

# Coastal morphology and beach stability along Thiruvananthapuram, south-west coast of India

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**Abstract** Shoreline changes are largely dependent on coastal morphology. South-west coast of India is a high energy coast characterised by monsoon high waves, steep beach face and medium-sized beach sand. Waves are generally from west and west south-west during rough monsoon season and from south-west during fair weather season. Shoreline change along this coast is studied with reference to coastal morphological features. Various morphological features, modifications and chronological positions of shoreline are analysed with the information derived from multidated satellite imageries, toposheets and GPS shoreline mapping along with extended field survey. Image processing and GIS techniques have been used for the analysis of data and presentation of results. Sediment accumulation on the leeward side of artificial structures such as harbour breakwaters and groynes is used as a sediment transport indicator. Artificial structures such as seawalls, groynes and harbour breakwaters modify morphology. Shoreline south of headlands/promontories and breakwaters are stable or accreting due to net northerly longshore sediment transport while erosion tendency is observed on the north side. Lateritic cliffs fronting the sea or with seasonal beach undergo slumping and cliff edge retreat as episodic events. Spits adjoining tidal inlets are prone to shoreline variations due to oscillations of inlet mouth. Interventions in the form of inlet stabilization and construction of coastal protection structures trigger erosion along adjoining coasts. Seawalls constructed along highly eroding coasts get damaged, whereas those constructed along monsoon berm crest with frontal beaches for protection against monsoon wave attack are retained. Fishing gaps within seawalls are areas of severe temporary erosion during rough monsoon season. Accretion or erosion accompanies construction of harbour breakwaters in a stable coastal plain. Close dependence of shoreline changes on morphology necessitates detailed understanding of impacts on morphology prior to introducing any intervention in the coastal zone.

**Keywords** Shoreline changes · Morphology · Breakwaters · Groynes

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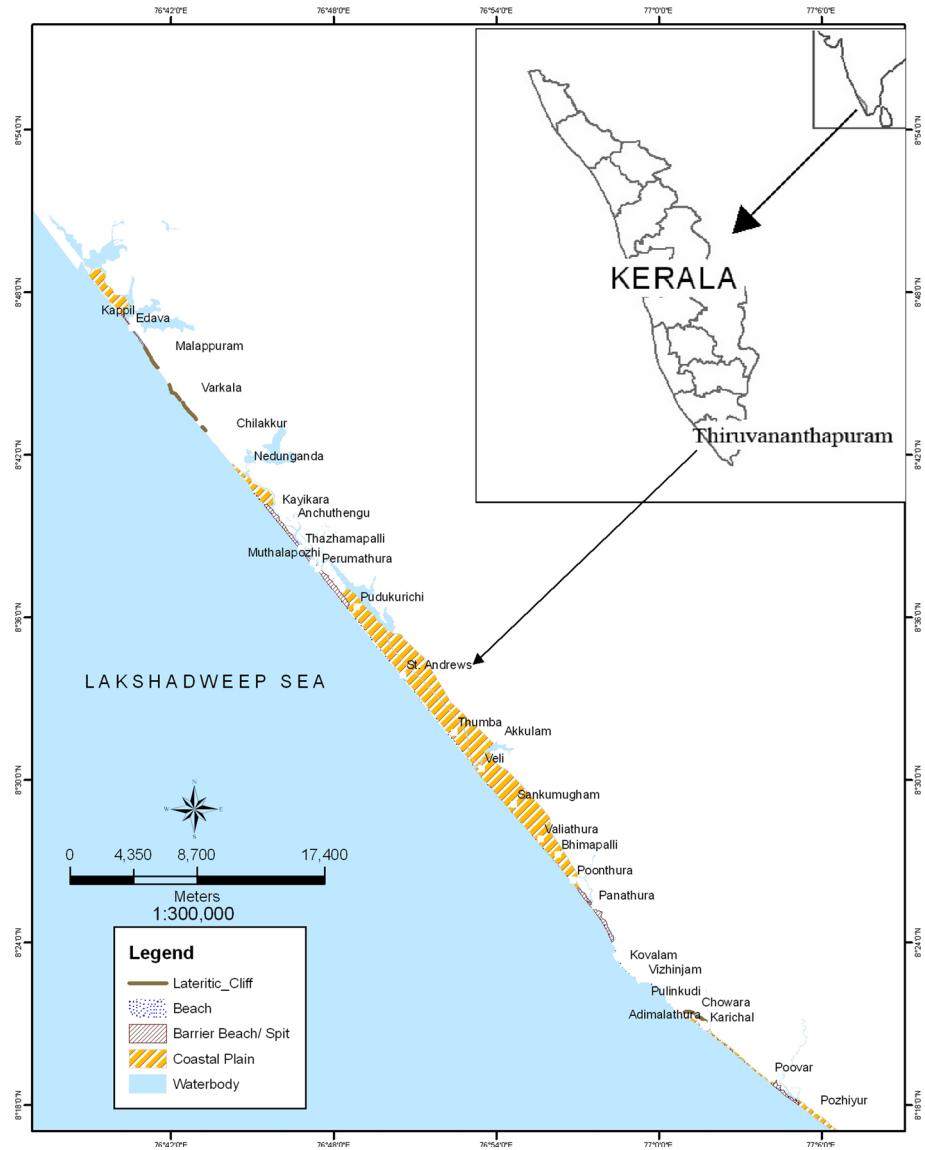
## 1 Introduction

The coastal zone is one of the most diverse and dynamic environment in the earth system. Geologic, physical, biologic and anthropomorphic factors are responsible for shaping the coast and keeping it in constant modification. Precise information on coastal erosion based on past and recent shoreline changes is essential to address the increasing threat to life and property in the coastal zone. These changes could be long term, short term, seasonal or episodic and result in coastal erosion or accretion. Waves, currents, tides and winds, as well as anthropogenic activities cause coastal erosion. The nature and quantum of shoreline changes are dependent on coastal morphologies such as beaches, barrier beaches, frontal beaches, coastal plains, tidal flats, tidal inlets, headlands, bays, rocky cliffs and earth cliffs. It is well known that beaches adjacent to tidal inlets are unstable and could be ‘erosion hotspots’ (Galgano 2009). Interventions to stabilise inlets further aggravate coastal erosion. It is established that the presence of artificial protection measures like seawalls, groynes and breakwaters could trigger shoreline changes (Bakker et al. 1970; Komar 1998; Cuadrado et al. 2005; Kim et al. 2009; Thomas et al. 2013). The role of climate change for increasing coastal erosion is established by Zhang et al. (2004). Coastline retreat is the one of the best indicators of coastal erosion (Chabban et al. 2012). Many methods have been proposed to measure coastal retreat. These are (1) the baseline approach (Dolan et al. 1978); (2) the dynamic segmentation approach (Liu 1998; Li et al. 2001; Srivastava et al. 2005); (3) the area based approach (Ali 2003); and (4) the buffering and nonlinear least squares estimation approach (Kim et al. 2009). The baseline approach is being used by various researchers successfully. The same approach was used in this particular study to understand coastal erosion with respect to morphology.

The nature of coastal erosion along Thiruvananthapuram, which is part of the south-west coast of India, has been studied by many researchers (Thomas et al. 1986; Kurian 1987; Baba et al. 1987; Kurian and Baba 1987; Thomas 1988; Sreekala et al. 1998; Shamji et al. 2010; Shaji 2014; Noujas and Thomas 2015). Earlier studies using Survey of India toposheets, satellite imageries and aerial photographs have provided a baseline understanding on shoreline change and associated erosion and accretion along this coast (Sreekala et al. 1998). Recent study conducted by National Centre for Sustainable Coastal Management (NCSCM 2011) reported locations of erosion occurrence along Kerala coast with maximum occurrence of erosion zones along Thiruvananthapuram (NCSCM 2011). Shoreline change, other than the normal seasonal dynamics of shoreline, was analysed with respect to the specific morphologies along this high energy coast. The study analyses long-term and short-term shoreline changes using field mapping and geospatial techniques. The role of natural morphologies and artificial coastal protection and other structures in coastal erosion is examined.

## 2 Regional setting

The study area extends along the south-west coast of India for about 78 km of the Thiruvananthapuram coast (Fig. 1). It extends from Pozhiyur to Edava between  $8^{\circ} 17' 20.50''$  N;  $77^{\circ} 06' 09.06''$  E and  $8^{\circ} 46' 31.95''$  N;  $76^{\circ} 40' 38.07''$  E. Thiruvananthapuram coast is a high energy coast characterised by high waves, steep beach face and medium-sized beach sand. Coastal plains, barrier beaches/spits, pocket beaches and cliff/promontories are the major morphological features along the coast. Five tidal inlets are present along the study region, and most of them are seasonal. Coastal protection structures such as



**Fig. 1** South-west coast of India (Thiruvananthapuram) and its morphology

groynes and seawalls are present in southern sector and northern sector of the study region. Harbour breakwaters are also present both in the northern (Muthalapozhi) and southern sectors (Vizhinjam).The coast gains social, economic and environmental significance due to its high density of coastal population. Also the coast is well known for renowned tourism destinations like Kovalam and Varkala. One of the largest interventions in the nearshore waters of this coast is the ongoing reclamation of about 66 ha of coastal waters and construction of 3.2 km long breakwater for the upcoming Vizhinjam International Deep

water Multipurpose Seaport (Phase 1), which has the potential to cause major shoreline shift and other morphological changes in the region.

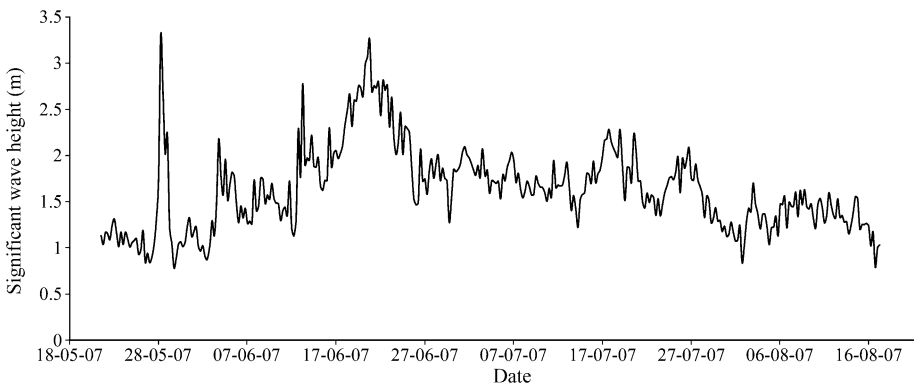
Kumar and Deo (2004) identified south-west monsoon (June to September); post-monsoon (October to January); and pre-monsoon (February to May) as the major seasons for discussing wave climate and coastal processes along the west coast of India. The concept of fair and rough seasons consisting of November to April and June to September, respectively, was used by Baba and Kurian (1988) while describing the coastal and nearshore processes and waves along the south-west coast of India. May and October are transitional months. The rough season represents mostly monsoon months while the fair season represents both pre-monsoon and post-monsoon months. The significant wave height ( $H_s$ ) recorded at Valiathura during monsoon season was in the range of 0.78–3.3 m (Noujas et al. forthcoming 2017). Monsoon wave conditions are a series of storm events of about one week duration as evidenced by the lows and highs in the wave heights (Fig. 2; Noujas et al. forthcoming 2017). The increasing  $H_s$  indicated an active monsoon while decreasing  $H_s$  indicated breaks in monsoon (calm periods in the monsoon season). During monsoon, zero crossing wave period ( $T_z$ ) varied from 5.3 to 13.1 s with an average of approximately 8 s and wave direction was in the range 220–254° (Noujas et al. forthcoming 2017).

The  $H_s$  is low during fair season and majority of wave heights fall below 1 m (Baba et al. 1984). The  $T_z$  is in the range 8.4–11.1 s with an average of 9.8 s. The wave direction ranges between 199 and 214° (Noujas et al. forthcoming 2017).

The sediment transport direction depends on the wave angle with respect to the shoreline. The shoreline normal is approximately 230° with respect to true north along Thiruvananthapuram coast. Hence, the sediment transport during June to August is predominantly southwards and for the remaining period, it is towards the north. The net sediment transport along the study region is towards north and approximately  $(0.72-1) \times 10^5 \text{ m}^3/\text{year}$  (Sajeev et al. 1997; Thomas et al. 2010; Noujas et al. 2014).

### 3 Methodology

Coastal morphologic features and artificial structures in the study region were delineated from Survey of India toposheets and satellite imageries coupled with extensive field mapping. The toposheets used pertained to the period 1989–1990 in 1:25,000 scale while



**Fig. 2** Significant wave height ( $H_s$ ) at Valiathura during the rough season (after Noujas et al. forthcoming 2017)

satellite imagery was IRS-P6 LISS IV of 2006 having spatial resolution of 5.8 m. Shoreline mapping was carried out during 2010–2011. The entire coast was surveyed during the year 2014 for delineating the artificial structures and other coastal morphologies. Coastal scientists use shoreline indicators such as vegetation line, high water line, low water line, land–water boundary, still water line or similar indicators for delineating shoreline from different data sources. A shoreline indicator is a feature that is used as a proxy to represent the “true” shoreline position. When shorelines are extracted from different data sources for comparison like in the present study, appropriate signature or indicator for shoreline has to be used for making the extracted shorelines comparable. In a micro-tidal high energy coast like the south-west coast of India, the spatial difference between different shoreline indicators may not be significant. On a perusal of different data sets, it was observed that the Low Water Line (LWL) given in the toposheet is close to the Still Water Line (SWL) mapped during field observations in fair season which was again comparable with the Land–Water Boundary (LWB) obtained from satellite imagery. Hence, ‘LWL, LWB and SWL’ were considered for extracting shoreline from toposheet, imagery and field observations, respectively. Satellite imageries during spring tide were not used for shoreline extraction since the reach of sea water goes beyond berm line during that period.

Toposheets were georeferenced, vectorised and used as base map. The LWL was extracted from the georeferenced toposheets and LWB visually interpreted from georeferenced IRS P6 imagery. It was ensured that there was one to one matching of identified control points both in the toposheet and the imagery. Using toposheet as the base map, satellite imageries were superimposed by taking sufficient Ground Control Points (GCPs). Shoreline mapping using GPS survey was relied upon to get the present shoreline. It was ensured that the shoreline measured using GPS was tied to the control points identified in the toposheet and the imagery. Extraction of shoreline was done after dividing the entire coastal stretch into morphological subcells with sufficient number of GCPs in each subcell. Through this process, whatever error that occurs due to accuracy and resolution limitations of GPS and imageries or distortions in base maps was confined within each sector. This could reduce the spatial errors getting accumulated and compounded. This approach was successfully used for the Panchayat Resource Mapping undertaken for the state of Kerala (Chattopadhyay et al. 2004).

The entire Thiruvananthapuram coast was visited, and detailed sketch has been prepared to understand the role of natural morphologies and artificial structures in causing or accelerating coastal erosion. Shoreline modifications and erosion-accretion due to breakwaters and groynes were also obtained by comparing multidated maps, imageries and GPS shoreline. The shoreline prior to the construction of breakwaters and groynes was obtained from Survey of India toposheets. Present shoreline has been delineated from satellite imageries and GPS shoreline mapping.

## 4 Results

### 4.1 Coastal geomorphology

Coastal morphological features along this coast were identified (Fig. 1 and Tables 1, 2). All the tidal inlets in the study sector are seasonal and open only during monsoon or when dredged open. Two of the inlets, Karichal and Veli, are associated with small water bodies and do not have adjoining barrier beaches/spits of significance. The Pozhiyur and

**Table 1** Headland/Cliff along the south-west coast of India

Name of the headland	Type (lateritic/hard rock)	Length and elevation of the headland/cliff	
		Length (km)	Elevation (m)
Adimalathura–Chowara	Lateritic	1.5	50
Pulinkudi	Hard rock	1.3	40
Vizhinjam	Hard rock	1	40
Kovalam	Hard rock	1.5	40
Varkala	Lateritic	2	40
Malappuram (Varkala)	Lateritic	1	40
Edava	Lateritic	1.4	40

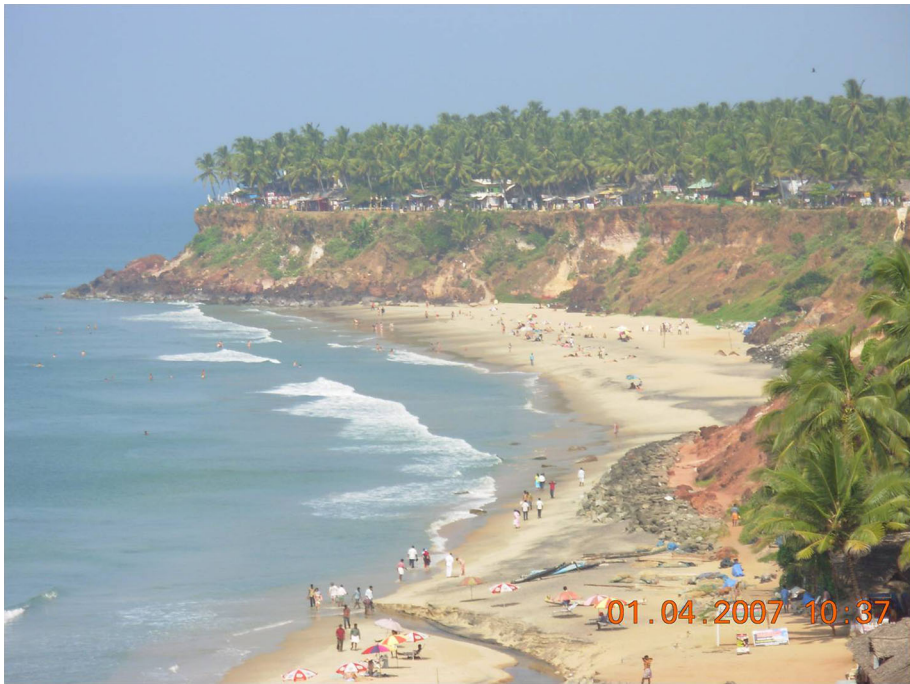
**Table 2** Barrier beach, spit and tidal inlet along the south-west coast of India

Tidal inlet	Location (Lat\Long)	Land form
Neyyar (Pozhiyur)	8° 18' 25.36"N, 77° 04' 39.86"E	Spit
Karichal (Adimalathura)	8° 20' 45.39"N, 77° 01' 42.70"E	Beach
Karamana (Panathura–Poonthura)	8° 25' 34.69"N, 76° 57' 28.26"E	Spit
Veli	8° 30' 33.67"N, 76° 53' 14.70"E	Beach
Muthalapozhi	8° 38' 04.32"N, 76° 47' 15.10"E	Barrier beach/spit
Edava–Kappil	8° 46' 11.44"N, 76° 40' 55.6"E	Barrier beach/spit

Panathura inlets have spits. The barrier beach south of Muthalapozhi inlet is wider while on the north side it extends as a narrow barrier beach which gets widened further north. The spits on either side of Kappil inlet are very narrow.

Coastal plains of Thiruvananthapuram are generally narrow. The sandy coast south of Pulinkudi headland extends from Adimalathura to Pozhiyur and further south. This sector of sandy coast is very narrow, and the width is limited by lateritic cliffs and hills. The coastal plain extending from Poonthura in the south to Pudukuruchi in the north is comparatively wider. Rocky headlands are located along Vizhinjam–Kovalam coastal stretch. Pulinkudi–Vizhinjam sector has both lateritic and rocky coast. Major lateritic cliffs are at Chowara and Varkala–Edava sector. The Chowara cliff is landward of settlements and fronted by very wide beach which has a width of about 400 m. Being much landward of the active beach zone this cliff does not have any significant influence on coastal processes. It is not considered for its influence on coastal process in the present study. The Varkala cliffs/promontories are fronting the sea with or without seasonal frontal beach. The 'cliff/promontory outline' is irregular and has pocket beaches in between. The pocket beaches of Vizhinjam–Kovalam are backed by rocky terrain except the 'Light House' and 'Kovalam north' beaches which are backed by laterites or elevated garden lands. The Varkala–Edava sector has pocket beaches backed by lateritic cliffs and promontories (Fig. 3).

Construction of coastal protection structures like seawalls and groynes and breakwaters for fishery harbour (Fig. 4 and Table 3) has substantially modified the coastal features. Constructions are also carried out for inlet stabilization. Seawalls extend for over 20 km.



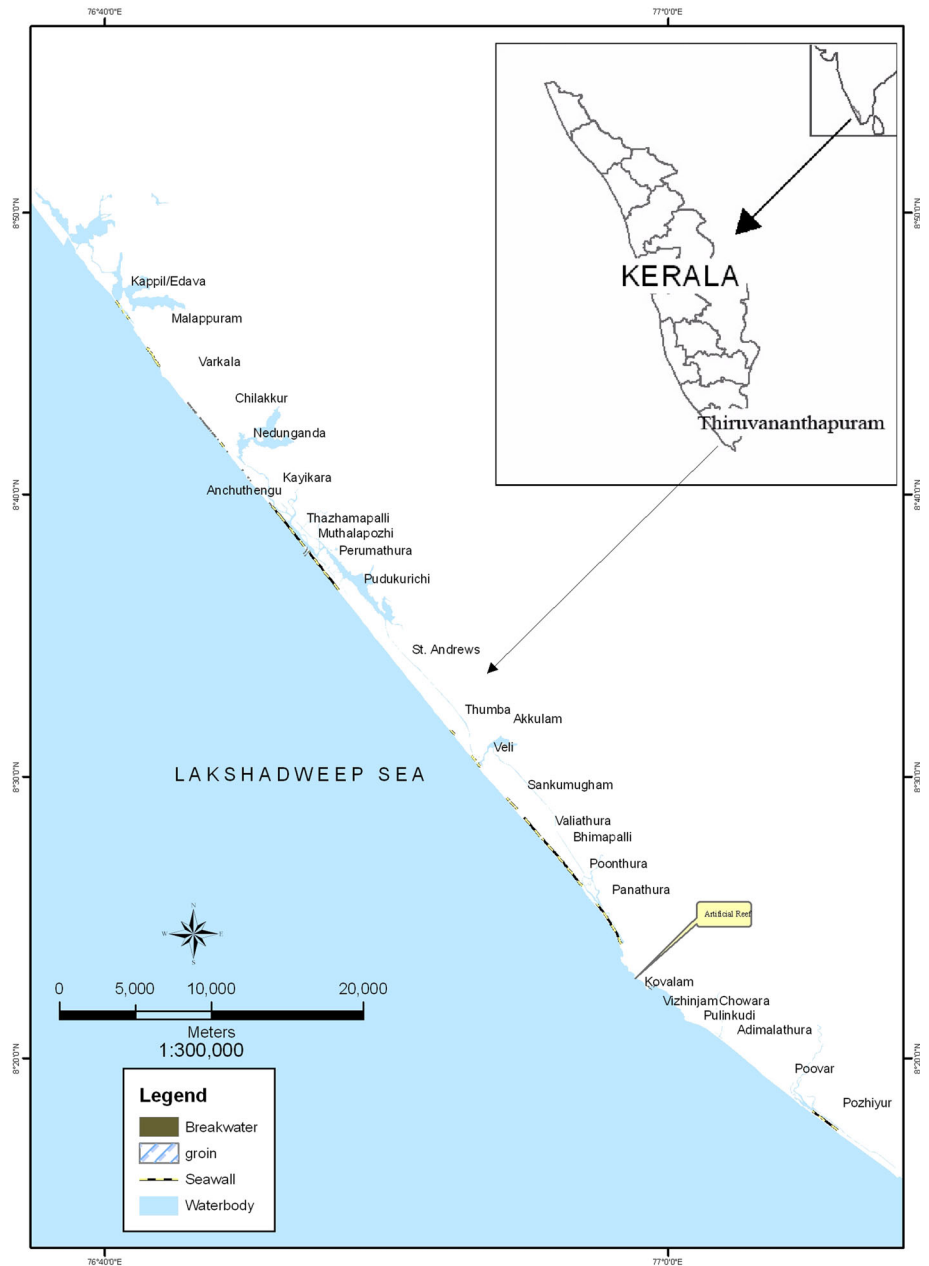
**Fig. 3** Lateritic cliff and frontal beach at Varkala

These are provided with ‘fishing gaps’ of 30–40 m to facilitate traditional fishing. Groynes at Panathura, Poonthura and Chilakkur together cover about 4 km. Groynes at Chilakkur still remain intact though these were constructed as early as 1890s (Moni 1970). At the same time some of the groynes at Panathura–Poonthura sector, though constructed as recently as 2008–2010, show collapsing tendency. Unlike Chilakkur groynes, the Panathura–Poonthura groynes are supported by seawalls. Groynes further south of Chilakkur along Anchuthengu sector are buried under beach sand and get exposed only during monsoon erosion. The other coastal protection structures are ‘artificial surfing reef’ system (submerged) constructed in 2009 in the nearshore of ‘Lighthouse beach’ at Kovalam (ASR Limited 2010) and revetments bordering seasonal beaches along recreational locations at Sankumugham, ‘Kovalam beach’ and ‘Lighthouse beach’.

#### 4.2 Shoreline change

Shoreline changes occur with the change in wave climate associated with rough and fair seasons. The beach gets eroded with the onset of monsoon season when high and steep waves approach the coast. This causes the formation of a storm profile which gets modified with monsoon breaks and reactivated due to succeeding monsoon events (Thomas and Baba 1986). Beach building starts after monsoon season and it takes place as a slow process compared to erosion events. It is initiated when long period swell waves approach the coast during the fair weather season after monsoon.

Shoreline changes over different periods of time are given in Table 4 and in Figs. 5, 6, 7, 8 and 9. Considering the limitation of spatial accuracy of the data used for estimating



**Fig. 4** Manmade coastal structures (artificial coastal morphology)

shoreline changes, a variation of up to 10 m is considered as ‘no change’. Seasonal erosion and accretion associated with shoreline dynamics due to monsoons is not considered here to assess shoreline changes. During 1989–2006, major accretion leading to 81 m and 78 m increase in beach width was noticed at Adimalathura and Perumathura, respectively.



**Table 3** Artificial structures along the study area

Artificial structure	Site	Location	Remarks
Harbour breakwater	Vizhinjam	8° 22' 35.64"N 76° 59' 23.24"E	North arm of the breakwater having length 420 m and south arm having length 270 m
	Muthalapozhi	8° 37' 58.36"N 76° 47' 07.17"E	North arm having length 340 m and southern arm having length 540 m (modification work is in progress)
Seawall	Pozhiyur	8° 17' 50.98"N 77° 05' 27.61"E	1.4 km length
	Kovalam–Panathura	8° 24' 02.33"N 76° 58' 19.55"E	3.1 km length
	Poonthura–Valiathura	8° 26' 06.17"N 76° 56' 57.31"E	4 km length (seawall is damaged in most of the locations)
	Valiathura–Sankunmugam	8° 27' 53.37"N 76° 55' 27.26"E	2.6 km length (seawall is not in good condition at few locations)
	Veli	8° 30' 22.53"N 76° 53' 18.36"E	0.75 km length (on either side of Veli inlet)
	Thumba	8° 31' 30.08"N 76° 52' 24.87"E	0.4 km length
	Pudukurichi–Perumathura	8° 36' 37.02"N 76° 48' 18.13"E	3.2 km length (Seawall is much landward)
	Thazhampally–Poothura	8° 38' 09.5"N 76° 47' 04.27"E	3.6 km length
	Nedunganda	8° 41' 40.91"N 76° 44' 13.48"E	0.4 km length (new seawall)
	Edava	8° 44' 42.16"N 76° 41' 50.44"E	2.5 km
Groynes	Panathura	8° 25' 22.13"N 76° 57' 32.42"E	2 short Groynes having length 35 m and 25 m
	Poonthura	8° 26' 09.57"N 76° 56' 53.89"E	8 short transitional groynes having maximum length about 50 m (2 groynes damaged)
	Chilakkur	8° 42' 04.12"N 76° 43' 55.28"E	25 shorter groynes having length 20–30 m

Accretion in Perumathura was confirmed from the study by Noujas et al. (2014); similarly Adimalathura was identified as less sensitive/accreted areas from earlier and recent studies (Shaji 2014; Baba, et al. 2009; Sreekala et al. 1998). During the same period significant erosion of 26–120 m was noticed immediately south of Vizhinjam harbour and along the Panathura–Poonthura–Bhimapalli sector. During the subsequent years of 2006–2011 no major changes were noticed except north of Poonthura groyne field at Bhimapalli, Valiathura and Thazhampally which are erosion hotspots of Thiruvananthapuram coast (Noujas and Thomas 2015). Morphological scenario of promontory/headland and tidal inlet coupled with structural interventions like inlet stabilization, harbour breakwaters, groynes and seawalls caused the observed shoreline changes. These structural interventions are regularly maintained and have become permanent and similar to morphological features. The term 'artificial morphologies' is appropriate for such structures.

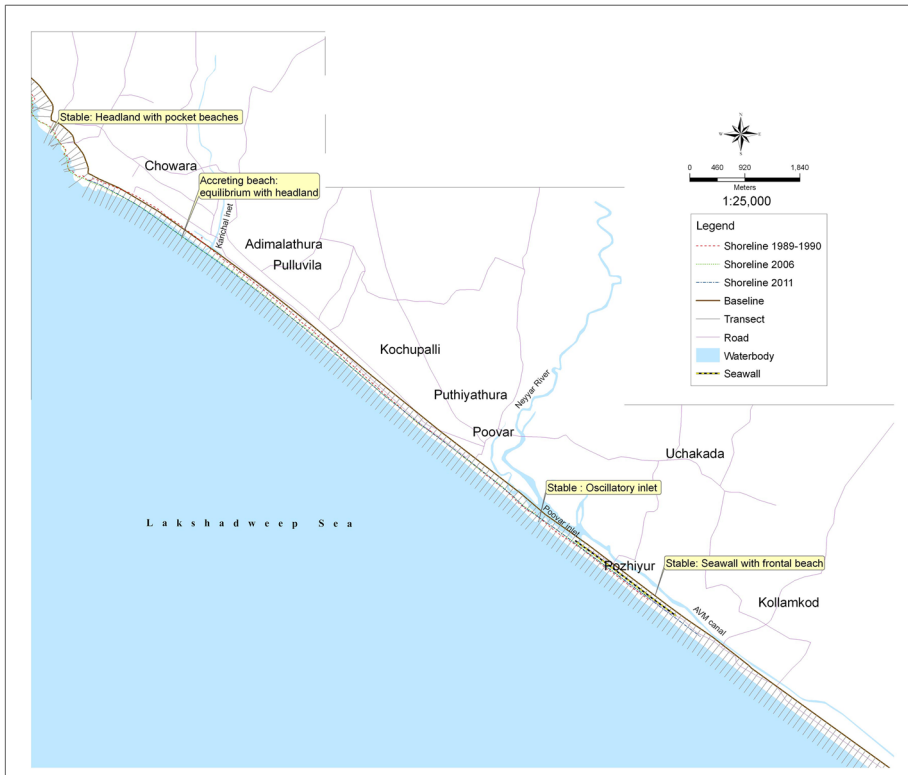
**Table 4** Shoreline variations along selected locations

Location	1989–2006	2006–2011	1989–2011
Pozhiyur	– 27.00	+ 5	– 22.00
Poovar	+ 3.00	– 4.00	– 1.00
Adimalathura	+ 81.00	+ 9.00	+ 90.00
South of Vizhinjam harbour	– 70.00	–	–
Kovalam beach	– 70.00	+ 10	– 60.00
Panathura	– 120.00	+ 18	– 102.00
Poonthura (groynes south/spit)	– 80.00	– 30.00	– 110.00
Poonthura (between groyne)	– 50.00	+ 15.00	– 35.00
Poonthura (groynes north)	– 47.00	– 31.00	– 78.00
Bhimapalli	– 26.00	– 37	– 63.00
Valiathura	– 15.00	– 25	– 40.00
Sankumugham	– 23.00	– 8.00	– 31.00
Veliinlet	– 14.00	+ 4.00	– 10.00
St. Andrews	+ 7.00	+ 6.00	+ 13.00
Perumathura	+ 78.00	+ 14.00	+ 92.00
Thazhampalli	– 20.00	– 32.00	– 52.00
Chilakkur	– 18.00	+ 6.00	– 12.00
Varkala	– 14.00	–	–
Edava	+ 10	– 20	– 10.00

## 5 Discussion

The present study shows that 26% of the Thiruvananthapuram coast undergoes erosion (Table 5). An earlier study conducted by NCSCM (2011) found that 23.3% of the Thiruvananthapuram coast undergoes erosion. Both the studies provided comparable results showing high erosion along Thiruvananthapuram coast. Shaji (2014) has observed that 72% of coastline falls in high or medium sensitive area. Unlike the earlier studies, extensive field work was carried out in the present study for confirmation of the results obtained from geospatial analysis.

The dependency of shoreline changes on morphology, both natural and artificial, is analysed with respect to different morphological features (Table 5). Out of the 27 km protected coast, about 14 km consisting of sectors like Panathura, Poonthura, Bhimapally, Valiathura and Thazhampally are highly prone to erosion in spite of being protected by seawalls and groynes. This is due to the presence of harbour breakwaters or being close to inlets and spits. About 3 km of earth cliff directly fronting the sea at Varkala–Edava sector is prone to episodic erosion. About 50 km of the coast is stable, which also includes rocky coast and coastal plains having seawalls maintaining sufficient frontal beach. Based on the above discussion, the factors affecting the erosion are analysed in detail with respect to natural and artificial morphologies.

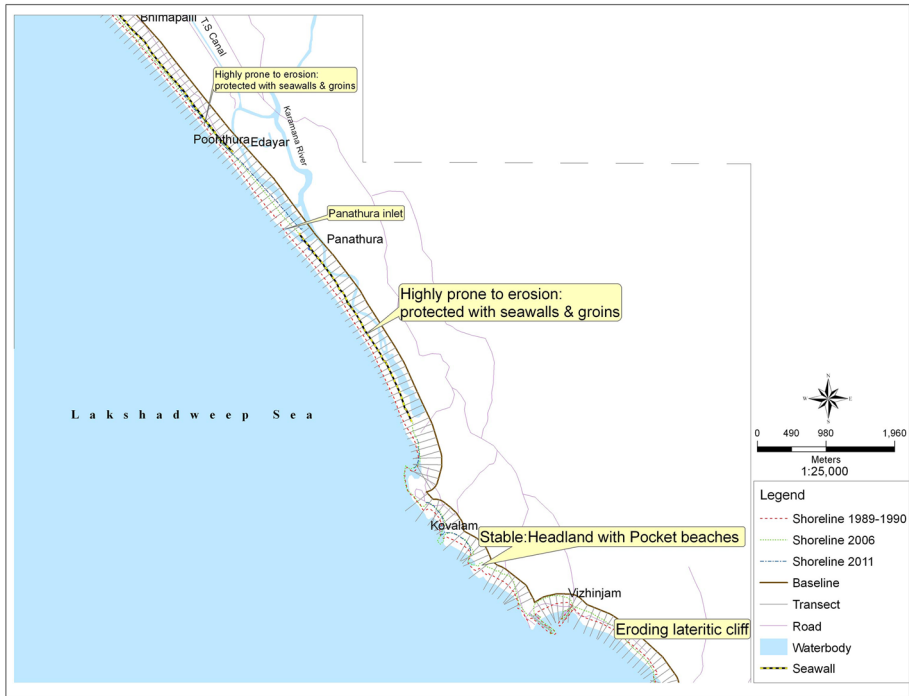


**Fig. 5** Shoreline change: Pozhiyur–Chowara sector

### 5.1 Pocket beaches and cliffs/promontories

There are 12 pocket beaches present in Thiruvananthapuram coast. Pocket beaches are dynamically stable and undergo seasonal erosion/accretion (Fig. 10). These variations are in tune with the rough and fair season. Such coastal systems are prominent along the Pulinkudi–Vizhinjam–Kovalam coastal sector. Shoreline along pocket beaches of Varkala has not shown significant variation in the recent years though the cliff has undergone slumping and retreat during 1989–2006. The cliffs landward of the pocket beaches being lateritic, undergoes scouring at the base during rough season which leads to slumping and cliff edge retreat as episodic events. Slumping of cliff edges at Varkala and Vizhinjam is evidence for such episodic events (Fig. 11).

Accretion is observed immediately south of promontories/headlands as is seen at Adimalathura and Chilakkur. This is indicative of net northerly transport along this sector which goes well with the earlier observations that the northward longshore transport is dominant during the beach building period (Noujas et al. 2014; Thomas et al. 2010). When northerly longshore transport is blocked by promontories/headlands beach gets developed towards south. Due to the same reason, the coast immediately north of headlands such as Panathura (north of Kovalam headland) and Edava (north of Varkala cliff) is observed to be eroding (Figs. 6, 9). Cliff erosion (Fig. 11) immediately south of Vizhinjam bay and promontory is a deviation from the above observed pattern. The presence of harbour



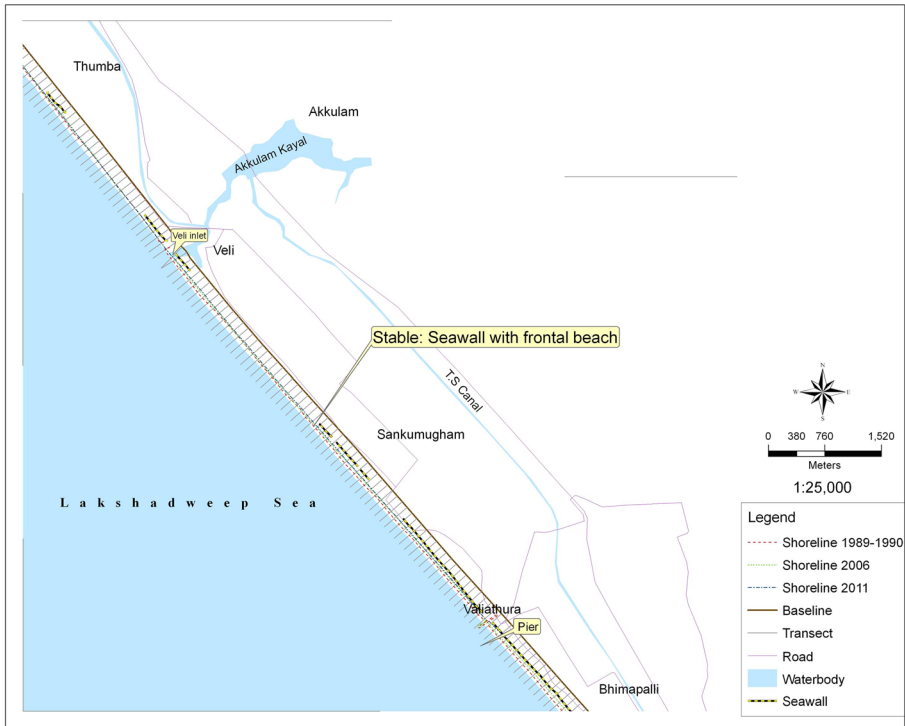
**Fig. 6** Shoreline change: Vizhinjam–Poonthura sector

breakwaters that extend from the headland, orientation of the one of the breakwaters towards south-east and associated modifications to coastal and near shore processes could be the reason. It requires further studies to understand this deviation in detail.

## 5.2 Coastal plains

Coastal plain south of Poovar/Pozhiyur inlet is dynamically stable. The inlet is seasonal and open only for a short period during monsoon. There are no natural or artificial morphologies to interfere with longshore sediment transport. Seawalls have been constructed with frontal beaches as a continuation of inlet stabilization. Beach still continues to remain dynamically stable. Fishing gaps in between are affected by end erosion and ‘wave pushing’ during monsoon. A pressure gradient develops towards the gap within seawalls and wave/swash pushes into the gap causing temporary erosion.

The coastal plain north of Poovar/Pozhiyur inlet up to Adimalathura remains dynamically stable with multiple berms. The shoreline of this region has been showing accretion tendency which was also supported by Shaji 2014. The widening of the beach has created a backward sloping and wide backshore (Fig. 12) which gets flooded when there is any flooding from the sea due to increased wave set up as a result of highly grouped remotely forced waves (*kallakadal*) synchronised with spring high tide (Kurian et al. 2008; Thomas et al. 1986). This becomes a serious problem usually along accreting and wide beaches in high energy coasts during fair season when the waves are otherwise low.



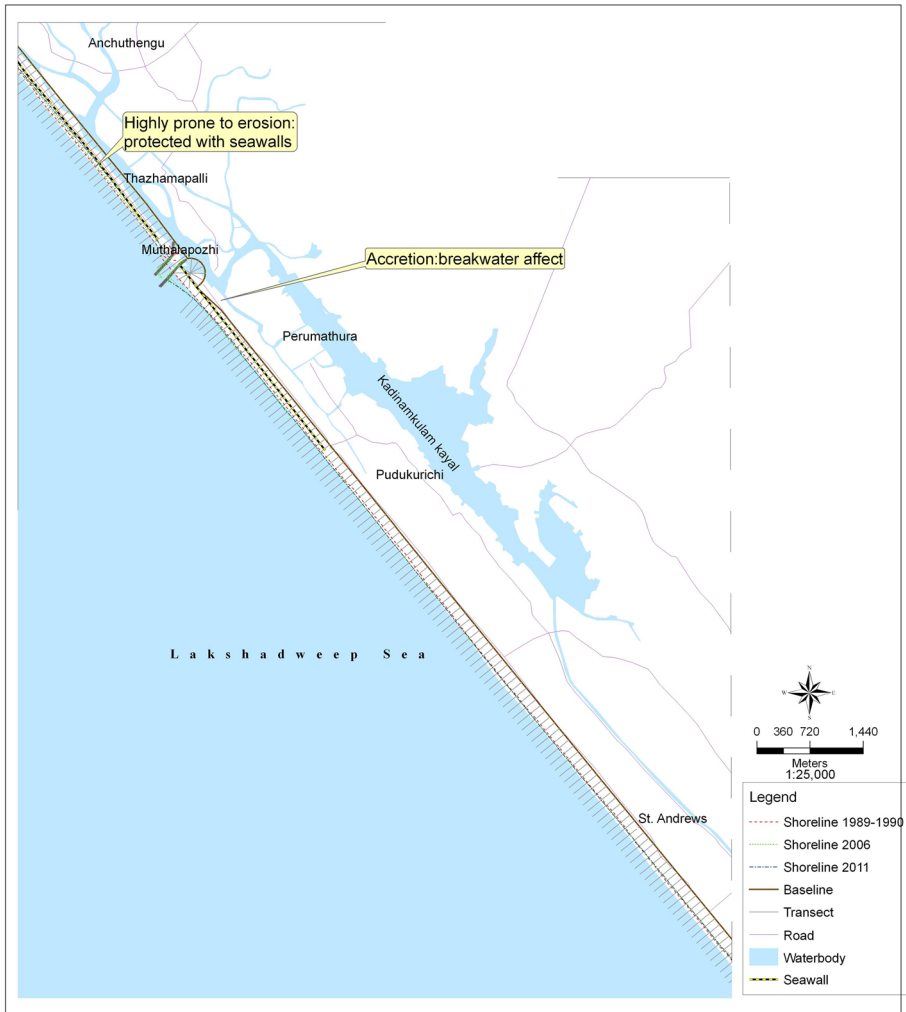
**Fig. 7** Shoreline change: Bhimapalli–Thumba sector

The coastal plain along Veli–Pudukurichi sector is also dynamically stable with seasonal erosion/accretion (Figs. 7, 8). Similar situation is observed along Anchuthengu–Nedunganda sector (Fig. 9).

### 5.3 Barrier beach, spits and inlets

Coastal engineering or other types of intervention have been carried out at tidal inlets to keep them open all through the season or to prevent the natural oscillation of the inlet mouths. Poovar/Pozhiyur and Veli inlets are normally forced open when there is upstream flooding. There are no significant changes to the shoreline near to these inlets except for the monsoon oscillations.

The Panathura/Poonthura inlet has been significantly modified. The beach being north of Kovalam headland is morphologically unstable due to blockage of the predominant northerly sediment transport during fair weather period (Ajeesh 2011). This coupled with interventions in the form of artificial stabilization of the Panathura inlet, made the coastal belt vulnerable to erosion. This necessitated the construction of seawalls and groynes at Panathura and Poonthura. Even with the presence of coastal protection measures in place this sector remains highly prone to erosion requiring frequent maintenance of the structures. These locations are among the erosion hot spots identified by Noujas and Thomas (2015). The influence of the Kovalam headland gets considerably reduced further north at Valiathura and the shoreline is dynamically stable.



**Fig. 8** Shoreline change: St Andrews–Muthalapozhi sector

### 5.4 Seawalls, groynes and breakwaters

Shoreline variations near coastal protection structures like seawalls, groynes and breakwaters depend mostly on the morphology of the coast where these are constructed. The harbour breakwater at Vizhinjam has been constructed at a headland-pocket beach system while the Muthalapozhi breakwaters are constructed on either side of a seasonal tidal inlet. The Vizhinjam breakwaters have not caused any shoreline change along the rocky headlands or pocket beaches on the northern side. The sandy coast towards south was affected by erosion during the construction of north breakwater (Machado and Baba 1984). With the construction of south breakwater the lateritic cliff on the southern side got eroded (Fig. 6). The response of the shoreline to the breakwaters at Muthalapozhi inlet along the northern sector was different. Sediment got accumulated south of the breakwater after its



**Fig. 9** Shoreline change: Anjuthengu–Varkala sector

**Table 5** Length of coast belonging to different shoreline stability status

Total	Length of Protected coast (km)				Status of shoreline change (km)				
	SW	RT	GN	AR	Stable		Eroding		
					RK	SD	CF	ST	PE
78.0	22	1.3	4	0.1	5 (6.4%)	48.0 (61.5%)	5.0 (6.4%)	0.9 <sup>a</sup> (1.2%)	14.0 (18%)

<sup>a</sup>Close to inlet

SW seawall, RT revetment, GN groyne, AR artificial reef, RK rocky, CF earth cliff, SD sandy coast (includes seawall/cliff having frontal beach), ST spit, PE protected but prone to erosion

construction and about 100 m shoreline advancement was observed. North part of the coast experienced erosion (Fig. 13). Two groynes have been constructed at Panathura along the southern sector for coastal protection. Beach formed in between in the groyne cell and southern side of the groynes. There is no beach in the north side of the northern most groyne (Fig. 14). Pattern of sediment deposition and shoreline change indicates a net



**Fig. 10** Seasonal erosion at pocket beach

northerly sediment transport along this sector which was also supported by an earlier study (Noujas et al. 2014).

Sand removal from the seasonal beach at ‘Lighthouse beach’ for construction of a revetment has significantly reduced the sediment availability in the seasonal beach (Ajeesh 2011). This has led to lowering of berm height. The period during 1989–2006 has shown marginal erosion on the land part of Kovalam beach. But construction of a small building (mosque) right on the seasonal ‘Kovalam pocket beach’ has induced erosion immediately north within the pocket beach. It is evident that any morphological modification through construction activities would induce erosion along dynamically stable pocket beaches (Fig. 15).

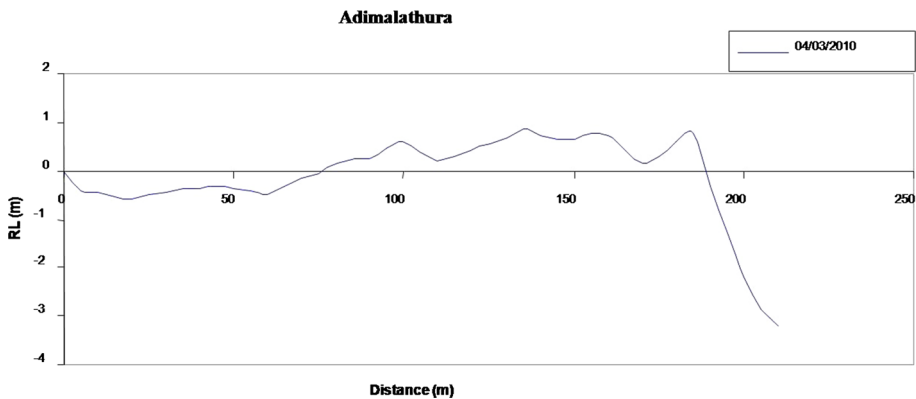
Sankumugham and Pozhiyur sectors have dynamically stable beaches and seawalls are constructed along the monsoon berm crest. These have seasonal frontal beaches where the shoreline variation is due to monsoonal erosion/accretion process. Seawalls constructed along this sector are primarily to protect the dwelling units during monsoon season. Pudukurichi–Perumathura sector has accreted and the shoreline has advanced positioning the seawalls further landward of the monsoon berm crest. Accretion along this sector started after the construction of Muthalapozhi breakwater (Noujas et al. 2014). Seawalls along dynamically stable beaches and accreting beaches do not cause any significant morphological modifications. But seawalls along eroding beaches are affected by toe scouring and slumping and frontal beaches disappear.

The Kovalam–Panathura–Poonthura–Bhimapalli–Valiathura coastal stretch is highly eroding and the seawalls do not have frontal beach (Fig. 16). Being on the northern side of Kovalam headland, the area is prone to erosion which is further aggravated by the





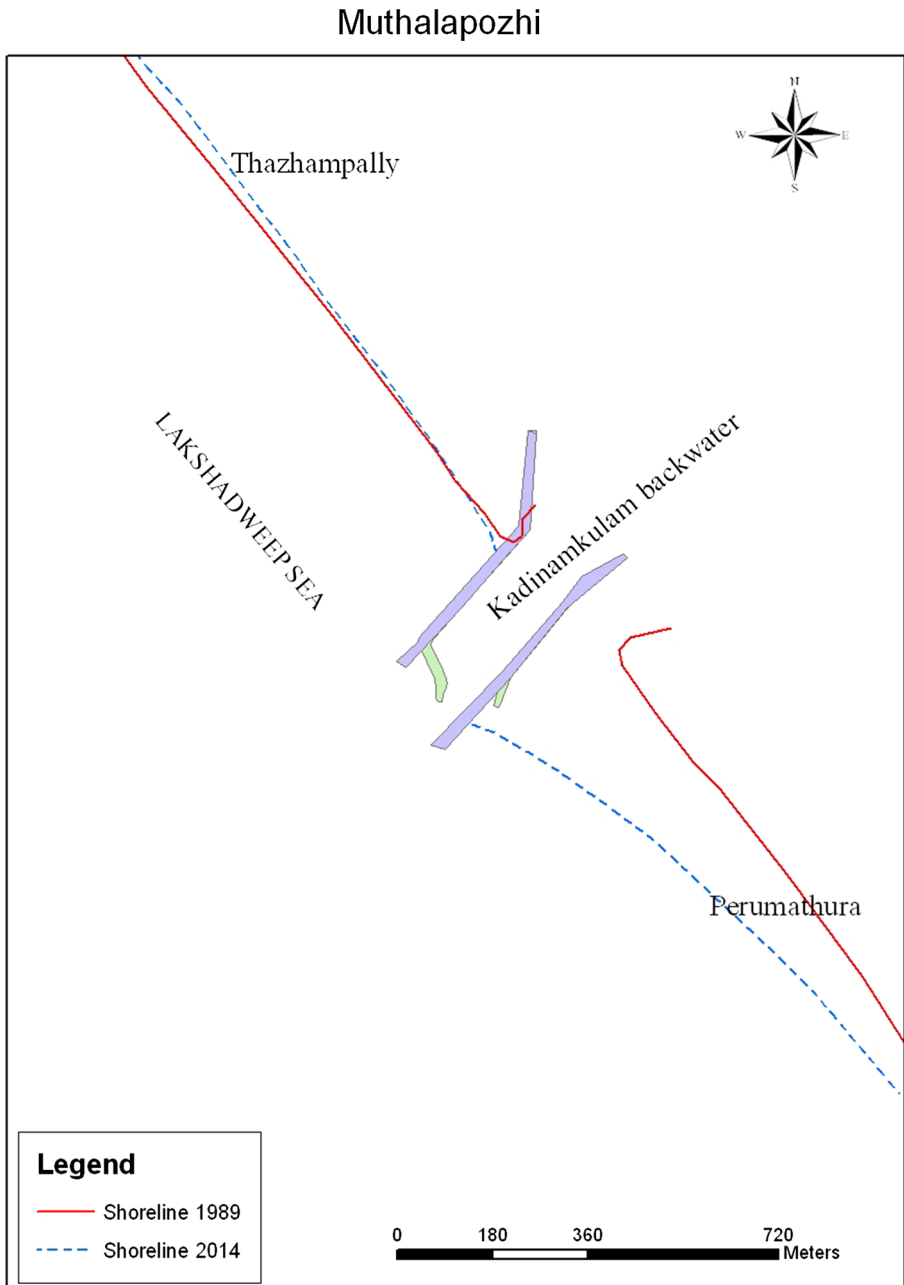
**Fig. 11** Cliff erosion south of Vizhinjam harbour



**Fig. 12** Typical profile of an accreted beach at Adimalathura

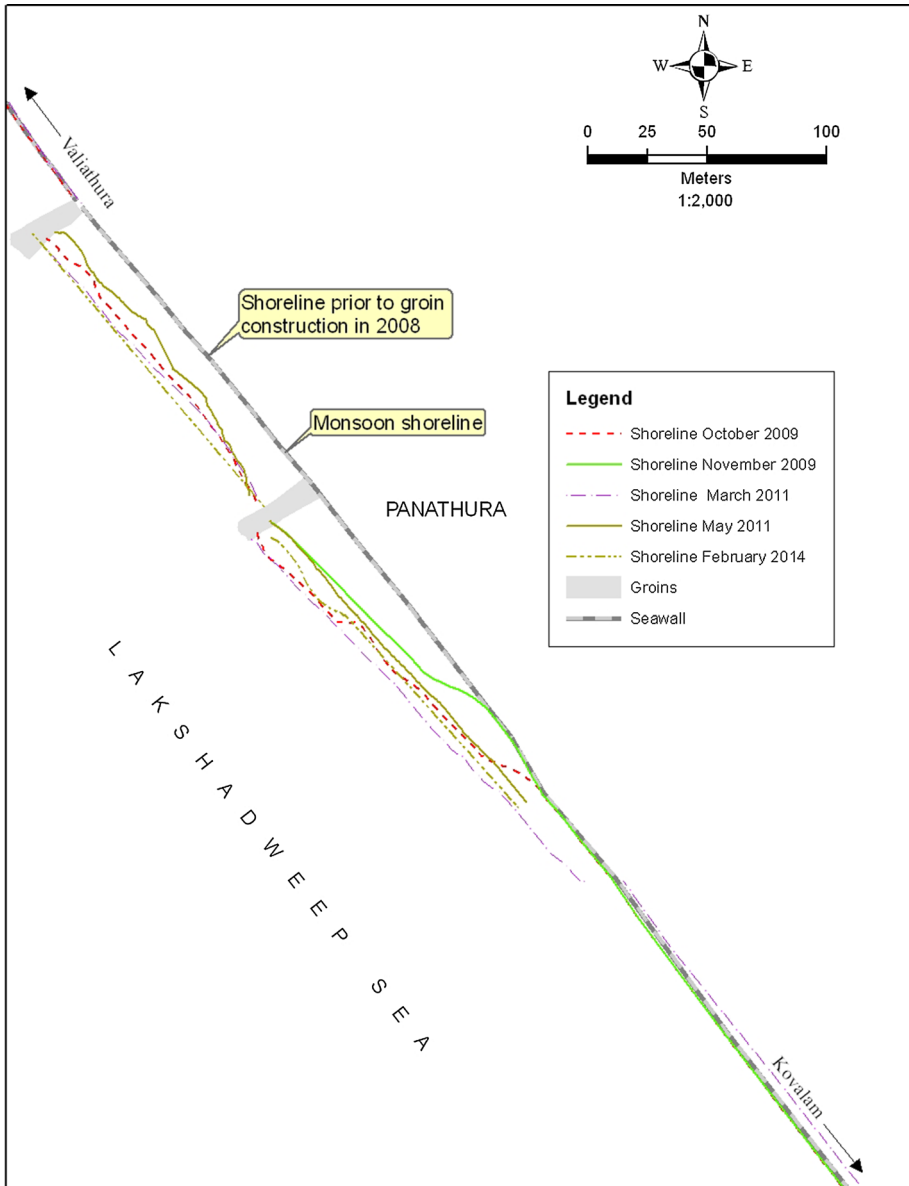
construction of seawalls. The seawall constructed at Thumba is seaward of the monsoon berm crest. Hence, monsoonal end erosion is significant even though this coast is otherwise dynamically stable.

There are 2 types of groynes constructed along this coast. The short groynes at Chilakkur were constructed on a dynamically stable coast in 1890s. These were constructed to provide a precautionary protection for Trivandrum–Shornur (T–S) canal, part of which passes very close to the sea landward of a stable beach. Construction of T–S canal near Chilakkur was completed in 1880. The coast and the groynes still remain stable along this



**Fig. 13** Long-term shoreline change at Muthalapozhi harbour inlet

coast. The groynes at Panathura and Poonthura are transitional and recently constructed along these highly eroding coasts and are backed by seawalls (Fig. 6). Seasonal beaches are formed in some of the ‘groyne cells’ on the southern side of the groynes during every



**Fig. 14** Shoreline variation at Panathura

fair weather season, which disappear during the succeeding rough monsoon season (Fig. 14). Few of these groynes started getting damaged within a short span of few years.



**Fig. 15** Impact of building construction on a stable pocket beach at Kovalam



**Fig. 16** Damages to seawall without frontal beaches at Bhimapally

## 6 Conclusions

Shoreline change along the south-west coast of India is largely dependent on coastal morphology. Rocky headlands and associated pocket beaches are least affected by shoreline changes. Shoreline south of headlands promontories and breakwaters are stable or accreting due to a net northerly longshore sediment transport whereas the shoreline to the north shows erosion tendency which gets enhanced by anthropogenic interventions. This is evident from shoreline modifications on the northern side of Kovalam headland, Varkala cliff and Muthalappozhi breakwater. Cliff erosion immediately south of Vizhinjam promontory and bay is a deviation from the above observed pattern which may be due to harbour breakwaters extending from the headland and orientation of one of the breakwater towards south-east. Lateritic cliffs fronting the sea or with seasonal beach undergo slumping and cliff edge retreat as episodic events. Spits adjoining tidal inlets are prone to shoreline variations due to oscillations of inlet mouth. Interventions in the form of inlet stabilization and construction of coastal protection structures trigger erosion along adjoining coasts. When seawalls are constructed along the monsoon berm crest of stable beaches to protect dwelling units from monsoonal erosion, seasonal frontal beaches are retained and shoreline variations, other than seasonal changes, are not significant. Seawalls constructed along highly eroding coasts get damaged due to toe erosion and require regular and frequent maintenance. Fishing gaps within seawalls are areas of severe temporary erosion during rough monsoon season. Accretion or erosion accompanies construction of harbour breakwaters in a stable coastal plain. Close dependence of shoreline changes on morphology necessitates detailed understanding of impacts on morphology prior to introducing any intervention in the coastal zone.

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