



# End point rate analysis and estimation along the southwest coast of Kanyakumari, Tamil Nadu, using geospatial techniques

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## Abstract

The Kanyakumari district lies on the southern tip of Tamil Nadu, India. Nowadays, the economically wealthy coast of this district is profoundly altered in its natural existence, which can be deliberated by using Remote Sensing techniques. In this present study, shoreline change inquiry has been attempted at Vilavancode and Kalkulam taluks using the multitemporal satellite data of Landsat 7 ETM+ and the Sentinel for a decade from 2009 to 2019. The shoreline has been demarcated and the End Point Rate is estimated by using the Digital Shoreline Analysis System. The shoreline changes statistics have been categorized into seven classes based on the rate of changes: high erosion, medium erosion, low erosion, stable, low accretion, medium accretion, and high accretion. This investigation helps to sense regional fluctuations and reveals that the area subjected to landward shoreline shift is higher than the seaward shoreline shift during this period. The villages of Iraviputhanthurai (10.61 m/yr), Inaiyam (4.01 m/yr), Mandacaud (8.17 m/yr), and Kodimunai (4.12 m/yr) are subjected to high erosion, whereas high accretion is perceived at the Irayumanthurai village (4.13 m/yr). The impact of coastal erosion on site-specific shorelines is considered in this research. This finding will be helpful for coastal management to reduce the loss of economy and safeguard the future coastal environment.

**Keywords** End point rate (EPR) · Digital shoreline analysis system (DSAS) · Erosion · Accretion · Kanyakumari

## Introduction

Shoreline erosion, storm surges and extreme events have resulted in severe loss of human life, damaging the ecosystem along India's coastal area (Saxena et al. 2012). As a unique feature on the earth's surface (Li et al. 2004), the shoreline is thriving as a contact line between land and a large water body. Shoreline undergoes continuous changes because of its dynamic environment, which is highly vulnerable to erosion and accretion (Prasad and Kumar 2014; Mentaschi et al. 2018). The coastal area has become more prone and vulnerable to natural and human-made hazards, leading to erosion. The regular monitoring of shoreline change helps to predict the nature and manners that caused changes in any specific area, evaluate the human impact, and plan the

managing strategies (Kasinatha Pandian et al. 2004; Nassar et al. 2019).

Coastal zones are subjected to rapid erosion by natural processes and slightly by anthropogenic activities over a long period of time (Masria et al. 2014; Chen et al. 2019). The physical process of tidal inundation, sea-level rise, land subsidence, erosion, and sedimentation are instrumental in making the coastal area a highly active environment in the shoreline change and coastal landscape development. Coastal erosion, flooding of wetlands, estuaries, and saltwater intrusion threaten the coastal zone's socio-economic activities and infrastructure (Kos'yan et al. 2012; Jonah et al. 2017). The coast's erosion and accretion rates are an effect of wave-induced longshore currents and dynamic coastal processes (Hegde 2010; Cherian et al. 2012). Coastal zones are exposed to a vibrant natural process that usually causes changes in a long and short time span (Bouchahma and Yan 2014). In order to recognize these changes, shoreline computation helps to understand coastal morphodynamics by detecting erosion and accretion (Armenio et al. 2019). The periodical and historical changes can be predicted accurately by the multitemporal

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satellite data (Sheik and Chandrasekar 2011; Yan et al. 2021). Apart from other conservative methods, another effective way for change detection is by evaluating through satellite data (Saranathan et al. 2011).

Remote-sensing satellite images are effectively used to monitor the shoreline changes in different parts of the world. Space technologies can provide information over a large area on a repetitive basis and therefore are very useful in identifying and monitoring various earth surface features. Remotely sensed data provide valued primary alterations estimations and is an exclusive tool for research and monitoring coastal areas and deltaic environments (Ciavola et al. 1999; Yang† et al. 1999; Al-Zubieri et al. 2020). Various investigations use several spatio-temporal quantitative and qualitative analyses to forecast the shoreline changes (Chauhan et al. 1996; Chandrasekar 2013; Nassar et al. 2019). GIS integrates the thematic information derived from the satellite data for the integrated coastal zone management (Desai et al. 2000; Yan et al. 2021). To discover the changes, Digital Shoreline Analysis System (DSAS), which is an extension in the ArcGIS software, can be used to calculate the shoreline's change rate (Thieler et al. 2009; Bera and Maiti 2019). The shoreline change rate is computed using satellite imageries and the End Point Rate (EPR) technique (Ciritci and Türk 2020), which is more accurate and reliable (Sebat and Salloum 2018). The degradation of the coast creates a more significant impact on humans, infrastructure and coastal lands (Nassar et al. 2021). To maintain the coastal environment, its consistency is maintained substantially by constructing groins, seawalls, and breakwaters, which prevent the removal of beach sediments from the coastline. On the contrary, in some cases, the shoreline gets transformed by the sea walls, groins, breakwaters, and jetties as they disturb the sediment dynamics (Mahapatra et al. 2014). Thus, predicting coastal changes is challenging for researchers (Nithu Raj et al. 2019).

Former disclosure on shoreline changes and coastal ecological changes on the coast of Kanyakumari elucidates that the stability of this coast is pronely vulnerable, which is highly influenced by natural and anthropogenic activities (Sheik and Chandrasekar 2011; Kaliraj et al. 2014, 2017a). With the sand mining and shifting of eroded sediments by the waves drifted by the coastal constructions, the coast is highly modified, resulting in economic loss and risk of human migration (Joevivek et al. 2019).

This study explores the erosion and accretion rate with multitemporal satellite images. The dynamic changes on the two taluk's coast, namely Vilavancode and Kalkulam of Kanyakumari district of Tamil Nadu for the past ten years from 2009 to 2019, are gathered through this satellite-based study. The investigation discloses the effects of

economic-based constructions, mainly fishing harbors and jetties along the coast during this study period to delineate the shoreline changes. The Remote Sensing and GIS-based studies were used for assessing the shoreline alteration by computing the End Point Rate (EPR). Collecting the real-time information about the changes provides a way for further developmental movement in coastal change studies by providing a way to formulate the coastal risk management plans along this coast.

## Study area

The study area for the present study lies on 77° 5' E to 77° 21' E Longitude and 8° 7' N to 8° 19' N Latitude. It comprises two taluk's coastal stretch Vilavancode and Kalkulam, in the Kanyakumari district of Tamil Nadu state in peninsular India, extracted from the 1:50,000 scale map of Survey of India (SOI) toposheet, as shown in Fig. 1. The entire coastal stretch is about 33.5 km, comprising the two taluks, Vilavancode and Kalkulam, with a coastal length of 19.2 km and 14.3 km, respectively. The Thamirabarani River and the Valliyar River drain into this region's sea. The study area prevails in sub-tropical climatic conditions with the annual average rainfall ranging from 826 to 1456 mm and the temperatures ranging from 23.78 to 33.95 °C (Kaliraj et al. 2017b). This region's geological features are mainly sandy beaches, shoreline terraces, sand dunes, and rocky shores. Sandy beaches and newly formed ridges are seen along the East of Inaiyam Puthanthurai and Colachel coast and rocky boulders made of igneous rock and silt clay materials along the Muttam coast. Sand dunes are distributed intermittently and parallelly along the nearshore area.

## Geological overview

The geological setting is an essential factor to be considered when analyzing the development of coastlines. The coastal responses to hydro-meteorological and anthropogenic aspects depend on the composition and the amount of initially deposited sediments (Jarmalavičius et al. 2017). The study area's onshore margin comprises Late Quaternary deposits of complex granite-biotite-illuminant underlain sandstone interlined with sand, silt, and clay partings overlaid by sandy materials (Loveson 1994). Sandy beaches are formed on the Colachel and Simonkudiyiruppu coastal stretches due to the swashing of a large number of sediments resulting from waves (Henry et al. 2010). The geology of the study area encompasses Aeolian, Fluvial, Fluvio-Marine, Marine, and Sandstone with clay deposits and is defined along the shoreline. The



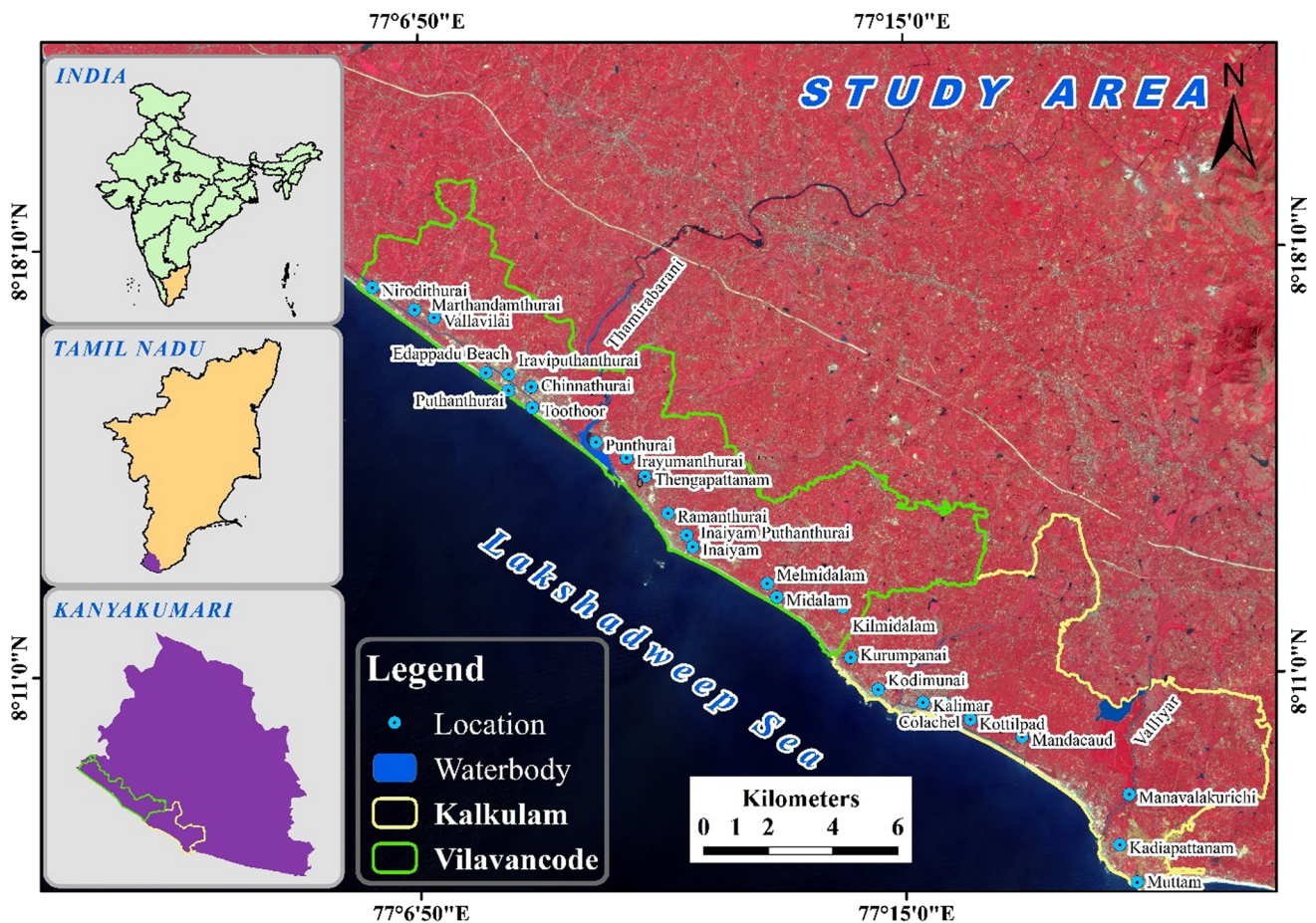


Fig. 1 Study area

marine deposits of sand, silt, clay are mainly found along the Thamirabarani creek. In the other coastal parts of the study area, Fluvio-Marine sediments of clayey sand deposits are found (Fig. 2). The soil type prevailing in the coastal region is sandy. Sand dunes are also found in the coastal stretch with a slight exposure of older coastal plains and sandstone boulders.

## Materials and methods

The shorelines are extracted from the multi-resolution Landsat 7 ETM+ and the Sentinel 2B data provided by the United States Geological Survey (USGS) Earth Explorer portal for the years 2009 (dated 14th February) and 2019 (dated 9th, January), respectively. The base map is prepared using the Survey of India (SOI) toposheet with a scale of 1:50,000. The coastal taluk boundary is digitized

from the Coastal Zone Management Plan (CZMP) map of 2018 with a scale of 1:25,000 provided by the National Centre for Sustainable Coastal Management (NCSCM). The Geology map is developed from the map published by the Geological Survey of India (GSI) in 1995 with a scale of 1:500,000. The images are registered with their coordinates, and Geometric corrections are applied with UTM-WGS 84 projection using ArcGIS 10.7. A buffer of 5 km from the shoreline is considered for the Geology map. Using Digital Shoreline Analysis System (DSAS) technique, the historic shoreline shift analysis can be demarcated from the multi-temporal satellite images by defining the baseline and casting the transects to figure the End Point Rate (Duru 2017). A statistical measurement of shoreline change using the predefined software in spatial and temporal aspects was analyzed in the study area using remote sensing and Digital shoreline Analysis System (DSAS)-GIS techniques. Though this is a

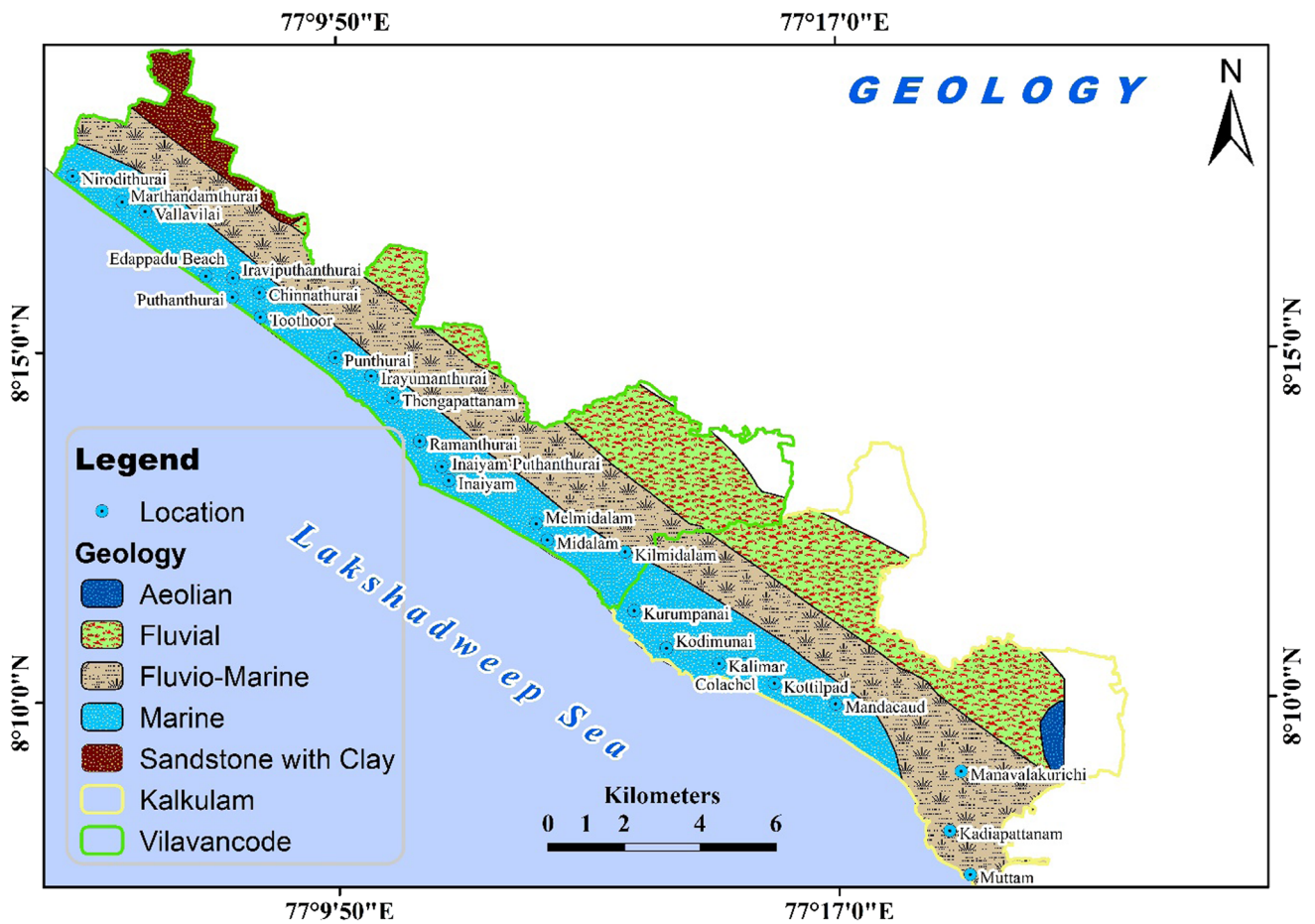
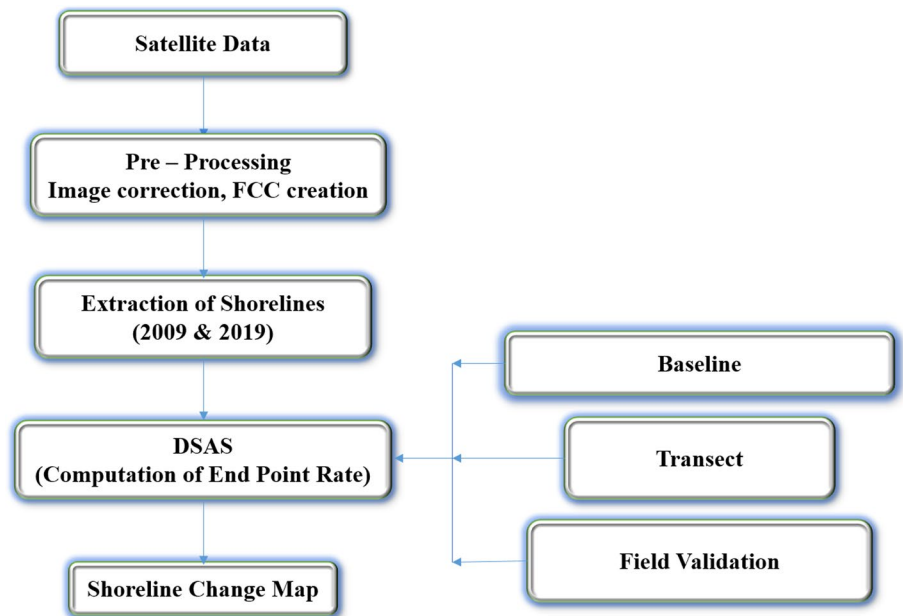


Fig. 2 Geology map of the study area

Fig. 3 Methodology



traditional method of quantifying shoreline change rate, it is widely used because of its accuracy and reliability (Kaliraj et al. 2014). The shorelines, baseline construction, casting of the transects, calculating the distance of baseline and shorelines in each transect to calculate the shoreline change rate are done using DSAS (Thieler et al. 2005). The EPR is calculated by dividing the distance of shoreline movement by the time elapsed between the earliest and the recent shoreline. The total number of transect cast for this present study is 336 on the shoreline that has been extracted from the multispectral images with a 100 m spacing is also carried out through DSAS to compute the End Point Rate. The shoreline change rate for ten years is figured out using this method. A flowchart of the methodology is given in Fig. 3.

### Results and discussion

The present study endeavors the shoreline change characteristics for a decade at the selected coastal regions of Kanyakumari. The regions of Kanyakumari and Ovari have experienced severe erosion (Natesan and Subramanian 1994). The coastline of the two taluks studied in this work shows the dynamic behavior of erosion and accretion processes at different time intervals (Murali et al. 2015). The rate of erosion and deposition is characterized into seven categories as high erosion ( $> -4$  m/yr), medium erosion ( $-4$  to  $-2$  m/yr), low erosion ( $-2$  to  $-1$  m/yr), stable ( $-1$  to  $1$  m/yr), low accretion ( $1$  to  $2$  m/yr), medium accretion ( $2$  to  $4$  m/yr) and high accretion ( $< 4$  m/yr) (Bagdanavičiute et al. 2012; Mahapatra et al. 2014; Velsamy et al. 2020) is shown in Fig. 4. The shorelines of the Vilavancode and Kalkulam taluk are

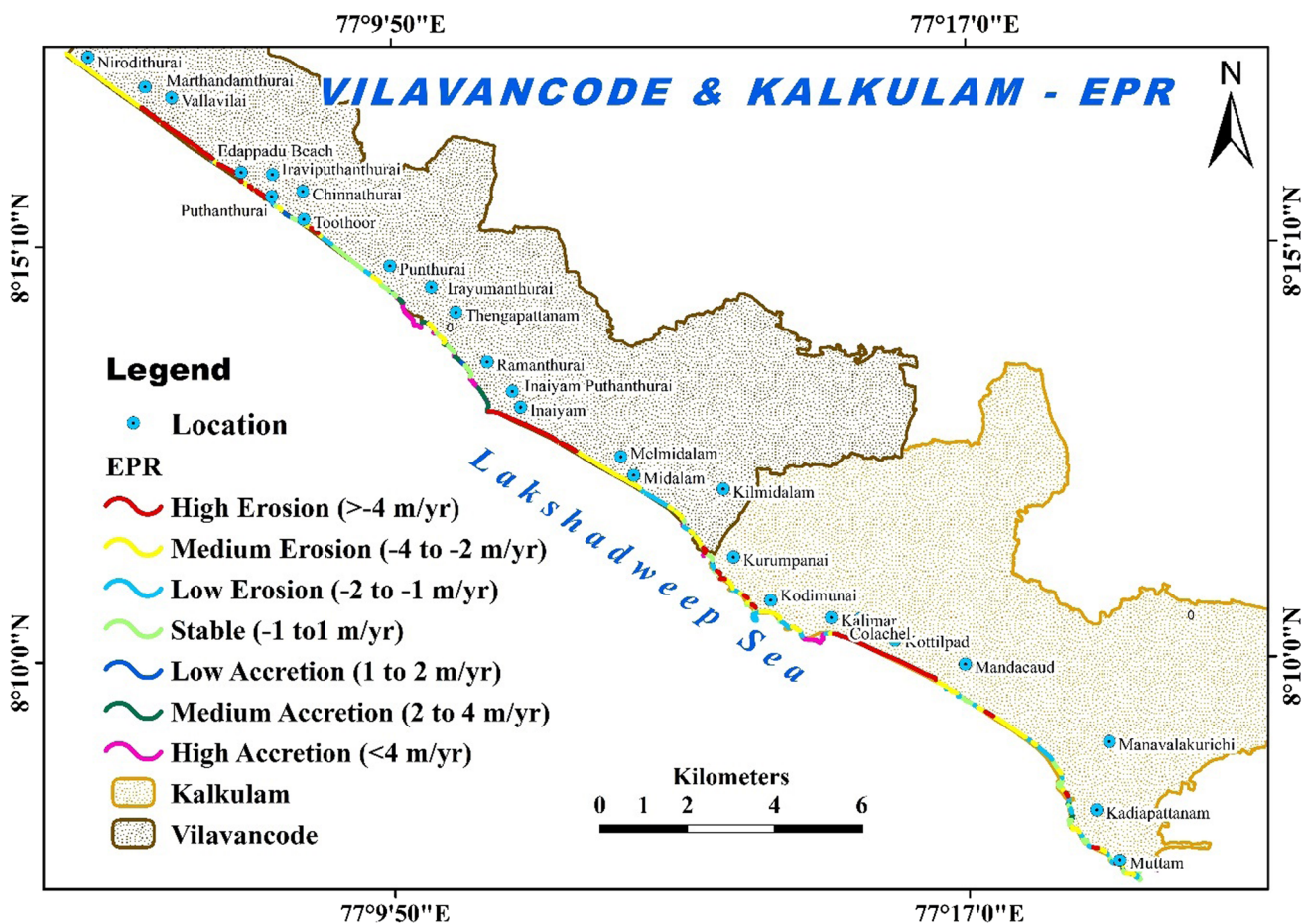


Fig. 4 Vilavancode and Kalkulam—end point rate map

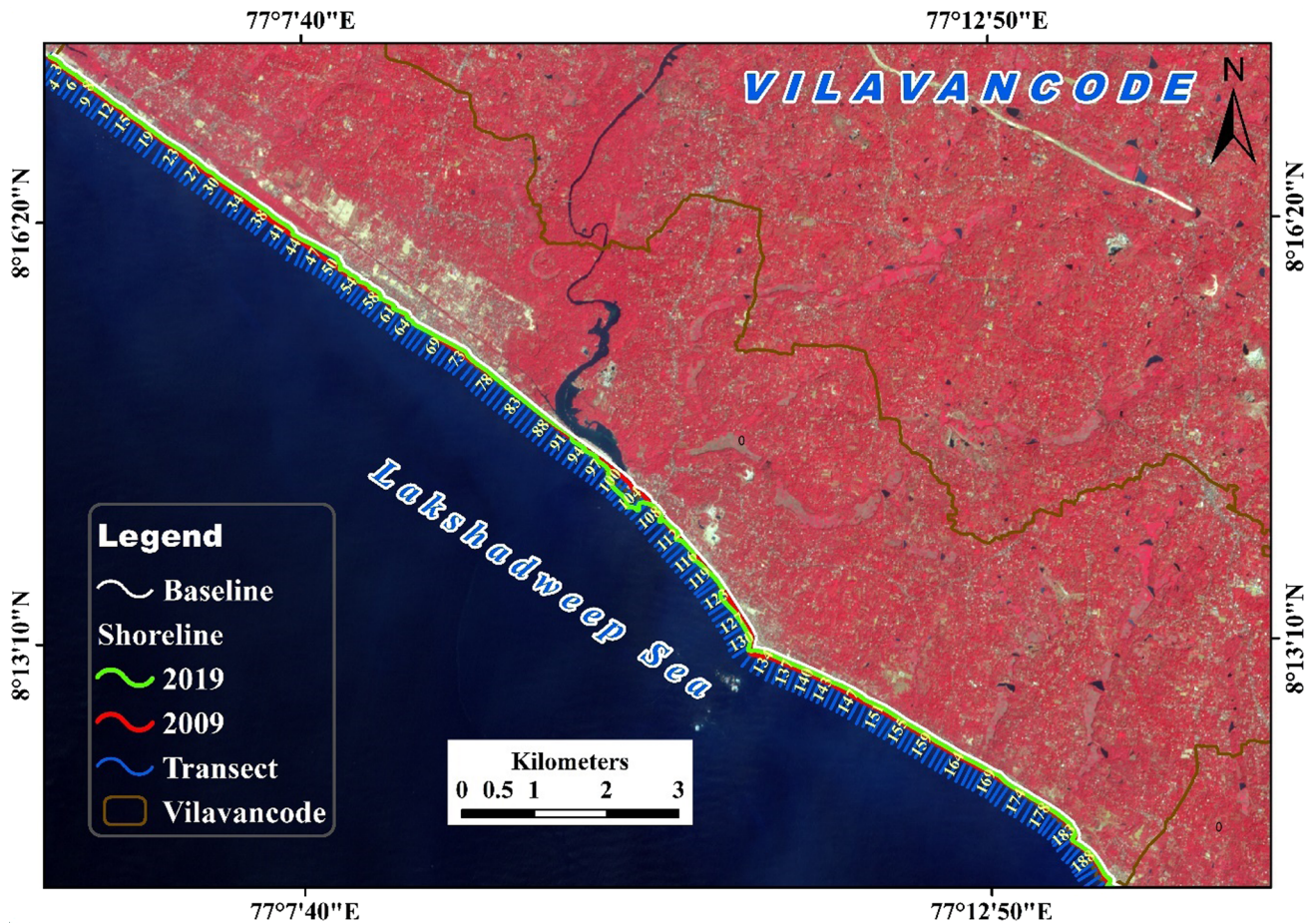


Fig. 5 Vilavancode—Transect map

differentiated concerning the casted transects. The transects 1 to 192 (Fig. 5) imply the Vilavancode shoreline and the transects 193 to 336 (Fig. 6) indicate the Kalkulam shoreline. The land expansion and land forfeiture segregation are distinguished from the casted transects numbers to quantify the EPR through DSAS.

### Shoreline change analysis

The study area is subjected to changes constantly. The erosion and accretion zones are delineated, identifying horizontal displacement and computation of shoreline change rate (Natesan et al. 2013). The erosional and depositional changes from 2009 to 2019 are portrayed in the EPR graph, which is shown in Figs. 7 and 8. End-point rate estimation is the most common and extensively used method for shoreline change calculation and future shoreline prediction.

### Rate of shoreline change

Table 1 shows the predicted rate of shoreline changes for Vilavancode and Kalkulam Taluks. The shift in erosion and accretion rate has been tabulated as a minimum and maximum change. The negative values signify the erosional rate and the positive values represent the accretion rate. Figures 5 and 6 show the map that classifies the Vilavancode Taluk and the Kalkulam Taluk shoreline concerning the transects.

In Fig. 7, the trend starts with a declining face. Transect 1 to 22 shows a medium rate of erosion at a maximum of 3.99 m/yr to a minimum of 2.29 m/yr. The highest Erosional rate of 10.61 m/yr, to a minimum of 4.41 m/yr, is noted from 24 to 58. From transect 59 to 77, low erosion is recorded with a maximum of 1.91 m/yr to a minimum of 1.36 m/yr. It shows a stable shore from the transect 78 to 95 with values ranging from 0.86 m/yr towards erosion and 0.95 m/yr towards accretion. The trend upsurges towards the positive side from transect 96 to 106, not because of accumulation but by the construction of jetties along the



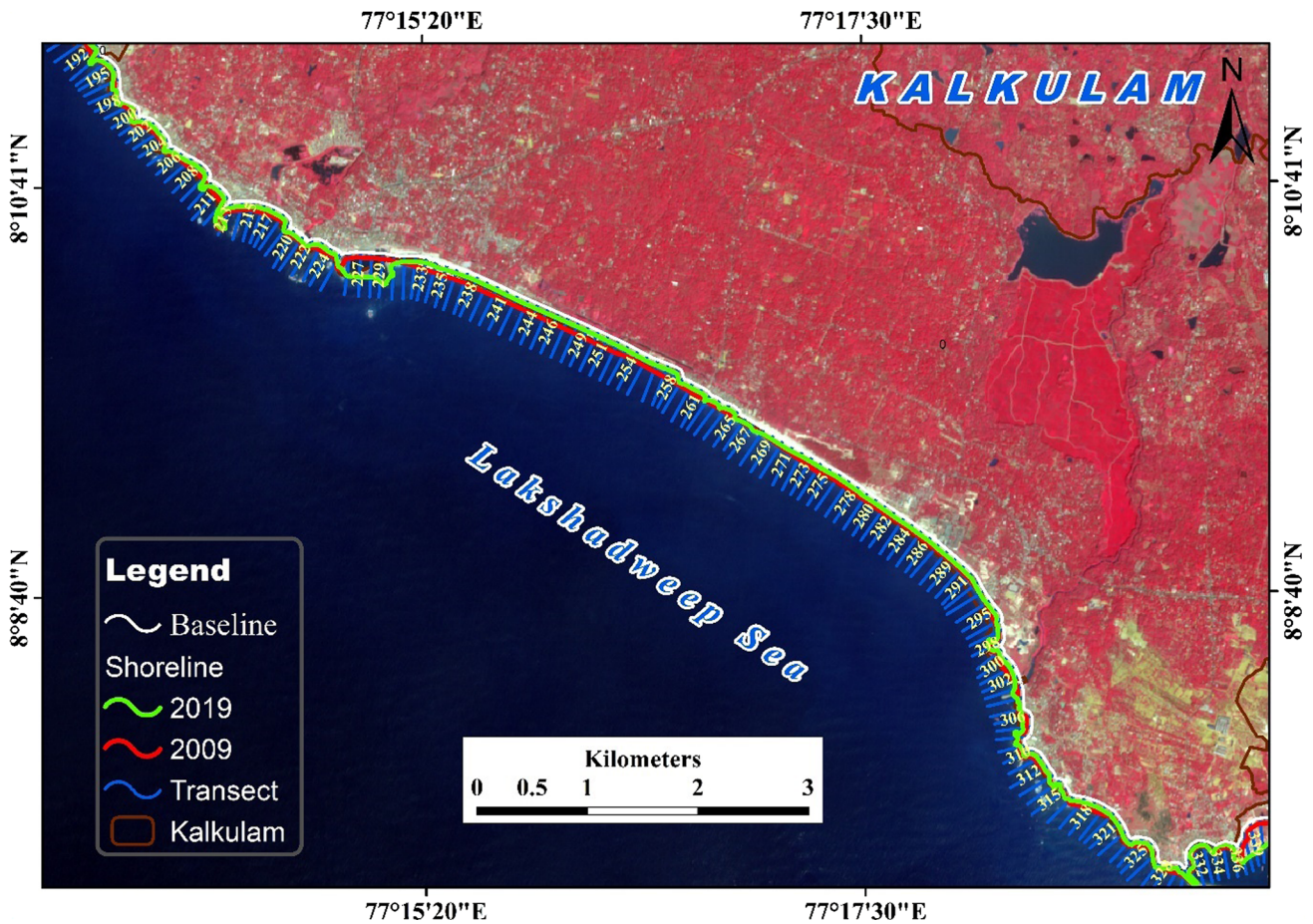
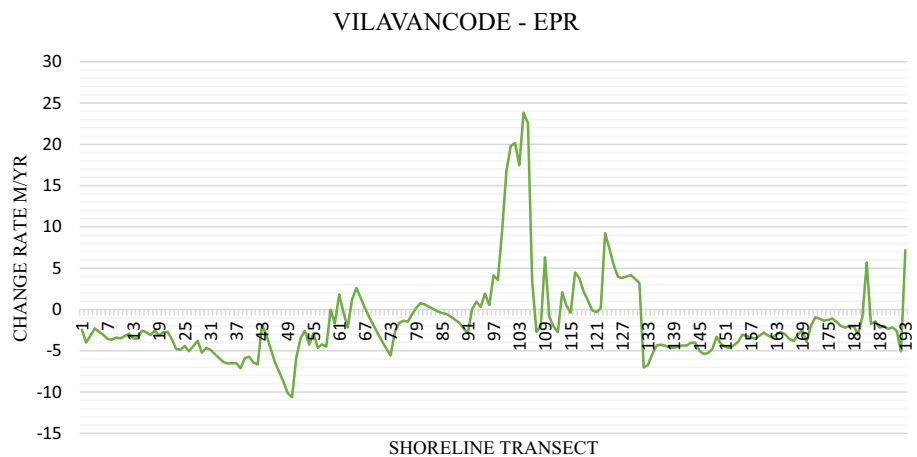


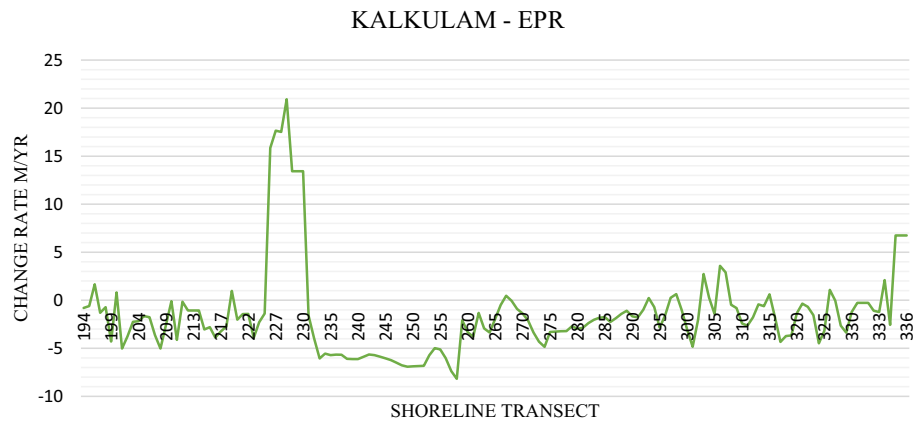
Fig. 6 Kalkulam—Transect map

shoreline’s creek. Again, the movement increases positively and is slightly high from transect 107 to 131 with a maximum depositional rate of 9.23 m/yr and a minimum of 4 m/yr. This accretional rate is due to the construction of the geo-membranes in this region. The erosional rate is high from transect 132 to 153, with 7.01 m/yr to 4.01 m/

yr, due to the wave drift created by the constructed geo-membranes. Medium erosion was noted at 3.95 m/yr to 2.51 m/yr from the transects 154 to 170. Low erosion is pointed out from transect 171 to 177 with a rate of a maximum of 1.98 m/yr to a minimum of 1.1 m/yr. From 178 to 191, medium erosion at the rate of 3.02 m/yr to 2.01 m/yr

Fig. 7 Vilavancode—end point rate trend



**Fig. 8** Kalkulam—end point rate trend**Table 1** Rate of shoreline change in m/yr

Taluk	High erosion		Medium erosion		Low erosion		Stable		Low accretion		Medium accretion		High accretion	
	Max	Min	Max	Min	Max	Min	Min	Max	Min	Max	Min	Max	Min	Max
Vilavancode	-10.6	-4.01	-3.99	-2	-1.98	-1.1	-0.94	0.95	1.09	1.92	2.09	4	4.13	23.8
Kalkulam	-8.17	-4.12	-3.91	-2.02	-1.97	-1.02	-0.99	0.97	1.08	1.66	2.1	3.58	6.75	20.9

\*(-) Negative values represent erosion

is noted and in transect 192, high erosion of 5.07 m/yr is indicated.

The graph (Fig. 8) represents the EPR of Kalkulam taluk. It shows an undulating trend with both erosional and accretional values. In this region, the trend pattern starts with an alternate crest and trough with a low erosion rate from transect number 193 to 200 with a maximum range of 1.3 m/yr. The medium erosion rate is noted from transect 201 to 218 with a maximum of 3.89 m/yr to a minimum of 2.18 m/yr. From transect 219 to 226, a low erosion rate is noted with a maximum of 1.44 m/yr and a minimum of 1.43 m/yr. This intense erosion is the upshot of the constructed geo-membranes. The crest is very high from transect 227 to 232, representing the accretion rate. This trending is due to the active fishing harbor in the locality. The movement declines from transect 233 to 258 and it is gradual in the negative part, which shows erosion with a maximum range of 8.17 m/yr to a minimum of 4.99 m/yr. The erosion is high due to the impact of the wave drift created by the constructed fishing harbor. From transect 259 to 283, a rate of medium erosion is noted with a maximum range of 3.79 m/yr and a minimum of 2.03 m/yr. From the transect 284 to 291, low erosion is noticed, with a maximum of 1.87 m/yr to a minimum of 1.09 m/yr. The sea wall plays as a barrier from the

transects 292 to 299, keeping the shore stable. From the transects 298 to 336, the trend shows an alternate rate of low erosion and stable shoreline change due to the rocky geology and the river's deposits maintaining the shoreline at this region.

### Vilavancode taluk

The coastal villages in this taluk are Nirodithurai, Mart-handamthurai, Vallavilai, Iraviputhanthurai, Puthanthurai, Chinnathurai, Toothoor, Punthurai, Irayumanthurai, Then-gapattanam, Ramanthurai, Inaiyam Puthanthurai, Inaiyam, Melmidalam, and Kilmidalam. The geological setting in this region is mostly of marine deposits (Fig. 2) with sand and silt, which is highly prone to erosion. High erosion at a maximum of 10.61 m/yr is noted at Edappadu beach in Iraviputhanthurai and a minimum of 4.01 m/yr at Inaiyam Village. Regarding medium erosion, a maximum of 3.99 m/yr at Nirodithurai village and a minimum of 2 m/yr at Midalam. Low erosion recorded is at the peak of 1.98 m/yr at the village of Melmidalam and a minimum of 1.1 m/yr at Midalam beach. For the stable shoreline, a minimum rate noticed is 0.94 m/yr at Melmidalam as erosion and a maximum of 0.95 m/yr at Irayumanthurai as accretion. The maximum amount of low accumulation noted in this area is at a maximum of 1.92/







Fig. 9 Modification of the shoreline due to Jetties, Accretion zone on the other side of the construction



Fig. 10 Shoreline modification due to the construction of jetties and the accretional zone

yr at Punthurai and a minimum of 1.09 m/yr at Inaiyam Puthanthurai. Medium accretion is at a maximum of 4 m/yr at Inaiyam Puthanthurai and a minimum of 2.09 m/yr at Then-gapattanam. High accumulation is perceived at a maximum of 23.83 m at Thengapattanam inlet is the jetties constructed to protect the shoreline and fishing harbor (Fig. 9) and a minimum of 4.13 m/yr at Irayumanthurai beach.

### Kalkulam taluk

This taluk comprises the coastal villages of Kurumpainai, Kodimunai, Kalimar, Colachel, Kottilpad, Mandacaud, Manavalakurichi, Kadiapattanam and Muttam. In Kalkulam taluk, few coastal areas till Mandacaud cover the geology of Marine sediments and Fluvio-Marine sediments (Fig. 2) at the rest of the area followed by an exposure of rocky boulders at the Muttam region. In this region, the high erosion rate is maximum at Mandacaud of 8.17 m/yr and a minimum of 4.12 m/yr at Kodimunai. Medium erosion rate, maximum of 3.91 m/yr, is observed at Colachel and a minimum of 2.02 m/yr at Kodimunai beach. A low erosion rate is noticed at a maximum of 1.97 m/yr at Mandacaud and a minimum of 1.02 m/yr at Manavalakurichi. It is stable at a maximum of 0.99 m/

yr at Manavalakurichi and a minimum of 0.97 at Colachel. The maximum low accretion rate of 1.66 m/yr at Kurumpainai and a minimum of 1.08 m/yr at Muttam. The medium accretion zone at a maximum of 3.58 m/yr at Kadiapattanam and a minimum of 2.1 m/yr at Muttam. High accumulation is noted at a maximum rate of 20.93 m/yr at Colachel is the fishing harbor's construction (Fig. 10). A minimum of 6.75 m/yr at Muttam is also due to the geomembrane construction in this area.

### Aspects inducing erosion and accretion

The alteration of the coastal landforms like the beaches, sand dunes, and beach ridges are mostly due to the wave's hydrodynamic action, tidal movement, littoral current, and backwash. The construction of the wave breakers and the geo-membranes also play a vital role. The seawalls structure has resulted in shifting erosion sites from one place to another adjacent area, whereas breakwaters have acted as barriers for littoral drift (Shetty et al. 2015). The intensity of the monsoon that transports the sediments influences the erosional and accretional process on India's west coast (Narayana et al. 2000). The high erosion noted at the Edappadu beach is due to the seasonal wave action.

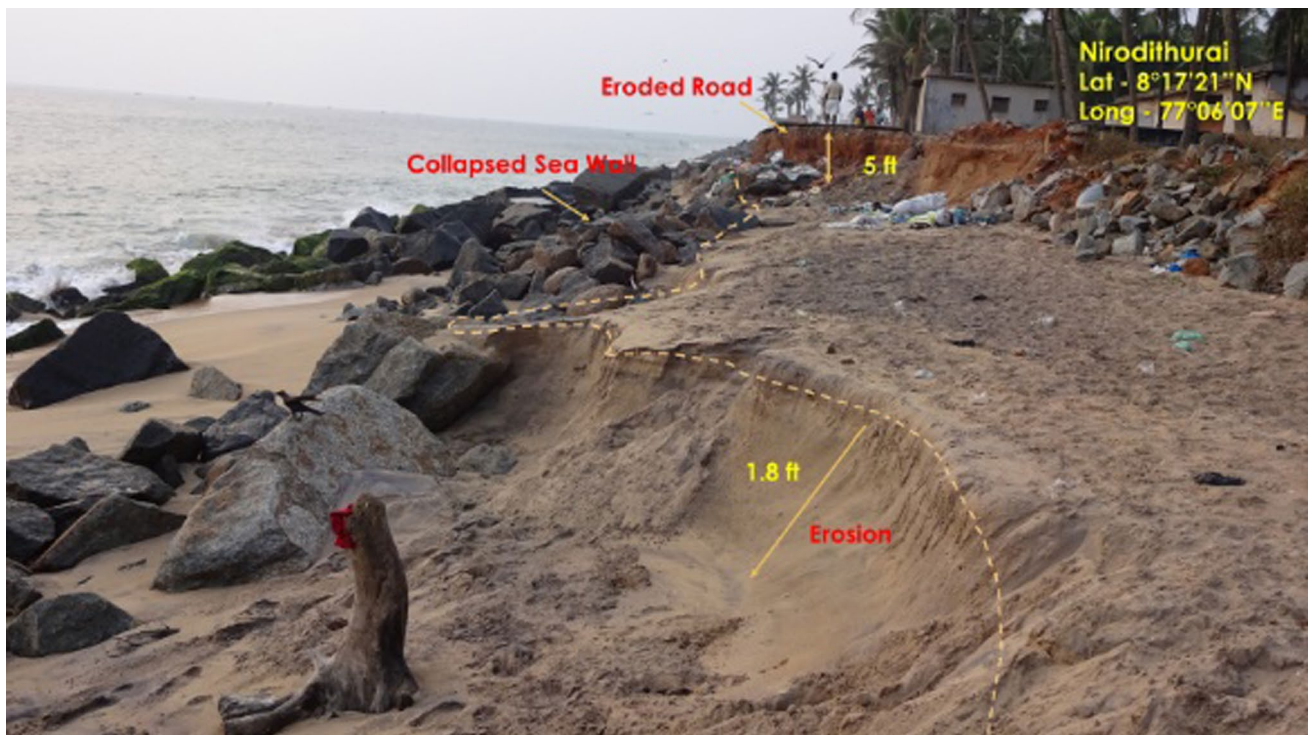


Fig. 11 Eroded shoreline



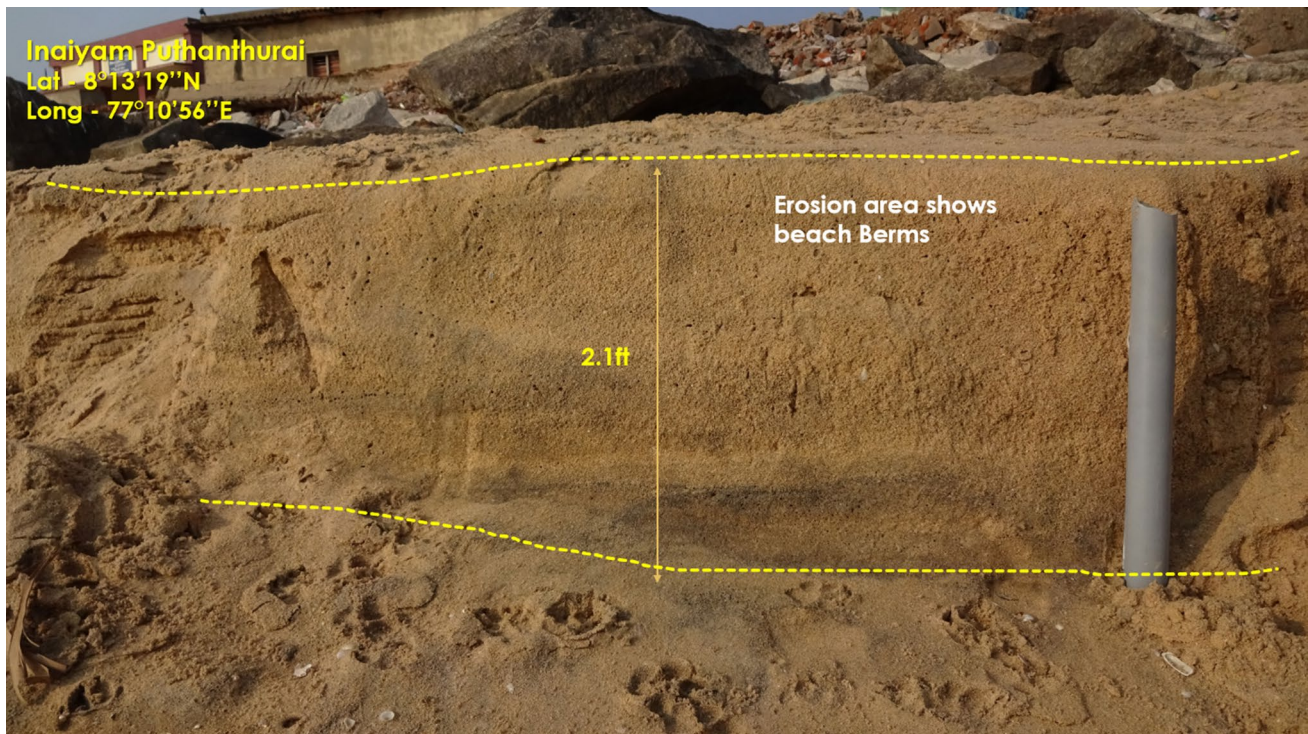


Fig. 12 Beach berm

The high erosion rate found at Inaiyam and Mandacaud is due to the wave drift created by the constructed jetties. Accretion zones are spotted in the Inaiyam Puthenthurai region because of the sediments deposited by the Thami-rabarani River. The impacts of waves redirected by the jetties constructed along the river outlet area to the sea are also significantly less in Thengapattanam region. Medium erosion is noticed at Kadiapattanam due to the sediments deposited by the Valliyar River. The shore is subjected to a high and medium erosion rate along the whole stretch compared to the accretional rate.

### Environmental assessment and human impacts

The change in wave direction by the anthropogenic constructions plays a significant role in both erosion and accretion. Figure 9 shows the impacts caused by the jetties constructed along with the river mouth in the Thengapattanam region. The high deposition caused by the wave drift is noticed evidently in this area. The impact of the seasonal wave is seen in Nirodithurai and Inaiyam Puthanthurai region, with a high erosion that even engulfs the west coast road (Fig. 11). Throughout the coast, crescent-shaped beaches are seen due to alternate erosional and depositional patterns. Natural and anthropogenic activities, which govern the integrity of coastal landforms and sedimentation, significantly impact

the coastal environment. Due to the angle of wave approach and littoral current, which channel suspended sediments into the surrounding coastal area ends up with severe erosion. During the previous decade, the development of artificial structures such as groins, revetments, and seawalls has caused massive alterations in the research region; they have disrupted sediment flow by diverting littoral current and wave direction resulting in a change in beach morphology. This process occurs unceasingly, but these structures have caused erosion on the downdrift side and accretion on the updrift side. The angle of waves approaching the coastline is a significant factor in determining this. Sand dunes along the shore have been lost due to anthropogenic effects, such as the removal of vegetation and unregulated placer mining. Mining activities alter the beach morphology on this coast, causing seawater intrusion and increased turbidity in the close shore zones. The removal of sand dunes has ruined a large portion of the coastline length. In the mined area, seawater flooding is evident. The risk of erosion and seawater intrusion, communities instability and changes in coastal landforms appear apparent in these locations. The physical impact evaluation concludes that coastal dunes on the Southwest coast are particularly susceptible to risks caused by nature or by human activity.

## Conclusion

The energetic changes in the study area coast for a decade are analyzed using the multi-resolution satellite images by computing the End Point Rate. From 2009 to 2019, erosion was observed in the following villages: Nirodithurai, Vallavilai, Puthanthurai, Iraviputhanthurai, Inaiyam, Melmidalam, Kottilpad, Mandacaud, Kodimunai, and Manavalakurichi. Among these, Puthanthurai, Inaiyam, Kottilpad, and Mandacaud are at high risk of erosion due to the littoral drift caused by the constructed wave breakers and jetties follow-on in considerable land degradation along the coast. The limitation of land progression in the said areas reveals that the erosional rate is higher than the accretional rate. Overall, Inaiyam Puthanthurai and Punthurai are subjected to minor accretion due to the sediments driven towards the beach and deposited along the Thamirabarani creek. The Valliyar River deposits tend to shift the shoreline seawards at Kadiapattanam. The rocky coastal geology at Muttam maintains the shoreline in this region.

Erosion causes the loss in the terrestrial part both in natural and economic levels. In contrast, accretion causes a much lesser amount of establishment in new landmass along the study area coast. Young beaches, sand dunes, and beach berms (Fig. 12) found at specific locations are formed because of the longshore drift resulting in subsequent erosion and deposition activities. The field study also reveals the shift in the shoreline at various locations by erosion and accretion due to anthropogenic activities and waves drifted by human-made coastal structures. Thus, the result warns the coastal people that the continuous erosion fallouts in severe damages, which the proper coastal management plans by the lawmakers may prevent further erosion.

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## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

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