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Erosion Trend Analysis of Coastline along Ponnani Region Using Multitemporal Images

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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. Results 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 the 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. The areas with accelerated erosion along the coast of Ponnani need sustainable management and protective measures.

Keywords

Remote sensing, GIS, Coastal erosion, Shoreline change, and Erosion trend analysis

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Introduction

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 (Dey *et al.*, 2002). The coastal zone of the world is under increasing stress

due to the development of industries, trade and commerce, tourism and resultant human population growth and migration, and deteriorating water quality. The shoreline, which is defined as the position of the land-water interface at one instant in time (Genz *et al.*, 2007) is a highly dynamic feature and is an indicator for the coastal erosion and accretion. Shoreline geometry depends on the interactions between and among waves, tides,

rivers, storms, tectonic and physical processes. Beach erosion and accretion or shifting shorelines and sea-level rise are a chronic problem along most shorelines worldwide since centuries disturbing a dynamic equilibrium.

Developing periodic scientific databases on various environmental indicators such as water quality, problematic areas etc. and carrying out regular assessment and analysis of the condition of the ecosystem is necessary to ensure sustainable development. Coastal zone monitoring, mapping and assessment can be accomplished with the aid of remote sensing, GIS and GPS and the results can be used for sustainable management of coastal areas. The modern spatial technologies of remote sensing, GIS and GPS are extremely valuable in the development of databases and to analyse coastal area periodically in an integrated way and to develop management action plans. Remote sensing technology is useful for assessing the coastal environment and monitoring the changes that have occurred over time in the coastal zone (Nayak, 2000). The availability of synoptic, multitemporal, and multispectral data from various satellite platforms, viz. IRS, LANDSAT, SPOT, etc. has been helping to generate information on varied features of the coastal environment.

Remote Sensing imageries use different wavebands to record the reflected energy from various features of the earth. This technology has been using commonly to map the shoreline and it offers the potential of updating maps frequently (Frihy and Lofty, 1997). These remotely sensed data can be used to evaluate the coastal processes like erosion or accretion and shoreline changes. Remote sensing satellite images have been effectively used for monitoring shoreline changes in different locations (Rao *et al.*, 1984; Alesheikh *et al.*, 2007).

Geographic Information System (GIS) is designed to work with spatial data referenced by geographical coordinates. The major advantage of GIS in assessing the coastal erosion is that it allows identifying the spatial relationships between features and the temporal changes that have occurred within an area over a period. For measuring and monitoring coastal erosion and accretion, satellite imagery is useful in extracting the shorelines, and GIS has been used extensively to overlay multitemporal shoreline maps to detect and visualize the changes over time.

Seacoast of Ponnani area in Malappuram district, Kerala, India has been facing erosion. There are several houses of especially anglers near to the coastal area, which are facing the 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 to develop proper erosion control measures along the coast. The present study was undertaken to apply remote sensing to assess the temporal changes on the coastal areas of Ponnani and to study the extent and magnitude of the coastal erosion over a period of 17 years.

Materials and Methods

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 seashore 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 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 areca nut 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 a seawall, with some frontal beach left. 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:

- Zone 1 - Kuttayi,
- Zone 2 - Padinjarekkara Azhimukham
- Zone 3 - Ponnani
- Zone 4 - Puthuponnani
- Zone 5 - Veliyamcode
- Zone 6 - Palappetty
- Zone 7 - Andathode
- Zone 8 - Punnayur
- Zone 9 - Edakkazhiyur and
- Zone 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 alluvium. Alluvial soils are soils of the low lands and are mainly seen along the coastal plains and valleys. The texture of these soils ranges from exclusively drained to moderately well-drained sand to sandy clay in nature.

Landsat Thematic Mapper (TM) imageries of the coast of Ponnani region acquired for different 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.

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 2014 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 (EPR) 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 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.

Results and Discussion

Erosion trend analysis

The trend in the temporal variation of erosion rates along the study area was explored by estimating the rate of erosion occurred at each coastal zones namely Kuttayi, Padinjarekkara Azhimukham, Ponnani, Puthuponnani, Veliyamcode, Palappetty, Andathode, Punnayur, Edakkazhiyur, and Chavakkad in different periods during the period under study. Data is provided in appendix I. According to the erosion rates, the erosion

affected areas are classified as;

High (Erosion rates more than -4 m/year)
Medium (Erosion rates between -2 and -4 m/year)
Low (Erosion rates between 0 and -2 m/year)

Kuttayi beach lies at the location between 10°51'31" N, 75°53'44"E and 10°48'33" N, 75°54'22" E. This coast is adjacent to Padinjarekkara Azhimukham where the Bharathapuzha and Tirur River joins and drain into the Arabian Sea. This coast was under severe erosion before 2002 with a maximum rate of -3.82 m/year in 1999 and followed by -3.25 m/year in 2001 (Fig. 3). However, after 2003 there was an abrupt reduction in erosion rate, which may be due to the construction of the breakwater at Padinjarekkara, which lead to the deposition of sand near the structure. The Net Shoreline Movement (NSM) that was calculated at this zone was -10.7 m during

the period under study (Table 1). The average landward shift of the shoreline at Kuttayi coast was around 1 m per year. The study of shoreline changes at Kuttayi coastal zone reveals its low erosion rate, which indicates fair stability of the coast.

Padinjarekkara Azhimukham extending between 10°48'33" N, 75°54'22" E and 10°47'09" N, 75°54'42" E was the zone with the maximum erosion rate during the seventeen years under study (Fig. 3). The variation of erosion rate here is having a similar pattern as that of Kuttayi zone in which a drastic variation in shoreline change was identified after 2001. The Net Shoreline Movement was recorded as -11.1 m (Table 1). Ponnani zone lies between 10°47'09" N, 75°54'42" E and 10°45'35" N, 75°55'26" E to the south of the Padinjarekkara zone. Erosion trend analysis along this coast is

given in Fig. 3. Erosion along this coast follows a different pattern than that in Padinjarekkara and Kuttayi zones. The coast was identified with more coastal changes before 2003 and the estimate crossed -4 m/year. Some parts of the coasts are protected with sea wall. After 2003 erosion rate reduced to a value of -2.56 m/year in 2007 and again increased to -2.98 m/year during 2009 and it has reached a high rate of -3.86 m/year in 2013. As in the case of Padinjarekkara coast, Ponnani zone is also categorized as eroding coast. During the seventeen-year study period, the estimated NSM at this coast was -11.3 m (Table 1). A speciality of this coast is the presence of mangroves in this place, which are found distributed over the shores of Ponnani near the fishing harbour.

Puthuponnani coast extends south of Ponnani zone between 10°45'35" N, 75°55'26" E and 10°43'26" N, 75°56'22" E. It is in this zone that the Lake Biyyam joins the Arabian Sea. Like the Ponnani zone, a major portion of the coastline is protected with sea wall except for the stretch where the Biyyam Lake joins the sea. Results (Fig. 3) show a varying pattern over the study period. The coast had higher erosion before 2003 and the reduction in erosion rate after 2003 may be due to the influence of the erected sea wall. The coast has experienced a medium erosion rate of average value -3.25 m/year from 2003 to 2007. This value is almost equal to the rate of erosion that Ponnani zone has experienced in 2002. However, after 2007, the coastline had recorded high erosion rates, which cross -4 m/year during 2009 and 2016, and in 2011 it was -3.62 m/year.

The NSM recorded at this zone was -11.1 m (Table 1) that indicated that the coastline has reached the sea wall, which was 10-15 m away from the sea, initially. This means that the coastline without protection has advanced 11 m landward during the seventeen years of

the study period and this landward advancement was found to be more near the point where the Lake Biyyam joins the sea. This coastal zone is also categorized under the eroding coast.

Veliyamcode beach is located to the south of Puthuponnani area and lies between 10°43'26" N, 75°56'22" E and 10°42'27" N, 75°56'50" E. Fig. 3 shows that Veliyamcode is an eroding coast. During 1999-2002 rate of erosion was recorded as more than -4 m/year with maximum erosion in 1999. In 2003 the coastal change was found to be -2.65 m/year and reached a minimum change in 2005 with a rate of -2.03 m/year. The erosion rate observed has increased in 2007 and followed by more coastal changes in the proceeding periods. After 2007, the coast has undergone a higher erosion rate in the year 2009 with an estimated erosion rate of -3.81 m/year. The NSM recorded at this place was -10.85 m (Table 1). Veliyamcode zone is also categorized under the eroding coasts.

Palappetty coast extends south of Veliyamcode between 10°42'27" N, 75°56'50" E and 10°41'10" N, 75°57'22" E. The erosion pattern along this coast is somewhat similar to the Veliyamcode zone. The coast has experienced maximum erosion during 1999 with a rate -4.78 m/year and followed by a gradually reduced shoreline change until 2005 (Fig. 4). After this period, erosion was found to be increasing and reached a higher value in 2009 like in the Veliyamcode zone. However, a sudden reduction in erosion was noted in 2011, which was -2.15 m/year, and again in 2016, it has increased to -3.26 m/year. Palappetty is a place that undergoes severe erosion during every monsoon season. In this study, this region had recorded a higher erosion rate during 2009. Like the other four coastal zones, this place also is coming under the eroding coast category with NSM of -15.65 m

in the period under study (Table 1).

Location of Andathode coast is between 10°41'10" N, 75°57'22" E and 10°39'44" N, 75°58'02"E to the south of Palappetty coast. Analysis (Fig. 3) shows that this area is not under severe erosion as the coast has not experienced erosion rate more than -2.5 m/year. The maximum erosion estimated along the coastline was -2.36 m/year in 1999 in which all other coasts have experienced highest erosion. From 1999 to 2007, the erosion rates reduced gradually with an increase in 2005. In 2009, the year in which all the previous coast zones also experienced comparatively high erosion, this coast was found to have an erosion rate of -1.98 m/year which is the maximum rate after 2001. The results reveal that Andathode coast was under medium erosion with estimated NSM of -7.3 m (Table 1). In this zone, the area where people live and cultivate is away from the coastline, thus avoiding the threat of destruction, as seawater does not reach this area. This is not an artificial coast and is categorized under low erosion areas.

Punnayur zone lies to the south of Andathode zone between 10°33'44" N, 75°58'02"E and 10°37'45" N, 75°58'53" E. Erosion pattern

over this area is different from other zones. This area has not experienced erosion more than -2 m/year except in 2009 (Fig. 4). During 1999, the coast has undergone less erosion with a rate -1.56 m/year and up to 2003 erosion was gradually increasing to a value of -1.78 m/year. During 2005-2007, erosion was very less which again increased to a maximum rate of 2.02 m/year. Seawater entered into few houses and caused the loss of properties (Anon., 2012) in the monsoon season. Punnayur coast is the place identified with more erosion than that in 1999. The NSM calculated for this coast was -8.9 m and is categorized under low erosion areas (Table 1).

Location of Edakkazhiyur coast is between 10°37'45" N, 75°58'53" E and 10°35'29" N, 75°59'59" E and it is situated to the south of Punnayur area. The erosion trend analysis (Fig. 4) along this area reveals that it had a maximum rate of erosion during 2009 and this value crossed erosion rate during 1999 like in the case of Punnayur coast. But the highest erosion rate recorded in this area was -1.59 m/year, which is comparatively low. From 2005 to 2013 the coastline has undergone almost similar erosion process with an increase in 2009.

Table.1 Net Shoreline Movement in the coastal zones

Place	Erosion (m/year)	Accretion (m/year)	NSM (m)
Kuttayi	-1.18	0.78	-10.7
Padinjarekkara	-1.14	1.12	-11.1
Ponmani	-1.42	1.25	-11.3
Puthuponnani	-2.74	1.1	-11.1
Veliyancode	-3.39	1.32	-10.85
Palappetty	-3.71	1.56	-15.65
Andathode	-1.82	1.15	-07.3
Punnayur	-1.26	0.96	-08.9
Edakkazhiyur	-1.35	1.16	-05.25
Chavakkad	-2.45	1.14	-05.75

Figure.1 Study area

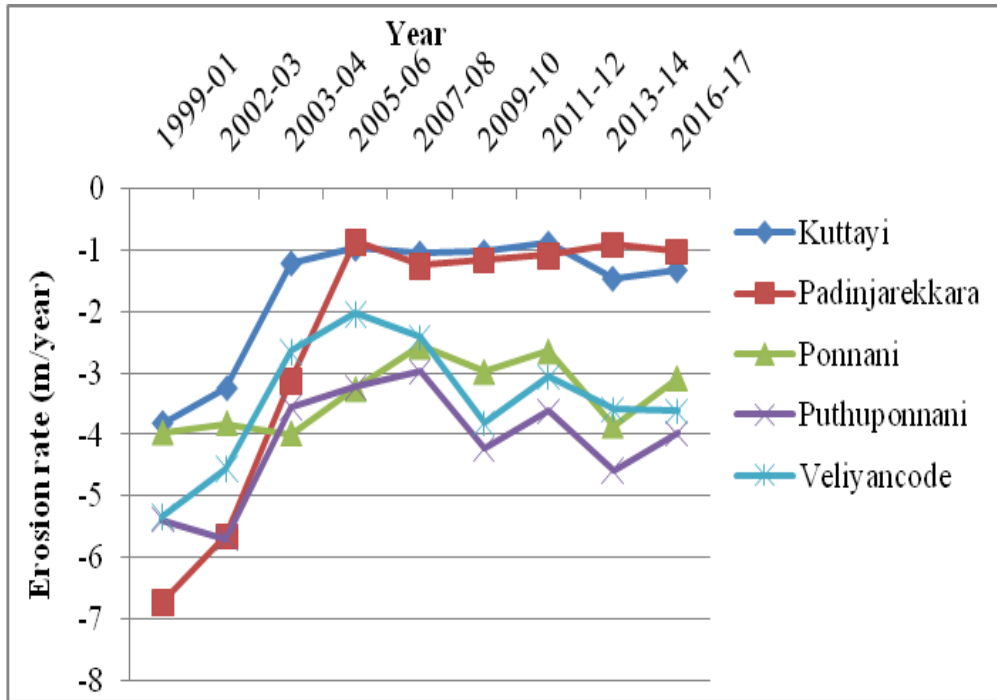


Figure.2 Erosion assessment by creating transects

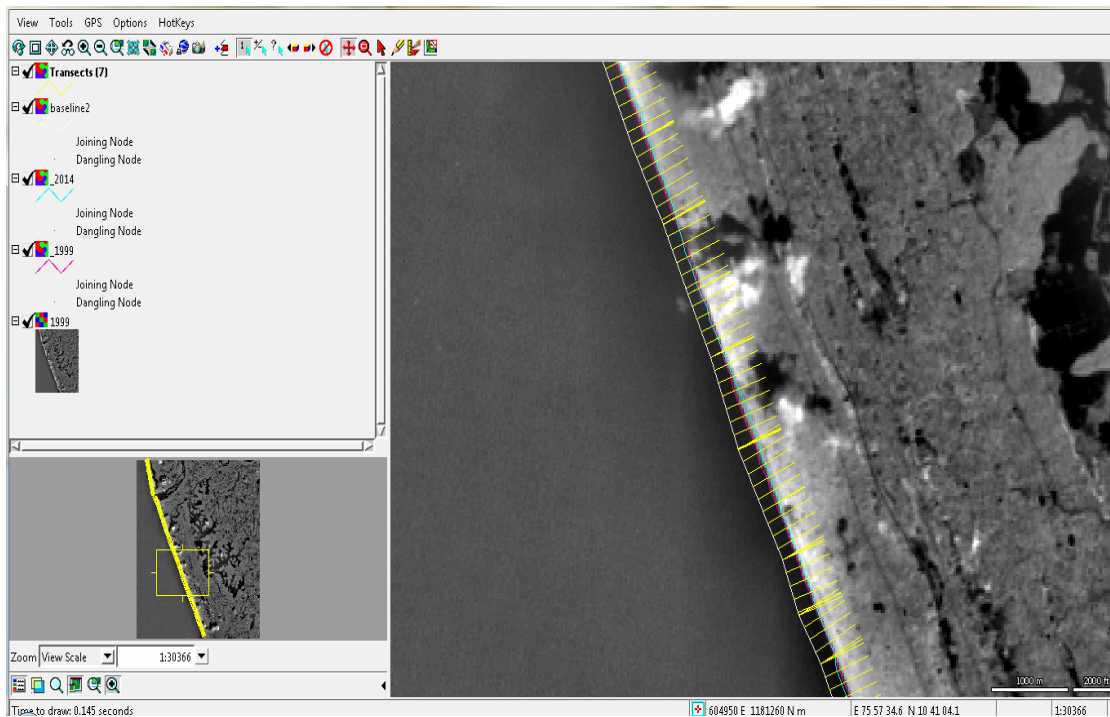


Figure.3 Erosion trend of Zone 1 to 5

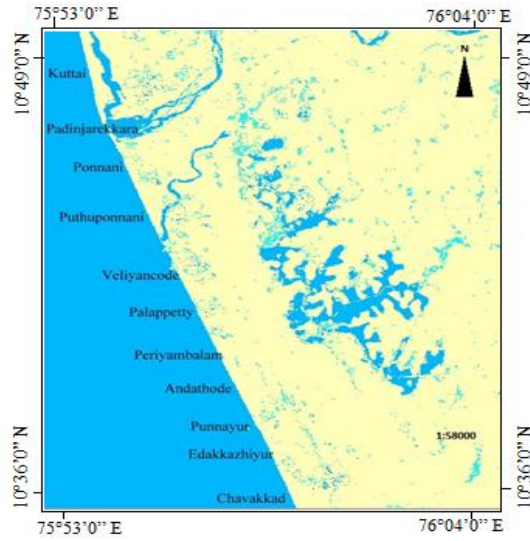


Figure.4 Erosion trend of Zone 6 to 10

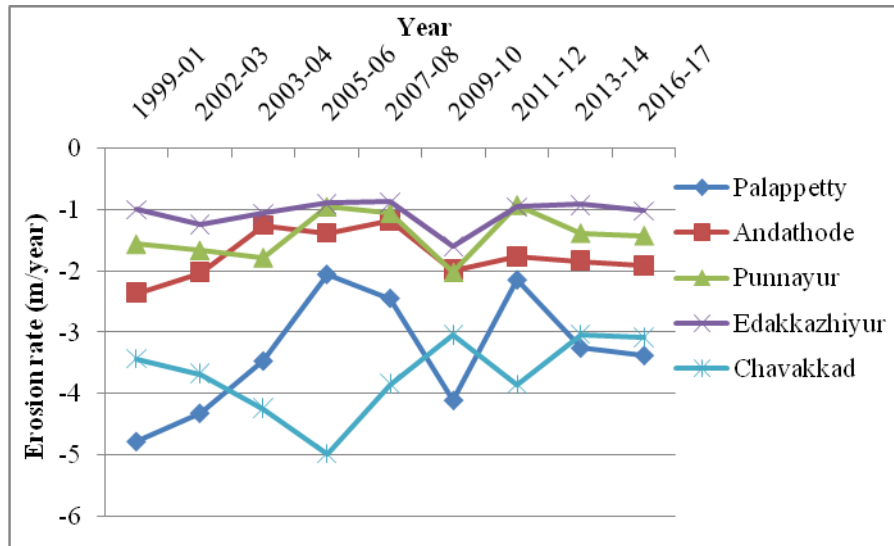


Figure.5 Erosion at the end of the structure



Figure.6 Damaged sea wall at Veliyamcode coast



The NSM calculated in this zone was -5.25 m and this zone is coming under low erosion areas (Table 1). Chavakkad zone lies to the south of Edakkazhiyur coast between 10°35'29" N, 75°59'59" E and 10°33'21" N, 76°0'57" E. This coast has experienced erosion rate more than -4 m/year. The NSM estimated for this area was -5.75 m during the 15 years under study (Table 1). The highest rate of erosion calculated along the coast was -4.98 m/year in 2005 (Fig. 4). After this, erosion recorded was found to be less than -4 m/year in 2007 and 2011 but an increasing trend was observed after 2013. The average erosion was much more on this coast, compared to Edakkazhiyur. This coast is also categorized under eroding coasts and the higher erosion rate over this area is a matter of concern.

The overall analysis of the extent of erosion by direct inspection at various parts (Ponnani, Bharathapuzha River mouth, Veliyancode and Palappetty zone and Periyambalam beach in Punnayur zone) of study area revealed that many parts of the shoreline with or without protection are under the threat of accelerated erosion. Analysis of erosion trend along Ponnani coast showed continuous erosion every year with a decreasing trend from 1999

to 2011 and a sudden increase in the rate in 2013. This may be due to the entry of surging waves to the land through the gaps formed in the sea wall (Anon, 2013). During every monsoon season, people along the coastal belt here face the threat of destruction by the furious waves.

The estuary here is protected against erosion with the aid of two breakwaters of 780 m (north) and 570 m (south) constructed with a centre-to-centre distance of 270 m. It was observed that there was a tremendous reduction in the coastal changes after the establishment of the breakwaters in the estuary. The analysis of the shoreline change data shows that there is considerable accretion and net advancement of coastline on the north breakwater (between Kuttayi and Padinjarekkara) and net erosion on the south of southern breakwater (Ponnani). Similar result has been reported by Tang *et al.*, (2017). The estimate of the erosion trend of the estuary in the present study is analogous to the results reported in two other previous studies (Kunhimammu *et al.*, 2008 and Ramesh *et al.*, 2013). As this is a protected shoreline, it is an artificial coast and even though the zone is provided with erosion control structures, it is an eroding coast. The

rise of sea level during monsoon is more in this area, leading to high erosive velocities of waves but the breakwaters ensure protection along the coast.

Out of the 35 km coastal stretch under study, around 10 km stretch is protected with sea wall. Construction of sea wall is intended to protect the upstream end of coastline from erosion; however, this also causes increased erosion. 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. The increased depth of water near the sea wall will produce high-energy waves causing destruction of the structure as the waves gets stronger. The increased erosion rates after 2009 may be due to the destruction of the sea wall and here the inadequacy of the present sea wall to resist the high-energy waves can be recognised. Inadequacy of seawall due to scouring has been reported by Ahmad *et al.*, (2019).

Construction of sea wall is intended to protect the upstream end of coastline from erosion; however, this also caused increased erosion in some parts of the coast. 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. The increased depth of water near the sea wall will produce high-energy waves causing destruction of the structure as the waves gets stronger. Bush *et al.*, (2004), and French *et al.*, (2001) have also reported similar process.

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 in Ponnani coast (Anon., 2009). The mangrove forest present in the coast was found to be not effective on the eroding process, as it could not significantly dissipate the wave energy. Similar results have been reported by Ngyuen and Luong (2019). Mangroves were identified along the banks of Tirur River also but it has no role in controlling the coastal erosion. Mangroves can reduce erosion as they store water for long periods and their capacity during heavy rainfall to retain excess floodwater results in maintaining a constant flow as well as less erosive effects of sea waves (Triyanti *et al.*, 2017). However, there is no significant cover of mangroves there to have an impact on the coastal erosion and at present; the mangroves in Ponnani are nearing extinction.

Sea erosion at Puthuponnani worsened and the surging sea waves destroyed houses and coconut trees along the coastal belt (Anon, 2012; Anon, 2013). High erosion rate was observed along Puthuponnani coast during this period. The fluctuating coastal erosion due to wave action along the southwest coast of Kanyakumari has been reported by Kaliraj *et al.*, (2013). Sea wall at different parts along Veliyamcode coastline was found to be damaged (Anon., 2009).

Damage of many houses, sea wall and uprooting of several trees due to tidal waves during monsoon season were reported by Anon, 2004 and Anon, 2012. However, attempts to form a green wall with casuarinas did not yield the expected results, as the lashing tidal waves uprooted most of them. This shows that the already built structure was inadequate to resist the erosive high-energy waves in this coastline. During the time of

monsoon, destruction of trees, houses, and sea wall occurs every year in this zone.

In conclusion, the Ponnani coast was found to an active eroding coast. The highest coastal erosion rate of -3.71 m/year in the long-term erosion assessment was observed at Palappetty. 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.

The erosion trend analysis shows that the erosion rate is decreasing from the point of commencement of the breakwater at the mouth of the Bharathapuzha River to the Southern side where shoreline protection structures are in place. However, it was found that these structures could not withstand the continued severe erosive action of the wave action during the monsoon season, failing these structures at many places causing loss of life and property along the coast during fierce monsoon climate. This indicates that the accelerated erosion at these spots led to the instability of the structure and additional measures are required at these spots.

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