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Coastal Morphology and Long-term Shoreline Changes along the Southwest Coast of India

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ABSTRACT

The part of southwest coast of India extending from Poovar in the south to Kasaragod in the north is considered as one of the highly dynamic coastal areas of Indian peninsula. Over the years due to rapid urbanization as well as other natural and anthropogenic activities, the coast is under severe pressure which in turn has reduced the percentage status of healthy / stable coast. Unscientific shoreline protection methods adopted without conducting appropriate studies to assess the suitability of the said method to a particular coastal stretch has often led to negative impacts. As a result, many areas that were once stable have turned eroding and in certain cases, the observed extent of erosion is severe warranting immediate protection measures. In this context, a study was carried out to assess the long-term shoreline changes along the southwest coast and to decipher the causative factors responsible for these changes. Accordingly, a 46 year period from 1968 to 2014 was studied using multi-dated shoreline images and Survey of India (SOI) topographic charts. The DSAS software (USGS) is used to compute the rate of shoreline changes along different sectors of the coast and accordingly the entire coastal stretch is classified into 7 classes depicting the present status (stable / dynamically stable / unstable) of the coast. The analysis revealed that almost 60 % of the coastline is eroding with about 29 % showing an accreting trend.

INTRODUCTION

The part of southwest coast of India which extends from Poovar in the south to Kasaragod in the north is one of the highly dynamic coastal stretch of the Indian peninsula. It covers about 90 % of the Malabar Coast (historical) which extends from Goa to Kanyakumari. It comprises of a narrow strip of coastline which forms part of the coastal plain between the Western Ghats on the eastern side and Arabian Sea towards the west. The variations in coastal geomorphology settings of the coast make it different from other coastal areas of the Indian peninsula which is quite evident from the observed spatial and temporal changes in wave climate and related coastal processes (Sajeev, 1993). But over the years, coastal development activities related to tourism, recreation, industries and spurt of other activities linked to globalization along this part of the coast have led to the deterioration of the coastal environment with erosion being one of the major issues (Mallik, 1987). As a result many of the world famous beaches along the southwest coast are on the verge of extinction and this in turn has affected the marine ecosystem which includes the flora and fauna, as they are very much dependent on the coastal environment. In this context an attempt has been made to study the long-term shoreline changes along the southwest coast of India.

STUDY AREA

The study focuses on the 590 km long coastal stretch which extends from Kasaragod in the north to Poovar in the south. It covers the entire coastal stretch of State of Kerala which lies sandwiched between the Lakshadweep Sea on the west and the southern part of the Western Coastal Plains which skirts the Indian subcontinent with the Western Ghats on the eastern side (Fig. 1). The latitude / longitude co-ordinates for the northern and southern boundaries are 12°45' N, 74°51' E and 08°17' N, 77°05' E respectively. The coastal stretch has varying morphological features as we move from south to north. Generally, the coastal landforms of the Kerala are composed of sandy beaches, cliffs, rocky headlands, spits, estuaries, lagoons, barrier beaches, etc., depending on the geology of the location.

COASTAL GEOMORPHOLOGY

The average distance of the coast from the Western Ghats is around 100 km and the coastline is generally oriented in the NNW to SSE direction. The 590 km long Kerala coast is intercepted by 41 rivers which originate from the Western Ghats and flow towards the west. The rivers eventually debouch into the Arabian Sea through inlets and these inlets are connected to the sea via estuaries/lagoons. There are 48 inlets along the Kerala coast out of which 20 are permanent, whereas the remaining 28 are seasonal (remain open only during the monsoon period of June – September). The seasonal inlets mostly remain closed during the fair season and this can be attributed to spit formation at the inlets due to longshore sediment transport induced deposition. The seasonal inlets are normally cut open during monsoon to discharge the heavy surface runoff from the rivers into the sea to reduce the flooding risk within inland and coastal areas. It is observed that along the southwest coastal stretch, the river mouths with untrained inlets exhibit a seasonal as well as spatial shift in their position depending on the magnitude and direction of the longshore sediment transport. In addition, the overall sediment discharge from these rivers through estuaries / lagoons to the inlets / outlets is also a deciding factor in the observed spatial shift of the inlet locations. Over the years, the contribution due to this component has become insignificant at several locations as there is hardly any discharge of sediments taking place mainly due to damming of rivers, river sand mining etc. (Padmalal and Maya, 2014). But the monsoon period with heavy rainfall during which the surface flow and currents are maximum is an exception. The drastic reduction in the supply of sediments through rivers and other sources onto the beach has badly affected the stability of the south-west coast in recent years (Black et al., 2008). Of the various factors that affect the sediment supply it is observed that anthropogenic activities play a major role (Sheela Nair et al., 2007; Kuntae and Wagle, 2001).

Geology and Coastal Landforms

The coastal plains are generally low lying areas with elevation < 8 m above the MSL (Fig. 2). It has been reported that Kerala coast comprising of beaches, alluvium, barrier flats, shell deposits were formed during late Quaternary period (Soman, 1997). Unlike the east coast of India, this part of the west coast is devoid of deltas which

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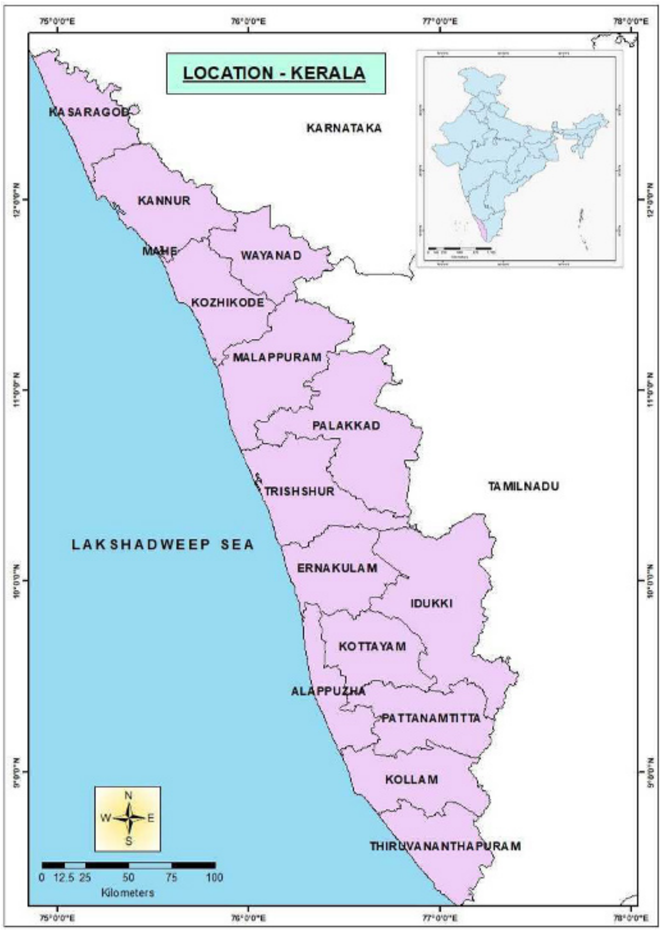

Fig. 1. Location map of the study area – southwest coast of India.

make the coastal processes different from other regions. Both submergent and emergent features are observed along this stretch of the coast. The presence of lakes and backwaters observed adjoining the coast at certain locations are signatures of submergent features whereas the barrier spit formations are evidence of emergent features (Ahmed, 1972). These features can be attributed to long-term changes in sea level, climatic conditions, lithology, structure and non-tectonic movements (Nair and Padmalal, 2004; Jayalakshmi et al., 2004). The Kerala coast being tectonically stable, it can be presumed that the observed sea level change is mostly due to glacio-eustatic impact. Both erosional and depositional features are seen all along the coast. The coastal area is highly dissected by the presence of rivers, lagoons, lakes, estuaries etc. and the observed landscape is the result of tropical climate induced Tertiary denudation (Subramanian and Rao, 1984). Incidentally, this part of the coast also has the largest spit formation along the west coast of India. The spit is located along the Aleppey-Cochin coast and has a shore parallel length of 84 km and is 10 km wide (Ahmed, 1972). The spit separates the coast from the famous Vembanad Lake which is also the second largest lagoon in India after the Chilka Lake. The Ashtamudi and the Kadalundi estuaries are typical examples of two incised river mouths uplifted during the Quaternary period and they tend to be perpendicular to the coast. The southern part of the coast i.e. towards south of Kollam headland and the northern part towards north of Kadalundi estuary are lateritic and rocky in nature. Coastal cliffs of crystalline rocks and Tertiary sediments are prominent along this stretch. They are found exposed in isolated patches both along the northern and southern parts of the coast (Soman, 1997). Prominent palaeo-strandlines are observed along the central part of the Kerala coast, i.e. from Alappuzha to Ponnani and the sediments are mostly alluvium from recent deposits. The Western Ghats being almost parallel to the coast, during the monsoon season, the moisture-laden westerly winds are intercepted by the mighty mountain range causing heavy rainfall on its western side. The presence of estuaries and lagoons are more along the central and northern parts of the coast. The formation of mud banks (Gopinathan and Qasim, 1974) during the monsoon season at particular locations along the Aleppey, Trichur, Calicut, Kannur and Kasaragod is a unique feature typical of this coast. The world famous heavy mineral deposits in the beach sands at Chavara, located along the Neendakara–Kayamkulam coastal sector in the southern region of the southwest coast of India, is another distinctive feature and the selective deposition of placers in this region is attributed to the coastal hydrodynamics of this region (Kurian et al., 2001; Black et al., 2008). The concentration of heavy mineral in the beach sands is mainly due to the reworking of the sediments from the barrier beach (both landward and seaward sides) due to the combined action of low to moderate swells and tidal waves (Rajith et al., 2008; Prakash et al., 2016).

Nearshore Climate and Beach Processes

The climate is that of a typical tropical maritime coast. The region has three distinct seasons viz. the pre-monsoon from February–May, the southwest monsoon from June to September and the post-monsoon during October–January. Moderate to heavy rainfall is received during the southwest monsoon season. The region also experiences rain during the post-monsoon season due to the action of northeast monsoon winds. On an average the Kerala coast receives rain varying between 90 and 350 cm / per year, of which 60 % is during the southwest monsoon (June – September) and another 30 % during the northeast monsoon (October – January).

Waves, currents, wind and tides are the driving forces that control

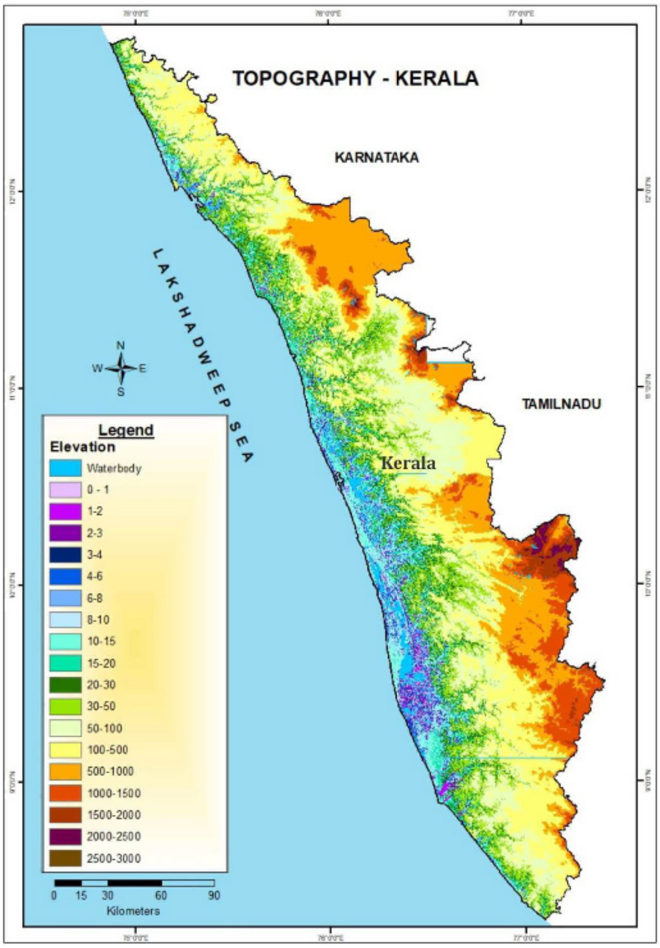

Fig. 2. Topography of Kerala.

the nearshore and beach processes. The nearshore and beach processes along the Kerala coast vary both spatially and temporally mainly due to the changes in coastal morphological features and variation in the characteristics of the driving forces (Prasad et al., 2016). Kerala coast being a micro-tidal coast, the wave climate dictates the coastal processes.

Nearshore Waves

The wave spectra for the deep water and shallow water low energy conditions are closely represented by Bretschneider-Scott spectral forms. For the high energy conditions, the high frequency component of the waves matches with the Kitaigorodskii form and the total energy spectrum is close to the TMA spectrum (Hameed, 1989). High waves with significant wave heights more than 2.5 m occur during the monsoon season. The wave heights during the remaining period are less than 1 m. Dominance of southerly swells from the southern Indian Ocean is observed throughout the year, except during the monsoon season when the locally generated westerly wind waves become more active. The southern part experiences high wave activity (Trivandrum has recorded a maximum wave height of 6.5 m as reported by Baba et al. (1988)) compared to the central and northern parts. Ponnani and Kasargod in north Kerala also experience reasonably high wave activity, but the intensity is comparatively less. Baba and Joseph (1988) after studying the one year wave observations off Cochin and Trivandrum concluded that the wave spectra remain multi-peaked almost throughout the year. Because of the spatial variation in the nearshore wave heights along the Kerala coast there is a corresponding variation in the wave breaking characteristics as well. The wave breakers are mostly of the plunging/spilling type along the high and medium energy coast during the rough season where as it is of plunging and collapsing type during the fair season. For the low energy coast, the breakers are mostly of spilling type (Thomas, 1990). Surging breakers are also observed particularly when the beaches are very steep. Due to inter and intra-seasonal variations in the coastal morphology, particularly the beach characteristics, there is a corresponding change in the breaker characteristics which in turn affects the beach state all along the Kerala coast (Baba and Kurian, 1988).

Longshore Currents

Variation in breaker wave heights and the oblique approach of these waves with respect to the shoreline result in movement of water parallel to the shore known as longshore current. The currents along the Kerala coast are complex in nature as it is dependent on various factors like wave parameters (height, period and direction), sediment characteristics, beach slope, coastline orientation, wind velocity etc. (Hameed et al., 2007). The longshore currents are predominantly northerly during the fair season whereas it is mostly towards south during the monsoon season. The post-monsoon season experiences relatively higher current compared to the pre-monsoon season (Hameed et al., 2007). Even though the current shows a uniform direction trend all along the coast for a given season, there is a distinct spatial variation in the magnitude. Currents with magnitude of 1.5 – 2.0 m/s were reported at Alleppy and Calicut (Baba, 1984). Unlike the waves, the northern part of the Kerala coast in general experience higher currents showing that the variation in the current is not proportional to the wave intensity. This can be attributed to the large influence of breaker approach angle (Hameed et al., 1984).

Tide

The southwest coast of India falls under the micro-tidal range. This is because of the narrow shelf width and geo-morphological features of this region. The tidal range increases from south to north with values ranging from 0.9 – 1.8 m (Tide Table, 2017).

Sea Level Variations

Based on analysis of altimeter data for the period 1993–2012 Unnikrishnan et al. (2015) have reported that that the rate of sea level rise is more or less spatially homogeneous over most of the north Indian Ocean, reaching values close to global mean sea level rise trend of 3.2 mm/y for the same period. According to their analysis, the net sea level rise trend (derived from the tide gauge data) for the Kochi station shows a rise of 1.81 mm/y during the period 1939–2007.

Sediment Grain Size

The sediment grain size also exhibit significant spatial variation from south to north Kerala. The grain size gives an indication of wave energy level (Komar, 1976). The average mean grain size as reported by Baba and Kurian (1988) and Prakash et al. (2016) are presented in Table 1.

The beach morphology in general depends on factors like the wave characteristics, sediment grain size and the interaction between the waves and sediments which in turn decides the sediment transport processes (Pethick, 1984).

Shelf Gradient

There is a distinct variation in the shelf gradient also from south to north along the Kerala coast as depicted in Table 2. The shelf gradient gradually decreases from Trivandrum to Kannur beyond which an increase in the gradient is observed. The shelf gradient gives a direct indication of the wave energy intensity along the coast. Kurian (1987) demarcated the Kerala coast into three different categories viz. high, medium and low based on the nearshore bottom slope. Accordingly, the Trivandrum coast in south experiences maximum wave activity, whereas the Thalassery coast in the north sector has the lowest waves.

Shoreline Changes along the Southwest Coast of India

As described earlier, the factors responsible for the shoreline changes are both natural and anthropogenic. For studying the long-term stability of any coast, it is necessary to conduct a detailed analysis of the shoreline changes over the period under consideration. This is because the shoreline being dynamic in nature is susceptible to changes

Table 1. Mean sediment grain size along the Kerala coast.

Location	Mean Size (mm)
#Trivandrum	0.35
*Kollam	0.25
#Alapuzha	0.30
#Kozhikode	0.23
#Thalassery	0.21

#Baba and Kurian (1988), *Prakash et al. (2016)

Table 2. Variation of shelf gradient along Kerala coast.

Location	Shelf Gradient (x 10^{-3}) from the shoreline to isobaths (Kurian, 1987)			
	10 m	20 m	30 m	50 m
Trivandrum	33.33	40.00	7.50	4.54
Kollam	4.56	6.25	5.26	2.82
Alapuzha	2.86	1.74	1.67	1.72
Kochi	2.08	1.80	1.45	1.38
Ponnani	3.70	2.47	1.72	1.86
Kozhikode	2.08	1.96	2.04	1.19
Thalassery	2.22	2.30	2.00	1.42
Kasaragode	3.70	2.66	2.88	2.08

induced by the various driving factors, of which some may have substantial influence. Many studies have been carried out both at national and international level for studying various aspects of shoreline changes adopting different approaches (Bhat, 1995; Kurian et al., 2007; Kumar and Jayappa, 2009; Rajasree et al., 2016; Burningham and French, 2017). But studies related to long-term shoreline changes along the southwest coast of India are limited, probably because of lack of availability of fine resolution satellite images and field data with the desired spatial and temporal coverage (Hameed, 1988; Sreekala et al., 1997).

A review of some of the studies pertaining to shoreline changes along the Kerala coast has been carried out to identify the gaps if any. The stability of coastline from Manakkodam to Thottapally was studied by Udayavarma and Varadachari (1977) and they concluded that the coastal sector of Alleppey to Manakkodam was stable. The shoreline changes in connection with the structures constructed along the Kerala coast was studied by Murty and Varadachari (1980). Hameed (1988) studied the beaches of Alleppey and stated that the beach is in dynamic equilibrium. By comparing multi-dated satellite images, aerial photographs and topographic maps, Sreekala et al. (1997) investigated the long-term erosion / accretion trend along the Kerala coast. Based on their studies, the erosion / accretion zones along the Kerala coast was demarcated. But over the years due to rapid development activities in the coastal area and influence of natural factors, the Kerala coast has witnessed drastic changes which imply that the old-erosion / accretion zones are no longer valid (Sreekala et al., 1997; Narayana and Priju, 2006; Kurian et al., 2007; Sheela Nair, 2014; Prasad et al., 2016). This is mainly due to the construction of ill-conceived shore protection structures, beach sand mining, port and harbor development etc. in addition to the natural factors such as 2004 Tsunami event, coastal flooding, mud bank formations etc. (Kurian et al., 2006; Prasad et al., 2016). In this context, the present study has been taken up to estimate the long-term shoreline changes along the Kerala coast.

DATA AND METHODOLOGY

The data used to study the long-term shoreline changes along the southwest coast of India consists of the SOI topographic chart, shoreline mapped using GPS (shoreline survey data of NCESS) and multi-dated satellite images. Data sources and other details are presented in Table 3. For obtaining the shoreline position, the land-water boundary from multi-dated satellite images and the High Water Line (HWL) from the SOI topographic maps are demarcated and then digitized to derive the shorelines. The digitized shorelines derived from various sources are then geo-rectified. For geo-rectification of the SOI topographic chart, Ground Control Points (GCP) were used and the image was projected to Universal Transverse Mercator (UTM) with reference to WGS-84 datum utilizing the ESRI ArcGIS 10.3 software. For computation of rate of change of shoreline, the Digital Shoreline Analysis System (DSAS) software developed by the United States Geological Survey (Thieler et al., 2009) was used. DSAS software calculates the shoreline rate of change statistics from a temporal series of multiple shoreline positions and generates orthogonal transects at user defined interval for computation of shoreline changes. Normally the baseline vector is taken as the shoreline vector from the oldest imagery available in the data set. The orthogonal transects are drawn from the baseline at pre-defined intervals in such a way that they will cover all the shoreline vectors considered for the analysis. For computation of rates of shoreline changes using DSAS, four different methods are available: (1) End Point Rate (EPR) (2) Linear Regression Rate (LLR) (3) Weighted Linear Regression (WLR), and (4) Least Median of Squares (LMS). Of these the EPR and LRR methods are being widely used (Kaliraj et al., 2014; Natesan et al., 2015) for the estimation of the rate of shoreline changes and the same has been adopted for the present study. The rate of shoreline change using the EPR method is estimated by dividing the distance moved by the shoreline during the period under consideration by the time elapsed. The LRR method computes the rate of change by fitting least-squares regression lines to all the shoreline points (showing temporal variations) for a particular transect. The regression line is placed so that the sum of the squared residuals is minimized and the linear regression rate is the slope of the line.

In this study, an onshore baseline was created at a distance of approximately 3 km behind the shorelines. From this base line, orthogonal transects at 100 m interval along the coastline directed towards offshore were generated. For detailed analysis of the shoreline changes along the Kerala coast, the EPR and LRR computations were carried out at each of the transects. The rate of change of shoreline derived for each transect is then compiled to understand the stability of the different sectors of the coast by demarcating the erosion/accretion regimes. Positive sign for shoreline change indicates accretion and negative corresponds to erosion. For ease of presentation, the shoreline changes observed are classified into 7 classes as given in Table 4 to study the erosion / accretion pattern.

Table 3. Shoreline data used for the study

Sl. No.	Name	Data Source	Publisher	Year	Survey / Acquisition	Scale / Resolution
1	Shoreline 1968	Topographic chart	SOI	1967–1968	1963–1965	1:50000
2	Shoreline 1990	Landsat TM mosaic	GLCF	2002	1988–1992	30 m, 90 m
3	Shoreline 2000	Landsat 7	GLCF	2002	2000	30 m
4	Shoreline 2010	CARTOSAT	NRSC	2010	2010	2.5 m
5	Shoreline 2014	CARTOSAT	NRSC	2014–2015	2015	2.5 m

SOI – Survey of India; GLCF – Global Land Cover Facility;
NRSC – National Remote Sensing Centre

Table 4. Criteria for shoreline change classification.

EPR / LRR Value	Class
< -5	Very High Erosion
-5 to -2.5	High Erosion
-2.5 to -0.5	Moderate Erosion
-0.5 to 0.5	Stable
0.5 to 2.5	Moderate Accretion
2.5 to 5	High Accretion
>5	Very High Accretion

RESULTS AND DISCUSSION

The long-term shoreline changes along the Kerala coast for a period of 46 years from 1968 to 2014 has been studied based on the shoreline data derived from topographic chart and multi-dated satellite images. The rate of shoreline changes have been computed adopting both EPR and LRR methods (Fig. 3) and the results are found to be more or less similar. The advantage of the EPR method is that the computation is simple, but this method uses only two data points to delineate the rate of change, where it assumes a linear trend. The advantage of LRR method is that this uses the statistical tests for the computation and all the shorelines are used regardless of changes in trend or accuracy. This method assumes a linear trend and is sensitive to statistical outliers (Genz et al., 2007).

As per the present study, the erosion and accretion percentages for the entire Kerala coast is about 59.5 % and 28.6 % respectively.

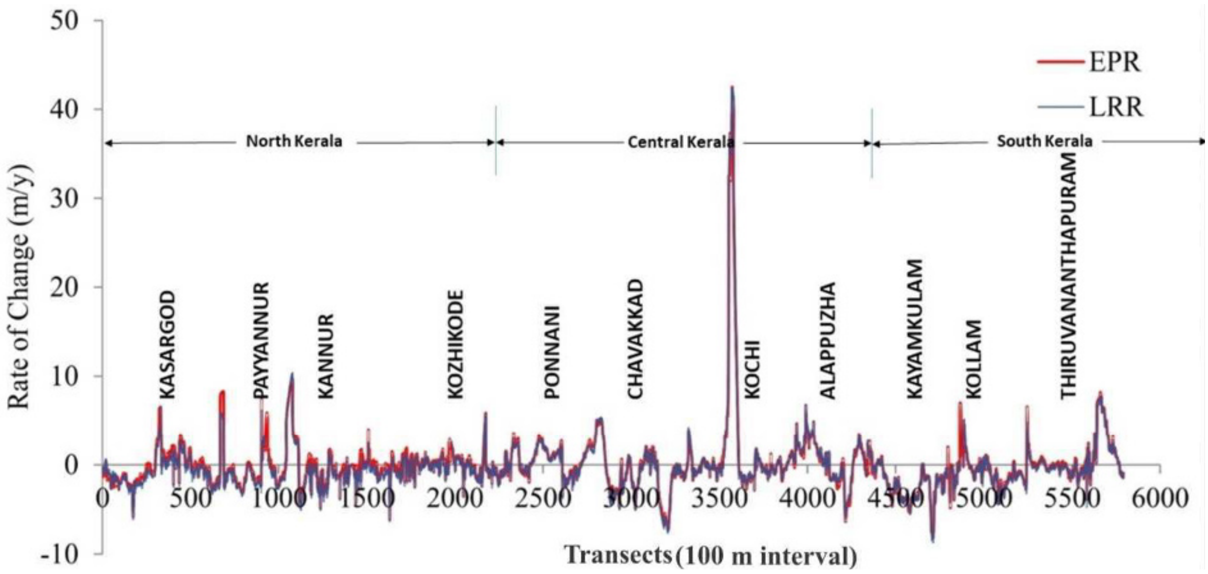

Fig. 3. Computed rate of shoreline change along the Kerala coast during 1968 – 2014 using EPR and LRR methods. (EPR – End Point Rate; LRR – Linear Regression Rate).

The shoreline change in percentage along the Kerala coast is shown in Fig. 4. As per the computed results, the maximum percentage of erosion is (21.6 %), under the 25 – 50 m shoreline change category. The second largest erosion of 18.5% is observed in the range of 50 – 100 m. Within the 0 – 25 m category the observed erosion is about 11.2 %. For the remaining 8 %, the shoreline change is more than 100 m indicating high erosion. The percentages accretion under various categories of 0 – 25 m, 25 – 50 m and 50 – 100 m are 5.7 %, 9.8 % (maximum) and 5.8 % respectively. The remaining 7.2 % falls under the above 100 m accretion classification.

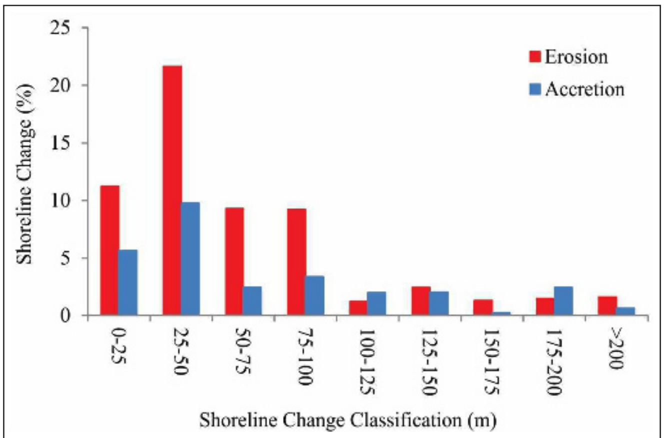

Fig. 4. Shoreline change in percentage along the Kerala coast.

Table 5. Comparison between End Point Rate and Linear Regression Rate based classification.

Sl. No.	Class	Percentage of Erosion/ Accretion	
		EPR	LRR
1	Very High Erosion	1.7	1.8
2	High Erosion	8.5	9.9
3	Moderate Erosion	35.0	38.9
4	Stable	26.0	23.8
5	Moderate Accretion	20.0	17.2
6	High Accretion	5.9	4.8
7	Very High Accretion	2.8	3.5

Comparision of the rate of shoreline changes computed using the EPR and LRR is presented in Table 5. It is evident from the table that percentage rates obtained by both the methods are more or less same. The computed percentage rate under the erosion classification is 45.2 as per the EPR method, where as it is 50.2 by the LRR method. The percentage of accretion computed by EPR and LRR methods are 28.7 and 25.5 respectively. The computed EPR and LRR rates (%) under the stable beach classification are 26 and 23.8 respectively.

The variation in shoreline changes along the Kerala coast is discussed in the following sections. For convenience of discussion, the coast is divided into three sectors viz. south, central and north Kerala coast.

North Kerala

The north Kerala coast which extends from Beypore (Calicut) in the south to Kasaragod in the north shows a maximum accretion of 7.8 m/y for the Kannur coastal sector by the EPR method, whereas it is 5.8 m/y by LRR for the same location. From Fig. 5a&b, it can be seen that very high erosion is observed to the north of Vadagara (5.22 m/y by EPR method) and high erosion towards north of Payannur (1.85 m/y by EPR) and on either side of Kannur coast. In general, the northern part of this sector extending from Thalassery to north of Kanhangad shows moderate erosion (5.32 m/y as per EPR), whereas the region further north of Kanhangad up to Kasaragod remains more or less stable. Compared to the adjoining coast, the Quilandy sector remains stable throughout and this can be attributed to the occurrence of mud banks in this region during the monsoon. The sector extending from Calicut to south of Thalassery also remains stable. However the region to the south of Calicut beach upto Parappanangadi (south of Beypore) is under moderate erosion which is different from the results of Sreekala et al. (1998).

Central Kerala

For analysis, the sector from Thottapally in Alappuzha to Parappanangadi (Malappuram) has been considered as the central Kerala coast (Fig. 5a&b). As per the results, the coast comes under the moderate accretion classification. The computed EPR and LRR for the Kochi coastal sector show a maximum accretion rate of 43 m/y and 42 m/y respectively and this incidentally is for the Puthuvype region. The region immediately to the south of Cochin inlet is under

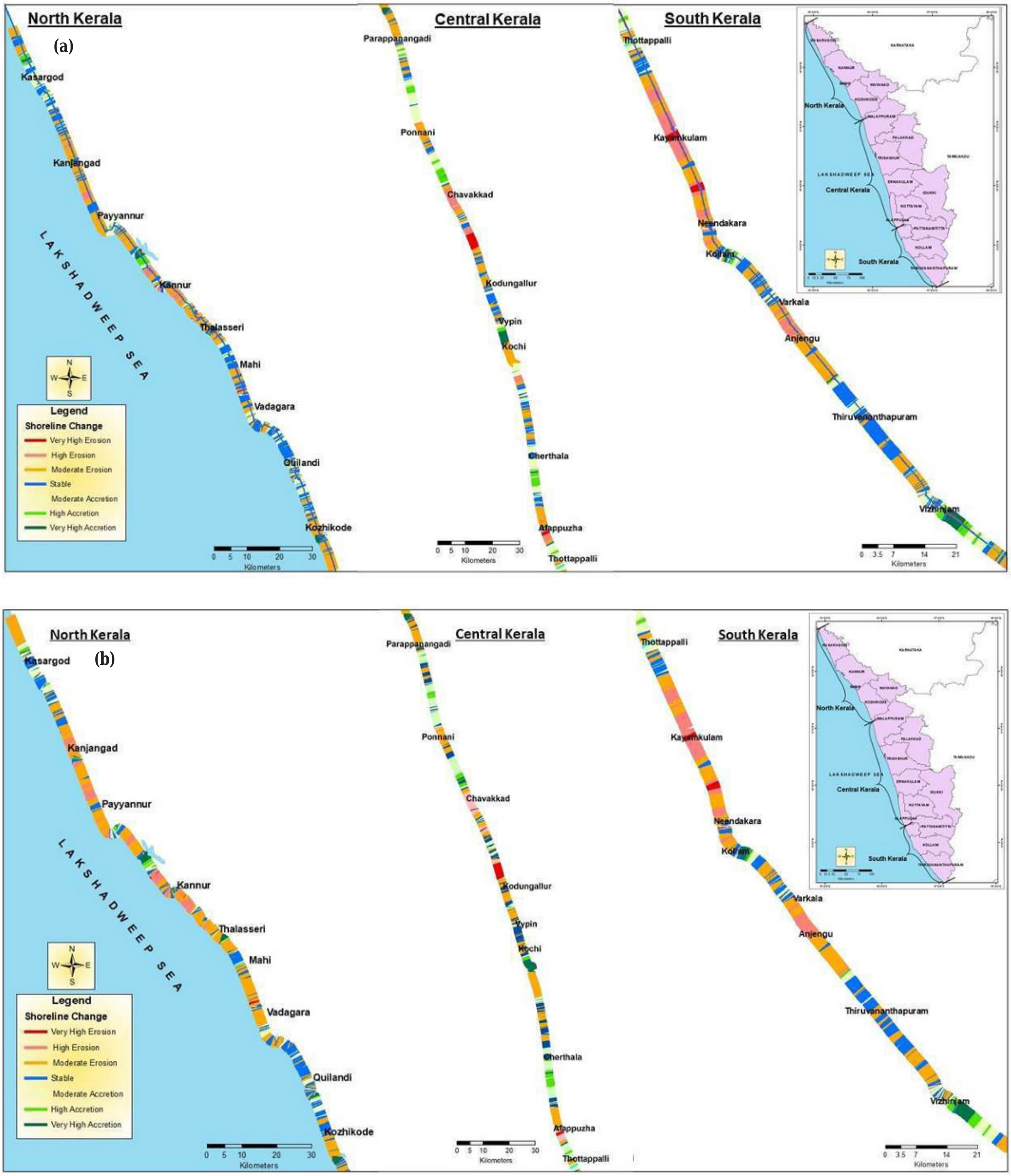

Fig. 5. Erosion/accretion rate represented by **(a)** EPR and **(b)** LRR along the Kerala coast (north, central and south) during the period of 1968–2014. (EPR – End Point Rate; LRR – Linear Regression Rate).

moderate erosion and similar observations were made by Narayana and Priju (2006) and Kurian et al. (2007).

As per the present analysis, the stretch from Munambam to Elamkunnapuzha is stable as reported by Narayana and Priju (2006) for the period 1966–1995. Similar trend was reported by Kurian et al. (2007) based on the studies conducted during the period 1985–2000, except for the Elamkunnapuzha region, which was showing a low erosional tendency. The Elamkunnapuzha to Vypin sector (Fig. 5a & b) shows high accretion for a stretch of 6 km (approx.) with a maximum accreting width of about 1.9 km at Puthuvaippu area, where a tongue formation is seen with an area of 3.5 km^2. This is in confirmation with Kurian et al. (2007) wherein a high accretion of 3.96 km^2 was reported during the 15 year period, 1985–2000. Narayana and Priju (2006) also reported an accretion of 2.8 km^2 north of Cochin inlet during the period between 1966 and 1995 and an increase in area of 0.38 km^2 from 1995–2000. The observed high accretion rate can be attributed to the re-deposition of dredged spoil from the Cochin port which is disposed offshore. Due to the dominance of northerly sediment transport, a major portion of the disposed material gets re-deposited to the north of the inlet. This has led to the formation of a wide beach and field observations confirm that the beach continues to accrete as the sediment from the dredge spoil is available throughout. Further north, very high erosion (5.25 m/y as per EPR) is observed along the Kodungallur – Chavakkad stretch. The stability observed at selected locations along the Alappuzha coast and to the north of Ponnani can be linked to mud bank formations. However the Ponnani coast which was earlier reported as an accreting beach by Sreekala et al. (1998) is presently under moderate erosion.

South Kerala

The south Kerala coast considered for the study extends from Poovar (Trivandrum) in the south to Thottapally in Alappuzha (towards north). Along the Kollam coast, accretion is observed with EPR values of 6.4 m/y at Kollam beach (Fig. 5a&b). Towards south of the Thangassery harbor, high rate of accretion is noticed which can be attributed to the presence of the prominent Thangassey headland. The headland traps a considerable portion of the northerly longshore sediment transport. Further north, beyond the headland, very high erosion is observed as can be seen from the computed EPR and LRR values of 6.4 m/y and 7.3 m/y respectively at Ponmana. This corroborates well with the observations made by Prasad et al. (2016), wherein the impact of unsustainable sand mining has been reported as very high. In general, the beaches in the southern part of this sector appear to be more stable than the northern part.

Present Status of the Kerala Coast

Based on the results of the study and the morphological characteristics, the erosion/accretion pattern observed along the Kerala coast can be categorized as follows:

Dynamically Stable Beach with Seasonal Erosion/Accretion

More than 50 % of the Kerala coast falls under this category, wherein the primary reason for erosion is due to the influence of monsoonal and non-monsoonal waves. It is observed that these types of beaches after being subjected to seasonal erosion, are capable of completely regaining their original shape (with negligible net erosion/ accretion) during the ensuing fair season, if they are devoid of any interventions, particularly hard structures. Examples are the Shankumugham beach at Trivandrum, Kollam beach, Alleppey beach, Kozhikode beach, Muzhupilangad beach etc.

Erosion Induced Due to Anthropogenic Activities

The stability of the coastal stretches under this category is badly affected due to the shortage of sediment supply to the coast. Anthropogenic activities like construction of hard structures (breakwaters, seawall, groins etc.), dredging of channels and other activities like beach / river sand mining, damming of rivers etc. have a negative impact on the coast. Typical examples are the high erosion witnessed at Ponmana, Chavara coast (beach sand mining); erosion to the north of breakwaters at Muthalapozhi, Kayamkulam and Puthiyappa (Kozhikode) inlets; severe erosion observed to the south of Cochin inlet (dredging of sediments from the ship channel) etc.

Mud Bank Induced Erosion

Selected stretches along the central and north Kerala coast are influenced by the occurrence of mud banks during the monsoon season. It is observed that if the mud bank occurs repeatedly at the same location (more or less) for a few years, that particular stretch of the coast will have an accreting tendency, whereas the adjoining coast will undergo erosion. Examples are beaches between Arattuppuzha and Andhakaranazhi; Azheekkal and Chaliyum; beach to the north of Quilandy harbour up to the Nandi headland etc.

CONCLUSIONS

The long-term shoreline changes along the southwest coast of India for the 46 year period, 1968–2014 has been studied in detail using the data derived from multi-dated satellite images and the 1968 SOI topographic chart. For the estimation of rate of shoreline changes, the DSAS software of USGS was used adopting the End Point Rate (EPR) and Linear Regression Rate (LRR) methods. As per the study it can be concluded that almost the entire stretch of the Kerala coast has undergone drastic changes over the years, of which the anthropogenic activities like construction of hard structures along the coast, beach and river sand mining, construction of dams across major rivers etc., have contributed to the deterioration of the coast in general. The reduction in availability of sediment all along the coast (beach / nearshore) is a matter of growing concern as it directly affects the natural equilibrium of the coast and thereby its stability.

The rate of shoreline change along different sectors of the coast was computed and the changes observed are presented in 7 classes under which the rates are quantified. The analysis of the results revealed that almost 60 % of the coastline is eroding whereas about 29 % shows an accreting trend. Based on the results of the study and the morphological characteristics, the erosion / accretion pattern observed along the Kerala coast can be broadly categorized into three viz. dynamically stable beach with seasonal erosion / accretion, beaches undergoing erosion due to anthropogenic activities, beaches affected by mud bank induced erosion. Even though as per the present study the total eroding percentage of the Kerala coast is about 60 %, field observations indicate that the total percentage can be as high as 75 – 80 %. This is because a few of the critically eroding sectors are not reflected in the analysis as they are presently being maintained intact by construction of well protected seawalls and other measures. The results of the present study cannot be used for a one to one comparison with those reported in the earlier studies as there have been considerable changes in the coastal morphological features mainly due to anthropogenic activities like construction of breakwaters, seawalls, groins, mining activities, dredged spoil disposal etc. Even then few attempts have been made to compare with the results of the earlier studies and wherever possible explanations have been given for the deviation. Prediction of future trends based on this study may not be realistic as the shoreline features along the southwest coast of India is constantly changing due to both natural and human interventions of which the latter plays a major role.

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