The Andaman and Nicobar Islands' Coastal protection in Light of nearshore Environmental Production

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Abstract
The Andaman and Nicobar Islands experienced catastrophic damage from the December 2004 tsunami, resulting in significant loss of human life, biodiversity and mangrove ecosystems. This study aims to analyze the coastline changes around the Andaman Islands from 1990 to 2020, leveraging recent advancements in remote sensing and geographic information systems (GIS). The Digital Shoreline Analysis System (DSAS), a pivotal GIS tool, was utilized to calculate the rate of shoreline change in meters per year. The study integrated high-resolution satellite imagery and advanced geospatial techniques to accurately track and analyze shoreline dynamics. Inputs for DSAS included merged shorelines and a defined baseline, from which transects were systematically constructed to intersect the shorelines, allowing for precise rate calculations at each intersection point.

The result revealed the most alarming rate of erosion, indicating that Rutland island experienced the highest erosion rates, with the western side showing extreme erosion rates of -41.73 m/year and -51.18 m/year as determined by the End Point Rate (EPR) and Linear Regression Rate (LRR) methods.

Additionally, several islands in Andaman region underwent considerable shoreline retreat, showing a direct threat to coastal settlements, marine life and local civilizations. These findings highlight the severe impact of natural disasters on coastal regions and underscore the importance of advanced geospatial tools in coastal management, guiding disaster resilience planning and fostering ecosystem restoration effort to safeguard the coastal environment of Andaman and Nicobar Islands. Also, this study recommends enhancing existing methodology by incorporating AI and machine learning- based shoreline detection techniques for a modern approach.

Keywords: Digital Shoreline Analysis System, Geographic Information Systems (GIS), Shoreline Dynamics, Remote Sensing, Coastal Erosion.

Introduction

The shoreline, which separates land from the sea, is constantly shifting due to the changing environmental conditions. The coastal region experiences a number of changes as a result of human activities and natural disasters, including changes to the coastline, rising sea levels, erosion or accretion etc. The size, boundaries and shape of this system constantly change under the influence of different factors, both natural and anthropogenic activities[3]. Natural elements that have an impact on the dynamics of the coastal zone include wind, precipitation, coastal vegetation, ice and river runoff. Anthropogenic factors influencing the coastal include building construction, industrial development, dredging and mining. The detection of these changes in the coastal region depends heavily on remote sensing and GIS[4]. A GIS application called DSAS is used to track changes in shorelines using satellite imagery.

The Andaman and Nicobar Islands forms a collection of islands located at the confluence of the Bay of Bengal and the Andaman Sea, one of India's seven union territories. There are approximately 572 islands overall in the 7,950 km² of the Andaman islands[15]. The coastline represents a dynamic and physically active boundary between land and sea. The coastline has changed as a result of both natural and human activity. Erosion and accretion are the major factors[6]. Sea level rise contributes to erosion, whereas sediment deposition along the shore causes accretion[1]. The process significantly impacts on the coastal region[5]. The geophysical approach, satellite data and other techniques have all been used to find these changes[7]. ArcGIS incorporate a specialized tool called DSAS to find these changes[7,11].

Recent advancements in remote sensing technology including high-resolution satellite imagery and UAV (Unmanned Aerial Vehicle) data have significantly improved the accuracy and efficiency of coastal monitoring and management[9]. The fragile coastal ecosystem is at serious risk of collapse, potentially leading to severe loss in marine biodiversity and natural resources[10]. The 2004 earth quake followed by Tsunami in Indian Ocean caused significant landscape changes in the Andaman and Nicobar islands[12].

As a result, the coastal region experiences several changes, including changes to the coastline, changes in land use and land cover (LULC)[13], loss of biological diversity, pollution that affects species[16], changes to the groundwater, an increase in sea level and changes to agricultural patterns. As

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a result, the conservation and repair of the green belt, which are severely threatened, are vital[17,19]. The present study utilizes remote sensing and GIS techniques to detect and analyzing the changes in both coastline and LULC[2].

The Andaman Islands and Nicobar Islands, separated by the 10° N parallel, with the Andaman to the north of this latitude and Nicobar to the south. These 572 islands extend from 6° N to 14° N latitudes and from 92° to 94° E longitude. The present study aims to utilize remote sensing and GIS techniques to monitor and analyze the coastline and LULC in the Andaman and Nicobar Islands. This research seeks to identify the primary factors driving these changes and assess their impact on the region's ecological balance.

Material and Methods

Source data: The Andaman Islands is divided into three parts namely, North Andaman, Middle Andaman and South Andaman. Mayabunder is capital for North and Middle Andaman, Port Blair is capital and administrative headquarters for South Andaman and Car Nicobar is capital of Nicobar. The population is about 380,500 by 2012 census with Port Blair being the most densely populated area. A total of 48,675 hectares (120,280 acres) of land is used for agriculture purposes. Paddy, the main food crop, is mostly cultivated in Andaman group of islands. The study area map is shown in figure 1.

The estimates of shoreline change are based on a comparison of four historical shorelines driven from multi-temporal satellite imager. Landsat's satellite data for the years 1990, 2000, 2010, 2015 and 2020 were freely downloaded from United States Geological Survey (USGS) plotforms - www.landsat.org and http://glovis.usgs.gov. Details of the satellite datasets, including their acquisition data's are provided in the table 1.

Methods: The methodology involves employing Landsat data to analyze changes in the coastline influenced by wind, currents and tides. The key components of this approach include geo referencing the satellite data, digitizing the data with GIS software, generating a Land Use/Land Cover (LULC) map and identifying overall changes in LULC using GIS. Additionally, the shoreline change rate is determined using the DSAS tool, which involves digitizing shorelines and appending them. A geo database was created to digitize and record all the shorelines. After digitizing the coastline, the date and uncertainty were added to the attribute table. All shorelines from different years were then appended and merged using ArcGIS' append and merge tool.

Figure 1: Study Area Map

Table 1
Details of the satellite data and their acquisition dates

S.N.	Satellite	Sensor	Acquired	Path/Row	Spatial	Source
1	L 4-7	TM	1990	134/51, 134/52 & 134/53	30m	USGS -
2	L 7	ETM+	2000	134/51, 134/52 & 134/53	30m	USGS -
3	L 4-7	TM	2010	134/51, 134/52 & 134/53	30m	USGS -
4	LC-8	OLI	2015	134/51, 134/52 & 134/53	30m	USGS -

The shoreline rate is computed using statistical methods from the created transects; the LRR and EPR methods are selected from the available ones. The output, initially in .dbf format, was converted into Microsoft Excel. For example, a recent investigation along the Ganges river deltaic coast of Indian border and Bangladesh employed these techniques to analyze shoreline marks over a period of 40 years, providing the details of an average erosion rate of 0.27 m/year using the LRR method and 0.62 m/year using the EPR method[18]. A similar research conducted on the eastern coast of Indian sea compared the accuracy of LRR and EPR models in predicting shoreline positions[14].

The research shows that the LRR model demonstrated most accuracy with a mean square root error of 31.14 m and a correction coefficient of 0.948, compared to the EPR models value of root mean square error of 79.96 m and a correction coefficient of 0.822. Based on these two findings, one can suggest that both LRR and EPR methods are widely and commonly used for shoreline change research analysis, but the LRR methods may offer better accuracy.

Transects: Input from the digital shoreline analysis system (DSAS), including the combined shorelines and baseline were used to generate transects. Transects were created perpendicular to the baseline with an 800 m length and a 500 m spacing in the water and land to estimate the erosion and accretion zone. The rate of change of the coastline for each year is calculated for each transect. Ultimately, the shoreline's erosion and accretion rates were separated into the nine groups shown in table 2. This classification helps to identify the high risk erosion zone and regions which undergo the natural accretion processes, thereby supporting improved coastal management and planning.

Based on the indication given in the table 2, the shoreline changes are classified into categories ranging from very high erosion zone to very high accretion, essential to understand the coastal dynamics and management. Erosion prone areas indicate the region which is vulnerable to infrastructural damage and highly coastal retreat. Accretion – prone zones are crucial to balance the marine ecology and coastal resilience. Also, this zone provides the information on beach formation and wetland expansion and most importantly the natural sediment deposition. The stable shoreline areas refer the minimal and or no noticeably shoreline displacement changes over the period of time.

Shoreline Result: The southern coastline of Great Nicobar Island's, especially at Indira Point, sank by 2.5 to 3.0 meters. As a result of this subsidence, several structures including 23-meter-tall lighthouse tower, whose base is currently submerged in roughly 3 meters of water, were submerged as a result of this subsidence. In addition, the tsunami destroyed a helipad, a number of homes and surrounding vegetation, illustrating the catastrophic effects on the island's natural environment and infrastructure[6]. Based on the shoreline erosion and accretion rates, nine categories were established as shown in table 2. These created transects compute the annual shoreline rate. Table 3 provides details on the total number of transects and coastline length for various islands within the Andaman and Nicobar archipelago. This table facilitates targeted analysis and management plans for each island.

Table 2
Classification of Shoreline

S.N.	Rate of Shoreline Change (m/yr)	Shoreline Classification
1	>-3	Very High erosion
2	>-2 to <-3	High erosion
3	>-1 to <-2	Moderate erosion
4	>-1to<0	Low erosion
5	=0	Stable
6	>0 to <1	Low Accretion
7	>1 to <2	Moderate Accretion
8	>2 to <3	High Accretion
9	>3	Very High Accretion

Table 3
List of Total Number of Transects

S.N.	Island Name	Shape Length	Total Number of Transects
1	North Andaman	331572.931	581
2	Middle Andaman	240122.091	454
3	South Andaman	398067.684	643
4	Andaman	110847.796	194
5	Rutsland	75709.6596	117
6	Little Andaman	146371	243

Results and Discussion

North Andaman: The rate of shoreline change for North Andaman was calculated. Maximum erosion rates of -15.32 m/year and -14.7 m/year were observed along northern side. Maximum accretion rates of 15.8 m/year (EPR) and 20.08 m/year (LRR) were observed near the Diglipur harbour and Aerial bay. On comparing northern and southern side, the northern side leads to more accretion and erosion is more in southern side. The EPR and LRR graph are shown in figure 2.

Fig. 2 shows that the shoreline of north andaman island is changed in a considerable range and these shoreline changes arised due to various processes including wave action (Tsunami, 2004), sediment transport from the harbour and coastal area invasions and other human activities like coastal developmental projects and deforestation activities by individual and by Government. This would lead to ecosystams damage and marine infrastucture like mangroves and marine habitats.

Middle Andaman: The Middle Andaman region is high in risk due to the monsoonal variations, tectonic activity. The eastern side of Middle Andaman was examining for this analysis. The maximum erosion rates of -5.61 m/year and -4.23 m/year were observed near the lower end of eastern side from EPR and LRR rates. Maximum accretion rates of 7.96 m/year (EPR) and 6.32 m/year (LRR) were recorded at upper end of eastern side. The strong erosion rates at the lower and eastern end of middle Andaman could be from strong sea currents, storm surges and sediment displacement due to tidal movements. The maximum accretion rates at the upper eastern end might be from the long shore drift patterns, sediment deposition from monsoonal rivers or estuaries and replenishment sediment process. The northeast and a initial southwest monsoons could be a role player in creating these patterns. These changes could create an amount of landmass and possible impact on biodiversity in mangrove ecosystems. Accretion part of land expansion in certain regions leads to unstable landforms, prone to future erosion. EPR and LRR result of shoreline for these islands are shown in figure 3.

Andaman Islands: The shoreline change in main Andaman island was estimated using EPR and LRR methods. Maximum erosion rates of -9.16 m/year and -7.35 m/year were observed, indicating significant land loss along the coastal stretches and in few places, the changes are remarkable. Maximum accretion rates of 5.51(EPR) and 5.1 m/year (LRR) are noticed at western upper end. This is because of the sediment deposition due to localized sediment transport and potential anthropogenic activities. The EPR and LRR result of shoreline for these islands represents erosion are given in figure 4.

South Andaman: The costal changes over time in South Andaman was analyzed by EPR and LRR. Maximum erosion rates of -24.57 m/year and -28.51 m/year were observed along eastern side from EPR and LRR rates, indicating the severe coastal retreat and the eastern coastline is extremely vulnerable to wave action, monsoon influences and potential sea-level rise. Maximum accretion rates of 9.68 m/year (EPR) and 11.51 m/year (LRR) are noticed at upper side of South Andaman highlighting the areas of significant sediment deposition.

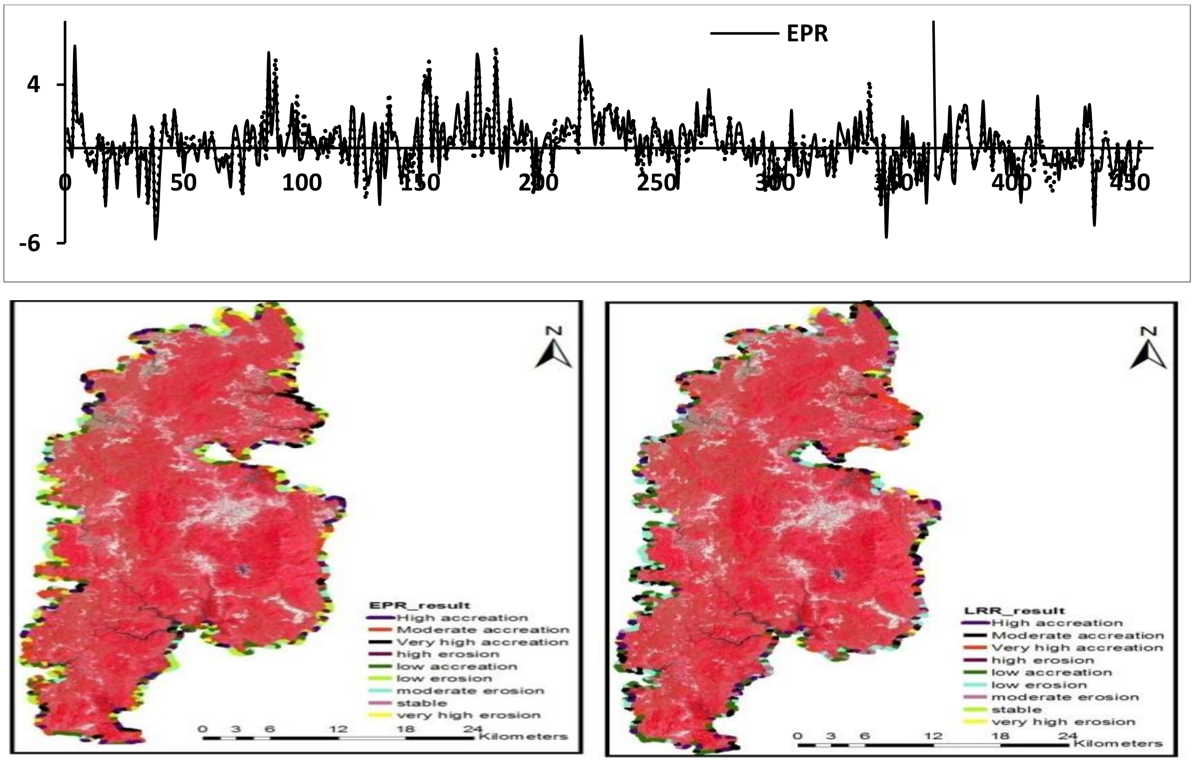

Figure 2: EPR and LRR of North Andaman

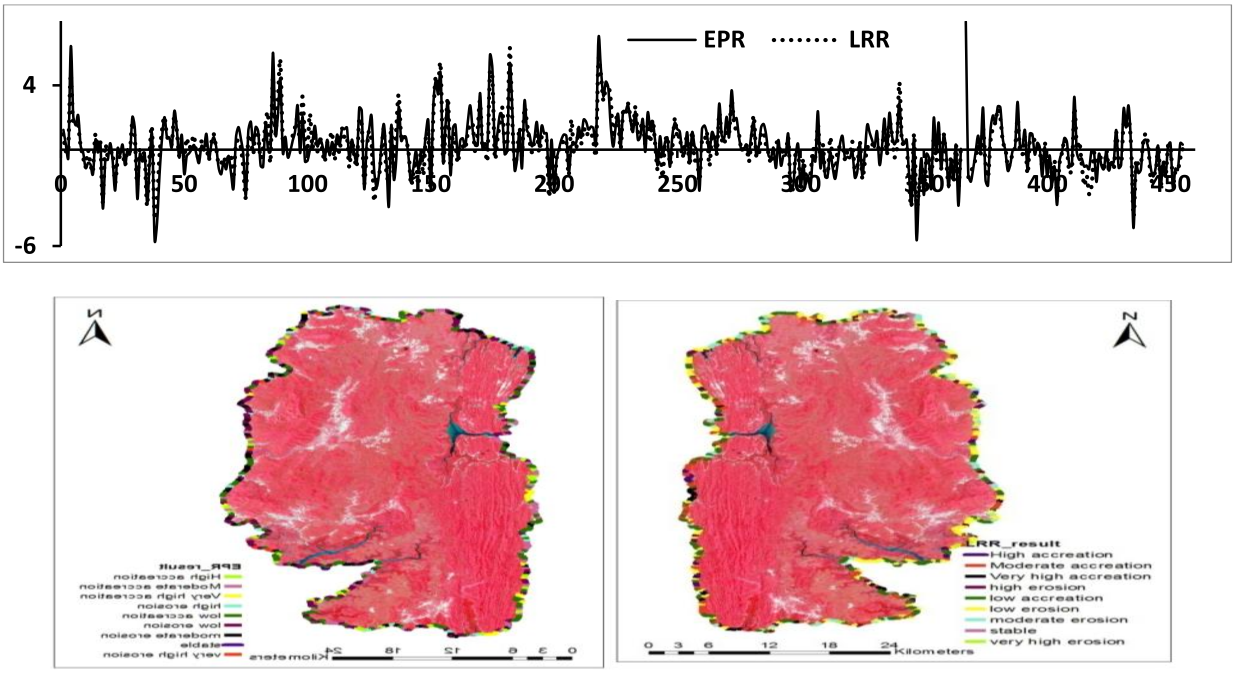

Figure 3: EPR and LRR of Middle Andaman

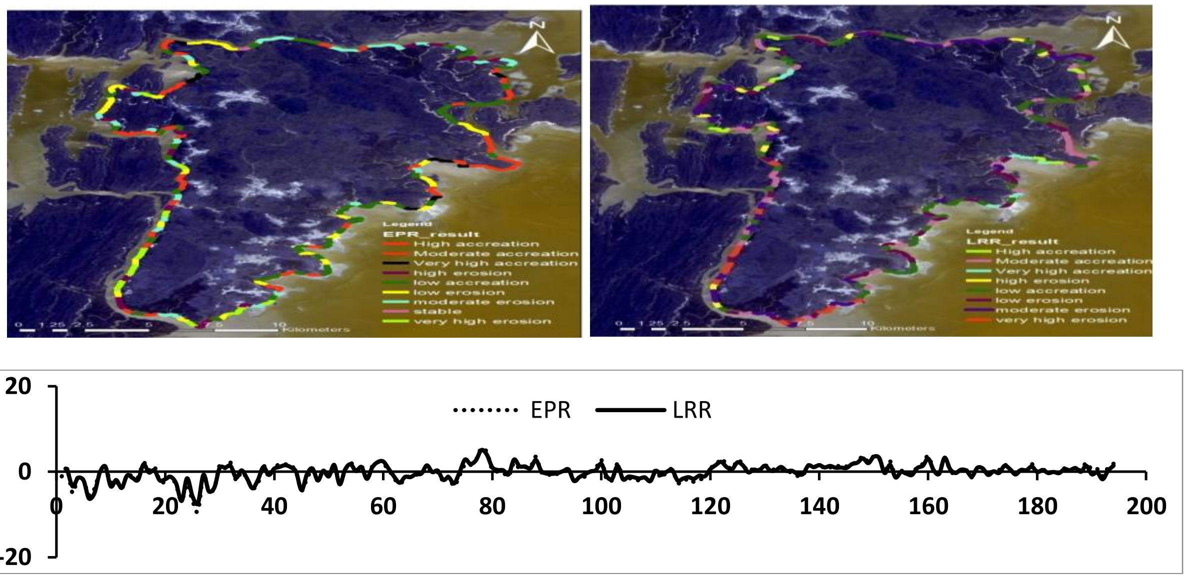

Figure 4: EPR and LRR of Andaman Island

This is due to the human induced changes including coastal modifications or mangrove restoration and the combined natural sediment transport and reduced wave energy. The EPR and LRR results of shoreline for these islands are shown in figure 5 which represent erosion and accretion regimes along the south Andaman coastal. The maximum erosion rates on the eastern side south Andaman Island may create threats to main tourism zones and fisheries, in turn this will impact the economical growth of India, as the Andaman is one of the country's key contributes to tourism revenue.

Rutland Islands: The rate of change of shoreline for Rutland islands was calculated using EPR and linear regression rate (LRR) methods. The results of EPR and LRR reveal the maximum erosion rates of -41.73 m/year and -51.18 m/year observed along the western side from EPR and LRR rates. This is considered as severe erosion rate in that particular ecological zone. Maximum accretion rates of 8.40 m/year (EPR) and 8.20 m/year (LRR) are noticed at upper end. The Rutland island zone is the most extreme coastal shoreline erosion part among the other Andaman region, indicating the substantial coastal threats. Fig. 6 represents erosion and accretion regimes along coastal of Rutland islands. The EPR and LRR result of shoreline for these islands is shown in figure 6. The figure provides the insights into the long-term shoreline evolution. The results suggest the presence of strong hydrodynamic forces, sediment loss subsidence affecting the stability of the shoreline. The western end of Rutland island showing the maximum erosion was caused by high energy wave action littoral drift and or strong storm surges which will accelerate the land loss more.

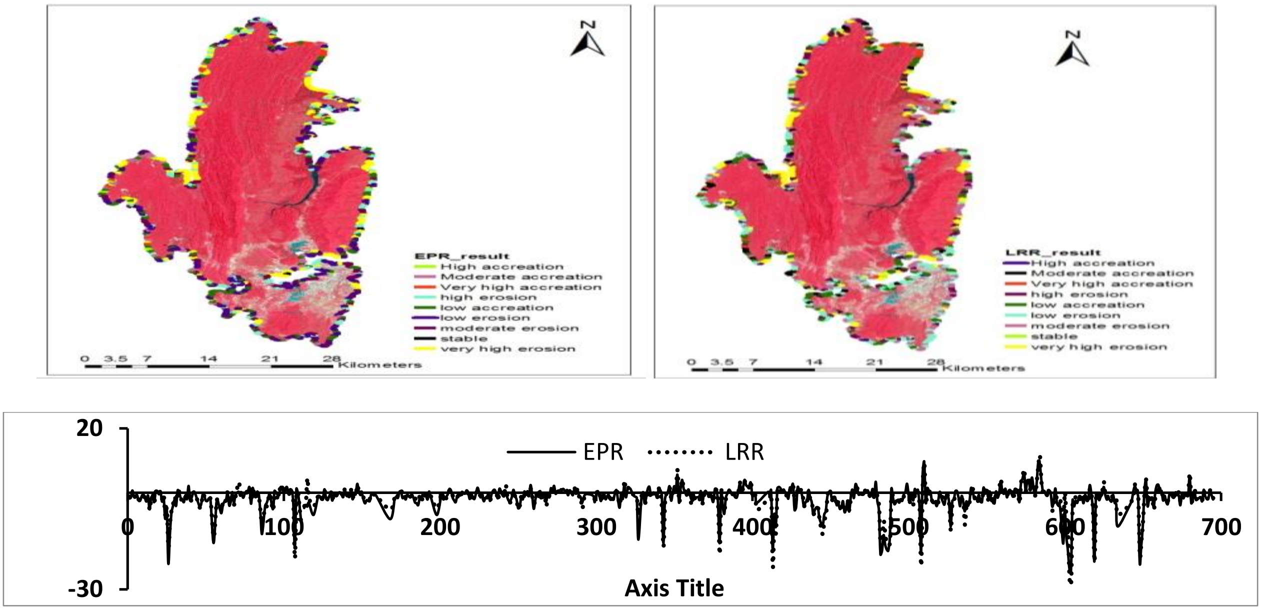

Figure 5: EPR and LRR of South Andaman

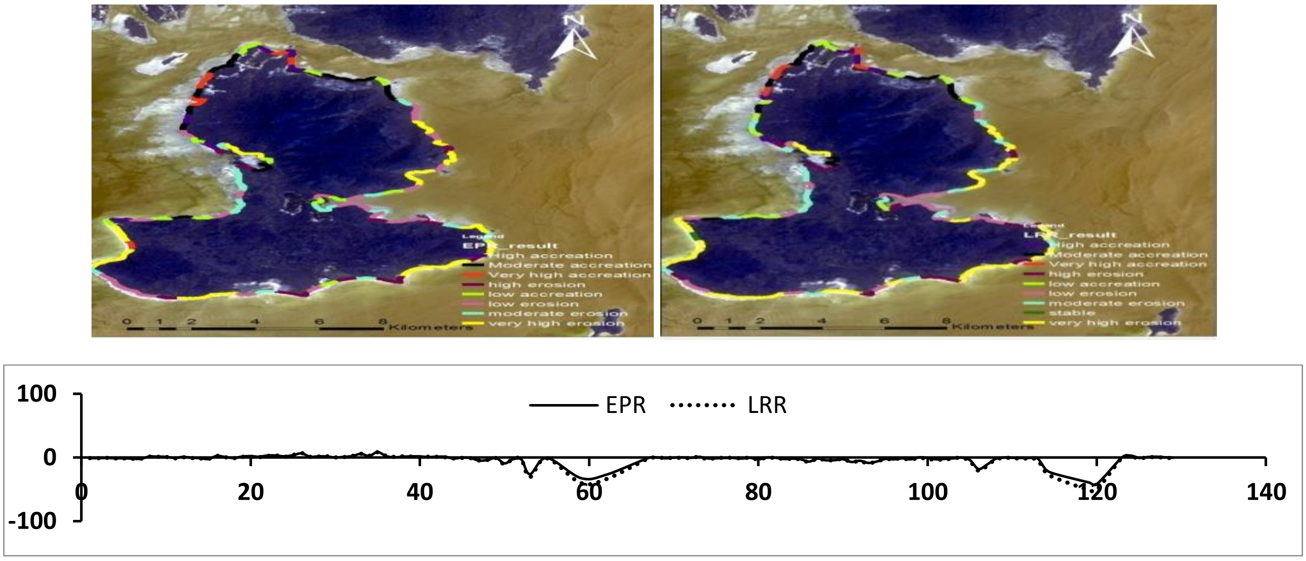

Figure 6: Rate of Shoreline Change for Rutland Andaman

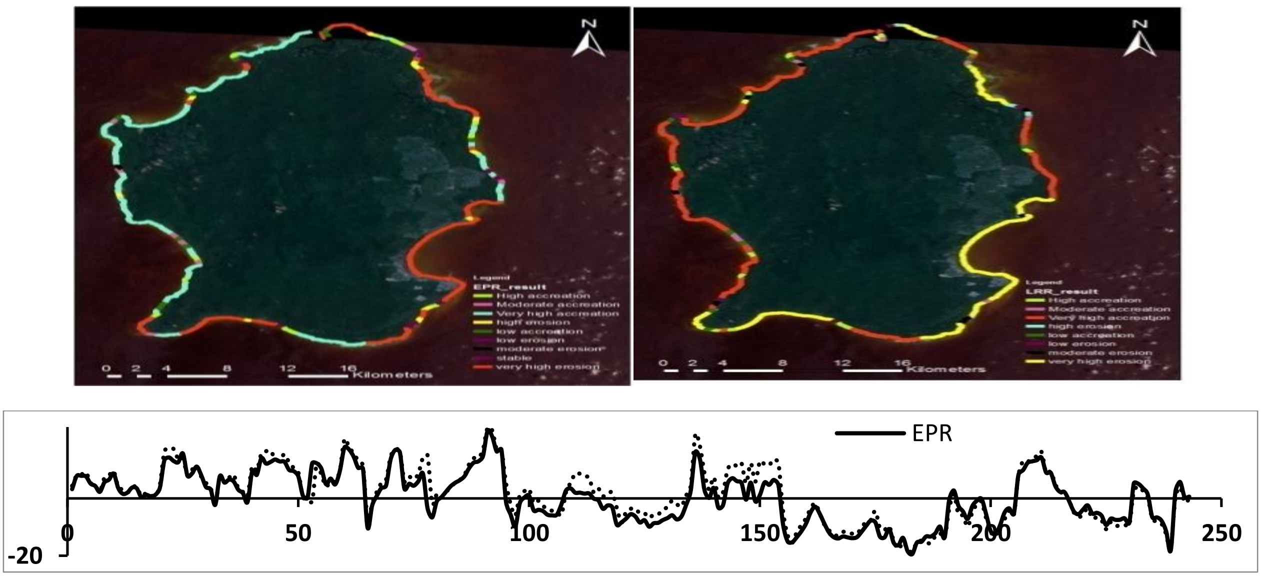

Figure 7: EPR and LRR of Little Andaman

Also, the upper end of Rutland island exhibits a strong accretion, could be from sediment deposition due to strong upper ocean currents or the close geomorphologic features that act as natural sediment traps. However, the sharp contrast between erosion and accretion across the island demonstrates the complex coastal processes that shape shoreline dynamics.

Little Andaman: The rate of shoreline changes for Little Andaman Islands was calculated. Maximum erosion rates of -19.34 and -18.59 m/year were observed near south little Andaman from EPR and LRR rates. Meanwhile the maximum accretion rates of 23.56 (EPR) and 24.71 m/year (LRR) were noticed at north side of Andaman suggesting the substantial sediment deposition. The stark variations between the maximum erosive south end region and the accreting north end region highlight the influence of coastal currents high tidal actions and redistribution of different sediment patterns. The potential tectonic plate activity and monsoonal changes along with the geomorphology of the island play a crucial role in changing and shaping the little Andaman shoreline[20].

The EPR and LRR results of shoreline for these islands are shown in figure 7. The mangrove cover, riverine sediment influx and near shore bathymetry also contribute to the variations in accretion and erosion of the shoreline. The Little Andaman is one of the homes for many ecologically important habitats and indigenous communities. These changes in shoreline will create socio-economics and environmental implications in the region and will affect the tourism and biodiversity of the little Andaman region.

Adaptation Measures: Special attention should be paid to low-lying coastal areas that are particularly vulnerable to erosion, necessitating their delineation as high-risk zones. Mitigating the effects of erosion due to anthropogenic activities should be given the highest priority. Both natural factors (such as littoral drift, tidal action and near shore bathymetry) and anthropogenic activities (including the construction of seawalls, groins, or breakwaters) significantly modify the shoreline configuration and control the erosion and accretion of coastal zones. Recent advancements in satellite measurements and GIS techniques provide enhanced capabilities to accurately delineate high erosion risk zones. Establishing a suitable policy framework and implementing adaptive measures are crucial in preventing further ecological and economic losses in the future. Governmental and individual citizen participation in coastal development regulations, disaster management plans and early warning systems must be emphasized as critical steps.

Conclusion

The analysis of EPR and LRR results reveals pronounced coastal dynamics, with maximum erosion rates of -41.73 m/year and -51.18 m/year occurring on the western side of Rutland Island due to harmful wave action. Conversely, the highest accretion rates, 23.56 m/year (EPR) and 24.71 m/year (LRR), were observed near Hubby Harbor in Little Andaman, attributed to the settlement of sandy beaches. These findings highlight Rutland island as the most affected area, emphasizing the urgent need for targeted coastal protection measures. Various methods are available to protect shorelines including constructing groins, seawalls and preserving dunes and vegetation.

The selection of appropriate methods depends on specific factors such as wave action, tsunami effects, saltwater intrusion and beach type. Implementing the most suitable strategies based on these criteria is crucial for safeguarding vulnerable coastal areas and mitigating further ecological and economic impacts. Government has to take into consideration about the long term factors such as increasing sea level, surges from storm, climate changes and tectonic influences in the region and initiatives have to be implemented in a regular basis. Advanced satellite measurements and GIS techniques play a pivotal role in accurately identifying high-risk zones, enabling the development of effective policy frameworks and adaptive measures to preserve and to protect our coastlines for future generations.

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