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GIS-BASED ESTIMATION OF SHORELINE CHANGE AT THE OLIE PIER HARBOR HERITAGE SITE, MANGGAR, EAST BELITUNG, INDONESIA

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Abstract: The coastal area is a dynamic region influenced by continuous interactions between land and the sea. Changes in

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coastal compositions are closely related to shoreline instability. This study analyzes coastline changes at the Olie Pier Heritage Site, Manggar, East Belitung, Indonesia, using statistical-based techniques EPR (End Point Rate) and NSM (Net Shoreline Movement) 2015 to 2023. The DSAS (Digital Shoreline Analysis System) was employed to calculate the shoreline alterations in every transect with a distance of about 100 m. The study area is generally predominated by a moderate abrasion. The EPR and NSM values indicate a potential for future shoreline changes, considering the present status and future estimations of oceanographic parameters (currents, wind, waves, tides). The highest erosion is identified in the Lalang Village with a shoreline retreat (NSM) of -65.38 m and a retreat rate (EPR) of 8.78 m/year. On the other hand, the highest accretion is observed in the Baru Village with a NSM of -56.68 m and EPR of 7.61 m/year. The implications of these shoreline changes on the heritage site and the coastal environment contribute to the management of coastal areas amidst global environmental challenges. This study provides valuable insights into conservation and sustainable development efforts in the coastal region of East Belitung.

Keywords: End Point Rate (EPR), Digital Shoreline Analysis System (DSAS), Net Shoreline Movement (NSM), Olie Pier site, East Belitung

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INTRODUCTION

The coast has a shoreline formed by the meeting of land and sea. Coastal areas are the most vulnerable to changes, both in the short and long term. This is because the coastal areas are influenced by the continuous interaction of the land and sea, such as the activities of currents and waves generated by the winds and tides (Baig et al., 2020). In this case, the changes in the coastal area are typically associated with the coastline change.

The coastline, the boundary between land and sea, undergoes continuous and dynamic changes over time (Mentaschi et al., 2018). The coastline changes are related to the resilience of coastal conditions, including topographical and geological features and the interaction with waves, tides, and winds. Extreme waves and abrasion are the main threats of coastline change (Opa, 2011). According to the Agency of Meteorology, Climatology, and Geophysics Science (BMKG) of 2010, extreme waves are defined as significant sea waves that reach a wave height greater than 2 meters. Extreme waves are also accompanied by strong winds that can trigger abrasion phenomena. According to Amri et al. (2016), abrasion is the erosion of soil/coast or the depositions of sand hills by the movement of waves, tidal water, wave currents, or water flow. In such cases, the coastal area diminishes as a result of erosion by seawater, leading to a retreat of the shoreline. Indonesia is a vulnerable country that has 5243.76 Km erosion shoreline in year of 1990-2020 (Zhang et al., 2024)

The coastline change is caused by the contributing factor from nature or human activities (anthropogenic). Nature's contribution is influenced by waves, currents, and tides (Permana et al., 2022). Meanwhile, human-related factors, such as human activities that disrupt coastal environment stability, whether intentional or unintentional, contribute to shoreline changes. Coastal area conversion, jetty construction, mangrove deforestation, and other intensive activities conducted in coastal areas can impact the coastline change. Mining can also influence the coastline changes due to excessive extraction of mineral deposits from the earth, causing damage. In some regions in Indonesia, mining is a significant economic driver for communities, as seen in the Bangka Belitung Islands, where tin mining is crucial for improving the local economy and fulfilling their daily needs. It is further supported by Bangka Belitung Islands' potential as Indonesia's largest tin (Sn) producer. This is due to the strategic location of Belitung, which intersected with the Metal Mineralization Belt in western Indonesia. The potential of tin mining has been exploited for centuries and has become one of Indonesia's significant sources of foreign exchange. The Province of Bangka Belitung Islands is located at 104°50’ - 109°30’ East and 0°50’ - 4°10’ South, near the Province of South Sumatera. East Belitung is a district within the Bangka Belitung Islands province. Geographically, it is situated between the coordinates of 107º45’ - 108º18’ East and 02º30’ - 03º15’ South, with the district capital in Manggar. East Belitung is a significant contributor to Indonesia as it has been a maritime trade route since ancient times. However, the phenomenon has led to the collapse of pine trees and mangrove vegetation due to wave impacts, as seen along the coastline of Manggar areas. Abrasions also cause a decline in the biodiversity of organisms due to the continuously changing environment. Moreover, continuous ocean waves eroding the coastline also result in changes to the shoreline, affecting the damage and the submersion of some land areas and coastal tourist attractions in East Belitung. According to research by Intan (2014), ceramic artifacts from a sunken ship site were found in the waters of Belitung. Additionally, a Dutch heritage site, Oli Pier Dock, sank due to severe abrasion in those waters.

The community in East Belitung relies on the tin mining sector to fulfill their daily needs. The unconventional mining process using simple mechanical tools can potentially damage and pollute the environment significantly. Unconventional tin mining, or Artisanal and Small-Scale Mining (ASM), is increasingly encroaching into coastal areas, affecting changes in coastal topography, making it steeper, and intensifying coastal erosion. Furthermore, dredging activities from the seabed and the continuous conditions of sea waves eroding the coast can change the coastline. In this context, understanding changes in the coastline is crucial for assessing coastal area management plans and conducting hazard analysis resulting from the land and sea interactions in that region. If these conditions are left without preventive measures, coastal erosion will persist, leading to the loss of structures on the mainland due to the continuous influx of seawater. The change in the coastal area can be analyzed using remote sensing technology, specifically through satellite imagery (Arifin et al., 2023). According to Kasim (2012), the advantage of using satellite imagery is the ability to quickly monitor coastline changes and observe a wide study area. Remote sensing technology operates based on the Geographic Information System (GIS) principle, which has unique capabilities in handling spatially referenced data related to Earth's phenomena. The remote sensing technology used in this research is Sentinel-2A Imagery in 2015 and 2023. A Geographic Information System (GIS) is employed to identify the changes in the coastline at the heritage site of Olie Pier, Manggar, East Belitung, Indonesia. Moreover, the main factors contributing to coastal erosion in this area are also identified, including both natural factors and human activities.

MATERIALS AND METHODS

Study Area

East Belitung is a regency within the Province of Bangka Belitung Islands. Geographically, it is located between the coordinates of 2º 30’ − 3º15’ South and 107º45’ − 108º18’ East, with the regency capital in Manggar. The research was conducted in some villages: Sukamandi Village in Damar District and Baru Village, Kurnia Jaya Village, Lalang Village, and Padang Village in Manggar District (Figure 1). Belitung Regency is an archipelagic region (85% facing the sea) and arranged of 195 km shoreline. The coastal instability in East Belitung has been occurring for a long time, leading to the uprooting of pine trees and damaging the mangrove vegetation. This issue is frequently reported in the coast of the Manggar region, directly facing the Karimata Strait.

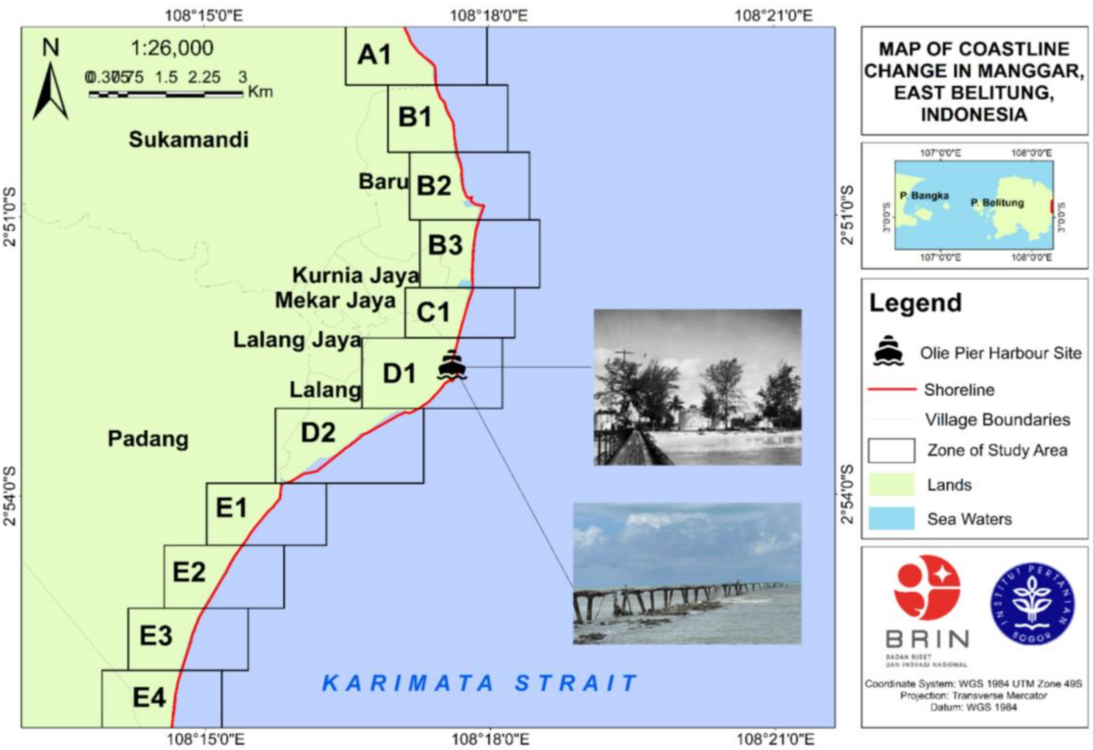

Figure 1. Map of the study area

Table 1. Research materials

Data Type	Data Source	Resolution	Time	Provider
Data GPS Handheld	Field Survey	5 m	2023	BRIN
Sentinel-2A Imagery	National Research and Innovation Agency Indonesia	10 m	2015 and 2023	BRIN
RBI Map	tanahair.indonesia.go.id	1:10,000	2019	-
Tides	https://www.tpxo.net/	0.083º	2015-2023	Oregon State University (OSU).
Winds	https://cds.climate.copernicus.eu/	0.083º	2015-2023	European Centre for Medium-Range Weather Forecasts (ECMWF)
Winds	https://cds.climate.copernicus.eu/	0.083º	2015-2023	European Centre for Medium-Range Weather Forecasts (ECMWF)
Waves	https://cds.climate.copernicus.eu/	0.083º	2015-2023	European Centre for Medium-Range Weather Forecasts (ECMWF)
Currents	https://data.marine.copernicus.eu/	0.083º	2015-2023	European Space Agency (ESA) and European Commission

Data Acquisition

The primary data was coastline marking using GPS (Global Positioning System). The secondary data consists of Sentinel-2A imagery, Indonesian topographical maps with a scale of 1:10,000, and other supporting data such as tides, currents, winds, and waves. The coastline marking was performed using an approach known as Ground Control Point (GCP). The field observation is imperative as the basis to examine and validate the results yielded from the satellite imagery. Meanwhile, the primary analyzed data was derived from Sentinel-2A from 2015 and 2023, considering other oceanographic regimes, such as tides, winds, currents, and waves. Oceanographic supporting data is essential in assessing the coastline alteration. According to Handiani et al. (2022), coastal damage is often influenced by natural factors such as coastal currents, sediment transport, changes in sea level, and ocean waves. Ocean waves are typically generated by various factors, such as wind, tides, currents, and others. Furthermore, according to Dewi et al. (2020), the main parameters causing changes in the coastline are waves, tidal differences, currents, wind, bathymetry, and coastal morphology, such as slope or topography and lithology (rock composition). Sea waves consist of a series of waves moving towards the coast and changing shape due to wave transformation, leading to coastal abrasion, damaging the coastline, and threatening coastal infrastructure.

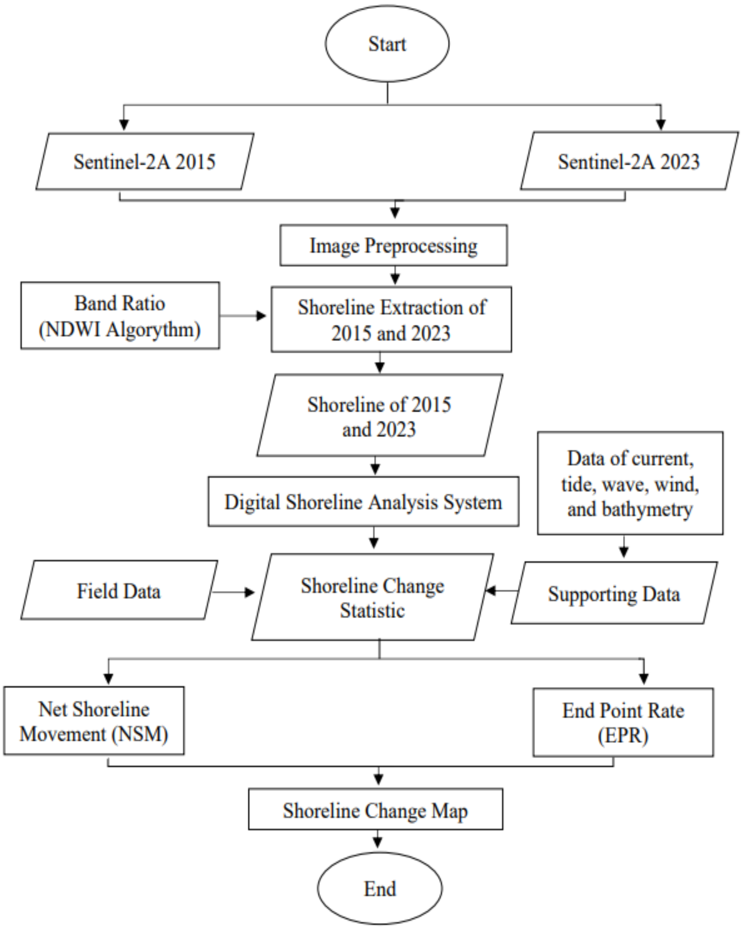

Figure 2. Flow chart of data processing

Data Processing

The research was conducted in several stages, including field observations, processing Sentinel-2A satellite imagery, and handling supporting data. The procedures are illustrated in Figure 2. Data processing begins with preprocessing, followed by coastline extraction and analysis of coastline changes in 2015 and 2023. Additionally, supporting oceanographic data that influences coastline changes, such as tides, winds, waves, and currents, was processed. The imagery utilized in this study is from Sentinel-2A. The following are the bands from the Sentinel-2A imagery (Table 2).

Table 2. Characteristic of Sentinel-2A image bands used (ESA 2015)

Band	Wavelength (µm)	Spatial Resolution (m)
Band 2 - Blue	0.490	10
Band 3 - Green	0.56	10
Band 4 - Red	0.665	10
Band 8 - NIR	0.842	10

Preprocessing Image

Preprocessing stage is the phase of preparing images through band combination, image cropping, and image correction. The bands were combined through layer stacking, followed by the cropping stage to narrow down the study area. According to Darmiati et al. (2020), cropping can be done based on the number of pixels, coordinates, or enlargement (zooming) of a specific area. Geometric correction is a step in correcting image distortions caused by spatial distortions of objects, ensuring that the recorded positions of objects match the field coordinates. Image correction includes geometric correction, radiometric correction, and atmospheric correction. According to Ismail (2012), geometric correction is necessary due to disturbances caused by scanning motion discrepancies, resulting in noise in the scanning system, rotational motion, Earth curvature, changes in the height of the sensor carrier, and changes in the sensor carrier's viewing angle to the object. Radiometric correction is performed to improve pixel values that do not correspond to the true spectral reflectance or emission values of objects. Atmospheric correction aims to reduce the object's reflectance from the total Top of Atmosphere (ToA) radiation after normalizing lighting conditions and eliminating atmospheric effects (Prananta and Kurniadin, 2021). In this study, atmospheric correction was carried out using the Dark Object Subtraction (DOS) method.

Shoreline Extraction with NDWI Algorithm

Before applying the DSAS, the shoreline was extracted using the NDWI (Normalized Difference Water Index) method on Sentinel-2A imagery. NDWI is an algorithm for identifying the presence of water bodies because water bodies can absorb wavelengths of visible and infrared light with sufficient intensity (Anggraini et al., 2017). According to Ahmad et al. (2021), NDWI optimizes water reflectance by utilizing the green wavelength and reducing the reflectance from the infrared band on water so that vegetation or land around the coast can utilize the NIR reflectance values. In this context, the NDWI algorithm is employed to obtain the boundary between land and sea, separated from sand and vegetation.

The research by Prayogo et al. (2021) explains that the NDWI method produces water body boundaries with better land object distinction than the Sobel Filter method. Therefore, the NDWI technique can be applied as a threshold value for the boundaries of both features in the infrared band type (Kasim, 2012). Here is the formula of the NDWI algorithm.

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

The combination of green and NIR bands is employed for land observation and coastal boundary delineation with vegetation, as proposed by Riantiyastika (2022). Furthermore, the NDWI algorithm can be extended to assess the conditions of a water body experiencing erosion or accretion. After obtaining the image results using the NDWI algorithm, a raster to vector format is converted to acquire the coastline boundaries in the study image.

Digital Shoreline Analysis System (DSAS)

The analysis of coastline changes in this study was conducted utilizing the Digital Shoreline Analysis System (DSAS) method. This method requires a minimum of three shoreline datasets, namely the baseline serving as the reference line and two shoreline datasets employed as research materials. According to Wawan et al. (2022), the DSAS method offers advantages in discerning the distribution of coastal change phenomena and evaluating the extent of changes along the desired transect. The proximity of the transect utilized directly influences the level of detail in the acquired data.

This study's determination of coastline change distances employed the Net Shoreline Movement (NSM) method. NSM was utilized to compute the distances of coastline changes from the earliest available data to the most recent (Himmelstoss et al., 2018). Specifically, the study considered the 2015 data as the longest coastline change and the 2023 data as the most recent shoreline data. Meanwhile, the baseline used 2019 data because the information base map (RBI Map) was available that year. Then, the NSM method yields two distinct values: positive (+) and negative (-). A positive value signifies the advancement of the coastline in a given coastal area, commonly referred to as accretion. Conversely, a negative value indicates the recession of the coastline, termed abrasion (Prahesti et al., 2021).

Furthermore, the study employed the End Point Rate (EPR) method, a technique aimed at calculating the rate of coastline change (expressed in meters per year). It involves assessing the displacement of a shoreline position over a specific timeframe, as delineated by Baskoro et al. (2018). The EPR method is carried out by dividing the distance between the oldest (2015) and the newest (2023) shorelines. The categories of coastline change rate can be seen in Table 3.

According to Limber et al. (2007) and Achmad et al. (2020), the EPR calculation is as follows:

$$Rse = \frac{X_o}{t} \quad (2)$$

Rse = Rate of shoreline position change (meter/year);

X_o = Distance of shoreline position change (meter); t = Time span of shoreline position (years)

Table 3. Categories of coastline change rate (Source: Setyandito and Triyanto 2007)

Rate of coastline change (meter/year)	Category
< -10	Severe Abrasion
-9,99 – -5	Heavy Abrasion
-4,99 – -2	Moderate Abrasion
-1,99 – 0	Light Abrasion
0 – 2	Light Accretion
2 – 5	Medium Accretion
5 – 10	Heavy Accretion
> 10	Severe Accretion

RESULTS AND DISCUSSION

Research Site Conditions

Belitung Regency has a coastline stretching approximately 195 km. The Belitung region is also archipelagic, with 85% of its sub-district area facing the sea. East Belitung Regency has diverse coastal landscapes. The predominant type of beach in East Belitung includes sandy beaches. The coastal topography is formed by land with elevations ranging from 0 to 20 meters and a gently sloping beach (Cahyani et al., 2012). East Belitung predominantly features a coastline with a gentle slope. Therefore, the oceanographic conditions in East Belitung waters influence the coastal conditions along its shores. Here are the existing coastal conditions in East Belitung (Figure 3).

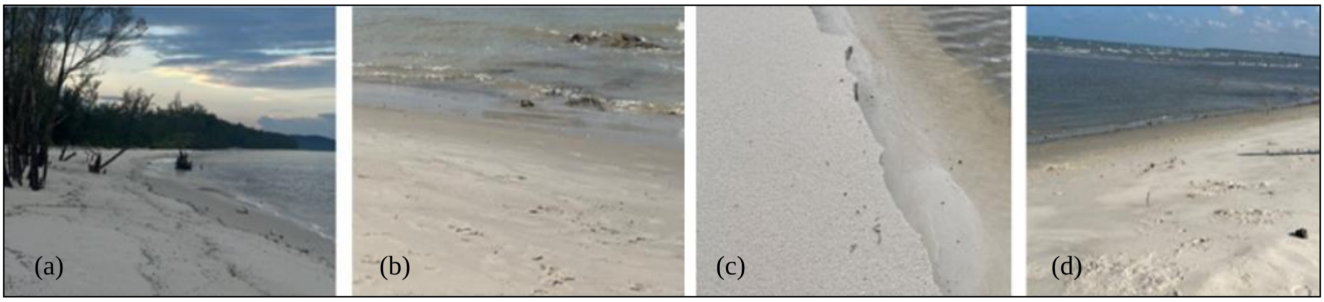

Figure 3. Beach conditions in (a) Tambak Beach, photo taken on June 19, 2023 (b) Nyiur Melambai Beach, photo taken on June 18, 2023 (c) Serdang Beach, photo taken on June 17, 2023 and (d) Mudong Beach, photo taken on June 18, 2023. (Source: private document-Authors, 2023)

Tide Analysis

Tides are the periodic rise and fall of the sea surface caused by the gravitational forces of the moon and the sun. Tidal data processing involves using tide values over 30 days, specifically from June 1, 2023, to June 29, 2023. This processing is obtained by comparing tidal prediction models with measurement data at the BIG Belitung station, resulting in the tidal component values occurring in East Belitung (Table 4). Subsequently, the Formzahl number is calculated using harmonic constants obtained from the tide model. The Formzahl number obtained is 3,18 meters. This value indicates that the tides in all segments fall into the diurnal tide type, meaning there is one high tide and one low tide per day (Fadilah et al., 2014).

Table 4. The tidal component in East Belitung

	So	M2	S2	N2	K2	K1	O1	P1	M4	MS4
A (cm)	-1.35	4.94	17.09	3.59	0.39	41.16	29.04	13.58	0.12	0.19
g	-	334.1	345.8	97.1	345.8	24.7	213.2	24.7	101.4	130.4

Wind Analysis

The speed and direction of wind data in East Belitung are displayed in the wind rose (Figure 4). The West Season (December - February) shows the wind moves from the northwest to the southeast. East Belitung has wind speeds ranging from 0.03 to 10.14 m/s with an average speed of 4.56 m/s. In Transition Season I (March - May), the dominant winds move in the southeast and northwest regions of East Belitung. During Transition Season I, wind speeds range from 0.05 to 9.13 m/s with an average speed of 3.03 m/s. In the East Season (June - August), the wind in the East Belitung region moves from the southeast to the northwest. Wind speeds during the east season in East Belitung range from 0.01 to 11.90 m/s, with an average speed of 5.20 m/s. In Transition Season II (September - November), the wind moves from the southeast to the northwest, but the wind conditions in the northwest region of East Belitung still influence the wind speed. Wind speeds during Transition Season II in East Belitung range from 0.08 to 10.14 m/s, with an average speed of 3.60 m/s

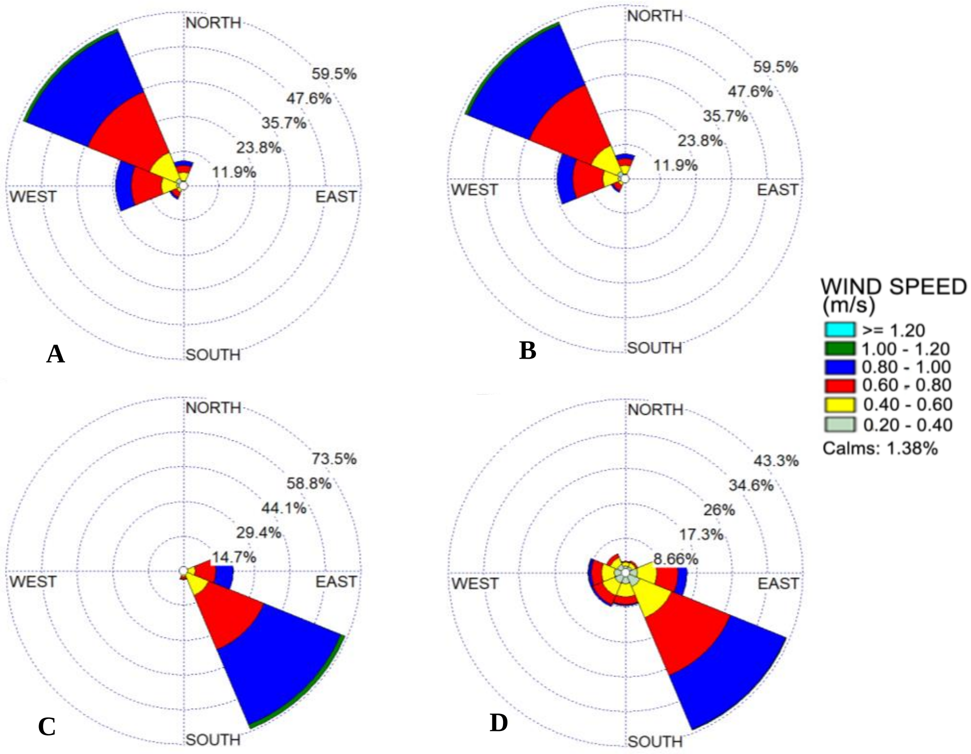

Figure 4. Wind rose of wind direction and speed (A) West Season, (B) Transition Season I, (C) East Season, and (D) Transition Season II. (Source: data processing - Authors, 2023)

The speed and direction of wind data in East Belitung are displayed in the wind rose (Figure 4). The West Season (December - February) shows the wind moves from the northwest to the southeast. East Belitung has wind speeds ranging from 0.03 to 10.14 m/s with an average speed of 4.56 m/s. In Transition Season I (March - May), the dominant winds move in the southeast and northwest regions of East Belitung. During Transition Season I, wind speeds range from 0.05 to 9.13 m/s with an average speed of 3.03 m/s. In the East Season (June - August), the wind in the East Belitung region moves from the southeast to the northwest. Wind speeds during the east season in East Belitung range from 0.01 to 11.90 m/s, with an average speed of 5.20 m/s. In Transition Season II (September - November), the wind moves from the southeast to the northwest, but the wind conditions in the northwest region of East Belitung still influence the wind speed. Wind speeds during Transition Season II in East Belitung range from 0.08 to 10.14 m/s, with an average speed of 3.60 m/s.

Wave Analysis

The direction and height of the wave along the coast of East Belitung Regency are visualized using a wave rose (Figure 6). The wave patterns along this coastal area tend to be consistent each year. The highest waves occurred during the West Season in 2021, reaching a height of 0.7 meters. The lowest waves occurred during the Transitional Season I, with a height of only 0.2 meters. The average wave height over the 5 years is 0.46 meters. Waves generated by winds moving near the coast can erode coastal areas, influencing the shape and slope of the coastline (Hasanudin and Kusmanto 2018). This phenomenon contributes to the advancement or retreat of the coastline (Ginanjar et al., 2021).

During the West Season, the average wave height in the East Belitung region is 0.52 meters. In Transitional Season I, the average wave height in the East Belitung region is 0.3 meters, while in the East Season, the wave height reaches 0.57 meters. Waves moving from deep to shallow waters create wavefronts that bend and move parallel to the coast. The refraction of waves affects the distribution of wave energy (Sadono et al., 2014). Waves are generated by the coastline windbreak, causing longshore currents (Dewi et al., 2020).

Current Analysis

The spatial distribution of seasonal currents was obtained from the https://resources.marine.copernicus.eu/ site from 2015 to 2023 (Figure 5). The depiction of these seasonal currents is visualized as a current distribution map. In this case, the current visualization is divided into four seasons, namely the West Season (December - February), Transition Season I (March - May), East Season (June - August), and Transition Season II (September - November). The water current speeds during these four seasons range from 0.008 to 0.554 m/s, with an average current speed of 0.141 m/s.

During the West Season (December - February), surface currents at the research location move southwestward with current speeds ranging from 0.03 to 0.55 m/s. Meanwhile, during the East Season (June - August), currents move northwestward with speeds ranging from 0.02 to 0.24 m/s. The Transition Seasons I (March - May) and II (September - November) are periods of transitioning current directions. The current strength is relatively low during these periods, and the sea is relatively calm. However, the Transition Seasons can result in the occurrence of longshore currents. This phenomenon affects changes in the coastline due to sediment movement, leading to erosion or accretion (Ukkas, 2009).

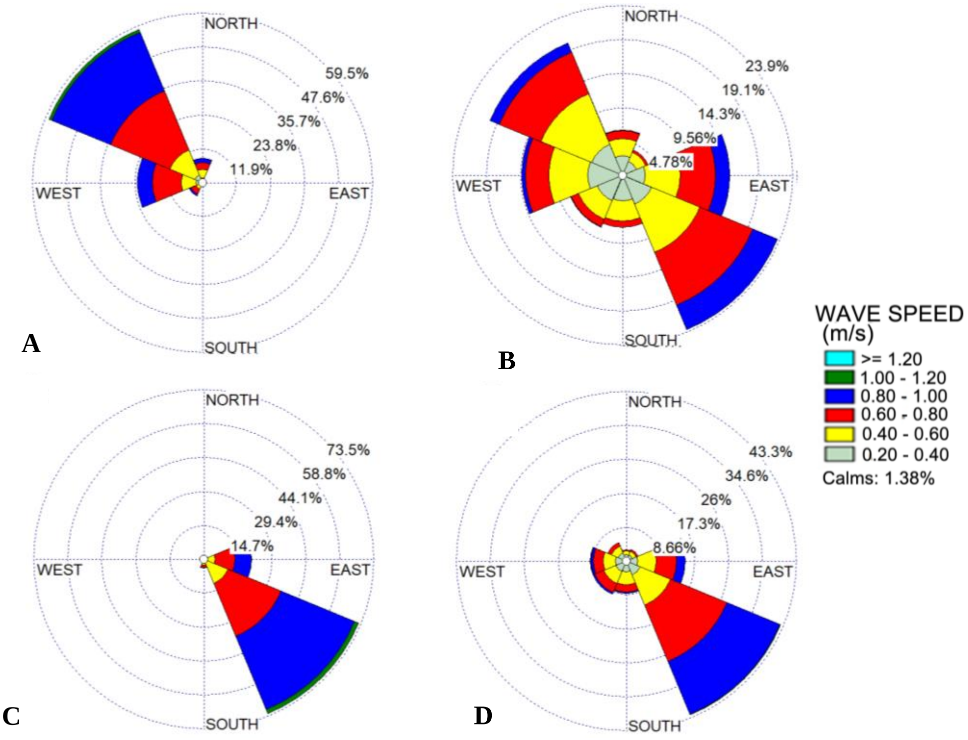

Figure 5. Wave rose of wave direction and speed (A) West Season, (B) Transition Season I, (C) East Season, and (D) Transition Season II. (Source: data processing - Authors, 2023)

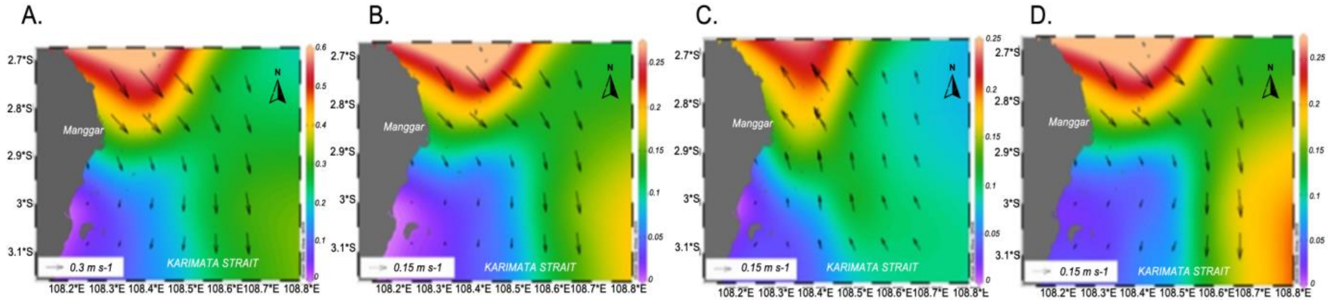

Figure 6. Current direction and speed (A) West Season, (B) Transition Season I,
(C) East Season, and (D) Transition Season II, (Source: data processing - Authors, 2023)

Shoreline Change Analysis

In this research, the analysis of coastline changes is divided into several zones (Figure 7). The dominant phenomenon of coastline change in East Belitung is moderate abrasion. Sub-zone D2 has the highest distance of coastline change experiencing abrasion, with a value of -65.38 meters, while the most significant coastline change experiencing accretion occurs in sub-zone B2, with a value of 56.68 meters. The highest rate of coastline change during erosion occurs in sub-zone D2 with a value of 8.78 meters per year, while the highest rate in accretion phenomena occurs in sub-zone B2 with a value of 7.61 meters per year (Table 5). In this case, there is a significant relationship between the distance of coastline change and its rate. The higher the rate of coastline change, the greater the value of the change.

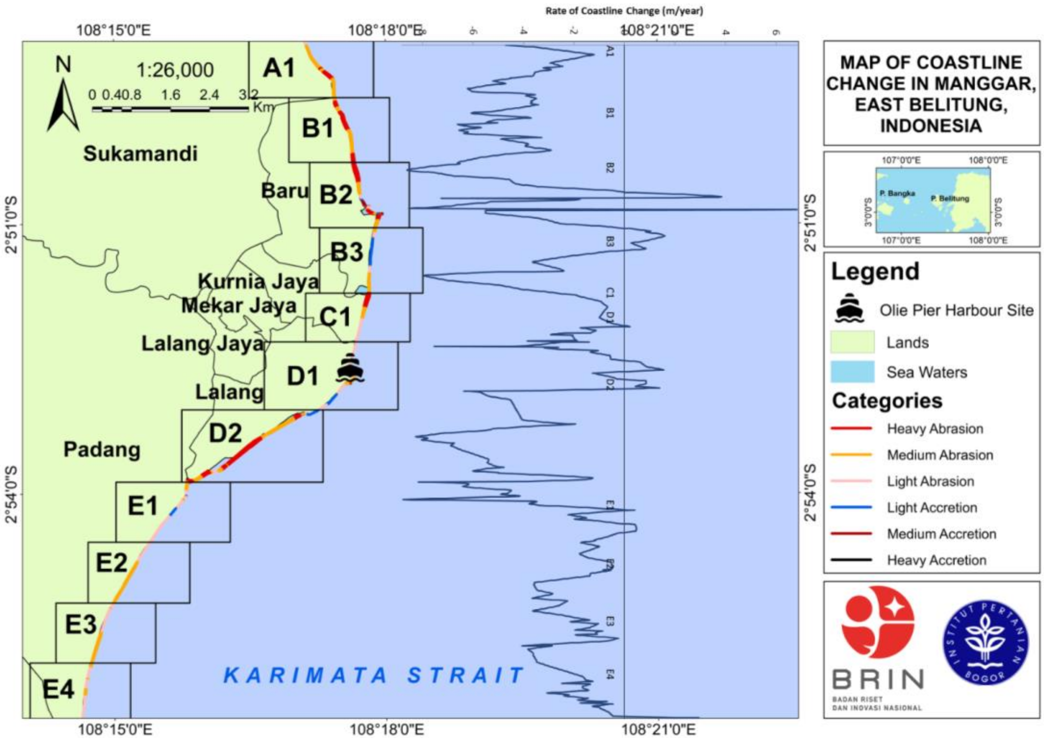

Figure 7. Map of coastline change in Manggar, East Belitung Timur from 2015 - 2023 (Source: data processing - Authors, 2023)

Table 5. Result of coastline change analysis

Zone	Net Shoreline Movement (NSM)			End Point Rate (EPR)			Dominant
	Low	High	Average	Low	High	Average	
A1	-46.33	-8.91	-27.05	-6.22	-1.20	-3.63	Medium Abrasion
B1	-49.33	-21.66	-36.91	-6.62	-2.91	-4.96	Medium Abrasion
B2	-64.09	56.68	-25.93	-8.61	7.61	-3.48	Heavy Abrasion
B3	-59.26	12.01	-20.28	-7.96	1.61	-2.72	Medium Abrasion
C1	-33.55	-5.01	-13.55	-4.5	-0.67	-1.82	Light Abrasion
D1	-56.08	11.71	-7.64	-7.53	1.57	-1.03	Light Abrasion
D2	-65.38	10.41	-34.64	-8.78	1.40	-4.65	Heavy Abrasion
E1	-62.52	3.55	-9.62	-8.40	0.48	-1.29	Light Abrasion
E2	-27.16	-3.66	-17.27	-3.65	-0.49	-2.32	Medium Abrasion
E3	-30.18	-1.86	-17.40	-4.05	-0.25	-2.34	Medium Abrasion
E4	-22.89	21.96	-10.87	-3.07	2.95	-1.45	Light Abrasion

Zone B is the coastal area of Baru Village, Manggar Subdistrict. Zone B is divided into sub-zones: sub-zone B1, B2, and B3. In this study, the furthest accretion occurs in sub-zone B2, which is 56.68 meters, with a rate of 7.61 meters per year. This accretion is because Zone B, specifically Serdang Beach, is located near former tin mining areas. Inactive onshore mining areas can lead to the deposition of sediments carried by rivers around the beach, resulting in land addition towards the sea (Kurniawan et al., 2019). Additionally, Zone B still has the flow of a large river estuary near the downstream of the Manggar River, causing accretion due to high sedimentation. According to Pabintan et al. (2019), accretion generally occurs in the downstream part of the river because sediments downstream will slow down and stop, leading to the accumulation and deposition of sediments causing accretion. As the area moves away from the former mining area, Zone B experiences severe and moderate erosion. This is because the coastal conditions in Zone B, namely Serdang Beach, have a sandy beach type. Waves easily erode the shoreline in coastal areas with sandy and muddy beach types.

Zone D is the coastal area of Lalang Village, Manggar Subdistrict. Zone D is divided into several sub-zones, namely sub-zones D1 and D2. Sub-zone D1 is divided into 172 transects, where the dominant phenomenon is mild erosion. Sub-zone D2 is divided into 317 transects, where severe erosion occurs. The coastal conditions of Lalang Village are characterized by a sandy beach with a narrow shoreline and rarely found river estuaries. According to Pamungkas et al. (2021), waves will more easily erode coastal conditions with sediment composed of sand and mud, resulting in low resilience. In this study, the highest erosion phenomenon occurs in sub-zone D2, with a shoreline retreat distance of 65.38 meters and a retreat rate of 8.78 meters per year. This area also lacks wave breakers, potentially exacerbating coastal erosion. Considering oceanographic factors, such as currents and waves, the dominant direction is from the southeast of East Belitung. Lalang Village has a geomorphological condition that slightly protrudes into the ocean compared to other coastal areas. This continuous exposure causes the currents and waves from the southeast to continuously erode the coastal area of sub-zone D2, as no wave breakers or jetties obstruct them. Therefore, the highest erosion occurs in sub-zone D2. The Olie Pier Cultural Site is one of the remaining pieces of historical evidence on the coast of East Belitung. This Olie Pier site is an old pier located right on the beachfront, which was once used as a docking place for oil-carrying ships.

However, its condition has deteriorated over time, with some parts of the pier only consisting of support posts. In this study, the Olie Pier site, located in sub-zone D1, predominantly experienced mild abrasion. Sub-zone D1 has the furthest abrasion distance of 56.08 meters with a retreat rate of 7.53 meters per year, classifying it as a mild abrasion phenomenon. The Olie Pier site in Lalang Village has a mixed sediment type of fine sand and rocks. Therefore, the changes in the coastline in sub-zone D2 are minimal. According to Nasir et al. (2015), rocky shores generally have low vulnerability because the rocks resist the impact of waves on the shoreline, resulting in minimal abrasion.

CONCLUSION

The coastal area of Manggar Subdistrict, East Belitung, from 2015 to 2023, experienced changes in its shoreline, both through erosion and accretion. The highest erosion occurred in Lalang Village (sub-zone D2), with a shoreline retreat of 65.38 meters and a retreat rate of 8.78 meters per year. In addition to erosion, the Manggar coast also experienced instances of accretion. The highest accretion occurred in Baru Village (sub-zone B2), with a shoreline advancement of 56.68 meters and an advancement rate of 7.61 meters per year.

The dominance of shoreline changes on the Manggar coast falls under the moderate erosion category. Oceanographic factors such as currents, waves, tides, wind, and bathymetry significantly influence the phenomenon of shoreline changes in Manggar, East Belitung. It is due to the conditions of the waters in East Belitung being in open waters directly adjacent to the Karimata Strait, causing the generated wave energy to impact the increasing wind speed.

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