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Original Article

Analysis of shoreline change along the coast of Rembang, Indonesia, using digital shoreline analysis system

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Abstract

The shoreline has dynamic conditions that affect coastal regions through erosion and accretion. This research aims to determine the shoreline change rate using Net Shoreline Movement (NSM) and End Point Rate (EPR) values in Rembang Regency in 2015 – 2021 and the impacts on the environment in the coastal area. The data were obtained from Sentinel 2A satellite imagery for 2015, 2018, and 2021. Also, field observations were conducted to measure the beach slope and collect sediment samples at several research points for analysis of sediment type and grains as supporting data. The research method used was descriptive quantitative. Satellite image analysis was done using ArcGIS 10.8 with the assistance of the Digital Shoreline Analysis System application to assess erosion and accretion rates using the Net Shoreline Movement and End Point Rate values. The results showed that the Rembang shoreline changed along 4.86 km from 2015 to 2021, with erosion of -9.92 m and accretion of 13.96 m (NSM) or -1.65 m/year and 2.33 m/year (EPR).

Keywords: shoreline, DSAS, erosion and accretion, Rembang

1. Introduction

The coast is impacted by complex and varied natural processes (Darmiati & Agus, 2020). Changes in the shoreline can occur due to natural processes and human intervention (Li *et al.*, 2022; Zhang, Li, Fan, Xu, & Hou, 2021). These changes vary over time based on coastal topography, climate, vegetation, and sediment transport (Agustin & Syah, 2020; Dang *et al*., 2022). Changes in the shoreline can occur through erosion, which is the movement of sediment landward, or accretion, which is the movement of sediment seaward (Fajrin, Muskananfola, & Hendrarto, 2016; Siyal *et al.*, 2022).

This condition occurs in Rembang Regency, which has six coastal districts, and the community widely uses the area for tourism, aquaculture, ports, industries, and mangrove conservation, which are common land uses on the northern coast of Java (Citra, Muskananfola, & Purnomo, 2022; Muskananfola, Hartoko, & Latifah, 2023b). Natural and human activities that occur on the coast of Rembang Regency affect the structure of the shoreline and cause erosion and accretion each year.

From 2003 to 2014, a study on changes in the shoreline of Rembang Regency was conducted by Setiyarso, Muryani, and Sarwono (2016) using Ikonos satellite imagery and conventional polyline techniques. The results showed that accretion was dominant on the west coast, and erosion was dominant on the east coast of Rembang Regency. In this current study, shoreline changes were determined using imaging by the Sentinel 2-A multitemporal satellite, which was analyzed using the Digital Shoreline Analysis System (DSAS) to determine detailed shoreline changes effectively (Sam & Balasubramanian, 2022).

DSAS has been used for shoreline change analysis by Baral, Subhasis, Rabindro, and Sujit (2018); Kumar, Sajan, Ojha, and Soren (2021) and Muskananfola, Supriharyono, and Febrianto (2020). The research by Muskananfola *et al.*, (2020) showed that the Sayung shoreline experienced severe erosion with a rate of -4 m to -65 m, averaging -25 m/year. The use of DSAS allows for statistical calculations of the shoreline at specific transects to observe erosion and accretion (Kumar *et al.*, 2021; Nithu, Gurugnanam, Sudhakar, & Francis, 2019; Sam & Balasubramanian, 2022). Monitoring of shoreline

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changes should be conducted to provide an overview and recent data on coastal erosion and accretion. This research aimed to analyze the change, erosion, and accretion rates in Rembang Regency. The research results will benefit coastal management and provide beneficial information for coastal potential development, policy-making, and mitigation in the coastal region of Rembang Regency.

2. Research Method

2.1 Study area

The study was conducted at Rembang Regency (Figure 1). The six coastal districts of Rembang Regency are Kaliori, Rembang, Lasem, Sluke, Kragan, and Sarang. The research location was determined using purposive sampling, where the plot selection was intentionally made and adjusted to the research objectives. Along the coast of Rembang Regency are buildings such as breakwaters in Sarang District and groins in Kaliori District. Apart from that, there are mangrove conservation locations in Rembang District, which can prevent erosion, as well as buildings such as ports, settlements, power plants, and fish farms in several districts, which can influence the rates of erosion and accretion. The study area is located on the northern coast of Java, which oceanographically experiences 4 seasons, i.e. west season, east season, and transitional seasons one and two (Muskananfola, Erzad, & Hartoko, 2021; Muskananfola, Latifah, Hartoko, Febrianto, & Winterwerp, 2023a). Tidal characteristics show that the tidal range of neap and spring tides ranges between 0.1 m and 1.1 m (Dishidros, 2017). The tides are mixed semidiurnal, where two high tides and two low tides of different heights occur daily.

The ocean waves in the northern waters of Java Island during the west and east seasons have a more wavy character, with higher waves than in the transitional season (Muskananfola *et al.*, 2021). The northern waters of Java generally have strong winds and high waves during the western season, which can cause beach erosion, accretion, and changes in the shoreline (Muskananfola, Maulana, Anggoro, & Suryanti, 2022). The wave height in Rembang Regency ranges from 0.5 - 2.24 m (Hanan, Anugroho, & Helmi, 2015). The dominant wind is from the east with a speed of 2-4 m/s (39.97%) during the east season and from the west during the west season with a speed of 2-4 m/s (21.96%) (Muskananfola *et al*., 2022).

2.2 Data collection

The data used in this study were obtained from Sentinel 2A satellite images for 2015, 2018, and 2021. The study used Band 3 (560 nm) and Band 8 (835,1 nm) of Sentinel 2A satellite data and on-site beach slope and sediment measurements. Beach slope and sediment data were obtained directly from the field in October and used as supporting data in the research. Slope and sediment data were collected in the Kaliori District (Pasir Putih Beach) and Rembang District (Pulo Swalan Beach). These locations were chosen because, based on the results of the analysis, the two sub-districts have high erosion and accretion values. Slope data were taken by pulling a roll meter along 10 meters from the highest tide limit towards the sea, after which the height of

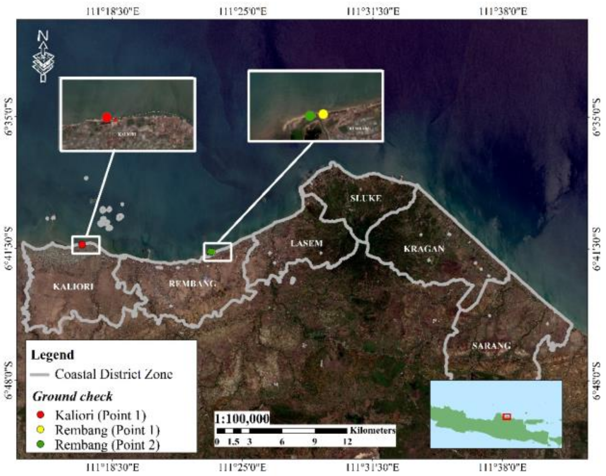

Figure 1. Research locations in Rembang Regency consisting of 6 zones of coastal districts

the end of the roll meter was measured with the bottom of the water. The slope is measured using the arctan formula of the division of height and length obtained. Sediment collection was carried out using pipes at a distance of 10 and 20 cm from the surface to determine differences in sediment texture based on depth.

2.3 Data analysis

Satellite image analysis included separating water and land using the Normalized Difference Water Index (NDWI) (Anggraini, Sartono, & Maryani, 2018) given by the following equation.

$$\text{NDWI} = \frac{\text{Band Green} - \text{Band NIR}}{\text{Band Green} + \text{Band NIR}} \quad (1)$$

where Band Green = Band 3; Band NIR = Band 8

Values of NDWI greater than 0 were assumed to be water, while those less than or equal to 0 were assumed to be land. After digitizing the shoreline and creating a baseline, the data were overlaid, and transect lines were transformed into quantitative spatial data using the Digital Shoreline Analysis System (DSAS) application. The erosion and accretion rates were analyzed using Net Shoreline Movement (NSM), and End Point Rate (EPR) values through DSAS using the following equations (Muskananfola et al., 2020). The interval of each transect was 100 meters.

$$\text{NSM} = \text{Dt2} - \text{Dt1} \quad (2)$$

where Dt2 = Distance to the earliest shoreline for each transect; Dt1 = Latest shoreline distance for each transect

$$\text{EPR} = (\text{D1}-\text{D2})/(\text{t1}-\text{t0}) \quad (3)$$

where D1 and D2 = Distance between the shoreline and baseline; t1 and t0 = Dates of the two shoreline positions

The coastal slope angle was analyzed using the equation according to Kalay, Lopulissa, & Noya (2018) with the following gradient classification:

Slope (β) = arctan y/x (4)

with x = distance of the observation plane; y = vertical distance of the coastal plain to the x-axis

The sediment grain analysis was conducted to determine the size and type of sediment. Sediment samples were soaked, dried at 100°C and sieved using a sieve shaker and a stack of sieves with threshold diameters of 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.063 mm, and 0.032 mm to separate sediment grain sizes (Buchanan, 1984; Muskananfola, 1994). The results were further analysed using GRADISTAT with arithmetic mean statistics and processed in a triangular diagram format (Blott & Pye, 2001).

3. Results and Discussion

3.1 Shoreline length

Shoreline mapping was carried out using the NDWI formula to distinguish water and land. Determination of the shoreline used bands 3 and 8 from the Sentinel 2A satellite. The results are presented in Figure 2. The length of the shoreline increased from 70.59 km in 2015 to 72.37 km in 2018 and 75.45 km in 2021.

The obtained results prove the existence of changes in the length of the shoreline related to erosion and accretion phenomena. The results indicate that the length of the shoreline in Rembang Regency tended to increase every year; the data show that in 2015-2018, the coastal area of Rembang Regency experienced a shoreline change of 1.78 km. In 2018-2021, the shoreline change was 3.08 km, and in 2015-2021 it was 4.86 km.

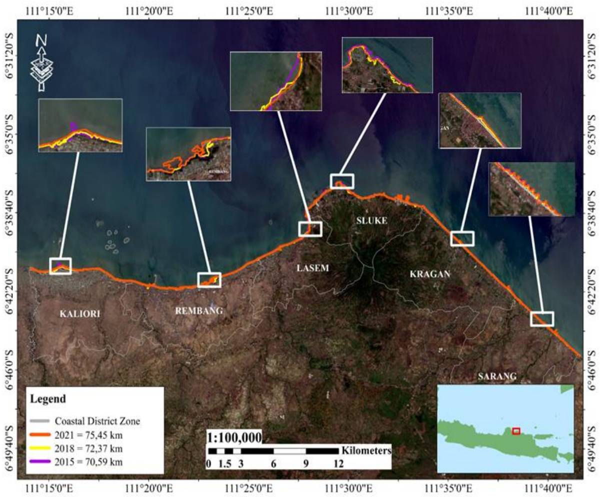

Figure 2. Shoreline change in Rembang Regency in 2015, 2018 and 2021**:** In 2015, it had a length of 70.59 km; in 2018, it had a length of 72.37 km, and in 2021, it had a length of 75.45 km.

3.2 Erosion and accretion

The results of the analysis of erosion and accretion for 2015 – 2021 based on the Net Shoreline Movement (NSM) are presented in Figures 3 and 4.

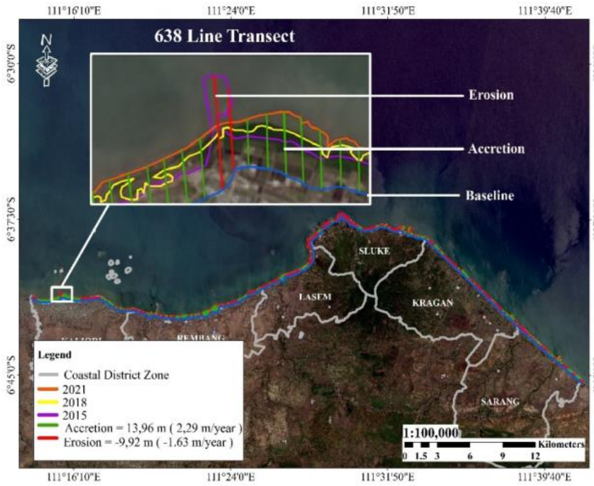

Figure 3. DSAS analysis based on Net Shoreline Movement (NSM) and End Point Rate (EPR) value

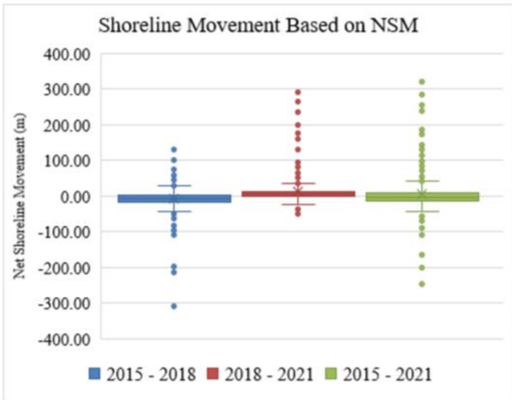

Figure 4. Box-whisker chart of shoreline movement based on NSM

In Figures 3 and 4, negative values (-) indicate that the shoreline is moving inland (erosion), while positive values (+) indicate that the shoreline is moving seaward (accretion). In 2015-2018, the shoreline experienced erosion by on average -12.56 m, with the highest value occurring in the transect line of Kaliori District. In 2018-2021, the shoreline tended to experience accretion by on average 14.88 m, with the highest value occurring in the transect line of Rembang District. The shoreline tended to experience accretion from 2015 to 2021. Rembang Regency experienced a moderate erosion of -9.92 m and an average accretion of 13.96 m. Rembang District had a high accretion rate due to the presence of mangrove conservation. Mangroves have been found to effectively protect shorelines by slowing down and preventing erosion; this aligns with Siyal *et al.*, (2022) and Sohel *et al.*, (2021).

The DSAS analysis results based on the NSM are presented in Table 1. This table indicates high erosion along zone 3 (Lasem District) of -16.02 m and the highest accretion along zone 2 (Rembang District) of 30.59 m. The study showed that the western part of Rembang tended to experience accretion, while the eastern part tended to experience erosion based on the Net Shoreline Movement (NSM). This result is consistent with previous research by Setiyarso, Muryani, and Sarwono (2016), which stated that the west coast of Rembang, which is dominated by a bay, experiences coastal accretion, while the east coast facing the northeast experiences coastal erosion.

The shoreline movement based on EPR calculation is shown in Figure 3 and Figure 5. From 2015 to 2018, the area tended to experience erosion, with an average rate of -4.19 m/year and the highest value at the Kaliori District transect line. From 2018 to 2021, the area tended to experience accretion, with an average rate of 4.96 m/year and the highest value at the Rembang District transect line. Rembang Regency experienced an average erosion rate of -1.65 m/year and an average accretion rate of 2.33 m/year. The accumulation of sediment trapped in the mangrove conservation area of Rembang District may contribute to the accretion of the shoreline. This finding is consistent with the results of Ng Casey and Ong (2022), Krauss *et al.*, (2014), and Krauss *et al.*, (2017), who reported that sediment accumulation also contributes to land accretion on the coast.

Average erosion and accretion results based on EPR calculation are presented in Table 2. This table shows the highest average erosion along Zone 3 (Lasem District) at -2.64 m/year and the highest average accretion along Zone 2 (Rembang District) at 5.03 m/year. These results show that the western region of Rembang Regency experienced the highest average erosion and accretion compared to the eastern region based on the End Point Rate (EPR). Figure 6 below shows erosion and accretion phenomena at each transect line in 6 Districts.

The results on the coastal slope are shown in Table 3. These results show how the slope of the coastal area affects erosion and accretion values, where Kaliori District, with a steep slope, has a higher erosion value than Rembang District, with a gentle slope. These results are consistent with the statements of Buitrago, Rodríguez, Moreno, Ochoa, and Neal (2022) and Andrian and Purba (2014), which state that steeper slopes increase the amount of sediment carried to the waters, thus increasing the potential for erosion.

Ocean currents, longshore currents and waves near the coast can influence sediment transport. This is in line with Huda, Anugroho, Suryoputro, and Subardjo (2015); Kuang *et al.*, (2022), who state that the speed of ocean currents and waves can generate energy capable of carrying sediment from one place to another. Bottom topography and bathymetry do not vary too much in the study area at Rembang Regency to influence currents and wave movement, which in turn affect sediment movement (erosion and accretion). Sediment grain size distribution in Kaliori and Rembang districts is presented in Table 4.

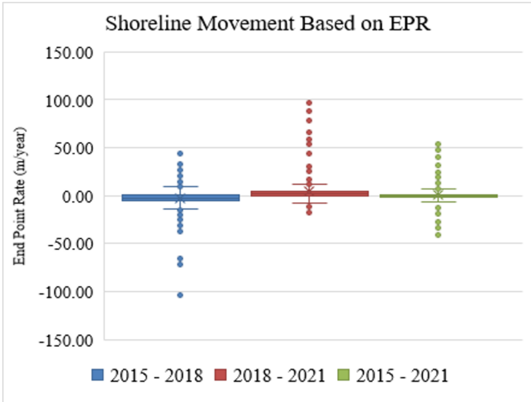

Figure 5. Box-whisker chart of shoreline movement based on EPR

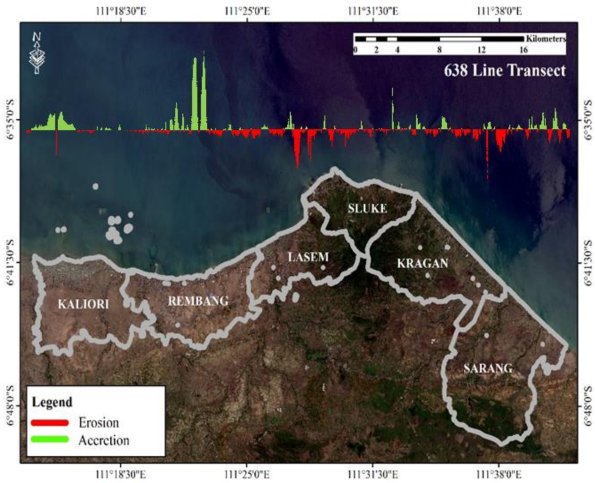

Figure 6. Graph of erosion and accretion rates for 2015 - 2021

Table 1. Each zone's erosion and accretion average value is based on NSM (m).

NSM	Kaliori	Rembang	Lasem	Sluke	Kragan	Sarang
Erosion (m)	-8.19	-5.21	-16.02	-13.04	-11.53	-6.65
Accretion (m)	27.51	30.59	2.82	5.56	6.38	4.72

Table 2. Erosion and accretion average value of each zone based on EPR (m/year)

NSM	Kaliori	Rembang	Lasem	Sluke	Kragan	Sarang
Erosion (m/yr)	-1.34	-0.86	-2.64	-2.15	-1.90	-1.09
Accretion (m/yr)	4.52	5.03	0.46	0.92	1.05	0.78

The percentages of sediment sorted in Sieve Shaker for samples from Kaliori and Rembang Districts are presented in Table 5. This table shows that the percentage of sorting value at Pasir Putih Wates Beach, Kaliori District, is Sandy with a depth of 10 cm, categorized as "poorly sorted fine sand" and 20 cm, categorized as "poorly sorted very coarse sand". The sediment type at Pasir Putih Wates Beach in Kaliori District is sandy with fine sediment at a depth of 10 cm; finer than at a depth of 20 cm and less separable. The sediment at Pasir Putih Wates Beach in Kaliori District has a poor sorting value, possibly due to a groin at the sampling location. This is in line with the statements made by Nguyen-Duong *et al.* (2022); Tang, Lyu, Shen, Zhang, and Su (2017); and Sakhaee and Khalili (2021) who stated that the presence of groin or breakwaters on the beach could affect the accumulation of sediment around them.

The percentage of sediment sorted in Sieve Shaker at point 1 observation in Pulo Swalan Beach, Rembang District, is Sand with a depth of 10 cm categorized as "moderately well sorted fine sand" and a depth of 20 cm categorized as "well sorted fine sand". The sediment type at Pulo Swalan Beach in Rembang District indicates a sandy beach with fine sediment at a depth of 10 cm that is well separated and a depth of 20 cm that is well divided at observation point 1.

The percentage of sediment sorted in Sieve Shaker at Point 2 of Pulo Swalan Beach, Rembang District, is sand with a depth of 10 cm, categorized as "moderately sorted fine sand" and 20 cm, categorized as "moderately well sorted fine sand". Observation point 2 shows fine sediment at a depth of 10 cm that is adequately separated and at a depth of 20 cm that is well separated. The sediment at Pulo Swalan Beach, Rembang District, has a reasonably good sorting value, indicating that the current stability in the area is sufficiently solid and stable, resulting in a diverse range of sediment grain sizes.

3.3 Impact of erosion and accretion on shoreline changes

The research results of Muskananfola et al. (2022) and Li et al. (2022) explain that natural and anthropogenic factors, such as oceanographic conditions, sediment type, vegetation, settlements, industries, ports, aquaculture, tourism, etc, cause changes in the shoreline. These statements are consistent with the research results that show that each coastal district zone in Rembang Regency has different slope angles, sediment characteristics, and land use, such as beach tourism, breakwaters, groin, mangrove conservation locations, ports, settlements, power plants, aquaculture, and industries, which affect erosion and accretion.

The accumulation of sediments on a coast can form new areas that can be used by the surrounding community as a location for mangrove rehabilitation, fishing boat repairs, or other activities (Pellón, Aniel-Quiroga, González, Medina, & Vidal, 2023). The accumulation of sediments causes shallowing and turbidity increases in the waters, affecting the waters' productivity and the visibility range of fish (Hartoko, 2010). Turbidity in the water is a factor that determines the dynamics of the bottom topography of the waters at various

Table 3. Calculation results of coastal slope

Station	Height (cm)	Length (cm)	Tan β	β	%
Rembang (1)	57	1000	0.057	3.262°	5.70
Rembang (2)	54	1000	0.054	3.091°	5.40
Kaliori	83	1000	0.083	4.745°	8.30

Table 4. Grain size and sorting values for Kaliori and Rembang Districts

Depth (cm)	Kaliori		Rembang (1)		Rembang (2)	
	Mean (µm)	Sorting (µm)	Mean (µm)	Sorting (µm)	Mean (µm)	Sorting (µm)
10	334.9	347.3	152.2	100.1	179.9	182.6
20	441.5	419.5	134.5	64.17	156.2	146.6

Table 5. Percentages of sediment sorted in sieve shaker

Mesh Size (mm)	Kaliori		Rembang (1)		Rembang (2)	
	10 cm	20 cm	10 cm	20 cm	10 cm	20 cm
2	8.1%	17.0%	0.4%	0.1%	7.5%	0.8%
1	11.5%	19.6%	0.6%	0.2%	2.1%	1.3%
0.5	10.3%	17.3%	0.6%	0.2%	3.4%	2.1%
0.25	19.2%	21.2%	3.9%	0.6%	6.8%	3.6%
0.125	48.8%	23.9%	77.3%	70.1%	68.2%	60.7%
0.063	1.9%	0.8%	14.1%	28.1%	11.5%	30.6%
0.032	0.0%	0.1%	3.3%	0.3%	0.1%	0.3%

depths (Rusydi & Masitih, 2021). Turbid waters enable sediment particles in the water column to settle into the seabed, causing varying forms of bottom morphology. Coastal sediment from an area that accumulates near mangrove vegetation can be a site for storing and gathering various components, including carbon. The ability of coastal sediment to store carbon in coastal ecosystems is estimated to be above 50% (Donato *et al.*, 2011). This indicates the crucial role of coastal sediments in storing carbon and mitigating global warming, apart from its main function as a habitat for marine organisms.

4. Conclusions

During the study period, from 2015 – 2021, the shoreline of Rembang Regency experienced a shoreline change rate of 4.86 km. This indicates that Rembang Regency has experienced an increase in the shoreline change rate from 2015 to 2021. The coastal areas of Rembang Regency from 2015 to 2021 experienced less erosion than accretion; the erosion rate was -1.65 m/year, and the accretion rate was 2.33 m/year. The increase in land area of certain parts of the shore and the accumulation of sediments in the mangrove vegetation area, which functions as carbon storage, are positive impacts of the shoreline change. The loss of land area on the other parts of the shore can be considered a negative impact as it may disrupt the marine ecosystems and the occurrence of siltation and turbidity.

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