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Shoreline Change Analysis of Amini Island, Lakshadweep Using Remote Sensing and GIS

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Abstract

Lakshadweep Islands, a chain of low-lying coral atolls located in Arabian Sea, are among the most climate sensitive regions of India. Its airport and residential areas are predicted to be affected by sea level rise. Their geographic isolation, limited land area, and low elevation make them particularly vulnerable to the impacts of climate change, including sea-level rise, coastal erosion, coral bleaching, and extreme weather events. As the inhabited islands depend heavily on marine and coastal ecosystems for their livelihoods and protection, monitoring shoreline dynamics is crucial for sustaining environmental and socio—economic resilience. This study investigates shoreline changes on one of the inhabited islands of the Lakshadweep Archipelago, Amini, using multi-temporal Landsat satellite imagery from 1990-2020. Amini being a small island in the atoll, is expected to be severely hit. Some workers have predicted that Amini will face major land loss along 60 to 70% of its shoreline due to sea level rise. The analysis was conducted using ArcGIS and the Digital Shoreline Analysis System (DSAS) version 5.0 to extract shorelines and calculate change rates. Using two statistical change rate metrics Net Shoreline Movement (NSM) and End Point Rate (EPR), shoreline change was quantified for three different periods: 1990-2000, 2000-2015 and 2015-2020. The highest average erosion was observed during the 1990–2000 period; of the total of 1454 transects generated, 64.5 % transects showed erosion. Of the total 1422 transects generated for 2000-2015, 78.8% transects showed accretion. These findings underscore the importance of integrated coastal zone management and sustained shoreline monitoring to guide adaptive planning and sustainable development in the environmentally fragile and inhabited islands of the Lakshadweep archipelago.

1. Introduction

Shoreline dynamics are a fundamental aspect of coastal geomorphological change detection, induced by natural forces and/or anthropogenic activities. In recent decades, climate change induced phenomena such as sea level rise, increased storm intensity, and changing sedimentation patterns have accelerated shoreline retreat (Kaliraj et al., 2015; MOEFCC, 2018). Low lying islands are particularly vulnerable due to their limited land area, low elevation, and vicinity to geo-hydro-meteorological natural hazards (Mimura et al., 2007).The use of remote sensing and GIS based tools for shoreline change detection has become increasingly prevalent, offering cost effective and scalable means of long-term coastal monitoring (Luijendijk et al., 2018; Maiti & Bhattacharya, 2009). Among these, the Digital Shoreline Analysis System (DSAS), developed by the U.S. Geological Survey, is widely recognized for its statistical robustness and capacity to process large sets of multi-temporal shoreline data (Thieler et al., 2009). DSAS employs metrics such as Net Shoreline Movement (NSM) and End Point Rate (EPR) to quantify rates of erosion and accretion, allowing for spatial and temporal trend analysis along coastlines (Thieler et al., 2009).

Several studies have examined various aspects of coastal dynamics and environmental vulnerability in the Lakshadweep archipelago. The smaller islands Chetlat and Amini are expected to have a major land loss. Projection mapping indicated that about 60-70% of existing shoreline would experience land loss in Amini and 70-80% in Chetlat (Jennath et al., 2021). The study done for 1972-2015 reveals that Amini Island shows an average Linear Regression Rate of −0.73 m/year, whereas those for lagoon and ocean sides of the island are −0.84 m/year and −0.62 m/year, respectively, indicating an erosional trend (Suganya et al., 2019).

Due to its low elevation, limited land area which is 2.6 km^2, and geographic isolation, Amini Island is highly vulnerable to coastal hazards, including erosion, storm surges, and sea level rise (LAPCC, 2012). Given its small size 2.6 km^2 and high population density (2956/km^2), even minor shoreline retreat can have serious implications for local infrastructure, freshwater availability, and livelihoods. Despite its significance, limited studies have focused on quantifying shoreline changes. This gap highlights the need for analysis of shoreline change.

2. Study area

Amini Island is one of the ten inhabited islands of the Lakshadweep Archipelago, located in the Arabian Sea, approximately 200-300 km off the southwestern coast of India (Fig. 1). Geographically, it lies at 11°7'19.79"N and 72°43'30.41"E and forms part of the northern Aminidivi subgroup of the archipelago. The island is oval-shaped,

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extending approximately 5.8 km in length and 1.6 km in width, covering a total land area of around 2.6 km^2 and is 2 to 3 m above mean sea level. It is densely populated, with a total population of 7,656 as per the Census of India - 2011.

Amini Island experiences a tropical maritime climate influenced by the southwest monsoon, with average annual rainfall of approximately 1600 mm, primarily occurring between mid-May and September. The island experiences occasional cyclonic disturbances during the pre- and post-monsoon seasons, especially from April to June and October to November (LAPCC, 2012). Temperatures range between 25°C to 35°C, and relative humidity typically fluctuates between 70% and 76% throughout the year. The island is surrounded by a coral reef and a shallow lagoon system that acts as natural barrier, moderating wave energy and reducing direct coastal impacts (Website of the UT Administration of Lakshadweep, 2025). The eastern and southeastern coasts of the island represent the windward side, as they face the open Arabian Sea and are directly exposed to the southwest monsoon winds and associated high-energy wave action. In contrast, the western side of the island, where a shallow lagoon is located, is the leeward side. Lakshadweep Islands have been experiencing increasing anthropogenic pressures such as population growth, coastal development, sewage discharge, pollution, dredging, sedimentation, and siltation (Panchang et al., 2023).

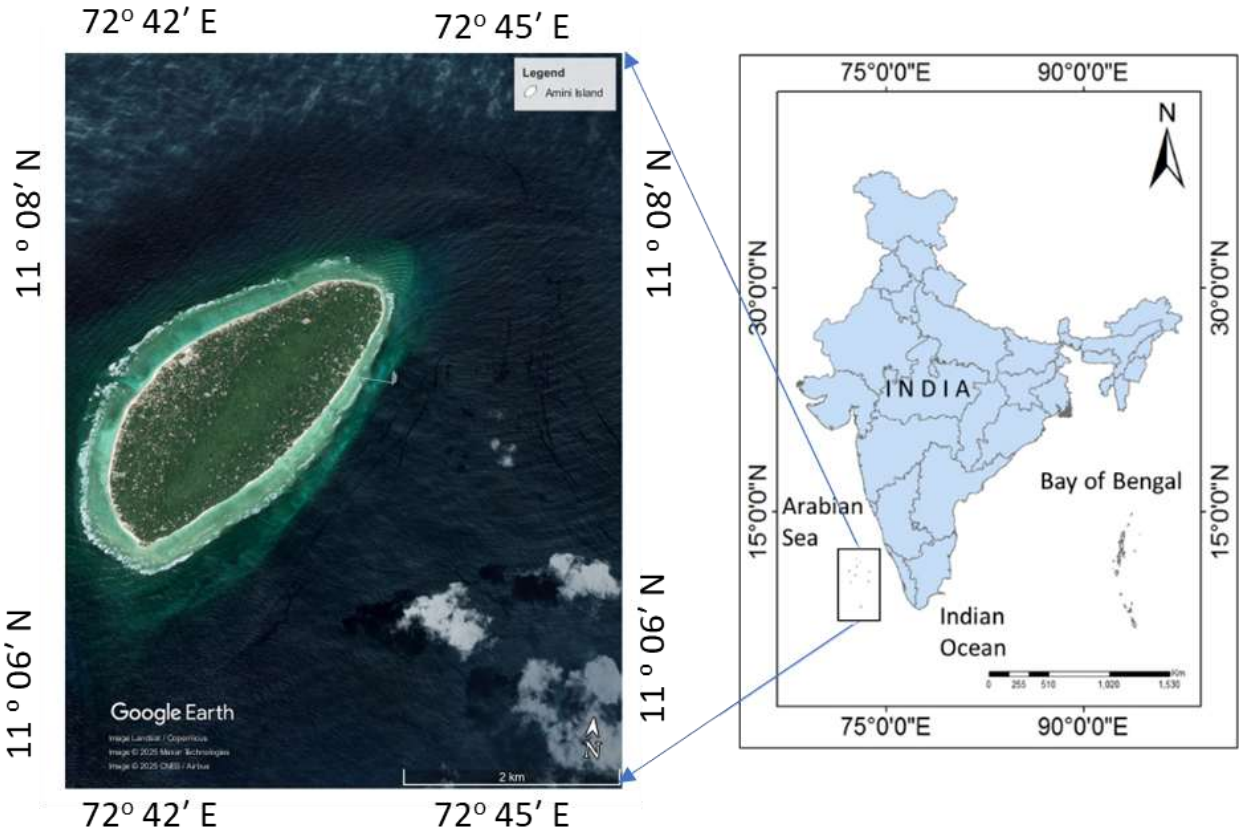

Figure 1. Map showing location & extent of the Amini Island within the Lakshadweep Atolls

3. Methodology

The present study uses multitemporal Landsat images from the year 1990-2020, along with ArcGIS and DSAS 5.0 to detect the shoreline changes. To extract the shoreline, Modified Normalized Difference Water Index (MNDWI) was used and the shoreline was digitised. A baseline was created 80 m oceanward from the shoreline, to calculate the rate of change. After digitizing of shoreline and creating the baseline, transects perpendicular to the coast were generated at 10 m intervals, using the DSAS tool around the entire island.

To study the changes that may have occurred during the period of study, two statistical methods were used, namely Net Shoreline Movement (NSM) and End Point Rate (EPR). The NSM is the distance between the oldest and youngest (most recent) shorelines on each transect and denotes only the distance, but not the rate of change per year. The EPR is calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shorelines. It provides a straightforward measure of the overall erosion or accretion rate and is used to calculate the statistics of the rate change per year.

4. Result

Shoreline change rates were calculated for three-time durations: 1990-2000 (10 years), 2000-2015 (15 years), and 2015-2020 (5 years) (Table 1).

Negative values of NSM and EPR indicate erosion, with the shoreline retreating by an average of 17.29 m between 1990 and 2000. Between 2000 and 2015, the mean NSM was 12.26 m suggesting a net accretion leading to prograding or advancing shoreline. During the 5-year period from 2015-2020 the mean

NSM was low (0.54 m), suggesting a slight accretion. The processes of erosion and accretion seem to be largely counter-balanced.

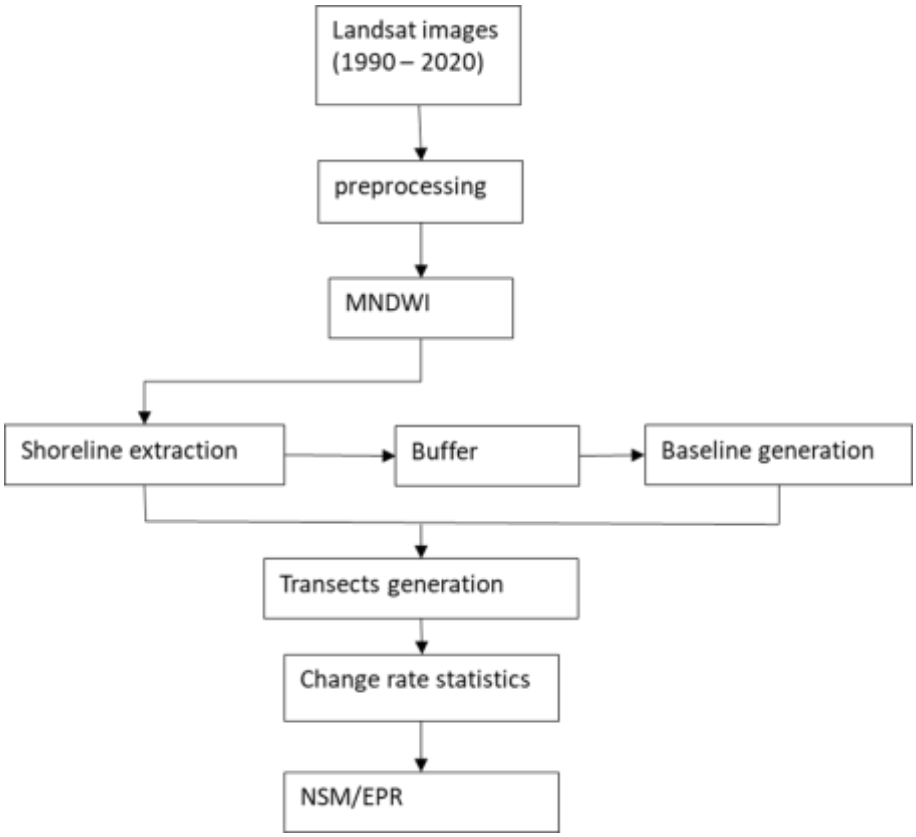

Figure 2. Flowchart depicting methodology adopted

	Duration	No. of transects	Average NSM (m)	Average EPR (m/yr)	Inferred Net Change
1	1990-2000	1454	-17.29	-1.73	Erosion
2	2000-2015	1422	12.26	0.81	Accretion
3	2015-2020	1444	0.55	0.11	Accretion

Table 1. Shoreline movement

5. Discussion

The present study assesses the shoreline change for 30 years between 1990 to 2020 for the inhabited atoll island Amini of the Lakshadweep Archipelago. The results summarise the net shoreline movements around the island in three-time intervals. Whilst the mean values (Table 1) serve as indicators of average trends of shoreline movements, the Figures 3 to 5 exhibit that different stretches of the coastline were subjected to different processes of erosion and accretion at different time intervals. This spatiotemporal information of processes prevalent along the coasts of such Islands, is extremely critical for effective coastal zone management.

During the decade 1990-2000, the NSM varied largely between a maximum of 43.66 m at the southern side, and a minimum of -111 m at the eastern side of the island. Similarly, the maximum EPR recorded was 4.38 m/yr, while the minimum was -11.17 m, making the mean EPR -1.73 m/year, suggesting erosion. 64.5% of the transects (Fig. 3), exhibit land loss. Among the total number of 1454 transects, 939 transects showed negative values. The eastern and southeastern coastal tracts of the Amini island experienced the highest levels of erosion.

Between 2000-2015, the maximum accretion (67.99 m) was observed at the southern side, while maximum erosion (-3.48m) was observed at southwestern side. The mean EPR observed was 0.81 m/year. The maximum EPR observed was 4.55 m/year while minimum EPR observed was -0.23 m/year. Of the 1422 transects generated for 2000-2015 (Fig. 4), 1121 transects i.e. 78.8% transects showed accretion. This accretion seems to be distributed almost uniformly all around the coastline, with maximum accretion to the east. These findings differ from those previously reported by Suganya et al. (2019) for the same duration for Amini. They had reported a very low average rate of erosion (0.06 m/yr) as against substantial accretion identified in the present study.

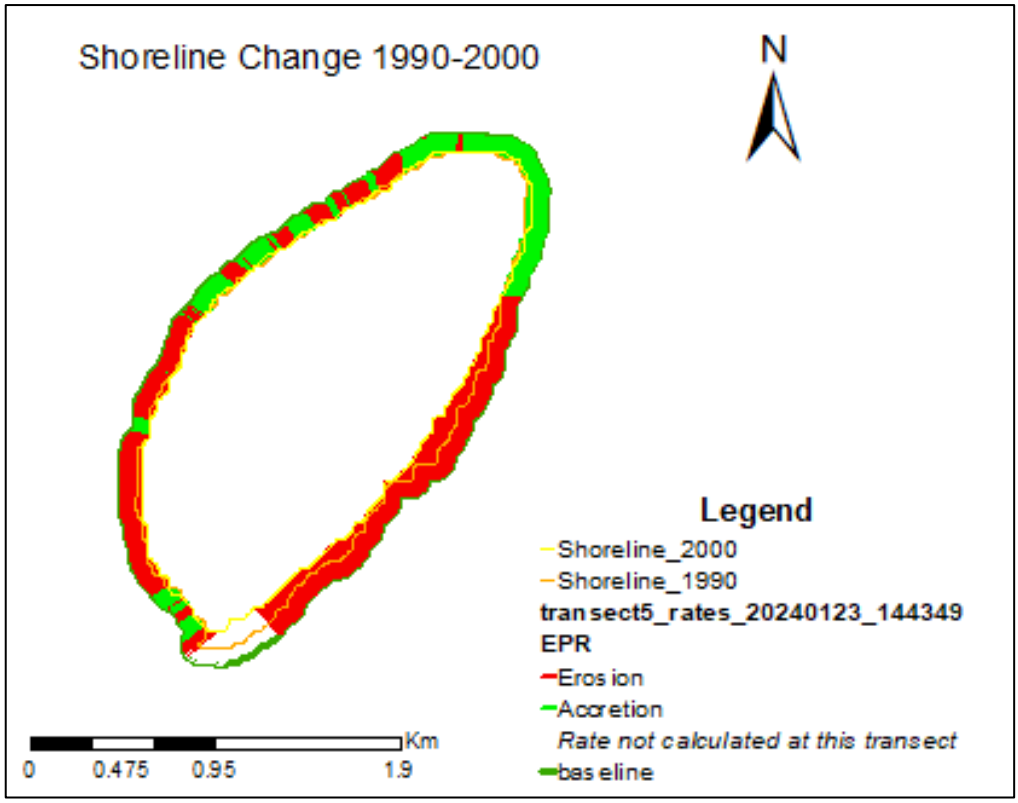

Figure 3. Erosion/Accretion map 1990-2000

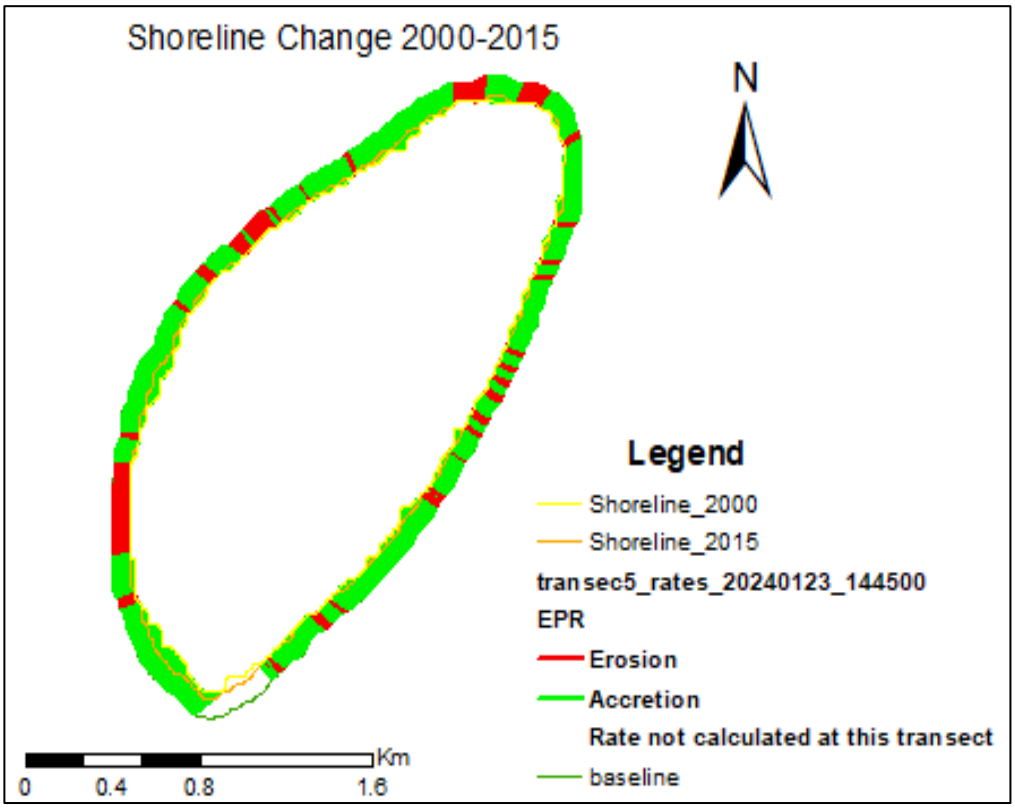

Figure 4. Erosion/Accretion map 2000-2015

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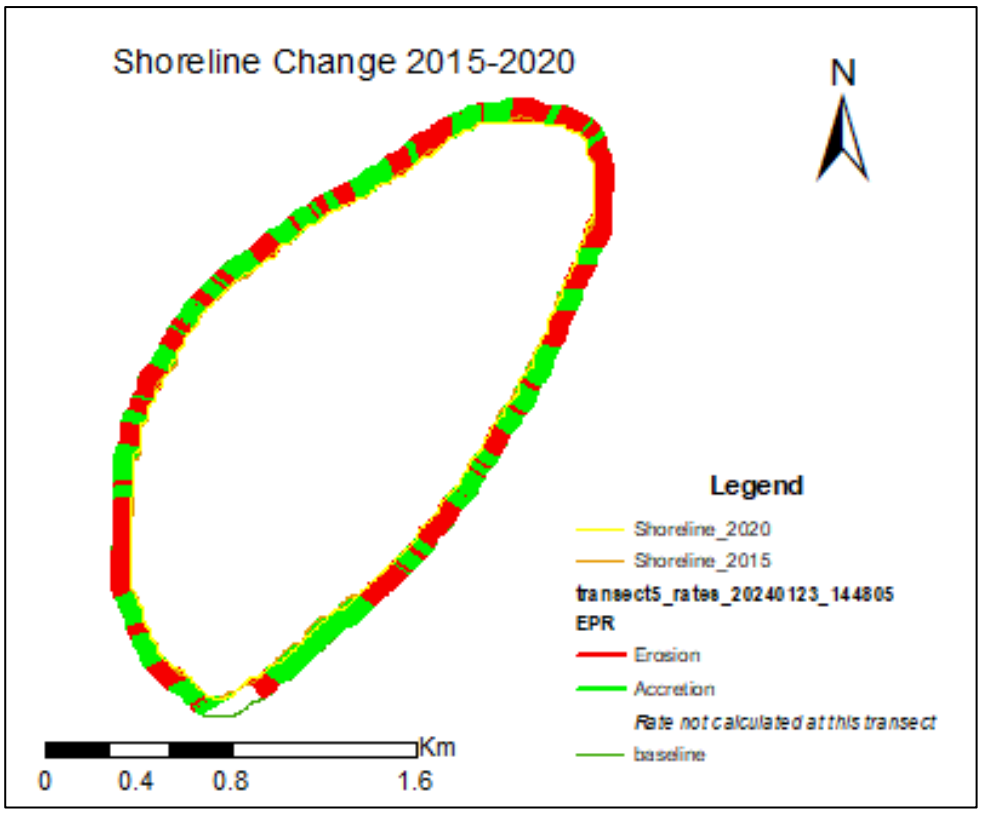

Figure 5. Erosion/Accretion map 2015-2020

Between 2015-2020, the mean NSM observed was 0.54 m. The maximum NSM recorded was 58.5 m. at the southern tip of the island and the minimum NSM recorded was -3.14 m at the north. The maximum EPR recorded was 11.92 m/year and minimum were -6.14 m/year. The mean value of EPR recorded was 0.11 m/year. As evidenced from Fig. 5 for 2015-2020, 48.8% transects shows erosion and 50.8% transects shows accretion, suggesting a largely stable coastline.

Quantifying the erosion in the first 10 years and the accretion in the next 20 years, there seems to be a net shoreline retreat by 5 m. However as stated before, these processes have varied spatiotemporally. The southwest stretch of the coastline has persistently shown significant erosion. This location however coincides with the navigational approach channel leading to the jetty, which needs to be continuously maintained by dredging. This explains the persistent retreat of the southwestern side of the coast throughout the 30 years period under investigation. In contrast, the eastern coast which was site of maximum erosion in the first decade has shown maximum accretion in the next two decades. The study exhibits the dynamic nature of coastal processes at Amini.

Further investigations are needed to ascertain if these dynamics are climate driven or human driven, to be able to better manage the coastline and its development. The almost uniformly rising coastline around the island, could also be suggestive of tectonic rise of the Amini Island at a time when there is concern over rising sea levels in the Lakshadweep Atolls.

6. Conclusions

The eastern coast of Amini atoll island which showed maximum erosion between 1990 and 2000, shows maximum accretion between 2000 to 2020.

The coast of Amini shows a net retreat of 5 m in three decades between 1990 and 2020.

The nearly uniform advancing coastline is suggestive of tectonic rise of the Amini Island, which may be counteracting the effects of sea-level rise.

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