tuticorin. They are found to be discontinuous at varying length and width. The beach ridges are found to be distributed few kilometers away from the Tuticorin coastline. Wave cut platform is present in Kalaiganapuram area which reveals high energy condition. Backwater zones are extensively present in Vembar to Kalaiganapuram area. Mudflat is present in and around Kallar River, whereas tidal flat is present near Veppalodai. The backshore of Kallar, Veppalodai and Tuticorin segment largely consist of salt pans. Dune complexes of medium to fine sand with heavy minerals are present between Vembar and Tuticorin area (Chandrasekar et al. 2003). This dune patterns are developed by the vigorous aeolian processes resulting in the migration of dunes with frequent changes in their shape and pattern from time to time, but generally they trends almost parallel to the coastline. The sand sheet in the coastal zone extending from Vembar to Kalaiganapuram and Taruvaikulam is implanted with rich black sand deposits. On the either side of Vaippar river and western side of Vembar river, deltaic plains were noticed. Bar deposits are identified on the Vaippar river mouth. These bars are experiencing changes in direction and shape due to littoral drift and tidal actions. The distributions of salt marsh are identified at Kallar and Tuticorin coastal sector. Few islands are observed in the study area. They are all few meters above the mean sea level and have a smooth outline with sparse vegetation and fringed with coral reefs. Based on the visual interpretation of integrated DEM and Landsat image of the study area reveals that the southern strait beaches with rocky exposure lying between Kallar to Vaippar river occupies around 0.42 km². However sandy beaches lying between Vaippar to Vembar has around 0.87 km². The coastal stretch has a gentle beach slope with marked crusts and troughs which are formed due to wave action. The beach between Kallar and Vaippar river mouth is highly indented due to the presence of rivers and creeks. The prominent sand flat is seen adjacent to the beaches in the study area which clearly indicates the growth pattern of beach. They are often found parallel to the coastline and it appears to be white to yellow tone in the image. The sand sheets are noticed near Sippikulam and they reflect in dull white tone with smooth texture. Well-developed marine terraces is noticed in the inland region of Kallar area with three steps like arrangement the entire formation is made up of beach rocks of marine calcareous sandstone. The compactness of such terraces varies from stage to stage and weathered calcareous sandstone forms the top two terraces followed by compact calcareous sandstone. The mudflat areas are seen near Kallar, Vaippar and Vembar rivers and they are classified on the basis of their relation with high tidal, sub-tidal, and inter-tidal zones. The high tide mudflat occupied in Tulukankulam and Vembar covers a vast area. These mudflats are covered with salt pan and vegetation which appears to be blackish blue tone with smooth texture. However, these mudflats are being reclaimed and converted into salt pan for salt production. The intertidal mudflats are noticed near Vaippar river mouth and are associated with salt marshes and grasses. The sub-tidal mudflat has been noticed at Kallar river mouth which covers an area of about 0.13 km². The water bodies in the study area include both stagnated as well as regular flowing water. It is represented by light blue to very dark blue tone depending on the depth, and its volume. They include creek, tanks, swale, river and shoals. The coastline of the study area is characterized by numerous creeks which are responsible for water logging of vast area throughout the year. The movement of the littoral currents along the coast is found to modify the mouth of swales at Periasamipuram. A prominent swale system is observed in the coastal plain between Periasamipuram and Vembar river mouth. The swale is almost parallel to the coastline with a width of around 1.5 km. Swales of linear depressions with clay and silty clay deposits are commonly noticed between the beach ridges. A longer and wider swale system divides the coastal region of Sippikulam and they are often used for salt production and also for land reclamation. Moreover, the backwaters are connected by small, linear and narrow swales to the sea by means of few creeks. The movement of littoral currents is responsible for the growth of shoals near the mouth of Vaippar and Vembar river. The movement of littoral currents dumps the sediment in front of river mouth which forms complex sandbars. The beach ridges are good indicators of regressive environment, and in the study area it is called as older coastal plains. They show bright yellow tone with rough texture and linear-curved linear pattern. On the basis of the nature of deposition, the beach ridges can be grouped into two zones namely Kalathur-Vaippar and Melmandai-Surankudi. The beach ridges are having moderately undulating terrain features of marine depositional type, formed during Pleistocene to recent age. The coastal plain between Vembar and Vaippar is marked by the

<table>
<thead>
<tr>
<th>Category</th>
<th>Tone</th>
<th>Shape</th>
<th>Texture</th>
<th>Location</th>
<th>Association</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy beach</td>
<td>White to grey, blue</td>
<td>Linear, crescent</td>
<td>Smooth</td>
<td>Adjacent to coast</td>
<td>Open coast</td>
<td>Made up of sand particles or corals</td>
</tr>
<tr>
<td>Sand flat</td>
<td>White to yellow</td>
<td>Regular to irregular</td>
<td>Medium</td>
<td>Mean high water line to</td>
<td>Beach</td>
<td>Coastal beach dunes</td>
</tr>
<tr>
<td>Sand sheet</td>
<td>Dull white</td>
<td>Irregular</td>
<td>Smooth</td>
<td>Adjacent to coast line</td>
<td>Beach</td>
<td>Tidal discontinuity</td>
</tr>
<tr>
<td>Mud flat</td>
<td>Blackish blue</td>
<td>Irregular</td>
<td>Smooth</td>
<td>In high tide, mid tide and low tide level</td>
<td>Low tidal influence</td>
<td>Made up of fine clay silt particles</td>
</tr>
<tr>
<td>Salt marsh</td>
<td>Dark brown</td>
<td>Irregular</td>
<td>Rough</td>
<td>Inter tidal area</td>
<td>Along with mud substrate</td>
<td>Usually occur in saline area</td>
</tr>
<tr>
<td>Water bodies</td>
<td>Blue</td>
<td>Meandering</td>
<td>Smooth</td>
<td>Inter tidal and supra tidal area</td>
<td>Mud flat</td>
<td>Interface between river and sea</td>
</tr>
<tr>
<td>Creek</td>
<td>Light blue to dark blue</td>
<td>Irregular</td>
<td>Smooth</td>
<td>Scatter all along the coastal plain</td>
<td>With land</td>
<td>-</td>
</tr>
<tr>
<td>Shoals</td>
<td>White</td>
<td>Varying, circular</td>
<td>Smooth</td>
<td>Near the beach on landward side</td>
<td>Aeolian environment</td>
<td>Depositional environment</td>
</tr>
<tr>
<td>Sand dune</td>
<td>Bright yellow</td>
<td>Linear, Curvilinear</td>
<td>Rough</td>
<td>Parallel to coast</td>
<td>Older coastal plain</td>
<td>Indicator of regressive environment of the sea</td>
</tr>
<tr>
<td>Salt pan</td>
<td>White/light blue</td>
<td>Rectangular/square</td>
<td>Smooth</td>
<td>Mud flats</td>
<td>On the land</td>
<td>Dry salt pans associated with water</td>
</tr>
</tbody>
</table>

Table 1. Image interpretation key for coastal geomorphology mapping
presence of well-developed massive beach ridges with less vegetation and more calcareous matter. Well-developed sand dunes are mapped along the coast of Kallar to Sippikulam. The width of sand dunes varies from 3 to 10 m. While majority of them are transverse in nature, few of them are barchans. The coastal sand dunes have vegetative cover consisting of casuarina, Palmyra and Prosopis as dominant vegetation. Near Pachayapuram, the sand dunes are being disturbed by mining activities. In the coastal plains between south of Vembar and Vaippar rivers, patches of teri dune complex have been observed with a thick cover of vegetation. They are elongated in nature with circular to ovoid shape and are trending in the north-east to south-east direction. A number of salt pans are mapped along the Tuticorin and Vembar coast. Among them, extensive area is covered with salt pan near Veppalodai, and Periyasamipuram. The active salt pan is appeared to be of shallow depressions with water and the dry salt pans appear to be in bright white tone. These geomorphological features make the study area a unique zone for potential placer mineral deposition.

5. Conclusions

The use of remote sensing and GIS provided a complete geomorphological characterization of the study area. It allowed us to map difficult geomorphological features assisted with field check. Several environmental conditions such as vegetation cover, anthropogenic infrastructures, slopes and other morphological constraints affect the morphological landforms in the study area. The micro level classification of coastal landforms such as beaches, sand flat, sand sheet, sandbars etc. are possible with the help of geospatial technology. However, the validation of the results has to be interpreted using relevant ground truth data. The earlier studies in this region are undertaken using low resolution satellite imageries with poor interpretation techniques. With the help of integrated DEM and Landsat imagery has provided a detailed description of the coastal landforms along Tuticorin-Vembar coast.

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