TEMPORAL CHANGES ON EROSION PROCESS ALONG PONNANI COAST, KERALA MULTI-TEMPORAL REMOTE SENSING IMAGE ASSESSMENT AND GIS

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Abstract - A study of coastal erosion along the Ponnani coast using multispectral imageries and GIS was undertaken to assess the temporal changes in coastal erosion, its extent, magnitude and trends in the region under study. The study utilized medium resolution LANDSAT imageries for the mapping and monitoring of the coastline erosion. The digital image processing software used for calculating the erosion rate was TNTmips 2014 professional version (Map and Image Processing System - MIPS) by MicroImages, Inc. The study revealed the usability of multispectral satellite imageries like that obtained from LANDSAT, IRS etc. satellites in assessing the temporal changes along the coastline by the combined application of remote sensing and GIS techniques. Both long-term and short-term erosion assessment showed that many places along the Ponnani shoreline are under severe erosion. Short-term erosion assessment revealed that many places were having coastal erosion rates more than -4 m/year. The impact of these shoreline protection structures and coastal processes on erosion process was also taken in to account in this study. The study revealed that Ponnani is an actively eroding coast with fluctuating erosion rates. The erosion rates were found to be high with a rate more than -4 m/year for about 35 km of the coastline considered.

Keywords - Remote sensing, Shoreline, Coastal erosion, Net Shoreline Movement, multispectral images

I. INTRODUCTION

The coastal zone is a complex environment, where the saltwater of the ocean meets the freshwater and/or the land meets the ocean. The coast was defined as "that space in which terrestrial environments influence marine environments and vice versa" [6]. The coastal zone represents varied and highly productive ecosystems such as mangroves, coral reefs, sea grasses and sand dunes. The coastal ecosystems harbour a wealth of species and genetic diversity, store and cycle nutrients, filter pollutants and help to protect shorelines from erosion and storms.

The coastal area is a highly dynamic environment with many physical processes such as tidal inundation, sea level rise, land subsidence, erosion, and sedimentation; these processes play an important role in the shoreline change and coastal landscape development [7]. The shoreline, which is defined as the position of the land-water interface at one instant in time is a highly dynamic feature and is an indicator for the coastal erosion and accretion[8]. The wearing down of the top surface of the land is called erosion, while accretion denote the building up of the loose materials at a place.

The coastal erosion is prevalent in over 70% of the world’s beaches and it is a serious hazard to many coastal regions (Addo et al., 2011). The loss of land mass due to the backward movement of sand towards the ocean as a result of the actions of natural forces like wind, tides, waves, and the ocean currents etc. changes the shoreline. Ministry of Earth Sciences, Hyderabad (2009) reported that In India about 40% of 7517 km long shoreline is affected by various degree of erosion varying from minor, moderate to severe. As much as 1248 km of the shoreline is getting eroded all along the coast. As per the report of the Environment and Forests Ministry of Government of India the long-term shoreline change was assessed for a period of 38 years from 1972-2010 and accordingly, 480 km of
the 569 km shoreline of Kerala is subjected to coastal erosion ranging from low, medium to high. Thus around 63% of Kerala coast (sum of high, medium, low and artificial coast) is being affected by the phenomenon. Sea coast of Ponnani area in Kerala, India has been facing erosion. There are several houses of especially fisher men near to the coastal area, which are facing threat of destruction due to sea erosion. This region is considered for this particular study to understand the extent and magnitude of the erosion problem and to suggest steps to prevent erosion. It is very important to study the erosion and accretion processes along the coast in order to develop proper erosion control measures.

In order to ensure sustainable development, it is necessary to develop accurate, up-to-date and comprehensive scientific databases on habitats, protected areas, water quality, and environmental indicators and carry out periodic assessment of the health of the system. Coastal zone monitoring and mapping can be accomplished with the aid of remote sensing, GIS and GPS and the results can be used for sustainable management of coastal areas.

II. MATERIALS AND METHODS

2.1 Study area

The study area selected was the coastline near Ponnani in Malappuram district, along the central coastline of Kerala extending from Kuttayi (10°51’31” N, 75°53’44” E) in the North to Chavakkad (10°33’21” N, 76°0’57” E) in the South. Ponnani is a sea shore town situated at the mouth of Bharathapuzha (Nila River), bounded by the Arabian Sea on the west and estuaries and backwaters on the northern side. This ancient scenic coastal town is located at around 10° 46′ 3″ N Latitude and 75° 55′ 30″ E Longitude. It has an average elevation of five metres above MSL and it is also the smallest taluk of the district. The major source of income for the people in the coastline is fishing. The additional source of income is agriculture involving rice, coconut and arecanut as the main cultivars. The tidal port at Ponnani is an important fishing harbour and houses the office of the Malappuram district fisheries board.

The Bharathapuzha river is the second longest river of Kerala, originating from the Anamalai Hills (1964 m above mean sea level) in the Western Ghats. The river below the confluence of Bharathapuzha and Gayathripuzha is also called the Ponnani river. Bharathapuzha flows through the
districts of Palakkad, Malappuram and Thrissur and drains into the Lakshadweep Sea near Ponnani town in Malappuram district.

There are several beaches along the Ponnani coastline. Padinjarekkara beach is the tidal mouth of Bharathapuzha where Bharathapuzha and Tirur river join and drains into the Arabian Sea. The major fishing harbour of Ponnani is situated on the southern side of the mouth of the Bharathapuzha river. Padinjarekkara beach is a beautiful, clean and unpolluted beach which forms the habitat of several migratory birds during the months of February and March. Veliyamcode beach is situated towards the south of the mouth of one of the tributaries of Bharathapuzha river. The whole beach is protected by sea wall, with some frontal beach left. Perumbadappu beach is situated just south of the Veliyamcode beach. Here the coast is considerably wider than that at Veliyamcode. The sea wall is 20-25 m away from the sea. The coastal area between Kuttayi and Chavakkad was considered for the study and the coastal area in between these two places was divided into 10 coastal zones like:

1) Kuttayi,
2) Padinjarekkara Azhimukham
3) Ponnani
4) Puthuponnani
5) Veliyamcode
6) Palappetty
7) Andathode
8) Punnayur
9) Edakkazhiyur and
10) Chavakkad

The Ponnani coast that extends over a length of 35 km between Kuttayi and Chavakkad which is interspersed with rivers, unprotected coast and coast with man-made sea erosion protection structures was considered for assessment of erosion. The Malabar Coast is generally rocky and lateritic on crystalline and tertiary formations with alluvial patches, but the Ponnani stretch is composed of purely alluvium. Alluvial soils are soils of the low lands and are mainly seen along the coastal plains and valleys. The texture of these soils range from exclusively drained to moderately well drained sand to sandy clay in nature.

The most potential aquifer in Malappuram district is alluvial aquifer. The coastal alluvium is essentially composed of sand, silt and clay. The ground water in these aquifers occurs under water table conditions. The domestic and agricultural needs of water are met by a large number of dug wells and filter point wells tapping this aquifer. The coastal alluvium aquifer can sustain medium to heavy duty pumping. Wherever the saturated sand thickness exceeds 5 m along the coast, filter point wells are feasible. Such potential areas for filter point wells are seen around Ponnani, Chamravattom, Mangalam, B.P Angadi, and Tirur. Open dug wells and shallow tube wells are feasible in the stretch of riverine alluvium with considerable thickness seen along the northern side of the Bharathapuzha River.

Landsat Thematic Mapper (TM) imageries of the coast of Ponnani region acquired for different time periods from 1999 up to June 2014 were used for the long-term erosion and accretion assessment. The short-term changes in erosion and accretion were analysed using multi-temporal images for periods of 1999-2000, 2002-2003, 2005-2006, 2008-2009, and 2013-2014. Landsat Thematic Mapper (TM) imageries have 30 m spatial resolution and are composed of seven spectral bands, namely blue, green, red, near IR, mid IR, SWIR and thermal IR. The Landsat imageries were downloaded using the geospatial search engine of United States Geological Survey (USGS) called “Earth Explorer”.

2.2 Image data processing False colour composites with different bands were tested for visualisation of the shoreline. Band 4 was found to be most effective for mapping shoreline and this was used for
the coastline extraction. Image pre-processing and coastal erosion assessment were carried out using the TNTmips software.

Landsat Thematic Mapper (TM) imageries of the coast of Ponnani region acquired for different time periods from 1999 up to June 2014 were used for the long-term erosion and accretion assessment. False colour composites with different bands were tested for visualisation of the shoreline. Band 4 was found to be most effective for mapping shoreline and this was used for the coastline extraction. Image pre-processing and coastal erosion assessment were carried out using the TNTmips software. TNTmips is a robust, full-featured GIS and image processing system. TNTmips has exactly the same features for Windows and Mac OS X and is available for both 32- and 64-bit systems.

The spatial filters used to obtain the discrete line between land and water were:

a) Grayscale LACE filter for enhancement of spatially varying contrast
b) P-median filter for noise reduction and
c) Volterra / unsharp Filter for edge enhancement of the imageries.

An SML script that generates transects, or lines orthogonal to a shore baseline, has been developed for use with TNT products. A baseline and at least two subsequent shoreline measurements are all that is required to produce transects (lines orthogonal to the baseline) with associated erosion rates. The erosion rate along each transect is provided as a DataTip over the transect.

Multitemporal Landsat TM imageries of 1999 and 2015 were used for analysing erosion trend analysis along the coast for periods of 1999-2000, 2002-2003, 2005-2006, 2008-2009, 2013-2014, and 2015-2016. The erosion rates are recorded as both an end point rate and a mean rate along each transect. The landward movement of the shoreline (erosion) was expressed as a negative number in this system. The End Point Rate (EPR) reflects the length along a transect between the earliest and most recent shorelines and the time between these two shoreline positions. If the distance along a transect between the earliest and most recent shorelines.

III. RESULTS AND DISCUSSIONS

The temporal changes on the erosion process along the coast of Ponnani was assessed to determine both long term and short term changes, using multi-temporal multispectral remote sensing image assessment and GIS. Imageries of 1999 and 2014 were used for long term assessment and imageries for the period 1999-2000, 2002-2003, 2005-2006, 2008-2009 and 2013-2014 were used for short term assessment of erosion. The image processing software used for this study was TNT mips® by MicroImages Inc. ©.

3.1 Long-term assessment of erosion

Ponnani coast was divided into 10 coastal zones: Kuttayi, Padinjarekkara Azhimukham, Ponnani, Puthuponnani, Veliyamcode, Palappetty, Andathode, Punnayur, Edakkazhiyur and Chavakkad. The estimation of long-term erosional process along Ponnani coast was carried out by calculating mean erosion rate at each coastal zone. The variation of erosion is shown in Table 3.1 and Fig. 3.1. The negative values represent erosion and positive values represent sand deposition or accretion.

| Place                      | Erosion (m/year) | Accretion (m/year) |
|----------------------------|------------------|--------------------|
| Kuttayi                    | -1.18            | 0.78               |
| Padinjarekkara Azhimukham  | -1.14            | 1.12               |
| Ponnani                    | -1.42            | 1.31               |
| Puthuponnani               | -2.74            | 1.1                |
The net rate of erosion along the coast during 1999-2014 was estimated as -2.18 m/year. This value reveals there have been significant changes along the coastal area during this 15 years period under study. Among the coastal zones Palappetty coast was having the highest erosion rate of -3.71 m/year and Padinjarekkara coast was having the lowest observed erosion rate. Ponnani, Puthuponnani, Veliyamcode and Palappetty coastal zones were found to have erosion rates of -2.42 m/year, -2.74 m/year, -3.39 m/year, and -3.71 m/year respectively. It was observed that around 36% of the coast experienced severe erosion.

The erosion rate assessment between 1999 and 2014 showed that the entire coast is eroding, even though there were some places with accretional process. Some areas in each coastal zone were found to have deposition of sand. But the mean rate of accretion was found to be very less when compared with the erosion rate around that place. The results show that sand deposition rate is maximum at the Ponnani coastal zone with a rate of 1.31 m/year and minimum at Kuttayi with a rate of 0.78 m/year.

Thus the long-term erosion assessment revealed that various zones of the coastal area between Ponnani and Chavakkad were facing severe erosion during the period of assessment. Even though some areas in these zones had experienced the accretion process, it was having very little effect on the net erosion as the entire Ponnani coast other than these areas is predominantly erosive.
Now, most of the coastal area is protected with sea erosion control structures. The fifteen year time duration of the analysis cover periods before and after the construction of the sea erosion control structures along the coast. Hence to better understand the influence of these structures on erosion/accretion rates and the seasonal variations in erosion process, erosion/accretion rates for different short term periods within the fifteen year period was also calculated.

3.2 Short-term assessment of erosion

The landward shifting of coastline during five different periods was explored for calculating the site specific erosion rates. There were interventions to stabilize the shoreline such as Sea Erosion protection structures (sea wall) by Water resources (Irrigation) Department, Government of Kerala, along the different erosion zones considered. This shoreline protection measures influenced the erosion pattern along the coast. Sea Erosion Prevention Work commenced along the Ponnani coastline in the year 2002, with breakwater structure at Padinjarekkara Azhimukham and sea wall along the coast between Ponnani and Puthuponnani. Kuttayi, Andathode, Punnayur, and Edakkazhiyur coastal zones are without any erosion protection structures while coastal zones of Padinjarekkara, parts of Ponnani, Puthuponnani, Veliyamcode, Palappetty, and Chavakkad are protected with sea wall. Eventhough some parts of this coast are protected with sea wall the long gap between the structure along the stretch was found under severe erosion and this may be one of the reason in higher erosion rates along the coasts with sea wall.

Shoreline changes were calculated for different time periods of 1999-2000, 2002-2003, 2005-2006, 2008-2009 and 2013-2014. Erosion trend analysis of each coastal zone was also conducted. Before 2002, places between Kuttayi and Palappetty had severe erosion and all other coastal zones were having an average erosion rate of -1.5 m/year. But after sea erosion prevention work was undertaken, Kuttayi, Padinjarekkara and Ponnani coastal zones were observed to have reduced erosion rates than that in Puthuponnani, Veliyamcode and Palappetty. The coastal zones protected with sea wall had reduced erosion rates whereas places without any protective structure continued to erode at higher rates. The short-term assessment of erosion is given in the Table 3.2.

Table 3.2 Short-term variation of erosion during different periods

| Place          | 1999-2000 (m/year) | 2002-2003 (m/year) | 2005-2006 (m/year) | 2008-2009 (m/year) | 2013-2014 (m/year) |
|----------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| Kuttayi        | -3.82              | -1.21              | -1.42              | -1.23              | -1.46              |
| Padinjarekkara | -6.74              | -3.13              | -1.19              | -1.02              | -0.91              |
| Ponnani        | -5.97              | -3.99              | -2.42              | -2.94              | -3.86              |
| Puthuponnani   | -5.39              | -3.55              | -3.94              | -4.12              | -4.59              |
| Veliyamcode    | -5.84              | -3.64              | -3.68              | -4.72              | -3.58              |
| Palappetty     | -4.78              | -3.47              | -3.83              | -4.04              | -3.19              |
| Andathode      | -2.36              | -1.25              | -2.21              | -2.42              | -2.51              |
| Punnayur       | -1.56              | -1.78              | -1.22              | -2.15              | -1.38              |
| Edakkazhiyur   | -0.99              | -1.05              | -0.25              | -1.09              | -0.92              |
| Chavakkad      | -4.04              | -3.67              | -3.91              | -3.87              | -3.03              |
The maximum erosion rate (-6.74 m/year) during the 15 years of study was observed in Padinjarekkara during 1999-2000 and the minimum erosion rate of -0.25 m/year was at Edakkazhiyur during 2013-2014. The long-term erosion analysis results showed that the places between Padinjarekkara and Palappetty were having more erosion rates compared to the other coastal zones. After 2000 these areas had experienced higher erosion rates more than -4 m/year and along with these places, Andathode and Punnayur also experienced more erosion than what they had in previous years. Among the different time periods considered, the period between 1999 and 2000 corresponded with maximum erosion rates in almost all the coastal zones. Padinjarekkara, Ponnani, Puthuponnani, Veliyamcode, Palappetty and Chavakkad coastal zones were observed to have high erosion rates with an average rate of -5.7 m/year and the minimum erosion rate was found at Edakkazhiyur with a rate of -0.99 during the same period.

Erosion at Puthuponnani coast showed continuous erosion every year with a decreasing trend from 1999 to 2011 and a sudden increase in rate in 2013. This may be due to the entry of surging waves to the land through the gaps formed in the sea wall [3].

At many places along this zone, the sea wall is destroyed by the high energy waves and the remains are ineffective in controlling the erosion. It was reported that steps are being taken to reconstruct the sea walls destroyed in sea erosion at Beevi and Marakadvu Masjids in Ponnani coast [2].

From Table 4.2, it is clear that Ponnani, Puthuponnani, Veliyamcode, Palappetty and Chavakkad are the coastal zones experiencing notable erosion rates. Table 4.2 reveals that the erosive coasts have almost three times more erosion rates than that of the other areas.
Figure 4.2 shows that after 2005-2006, erosion rates gradually reduced from that during 1999-2000. The highest variation in erosion rates with time was observed in Padinjarekkara, where there was maximum erosion rate among different coastal zones. Kuttayi and Ponnani, the coastal zones on either side of the Padinjarekkara Azhimukham, also experienced net reduction in erosion rates from 1999-2000 but during the last two time periods of 2008-2009 and 2013-2014 they had an increasing trend in erosion rates. The trends of erosion rates variation at Puthuponnani, Veliyamcode and Palappetty are somewhat similar as both these zones underwent higher erosion rates during 1999-2000 which further decreased except at Veliyamcode where the erosion rate of -4.59 m/year experienced in 2008-2009 was higher than 2002-2003. Sea erosion at Puthuponnani worsened and the surging sea waves destroyed houses and coconut trees along the coastal belt [1],[3]. Construction of sea wall is intended to protect the upstream end of coastline from erosion; however this also causes increased erosion [9]. An eroding coast supplies sediments to sediment transport. But when the erosion is controlled at certain sections by the establishment of seawalls, the supply of sand from this section of
the shoreline to the sediment transport along the adjacent shorelines will get stopped, thereby the shorelines at the end of structures is exposed to increased erosion [8].

Puthuponnani had a sharp drop in erosion rate from 1999-2000 to 2002-2003 and thereafter a steadily increasing trend. The least erosion rate estimated at Palappetty was -3.19 m/year during 2013-2014 and the maximum rate estimated was -4.78 m/year during 1999-2000. After 2000, this area had experienced higher erosion rate during 2008-2009 and it was estimated as -4.04 m/year. Andathode experienced similar erosion rate trends and the erosion rate estimated was more than -3 m/year. The land degradation at Punnayur was less than that at Andathode but this coast also experienced maximum erosion rate during 2008-2009. Punnayur, Edakkazhiyur and Chavakkad can be classified under high erosion rate areas as the estimated erosion rates are higher in every period. The erosion rates at Chavakkad were less than Puthuponnani and Veliyamcode and it experienced a maximum erosion of -4.04 m/year during 1999-2000. Among all the coastal areas, Edakkazhiyur was found with very less erosion rates compared to all other rates, and it experienced less than -1 m/year in three different periods with a minimum of -0.25 m/year during 2005-2006.

IV. CONCLUSION

A study of coastal erosion along the Ponnani coast using multispectral imageries and GIS was undertaken to assess the temporal changes in coastal erosion, its extent, magnitude and trends in the region under study. The study utilized medium resolution LANDSAT imageries for the mapping and monitoring of the coastline erosion by the combined application of remote sensing and GIS techniques.

The temporal change detection study on coastal erosion along Ponnani shoreline was carried out for the period between year 1999 and 2014 for analysing long term erosion along the coast and short term changes were analysed for periods between 1999-2000, 2002-2003, 2005-2006, 2008-2009, and 2013-2014. Both long-term and short-term erosion assessment showed that many places along the Ponnani shoreline are under severe erosion. Ponnani, Puthuponnani, Veliyamcode, Palappetty and Chavakkad are the zones identified with higher erosion rates. There were many places like Kuttayi, Padinjarekkara, Andathode, Punnayur and Edakkazhiyur with low erosion rates. The highest coastal erosion rate of -3.71 m/year in the long-term erosion assessment was observed at Palappetty. However, short-term erosion assessment revealed that many places were having coastal erosion rates more than -4 m/year. During 1999-2000, highest erosion rates were observed in almost all the zones, but after this period only three coastal zones have experienced more erosion than this. Hence the objectives of the study to apply remote sensing to assess the temporal changes occurred along the coastal areas of Ponnani, to determine the shoreline changes using digital change detection techniques and to study the extent and magnitude of the coastal erosion occurred were achieved.

The coastal erosion rates along the Ponnani shoreline are not only affected by hydrodynamic processes such as tidal fluctuation, high energy waves, littoral flows, and wind but also these are affected by other factors like coastal slope and existence of artificial structures. This is because the coastline is sensitive to coastal processes. Activities along the coast such as construction of buildings after filling and reclamation of low land, port development, establishment of sea wall etc. were found to have long-term impacts on the coastal accretion rates. The occurrence of high energy waves during monsoon season is the main reason for severe erosion occurring along the Ponnani coast. There are gaps in the shoreline protection structures due to their destruction and these areas were observed to have increased erosion rates, since there are no shoreline protection measures. The destruction of these structures at specific spots may be due to the variations that have occurred in the equilibrium of sediment transport before and after the construction of the erosion control structures. The construction of shoreline protection structures might have caused increment in the depth of water near the sea walls, resulting in the formation of high energy waves and subsequent destruction of the structures. The results of the analysis show that the coastline of Ponnani is very dynamic and the accretion rates
fluctuate seasonally and that many coastal processes as well as anthropogenic factors influence the change in this coast.

The coastal erosion study using remote sensing and GIS techniques provided realistic information about the erosion process along Ponnani area and this method can be successfully used for mapping and monitoring coastal changes.

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