Long-Time Shoreline Monitoring of the Cochin Estuarine System, Southwest Coast of India Using Multi Temporal Satellite Data

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Abstract— **Cochin Estuarine System (CES) is a unique complex system along the Indian coastline with a widespread area at the upstream. Increased human activities such as industrialization, coupled with over-population have become major environmental issues in recent years. Quantification of geomorphological changes that occurred over the decades was identified using Landsat Imageries of different years in comparison with Survey of India toposheet as baseline data. Shorelines from multiple years were manually traced from toposheet and Landsat imageries using ArcGIS software, Version 10.0. Quantitative comparison of inner island segments showed significant changes in island widths through time. The shoreline change rate has been estimated using statistical linear regression, end point rate and net shoreline movement method and cross-validated with regression coefficient (R^2) method. This study has given good insight into Cochin coastal zone changes during last 4 decades. These results can be used to quantify the extent and nature of the development change and to understand the surrounding environment, which in turn may help the planning agencies to develop sound and sustainable coastal zone management practices**.

Keywords— Cochin Estuarine System (CES); ArcGIS software; Geomorphological changes; shoreline change rate; regression coefficient

I. INTRODUCTION

Estuaries are commonly described as semi-enclosed bodies of water, situated at the interface between land and ocean, where seawater is measurably diluted by the inflow of fresh water (Hobbie, 2000). They are very dynamic systems in terms of hydraulic, morphological and ecological functioning. The interaction between various natural processes and human activities in an estuary is a very important factor. The natural factors which influence the changes in the estuaries largely depend on its geology and geomorphology, the nature of tidal waves impacting the coastline, changes in sea-level, climatologic conditions and sediment transport by long shore currents. Also the human activities that impact coastlines include dredging, construction of breakwater infrastructure, port construction, removal of backshore vegetation, land reclamation, construction of barrages and coastal control works etc.

Since ages estuaries have been densely populated areas. Of the 32 largest cities in the world, 22 of them are located along estuaries (Ross, 1995). Many estuaries around the world are at the same time economically important links between land and sea, providing access to harbours and inland waterways, and valuable natural environments, providing shelter, feeding and breeding grounds and nurseries to a wide variety of species. In the past, these functions could mostly be combined without much trouble, but now that man is interfering with these systems at an ever larger scale and is putting higher demands on navigability for larger ships, many estuarine ecosystems are stressed to the extreme (Vriend, 2003).

Coastal zone monitoring is an important task in national development and environmental protection. The extraction of coastlines should be regarded a fundamental research of necessity. Coastal zone and its environmental management require the information about coastlines and their changes. The coastline or shoreline can be geographically defined as a linear intersection of coastal land and the surface of a water body (Demirci et al., 2010). The coastline changes its shape and position continuously due to dynamic environmental conditions.

Coastline change detection can be done by comparing the topographic maps or aerial photographs of different periods. Moreover, satellite imagery has been used to describe coastal changes, and this method has been proved to be a unique tool for environmental research because the mapping of the coastline is accurate and provides with multiple and update information. Remote sensing techniques integrated with the Geographic Information System (GIS) have been used for many studies. The integrated method has been used in the coastal zone change detection due to repetitive and synoptic coverage, high resolution, multi-spectral data base and its cost effectiveness. Hence, in order to study the coastal processes in the study area, the shoreline change, and coastal geomorphology were analyzed using Remote Sensing and GIS tools.

II. STUDY AREA

Cochin ($9^0$58' N, $76^0$14' E) is situated in the state of Kerala on the SW coast of India. The Cochin Estuarine System (Fig. 1), approximately 320 km^2 in area, consisting of Vembanad lake and the surrounding islands, with six rivers (Periyar, Pampa, Achankovil, Manimala, Meenachil and Muvattupuzha) flowing into the estuary. The Cochin Estuary is the second largest wetland ecosystem in India, sustaining rich bio-resources.

The Cochin Estuary constitutes a complex estuarine system, characterized by an oxbow shape with its long axes running parallel to the coast and numerous islands. The estuary is connected to the Arabian Sea at two locations, Cochin (Lat.9°58'N) and Azhikode (Lat.10°10'N) and is divisible into two parts: the southern arm extending from Cochin to the south and the northern arm extending from Cochin to Azhikode. The Cochin inlet is about 450 m wide, whereas Azhikode inlet is relatively narrow. During December to April, a salinity barrier at Thanneermukkom virtually cuts off the tidal propagation further south and modifies the circulation in the remaining part of the estuary. The important features of the southwest monsoon that vary from year to year are the onset date, quantity of rainfall and the duration of the season, which eventually result in the variability of estuarine characteristics, including water level and flow.

The tides (as well as larger ships) enter and exit the Cochin Estuary through a perennially open narrow inlet, the cross sectional area of which is approximately 4234 m^2. The major sources of sediments to the Cochin harbour are mainly the two large rivers Muvattupuzha and Periyar (and the four other rivers, to a lesser extent). To counteract sedimentation in the Cochin harbour, dredging of the port area is carried out throughout the year. The Cochin port trust maintained three dredged channels: Approach channel (10km), Ernakulam Channel (5km), and Mattanchery channel (3km). The important channels inside the estuary are the Ernakulam and Mattanchery channels, which lie to the east and west of the Wiilingdon Island (Fig. 2).

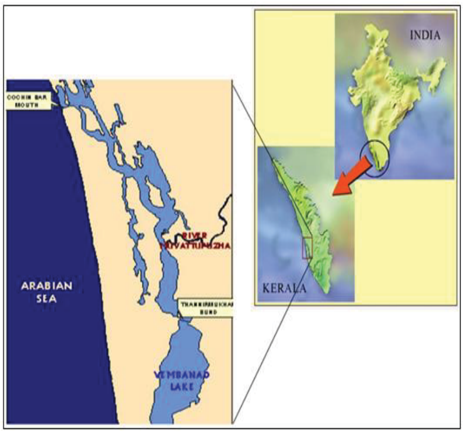

Fig.1. Location Map of Study Area

Major modifications that had taken place in the morphology and ecology of the system in the course of its history can be seen as combinations of natural processes and human interferences, of which the latter has lead to serious alterations to the system. The project to develop Cochin into a major portion the west coast of India commenced in 1920 and was completed in 1936, for which an area of about 365 ha was reclaimed. Thereafter, there were no major reclamations until the 1970s, when the fishery harbor with an area of 11 ha was reclaimed. This was followed by an integrated island development project, in which 142 ha was reclaimed. An equal area of the estuary was reclaimed for the southern extension of the port. Since then, the estuary has been subjected to substantial anthropogenic modifications for various projects for urban development and town planning, such as construction of foreshore roads, bridges, a shipyard, additional berthing facilities, a container cargo terminal, tourist sports development, and island development. Recognizing its socioeconomic importance, it has been included in the Ramsar site of the world's vulnerable wetlands to be protected (Wetlands, 2002).

The backwater system located between $09^0$30' N, $76^0$15' E and$10^0$10' N, $76^0$25' E is generally known as the Cochin backwaters. Constant mixing with the seawater through the tidal exchange gives the backwaters the characteristics of a typical estuary. The estuary depicts an interesting physiography dominated by several inner estuary islands. The port facilities are located at the mouth of the Cochin estuary. A highlight of the port is that it provides placid water spread, which retains its calmness even during the roughest weather, because the vast and extremely tranquil harbour basin is protected by the peninsular headlands on each side (Kumar, 2013).

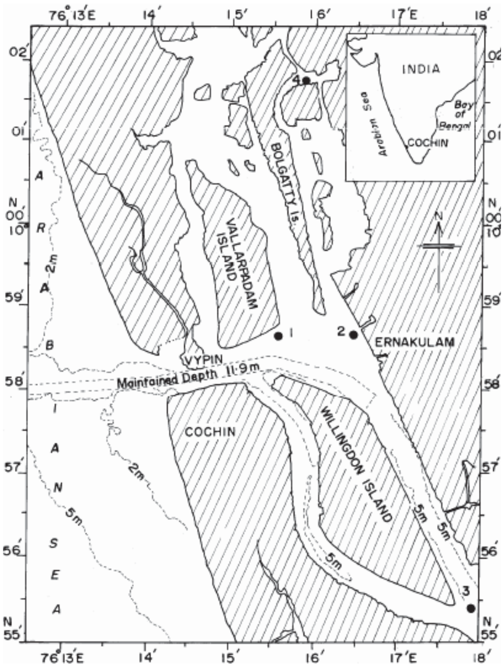

Fig. 2 Dredged channels in the study area

III. DATA SOURCES AND MATERIALS

Multi-resolution satellite data over the study area, such as Landsat MSS, TM, ETM+ and Landsat 8 of different dates have been acquired, as the same resolution data is not available over the chosen period (1973-2014). The archived Landsat images are freely available to the users so these are used. The ortho-rectified Landsat data were downloaded from the USGS global visualization viewer. The area is covered by the Survey of India (SOI) Toposheet No. 58B4, 58B8, 58C1C5, 58C6 at 1:50, 000 scales which were collected from Kerala Forest Research Institute, Trissur. Landsat data is typically used for coastal zones because of the multi-spectral and multi-temporal capabilities of the data. However, only multi-temporal data have been utilized that allow us to keep track of the various changes in characteristics of the coastal zone. The satellite data sensor's characteristics are summarized in Table 1.

TABLE 1. SATELLITE DATA SENSOR'S CHARACTERISTICS

Sensor	Characteristics		Path and Row	Date of Acquisition
	Spatial Resolution (m)	***Number of Bands***		
Landsat-1 MSS	60	4	155/53	February 10, 1973
Landsat-5 TM	30	7	144/53	January 24, 1990
Landsat-7 ETM+	30	8	144/53	October 26, 2000
Landsat-7 ETM+	30	8	144/53	February 10, 2005
Landsat 8 OLI-TIRS	30	11	144/53	February 11, 2014

IV. METHODOLOGY

The morphological change detection in Cochin estuary was studied by comparing satellite imageries of 1990 (Landsat-5 TM), 2000 (Landsat-7 ETM+) and 2014 (Landsat 8 OLI-TIRS) with the survey of India toposheet of 1970. The Survey of India toposheet (58C01, 58C06) was mosaicked for delineating the study area using image processing software ERDAS 9.2. It was then reprojected to Universal Transverse Mercator zone 43 north projection systems. For the satellite images, different band combinations were tried for better land-water interpretation and selected the suitable one. The layer stack option in Erdas 9.2 was used for this purpose. Geometric corrections were made to correct the inaccuracy between the location coordinates of the picture elements in the image data, and the actual location coordinates on the ground. The ground control points for geocoding satellite imageries were found with the help of georeferenced toposheet, and these points were uniformly distributed across the study area. A total of at least 25 prominent ground control points (GCP) was examined and matched in all images with the help of toposheet. The root-mean-square error was less than 0.5 pixels for each image. After georeferencing, the nearest-neighbour interpolation method was employed for rectifying and resampling the images into a geographic coordinate system and then reprojected to Universal Transverse Mercator zone 43 north projection systems. The study area was extracted using Erdas Imagine software. The land–water system for toposheet was digitized with the help of ArcGIS v.10 software, and onscreen digitization of the same was done for the satellite imageries to get an idea of the present position of the system. The vector representations of the Cochin estuary for 1970, 1990, 2000 and 2014 were overlaid by using the union option. The area under degradation and accretion was demarcated and represented based on changes as shape files. The area was calculated using calculate geometry option in the attribute table. The digitized image for the year 2014 with major islands was shown in Fig. 3.

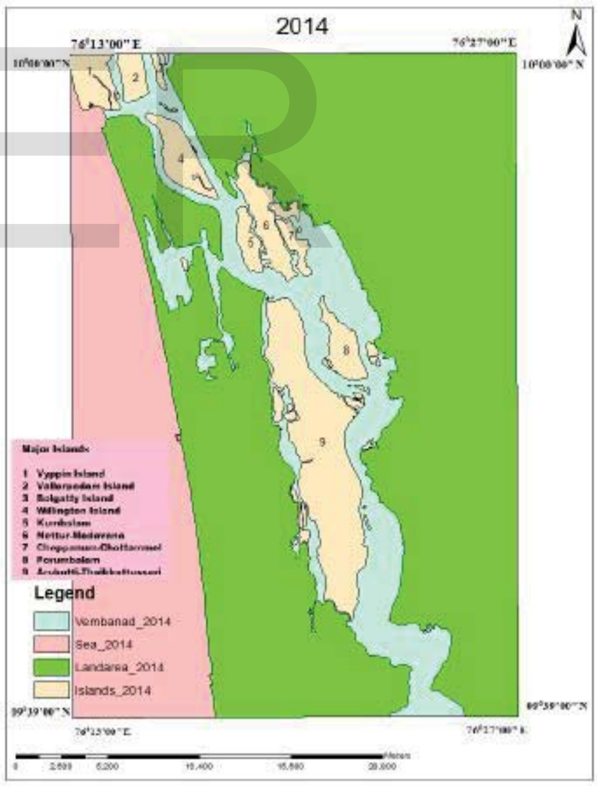

Fig. 3 Digitized image of the study area (*2014*)

To carry out shoreline changes study a Digital Shoreline Analysis System (DSAS), an extension of ARC GIS, was employed. Shoreline changes in the study area were analyzed in ESRI ArcGIS v 10.0 Software with five Landsat images of the years 1973, 1990, 2000, 2005, and 2014 and toposheet for the year 1970. The continuous shoreline positions during different years (1970, 1973, 1990, 2000, 2005 and 2014) were digitized through shape files with the utmost accuracy. The created shorelines were then merged for calculation purpose. It was done according to the period and method of calculation. For example, Linear Regression Rate (LRR) method needs all shoreline positions for the calculation. So, all the six shorelines were merged to a single feature class for LRR calculation. But for End Point Rate (EPR) method and Net Shoreline Movement (NSM) method accepts only two shoreline positions (latest and earlier) for the calculation. So they are merged for the periods 1970-1973, 1973-1990, 1990-2000, 2000-2005, 2005-2014, and 1970-2014. DSAS uses a measurement baseline method to calculate the rate-of-change statistics for a time series of shorelines. The baseline is the starting point for all transects and is therefore one of the most important components of the shoreline change analysis process. In this study, three baseline segments were created as per the shoreline conditions since the shoreline is not continuous. It was then merged to form a single feature class.

The procedure involves the selection of a baseline in the general direction of a shoreline, establishing transects perpendicular to the base line and then finally calculating the distance between the shorelines along various transects. The rate of change in shoreline positions has been estimated using Linear Regression Rate (LRR), End Point Rate (EPR) and Net Shoreline Movement (NSM) method and cross-validated with regression coefficient (R^2) method. The end point rate calculations are done by dividing the distance of shoreline movement by the time gap between the oldest and youngest shoreline in the data set. The major advantage of this method is ease of computation and calculations can be done on minimum two shorelines only. The EPR method is only good for short term shoreline change analysis as it only considers latest and the oldest shoreline position and suppresses all in other in long term analysis. Uses of LRR eliminate this difficulty. Here the shoreline shift is calculated by fitting a least square regression line to all shoreline points for a particular transects. The net shoreline movement (NSM) reports distance not rate. It reports the distance between the oldest and youngest shorelines for each transect. To carry out shoreline changes study a Digital Shoreline Analysis System (DSAS), an extension of ARC GIS, has been employed that do all these calculations. The inputs required for this tool are shoreline in the vector format, date of each shoreline, and transect distance. In this study, the transect spacing was given as 300 m and the transect length was set as 2300 m.

VI. RESULT AND DISCUSSIONS

A. Geospatial Analysis of Land-Water Interface

The land-water interface change was determined by overlaying the previously prepared digitized images. Fig. 4 shows the changes that occurred in the land–water interface in the estuary during 1970, 1990, 2000, and 2014.

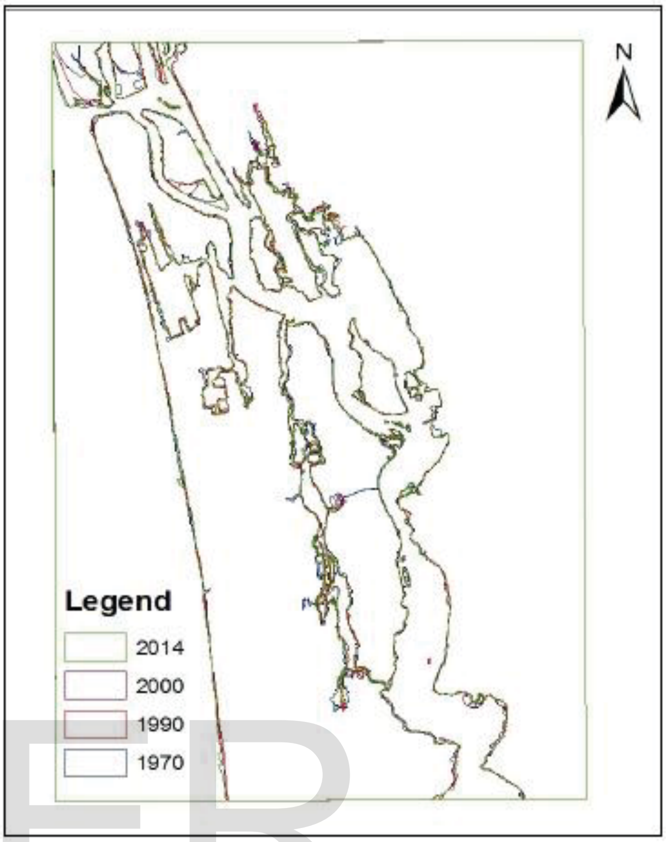

Fig. 4 Changes in land-water interface during 1970-2014

From the figure, it is clear that during the period of 1970–2014, major shoreline changes had taken place in the northern segments of the estuary mouth, whereas the southern zones exhibited only minor variations in the widths. The accretion in the major barrier island of Vypin Island resulted in the shifting of the shoreline in the seaward direction. During 2000–2014, the shoreline position in Vypin Island moved slightly to the east, resulting in erosion of land area. In 2004, tsunami waves hit these shores, which might have resulted in this change. But the overall changes from 1970-2014 resulted in accretion in the estuary mouth. Fig. 5 depicts the major shoreline changes observed in the estuary inlet and mouth. The bar mouth of the estuary was found to have protruded by 1.75 km towards the sea, resulting in a drastic reduction in the width of the estuary mouth. The shoreline receded by about 954 m at Elangunnapuzha (Malippuram) in Vypin. A recession of about 1.36 km occurred at the southernmost tip of the zone. The study reveals the major variation of the geomorphologic pattern in the mouth regions of the estuary.

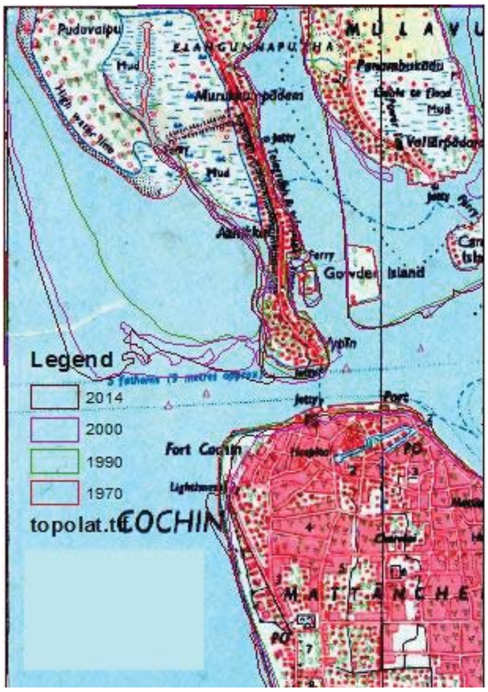

Fig. 5 Changes in the estuarine mouth

B. Changes in the Inner Estuary Islands

From the digitized images of each year, the area is noted for the major islands. Details of the quantitative comparison of morphological changes of the inner island segments are given in Table 2.

TABLE 2. AERIAL EXTENT OF MAJOR ISLANDS IN THE COCHIN ESTUARY

Major Islands	**1970 (km^2)**	**1990 (km^2)**	**2000 (km^2)**	**2014 (km^2)**
Vypin Island	3.3276	5.2987	6.8036	6.9654
Vallarpadam	1.7628	3.5282	3.4490	3.7373
Bolgatty Island	0.4971	0.4605	0.5503	0.8114
Willington Island	6.4664	6.4372	7.4745	7.9326
Kumbalam	3.2131	3.2308	3.2907	3.4092
Nettur–Madavana	8.1364	7.9896	8.5537	8.3649
Cheppanum–Chottammel	2.3765	2.4640	2.5317	2.5273
Perubalam	5.7568	5.7846	5.9679	6.0282
Arukutti–Thaikkatusseri	45.3230	46.6353	47.2753	47.1331

Accretion of 10.05 km^2 occurred during 1970–2014. During the 44-year period (1970–2014), the northern segments of the study area experienced major changes due to accretion and erosion of the land–water system in the estuary. The islands toward the northern part of the study area made major contributions to the morphological changes in the land–water system. Vypin Island accreted by about 3.64 km^2 offshore during the period 1970–2014. All of these have contributed to the narrowing of the estuary mouth, which is protruding toward the sea.

C. Shoreline Change Rate Analysis

The three analytical methods used to calculate shoreline change rate are Linear Regression Rate (LRR), End Point Rate (EPR) and Net Shoreline Movement (NSM). The rate calculation results for EPR and NSM methods are listed in Table 3 with negative values representing recession and positive values indicating accretion.

TABLE 3. SHORELINE CHANGE RESULTS FOR EPR AND NSM METHODS

	Year	**1970-1990**	**1990-2000**	**2000-2014**	**1970-2014**
EPR (m/y)	Mean	3.61	6.68	0.57	3.40
	S.D	17.6	14.33	5.85	10.51
	Max.	71.51	72.63	22.03	44.39
	Min.	-9.08	-20.76	-44.3	-2.34
NSM (m)	**Year**	**1970-1990**	**1990-2000**	**2000-2014**	**1970-2014**
	Mean	72.36	71.81	7.54	149.99
	S.D	353.06	154.11	77.77	463.63
	Max.	1434.7	781.21	292.83	1958.17
	Min.	-182.21	-223.24	-588.87	-103.21

The rate calculation results of LRR method are listed in Table 4. The distribution of R^2 values is shown in Fig. 6.

TABLE 4. SHORELINE CHANGE RESULTS FOR LRR METHOD

	Year	**1970-2014**
LRR (m/y)	Mean	2.39
	S.D	11.27
	Max.	47.57
	Min.	-2.82

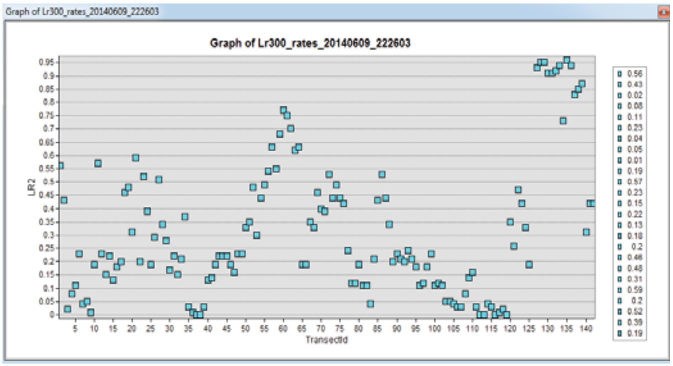

Fig. 6 Distribution of R^2 values obtained from LRR method

EPR for the entire shoreline shows that 96.5%, 14%, 82% 54% and 57% transects, records the accretion during the time span of 1970-1973,1973-1990,1990-2000, 2000-2005 and 2005-2014 respectively. Whereas the rest of the transect lines experience erosion during the same time span. In LRR method, the shoreline shift rate can be predicted by fitting a least square regression line with the observed shoreline position along a transect line. The distribution of R^2 value for all the transect lines throughout the shoreline shows some distinctive distribution pattern. Transect 126 to 139 have the R^2 value > 0.85 and shows a linear pattern, the rest of the transects shows R^2 value 0.85. The R^2 value fit well with shoreline category i.e. advancing and retreating shoreline classified based on the yearly change rate. The average shoreline movement within the period 1970 – 2014 is 150 m and maximum shoreline movement is 1958.17m. The transect wise study shows accretion in almost all directions. The rate of accretion is much higher than erosion rates. Results show a very dynamic shoreline behavior.

VI. CONCLUSIONS

In this study an attempt was made to examine the long-term morphological changes to assess the characteristics of deformations that had taken place in the Cochin estuarine morphology over the past 4 decades. Using multi-resolution satellite data along with the statistical techniques shorelines during different years around Cochin Estuary have been extracted. Results show a very dynamic shoreline behavior. The shoreline change rate computation was done by using Digital Shoreline Analysis System, an Arc GIS extension tool. All the calculations have been done using remote sensing and GIS techniques that fit with the empirical observations on the Estuary. Observed trends of the morphological changes generate concern in the background that the region may continue to remain vulnerable due to development pressures in the years ahead. The results obtained from this can be effectively used for long-term coastal zone management planning for the coming decades.

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