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Analysis of Lamong Bay Shoreline Changes Use Digital Shoreline Analysis System

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ABSTRACT

Lamong Bay is a strategic area, and in 2010 a port was built to improve competitiveness. This study analyzed shoreline changes in the western part of Lamong Bay in 2004, 2009, 2014, 2019, and 2024 using Landsat 7 ETM+ and Landsat 8/9 OLI/TIRS imagery. Data extraction used the Normalized Difference Water Index (NDWI) method in ArcGIS, while shoreline change analysis used the Digital Shoreline Analysis System (DSAS) with End Point Rate (EPR), Net Shoreline Movement (NSM), and Shoreline Change Envelope (SCE). The results show the highest accretion occurred in Romokalisari Village from 2004 to 2009 at 13.80 meters/year, and the highest abrasion occurred in the same village from 2019 to 2024 at -34.21 meters/year. Based on NSM, the highest accretion occurred in Romokalisari from 2004 to 2009 at 67.42 meters, and the highest abrasion occurred from 2019 to 2024 at -163.38 meters. Based on SCE, the highest change occurred in Romokalisari at 331.93 meters from 2019 to 2024, and the lowest change occurred in Osowilangun Village at 0.01 meters in the same period. Overall, accretion dominates the study area, but extreme abrasion in Romokalisari from 2019 to 2024 is influenced by reclamation. This study is expected to support sustainable coastal management and shoreline change mitigation.

Keywords: *Shoreline, Digital Shoreline Analysis System (DSAS), Teluk Lamong, Erosion, Accretion*

1. INTRODUCTION

Lamong Bay is one of the waters located in Surabaya, East Java, and is considered a strategic area in the maritime and logistics sector. There are several terminals in this area, one of which is PT. Terminal Teluk Lamong, a subsidiary of PT. Pelindo Terminal Petikemas. This terminal was designed to reduce logistics traffic congestion at the Surabaya Container Terminal. Additionally, Teluk Lamong is rich in coastal ecosystems, including mangroves that serve as habitats for marine life and protect against erosion. According to research conducted in the Teluk Lamong area, there are indications of significant sedimentation during high tides, which may indicate a high potential for land expansion in the Teluk Lamong area[1]. On the other hand, the Lamong Bay area plays a crucial role as a maritime transportation route and supports the survival of marine life, thereby holding significant economic and ecological value [2]. Around the Lamong Bay area, there are various industrial structures, one of which is a port. The high level of activity at the port can trigger changes in the shoreline through alterations in current and wave patterns, ultimately affecting coastal stability [1].

Therefore, it is important to conduct a study on shoreline changes in Lamong Bay to understand the accretion patterns and address future impacts on environmental stability, coastal stability, and the income of communities dependent on the productivity of the Lamong Bay area. In this study, coastal line changes were identified using Geographic Information System (GIS) methods, which were then processed using ArcGIS software and the Digital Shoreline Analysis tool to determine the area of Lamong Bay in 2004, 2009, 2014, 2019, and 2024. It is hoped that the results of this study will provide scientific information to support mitigation efforts and sustainable coastal management planning.

2. LITERATURE REVIEW

The coastline is a dynamic feature of the Earth's surface and is vulnerable to change [3]. Changes to the coastline can take the form of coastal retreat or coastal advance. Coastal retreat towards land is called abrasion, while coastal advance towards the sea is called accretion. The triggers for these changes come from both natural factors and human activities. Naturally, the coastline can change due to tidal movements, currents, and waves.

Meanwhile, factors stemming from human activities, such as land conversion programs, mangrove deforestation, and coastal infrastructure development, can cause erosion or accretion, thereby altering the coastline [4].
Tools that can be used in coastal line mapping analysis include remote sensing, utilizing various types of satellite imagery, such as Landsat, Sentinel, or UAV/Drone. Historical monitoring of the coastal line is highly feasible when using Landsat satellite imagery with good temporal resolution. In the current era, many techniques have been developed to improve the accuracy of shoreline extraction from Landsat imagery. The Normalized Difference Water Index (NDWI) is one method to enhance the spatial resolution and accuracy of shoreline mapping [5].

To analyze quantitative changes in the shoreline, the Digital Shoreline Analysis System (DSAS) software developed by the U.S. Geological Survey (USGS) can be used. This tool calculates the rate of shoreline change based on historical data, monitors coastal accretion and erosion, and supports decision-making in coastal zone management. DSAS software has been widely used in various countries. For example, a study that used DSAS to analyze shoreline changes on the West Coast showed that this tool is effective in identifying areas experiencing significant abrasion and accretion. This technology can monitor shoreline changes spatially and temporally with a high degree of accuracy [6].

3. METHODOLOGY

3.1 Data

The Landsat satellite imagery used in this study are Landsat 7 ETM+ for the periods 2004 and 2009, and Landsat 8-9 OLI (Operational Land Imager)/Thermal Infrared Sensor (TIRS) for the periods 2014, 2019, and 2024, with Level 2 data sets.Guidelines for table and figure format and arrangement are described in the following sub-sections.

Tabel 1.The Landsat satellite imagery

No	Data	Recording Time
1	Landsat 7 ETM+ Collection 2 Level 2	29 September 2004, 09.24 a.m.
2	Landsat 7 ETM+ Collection 2 Level 2	29 October 2009, 09.26 a.m.
3	Landsat 8-9 OLI/TIRS Collection 2 Level 2	17 September 2014, 09.26 a.m.
4	Landsat 8-9 OLI/TIRS Collection 2 Level 2	11 June 2019, 09.35 a.m.
5	Landsat 8-9 OLI/TIRS Collection 2 Level 2	20 March 2024, 09.35 a.m.

The tidal data for Lamong Bay was obtained from the official website of the Geospatial Information Agency (BIG).

Tabel 2. tide data

Year	Month	MSL	HHWL	LLWL
2004	September	-3,96	205,8	22,0
2009	October	-5,33	220,5	22,5
2014	September	-4,12	183,5	20,2
2019	June	-3,72	215,3	27,9
2024	March	-3,58	197,8	22,5

3.2 Coastline Extraction

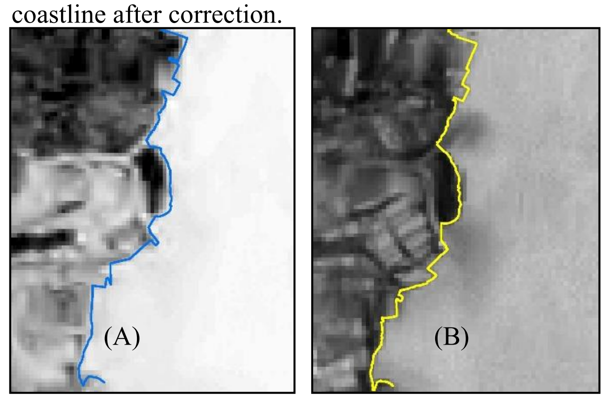
Coastline extraction was performed using ArcGis 10.7 software with the Normalized Difference Water Index (NDWI) method. The following equation was used:

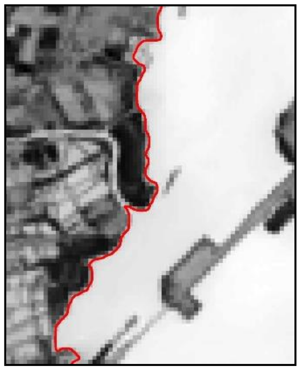
$$\text{NDWI} = \frac{(Green - NIR)}{(Green + NIR)}$$

3.3 Coastline Correction based on MSL

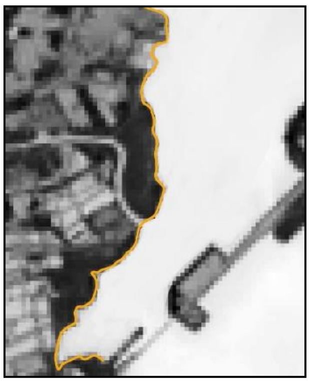
This coastline correction was performed before analyzing coastline changes to avoid coastline confusion, as the position of the coastline on satellite images can vary due to the influence of sea level at the time of image capture. Coastline correction was performed using the following steps:

1. Calculating the slope of the coastline ( ) by measuring the depth value (d) and the distance from the coastline to the depth (m) as illustrated in Figure 4.8 using the following equation;
$$\tan\beta \frac{d}{m}$$
2. Calculating the difference in sea level height at the time of satellite image acquisition with the Mean Sea Level (from the tidal calculation results.
3. Calculating the distance of the corrected tidal coastline shift (x) as illustrated in Figure 4.9 using the following equation :
$$x = \frac{\Delta\eta}{\tan\beta}$$
4. Performing coastline correction by shifting the coastline x meters inland during low tide and x meters seaward during high tide, as shown in the illustration of the coastline after correction.





(C) (D)



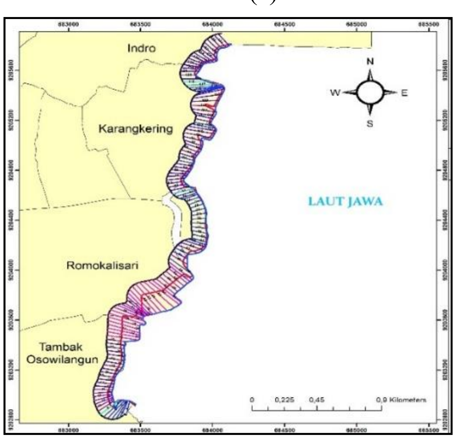
(D)

Figure1. (A)Coastline 2004, (B)Coastline 2009, (C)Coastline 2014, (D)Coastline 2019, (E)Coastline 2024.

3.4 Transect Settings

Transect settings are made in the Digital Shoreline Analysis System (DSAS) software by determining the monitoring path or line on the image to analyze changes occurring in a specific area. These transects are created based on image data from which the coastline has been extracted. Transects are useful for comparing changes in the coastline over time. The following are some of the transects created in each research period:

(a)



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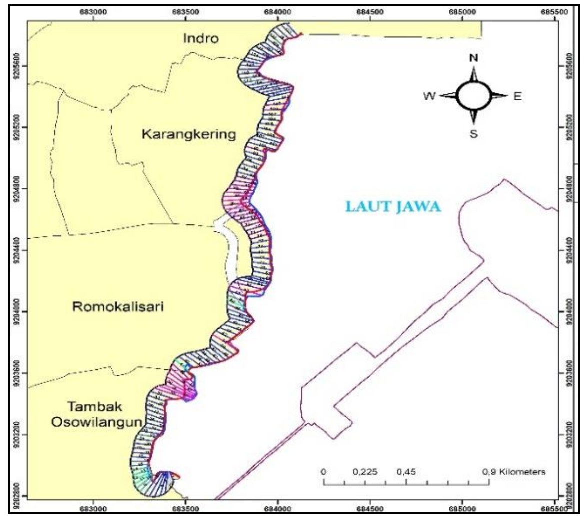

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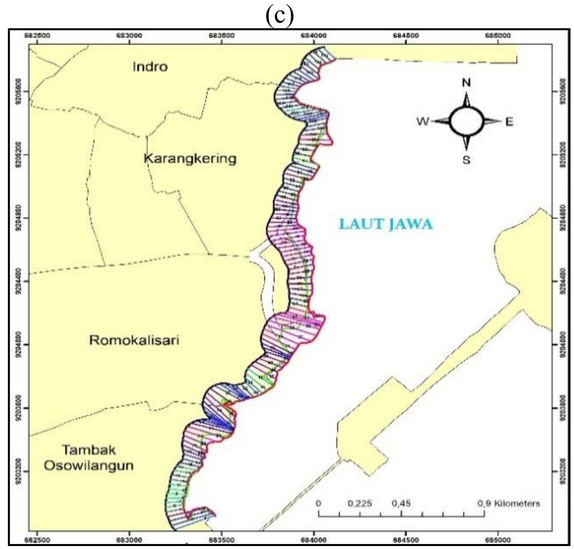

(d)

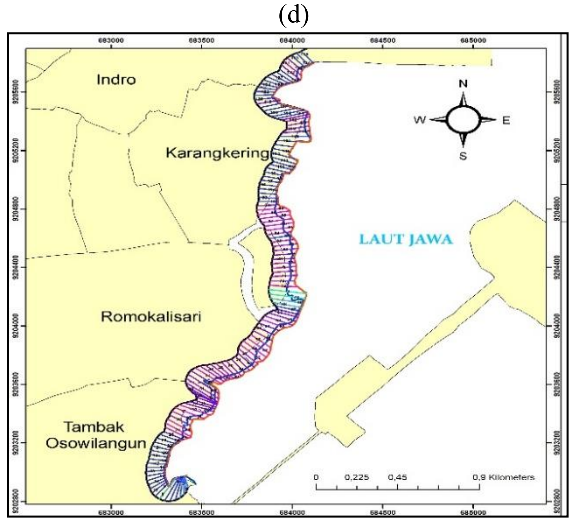

Figure 2. (a) Transect 2004-2009, (b) Transect 2009-2014, (c) Transect 2014-2019, (d) Transect 2019-2024.

4. ANALYSIS AND DISCUSSION

An analysis was carried out to determine the shoreline changes at the study location using DSAS software. After generating transects, the analysis was conducted using three methods: Net Shoreline Movement (NSM), Shoreline Change Envelope (SCE), and End Point Rate (EPR).

4.1 NSM Method Analysis

The NSM method indicates the value of shoreline change between the initial and final shoreline positions. A positive value indicates accretion, while a negative value indicates erosion. The following data/results were obtained after conducting the analysis using DSAS:

Table 3. NSM Method Calculation Results for 2004–2009

No.	Transect	Desa	NSM (Meter)			
			Maksimal	Minimal	Akresi Rata-rata	Abrasi Rata-rata
1	1 - 36	Tambak Osowilangun	166.65	-46.28	46.28	-15.17
2	37 - 82	Romokalisari	186.02	-18.73	67.42	-4.79
3	83 - 122	Karangkering	69.02	-29.68	16.41	-14.70
4	123 - 135	Indro	25.80	12.30	18.66	-

Table 4. NSM Method Calculation Results for 2009- 2014

No.	Transect	Desa	NSM (Meter)			
			Maksimal	Minimal	Akresi Rata-rata	Abrasi Rata-rata
1	1 – 40	Tambak Osowilangun	88.85	-15.48	19.80	-7.38
2	41 – 83	Romokalisari	66.37	-25.50	10.54	-5.03
3	84 – 122	Karangkering	46.97	-3.64	14.22	-1.33
4	123 - 134	Indro	9.69	-3.39	5.28	-1.82

Table 5. NSM Method Calculation Results for 2014- 2019

No.	Transect	Desa	NSM (Meter)			
			Maksimal	Minimal	Akresi Rata-rata	Abrasi Rata-rata
1	1 – 35	Tambak Osowilangun	85.80	-7.32	21.98	-4.78
2	36 – 78	Romokalisari	169.98	-4.83	50.57	-3.71
3	79 – 116	Karangkering	96.67	-5.70	27.09	-2.05
4	117 - 128	Indro	4.98	-2.44	1.58	-1.13

Table 6. NSM Method Calculation Results for 2019- 2024

No.	Transect	Desa	NSM (Meter)			
			Maksimal	Minimal	Akresi Rata-rata	Abrasi Rata-rata
1	1 – 42	Tambak Osowilangun	57.41	-7.29	16.00	-3.16
2	43 – 86	Romokalisari	69.98	-331.93	30.64	-163.38
3	87 – 123	Karangkering	78.63	-1.54	18.33	-0.66
4	124 - 135	Indro	33.44	0.90	2.09	-

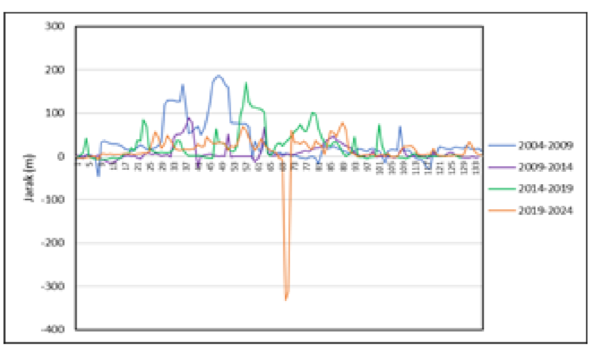

Figure 3. *Overall NSM Graph*

Overall, the study area predominantly experienced accretion, with the highest accretion occurring during the periods 2004–2009 and 2014–2019. In 2004–2009, the land addition occurred naturally as a result of sedimentation from small rivers that flow into the sea. However, during 2014–2019, the area experienced extreme erosion, with an average value reaching -163.38 meters. This indicates an unstable condition in the area, possibly due to environmental degradation in the coastal region or the construction of the Teluk Lamong Port, which involved reclamation processes. Reclamation structures can alter or narrow the natural flow of ocean currents and the direction of incoming waves. These changes may increase wave energy and current velocity, which, if not directly protected by mangroves or breakwater structures, can lea to erosion in the area

4.2 SCE Method Analysis

In shoreline processing using the Shoreline Change Envelope (SCE) method in DSAS, the results show the farthest distance of shoreline change regardless of time and direction, meaning it does not indicate whether accretion or erosion occurred in the location. The following data/results were obtained after conducting the analysis using DSAS:

Table 7. NSM Method Calculation Results for 2004- 2009

No.	Transect	DESA	SCE (METER)	
			Maksimal	Minimal
1	1 - 36	Tambak Osowilangun	166.65	0.17
2	37 – 82	Romokalisari	186.02	0.05
3	83 – 122	Karangkering	69.02	2.72
4	123 - 135	Indro	25.80	12.30

Table 8. NSM Method Calculation Results for 2009- 2014

No.	Transect	DESA	SCE (METER)	
			Maksimal	Minimal
1	1 – 40	Tambak Osowilangun	88.95	0.42
2	41 – 83	Romokalisari	66.37	0.01
3	84 – 122	Karangkering	46.97	0.03
4	123 – 134	Indro	9.69	0.47

Table 9. NSM Method Calculation Results for 2014- 2019

No.	Transect	DESA	SCE (METER)	
			Maksimal	Minimal
1	1 – 35	Tambak Osowilangun	85.80	1.95
2	36 – 78	Romokalisari	169.98	0.77
3	79 – 116	Karangkering	96.67	0.55
4	117 – 128	Indro	4.98	0.05

Table 10. NSM Method Calculation Results for 2019- 2024

No.	Transect	DESA	SCE (METER)	
			Maksimal	Minimal
1	1 – 42	Tambak Osowilangun	57.41	0.01
2	43 – 86	Romokalisari	331.93	3.69
3	87 – 123	Karangkering	78.63	0.20
4	124 – 135	Indro	33.44	0.90

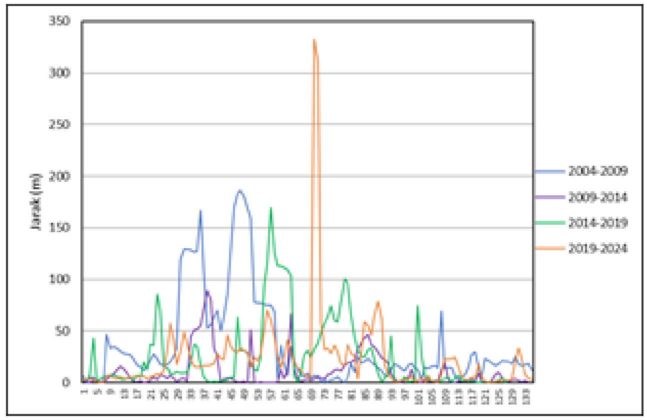

Figure 4. *Overall SCE Graph*

Overall, the analysis of shoreline changes every five years using the SCE method is shown in Figure 4. The figure indicates that the highest erosion occurred during the period 2019–2024. The maximum shoreline change was recorded in Romokalisari Village, with a value of 331.93 meters. Meanwhile, the smallest change occurred in Tambak Osowilangun Village, with a value of 0.01 meters.

4.3 EPR Method Analysis

In shoreline processing using the End Point Rate (EPR) method in DSAS, the results show the average distance of shoreline change per year. The following data/results were obtained after conducting the analysis using DSAS:

Table 11. EPR Method Calculation Results for 2004- 2009

No.	Transect	Desa	EPR (Meter/Tahun)			
			Maksimal	Minimal	Akresi Rata-rata	Abrasi Rata-rata
1	1 - 36	Tambak Osowilangun	34.92	-9.84	9.70	-31.18
2	37 - 82	Romokalisari	38.98	-3.93	13.80	-1.0
3	83 - 122	Karangkering	14.46	-6.22	3.44	-3.08
4	123 - 135	Indro	5.41	2.58	3.91	-

Table 12. EPR Method Calculation Results for 2009- 2014

No.	Transect	Desa	EPR (Meter/Tahun)			
			Maksimal	Minimal	Akresi Rata-rata	Abrasi Rata-rata
1	1 – 40	Tambak Osowilangun	17.69	-3.08	3.94	-1.47
2	41 – 83	Romokalisari	13.20	-5.07	2.10	-1.00
3	84 – 122	Karangkering	9.34	-0.72	2.83	-0.26
4	123 – 134	Indro	1.93	-0.68	1.05	-0.36

Table 13. EPR Method Calculation Results for 2014- 2019

No.	Transect	Desa	EPR (Meter/Tahun)			
			Maksimal	Minimal	Akresi Rata-rata	Abrasi Rata-rata
1	1 – 35	Tambak Osowilangun	35.92	-1.55	4.64	-1.01
2	36 – 78	Romokalisari	35.92	-1.02	10.69	-0.78
3	79 – 116	Karangkering	20.43	-1.20	5.72	-0.43
4	117 – 128	Indro	1.05	-0.51	0.33	-0.24

Table 14. EPR Method Calculation Results for 2019- 2024

No.	Transect	Desa	EPR (Meter/Tahun)			
			Maksimal	Minimal	Akresi Rata-rata	Abrasi Rata-rata
1	1 – 42	Tambak Osowilangun	12.02	-1.53	3.35	-0.66
2	43 – 86	Romokalisari	14.65	-69.51	6.54	-34.21
3	87 – 123	Karangkering	16.46	-0.32	3.23	-0.14
4	124 – 135	Indro	7.00	0.19	1.89	-

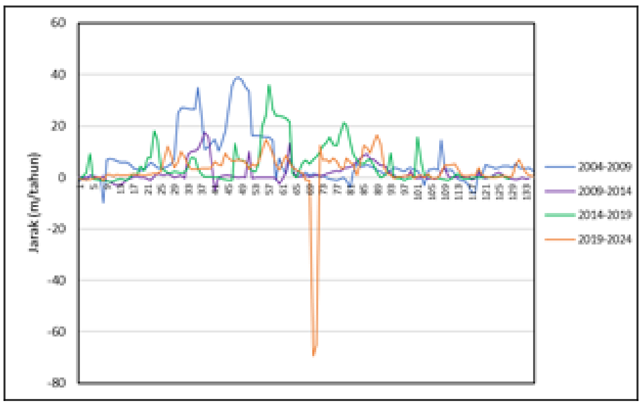

Figure 5. *Overall EPR Graph*

The combined graph of shoreline change analysis in five-year intervals is shown in Figure 5. The illustrates that the highest erosion occurred during the periods 2004–2009 and 2014–2019. From 2004 to 2009, land accretion occurred naturally due to sedimentation from small rivers discharging into the sea. Meanwhile, in 2019–2024, extreme erosion occurred with an average value reaching -69.51 meters. This indicates an unstable condition in the area, possibly caused by environmental degradation along the coast or the construction of Teluk Lamong Port, which involved reclamation processes. Reclamation structures can alter or narrow the natural flow of ocean currents and the direction of incoming waves. These changes can lead to an increase in wave energy and current velocity, which, if not directly protected by mangroves or wave-breaking structures, can result in erosion in the area.

5. CONCLUSIONS

The NSM method shows that in almost all observation periods, the area under study tended to experience accretion, where the average accretion values in all villages were greater than the average erosion values. However, extreme erosion occurred from 2019 to 2024, with an average value of -163.38 meters.

The EPR method provides information on the annual rate of shoreline change. Similar to the NSM results, almost all areas studied also tended to experience accretion, with average accretion values being greater than average erosion values. Nonetheless, extreme erosion occurred from 2019 to 2024, with an average value of -69.51 meters.

The SCE method shows the maximum distance of shoreline change from the oldest to the most recent shoreline during the observation period. For each observation period, SCE results indicate that the maximum distance of change occurred between 2019 and 2024, reaching 331.93 meters.

Overall, the results of all three methods indicate a significant trend of shoreline change in the study area. The shoreline in the area tended to experience accretion; however, extreme erosion also occurred during the 2019–2024 period, particularly in the Romokalisari area. This suggests instability in the region, possibly due to environmental degradation along the coast or the development of Teluk Lamong Port, which involved reclamation activities. Reclamation structures can alter or narrow the natural paths of ocean currents and wave directions. These changes can increase wave energy and current velocity in areas that are not directly protected by mangroves or wave-breaking structures, thus potentially causing erosion. In addition, other contributing factors to shoreline change include local hydrodynamic conditions such as currents, waves, and tides.

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