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# Coastline change rate estimation on the southern coastal districts of Tamil Nadu, India using the multi temporal google earth images and GIS based statistical approach

**Daswin Ebenezer M.[1] and Kumar M.[2]***
[1]Department of Environmental Engineering, Government College of Technology, Coimbatore, 641013, Tamil Nadu, India
[2]Department of Civil Engineering, Government College of Technology, Coimbatore, 641013, Tamil Nadu, India
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*to whom all correspondence should be addressed: e-mail: kumargeo_77@gct.ac.in
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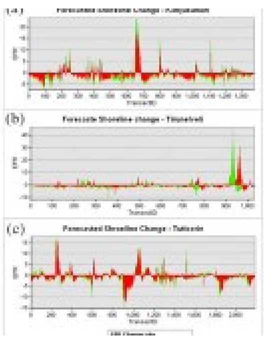
## Graphical abstract



## Abstract

Coastal erosion is the process of wearing away material from the coastal profile due to an imbalance in the supply and export of material from a particular section of the coast which cause property damage, and the loss of land. This study investigates the rate of erosion and accretion along the southern coast of Tamil Nadu which was exposed to a lot of tourism and development activities. The shorelines were delineated for the years 2000,2005,2010,2015 and 2020 on the high-resolution multi-temporal satellite images in the Google Earth Pro software by visual interpretation. The long-term and short-term changes were studied by three statistical parameters functionalized in DSAS v 5.0 tool in ArcGIS 10.6 software such as endpoint rate, net shoreline movement and linear regression rate (Cenci et al., 2018). The positions of the shoreline in 2030 and 2040 are forecasted using the Kalman filter-based forecast tool in DSAS and the changes were analysed. During the study period, the average rate of changes in Kanyakumari is -1.26 m/year, Tirunelveli is -1.01 m/year and Tuticorin is -1.09 m/year. the transects showed significant erosion along 19.54% of Kanyakumari, 3.79% of Tirunelveli, and 17.81% of Tuticorin coasts, and significant accretion is observed in 1.31% of Kanyakumari, 1.07% of Tirunelveli and 3.02% of Tuticorin coasts. The outcome of shows that erosion is prevailing on the Kanyakumari coast and erosion is prevailing in Tuticorin.

**Keywords.** DSAS, shoreline change, coastal erosion, shoreline prediction, google earth

## 1. Introduction

The coast is an interface between the land and sea which comprises coastland, intertidal area and aquatic systems including estuaries, wetlands also rivers and beaches. These coastal landforms are disturbed by intensified natural and anthropogenic activities including sea-level rise, coastal erosion, tourism, and exploitation of resources. Over 80% of the world's beaches are affected by coastal erosion which ranges from 1 cm to 30 m per year due to rapid coastal development. Spatiotemporal monitoring of the coastal environments will assist in the monitoring and prediction of the coastal erosion hazard (Nassar et al, 2019; Bheeroo et al.,2016). Shoreline computation is one of the vital parameters to determine the coastal erosion and accretion rate which intern used to predict the future shoreline positions (Baig et al., 2020). Coastal erosion is a natural process which occurs when transported materials from the beach are not replaced by new material deposition.

Shorelines are interpreted in several ways such as datum-based shorelines, wet-dry lines, high tide lines or high-water lines. Traditionally, shoreline positions were determined by field survey, from toposheets and using aerial photos which induced errors of 3 to 4 meters (Mishra et al., 2021). Satellite remote sensing is widely used to investigate coastal erosion over a period due to its temporal and spatial coverage and also due to its availability and cost-effectiveness. Medium resolution images such as Landsat, and Sentinel 2 images are available for free of cost with the high temporalresolution, they are very effective in national and global scale analysis. Due to the highly dynamic and complex nature of the shoreline, it is better to use high-resolution satellite images. Aerial photos from drone surveys and LiDAR surveys provide high-resolution images but they are expensive and time-consuming. Google Earth Pro satellite images are very effective for land used mapping and shoreline mapping as they don't require pixel values. GE has satellite images of medium to high-resolution images with high temporal resolution (Warnasuriya, Gunaalan and Gunasekara, 2018). Coastal erosion and shoreline change studies were carried out using DSAS software using different satellite products (Bouchahma, Majed and Wanglin Yanm, 2014).

In this study, the coastal erosion and accretion dynamics of the southern coastal regions of Tamil Nadu were analysed for the past 20 years (2000 – 2020) using the high-resolution temporal satellite images of Google Earth Pro v7.3.4.8642, and change rate statistics were analysed using DSAS v5.0 extension in ArcGIS 10.6 software. The statistical methods such as Net Shoreline Movement (NSM), End Point Rate (EPR) and Linear Regression Rate (LRR) Prediction of the shoreline position over the short term (10 years) and long term (20 years) periods was also conducted using the calculated shoreline change rate.

## 2. Study area

The study area is the coast of southern Tamil Nadu which comprises the coast of Kanyakumari, Tirunelveli and Tuticorin Districts. It is located between latitudes of 8° 4′ 38.25″ N to 9° 6′ 42.5″ N and longitudes of 77° 5′ 14″ E to 78° 7′ 57.8″ E (Figure 1). The study area is divided into three zones viz Kanyakumari, Tirunelveli and Tuticorin. The coastline length of these zones is 72km, 48.9km and 163.5km in Kanyakumari, Tirunelveli and in Tuticorin respectively. The majority of the people in these coastal regions are employed in salt pans, sea-borne trading, fishing and tourism. The Kanyakumari coast is heavily influenced by tourism and developments. Tuticorin is one of the major ports in India.

The drainage pattern along these coasts is controlled by a major river, Thamirabarani and minor streams like the Palaiyar, Nambiyar and seasonal streams (Sheik and Chandrasekar, 2011). Most of the study areas have a sandy beach and some parts have rocks. The southwest and northeast monsoons have an impact on the coast of Tamil Nadu. Along the study region, the wind speed varies from 36 to 50 kilometres per hour during the southwest monsoon and from 20 to 80 kilometres per hour during the northeast monsoon. (Sheik and Chandrasekar, 2011). These coastal regions are having various coastal geomorphological features such as beaches, beach ridges, cliffed coast sand dunes, and beach terraces.

## 3. Materials and methods

In this approach, the multi-dated image was super positioned from various sources in order to extract the historical shoreline positions. The Google Earth Pro v7.3.4.8642 images with the approximate resolution of 0.31 to 2m (Warnasuriya, Gunaalan and Gunasekara, 2018) were used to extract the shoreline positions for the years 2005, 2010, 2015 and 2020. The Landsat 7 ETM+ data were collected from the US Geological Survey Earth Explorer website and used to extract the shoreline position for the year 2000 (Nassar et al., 2022). The high-water line was considered as the shoreline in this study, and the shorelines were delineated by visual interpretation and on-screen digitization. The ArcGIS 10.6 software and the integrated DSAS v5.0 extension were used to extract the shoreline and calculate the shoreline change statistics. Globally, the DSAS tool is being used by both national and state governments to support resource management, crucial coastal decision-making, and development initiatives. (Baig et al, 2020).

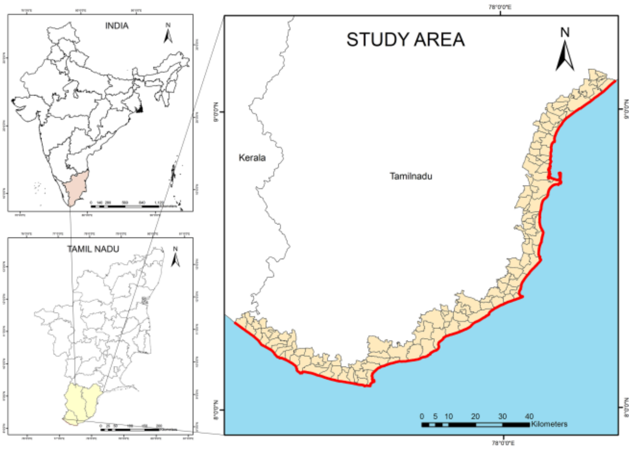



**Figure 1.** Location of the study area along southern coast of Tamil Nadu

### 3.1. Extraction of shorelines

The tilt of the image in the study area were adjusted in Google Earth Pro software before delineating the shorelines in order to reduce the geometric distortions, also the scale of the image was kept similar throughout the digitization process. To avoid the errors caused due to zoom level the eye altitude was kept at a similar altitude (Warnasuriya, Gunaalan and Gunasekara, 2018). The shorelines were digitized in the Google Earth Pro software using the create path tool. These shorelines were saved in KML (Keyhole Markup Language) file format. In the ArcGIS 10.6 software, the shorelines in KML format were converted to Layer files using the KML to layer tool which is comfortable with further analysis. The pan-sharpened Landsat 7 ETM+ image of the year 2000 was used to extract the shoreline in the ArcGIS 10.6 software by digitization. The extracted shorelines were projected into WGS 1984 UTM zone 43N coordinate system in ArcMap. These shorelines were stored inside a personal geodatabase in a separate feature class and necessary attribute data such as ID, date, and uncertainty was added as required by the DSAS tool for the shoreline change rate statistical analysis.

The baseline is the starting point of transects towards the shorelines, it was delineated from the buffer created around the shoreline's positions.

### 3.2. Delineation of zones and transects

The study area was divided into three zones viz Kanyakumari coast, Tirunelveli coast and Tuticorin coast based on the administrative boundaries of each district. The shoreline data for each of the three zones were used to create a buffer zone around that with a distance of 500m, it was later used for the delineation of the baseline position. The delineated baseline is stored inside the personal geodatabase as another line feature class. In DSAS v5.0 the baselines and the associated shorelines were used to generate the transects from the baseline to the shorelines with 50 m interval and at a search distance of 1500 m from the baseline. The interaction of transect and shorelines position were provided the location and time information that was further used to calculate the change rate statistics.

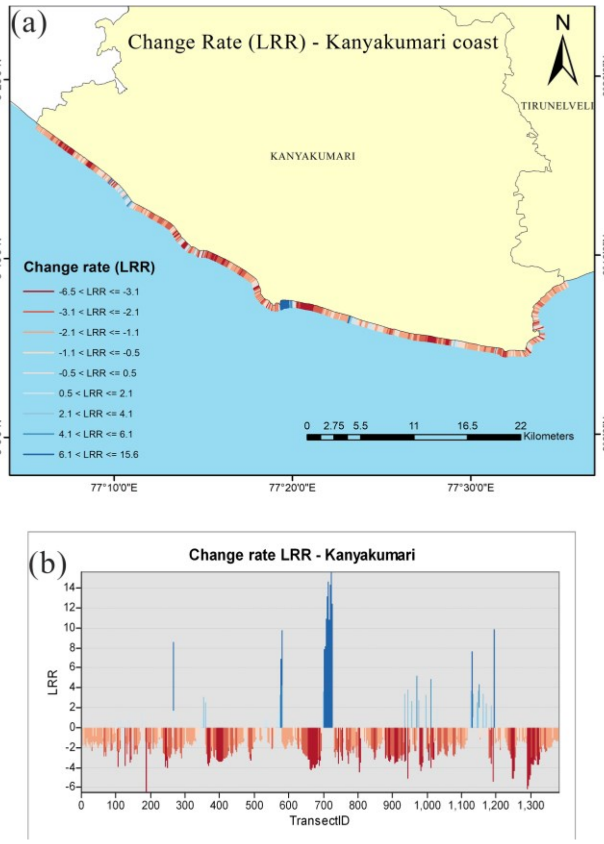



**Figure 2** (a) Transect depicting erosion/accretion rate based on LRR method in Kanyakumari (b) distribution of coastal erosion/accretion along Kanyakumari coast

*3.3. Shoreline change statistics*

DSAS v5.0 extension of ArcGIS 10.6 software has some pre-defined statistical algorithms that allow the users to calculate the shoreline change rate using the geo-rectified multi-time series shorelines at each transects with the user-defined intervals (Bheeroo et al., 2016). A variety of statistical techniques, including net shoreline movement (NSM), end point rate (EPR), and linear regression rate (LRR), were used to calculate the change rate statistics for the assessment of the pace of coastal erosion (Esmail et al., 2019).

The net shoreline movement simple statistics provide the change in shoreline distance (m) between the oldest (2000) and youngest (2020) shorelines as shown in the following equation (Eq.1). It only considers two shorelines i.e. The youngest and oldest shoreline position. The positive sign indicates accretion and the negative sign indicates erosion.

$$NSM = P1 - P2 \tag{1}$$

Where P1 is the position of the youngest shoreline and P2 is the position of the oldest shoreline.

The NSM method is used for the short-term change detection between any two shorelines.

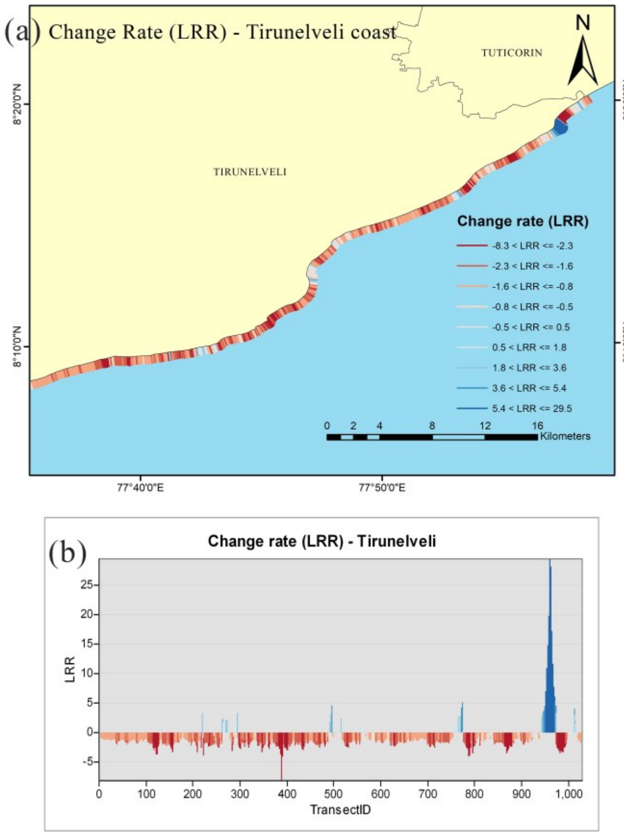



**Figure 3** (a) Transect depicting erosion/accretion rate based on LRR method in Tirunelveli (b) distribution of coastal erosion/accretion along Tirunelveli coast

The end point rate (EPR) is a simple point rate statistic, it was calculated by dividing the distance (NSM) between the oldest and youngest shoreline by the number of years between them as shown in the following equation (Eq.2). This method also considers only two shoreline positions like the NSM method (Mishra et al., 2021).

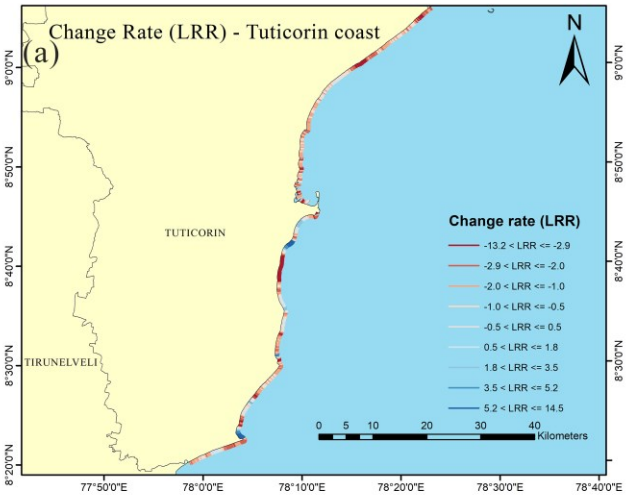
$$EPR = \frac{P1 - P2}{Y2 - Y1} \tag{2}$$

Where P1 is the position of the youngest shoreline, P2 is the position of the oldest shoreline, Y1 is the date of the oldest shoreline and Y2 is the date of the latest shoreline.

The Linear Regression Rate (LRR) determines the change rate by fitting a least square regression line to all shoreline intersects for each transect, so that the sum of the squared residual is minimum (Deepika et al., 2014; Mishra et al., 2020). The shoreline change rate is given by the slope of the regression line for each transect. Unlike EPR and NSM this statistical method considers all the shoreline positions and produces a reliable output based on all the data available. The change rate is calculated in the LRR method as shown in the following equation (Eq.3).

$$L = mx + b \tag{3}$$

Where L is the distance in meters between the baseline and shoreline, x represents the time interval in years, m is the slope in m/year and b is the y intersect.



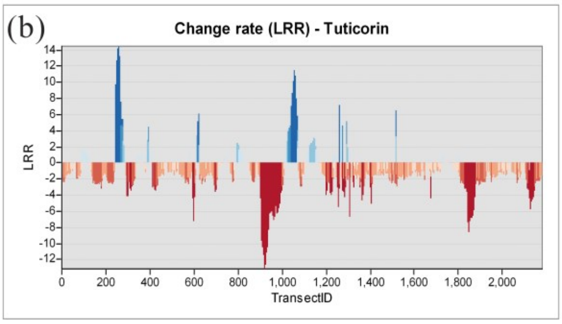




**Figure 4 (**a) Transect depicting erosion/accretion rate based on LRR method in Tuticorin (b) distribution of coastal erosion/accretion along Tuticorin coast

### *3.4. Prediction of shoreline position*

The forecast tool in DSAS v5.0 is used to predict the future shoreline positions. The forecast tool uses the Kalman filter model, it predicts/forecasts the shoreline position for each successive time step until another shoreline observation is encountered. Whenever a shoreline observation is encountered, the Kalman Filter performs an analysis to minimize the error between the modelled and observed shoreline positions to improve the forecast, including updating the rate and uncertainties (Long and Plant, 2012; Ciritci, and Türk, 2020), that are used to predict the shoreline position. In DSAS v5.0 the shorelines can be predicted for 10 or 20 years into the future based on the historical position of shorelines.

## 4. Results

The DSAS tool generated transects in 50 m intervals as given in the parameters. In the Kanyakumari coastal region, 1384 transects were generated, in the Tirunelveli coastal regions 1031 transects were generated and in the Tuticorin coastal region, 2182 transects were generated. These transects were used to study the long term and short-term coastal erosion. The long-term coastal erosion was studied using NSM and LRR statistical methods. The short-term change rate was studied with the EPR change rate statistical method.

### *4.1. Long term erosion and accretion*

The long term shoreline change rates indicate the erosion and accretion process of the coast and it was used in the prediction of the future position of the shoreline.

#### *4.1.1. Net shoreline movement*

The zone wise changes in the shoreline between the years 2000 and 2020 were calculated with the generated transects and the intersection with the shoreline's positions. During the study period, the Kanyakumari coast experienced an average change of -31.85 m, and maximum erosion of -169.91 m was observed near Kanyakumari beach which is one of the popular tourist places in Kanyakumari District. The maximum accretion of 241.82 m was observed on Kadiapattanam beach situated on the western side of Kanyakumari. The accretion is very high in Kadiapattanam and the erosion is moderate to high along the entire district and it is high on the Colachel and Ganapathi Puram coast. The statistics are given in Table 1.

On the Tirunelveli coast, an average change of -29.24 m was observed between 2000 and 2020 and a maximum erosion of -150.04 m was experienced by the Vijayapathi village beach. A maximum accretion of 487.98 m was observed on the Kuttam coast. The accretion is very high in the Kuttam village, on the Tirunelveli coast, the overall change is minimal compared to other coasts in this study area.

On the Tuticorin coast, the overall average change of -28.77 m was identified in the study period. The maximum erosion of -251.02 m has occurred in Punnaikayal beach where the Thamirabarani river discharged into the sea and a maximum accretion of 288.22 m was observed near Manapad beach.

#### *4.1.2. Linear regression rate*

In this regression-based change detection method, the rate of changes was obtained by fitting a regression line for each transect intersection with the shoreline of the years 2000, 2005, 2010, 2015 and 2020. The rate of change is based on the shoreline position in these years (Table 2). In this study period, the average change that happened on the Kanyakumari coast was -1.26 ± 0.29 m/year. Higher erosional rates of -5.11 to -6.13 m/year were observed near Vilavancode village Higher deposition rates of 9.95 to 15.59 m/year were observed in Kadiapattanam beach on the western side of the Kanyakumari district and a significant amount of erosion was occurred along 19.45 % of the coast, only 1.3 % of the transect shown the significant deposition (Figure 2).

**Table 1.** Long-term change rate statistics retrieved using NSM method

| Descriptive statistics (based on NSM) | Kanyakumari | Tirunelveli | Tuticorin |
|---|---|---|---|
| Total number of transects | 1384 | 1031 | 2184 |
| Average Distance (m) | -31.85 | -29.24 | -28.77 |
| Number of transects that are erosional | 1144 | 895 | 1716 |
| Percent of all transects that are erosional | 82.66 | 86.89 | 78.57 |
| Maximum erosion (m) | -169.91 | -150.04 | -251.02 |
| Average of all erosion transects (m) | -45.62 | -42.03 | -46.42 |
| Number of transects that are accretional | 126 | 85 | 254 |
| Percent of all transects that are accretional | 9.10 | 8.25 | 11.63 |
| Maximum accretion (m) | 241.82 | 487.98 | 288.22 |
| Average of all accretion transects (m) | 65.82 | 89.24 | 68.31 |
| Number of transects that are stable | 114 | 50 | 214 |
| Percent of all transects that are stable | 8.24 | 4.85 | 9.80 |
| Average of all stable transects (m) | -1.61 | -2.19 | -1.91 |
| Overall Standard Deviation | 42.53 | 49.83 | 53.38 |

**Table 2.** Long-term change rate statistics retrieved using LRR method

| Descriptive statistics (based on LRR) | Kanyakumari | Tirunelveli | Tuticorin |
|---|---|---|---|
| Average rate of change (m/year) | -1.26 | -0.97 | -1.07 |
| Number of erosional transects | 1118 | 854 | 1548 |
| Percent of all transects that are erosional | 80.78 | 82.83 | 70.88 |
| Percent of all transects that have statistically significant erosion (%) | 19.45 | 3.79 | 17.84 |
| Maximum value of erosion (m/year) | -6.48 | -8.21 | -13.15 |
| Average of all erosional rates (m/year) | -2.02 | -1.70 | -2.14 |
| Number of accretional transects | 144 | 97 | 295 |
| Percent of all transects that are accretional | 10.40 | 9.41 | 13.51 |
| Percent of all transects that have statistically significant accretion (%) | 1.3 | 1.84 | 3.03 |
| Maximum value of accretion (m/year) | 15.59 | 29.45 | 14.49 |
| Average of all accretional rates (m/year) | 3.72 | 4.7 | 3.4 |
| Number of stable transects | 122 | 80 | 341 |
| Percent of all stable transects (%) | 8.82 | 7.76 | 15.61 |
| Average of all stable transects (m/year) | -0.08 | -0.05 | -0.07 |
| Overall Standard Deviation | 2.34 | 2.75 | 2.74 |

The Tirunelveli coast has experienced an average change of -0.97±0.57 m/year during the study period. Higher accretional rates of 5.39 to 29.45 m/year were observed in kuttam beach. Higher erosional rates of -4.01 to -8.21 m/year were observed in Vijayapathi village and near Uvari erosional rates are between -3.98 to -4.19 m/year. Around 3.79% of the transect in Tirunelveli showed significant erosion and only 1.84% of the transects showed deposition and these coastal regions experience minimum changes during the study period (Figure 3).

An average change of -1.07+/-0.23 m/year occurred on the Tuticorin coast. The Punnakayal coast experienced the highest erosional rates of -9.19 to -13.1 m/year. In Manapad beach the deposition rate is high and it is in the range of 7.67 to 14.24 m/year. The Palayakkayal coast also experienced higher deposition rates of 6.59 to 11.39 m/year. On the Tuticorin coast. significant erosion was observed in 17.84 % of the transects and significant accretion was observed in 3.03 % of the transects during the study period (Figure 4).

*4.2. Short term changes*

The short-term changes were studied using the end point rate change statistics method. The changes that happened during the periods 2000 – 2005, 2005 – 2010, 2010 – 2015 and 2015 – 2020 for the study regions were calculated. It helps to identify the influence of certain events such as cyclones and the cyclical pattern of erosion and accretion in the zones.

During the period 2000 to 2005 the average changes observed were -6.32, -7.78 and -6.15 m/year on Kanyakumari, Tirunelveli and Tuticorin coasts respectively. In the entire study area, 91.54 % of the transects were erosional, 6.3 % of the transects were accretional and around 1.85 % of the transects were stable. A maximum erosion rate of -48.66 m/year was observed on the Tuticorin coast and a maximum accretion rate of 37.9 m/year was observed in the Kanyakumari coastal region.

In the period 2005 to 2010 the average change of -1.15. 0.94, and -0.46 m/year were detected on Kanyakumari, Tirunelveli and Tuticorin coasts respectively. Out of 4597 transects, 48.68 % showed erosion, 36.31 % showed deposition and around 14.97% showed stable behaviour with the maximum erosion of -23.61 m/year in Tuticorin and a maximum accretion of 72.82 m/year in the Tirunelveli coasts. The statistic of each zone is given in Tables 3–5.

**Table 3.** Short-term shoreline changes along the Kanyakumari coast

| Statistics (based on EPR) – Kanyakumari coast | 2000 – 2005 | 2005 – 2010 | 2010 – 2015 | 2015 – 2020 |
|---|---|---|---|---|
| Average rate of Change (m/year) | -6.32 | -1.15 | 1.59 | -1.47 |
| Average of all erosional rate (m/year) | -7.01 | -3.17 | -2.60 | -3.39 |
| Maximum Erosion rate (m/year) | -42.02 | -11.93 | -19.46 | -32.66 |
| Percentage of erosional transects (%) | 93.5 | 60.69 | 30.59 | 66.55 |
| Average of all accretional rate (m/year) | 5.58 | 3.07 | 4.12 | 3.65 |
| Maximum Accretion rate (m/year) | 37.9 | 28.34 | 52.4 | 14.62 |
| Percentage of accretional transects (%) | 4.34 | 25.29 | 57.77 | 21.82 |
| Percentage of stable transects (%) | 2.17 | 13.95 | 11.00 | 11.35 |
| Overall Standard Deviation | 5.26 | 3.64 | 5.86 | 3.97 |

**Table 4.** Short-term shoreline changes along the Tirunelveli coast

| Statistics (based on EPR) - Tirunelveli coast | 2000 – 2005 | 2005 – 2010 | 2010 – 2015 | 2015 – 2020 |
|---|---|---|---|---|
| Average rate of Change (m/year) | -7.78 | 0.94 | 1.07 | -1.61 |
| Average of all erosional rate (m/year) | -9.38 | -2.47 | -3.35 | -2.79 |
| Maximum Erosion rate (m/year) | -25.31 | -19.03 | -13.02 | -28.43 |
| Percentage of erosional transects (%) | 90.69 | 35.40 | 25.24 | 77.77 |
| Average of all accretional rate (m/year) | 8.87 | 3.84 | 3.44 | 5.57 |
| Maximum Accretion rate (m/year) | 23.59 | 72.82 | 72.56 | 29.01 |
| Percentage of accretional transects (%) | 8.34 | 47.33 | 55.53 | 10.87 |
| Percentage of stable transects (%) | 0.87 | 17.17 | 19.03 | 8.45 |
| Standard Deviation | 6.23 | 5.69 | 4.76 | 3.78 |

In the next period between 2010 and 2015 the average change rates were observed viz 1.59 m/year in Kanyakumari, 1.07 m/year in Tirunelveli and 1.5 m/year in the Tuticorin coastal regions. The study area had 4594 transects in which 24.68 % were erosional, 59.56 % were accretional and around 14.98 % were stable. The study experienced a maximum erosion of -44.85 m/year in Tuticorin and a maximum deposition of 72.6 m/year in the Tirunelveli coastal region. During this period, in all these three coastal regions the coastal accretion was predominant.

Between 2015 and 2020 the observed average change rates are -1.47, -1.61 and -1.65 m/year in Kanyakumari, Tirunelveli and Tuticorin respectively. In the entire study area, 4586 transects were generated, in which 69.93 % of the transects are erosional, 19.93 % of the transects were accretional and around 9.01 % are stable. A maximum erosional rate of -32.66 m/year was observed on the Kanyakumari coast and a maximum accretional rate of 38.66 m/year was detected in the Tuticorin coastal region.

*4.3. Predicted shoreline*

Based on the historical positions of the shoreline the future shoreline positions were predicted using the Kalman filter model in DSAS v5.0. The shorelines were predicted for the years 2030 and 2040, which were then used to find the change rates in future along the coast. The EPR model was used to calculate the change rate. The forecasted results for the years 2030 and 2040 are shown in Tables 6 and 7.

All three zones exhibit the erosional trends, the results show that the Kanyakumari coast will experience an average change rate of -1.3 m/year followed by the Tuticorin coast with -0.82 m/year and the Tirunelveli coast with -0.62 m/year.

From 2020 to 2030 the model predicted change in 1383 transects in that 1123 transects are erosional, 167 transects are accretional and the remaining 83 transects are stable. A maximum erosion of -7.58 m/year was observed on the Ezhudesam town coast and a maximum accretion of 24.05 m/year was observed on the Kadiapattanam coast.

In the Tirunelveli coast, out of 1031 transects, only 774 transects are erosional, 122 transects are accretional and the remaining 135 transects show stable behaviour. A maximum erosion rate of -11.9 m/year was observed in Vijayapati village and a maximum accretion of 46.55 m/year was observed near the Kuttam coast.

In the Tuticorin district 2212 transects were analysed in that 1321 transects are erosional, 431 transects are accretional and the remaining 422 transects remained stable. A maximum erosion rate of -15.5 m/year was observed in Punnakayal and a maximum accretion rate of 17.8 m/year was observed on the Manapad coast.

Based on the predicted shoreline position it was observed that the Tirunelveli coast is much more stable than the other coastal regions in the study area and the Kanyakumari coast is most likely to be affected heavily by coastal erosion.

For the period 2030 to 2040, the average rate of change is -0.88, -0.51 and -0.7 m/year on the Kanyakumari, Tirunelveli and Tuticorin coasts respectively. The outcomes show that on the Kanyakumari coast out of 1377 transects analysed 1018 have shown erosion, 169 transects shown accretion and the remaining 190 are stable. The predicted shoreline shows a maximum erosion of -6.4 m/year would occur on the Ezhudesam coast and a maximum accretion rate of 17.22 m/year would occur on the Kadiapattanam coast (Figure 5).

**Table 5** Short-term shoreline changes along the Tuticorin coast

| Statistics (based on EPR) - Tuticorin coast | 2000 – 2005 | 2005 – 2010 | 2010 – 2015 | 2015 – 2020 |
|---|---|---|---|---|
| Average rate of Change (m/year) | -6.15 | -0.46 | 1.5 | -1.65 |
| Average of all erosional rate (m/year) | -7.09 | -3.34 | -3.41 | -3.87 |
| Maximum Erosion rate (m/year) | -48.66 | -23.61 | -44.85 | -23.13 |
| Percentage of erosional transects (%) | 90.71 | 47.34 | 20.68 | 68.36 |
| Average of all accretional rate (m/year) | 4.87 | 2.97 | 3.48 | 4.38 |
| Maximum Accretion rate (m/year) | 35.14 | 59.91 | 54.58 | 38.66 |
| Percentage of accretional transects (%) | 6.59 | 38.08 | 62.59 | 23.02 |
| Percentage of stable transects (%) | 2.11 | 13.34 | 15.59 | 7.79 |
| Standard Deviation | 5.48 | 5.11 | 5.84 | 5.05 |

**Table 6.** Forecasted change rates from 2020 to 2030 based on EPR

| Statistics based on EPR – 2020 to 2030 | Kanyakumari | Tirunelveli | Tuticorin |
|---|---|---|---|
| Average rate of change (m/year) | -1.3 | -0.62 | -0.82 |
| Average of all erosional rate (m/year) | -2.31 | -1.76 | -2.29 |
| Maximum Erosion rate (m/year) | -7.58 | -11.94 | -15.52 |
| Percentage of erosional transects (%) | 81.20 | 75.07 | 59.72 |
| Average of all accretional rate (m/year) | 4.82 | 5.80 | 2.89 |
| Maximum Accretion rate (m/year) | 24.05 | 46.55 | 17.8 |
| Percentage of accretional transects (%) | 14.87 | 15.76 | 32.63 |
| Average of all stable transects (m/year) | -0.01 | -0.12 | -0.04 |
| Percentage of stable transects (%) | 6 | 13.09 | 19.08 |
| Standard Deviation | 3.27 | 4.14 | 2.99 |

**Table 7.** Forecasted change rates from 2030 to 2040 based on EPR

| Statistics based on EPR – 2030 to 2040 | Kanyakumari | Tirunelveli | Tuticorin |
|---|---|---|---|
| Average rate of change (m/year) | -0.88 | -0.51 | -0.7 |
| Average of all erosional rate (m/year) | -1.75 | -1.32 | -2.04 |
| Maximum Erosion rate (m/year) | -6.4 | -7.58 | -12.6 |
| Percentage of erosional transects (%) | 73.93 | 74.10 | 60.08 |
| Average of all accretional rate (m/year) | 3.47 | 4.36 | 3.14 |
| Maximum Accretion rate (m/year) | 17.22 | 30.61 | 15.75 |
| Percentage of accretional transects (%) | 16 | 15.18 | 28.69 |
| Average of all stable transects (m/year) | -0.10 | -0.13 | -0.06 |
| Percentage of stable transects (%) | 13.80 | 14.65 | 22.63 |
| Standard Deviation | 2.41 | 2.70 | 2.76 |

In the Tirunelveli coast out of 1031 transects, 764 are erosional, 116 are accretional and the remaining 151 are stable. The maximum erosional and accretional rates observed are -7.58 m/year and 30.61 m/year respectively. Over 2187 transects were analysed on the Tuticorin coast in that 1314 transects have shown erosion, 377 transects have shown accretion and the rest of the 495 transects have shown stable behaviour. A maximum erosion of -12.6 m/year and a maximum accretion of 15.75 m/year was observed.

*4.4. Major changes*

The findings of the long-term changes were used to identify the areas that are undergoing severe changes in each of the zones and the reasons for the erosion/accretion were analysed with the historical google earth pro images.

In the Kanyakumari district, the construction of coastal protection structures such as groynes and seawalls near Kollankodu causes erosion at the Ezhudesam coast which is in the downdrift direction due to disturbance in the wave action and littoral current, in the Muttom coast the construction of fishing harbour leads to the accretion (Figure 6).

In Tirunelveli, near the Vijayapathi coast erosion occurred at Arivikarai boat park due to the wave action and the topography of that coastal region. The Kuttam beach was subject to deposition due to the construction of a breakwater (Figure 7).

In Tuticorin near Manapad, the discharge of the Karumeni river into the sea causes sediments to deposit and the formation of spit at the mouth of the river. Notably erosion was observed at the discharge of River Thamirabarani into the sea (Figure 8).

## 5. Discussion

This study. was conducted along the coast of Southern Tamil Nadu to analyse the coastal erosion over a period of twenty years using the multitemporal high resolution satellite images from Google Earth Pro v7.3.4.8642 and ArcGIS 10.6 with the help of the Digital Shoreline Analysis

System (DSAS) v5.0 tool. In this study, the shorelines of the years 2000, 2005, 2010, 2015 and 2020 were digitized in Google Earth Pro and the shorelines were stored inside a personal geodatabase with necessary attribute data. A baseline was drawn at a distance of 500 m from the shorelines and that act as a starting point for cast transects. With the help of statistics like net shoreline movement (NSM), endpoint rate (EPR), and linear regression rate (LRR), the change was examined on each coast in the research area.

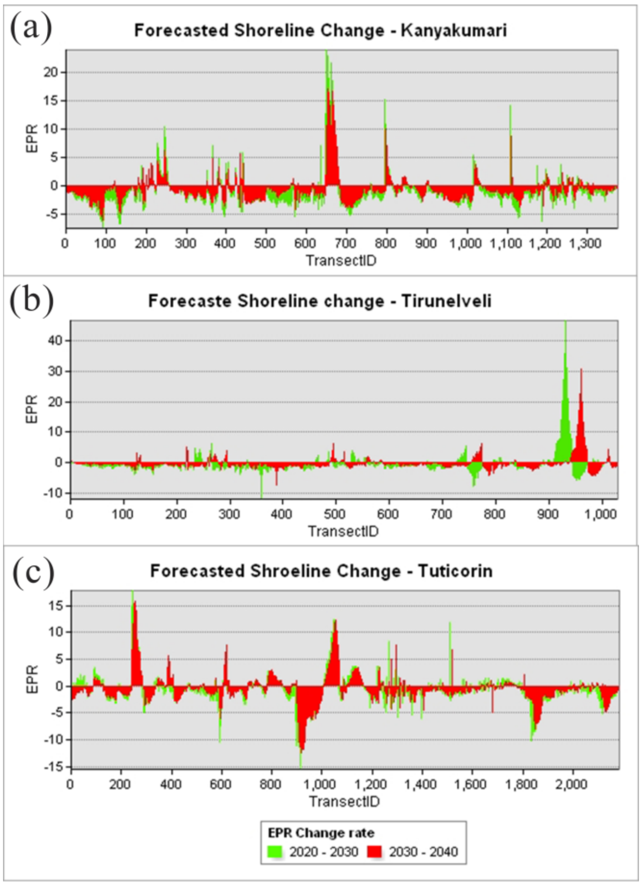



**Figure 5** Forecasted Shoreline Change from 2020 to 2030 and from 2030 to 2040 (a) Kanyakumari coast, (b) Tirunelveli coast, (c) Tuticorin coast

Based on the long-term change detection, a significant amount of erosion was observed along 19.45 percent of the transects in the Kanyakumari district, 3.79 percent of the transects in the Tirunelveli district and 17.84 per cent of the transects in the Tuticorin district. Significant accretion was observed along 1.3 percent of the transects in the Kanyakumari district, 1.84 percent of the coast in the Tirunelveli district and 3.03 per cent of the coast in the Tuticorin district. Overall, the Kanyakumari coast has experienced more erosion followed by the Tuticorin coast whereas the Tirunelveli coast is almost stable throughout the study period. The accretion rate was higher on the Tuticorin coast. The average rate of changes in the shoreline position from the year 2000 to 2020 in the Kanyakumari District is -1.26 m/year, in the Tirunelveli District is -0.97 m/year and in the Tuticorin District, it was -1.07 m/year. The higher accretional and erosional values (Table 1) were the result of disturbances in natural wave actions and littoral current, caused by the coastal development, protection structures, water bodies and human activities near the beach such as tourism.

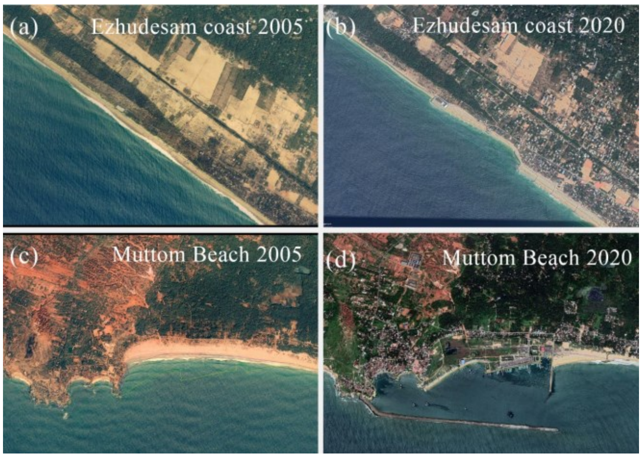



**Figure 6.** Major changes observed in (a) Ezhudesam and (c) Muttom beach of Kanyakumari District

The short-term change rates reveal that the rate of erosion is higher from 2000 to 2005 followed by the 2015 to 2020 period throughout the study area. Between 2000 and 2005 the erosion could be mainly caused by the tsunami waves. On the Kanyakumari coast the erosional trend decreased between 2010 and 2015 and the study area experienced significant accretion, the erosion trend again increased after 2015. On the Tirunelveli coast after 2005 the erosional trend decreased till 2015. Compare to other regions the Tirunelveli coast experienced less erosion. On the Tuticorin coast also the erosional trend decreased notably.

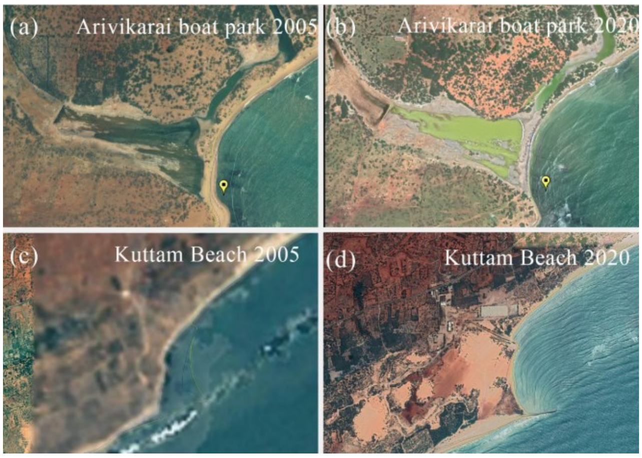



**Figure 7** Major changes observed in (a) Arivikarai boat park and (c) Kuttambbeach of Tirunelveli District

In the visual interpretation of the historical images of the heavily changed area, it was found that in this study area major erosion and accretion were caused by the discharge of water from the inland water bodies into the sea, the construction of coastal structures that disturbed the natural littoral current and sediment transportation along the coasts. The anthropogenic activities like the construction of infrastructures for tourism and the protection of the coast influence the natural wave action and sediment movement.

Based on the social and economic importance of the beaches, the coastal restoration option should consider the protection of land, buildings, groundwater, ecology, livelihoods and public and private infrastructure against future loss and damage caused by erosion along the coast. It is very much necessary to understand the behaviour of the coast at different time periods. It helps to understand the futuristic condition of the coast for better management.


**Figure 8** Major changes observed at (a) Thamirabarani river and (c) Manapad beach of Tuticorin District

Remedial actions such as artificial beach nourishment, dune building, and vegetation development will help to reduce coastal erosion. The construction of coastal protection structures near coastal villages will provide protection to the coastal community from coastal erosion.

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**Competing Interests**

The authors have no relevant financial or non-financial interests to disclose.

**Data Availability Statement**

The data used in this study were obtained from Google Earth Pro and USGS earth explorer (https://earthexplorer.usgs.gov/).

**Reference**

Baig M.R.I., Ahmad I.A., Shahfahad., Tayyab M. and Rahman A. (2020). Analysis of Shoreline Changes in Vishakhapatnam Coastal Tract of Andhra Pradesh, India: An Application of Digital Shoreline Analysis System (DSAS) *Annals of GIS,* **26**(4), 361–76. https://doi.org/10.1080/19475683.2020.1815839.

Bheeroo R.A., Chandrasekar N., Kaliraj S. and Magesh N.S. (2016). Shoreline Change Rate and Erosion Risk Assessment along the Trou Aux Biches–Mont Choisy Beach on the Northwest Coast of Mauritius Using GIS-DSAS Technique. *Environmental Earth Sciences,* **75**(5). https://doi.org/10.1007/s12665-016-5311-4.

Bouchahma M. and Yan W. (2014). Monitoring Shoreline Change on Djerba Island Using Gis and Multi-Temporal Satellite Data. *Arabian Journal of Geosciences,* **7**(9), 3705–13. https://doi.org/10.1007/s12517-013-1052-9.

Cenci L., Disperati L., Persichillo M.G., Oliveira E.R., Alves F.L. and Phillips M. (2018). Integrating Remote Sensing and GIS Techniques for Monitoring and Modeling Shoreline Evolution to Support Coastal Risk Management. *GIScience and Remote Sensing,* **55**(3), 355–75. https://doi.org/10.1080/15481603.2017.1376370.

Ciritci D. and Türk T. (2020). Assessment of the Kalman Filter-Based Future Shoreline Prediction Method. *International Journal of Environmental Science and Technology,* **17**(8), 3801–16. https://doi.org/10.1007/s13762-020-02733-w.

Deepika B., Avinash K., and Jayappa K.S. (2014). Shoreline Change Rate Estimation and Its Forecast: Remote Sensing, Geographical Information System and Statistics-Based Approach. *International Journal of Environmental Science and Technology,* **11**(2), 395–416. https://doi.org/10.1007/s13762-013-0196-1.

Esmail M., Mahmod W.E., and Fath H. (2019). Assessment and Prediction of Shoreline Change Using Multi-Temporal Satellite Images and Statistics: Case Study of Damietta Coast, Egypt. *Applied Ocean Research,* **82**, 274–82. https://doi.org/10.1016/j.apor.2018.11.009.

Long J.W., and Plant N.G. (2012). Extended Kalman Filter Framework for Forecasting Shoreline Evolution. *Geophysical Research Letters,* **39**(13), 1–6. https://doi.org/10.1029/2012GL052180.

Mishra M., Acharyya T., Chand P., Santos C.A.G., Kar D., Das P.P., Pattnaik N., Silva R.M. and Nascimento T.V.M.D. (2021). Analyzing Shoreline Dynamicity and the Associated Socioecological Risk along the Southern Odisha Coast of India Using Remote Sensing-Based and Statistical Approaches. *Geocarto International (*Taylor & Francis), **0**(0), 1–36. https://doi.org/10.1080/10106049.2021.1882005.

Mondal I., Thakur S., Juliev M., Bandyopadhyay J. and De T.K. (2020). Spatio-Temporal Modelling of Shoreline Migration in Sagar Island, West Bengal, India. *Journal of Coastal Conservation* **24**(4), 1–20. https://doi.org/10.1007/s11852-020-00768-2.

Nassar, Karim, Ahmed El-Adawy, Mohammed Zakaria, Reda Diab, and Ali Masria. (2022). Quantitative Appraisal of Naturalistic/Anthropic Shoreline Shifts for Hurghada: Egypt. *Marine Georesources and Geotechnology* **40 (5)**: 573–88. https://doi.org/10.1080/1064119X.2021.1918807.

Nassar K., Mahmod W.E., Fath H., Masria A., Nadaoka K. and Negm A. (2019). Shoreline Change Detection Using DSAS Technique: Case of North Sinai Coast, Egypt. *Marine Georesources and Geotechnology,* **37**(1), 81–95. https://doi.org/10.1080/1064119X.2018.1448912.

Sheik M. and Chandrasekar. (2011). A Shoreline Change Analysis along the Coast between Kanyakumari and Tuticorin, India, Using Digital Shoreline Analysis System. *Geo-Spatial Information Science,* **14**(4), 282–93. https://doi.org/10.1007/s11806-011-0551-7.

Warnasuriya T.W.S., Gunaalan K. and Gunasekara S.S. (2018). Google Earth: A New Resource for Shoreline Change Estimation—Case Study from Jaffna Peninsula, Sri Lanka. *Marine Geodesy,* **41**(6), 546–80. https://doi.org/10.1080/01490419.2018.1509160.