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ORIGINAL ARTICLE

Shoreline Changes from Mahabalipuram to Odiyur Lake Using Digital Shore Line Analysis System

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Abstract

Objectives: To examine the recent shoreline changes in the East coast of Tamil Nadu, India. **Method**: The current data set includes an evaluation of the morphological changes of the shoreline in the Indian state of Tamil Nadu, from Mahabalipuram to Odiyur Lake coastal stretch, using satellite images and DSAS (Digital Shoreline Analysis System) during a 17-year period. The research assesses the level of erosion and accretion along the coastline by utilizing statistical metrics, including EPR (End Point Rate) and NSM (Net Shoreline Movement). Five hundred sixty-one transects were created to assess shoreline changes over three coastal segments. **Findings**: The results reveal that the area between Kadalur Periya Kuppam and Kalpakkam underwent significant erosion, with peak rates of 7.5 meters per year and a coastal retreat of up to 119 meters. Conversely, sections from Odiyur to Mugaiyur and Kalpakkam to Mahabalipuram exhibited moderate to minimal erosion, with indications of accretion in particular areas. **Novelty/Importance**: The dataset demonstrates spatial variability affected by geomorphological characteristics and climatic disturbances, including cyclones. This study provides critical data for planners and policymakers to inform sustainable coastal management and erosion reduction in vulnerable shoreline areas.

Keywords: Shore line changes; Digital Shoreline Analysis System; End point Rate; Net Shoreline Movement

1 Introduction

The shoreline, coastline, or coast, is where land and sea meet. Sediment supply, littoral transit, secular sea level changes, hydrodynamics of the close coastline, river mouth process, storm surges, and coastal landforms all affect the shoreline's continual evolution. Human disturbances disrupt the natural ecosystem, causing coastal erosion [1].

The greenhouse effect drives biological littoral erosion. Global warming is expected to reach three °C by 2030 due to greenhouse gas emissions [2] Global warming, caused by greenhouse gas emissions, causes glacier retreat, rising sea levels, and surface pressure imbalances. The unusual pressure pattern alters wind direction. Due to wind direction changes, certain coastal areas suffer significant wave force while others experience less[3].

According to the fifth IPCC assessment report, the maximum emission RCP 8.5 scenario will generate a global Sea Level Rise (SLR) of 0.52 to 0.98 m by 2100 compared to 1986–2005. In contrast, RCP 8.5 forecasts ocean wave heights rising, especially in the tropics and southern ocean's highest latitudes. Unlike the northern oceans, a height emission scenario (SRES A2) for mean wave climate anticipates a 10% increase in Southern Ocean wave generation between 2079 and 2099. These shifts usually accompany mean wave period and direction changes[4].

The littoral is affected by waves, currents, tides, winds, and climatic and oceanographic factors. Sea level rise, coastline characteristics, and geomorphological factors affect its dynamics in addition to sand sources and sinks[5]-[6]. Land use management, vegetation cover, offshore bathymetry, bluff stratigraphy, and surface drainage affect coastal erosion rates[7]. However, construction activities along the coastline to build artificial structures, offshore dredging, river check dams that affect river flow, sand mining on the shoreline, and other human-made factors cause these erosion dynamics. These coastline changes must be analyzed throughout time and include uncommon events, if present. The scientific community regularly evaluates shoreline change because of its impact on land use management and the local economy.

Coastal erosion is a global threat to the environment and society. High population densities in coastal areas make this type of shoreline erosion and rising sea levels dangerous for large populations that depend on the coast's supplies. About 17% of India's population lives in this fragile coastal zone, the most dangerous shoreline in the world[8]. They live off maritime and coastal resources, as described. Due to India's large population's dependence on marine ecosystems, especially estuarine ones, they constitute the most critical component of the coastal environment. Thus, degradation must be avoided or handled sustainably. Various degrees of erosion affect 23% of the Indian coastline[9]. Degradation of the coastline destroys beaches and threatens coastal communities Consequently, an abundance of research has been conducted to investigate the impact of shoreline modifications (see Table 1).

Examining littoral changes in coastal regions helps identify the coastal erosion danger index by identifying vulnerable zones. Sea level rise, wave and tidal current patterns, geomorphology, geology, and human effect on the coast are used to quantify this[19]-[20]. These have caused soil subsidence, flooding, wetland loss, water quality degradation, and contamination of surface and subsurface water sources. This study is distinguished by its high-resolution transect-based methodology (561 transects) coupled with a multi-decadal analysis, offering localized insights crucial for focused coastal management strategies. The interplay between natural geomorphic characteristics (e.g., lagoons, barriers) and anthropogenic activity (e.g., coastal armouring, land use alteration) constitutes the primary determinant of variability.

The study examines the evolution of the Kancheepuram district littoral from Odiyur Lake (12.3496° N, 80.0395° E) to Mahabalipuram (12.6208°N, 80.1945°E). This strategy provides quick visibility into shoreline dynamics and helps decision-makers resolve coastal issues quickly.

2 Materials and Methodology

2.1 Study area

The area selected for the current study is Kanchipuram district, located on the East Coast of India. Kanchipuram district has a long Beach that stretches nearly 82 km. In this study, a section of shoreline has been chosen from Mahabalipuram (12.6208°N, 80.1945°E) in the North to Odiyur Lake (12.3496° N, 80.0395° E) in the South (Figure 1).

The study area, comprising many fishing villages, is located 50 km south of Chennai. The study area is divided into three segments. The first segment is from Odiyur to Mugaiyur, the second is from Kadalur Periya Kuppam to Kalpakkam, and the third is from Kalpakkam to Mahabalipuram (Figure 2). This shoreline undergoes erosion and accretion during monsoon and non-monsoon, respectively. In recent years, several cyclones have affected India's east coast.

2.2 Methodology

Details about the shoreline delineation and the various methodologies adopted are presented, and the period considered was from 2003 to 2019 (17 years). Maps of the coastal regions were collected from a GOOGLE EARTH professional source. From 2003 through 2019, 17 years of maps were collected. A line denoting the shore was constructed in the Google Earth source by incorporating satellite images from 2003 to 2019. Due to the satellite time interfering with the satellite photos, some beach lines had been torn up. So, using the Easting and Northing values from the Base data, the beach line was revised. The water tank closest to the study region was used as the study's baseline. Figure 3 shows the methodology employed to mark the shoreline using a Google Earth source until it is inputted into DSAS software.

Table 1. Summary of the Research work carried out

Study Area	Period Analyzed	Satellite Data Used	Key Findings	Shoreline Change Trends	References
Subarnarekha and Budhabalanga River Estuaries, Odisha (2024)	1991–2022	Landsat-5, Landsat-7, Landsat-8, Sentinel-2	• 44% of the coastline experienced accretion, • 23% faced erosion, • 7% remained stable.	Accretion: 1.05 m/year; Erosion: 0.45 m/year.	[10]
Paradip to Dhamra Coastline, Odisha (2021)	1973–2020	Multi-spectral satellite images	• Average shoreline shift: 286.03 m seaward in 67.3% of transects; • maximum seaward movement: 1843.06 m; • maximum landward movement: 1547.5 m.	Significant landward and seaward shifts observed.	[11]
Jagatsinghpur District Coast, Odisha (2022)	1990–2020	Landsat 5 TM, Landsat 8 OLI	• Severe erosion identified in Paradip town and Ersama tehsil.	Erosion hotspots detected in specific zones.	[12]
Cuddalore Shore, Tamil Nadu (2024)	2002–2022	Landsat series	• 15.38% of the shoreline (6.8 km) subject to high erosion; • 12.6% (5.6 km) experienced high accretion.	Dynamic changes with both erosion and accretion in different zones.	[13]
Digha Coast, West Bengal (2024)	1992–2022	Landsat series	• 70.70% of transects experienced erosion; • 29.30% showed accretion. • Highest accretion rate: 8.55 m/year; • highest erosion rate: -7.47 m/year.	Mean shoreline change rate: -0.54 m/year, indicating prevalent erosion.	[14]
Kutubdia Island, Bangladesh, (2016)	1972 to 2014	multi-temporal satellite images	• Erosion was dominant across the entire island. • Southern Shoreline faced severe erosion while the eastern, Western and Northern relatively less erosion over 42 years	Average rates of changes for north, south, east, and west segments ranged from -2.6 to -33.7 m/yr	[15]
Nagapattinam Coastal Stretch, India	2000, 2005, 2010, 2015, 2020 and 2021	Multi-temporal Satellite Images	• Accretion was predominantly observed in the Vedaranyam and Thirupoondi regions. • Erosion was more significant in the Tharangambadi, Nagapattinam, Poompuhar, Karaikal, and Thirumullaivasal areas.	The EPR and LLR methods enumerate the maximum accretion at rates of 22.35, 17.02 m/year and maximum erosion rates of -22.82, -10.84 m/year at the study area coastal stretch.	[16]
Vypin, Vallarpadam, and Bolgatty Islands, India	1973 to 2019	LANDSAT series	• coastal islands of Vypin, Vallarpadam, and Bolgatty have undergone significant shoreline changes by both erosion and accretion		[17]
South Andaman, India	1990 to 2023	Landsat images	• The eastern side of the island was severely affected by the tsunami and continues to experience erosion	Maximum coastal erosion rate was recorded at —410.55 meters per year, while the maximum accretion rate was 359.07 meters per year	[18]

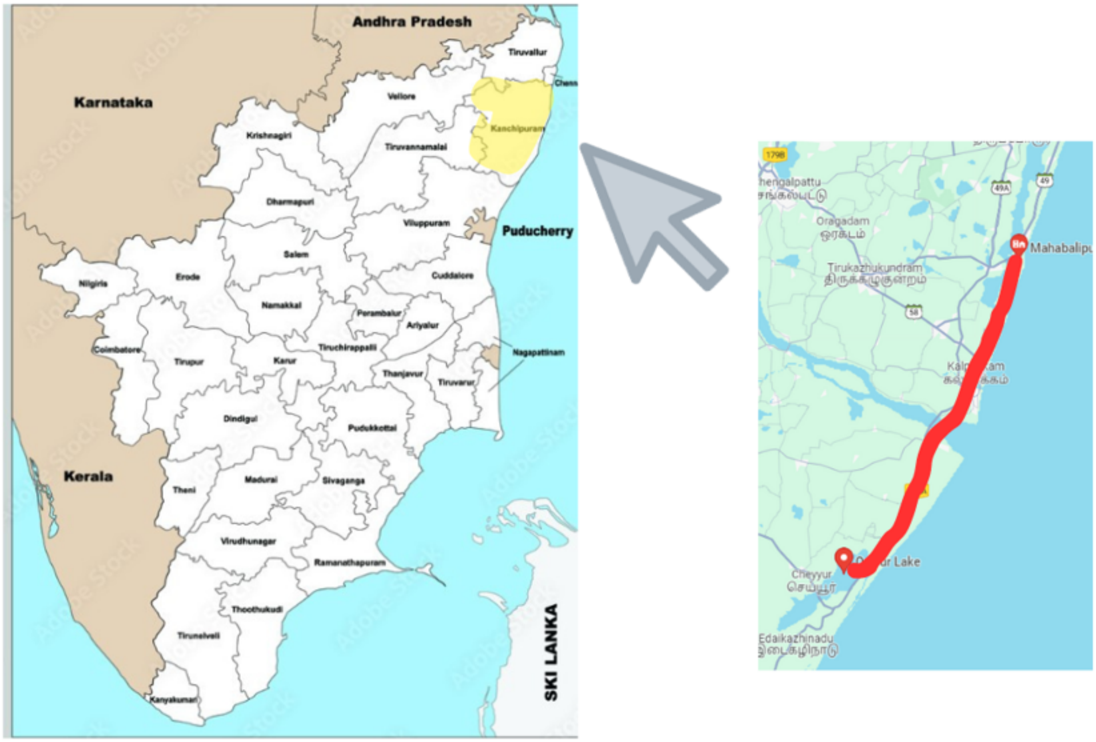


Fig 1. Map showing the study area

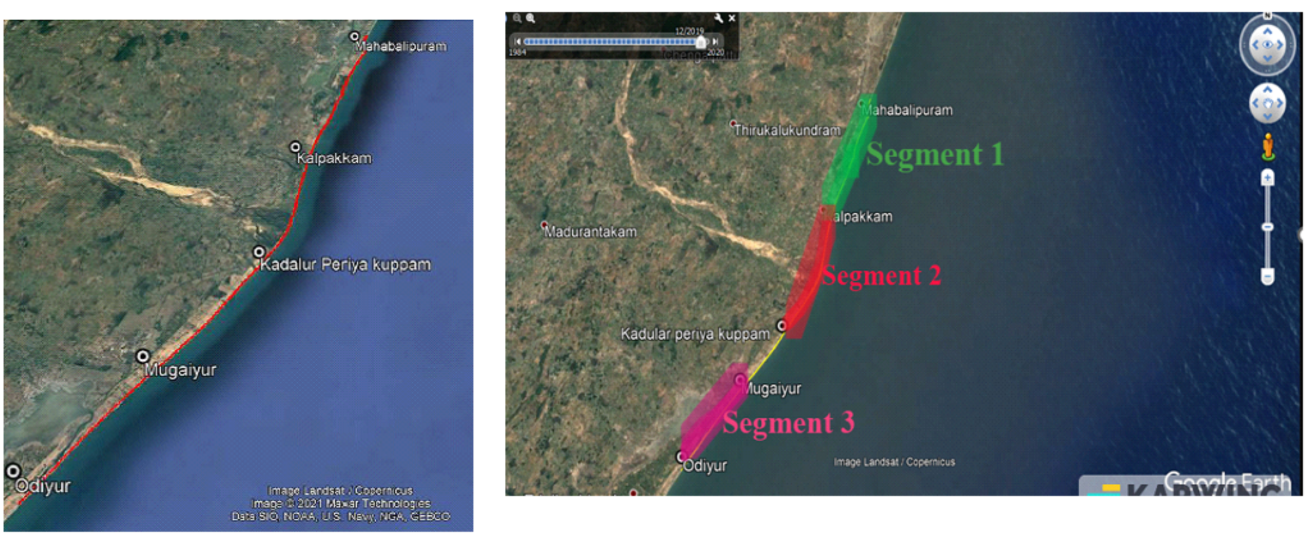


Fig 2. The stretch of the coastline selected for erosion analysis

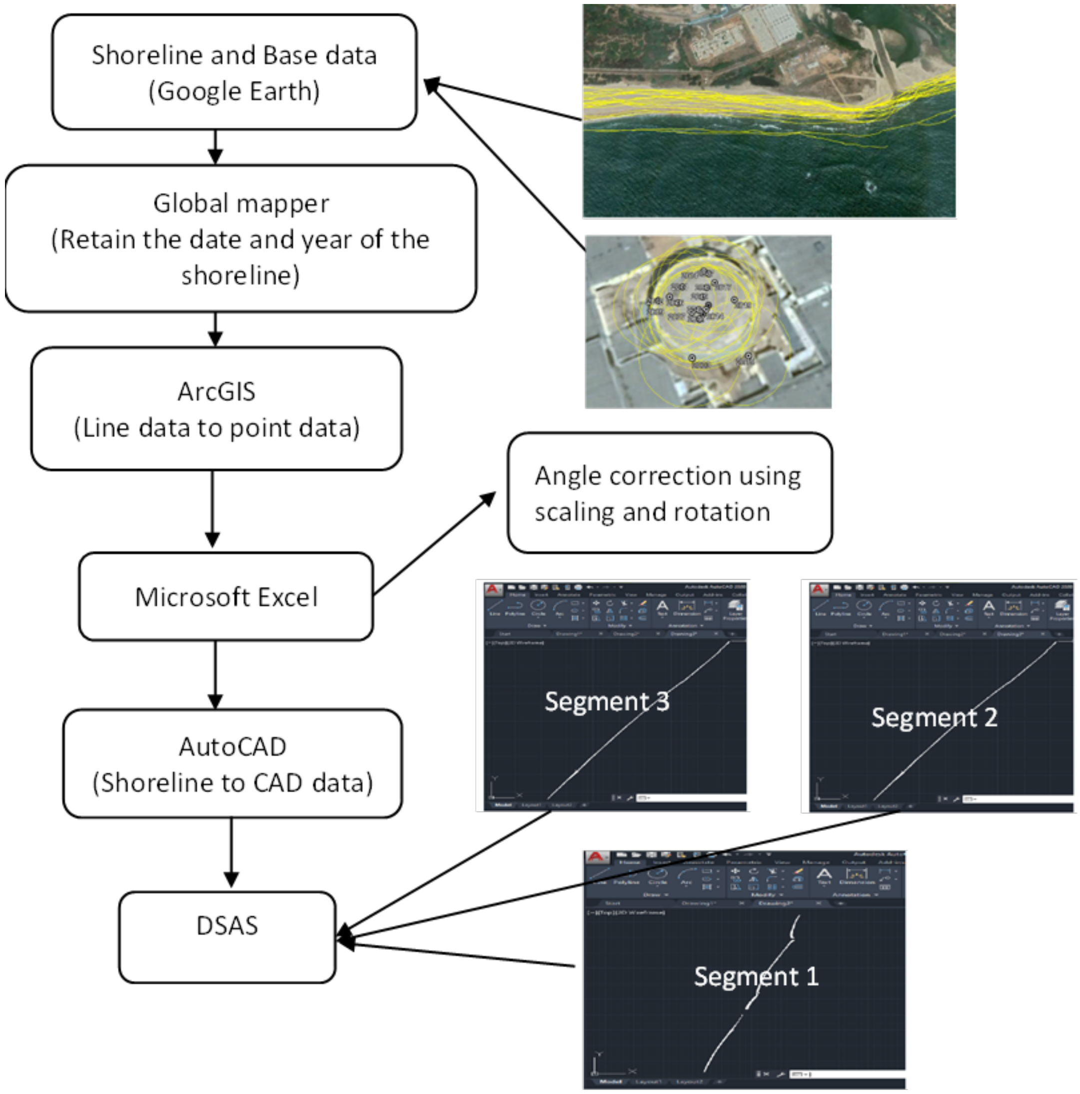


Fig 3. Image processing from Google Earth to DSAS

The methodology of sampling techniques for DSAS (Digital Shoreline Analysis System) in assessing shoreline changes involves a combination of geospatial tools, statistical methods, and field data collection. This technique provides a thorough understanding of shoreline dynamics, which is essential for effective coastal management and planning. The following are the primary aspects of the methodology retrieved from the published papers.

2.3 Data Collection and Preparation

High-resolution satellite imagery, notably Landsat, was utilized to delineate coastline positions throughout. These photos are frequently geometrically tailored and georeferenced for maximum precision.

• GPS Data: GPS surveys corroborate satellite data and provide ground truthing by validating captured coordinates against bathymetric charts [21].

2.4 Shoreline Extraction and Analysis

Image processing techniques, including the Normalised Difference Vegetation Index (NDVI) and the Land Surface Water Index (LSWI), improve shoreline characteristics in satellite imagery [22].

• Digitalization and GIS Integration: Shorelines are digitised and included in GIS platforms, where the DSAS tool is employed for analysis. The shoreline analysis will involve creating a geodatabase and locating transects normal to the beach [23].

2.5 Statistical Methods

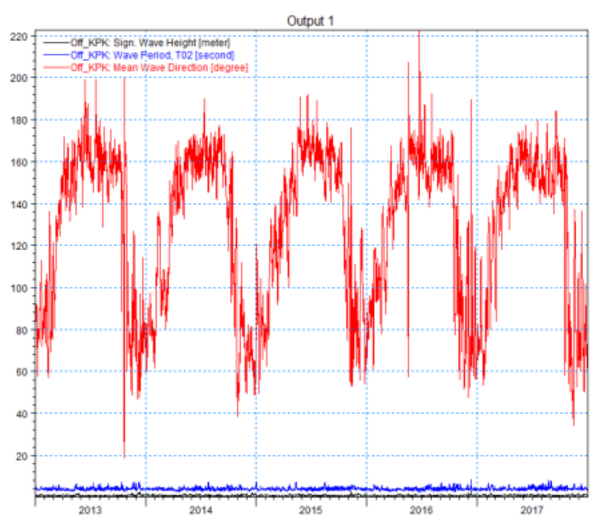
• Rates of shoreline alteration are developed using Linear Regression Rate (LRR) and End Point Rate (EPR). LRR provides a long-term average compared to EPR, which quantifies a change in starting and ending positions. Net Shoreline Movement (NSM) measures the total displacement, and the Weighted Linear Regression (WLR) evaluates the quality of data and the distribution of the time [24].

2.6 Implementation and Analysis

• Transect Analysis: Transect analysis along the seashore quantifies variations and identifies erosion and accretion zones [13]. Sedimentological and hydrodynamic data often enhance DSAS analysis, clarifying the mechanisms driving shoreline changes [25].

By utilizing the Digital Shoreline Analysis System (DSAS), shoreline changes such as erosion and accretion processes were comprehended through the computation of Net Shoreline Movement (NSM) and End Point Rate (EPR). DSAS computes the rate of littoral change as a time series using baseline data as its input. The calculation of EPR involves dividing the separation between the most recent and earliest shorelines. EPR is highly effective for evaluating shoreline change due to its computational simplicity and minimal dependence on shoreline data. "Net Shoreline Movement" refers to the spatial separation between the earliest and most recent elevations along the transect under investigation. The computation of the Net Shoreline Movement is based on the outcomes derived from examining the most recent and earliest shorelines during the designated period. The research results were additionally classified into three overarching categories of littoral phenomena: erosional features, depositional features, and the state of being unchanged, which was confirmed. [26]

A MIKE LITPACK FM module was used to validate the output of the DSAS software. Hydrometeorological, bathymetric, and sediment data (Table 2) were gathered to validate the coastal changes. From the National Institute of Ocean Technology (NIOT), Chennai, hydrometeorological data (Figure 4), including wave period, wave direction, and wave height, was obtained for the specified period. Bathymetry data (Figure 5) was obtained from the General Bathymetric Chart of the Oceans (GEBCO) open source, and the table underneath contains sediment data.



	Time	1:Off_KPK: Sign. Wave Height [meter]	2:Off_KPK: Wave Period, T02 [second]	3:Off_KPK: Mean Wave Direction [degree]
0	01-01-2013 00:00:00	0.840191	3.57042	78.2077
1	01-01-2013 06:00:00	0.804185	3.64755	79.4407
2	01-01-2013 12:00:00	0.804279	3.48029	77.1334
3	01-01-2013 18:00:00	0.842709	3.42922	75.5139
4	02-01-2013 00:00:00	0.795898	3.7002	82.7292
5	02-01-2013 06:00:00	0.752455	4.38769	89.7326
6	02-01-2013 12:00:00	0.759115	4.81614	92.0298
7	02-01-2013 18:00:00	0.801386	3.97079	89.3743
8	03-01-2013 00:00:00	0.839245	3.79528	84.0485
9	03-01-2013 06:00:00	0.796414	4.04317	86.5036
10	03-01-2013 12:00:00	0.763034	3.95759	87.4728
11	03-01-2013 18:00:00	0.755854	3.7886	87.0794
12	04-01-2013 00:00:00	0.708576	4.19228	88.7821
13	04-01-2013 06:00:00	0.679039	4.35834	89.5224
14	04-01-2013 12:00:00	0.73455	3.61107	83.9641
15	04-01-2013 18:00:00	0.782294	3.57221	85.1668
16	05-01-2013 00:00:00	0.750107	4.0713	89.1348
17	05-01-2013 06:00:00	0.768814	3.84139	89.5525
18	05-01-2013 12:00:00	0.843494	3.69385	90.3821
19	05-01-2013 18:00:00	0.907661	3.70324	91.4607
20	06-01-2013 00:00:00	0.923476	3.79146	88.6295
21	06-01-2013 06:00:00	0.922868	3.95704	88.1052
22	06-01-2013 12:00:00	1.00361	3.74123	83.6999
23	06-01-2013 18:00:00	1.05949	3.81177	79.9659
24	07-01-2013 00:00:00	0.973678	3.99464	81.0906
25	07-01-2013 06:00:00	0.9569	3.82125	79.5643
26	07-01-2013 12:00:00	1.02581	3.61764	71.3077
27	07-01-2013 18:00:00	0.968533	3.78172	73.135
28	08-01-2013 00:00:00	0.909387	3.6999	73.0471
29	08-01-2013 06:00:00	0.92805	3.48509	64.2257
30	08-01-2013 12:00:00	1.05098	3.53228	57.7385

Fig 4. Hydrometeorological data

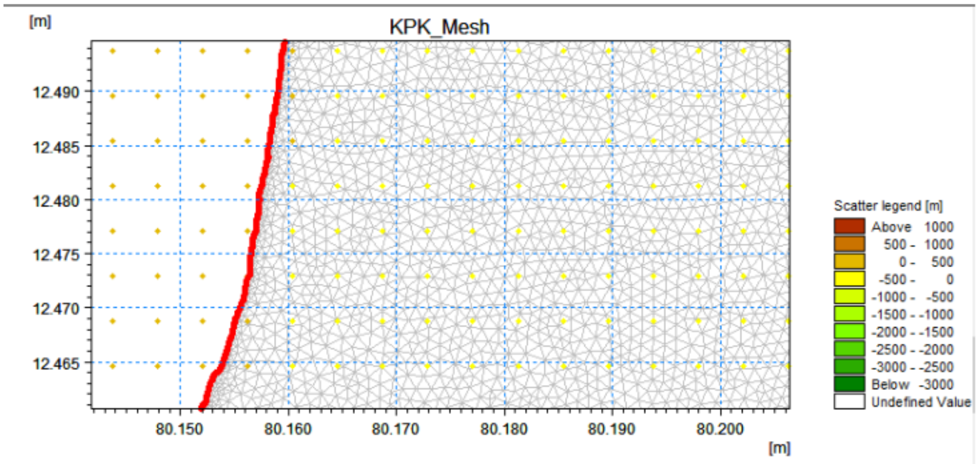


Fig 5. Bathymetric data

Table 2. Sediment data used for validation

S. No	Sediment Property	Value
1.	Sediment Type	Uniform sand
2.	Specific Gravity	2.65
3.	Mean Grain Size	0.2 mm
4.	Fall Velocity	0.40 m/s

3 Results and Discussion

The shoreline changes were calculated using DSAS software via Net Shore moment (NSM) and End Point Rate (EPR). The United States Geological Survey's DSAS tool generates, and models transition from theoretical baseline sites set back from the most recent shoreline. It then determines shoreline changes by calculating the distance between the baseline and shoreline locations. In this work, the coastline variations for 17 years were evaluated using 561 transects created by DSAS using an EPR statistical technique. Due to being perceived as more vulnerable, the study area was divided into three sections.

3.1 Net shore moment and End Point rate

Figure 6 shows the coastline changes from Odiyur to Mugaiyur. Among 561 transects, 241 transects undergo accretion, and 320 experience erosion. The average erosion rate is 1.5 m/year with a maximum of 2.5 m/year, and the average accretion rate is 4.5 m/year with a maximum of 8.2 m/year.

Figure 7 shows the coastline changes from Kadalur Periya Kuppam to Kalpakkam. Among 561 transects, 151 transects undergo accretion and 410 experience erosion. The average erosion rate is 2.0 m/year with a maximum of 7.5 m/year, and the average accretion rate is 1.0 m/year with a maximum of 1.8 m/year.

Figure 8 shows the coastline changes from Kalpakkam to Mahabalipuram. Among 531 transects, 280 transects undergo accretion, and 251 experience erosion. The average erosion rate is 1.5 m/year with a maximum of 10 m/year, and the average accretion rate is 1.5 m/year with a maximum of 10 m/year. Table 3 summarizes the maximum net shore moment and maximum end point rate during 17 years in the study area.

Table 3. Maximum End Point Rate and Net Shore Moment

S. no	Place	Endpoint rate (EPR) in M	Net shore moment (NSM) in M
1.	Odiyur to Mugaiyur	3	30
2.	Kadalur Periya Kumpam to Kalpakkam	7	119
3.	Kalpakkam to Mahabalipuram	9	110

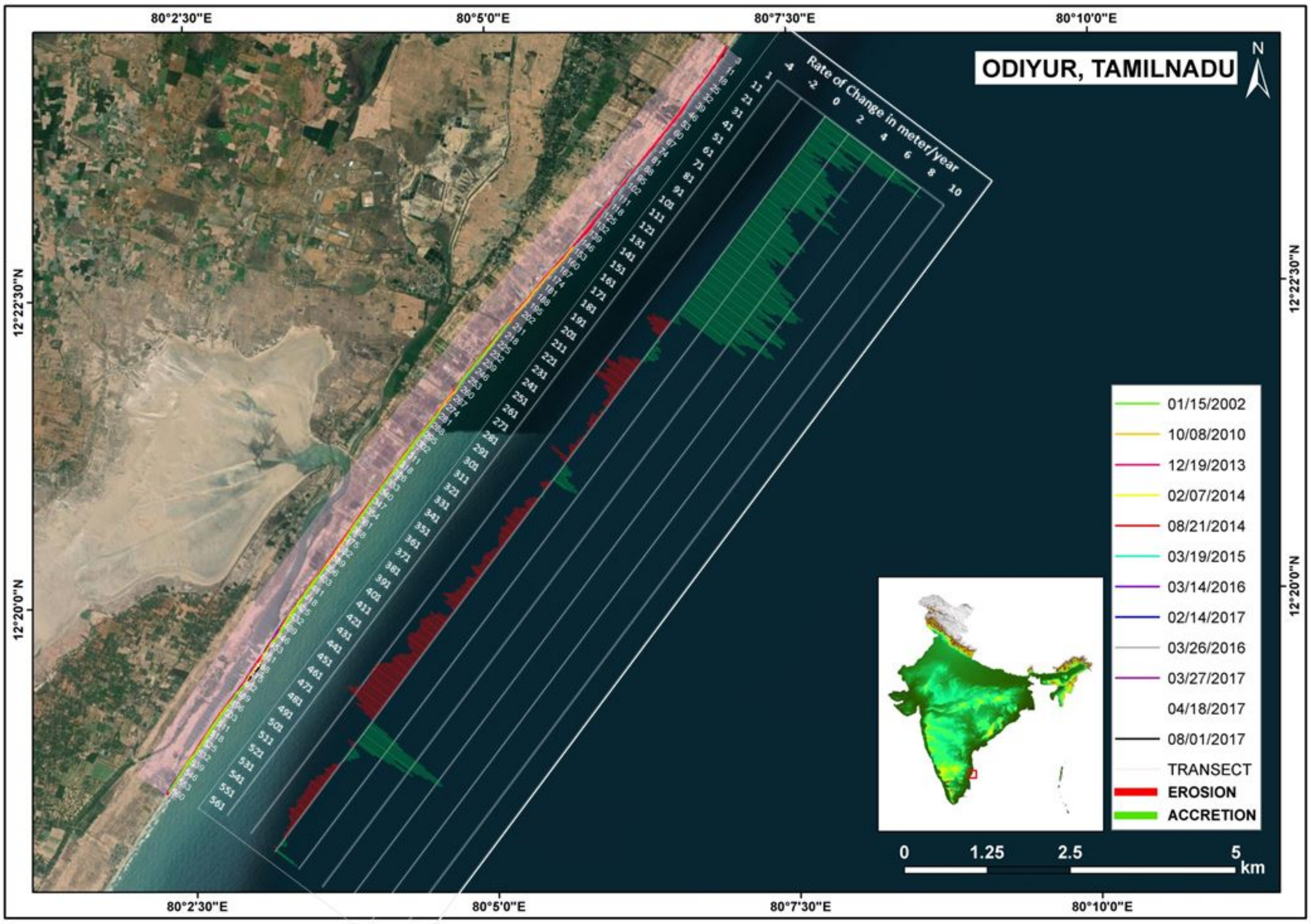


Fig 6. NSM and EPR of coastline changes from Odiyur to Mugaiyur

3.2 Discussions

This study estimated littoral change rates using two statistical methods, including EPR and NSM, which are reliable indicators for analyzing such changes. The results obtained from the study suggest that significant quantities of littoral changes were detected during the designated period. The findings indicated that the research site experienced significant alterations throughout the observed period, including marine transgression and erosion. The findings are denoted by positive and negative variables, which correspond to accretion and erosion. The present study quantified shoreline dynamics over 17 years along the Tamil Nadu coast between Odiyur and Mahabalipuram, utilizing the DSAS (Digital Shoreline Analysis System), which incorporates EPR (End Point Rate) and NSM (Net Shoreline Movement) methods. Results highlight significant spatial variability in the rates and extents of erosion and accretion across the three delineated segments of the coast.

Segment 3: Odiyur to Mugaiyur

This stretch exhibited more instances of erosion (57% of transects), yet the average rate of accretion (4.5 m/year) significantly exceeded the average erosion rate (1.5 m/year). In segment 3, i.e., from Odiyur to Mugaiyur, the occurrence of erosion is 33% greater than accretion. However, the rate of accretion is faster than the rate of erosion. Physiographic setups, including beach, beach ridge, older coastal plain, coastal plain, inselberg, pediment, moderately weathered/buried peneplain, shallow weathered/buried peneplain, Buckingham Canal, backwater, etc., influence these shoreline changes. Large lagoons, sand ridges, backwaters, as well as barrier islands indicate an active coast with accretion and erosion. Several islands had significant coastline accretion and erosion [13] - [14]. The high accretion rates observed here can be attributed to sediment deposition from backwaters and barrier systems in the region. These outcomes align with the conclusions of Magesh et al. (2022), who reported that sediment supply from the inland Buckingham Canal and the presence of sandbars contribute to depositional environments in similar physiographic settings [26]. Additionally, Srinivasalu et al. (2014) observed that dynamic changes in lagoon-barrier systems lead

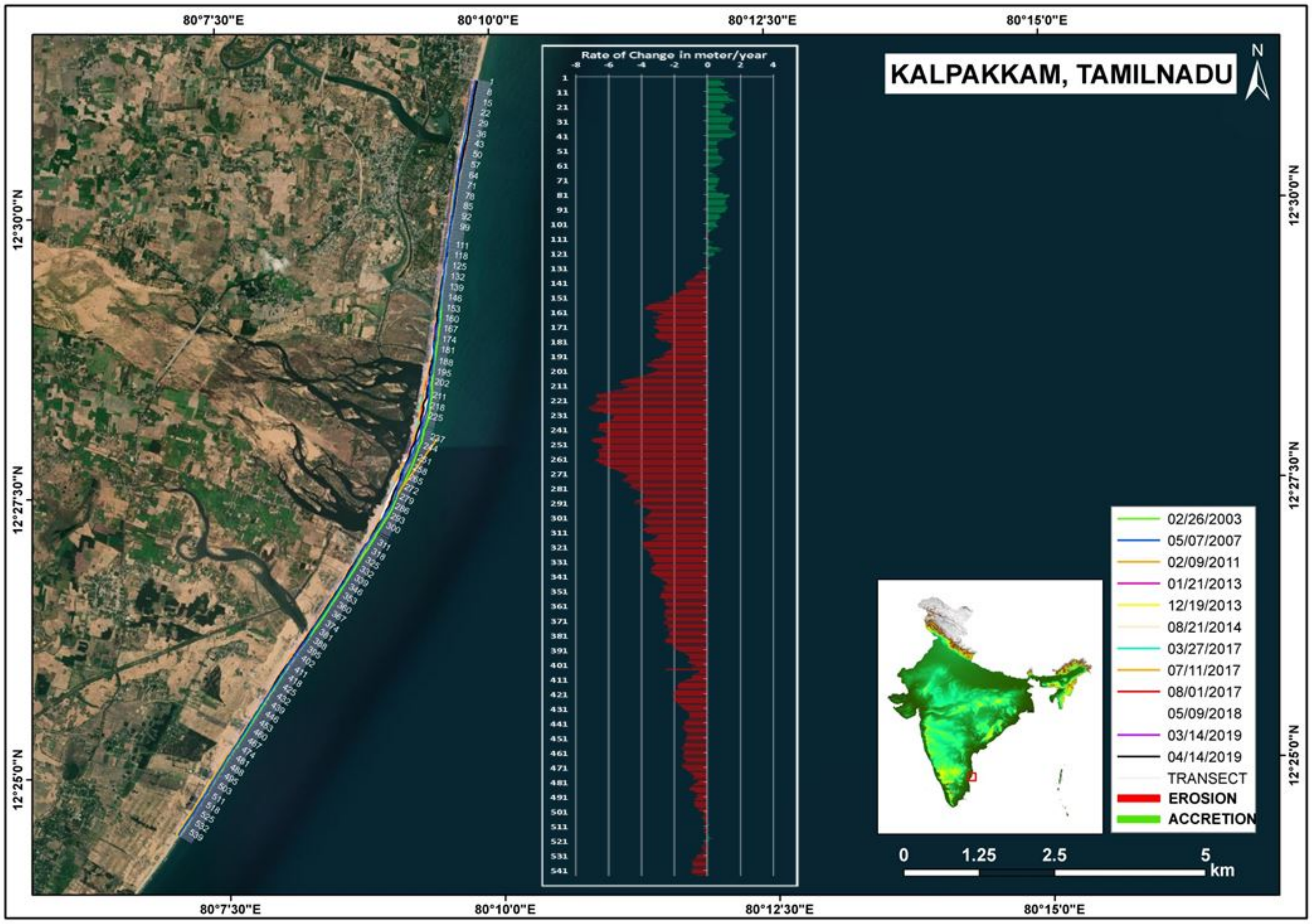


Fig 7. NSM and EPR of coastline changes from Kadalur Periya Kuppam to Kalpakkam

to alternating accretion-erosion cycles depending on monsoonal runoff and tidal energy, which aligns with our findings in this segment[(27)]. Despite the higher frequency of erosion, the dominance of accretion in terms of rate suggests that the sediment influx is higher but more spatially concentrated, potentially due to coastal engineering structures upstream that trap or redirect longshore sediments.

Segment 2: Kadalur Periya Kuppam to Kalpakkam

Kadalur Periya Kuppam (KPK) to Kalpakkam coastal area has been affected by severe shoreline changes or coastal erosion for the past 17 years. The occurrence of erosion, as well as the rate of erosion, is also high in the segment. This region shows pronounced and chronic erosion, with 410 of 561 transects (73%) affected. The average erosion rate (2.0 m/year) and maximum erosion rate (7.5 m/year) surpass those of accretion (1.0 m/year max). Erosion occurrence is 172% higher, and the erosion rate is 317% greater than accretion in the segment. The erosion rate agrees with Ramaiyan et al. (2021), who identified this segment as a high-risk erosion zone primarily influenced by wave refraction patterns and cyclonic storms[(28)]. Kadalur Periya Kuppam is located south of Kalpakkam between $12^0$26'52" N and $12^0$26'14.2" N to the south of Palar River, as well as north of a small creek. The stretch of 1.7km coastline comprises three fishermen's villages. The coastline is found to accrete and erode alternately during both non-monsoon and monsoon seasons. The impact of cyclonic events, such as Cyclone Jal (2010), Thane (2011), Nilam (2012), and Vardah (2016), is evident from the episodic yet severe retreat events corroborated by historical shoreline data[(15)]. Furthermore, this area lacks natural coastal buffers such as dunes or vegetation belts, and the proximity of fishing villages with unregulated development contributes to anthropogenic vulnerability. The southern drift shadow created by the Kalpakkam nuclear power station's breakwater further intensifies erosion by interfering with sediment transport, as discussed by Sundararajan and Rajamanickam (2019)[(29)].

Segment 1: Kalpakkam to Mahabalipuram

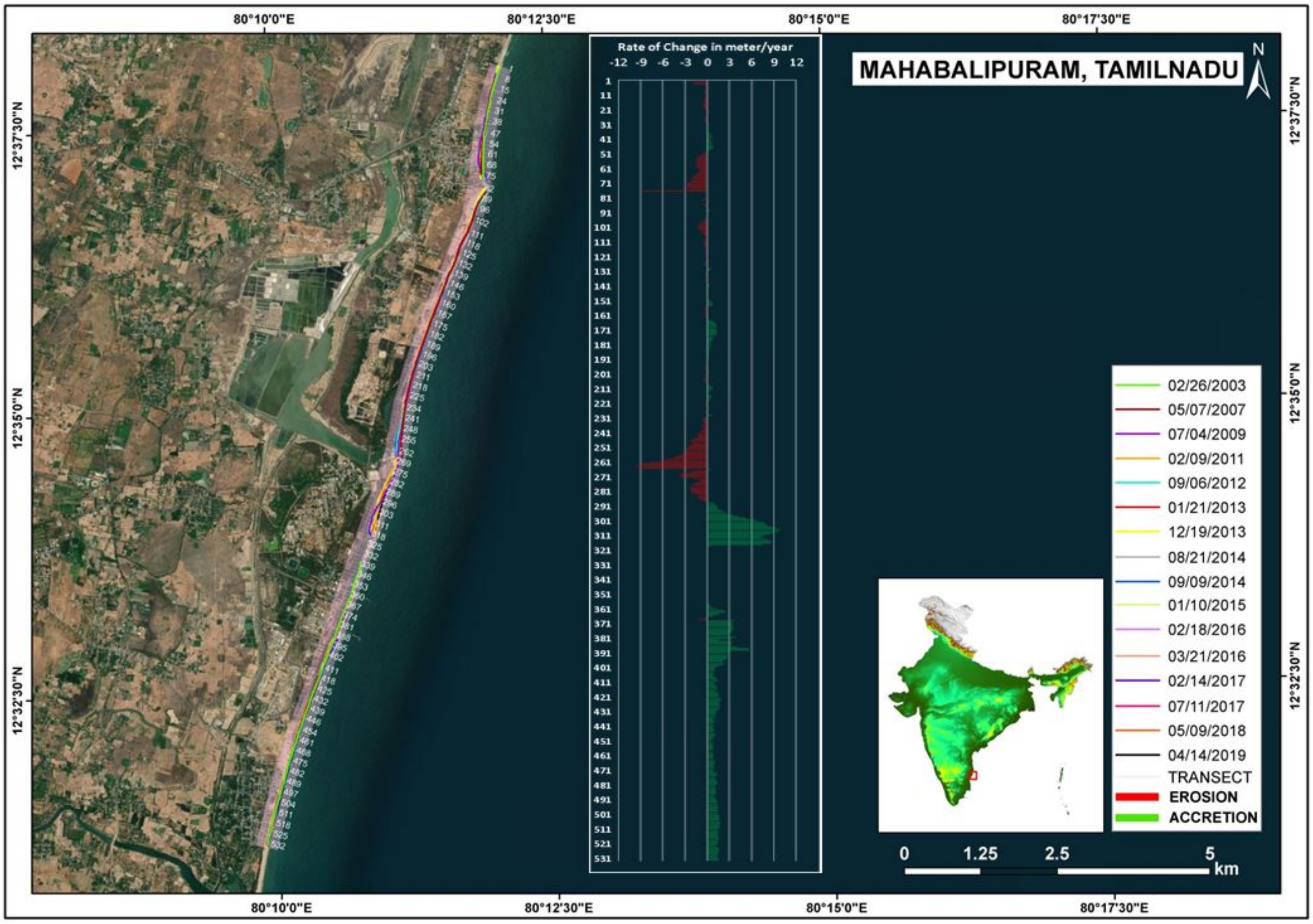


Fig 8. NSM and EPR of coastline changes from Kalpakkam to Mahabalipuram

Segment 1 from Kalpakkam to Mahabalipuram is moderately affected by shoreline changes and ranks second among the three segments. Accretion in the segment is 12% greater than the occurrence of erosion. Shoreline change is more even in this stretch, with a small amount of accretion (280 transects) over erosion (251 transects). The mean erosion and accretion rates are equal to 1.5m/year, and the system is in dynamic equilibrium. Segment 1: This segment, is Kalpakkam to Mahabalipuram, is moderately impacted by shoreline changes, and this segment is the second of the three segments. The segment demonstrates the accretion which is 12 percent more than the occurrence of erosion. The erosion rate = accretion rate. Segment 1 is identified as an archaeologically sensitive zone, going by the previous excavations made by the Archaeological Survey of India (ASI). A number of other temples that were submerged were also revealed when the erosion and excavation occurred due to the tsunami in 2004. This observation agrees with Gopalakrishnan et al. (2017), who highlighted that this section of the coast is under continuous reworking owing to the seasonal sediment transportation and seabed reorganisation following the tsunami. This extent is also prone to monsoonal influx of sediments through small estuaries and inlets, which also helps in the seasonal difference in the coastal processes [30]. The results of the present paper closely agree with the general trends provided in the recent articles on the Tamil Nadu coast. The same DSAS-based methodology was applied by Rajasekaran et al. (2020), who reported similar erosion hotspots in the area of Kalpakkam and Kadalur Periya Kuppam and mentioned the anthropogenic and hydrodynamic factors as the primary ones [31]. The scale of the detected shoreline change in our study falls into the interval estimated by Srinivasalu et al. (2020), who found the average erosion rates of 1.2-3.8 m/year on the segments of the same order.

3.3 Validation of the output

A model developed using the Hydrometeorological, bathymetric, and sediment data in the MIKE LITPACK FM module was used to validate the output of DSAS software. This model, employed for validation, calculates the movements of the coastline position concerning a straight baseline. In 2016, Cyclone Vardha severely affected the East Coast. For validation purposes, these cyclone changes are taken. The model simulates pre-cyclone shoreline changes from January 2014 to January 2015 and post-cyclone shoreline changes from January 2017 to December 2017. The simulation output is compared with the shoreline changes determined using DSAS software for the same period (Figure 9).

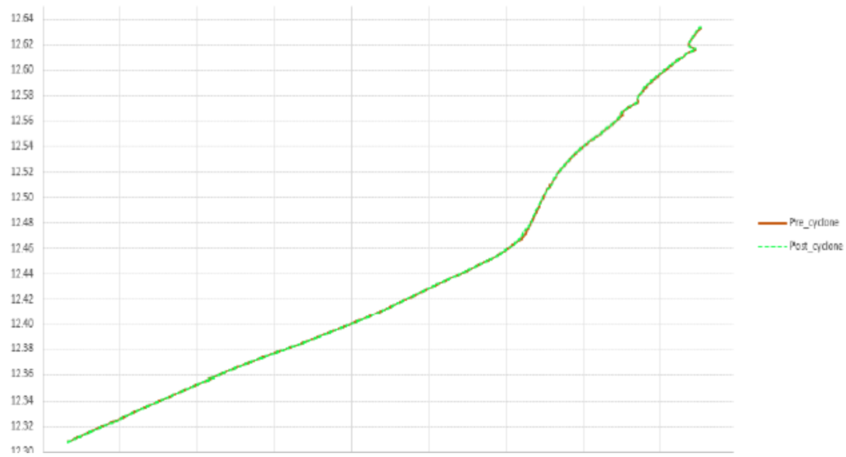


Fig 9. Validation of DSAS output with model

The standard remedial measures to prevent coastal erosion are the following: construction of a seawall, natural dune height increment, increase of shore vegetation, and creation of a mangrove forest. In this study, the area comprises many fishing villages. Due to this, shore vegetation and creating a mangrove forest are unsuitable remedial measures. Construction of submerged breakwater using sand-filled geosynthetic tubes may effectively control shoreline erosion for this study area.

4 Conclusion

This study has revealed that it is high time that some special shoreline management measures are taken, especially in the erosion-prone areas like the Kadalur Periya Kuppam to Kalpakkam stretch. By addressing the gap in long-term, segment-specific shoreline change analysis for this portion of the Tamil Nadu coast, the study provides a geospatial baseline to support local planning efforts. While the use of DSAS with satellite-derived shorelines offers reliable trend analysis, future work could enhance predictive capabilities through the integration of hydrodynamic modeling, high-resolution LiDAR data, and field-based validation. There is also scope to examine the socio-economic impacts of coastal erosion on local communities, enabling a more holistic approach to coastal zone management. This research ultimately advocates for a data-driven, region-specific strategy that combines scientific insights with policy planning to address the escalating threats posed by sea-level rise, extreme weather events, and unregulated coastal development.

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