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Detection of Coastline Change in Koddiyar Bay of Trincomalee District using Remotely Sensed Imageries and GIS Technology

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Abstract
Extraction of the coastline and the coastline change detection analysis are important tasks that have application in different fields such as coastal planning, disaster management, environmental management and modelling of coastal morphological changes. The development of remote sensing and GIS technologies are nowadays proved to be the most powerful and reliable tools for identifying coastline changes and mapping. The objectives of this study include to analyze the temporal and spatial change in coastline and to assess the localized trend of the variation in degree of erosion and accretion along the coastline by using multi-temporal satellite image data integrated with GIS in the Koddiyar Bay. In this study, topographical map for the period of 1975 and the Landsat Imageries for the years of 1999 and 2017 were utilized for coastline detection and erosion and accretion estimation at 22 random cross sections within six spatial zones of the study area. The coastline under Koddiyar Bay showed a continuously changing pattern over the period of time, from 1975 to 2017. However, spatial-temporal variation in each zone of coastline was observed. Overall non-uniform change pattern was observed in coastlines. Among six different zones in three zones, including zones three, four and six observed maximum coastal line changes. This change can be associated with natural and the anthropogenic activities in the coastal line areas. The results of this study can be used by different stakeholders to manage the coasts effectively and sustainably.

***Keywords**: Koddiyar Bay, coastline, remote sensing, GIS, erosion and accretion*

Introduction

About 70 percent of the world's population lives in the coastal zone. It is the most densely inhabited and industrialized part of almost every coastal country and contributes therefore significantly to the financial well-being of the people living in it. The concentration of people along the coast also creates pressure on coastal resources. The coastal zones are presently experiencing degradation in the form of surface and groundwater pollution, such as salt water intrusion, but also coastal flooding, erosion & accretion, land subsidence as impact from land-based settlements and mining activities. The challenge for coastal zone is to use the abundant but depleting coastal environment resources wisely, so that economic development can be achieved without destroying the resource base on which it is founded.

Most processes in the coastal zone are related to climate, ground water movement, tidal and marine action, long shore current, littoral cell circulation, ridge and runnel system, rip currents and Biogenic activities which determine their intensities and direction. The processes give rise to feedback mechanisms, that either counter-balance or re-in force their impact. Those acting on the land itself include weathering, mass movement and fluvial action. These processes not only alter the land surface but are the most effective means of transferring material from land to sea. Consequently, these processes play a significant role in varying the coast and coastline changes. The change in the coastline has large environmental importance. Coastline change is the direct result of coastal erosion. A large scale reduction or increase in the sediment supply, in a short period of time or a long period, creates a deficit/surplus in the sediment budget which causes coastline change[1].

The processes at sea include waves, currents and tides. Of these processes, waves are more important. When wind blows across water, there is a transfer of energy from the former to latter and the interface is thrown into waves. Waves may break progressively, expanding their energy over wide near shore tract. Such spilling waves are usually associated with sandy sea floors of gentle gradient. Where gradient are steeper, waves may plunge upon the sea floor and lose their form more or less instantly. Coastal erosion and accretion can become a risk to coastal infrastructure or other types of land uses. The combined effect of wind-generated waves, tidal waves and currents from rivers, produce a highly variable and complex near-shore hydro-dynamic system. By the movements of sediment on the sea floor and onshore and offshore the shaping of the coastline is taking place in a dynamic system in a continuous process. During the rough season, waves are higher, shorter and break closer to the shore than otherwise. This results in a strong swash or water movement up the beach face, a built up of water onshore, and a vigorous backwash and general undertow along the entire front. There is sand loss from the beach and deposition occurs in deep water offshore.

Coastline is the transitional line between land and sea. It is considered to be one of the most complexes, dynamic and sensitive geomorphic unit that need to be under constant observation to follow and monitor the continuous changes, occurring there[1]. Coastline is defined as the line of contact between land and the water body. It is one of the most important linear features on the earth's surface, which displays a dynamic nature. It could be regarded as the most unique feature on the earth's surface [2, 3, 4]. Coastline indicator could be identified by using coast morphological feature and non morphological features. Morphological features are those physical coastline such as berm crest, scrap edge, vegetation line, dune crest etc., while non morphological features are those related to water line as wetted boundary, wet-dry boundary, wet sand line, etc,[5,6,7].

Coastline change has become a topic of marvellous interest within the human dimensions of the Environmental change research scientists. Quantifying and understanding the extent and spatial distribution of coastline change is a crucial importance to the study of Environmental change at various scales. The coastline change detection analysis is an important task that has application in different fields such as coastal planning, disaster management, rate of erosion, environmental management and conceptual or predictive modelling of coastal morphological changes[1]. Availability of remotely sensed data made possible to study the changes in coastline in less time, at low cost and with better accuracy. Remote sensing technology and Geographic

Information System (GIS) provide efficient methods for analysis of coastline changes and visualize the results[8].

Coastline data was traditionally performed manually digitizing coastline from topographic maps, or interpreting and tracing coastline from aerial photographs. Recent technology allowed the automation of digitizing by using digital image processing methods [5]. Coastline change detection techniques approximately fall into four broad categories: (1) conventional ground surveying technique with high accuracy measurements; (2) modern altimetry technique uses radar or laser altimeters. It has great potential, but the measuring devices are not frequently available; (3) Aerial photographs provide sufficient pictorial information. But the frequency of data acquisition is low and the photogrammetric procedures including data acquisition and interpretation are expensive and time consuming; (4) multispectral satellite images provide a great advantage over the other available techniques to define the land/water boundary using the infrared parts of the spectrum[9,10]. Currently the most common methods in use are Geodetic survey and GPS with millimetre accuracy allowing high accuracy, but provide a survey for single points only. Remote sensing technique is increasingly competitive compared to the other methods mentioned, especially with reference to very high spatial resolution satellites. It allows a very speed data acquisition and processing with accuracies comparable. The ability to record the scene in multiple spectral bands is also important: it allows for much more information than the visible bands. The short revisiting time (a few days) also allow to carry out monitoring studies of the area under examination, by means of images acquired at different times. There are number of techniques that have been adopted to detect the coastline changes from the multi-spectral remote sensing images. Unsupervised classification and discriminate function change detection[8], cross section analysis[1], Band ratio methods[2,3,10,11], band combination methods[4], supervised classification and change matrix methods[12,13], vector overlay analysis[14], linear regression method [15], region growing image segmentation technique[16].

In this study topographical map and the multi temporal Landsat Imageries were utilized for coastline change detection at Koddiyar Bay of Trincomalee District over 42 years. Koddiyar Bay is one of the bays in Sri Lanka which is dynamic in nature due to the physical and anthropogenic factors. The localized trend of the variation in degree of erosion was estimated by dividing the coastal stretch in several erosion-prone regimes using remote sensing and GIS techniques.

Methods

Study Area

The present study was conducted to detect coastline changes in Koddiyar Bay of the Trincomalee District of Eastern Sri Lanka (figure 1). Koddiyar Bay is located in the south and south-eastern side and fairly regularly shaped, as well as enclosed and deep, forming a large natural harbour in the shores of the Indian Ocean. The bay is overlooked by terraced hills in the NW and its entrance is guarded by two headlands. Twenty kilo metre length of coast of the Koddiyar Bay was taken as study area which starts from Kinniya Bridge on the East to Sampoor cape on the east. The geographical coordinates of the study area start at the intersect of 81.183 decimal degree of East longitude and 8.508 decimal degree of north latitude and ends at the intersect of 81.281 decimal degree of East longitude and 8.508 decimal degree of north latitude. An average annual wind velocity of Koddiyar Bay is 4.5 (m/sec) which is the second highest in Sri Lanka, after Hambantota (5.5). Depth of the sea in the Koddiyar Bay is very high; Average depth of the sea with the half kilo meter from the coast is 10 fathoms. The Koddiyar bay coast covers by sand but north and south parts of the Koddiyar bay are covered by rock and the terrain behind the Koddiyar bay is alluvial plains. The coast of koddiyar bay are zones of interaction among processes related to tides and refracted waves entering the semi-circular bay and fluvial deposition. The mouths of three rivers, Uppu Aru, Mahaweli Ganga, Valavachar Aru, are found at Koddiyar Bay. Hence this bay has experiences of fluvial process.

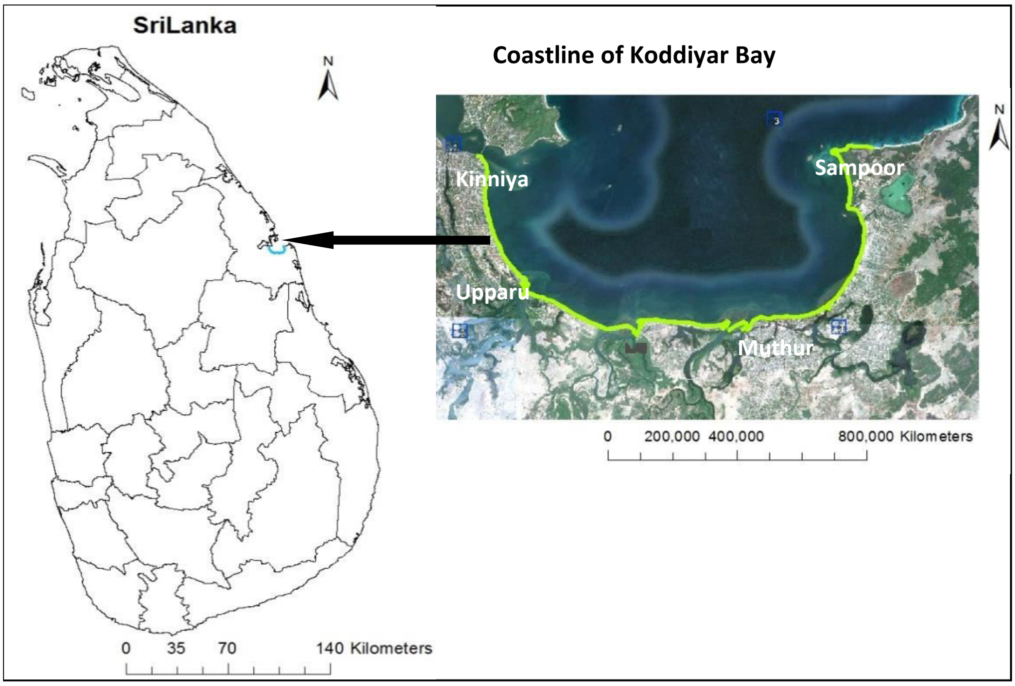

Figure 1: The Study area

Data Used

In this study, topographical map of Survey Department of Sri Lanka and Landsat satellite images between 1975 and 2015 were used to quantify the changes along the coastline of Koddiyar Bay. Topographical map of 1975, Landsat Thematic Mapper (TM) images from 11 September 1999 and Landsat Operational Land Imager (OLI) images from 09 April 2017 were used in the analyses. The images were downloaded freely from Global Land Cover Facility (GLCF) and United States Geological Survey (USGS) web pages. Path/ row of landsat images are 141/054 and those images present weak cloud coverage on the coastal area and a pixel resolution of 30 meters. These images were provided in a standard GeoTIFF format with a UTM projection, using the WGS-84 datum. Topographic map was scanned and geo-rectified using ground control points under the same projection and datum. Overall idea about the current and past nature of the coastal environment was gathered by the personal views of the community via community interviews

Image Processing

Image processing was carried out to calculate the Water Index using visible and infrared bands of the Landsat satellite. The Modified Normalized Difference Water Index (MNDWI) is one of the band ratios where the sum of visible bands are divided by the sum of the infrared bands and used to enhance the discrimination between land and water (Muhammad & Iqra, 2016; Ghosh et al, 2015). In fact, MNDWI was generated by combing the green and mid-inferred bands of the Landsat satellite. The green band is sensitive to water turbidity differences as well as sediment and pollution plumes because it covers the green reflectance peak from leaf surfaces. The mid- infrared band produces a strong contrast between land and water feathers due to the high degree of absorption by water and the strong reflectance by vegetation and natural features in the range. MNDWI was estimated as (Green-MIR)/(Green+MIR), where Green and MIR are the reflection in the green and mid-inferred bands of the TM and OLI images of 1999 and 2017. Threshold level slicing using a Boolean method was applied on the MNDWI images to distinct separate landmass from the water; the ratio is greater than one for water and less than one for land. The sharp edge between the two classes refers to the coastline (Fig. 2).

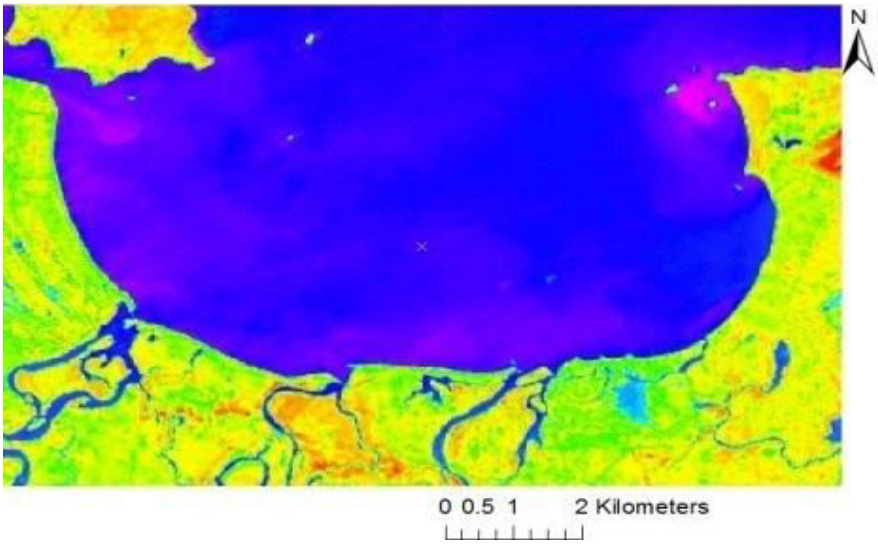

Figure 2: MNDWI Image, 1999

Change Detection

MNDWI images and topographical map were used to extract the coastlines in different periods using on-screen digitizing in the ArcGIS software and created coast line layers. Layers were overlaid together to detect the coastline position at each period. Coastline positions were highlighted to know the erosion/accretion sectors along the coast and changes were estimated. In order to highlight the local changes and spatial change pattern along coastline of Koddiyar Bay, six zones were created and named from one to six. Further 22 cross sections within the zones were taken arbitrarily, except in delta sites, almost at the 90 degree angle across all shorelines, digitized and amount of shift during certain time period was measured in different zones (Figure 3). It gives the spatial shift and erosion rate of shoreline in different zones over the time from the year 1975 to 2017. Average shift in meters was calculated and using duration of occurrence of change over the span of 42 years, erosion and accretion rate was calculated using following rate formula.

Rate of change meter /year = Average shift in zone / total time period

Results and Discussion

The results of this study correspond to one coastline vector map for each year (1975, 1999 and 2017) (Fig. 3). Measurements of the rate of change can be easily derived from these vector maps using standard GIS measurement tools. The coastline under Koddiyar Bay showed a continuously changing pattern over the period of time, from 1975 to 2017. Spatial-temporal variation in each zone of coastline was observed. Overall non-uniform change pattern was observed in coastline. The local change in the pattern of liner shift of the coastline was estimated by dividing the coastline stretch in several zones using the cross sections. In the time period from 1975 to 2017 minimum change was observed in Zone 5 (56.75 m) followed by zone 2 and 1. The maximum intrusion of water body into land was witnessed in Zone 4 (101.23 m) after that in zone 6, and zone 3 (Fig. 3). Temporal interval from 1975 to 1999 significant variability in coastline was noticed in the zone 4, that are located between deltas of Mahaweli Ganga and Valavachar Aru near Navaladi of Muttur. Considerable change was also detected in zones 6 and 3 near the Sampoor and Kinniya respectively (Fig. 4). During the temporal interval of 1999 to 2017, large variability in linear shift of coastline was detected in the zone 4. Apparently minor change was witnessed in other zones of shoreline as compared to zone 4 (Fig. 4). The changing trend of coastline showed the continued degradation and intrusion of sea into land except zones five and six where accretion was occurred because of relatively shallow sea depth and influences of wind and waves are minimum compared to the other zones. These two zones are not in direct contact with open sea. The eroded materials are mostly deposited in these zones. However other zones are exposed to open sea and are highly influenced by the strong wind and wave activities. The results confirm the general impression derived from field surveying including community interview of the local area. It is confirmed that erosion is occurred in zones from one to four.

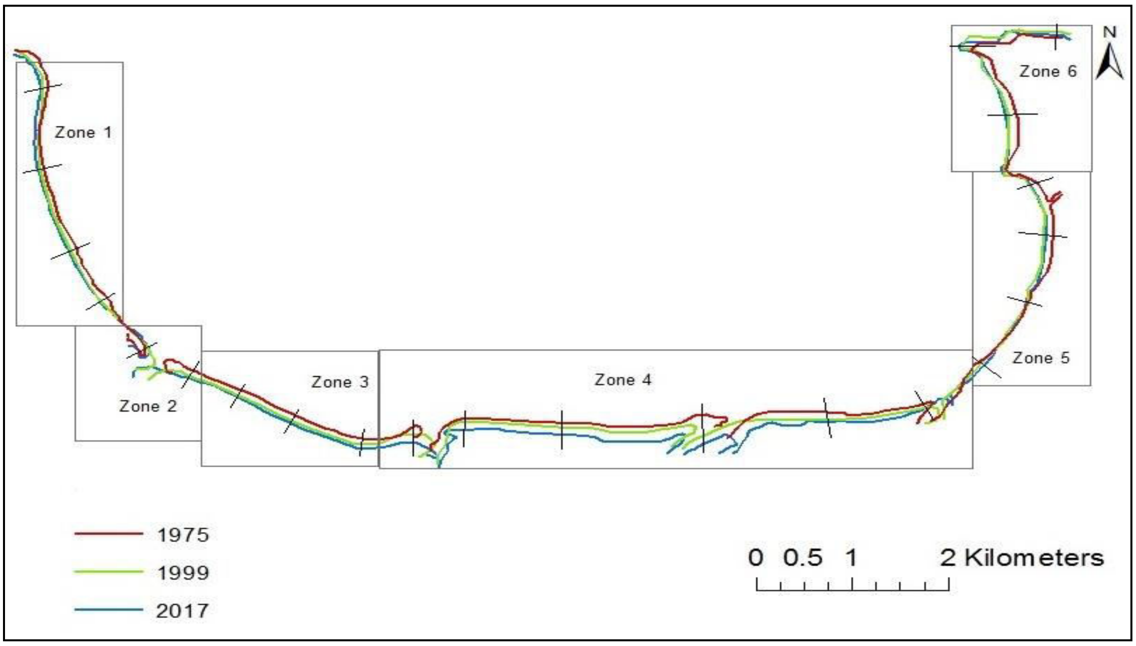

Figure 3: Map of zones, cross sections and spatial coastline change 1975 – 2017

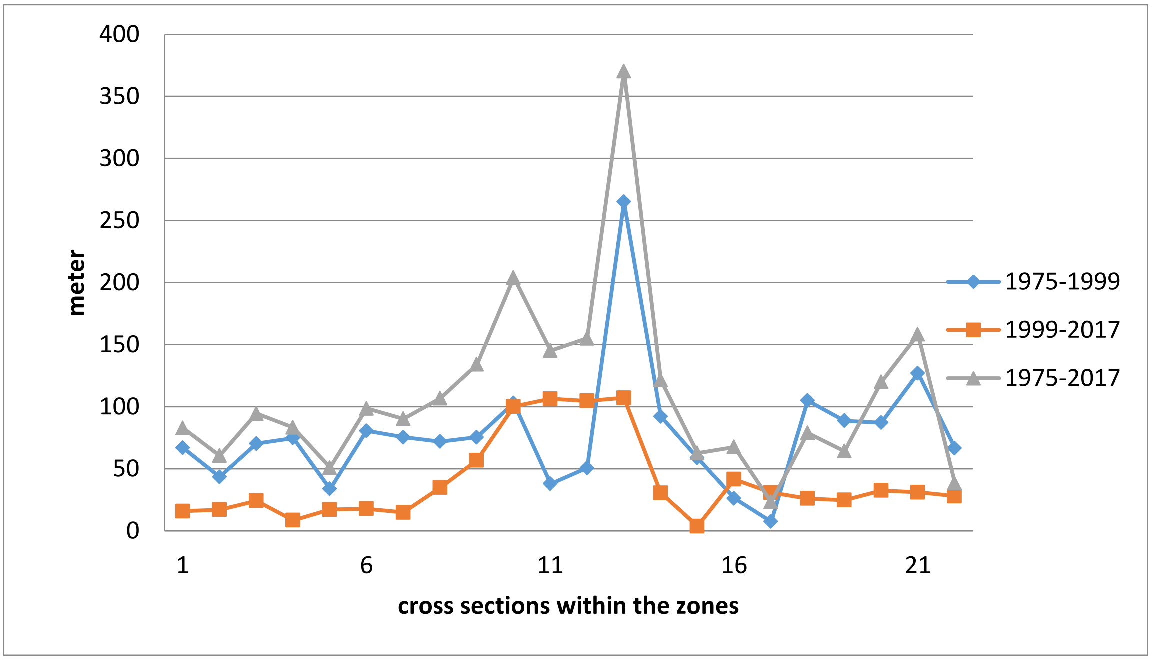

Figure 4: Temporal change in coastline 1975 - 2017

Erosion and accretion rate were estimated at each zone of coastline over the span of 42 years. Figure 5 gives the considerable evidence of the erosion in the central and western parts of the coastlines of the Koddiyar Bay, particularly in zones 3 and 4. Annual erosion rate is more than 4 meter in zone 4 where the influences of wind and waves are more significant in comparison to the other zones in the Koddiyar bay. Only the zone 4 is directly exposed to the Indian Ocean. In addition to the natural factors, anthropogenic activities such as fishing, building construction, clearance of vegetation cover and sand mining also contribute in certain scale for the erosion in the coastline of the Koddiyar Bay. In the eastern part of the coastline, particularly in the zones 5 and 6 the accretion is detected. Annual accretion rate is between one to three meters in these zones. These zones are located without indirect influences of winds and waves and are reserved as security zones where anthropogenic activities were completely banded due to the long lasting civil war erupted between government forces and Liberation Tigers of Tamil Elam (LTTE).

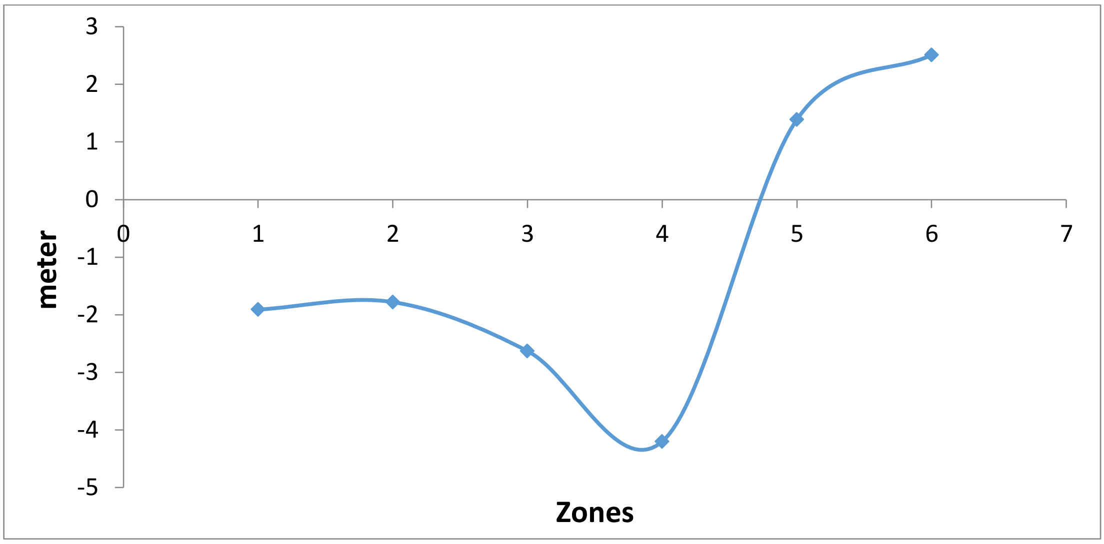

Figure 5: Annual erosion and accretion rate of coastline

Conclusion

From this study, spatial and temporal variability in coastline position, rate of change and erosion were assessed with moderate resolution satellite data. The coastlines extracted from topographical map satellite images in 1975, 1999, and 2017 were overlaid to establish the coastline changes in the Koddiyar Bay, Trincomalee, Sri Lanka. On the whole, there is no significant change in coastal line, however non-uniform change pattern was observed. The maximum change was observed in time period of 1999-2017. Among the six zones, coastal line changes were observed in three zones including zones four, six and three. The seacoast is an important natural resource of our nation. We should protect this fragile environment for sustainable uses. The integration of remote sensing and GIS has shown the potential in feature identification, feature extraction and change detection in coastal zones. Moderate resolution satellite imagery, Landsat, is proved to be effective to assess the coastal line change and erosion mapping. However, the results of the study can be further improved by using high resolution satellite data. With the detailed study of the causes of the coastal changes, particularly data such as wind, river discharge, human activities, we can make appropriate coastal zone management policy to protect the coasts effectively and sustainably.

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