

Multi-Decadal Shoreline and Morphological Change of The Jambudwip Island Using Landsat and DSAS (1972–2026)

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HIGHLIGHTS

- Landsat-derived shorelines from 1972–2026 were analysed using NDWI and the Digital Shoreline Analysis System (DSAS).
- A total of 226 transects at 100 m spacing quantified shoreline movement using EPR, LRR, NSM and SCE.
- Island area declined from about 876 ha in 1972 to about 313 ha in 2026, indicating substantial long-term morphological contraction.

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ABSTRACT

The Jambudwip Island in the Indian Sundarbans is exposed to rapid shoreline migration and morphological instability. This study quantified shoreline and areal changes over 54 years (1972–2026) using ten cloud-free Landsat MSS, TM and OLI/TIRS scenes. Water–land boundaries were delineated using the Normalized Difference Water Index (NDWI), and shoreline change was evaluated in the Digital Shoreline Analysis System (DSAS) using 226 transects spaced at 100 m. End Point Rate (EPR), Linear Regression Rate (LRR), Net Shoreline Movement (NSM) and Shoreline Change Envelope (SCE) were used to characterize the magnitude and rate of change. Short-term analysis showed the largest erosional episode during 1980–1990 (690.64 ha), whereas the largest accretion occurred during 1990–1995 (765.26 ha). After 2000, the island was predominantly erosional, including a net loss of 90.43 ha during 2020–2026. Over the full period, island area declined from approximately 876 ha to 313 ha. The maximum EPR values reported in the thesis ranged from -90.41 m yr^{-1} for erosion to $+42.01 \text{ m yr}^{-1}$ for accretion, while NSM reached approximately -4000 m and $+2000 \text{ m}$. The spatial pattern indicates greatest instability along the southern and western margins. The results demonstrate the value of multi-temporal Landsat data and DSAS for long-term monitoring of small, erosion-sensitive deltaic islands, while also highlighting the need for higher-resolution imagery, field validation and hydrodynamic information in future assessments.

1. INTRODUCTION

Coastal shorelines are dynamic boundaries whose positions respond continuously to interacting marine, fluvial, atmospheric, and terrestrial processes.

Tides, waves, river discharge, sediment supply, storm events, and relative sea-level change can alter the land–water interface over different spatial and temporal scales. Anthropogenic interventions,

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including embankment construction, modification of tidal channels, vegetation removal, and coastal development, can further disrupt sediment transport and modify patterns of erosion and accretion. Consequently, shoreline position represents an important indicator of coastal environmental change and provides a basis for assessing the vulnerability and morphological evolution of coastal landscapes (Maiti & Bhattacharya, 2009; Thakur et al., 2021).

These processes are particularly significant in low-lying deltaic environments such as the Indian Sundarbans, where the interaction of tidal processes, riverine sediment supply, cyclonic disturbances, sea-level variability, and human interventions produces a highly dynamic geomorphic setting. Islands within this delta may experience substantial shoreline retreat, localized accretion, fragmentation, and changes in planform geometry over relatively short periods. Previous remote-sensing investigations have demonstrated considerable spatial and temporal variability in shoreline behaviour across the Sundarbans and adjoining Hooghly estuarine region (Jayappa et al., 2006; Thakur et al., 2021).

Jambudwip is a small island situated in the Bay of Bengal near the mouth of the Hooghly River and approximately 8 km from the Bakkhali-Ganga Sagar mainland sector of South 24 Parganas, West Bengal. Its exposed coastal position, tidal environment, and dynamic sedimentary setting make it an appropriate natural laboratory for examining multi-decadal shoreline change. Earlier studies of islands in and around the Indian Sundarbans have identified substantial geomorphological changes associated with erosion and accretion (Jayappa et al., 2006; Thakur et al., 2021). More specifically, Das et al. (2021) investigated shoreline behaviour on Jambudwip using the Digital Shoreline Analysis System (DSAS) and demonstrated pronounced spatial variability in erosion and accretion around the island. These observations highlight the need for continued long-term assessment using an extended satellite record.

Remote sensing and geographic information systems (GIS) provide an effective and reproducible framework for investigating such changes because historical satellite archives permit shoreline positions to be reconstructed consistently over several decades. The Landsat programme is particularly valuable for long-term coastal monitoring because its sustained Earth-observation record enables systematic assessment of landscape and surface changes across multiple decades (Roy et al., 2014). Multi-temporal satellite imagery can therefore be used to delineate successive shoreline positions, quantify changes in island area and geometry, and identify persistent erosion and accretion zones.

The reliability of shoreline-change assessment has also improved through the development of

standardized geospatial analytical tools. The Digital Shoreline Analysis System (DSAS) provides a systematic approach for generating transects and calculating quantitative shoreline-change statistics from sequential shoreline positions (Thieler et al., 2009). Commonly applied metrics include the End Point Rate (EPR), Linear Regression Rate (LRR), Net Shoreline Movement (NSM), and Shoreline Change Envelope (SCE), which together characterize both the magnitude and rate of shoreline displacement. Subsequent developments in open-source shoreline-analysis systems have further demonstrated the utility of automated and reproducible approaches for multi-temporal coastal-change assessment (Gómez-Pazo et al., 2022). Spectral water indices such as the Normalized Difference Water Index (NDWI), combined with appropriate image preprocessing and visual verification, can additionally support consistent discrimination between water and terrestrial surfaces in multi-temporal satellite imagery.

Despite previous investigations of Jambudwip and other islands of the Indian Sundarbans, extending the observational record is important for distinguishing short-term shoreline fluctuations from persistent long-term morphological trends. Incorporating historical observations together with recent satellite imagery makes it possible to evaluate whether previously identified erosion and accretion patterns have persisted, intensified, diminished, or shifted spatially. Such information is important for understanding the geomorphic evolution of small deltaic islands and for identifying shoreline sectors experiencing sustained instability.

Accordingly, the present study aims to (i) prepare multi-temporal shoreline maps of Jambudwip; (ii) quantify temporal changes in island morphology and surface area; (iii) estimate short- and long-term shoreline-change statistics using EPR, LRR, NSM, and SCE; and (iv) identify spatially persistent erosion- and accretion-prone sectors. The study covers the period 1972–2026, providing a 54-year observational window that captures both episodic decadal changes and the cumulative long-term morphological trajectory of Jambudwip Island.

2. MATERIALS AND METHODS

2.1 Study area

Jambudwip lies in the Indian Sundarbans of South 24 Parganas district, West Bengal, close to the Hooghly estuary and the northern Bay of Bengal. The thesis locates the island near 21°34' N and 88°10'–88°12' E. The island is surrounded by a tidally active coastal environment and has undergone substantial historical changes in area and shoreline configuration.

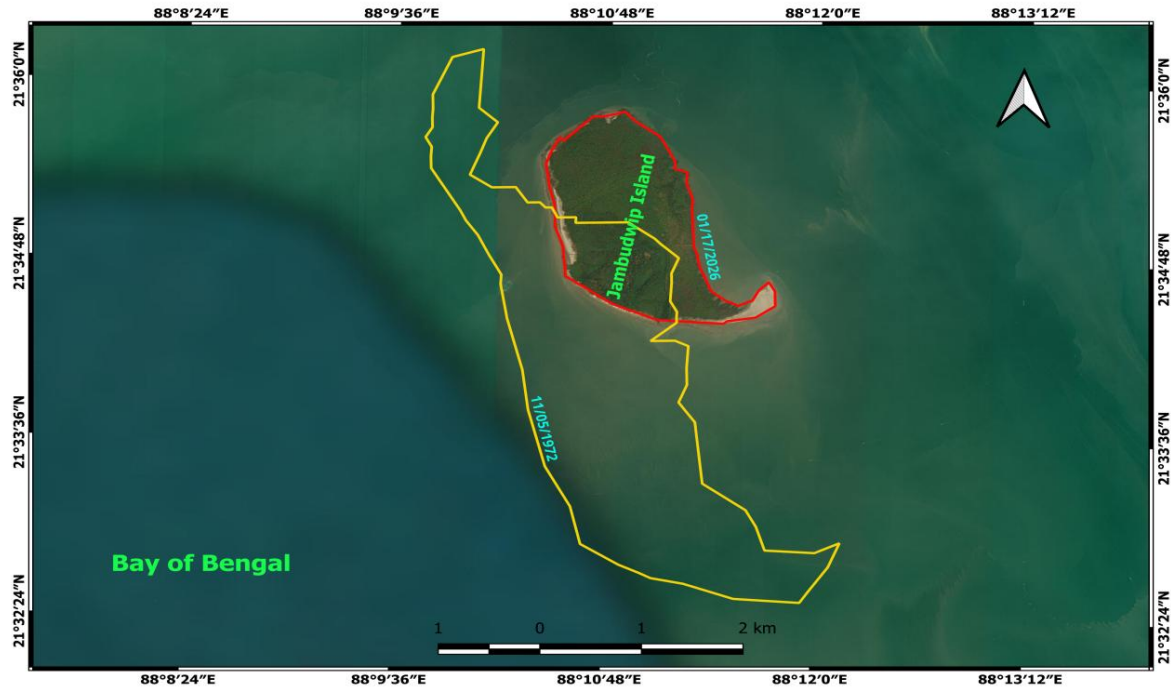


Figure 1. Location and multi-temporal shoreline context of Jambudwip Island.

2.2 Satellite data and preprocessing

Ten cloud-free Landsat scenes representing 1972, 1980, 1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2026 were used. The archive includes Landsat MSS, TM and OLI/TIRS imagery.

The orthorectified imagery was obtained from the U.S. Geological Survey archive and processed in ArcGIS 10.2. Because identical sensor resolution is not available over the full 54-year period, the analysis necessarily combines multiple Landsat sensor generations (Table 1).

2.3 Shoreline extraction using NDWI

To reduce subjectivity associated with manual visual interpretation, the water-land boundary was delineated using the Normalized Difference Water Index (NDWI). In general form, $NDWI = (Green - NIR) / (Green + NIR)$. The thesis implemented sensor-specific band combinations: Landsat MSS Band 4 and Band 6, Landsat TM Band 2 and Band 4, and Landsat OLI/TIRS Band 3 and Band 5. The extracted water boundary was converted to shoreline vectors for subsequent DSAS analysis.

$$NDWI = (Green - NIR) / (Green + NIR)$$

Table 1. Landsat imagery used for shoreline mapping.

Sensor	Acquisition date	Path/Row
Landsat-1 MSS	05 Nov 1972	148/045
Landsat-3 MSS	21 Feb 1980	148/045
Landsat-5 TM	30 Jan 1990	138/045
Landsat-5 TM	28 Jan 1995	138/045
Landsat-5 TM	26 Jan 2000	138/045
Landsat-5 TM	07 Jan 2005	138/045
Landsat-5 TM	21 Jan 2010	138/045
Landsat-8 OLI/TIRS	19 Nov 2015	138/045
Landsat-8 OLI/TIRS	01 Jan 2020	138/045
Landsat-8 OLI/TIRS	17 Jan 2026	138/045

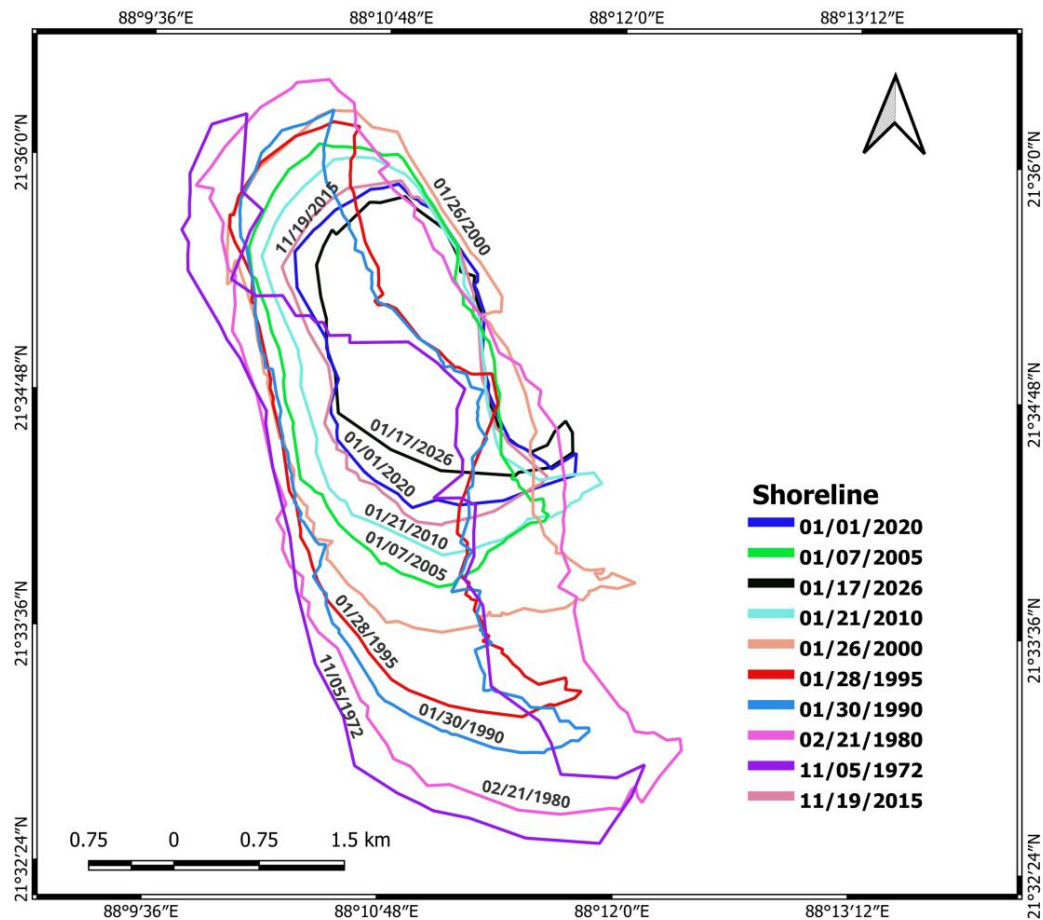


Figure 2. Multi-temporal shoreline positions used to characterize island migration and planform change.

2.4 DSAS configuration and shoreline statistics

Shoreline vectors were stored in a geodatabase with shoreline dates, and a reference baseline was established. Transects were cast approximately perpendicular to the shoreline at 100 m intervals, with a reported transect length of 2000 m and smoothing distance of 500 m. A total of 226 transects were generated. Positive shoreline-change values represent accretion and negative values represent erosion (Figure 2).

Four DSAS statistics were used. Shoreline Change Envelope (SCE) is the distance between the farthest and nearest shoreline positions at a transect, independent of time (Figure 3). Net Shoreline Movement (NSM) is the distance between the oldest and newest shoreline positions. End Point Rate (EPR) divides

NSM by the elapsed time between the oldest and newest shorelines. Linear Regression Rate (LRR) is the slope of a least-squares regression line fitted to all available shoreline positions at a transect and therefore uses the full temporal record.

$$\text{NSM} = d_{2026} - d_{1972}$$

$$\text{EPR} = (d_{2026} - d_{1972}) / (t_{2026} - t_{1972})$$

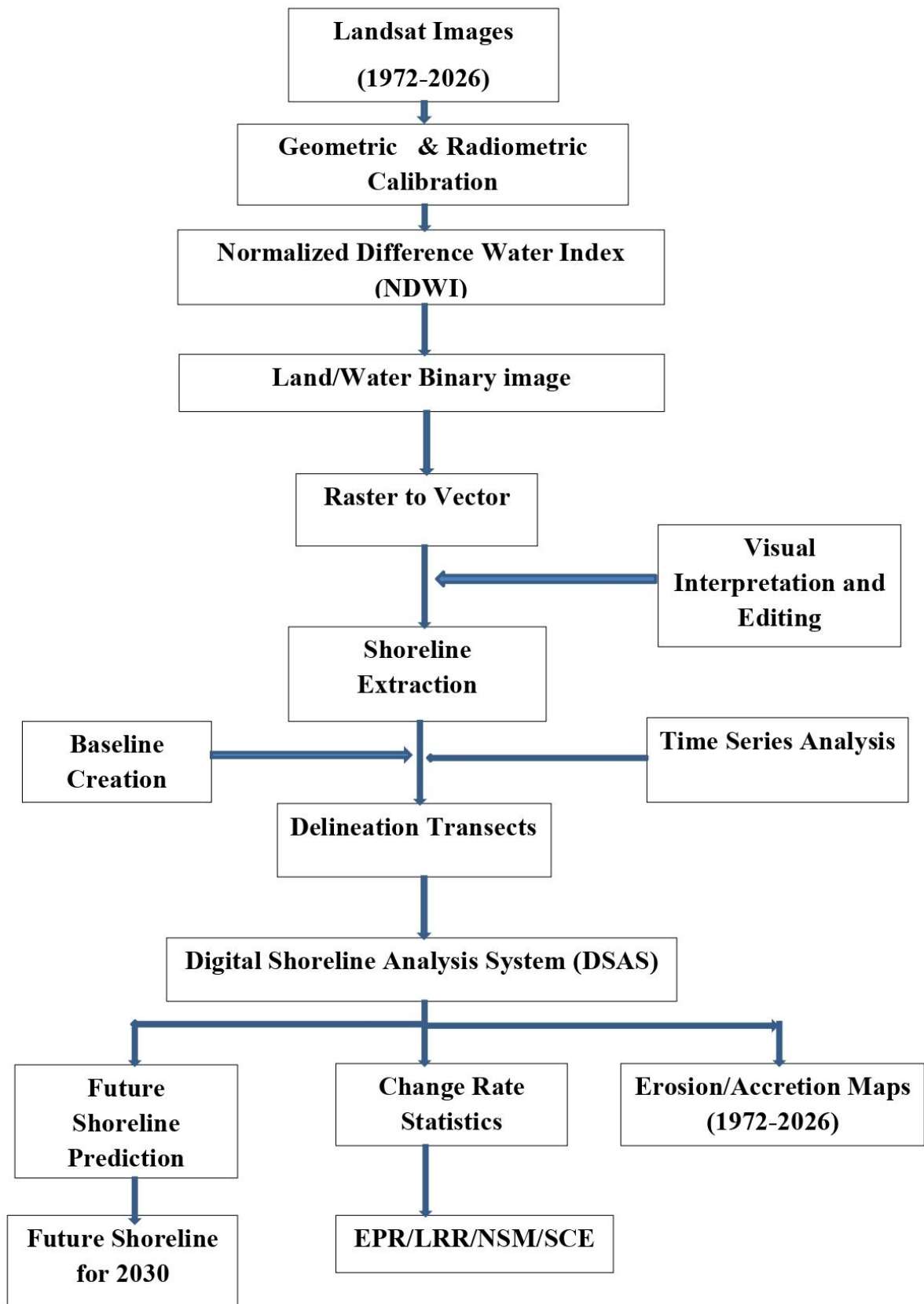


Figure 3. Workflow adopted for Landsat shoreline extraction, DSAS transect generation and change analysis.

3. RESULTS

3.1 Short-term erosion-accretion dynamics

The short-term record shows that Jambudwip did not evolve monotonically. Instead, large episodes of accretion and erosion alternated during the earlier decades, followed by a predominantly erosional phase after 2000. During 1972–1980, accretion (679.87 ha) exceeded erosion (143.59 ha), producing a net gain of 536.28 ha. The following decade reversed this pattern: 1980–1990 recorded 690.64 ha of erosion and

no reported accretion, corresponding to the largest net loss in the short-term analysis (Table 2).

The strongest recovery occurred during 1990–1995, when 765.26 ha of accretion and 73.77 ha of erosion produced a net gain of 691.49 ha. A smaller net gain persisted during 1995–2000. From 2000 onward, every analysed interval showed a negative net balance. The net losses were 267.96 ha (2000–2005), 93.21 ha (2005–2010), 136.47 ha (2010–2015), 25.11 ha (2015–2020) and 90.43 ha (2020–2026) (Figure 4).

Table 2. Short-term erosion-accretion balance reported in the thesis.

Period	Accretion (ha)	Erosion (ha)	Net (ha)	Rate (ha yr ⁻¹)
1972–1980	679.87	143.59	+536.28	+67.03
1980–1990	0.00	690.64	−690.64	−69.06
1990–1995	765.26	73.77	+691.49	+138.30
1995–2000	327.80	123.31	+204.49	+40.90
2000–2005	1.90	269.86	−267.96	−53.59
2005–2010	21.63	114.84	−93.21	−18.64
2010–2015	9.46	145.93	−136.47	−27.29
2015–2020	15.40	40.52	−25.11	−5.02
2020–2026	8.08	98.51	−90.43	−15.07

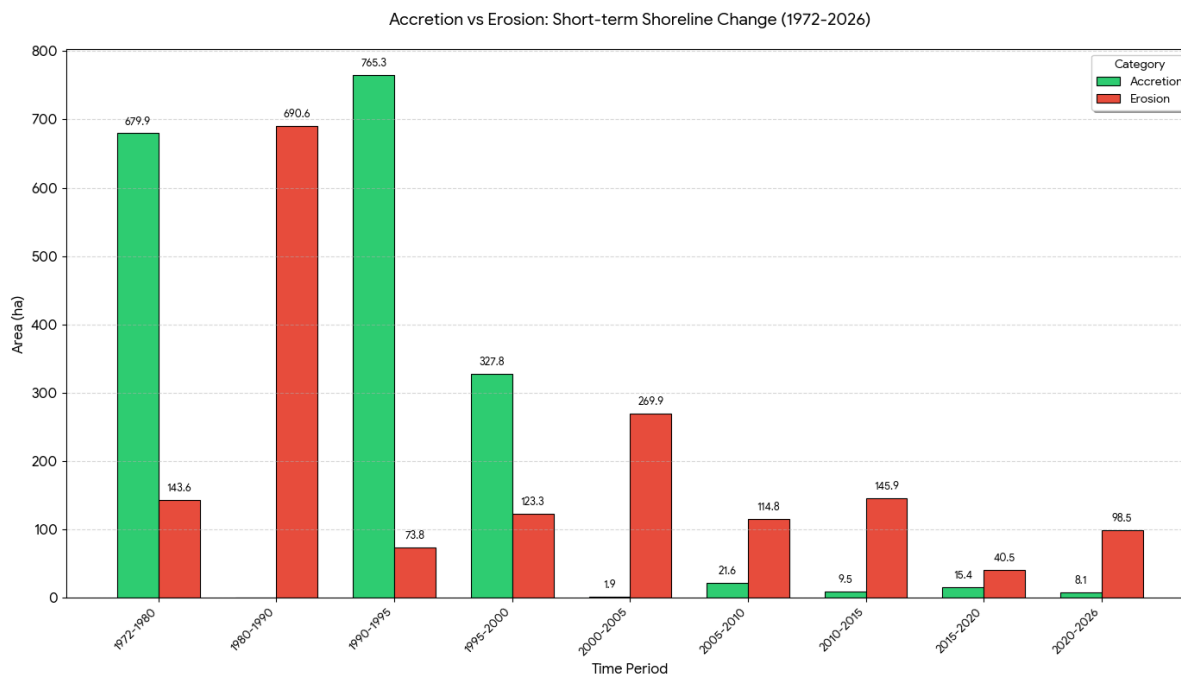


Figure 4. Short-term accretion and erosion by interval, 1972–2026.

3.2 Long-term morphological contraction

The cumulative record indicates sustained long-term erosion. Relative to 1972, the mapped eroded area increased from 143.59 ha by 1980 to 773.31

ha by 2026. The corresponding long-term erosion rate was 17.95 ha yr⁻¹ for 1972–1980 and 14.32 ha yr⁻¹ for the full 1972–2026 interval. Intermediate cumulative estimates remained high, including 576.74 ha by 2005, 644.41 ha by 2010, 711.90 ha by 2015 and 734.84 ha by 2020 (Table 3).

Table 3. Cumulative long-term erosion relative to 1972.

Duration	Eroded area (ha)	Rate (ha yr ⁻¹)
1972–1980	143.59	17.95
1972–1990	348.79	19.38
1972–1995	387.73	16.86
1972–2000	472.45	16.87
1972–2005	576.74	17.48
1972–2010	644.41	16.96
1972–2015	711.90	16.56
1972–2020	734.84	15.30
1972–2026	773.31	14.32

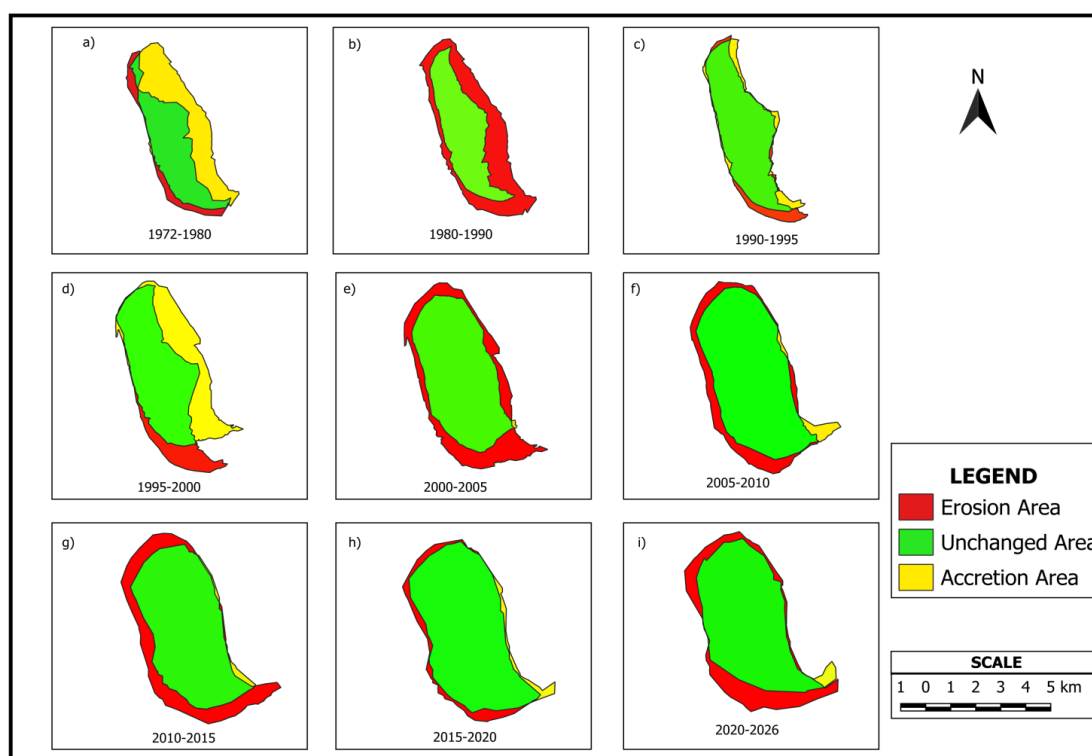


Figure 5. Long-term spatial pattern of erosion and accretion relative to the 1972 shoreline.

3.3 DSAS shoreline-change statistics

The DSAS results confirm strong spatial variability around the island. The thesis reports a maximum accretion EPR of +42.01 m yr⁻¹ and a maximum erosion EPR of -90.41 m yr⁻¹. NSM values reached approximately +2000 m in accreting sectors

and -4000 m in retreating sectors. EPR and LRR showed broadly similar spatial tendencies, with many negatives transects concentrated along the more erosion-prone coastal margins.(Figure 5)

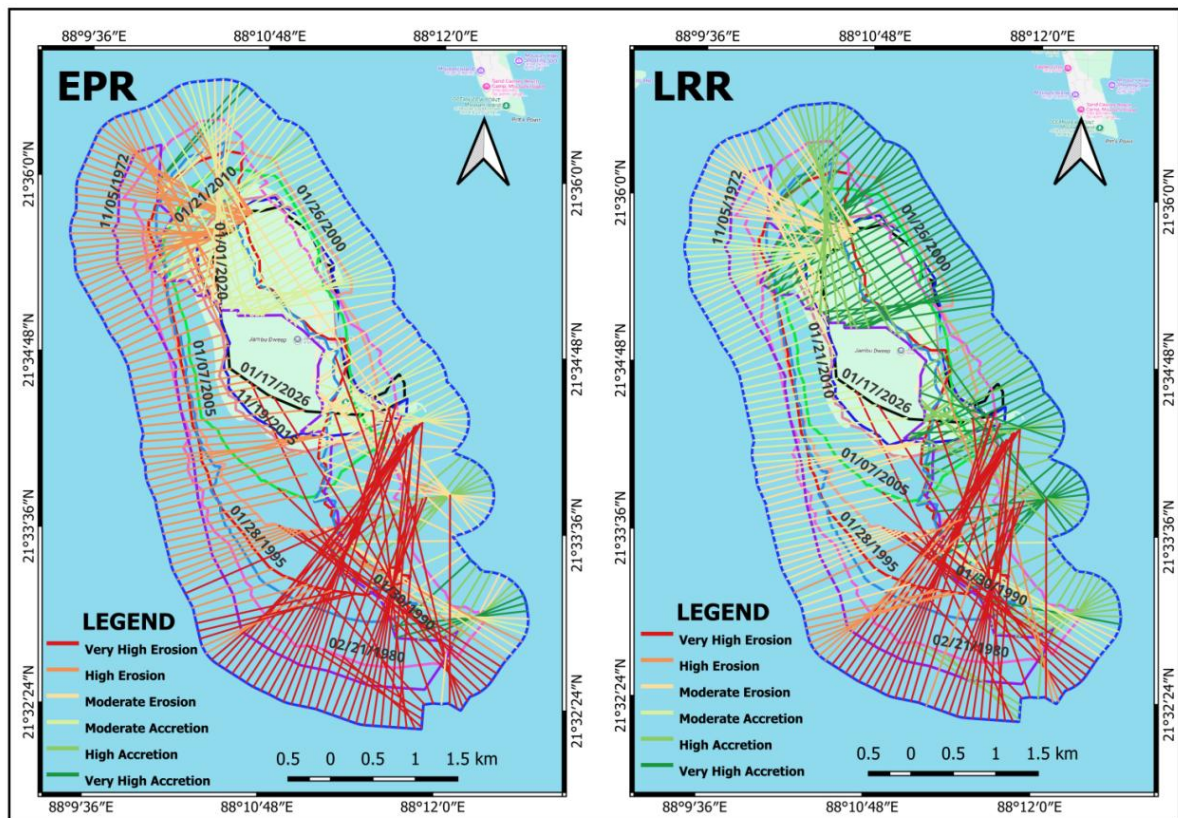


Figure 6. Spatial distribution of EPR and LRR shoreline-change classes.

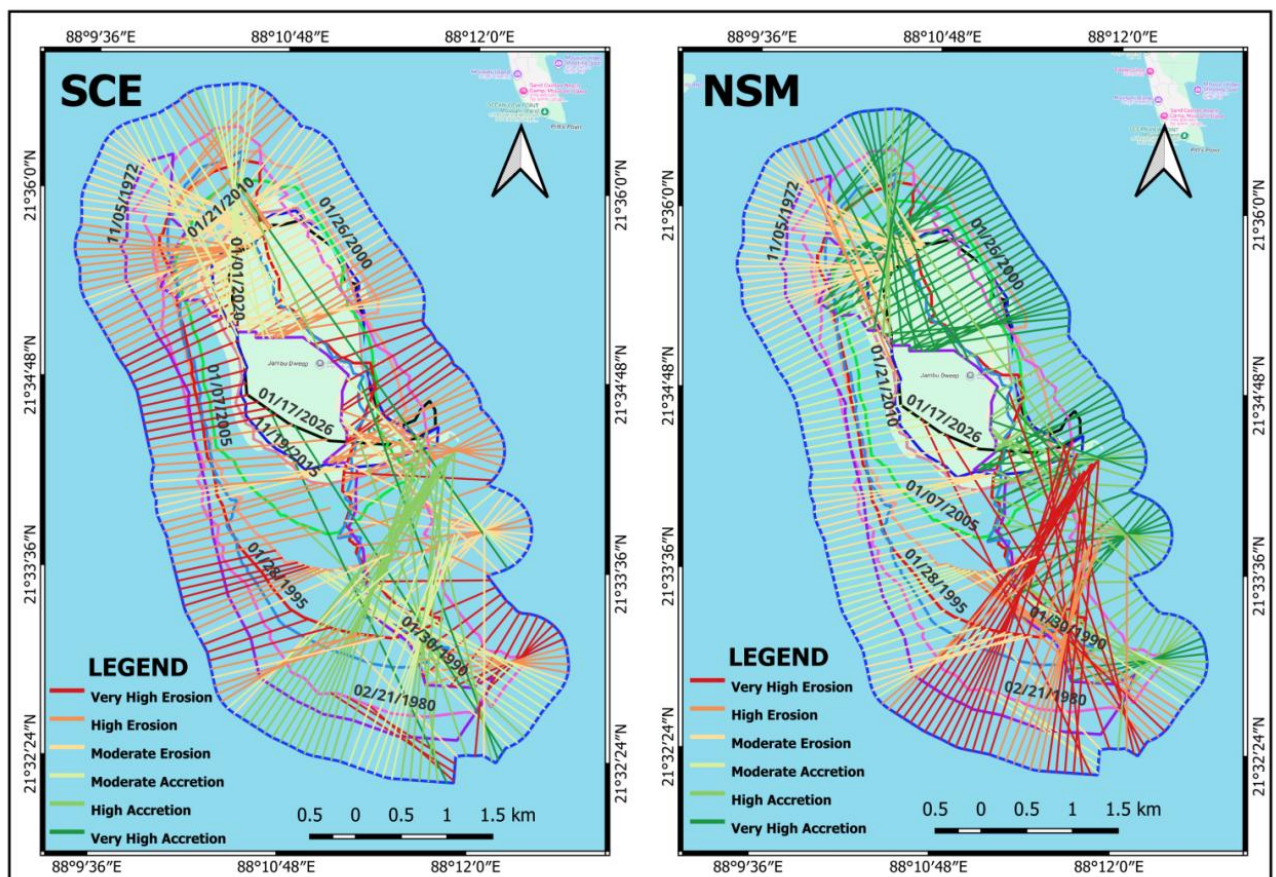


Figure 7. Spatial distribution of SCE and NSM shoreline-change measures.

3.4 Erosion and accretion hotspots

The mapped statistics identify the southern and western sectors as the principal erosion hotspots. These areas show repeated shoreline retreat across the multi-temporal record and correspond to the strongest negative DSAS transects. Accretion is more localized and is reported mainly along the eastern margin. The coexistence of retreat and deposition around a small island indicates redistribution of sediment rather than a spatially uniform shoreline response.

At the island scale, however, the net trajectory is clearly negative. The thesis reports a reduction in total island area from approximately 876 ha in 1972 to approximately 313 ha in 2026. Thus, even though episodic accretion occurred—most notably during 1990–1995—it did not offset the cumulative long-term loss.

4. DISCUSSION

The multi-decadal record demonstrates that Jambudwip is morphodynamically unstable. The alternation between strong accretion and erosion before 2000 suggests that shoreline position is sensitive to changes in sediment delivery and redistribution, tidal currents, wave forcing and event-scale disturbances. The persistent negative balance after 2000 is more consequential because it indicates that recent accretion has generally been insufficient to compensate for erosion.

The spatial concentration of retreat along southern and western margins is consistent with the broader literature describing high shoreline mobility in the Indian Sundarbans. Previous studies have documented severe land loss on Ghoramara and other estuarine islands and have linked morphological instability to interacting tidal, wave, sedimentary and relative sea-level processes (Jayappa et al., 2006; Paul et al., 2018; Sen et al., 2022). Das et al. (2021) similarly reported dominant erosion on Jambudwip using DSAS and multi-temporal satellite data.

The agreement in general spatial tendency between EPR and LRR strengthens confidence in the identification of erosion-dominated sectors. EPR is intuitive and useful for describing the net rate between two endpoints, whereas LRR uses all available shoreline dates and is less dependent on any single pair of observations. NSM and SCE provide complementary distance-based information: NSM expresses net displacement from the earliest to latest shoreline, while SCE captures the full positional envelope irrespective of temporal ordering.

Nevertheless, the numerical results should be interpreted within the limitations of the source data. The study combines MSS, TM and OLI/TIRS imagery with different spatial and spectral characteristics. Moderate Landsat resolution can

introduce uncertainty where the shoreline is narrow, diffuse or tidally inundated. The thesis also notes the absence of extensive GPS-based field validation, high-resolution UAV or Sentinel validation, detailed tidal correction, hydrodynamic modelling and explicit analysis of cyclone, wave-energy and sediment-transport forcing. These limitations mean that the results are strongest as evidence of long-term relative change and hotspot location, rather than as centimetre- or metre-scale shoreline positioning.

A further methodological issue is the use of a water-index shoreline in a strongly tidal setting. An NDWI-derived instantaneous waterline can shift with tidal stage as well as with geomorphic change. Future work should therefore incorporate acquisition-time tidal information, positional uncertainty for each shoreline, and confidence intervals for DSAS rates. Higher-resolution Sentinel-2 or UAV imagery could be used to validate recent shoreline positions and to quantify uncertainty associated with Landsat-scale extraction.

From a management perspective, the erosion hotspots warrant continued monitoring before major coastal interventions are considered. The thesis proposes erosion-control measures such as offshore breakwaters, revetments and beach nourishment. Such interventions should not be selected solely from shoreline-change maps; they require site-specific sediment-budget, wave, ecological and cost-benefit assessment because hard structures can transfer erosion downdrift. For an ecologically sensitive Sundarbans island, monitoring and nature-compatible measures should be evaluated alongside engineering options.

5. CONCLUSIONS

This study reconstructed 54 years of shoreline and morphological change on Jambudwip Island using ten Landsat observations, NDWI-based shoreline extraction and DSAS. The analysis used 226 transects at 100 m spacing and four complementary statistics—EPR, LRR, NSM and SCE—to characterize shoreline movement.

The principal finding is a long-term contraction of the island despite episodic accretion. The strongest short-term erosion occurred during 1980–1990 (690.64 ha), whereas the strongest accretion occurred during 1990–1995 (765.26 ha). After 2000, all analysed intervals showed a negative net area balance. At the full-period scale, the island area declined from about 876 ha in 1972 to about 313 ha in 2026, with erosion concentrated particularly along the southern and western margins.

The results establish a useful Landsat–DSAS baseline for continued observation of Jambudwip. Future studies should strengthen the analysis through high-resolution shoreline validation, tide-normalized extraction, explicit positional

uncertainty, field/GNSS observations and integration of waves, cyclones, sediment transport and hydrodynamic processes.

DECLARATIONS

Conflicts of Interest: The author declares no conflicts of interest.

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Author Contributions: The sole author was responsible for the conceptualization, methodology, data collection and curation, analysis, visualization, interpretation of results, writing of the original draft, and review and editing of the manuscript. The author has read and approved the final version of the manuscript.

Data Availability: The study used archived Landsat imagery obtained from the U.S. Geological Survey. Derived shoreline and DSAS outputs are provided by the corresponding author on request.

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AI Disclosure: The authors declare that artificial intelligence (AI) tools were used solely to assist in language refinement, organization, and editing of the manuscript. AI was not used to generate original research data, conduct analyses, or draw scientific conclusions. All technical content, interpretations, and final decisions were developed and verified by the authors, who take full responsibility for the accuracy, integrity, and originality of the work.

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