Shoreline change pattern analysis of Nagapattinam coastal stretch, Tamilnadu, India using digital shoreline analysis system (DSAS)

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Abstract

We analysed Nagapattinam coastal zones of southeast coast of India, using Multitemporal satellite images for five equal interval of time period (i.e. 2000, 2005, 2010, 2015, 2020 and 2021). 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. This modification is due to several disasters (like Tsunami, cyclone) and anthropogenic activities (like construction of harbours, excavation of beach sand, industrialisation of garbage dump, urbanisation and discharge of domestic sewage).

The Kalman filter model forecasting the shoreline by using statistical analysis shows 242 and 236 m in 2031 and 2041 accretion and erosion of -239 and -226 m in same period. The accretion was mainly observed in Vedaranyam and Thirupoondi and erosion was observed in Tharangambadi, Nagapattinam Poompuhar, Karaikal and Thirumullaivasal region. The outcome of this research ensures to create awareness to protect our shoreline and manage our coastal zones properly with several remedial measures for the future.

Keywords: Shoreline, DSAS, Erosion, Accretion, Kalman filter model.

Introduction

The words shoreline, coastline, seashore denote coast. Coast can be defined as the region where the land interfaces with the ocean, or as a demarcation line that separates the land from the ocean. The earth covers about 6,20,000 km (3,90,000 miles) of shoreline[21]. One of the nation's most significant environmental and economic resources lies within its coastal zones, where the dynamic interplay between land and sea is commonly referred to as the coast or shoreline[33]. The coastal zones play a wide role in the nature of the earth like geomorphology, meteorology and climatology[31]. Among Earth's diverse landforms, coastal landforms stand out as some of the most prominent and significant[30]. On earth's surface, the most dynamic zone is the coastal zone. The coastal zones are vulnerable to erosion and accession due to both natural activities such as tsunami, flooding, cyclones, storm surge wave action, changes in tides and wind and sea level changes[26] and anthropogenic activities.

Shoreline is responsible for changes in increases and decreases of sea level. The mapping of the coastal line is the way of identification of our boundary region in our selected coastal zones of Nagapattinam[5]. Nowadays there is a tremendous increase in anthropogenic activities like construction of harbours, excavation of beach sand, industrialisation of garbage dump, urbanisation and discharge of domestic sewage[16].

A significant portion of the world's population has chosen to reside in close proximity to coastal zones, often within 10 meters above mean sea level[4]. Analyzing shoreline changes plays a crucial role in understanding and identifying coastal dynamics[3]. Coastal zones are currently facing both natural and human-induced disruptions including factors such as rising sea levels, coastal erosion and coastal accretion. Alarmingly, more than 80% of the world's beaches are impacted by coastal erosion with erosion rates varying widely from 1.0 cm/year to a staggering 30 m/year[1].

Shorelines are mainly classified into five primary zones such as offshore, nearshore, surf shore, foreshore and backshore[21]. Offshore refers to the area of deeper water beyond the point at which waves begin to break. Friction between the waves and the sea bed may cause some distortion of the wave shape. Nearshore is the area of shallow water beyond the low tide mark within which friction between the seabed and waves distorts the wave sufficiently to cause it to break. There may be a breakpoint bar between the offshore and nearshore zones. The area between high tide and low tide mark is defined to be foreshore.

The area above high tide mark is affected by wave action only during major storm event is backshore[18]. Coastlines undergo two distinct categories of alterations: long-term changes and short-term changes. Long-term changes pertain to alterations in sea level relative to the land as well as fluctuations in the supply of sand to the coast. These modifications typically span over a period exceeding 50 years. Conversely, short-term changes represent the opposite of long-term changes, characterized by their complexity in

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understanding and predicting. Additionally, these short-term alterations in shoreline can exhibit significant variability along the coast and occur over a timeframe of less than 10 years[25].

The wave characteristics controlling the coastal zones due to the dumping of sediments are one of the major causes of shoreline changes[24]. The tides, waves and marine currents also affecting the coast which lead to cause erosion and the morphology estuaries, have been disturbed[28]. Tides come in two distinct forms: low tides signify minimal impact while high tides indicate significant effects[35]. The construction of harbour becomes positive issues in economy development but it leads to affecting the nearby coast and ocean flow patterns[15]. The coastal geomorphology study is the most interesting research in recent days[36].

The analysis of shoreline in a satellite imagery is an initial step to protect and create awareness among the people to maintain our coastal management[32]. Worldwide both natural and human systems are affected by the threat which is caused by the rising of sea level and extreme events to climate change in coastal areas. Coastline or shoreline calculation is one of the important factors in the finding of coastal accretion and erosion and the study of coastal dynamics[8].

In shoreline analysis, the outcomes often reveal coastal accretion and erosion. The presence of coastal erosion and accretion can have detrimental effects on both human well-being and the environment[2]. By using modern scientific tools like GIS and remote sensing plays an efficient part in analysing of prehistoric coastal zones[7,17]. Tamil Nadu coast is experiencing a growing crisis of coastal erosion and accretion and this phenomenon is significantly impacting the coastal population[27]. Nagapattinam, a chosen coastal zone in Tamil Nadu, attributes for a valuable land use and land cover feature in the form of mangrove forests. These mangrove forests play a crucial role in safeguarding the coastline and fostering a habitat that is well-known among various marine species[6,11].

For analysing the shoreline changes, limited number of tools are available in our GIS field. Among these tools, Digital Shoreline Analysis System (DSAS) plays an important role for analysing the coast[14,13]. The aim of present study is making shoreline analysis from 2000 to 2021 and forecasting analysis for 2031 and 2041[16]. Many shorelines analysis study were carried out related to EPR, LRR and NSM methods[22]. This study specifically concentrates on prediction analysis using Kalman filter model.

Material and Methods

Study Area: To comprehend the physical dynamics of a chosen coastal area and gain insights into shoreline dynamics, geospatial techniques and modeling are employed. The study area encompasses the coastal stretches along the Tamil Nadu coast, spanning from the Kollidam River mouth to Point Calimere. This study area lies between longitude and latitude of 79°45’ to 79°55’ and 10°15’ to 11°20’ respectively. The length of coastal stretches is around 188 kilometres. The Tirumalarajanar, Cauvery, Kaduvaiyar, Arasalar, Harichandranadi and Vettar rivers are some of the major rivers that drain into the Bay of Bengal within study area. The elevation in this coastal area ranges between 0 and 5 meters above mean sea level (msl).

This region has tropical humid climate with the annual average rainfall between 950 and 1500 mm. In the southern part of the study area, along the Vedaranyam canal, several aquaculture farms have been developed which play an important role in the economy of the district. The wave action is notable during both the summer and winter seasons bringing southwest and northeast monsoonal winds. The severe cyclonic storms, however, increased the wave action significantly[9]. Figure 1 shows the location map of the study area.

Methodology: Multi-temporal Landsat data including TM (Thematic Mapper) and OLI/TIRS (Operational Land Imager/Thermal Infrared Sensor), spanning five different years from 2000, 2005, 2010, 2015 and 2021, have been colleted from the Earth Explorer platform. These datasets were utilized for the shoreline analysis study and were obtained from the USGS archives[26]. The false colour composite (FCC) and true colour composite (TCC) are prepared by respective bands of TM, OLI/TIRS using ArcGIS 10.8 software for better visual interpretation. By using TCC and FCC, it becomes easier to interpret the shoreline for all five different years to the study site[34]. Figure 2 shows the shoreline map of the study area.

DSAS: Digital Shoreline Analysis System (DSAS) is an open source add on tool, which works within ESRI geographic information system (ArcGIS 10.8 software). The DSAS tool helps to analyse the various geometry line features of past and present of a selected coastal zone[14,31]. DSAS is used to evaluate the shoreline changes and predict the forecasting period changes. The process begins with the interpretation of shoreline data for six different years integrated into a single feature class. This feature class represents shorelines and is stored in a personal geodatabase. Following this interpretation step, an attribute table for the shoreline is generated, incorporating key attributes such as DSAS_date, DSAS_uncy (uncertainty), DSAS_type and shape length as outlined in the DSAS 5.0 version user guide. Once the attribute table is modified, the next step is to create another feature class within the same personal geodatabase which represents the baseline. This baseline feature class should use a projected coordinate system measured in meters.

Subsequently, one can generate an attribute table for the baseline feature class, incorporating attributes such as shape length, ID DSAS group, DSAS search, offshore and castdir, following the guidelines provided in the DSAS 5.0 version user guide[28].

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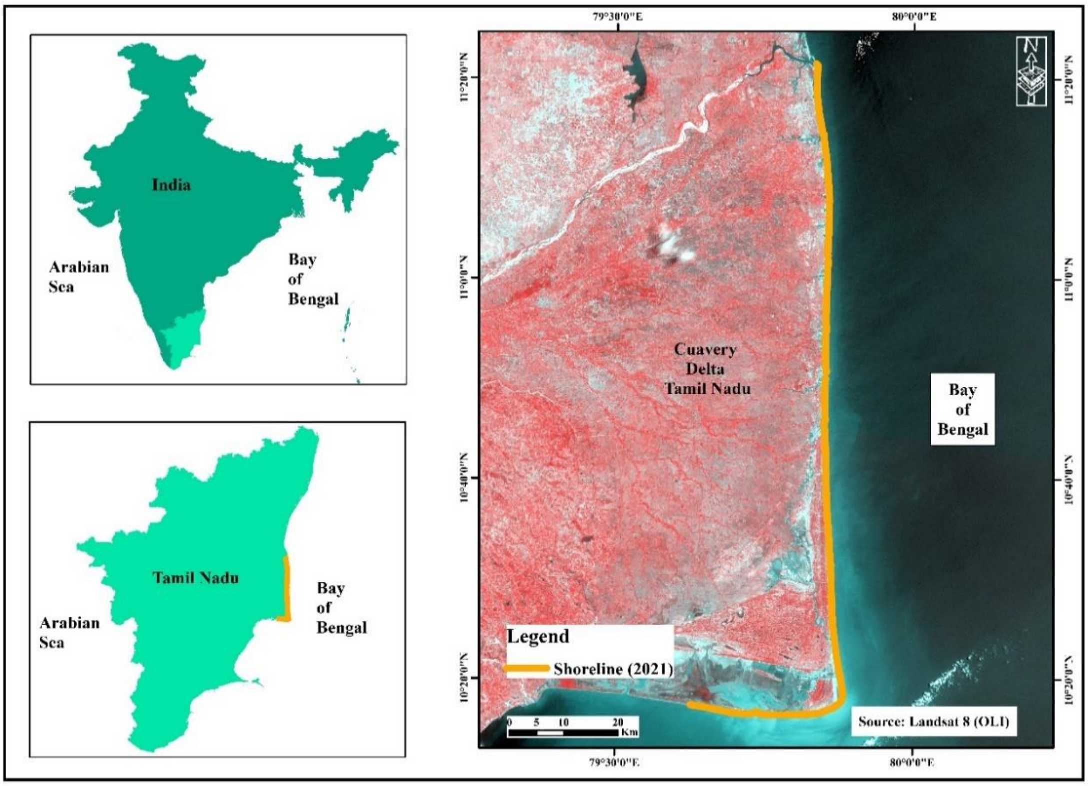

Figure 1: Location map of the selected coastal stretch of Nagapattinam

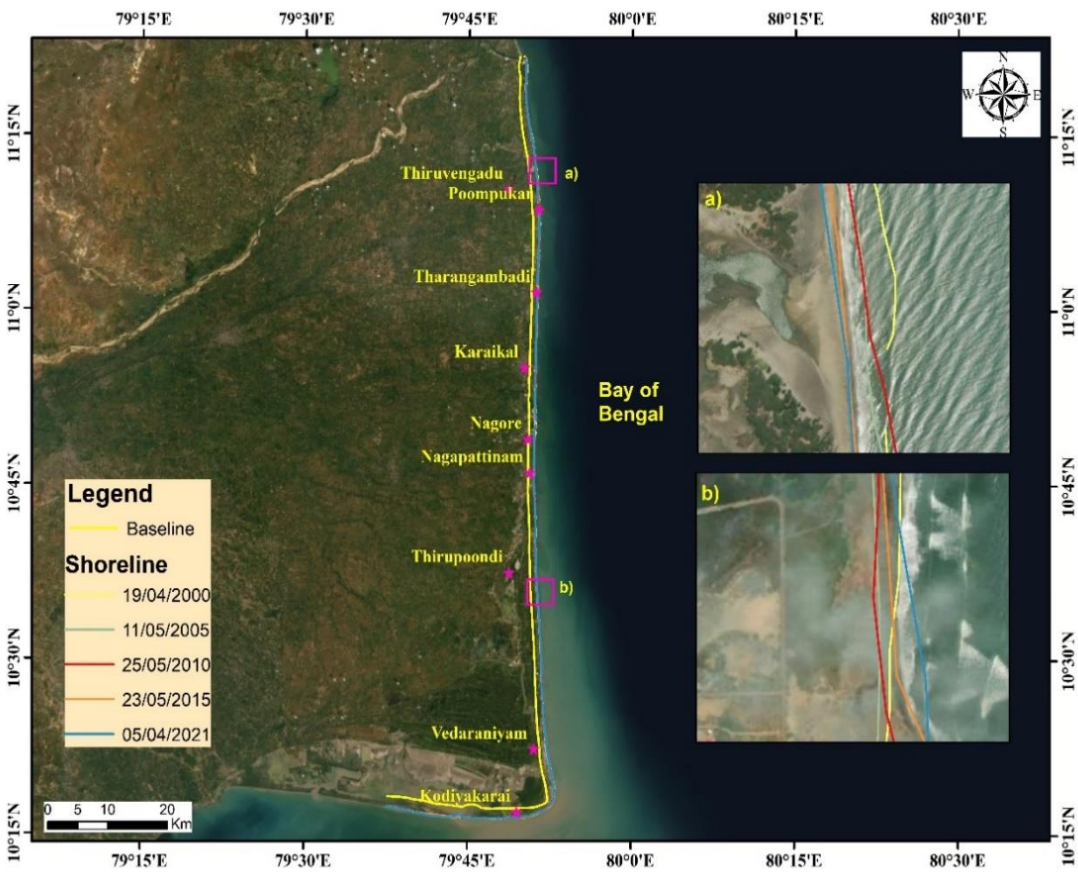

Figure 2: Map showing the shorelines for five different years 2000, 2005, 2010, 2015 and 2021 of selected south east Indian coast

Table 1
Various remote sensing data used for five different years for shoreline analysis

S.N.	Data source and sensor	Date of acquisition (DD/MM/YYYY)
1	Landsat 5 TM	19/04/2000
2	Landsat 5 TM	11/05/2005
3	Landsat 5 TM	25/05/2010
4	Landsat 8 OLI	23/05/2015
5	Landsat 8 OLI	05/04/2021

Upon completing the setup of both the shoreline and baseline feature classes, the next step is to configure the baseline, shoreline and metadata settings. Once these settings are carried out, transects are generated. The default parameters for generating transects are often the initial and straightforward choice in the transect generation process[19].

During the process, adjustments were made to improve the visualization of transects. These modifications included setting a maximum search distance of 2000 meters from the shoreline, ensuring that transects were spaced at regular 50-meter intervals perpendicular to the shore and applying a 2500-meter smoothing distance. These modifications resulted in the generation of a total of 2914 transects covering the entire study area. Subsequently, data from the transects feature class were utilized to calculate rate changes using statistical methods. The output containing these calculated rates was stored within the same personal geodatabase following the completion of the statistical analysis[27].

Statistical analysis: Within DSAS 5.0, there are numerous branches available to facilitate the statistical analysis of a specific shoreline. This statistical analysis can be broadly categorized into three major methods. The first method involves distance measurement, the second encompasses statistical techniques and the third pertains to supplemental statistics for linear and weighted regression. The distance measurement technique is executed using Net Shoreline Moment (NSM). Statistically, this is accomplished through two distinct methods: End Point Rate (EPR) and Linear Regression Rate (LRR). The EPR is calculated by dividing the NSM by the time elapsed between the oldest and most recent shorelines[23]. The EPR value is expressed in meters.

NSM is computed by measuring the distance between the oldest and most recent shorelines for each transect and its values are also represented in meters. The linear regression rate (LRR) estimates the rate of variation by fitting a least squares regression line to all the shoreline points of the transects. This method provides a noticeable means to anticipate future shoreline positions along with their associated confidence intervals[10]. EPR, LRR and NSM collectively indicate the conditions of transects in the coastal area, whether they are experiencing coastal erosion or coastal accretion. The following formulas are employed to calculate the EPR and NSM values (Equation 1 and 2) respectively:

$$\mathrm{EPR} = \frac{\mathrm{d2021} - \mathrm{d2000}}{\mathrm{t2021} - \mathrm{t2000}} \text{ m/year} \quad (1)$$

$$\mathrm{NSM} = (\mathrm{d2021} - \mathrm{d2000}) \text{ m} \quad (2)$$

where d2021 and d2000 are the distance separating the shoreline (2021) and baseline (2000); t2021 and t2000 are the shoreline positions during 2021 and 2000 respectively.

Prediction of forecasting shoreline: Nowadays the long-term planning of coastal management is facing a difficult role for making decision of future shoreline because it is difficult to predict the shoreline in a long-term. Simultaneously in an earth surface, shoreline plays one of the most important dynamic geomorphological features. But recently the difficult task is decreased by introduction of Kalman filter model, it is statistically based shoreline forecasting tool in DSAS tool bar. It generates the future shoreline via initialisation with linear regression rate along with the tool combining the historical shoreline position and the model derived shoreline position to predict the future shoreline with an uncertainty band.

The Kalman filter performs an analysis to reduce the error between the modelled and observed shoreline position in order to enhance the forecast by including the rate and uncertainty[20].

Results and Discussion

Upon performing the statistical calculations, the attribute table reveals both positive and negative values for the corresponding transects (EPR, LRR and NSM). Positive values in a transect indicate that the specific area is experiencing accretion while negative values in a transect indicate that the particular area is undergoing erosion[29].

In this study, the EPR analysis reveals the highest accretion rate to be 22.35 m/year and the lowest erosion rate at 0.51 m/year. Similarly, the LRR calculation demonstrates the highest accretion rate at 17.02 m/year and the lowest erosion rate at 0.51 m/year. Conversely, in this study, the EPR analysis identifies the highest erosion rate at -22.82 meters per year and the lowest accretion rate at -0.5 m/year. Similarly, the LRR analysis records the highest erosion rate at -10.84 m/year and the lowest accretion rate at -0.5 m/year. Regarding the NSM method, it indicates the most substantial accretion at a rate of 285 meters and the smallest accretion at a rate of 10.01 meters. Conversely, the NSM method highlights the most significant erosion at a rate of -251 m and the least accretion at a rate of -8.04 m.

Within this study area, significant accretion is primarily observed in zones near Vedaranyam and the Thirupoondi region while erosion is prevalent in the Tharangambadi, Nagapattinam, Poompuhar, Karaikal and Thirumullaivasal regions. Figure 3 illustrates the EPR, NSM and LRR maps. The erosion and accretion profiles for EPR, LRR and NSM indicate that the highest erosion rates occur in transects numbered 0 to 200 and 500 to 600 while the highest accretion rates are observed in transects numbered 300 to 400 and 1700 to 1900. Figure 4 displays the erosion and accretion profiles of LRR, EPR and NSM.

Prediction of 2032 and 2042 Shoreline: By using Kalman filter modelling, it is easy to predict the position of the particular shoreline for the year of 2031 and 2041 with the interval of 10 years[12]. For the year of 2031 and 2041, the rates are calculated by using three shorelines (via recent shoreline 2021, predicted shoreline 2031 and predicted shoreline 2041).

The predicted shoreline shows the maximum erosion of -242 and -236 m in the place namely Tharangambadi and the highest accretion was noted in the places namely Vedaranyam region at the rate of 239 and 226 m for 2031 and 2041 respectively. Figure 5 shows the predicted shoreline map for 2031 and 2041.

Conclusion

Nowadays remote sensing and geospatial technology play a vital role in a real world. With the help of DSAS 5.0, it is easy to monitor the shoreline changes between 2000 to 2021 for the study site from Kollidam river mouth to Point Calimere. In the Vedaranyam and Thirupoondi region of the study area, the highest accretion rates are observed, with EPR and LRR indicating rates of 22.35 and 17.02 meters per year respectively. Additionally, the NSM records a rate of 285 meters, signifying substantial accretion processes in this specific coastal area. The most pronounced erosion is indicated by EPR and LRR exhibiting rates of -22.82 and -10.84 m/year respectively. Additionally, NSM records erosion at a rate of -251 m in zones near to Tharangambadi, Nagapattinam, Poompuhar, Karaikal and Thirumullaivasal. This erosion is primarily attributed to the construction of sea walls designed to mitigate erosion.

Subsequently, the erosion pattern shifted to areas north of the sea walls and the jetty. The prediction analysis also shows the same high erosion at the same places at the rate of -242 and -236 m/year in 2031 and 2041 respectively. Placement of large rock, usually referred to as rip-rap, is the preferred and most common form of shore protection.

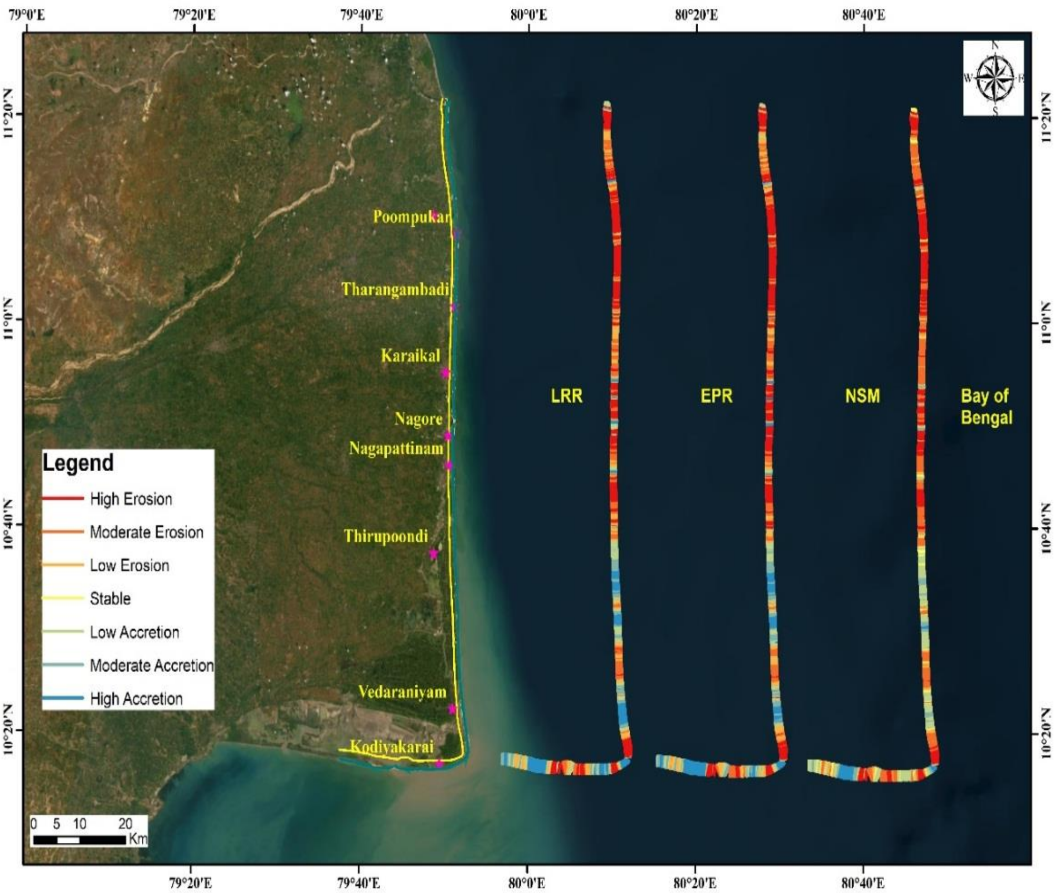

Figure 3: Calculate rates of LRR, EPR and NSM for selected southeast coastal zone of India between 2000 to 2021

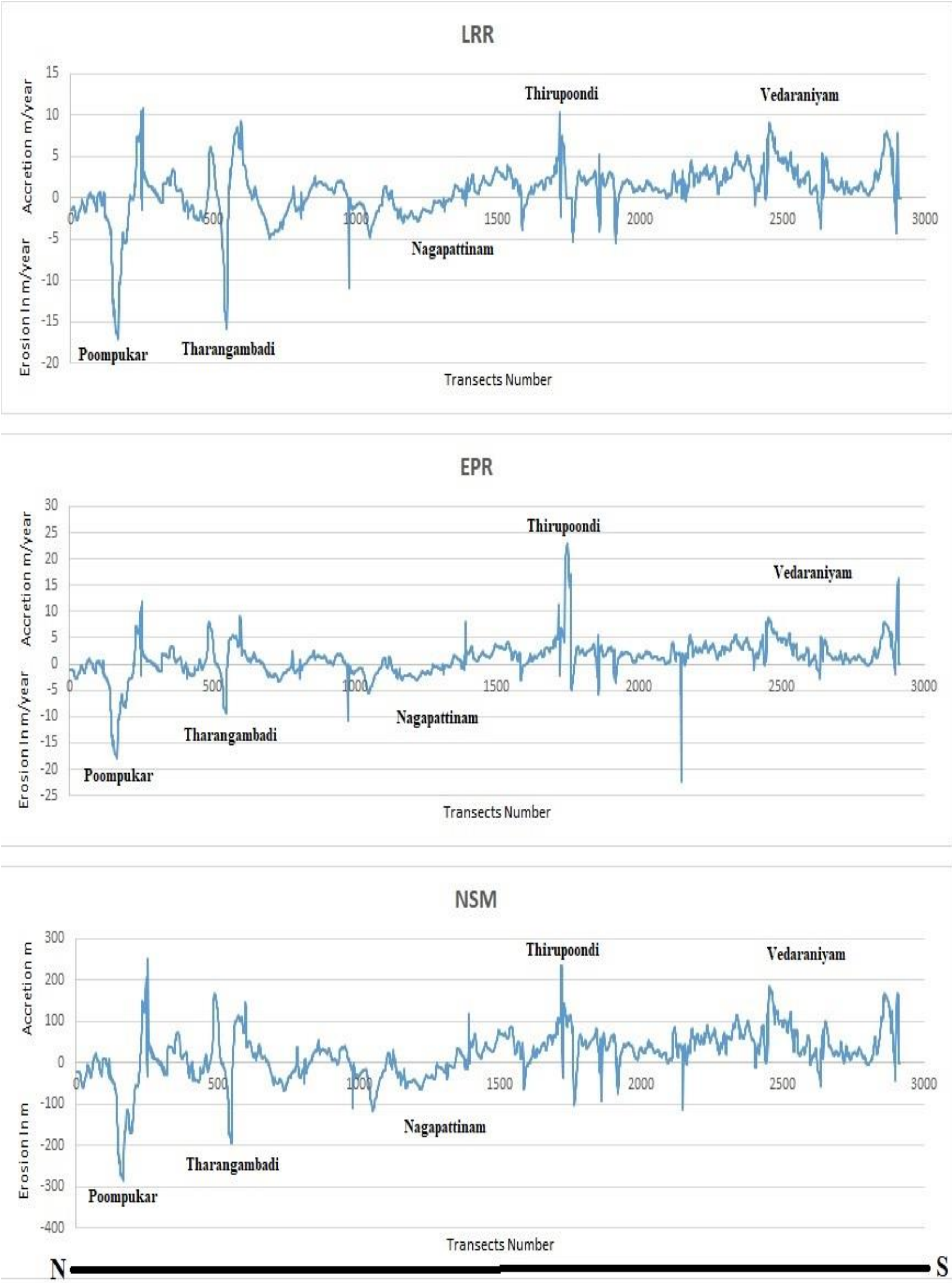

Figure 4: Erosion and accretion profile for NSM, LRR and EPR

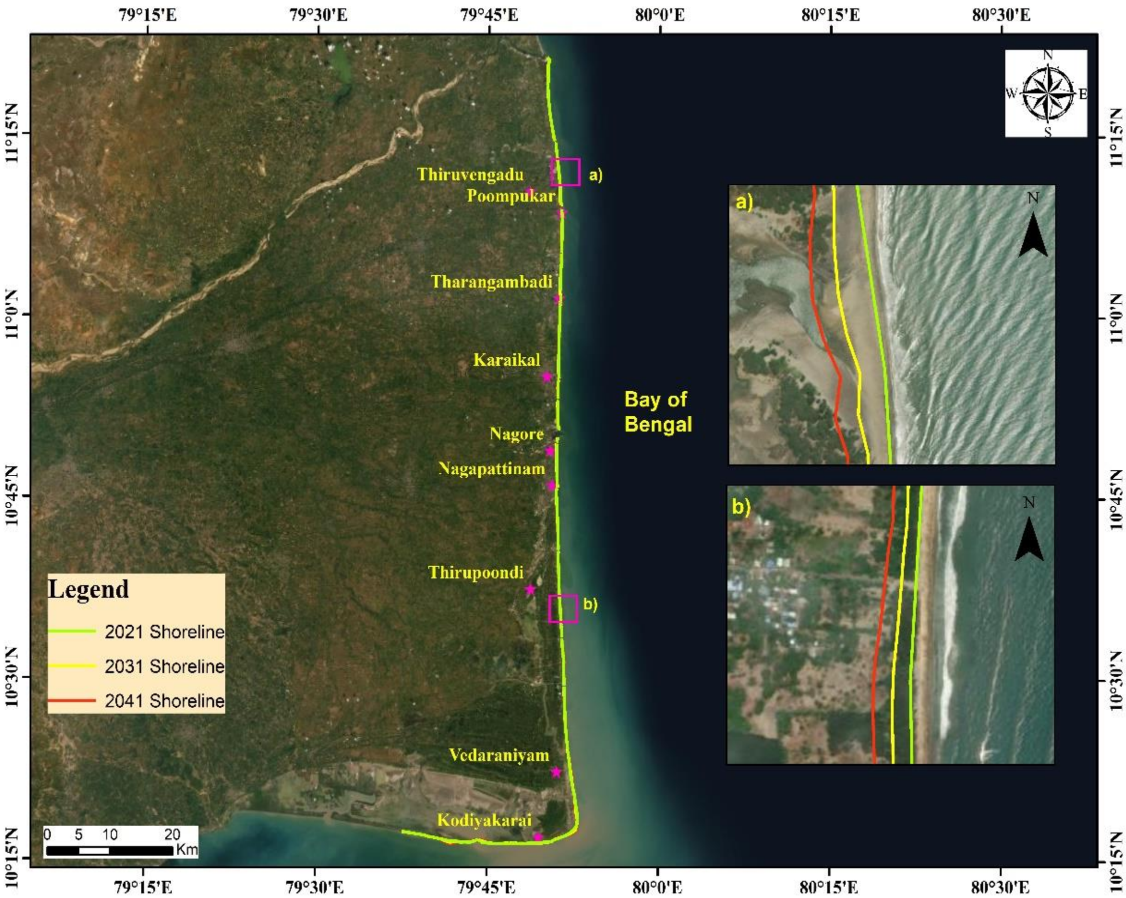

Figure 5: Forecasting shorelines of 2032 and 2042

Suggested measures for mitigating coastal erosion in affected regions include the installation of bulkheads (retaining walls), gabions (rock-filled wire baskets), articulating blocks (cable-connected concrete blocks), geo web matrix (thick, open-cell plastic grid), rip-rap (large rocks) and backfilling along the shoreline. These methods can effectively control and reduce coastal erosion. Additionally, restoration and rehabilitation of wetlands in specific areas such as Poompuhar and Nagapattinam are recommended as restoration measures. Sea grasses could also serve as a means of coastal defense by dampening waves, although they are rarely considered a sufficient solution.

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