

## **Geospatial Analysis of Long term Morphological Changes in Cochin Estuary, South West Coast of India**

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### **ABSTRACT**

Cochin estuary along the south west coast of India has undergone tremendous environmental changes due to continuous alterations. Geospatial information available since year 1967 has been compiled to evaluate the long term morphological changes. Quantification of geomorphological changes occurred over the decades was made to have an integrated profile to ascertain the changes in the extent. Topo sheet maps (1967) and satellite imageries for the years 2004 and 2011 have been interpreted. Quantitative comparison of inner island segments shows significant changes in island widths through time. It was found that the area covered by the islands within the estuary during the years 1967, 2004, 2011 were 81.62 km<sup>2</sup>, 89.26 km<sup>2</sup>, 89.52 km<sup>2</sup> and that by the water body were 130.68 km<sup>2</sup>, 121.3 km<sup>2</sup> and 118.01 km<sup>2</sup>. The shrinking rate of estuarine system was estimated as 0.288 km<sup>2</sup>/year. About 11 km<sup>2</sup> of island area was found to be prograded and 3 km<sup>2</sup> was eroded. In effect, the reduction in the aerial extent of the estuarine system was estimated to be 12.67 km<sup>2</sup>. The evolution of the western estuary margin has been characterized by a strong progradation during the past four decades. The results obtained conclusively point that the estuary is being inflicted with major geomorphic changes at several segments resulting into the reduction in extent. Geomorphic differences may lead to factors in modifying estuarine flows which ultimately affect the dynamic processes within the estuary. Observed trends on morphological changes generate concern in the background that the region may continue to remain vulnerable in the coming decades due to development pressures in the adjoining hinterlands.

**ADDITIONAL INDEX WORDS:** *Cochin Estuary, India, Morphological changes, shrinking rate, Hydrodynamic condition, Geo-Spatial Technique.*

## **INTRODUCTION**

The Indian coastline, about 7500 km long, supports a large number of estuaries, which are unique and scientifically interesting. These ecosystems also hold immense biological diversity with rich living resources. By virtue of their location, high productivity and services provide, estuarine ecosystems worldwide are often subjected to severe ecological pressures. Environmental issues in these zones are complex, where resource and management systems often confront with multiple conflicts. Estuarine functioning is case sensitive to changes in environmental factors and human interventions. Morphology of estuaries are generally characterized by the strong interplays between several factors including sedimentological and hydrodynamic processes. Substantial changes are taking place in the landscape of these systems as a result of the dramatic and rapid urbanization. The swift evolution of estuarine settings translates into extreme fragility in this environment. Advent and advancement of digital terrain technologies have spawned concomitant advances in the morphological studies of several urbanized estuaries worldwide (Billy *et al.*, 2012; Bu-Li Cui and Xio-Yan Li, 2011; Dai *et al.*, 2011; Gao *et al.*, 2010; Jiang, Li and de Swart, 2012; Wang and Townend, 2012).

The Cochin estuary (also called Vembanad Lake) is the second largest wetland ecosystems in India. It has been subjected to substantial anthropogenic modifications for several decades with the gradual draining of its extent and margins (Kumar, 1997). The increase in population and associated modifications that had taken place for urban development makes it essential that long term patterns of morphology be better documented and understood. This paper presents the results of the geospatial analysis of Cochin estuary to evaluate the long term morphological changes and to assess the dimension of the deformations that had taken place within the system. The study aims to quantify the dimensions of the geomorphological changes occurred over the decades to have an integrated profile and to discuss the scenarios with a point on application to the future.

## **ENVIRONMENTAL SETTING**

Cochin, (9° 58' N, 76° 14'E) situated in the state of Kerala on the southwest coast of India. Even though the backwaters are a hydraulic continuum spreading over the entire state, the backwater system located between 09° 30'-10°-10'N, 76°15'-76° 25' E is generally known as Cochin backwaters. Constant mixing with the seawater through tidal exchange gives the backwaters the characteristics of a typical estuary. The estuary depicts an interesting physiography dominated by several inner estuary islands

(Figure 1). The port facilities are located at the mouth of the Cochin estuary. A highlight of the port is that it provides an absolutely placid water spread which retains its calmness even during the roughest of weathers as the vast and extremely tranquil harbor basin is protected by the peninsular headlands on each side.

The estuary gained its economic importance after the establishment of Cochin Port in 1936 and has been greatly modified in the last few decades by intense human activities (Dixit, 1987; Kumar, 1994) and the estuary has been reported to be on the brink of an ecological disaster (Gupta *et al.*, 2009; Kumar, 1997; Martin *et al.*, 2011; Saraladevi, 1986). 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 led to serious alterations to the system. The project to develop Cochin into a major port on the west coast of India commenced in 1920 which was completed in 1936 for which an area of about 365 ha had reclaimed. There after there were no major reclamations till 1970s, when the fishery harbor with an area of 11 ha had been reclaimed. This was followed by an integrated development project for an island development project where in 142 ha had been 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, shipyard, additional berthing facilities, container cargo terminal, tourist sports development and island development. Recognizing its socio-economic importance, it has been included in the Ramsar site of world's vulnerable wetlands to be protected (Wetlands, 2002).

Along with Industrial pollution, indiscriminate reclamation was a major intervention, which reduced the estuarine volume by 40% as per the estimate made nearly three decades ago (Gopalan *et al.*, 1983). Deforestation in the hinterlands and construction of salinity barriers upstream of the estuary exacerbated the situation with increasing sedimentation (Balchand and Rasheed, 2000; Gopalan *et al.*, 1983; Kumar, 1997; Mallik and Suchindan, 1984; Menon, Balchand and Menon, 2000).

Extending from Azhikode (10°10' N, 76°15' E) in the north, to Alappuzha (09°30' N, 76°25' E) in the south, the Cochin estuary has been classified as one of the most productive estuarine systems along the west coast of India (Menon, Balchand and Menon, 2000) . The system is characterized by its long axis lying parallel to the coastline, with several small islands and interconnected waterways, and covers an

area of about 300 km<sup>2</sup>. The width of this estuarine system varies from 500 m to 4 km and the depth varies from 1 m to 15 m. The rivers that discharge freshwater into this estuarine system are Periyar in the north; Pampa, Achankovil, Manimala and Meenachil in the south and Muvattupuzha located midway between. The openings at Cochin with a width of about 450 m and at Munambam, provide perennial connections to the Arabian Sea. Cochin Port, situated near the Cochin gut provides the main entrance channel to this harbour. Until the construction of the spillway at Thottappally in 1955 and Thanneermukkam barrage in 1974 (for exploring the possibility of raising more rice crops in an year), the estuary was open up to Alappuzha in the south and the estuarine length was about 120 km (Kannan, 1979).

It is believed that the estuary attained its present configuration in the 4<sup>th</sup> century (Menon, 1913). It can be described primarily as a coastal marine environment, bounded by an alluvial bar parallel to the coastline, and connected to the Arabian Sea at intervals. Because of an intense flood in 1341 AD, parts of the present coastal districts of Ernakulam and Alappuzha were formed, thus, separating a distinct body of water from the sea with connecting channels at Thottappally, Andakaranazhi, and Cochin. A number of islands were also formed in the water body (Anonymous, 1973; Menon, 1913). The coastal plain of the region is found to be of recent geological origin, with its formation dating back to the early tertiary period. The sedimentary formations of the coast are of recent and subrecent formation (Kunte, 1995).

## **MATERIALS AND METHODS**

Erosion/Accretion of the Cochin estuary was studied by comparing satellite imageries of 2004 (IRS 1C LISS III and PAN) and 2011 (IRS P6, LISS-3) with the survey of India toposheet of 1967. The toposheet (58B4, 58B8, 58C1C5, 58C6) was geo-referenced and mosaiced for delineating the study area using image processing software ERDAS 9.x. The ground control points (GCP's) for geo-coding satellite imageries were found out with the help of geo-referenced toposheets and it was uniformly distributed across the study area. The overall accuracy expressed as the Root Mean Square Method (RMSE) for geo-referenced images was less than 0.8 pixel. After geo-referencing, nearest neighbor interpolation method was employed for rectifying and re-sampling the images into Geographic coordinate system and then re-projected to UTM (Universal Transverse of Mercator) zone 43 North projection systems. The land-water system was digitized with the help of software ArcGIS10 and

onscreen digitization of the same was done for the satellite imageries in order to get an idea about the present position of the system. The erosion and accretion of land-water system was demarcated by making use of analysis tools of ArcGIS10. The vector representation of Cochin estuary for the years 1967, 2004, 2011 were overlaid by making use of union option. The area under degradation and accretion was demarcated and represented based on their changes as shape files. The erosion and accretion of land-water system was demarcated by making use of Analysis tools of ArcGIS v.10. The vector representation of Cochin estuary for the years 1967, 2004, 2011 were overlaid by making use of union option (Kumar *et al.*, 2007).

## **RESULTS**

### **Geospatial Analysis of land water interface**

Figure 2 shows the changes occurred in the land water interface in the estuary during the years 1967, 2004 and 2011. It can be found that during the period of 1967-2004, major shoreline changes had taken place in the northern segments of the estuary mouth, where as the southern zones exhibited only minor variations in the widths. The accretion in the major barrier island of Vypin Island resulted into the shifting of the shoreline towards the seaward direction. During 2004 to 2011, the shoreline position in the Vypin Island was found moved slightly towards east resulting into the erosion of about 0.278 km<sup>2</sup> of land area. During the period, 1967-2011 too, the shoreline to the south of estuarine mouth moved gradually eastward. Comparative analysis of satellite imageries available for the region for the years 2004 and 2011 showed a marginal decline in the area of Vypin Island by about 0.278 km<sup>2</sup> landward. In 2004, the Tsunami waves have knocked these shores which might have resulted into this change.

Figure 3 depicts the major shoreline changes observed in the estuarine inlet/mouth. The bar mouth of the estuary was found protruded by 1.6 km towards the sea resulting into a drastic reduction in the width of the estuarine mouth. The shoreline receded by about 954 m at Elanguzha (Malippuram) in Vypin. A recession of about 1.36 km could be found occurred at the southernmost tip of the zone. All these had resulted into the accretion and major variation of geomorphologic pattern in the mouth regions of the estuary.

## Long term Trends in the Inner estuary Islands

Figure 4 shows the change detection of the islands within the estuary during 1967-2011 and Figure 5 depicts the change detection during 2004-2011. Details of the quantitative comparison of morphological changes of the inner island segments are given in Table 1. It can be found that an accretion of 11.01 km<sup>2</sup> and erosion of 3.07 km<sup>2</sup> occurred during the years 1967 to 2011. However, the net change occurred during 2004-2011 was found to be minor (0.264 km<sup>2</sup>). During the 44 years period (1967–2011), the northern segments of the study area experienced major changes due to accretion and erosion of land-water system in the estuary. By comparing the land-water system value output made available from the analysis for the year 1967 and 2011, it could be inferred that 12.67 km<sup>2</sup> of water body was lost due to accretion of 7.9 km<sup>2</sup> in the islands of the estuary. Analysis of the multi-temporal data during the period (2004-2011) showed a decrease of 3.29 km<sup>2</sup> area in the water body of the estuary and 0.26 km<sup>2</sup> of accretion in the islands within.

The islands towards the northern part of the study area made major contribution for the morphological changes in the land water system. The Vypin Island, the main barrier island accreted by 3.81 km<sup>2</sup> towards offshore during the period 1967- 2004. A net gain of 4.90 km<sup>2</sup> area of land could be observed.

As seen in Figure 4, the change in the aerial extent of islands in the estuary during the period 1967 to 2011, was with a net gain of 4.90 km<sup>2</sup>. The major changes in land area were seen in Vallarpadam Island, Willington Island and Vypin Island, whereas the islands such as, Perumbalam, Kumbalam, Nettur, Madavana, Arukutti, Thaikkatusseri, Cheppanum and Chottammel in the estuary exhibited with minor changes during this period.

Table 2 and Table 3 show the erosion and accretion occurred along the land water interface in the estuary during the period 1967 to 2011. Major morphological changes had taken place in the islands with an accretion of 11.01 km<sup>2</sup> and erosion of 3.07 km<sup>2</sup> occurred during this period. The northern segments of the study area experienced major changes due to accretion/ erosion.. However, the net change occurred during 2004-2011 was found to be minor (0.264 km<sup>2</sup>) as compared to the long term changes. In effect, the water body of the estuary had been found degraded to about 18.5 km<sup>2</sup> during the last 44 years (Table 3). Towards the southern region of the study area, not much changes was found in the landforms. Some small islands have found emerged above the Willington island and

Thannermukkam barrage and below the Perumbalam Island. A canal separating the Arukutti island and Thaikkatusseri island was found to be getting tapered during the past four decades.

Major changes were visible near the estuarine mouth; about 3.81 km<sup>2</sup> accreted towards the seaside in Vypin Island. The growth of Vallarpadam island towards the southern border found could be attributed to the dumping of sediment dredged from the navigation channels. Major changes were seen in Vallarpadam island, Willington island and Vypin island. Construction of the new Goshree bridge connecting Vypin, Vallarpadam and Bolgatty islands to the city province has brought a tremendous change in the landforms of the study area. All these have contributed to the narrowing of the estuarine mouth which is found protruded towards the sea, The observed changes are illustrated in Figure 6, which shows the total area of dredging in the inner channel (Ernakulam and Mattanchery channel) and outer channel (off shore) of the estuary. The bar chart shows the quantum of sediments removed since 1969. Considering the quantum of the material, the spatial and temporal variations in erosion and accretion might have links to the dredging of the channels in the estuary and associated processes. About 11.01 km<sup>2</sup> of island area was found accreted and 3.07 km<sup>2</sup> eroded during the period 1967 to 2011. The total area covered by the system during the year 1967 was found to be 130.68 km<sup>2</sup>. The aerial extent of the backwater system (121.3 km<sup>2</sup>) was reduced by 7.2% (9.382 km<sup>2</sup>) during 2004 and it was further reduced 2.52 % (3.29 km<sup>2</sup>) to the period 2011 (118.01 km<sup>2</sup>).

## **DISCUSSION**

Geospatial analysis presented in this study is similar to that used in Billy *et al.* (2012); Bu-Li Cui and Xio-Yan Li (2011); Dai *et al.* (2011); Gao *et al.* (2010); Jiang, Li and de Swart (2012) and Wang and Townend (2012). This method is very effective as it provide quantitative estimates of long term morphological changes. Results of the analysis in turn provide the integrated profile of the deformations that had taken place over the decades. In addition to the geospatial analysis of the inner estuarine zones, the present study highlights the geomorphic changes at the mouth region of the estuary. Geomorphic processes in these zones are complex and are the net result of several factors. In the study region, influx of sediments is highly variable with season and the sediment circulation in the near shore zones in the vicinity of the estuarine mouth also varies with seasons. In response to these, mouth configuration undergoes rapid changes. The integration of these results makes the present study more comprehensive.

The results obtained point that the estuary is being inflicted with major geomorphic changes at several segments and reduction in extent. From 1967 to 2011, the shrinking rate of the system was characterized by  $0.288\text{km}^2/\text{year}$ . The evolution of the western estuary margin has been characterized by a strong progradation during the past 44 years. The major changes were visible near the estuarine mouth; about  $3.81\text{ km}^2$  accreted towards the seaside in Vypin Island, the biggest barrier island of the Cochin estuary. The mouth has been shifted to 1.6 km towards the sea. About  $11.01\text{ km}^2$  of island area has been accreted and  $3.07\text{ km}^2$  got eroded during the period 1967 to 2011. The pattern observed demonstrate the major role play of urbanization taken place in the system in the form of harbor development. The total area covered by the system during the year 1967 was found to be  $130.68\text{ km}^2$  . The aerial extent of the backwater system ( $121.3\text{ km}^2$ ) was reduced by 7.2% ( $9.382\text{ km}^2$ ) during 2004 and it was further reduced 2.52 % ( $3.29\text{ km}^2$ ) to the period 2011 ( $118.01\text{ km}^2$ ).

The rapid pace in urbanization in the region has brought tremendous changes to the major islands in the estuary and the evolution of the western estuary margin has been characterized by a strong progradation during the past 44 years. Narrowing and squeezing of the estuary observed at several segments in effect pose a significant threat to estuarine habitats and functions. Geomorphic differences found in the land-water system may lead to several factors in modifying the structure of estuarine flows. Bulging of islands due to sedimentation and presence of new islands will result in reducing /altering the estuarine flows. Engineering construction and channel dredging directly transform the natural geometry of the estuary, which ultimately affect the dynamic processes, within. Present information obtained may help to develop strategies of management plans.

The estuarine environment owes its formation to a series of transgressions and recessions as a result of various natural forces that possibly acted on it over a period of millions of years (Kunte, 1995). Morphological characteristics are generally as a result of long-term changes in sedimentological and hydrodynamic features. The pattern observed demonstrates the major role of urbanization taken place in the system during in the last few decades. Observed trends on the morphological changes generate concern in the background that the region may continue to remain vulnerable due to development pressures in the years ahead. Tidally induced currents get modulated and respond differently to changes imposed to the natural propagation due to geomorphic alterations. Signatures of mixed standing waves was reported in the system recently (Kumar,2009). The trends obtained from the present investigations when overlaid to the standing wave signatures should be considered as a trend of potential consequences



resembling to those in more 'developed' similar ecosystems worldwide in terms of potential consequences. Detailed investigations are required to evaluate the physical variability and hydrodynamic response of the estuary due to the alterations on geometry to assess the long term impacts to the ecosystem.

From the results obtained, it was inferred that the signatures of the long term morphological changes were found to be characterized by strong progradation during the period of observation with the evolution of the western estuary margin. Estimates of the aerial extent revealed the drastic reduction and shrinking of extent of the estuarine system. The analyzed data records present only the differences in area extent. No attempt could be made to compute more important aspects such as volume which has linear links to flushing time scales, and carrying capacity. Geomorphic differences also lead to modify the estuarine flows. Tidally induced currents get modulated and respond differently as per the changes imposed to the natural propagation due to these alterations. Closely gridded bathymetry data is required to assess the changes in depths at different segments and the resultant reduction in volume. The present study may pave the way for detailed investigations for future. Synchronous environmental data would be useful in understanding the carrying capacity and problems and potentialities of fisheries, tourism and navigation.

## **CONCLUSION**

In the discussion above, we examined the long period geospatial information available at Cochin estuary along the south west coast of India. An attempt was made to examine the long term morphological changes to assess the characteristics of deformations that had taken place in the estuarine morphology over the past four decades. The present study conclusively proves the usefulness of geospatial analysis to quantify long term geomorphic changes. The maps produced using this technique serve as a broad indicator of one of the causative factors of the environmental degradation reported in the estuary.

This is a objective methodology to characterize the long term estuarine geomorphic changes. Detailed knowledge of the rate of changes in landforms and shoreline position is important in the development to setback planning, hazard zoning, erosion/accretion aspects, sediment budgeting, and conceptual /predictive modeling of estuarine morpho-dynamics. The results obtained can be effectively used by coastal managers and administrators to evolve clear picture of strategies for a long term management planning for the foreseeable part of the next decades.

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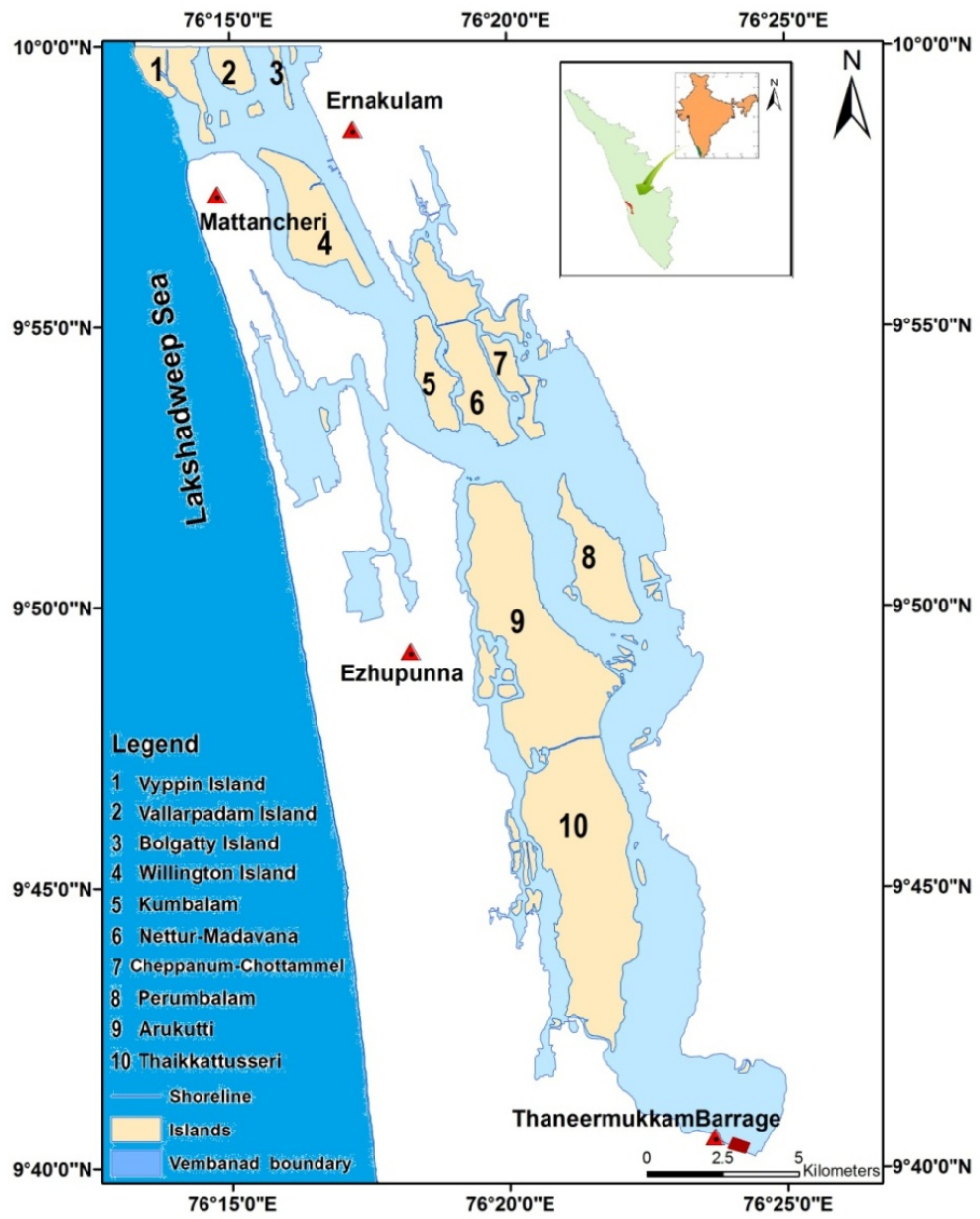


Figure 1

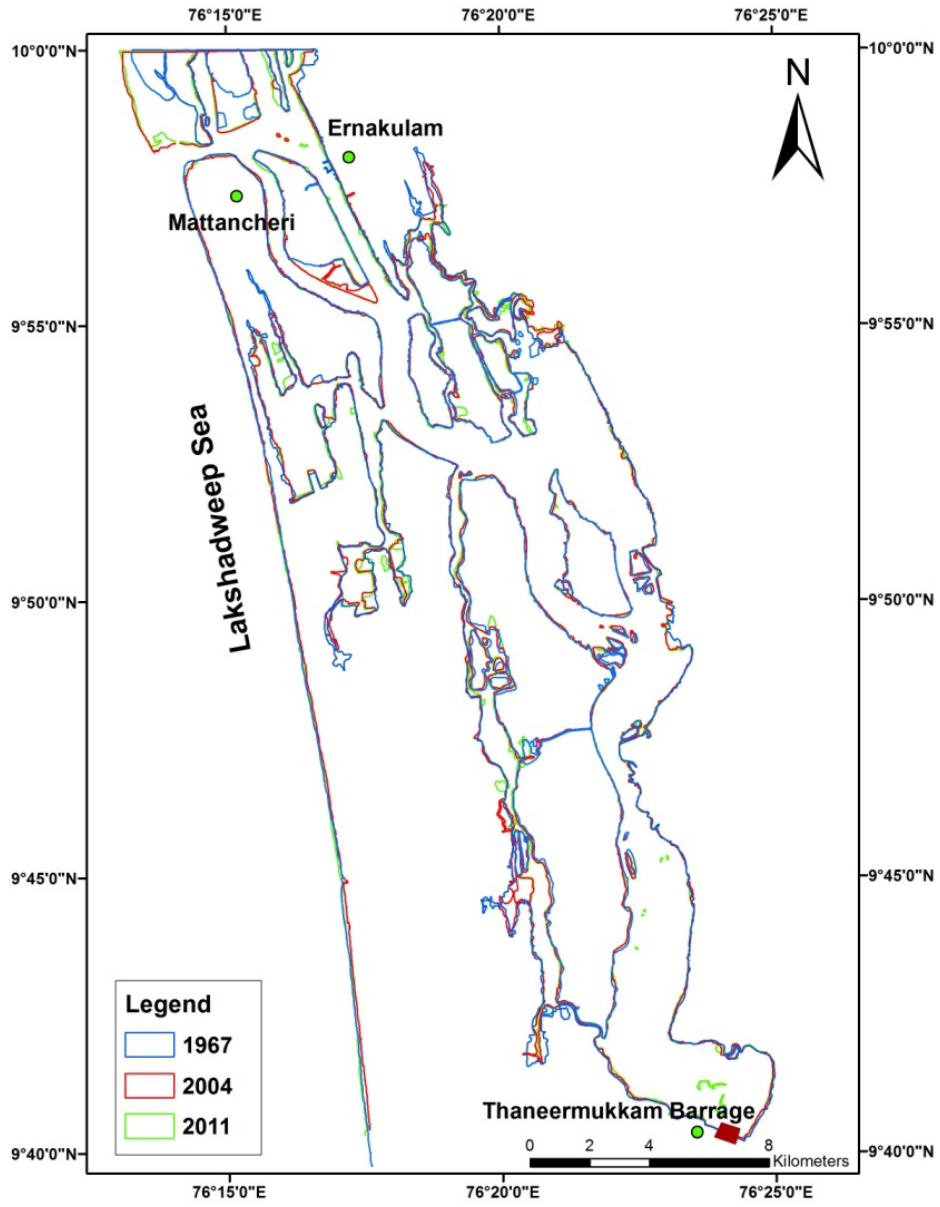


Figure 2

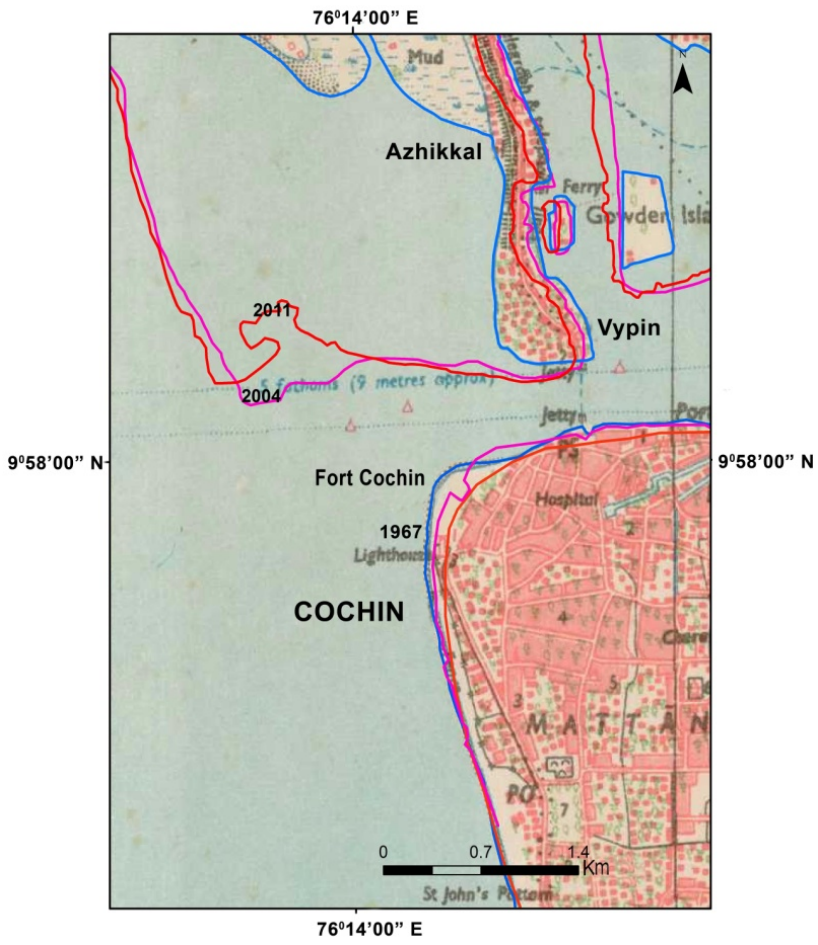


Figure 3

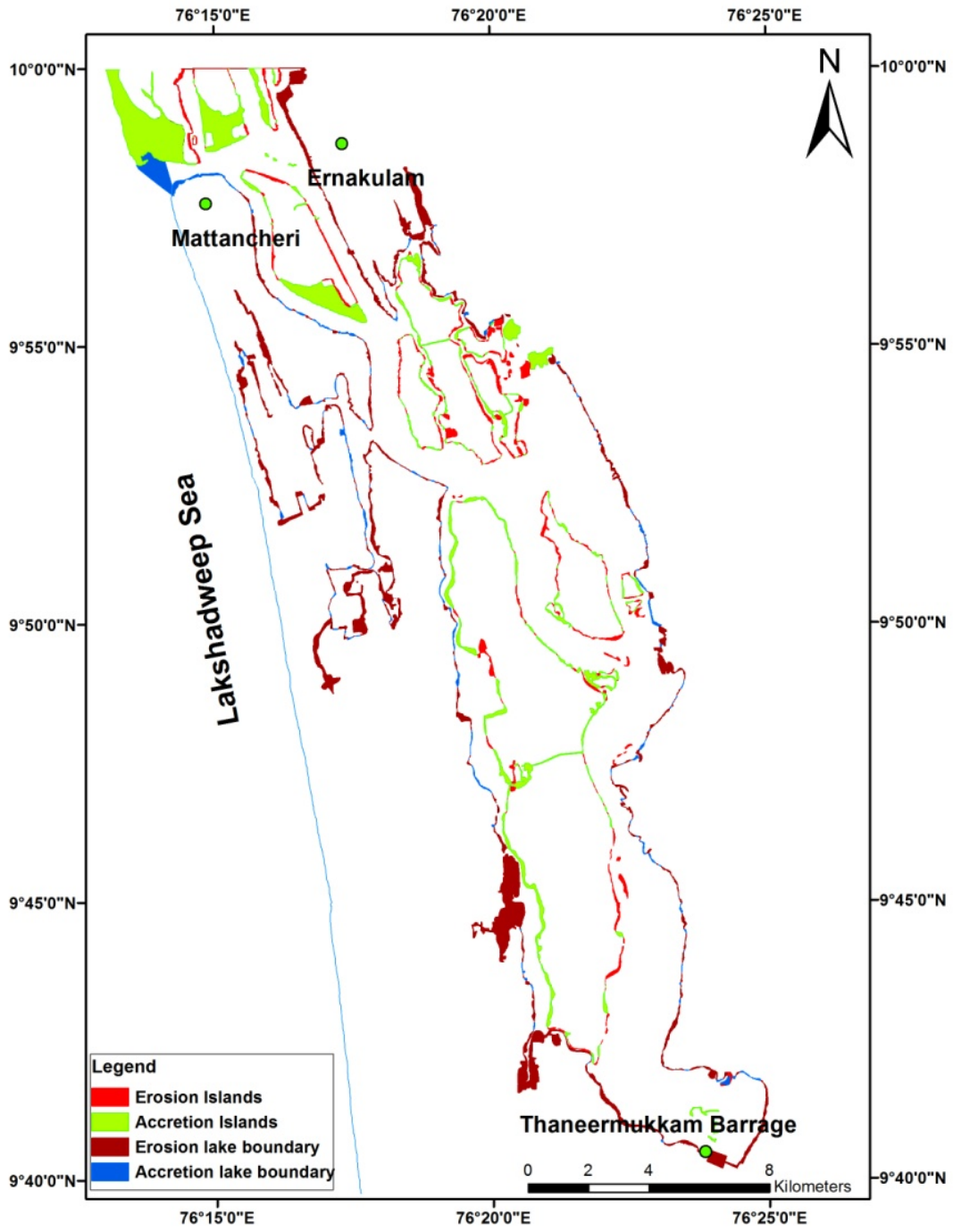


Figure 4



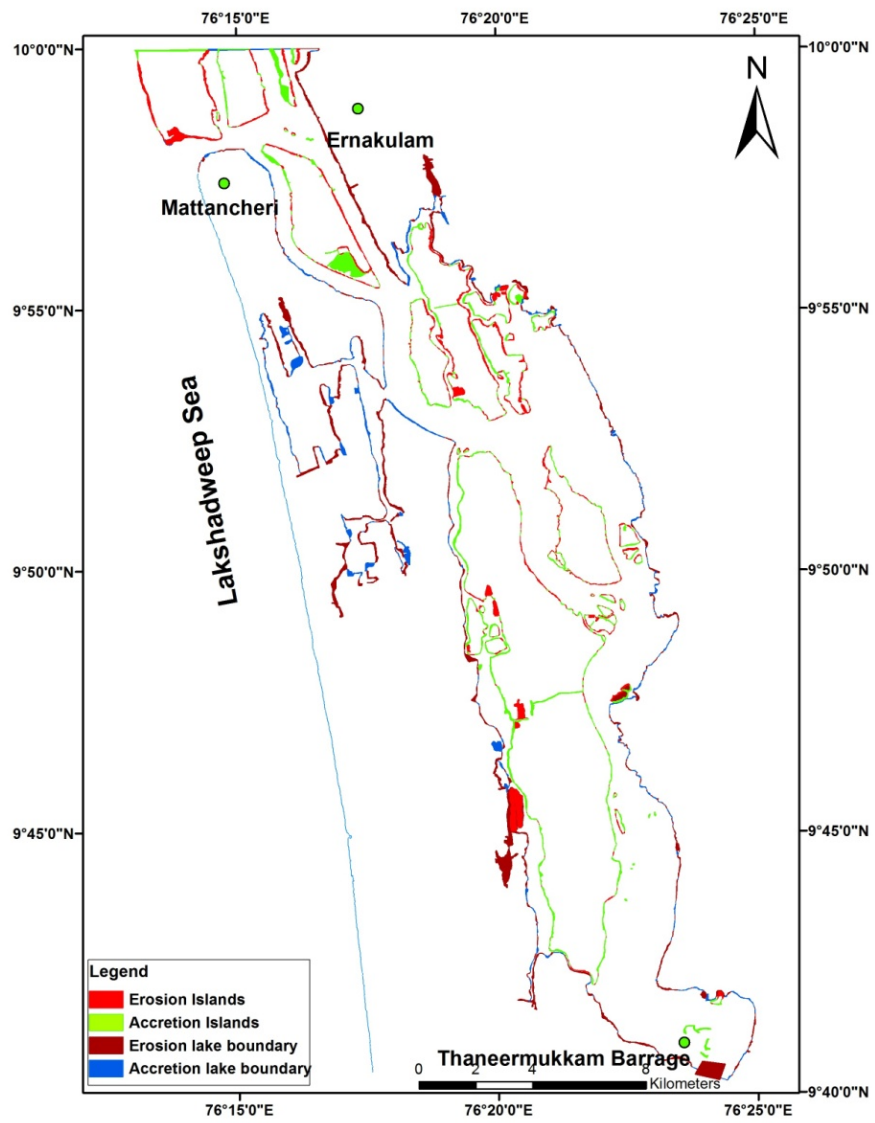
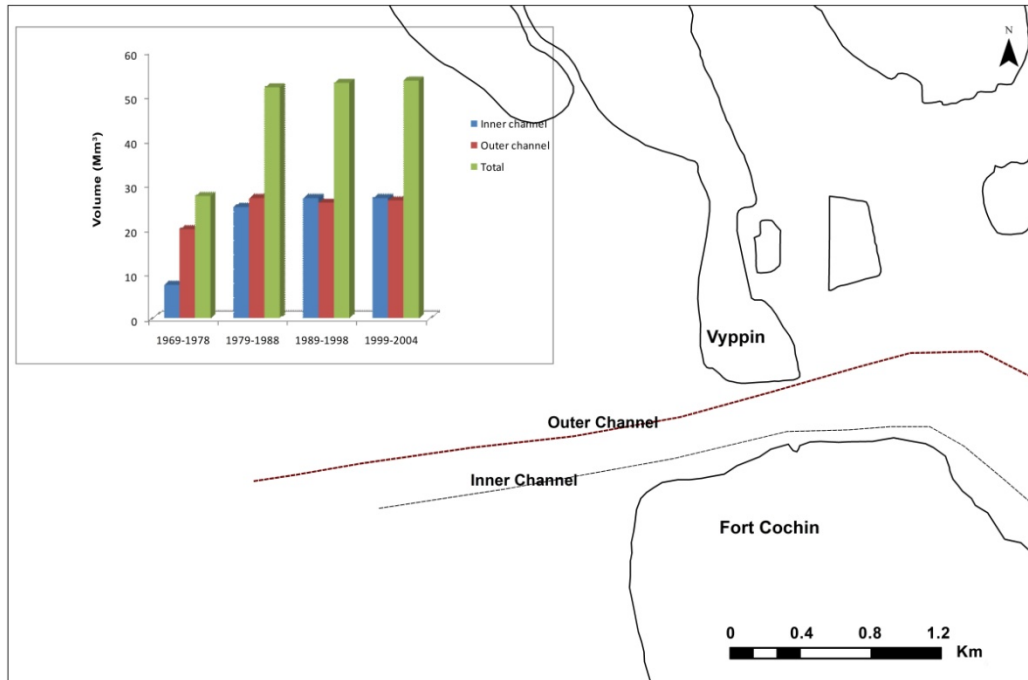


Figure 5



**Figure 6**

Table 1

<b>MAJOR ISLANDS</b>	<b>1967</b> <b>(Area in km<sup>2</sup>)</b>	<b>2004</b> <b>(Area in km<sup>2</sup>)</b>	<b>2011</b> <b>(Area in km<sup>2</sup>)</b>
VALLARPADAM	2.0462	3.4197	2.615
VYPPIN ISLAND	3.271	7.0849	6.847
BOLGATTY ISLAND	0.4696	0.505	0.7085
WILLINGTON ISLAND	6.4033	7.13522	7.68895
PERUBALAM	5.7585	5.814	5.79347
KUMBALAM	3.1928	3.1586	3.10156
NETTUR_MADAVANA	7.99695	8.269	8.03858
CHEPPANUM_CHOTTAMMEL	2.36526	2.3665	2.2934
ARUKKUTI_THAIKKATUSSERI	45.22	46.21	46.80

Table 2

Islands in Cochin estuary	Area	
	1967-2011	2004-2011
EROSION	3.07 km <sup>2</sup>	3.28km <sup>2</sup>
ACCRETION	11.01 km <sup>2</sup>	3.55km <sup>2</sup>

Table 3

Observations	Area	
	1967-2011	2004-2011
EROSION	18.5km <sup>2</sup>	5.66 km <sup>2</sup>
ACCRETION	5.9 km <sup>2</sup>	2.40 km <sup>2</sup>