Shoreline Stability Analysis At Merah Putih Beach, Bangkalan Regency

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Abstrak. Shorelines serve as a key indicator in monitoring environmental changes in coastal areas. Shorelines can change over various time periods, triggering coastal abrasion or accretion which can be detrimental. Therefore, it is necessary to conduct research on shoreline changes to minimize the losses that occur. The main objective of this study is to estimate abrasion based on Net Shoreline Movement, Endpoint Rate, and Shoreline Change Envelope. The quantitative approach utilizes remote sensing technology using the Normalized Difference Water Index algorithm, while the statistical approach uses data analysis obtained from the Digital Shoreline Analysis System method. This research was analyzed using Landsat 8 satellite images over a 12-year period (2013-2024). The results showed that shoreline changes at Merah Putih Beach, Bangkalan Regency during the 2013-2024 period indicated abrasion with an average shoreline distance of 14.99 meters and with an average rate of 1.37 m / year. According to the classification of the coastline in DSAS statistics, the two segments with a value of 0.511 meters / year and -0.768 meters / year are included in the moderate abrasion category. So that the beach during the 12-year period experienced a stable condition with a significant beach dynamics profile.

Keywords: *Shoreline, Landsat 8, Shoreline Change, Digital Shoreline Analysis System (DSAS), Coastal Abrasion*

1. Introduction

One of the areas that experience an increase or change in natural intensity and disturbances caused by human activities is the coastal area [1]. These changes are influenced by natural and non-natural factors. Changes influenced by natural factors include hydroseanographic factors in the waters, while changes influenced by non-natural factors such as human activities include sand mining and coastal natural resources that can cause shoreline changes resulting in abrasion and accretion in coastal areas [2]. According to [3], about 70% of coasts around the world experience shoreline changes characterized by coastal abrasion or accretion. Abrasion or coastal accretion is a serious problem for countries with rapid population growth

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in coastal areas, especially Indonesia. One of the regions in the coastal area of Indonesia is the coastal area of Madura Island with high sedimentation activity that has a significant influence on shoreline changes [4].

The shoreline can be described as the boundary line between the sea and land that serve as a significant connecting area for various processes such as physics, chemistry, biology, and geology. In addition, the coastline is used as one of the key indicators in monitoring environmental changes in areas along the coast [5]. Shoreline fluctuations are influenced by ocean dynamics that take place along with natural processes that can result in the displacement of sediments in coastal areas [2]. Therefore, it can be concluded that the coastline is a confluence zone that is affected by short-term movements due to waves, tidal fluctuations and coastal slope. The complex relationship between local and regional characteristics of coastal conditions that occur temporally and spatially has an influence on shoreline dynamics [6].

Shoreline dynamics is a phenomenon of changing the shape of the coast which is characterized by moving the coastline towards the sea or land. This phenomenon can have an impact on ecosystems, socio-economics and infrastructure damage that is detrimental if a study of shoreline stability is not carried out. This underlies why research on shoreline stability is important, namely as a mitigation step to minimize the losses that can be caused by the impact of shoreline changes. The dynamics of the shoreline can be detected and analyzed using remote sensing techniques. The application of remote sensing techniques to analyze shoreline development is an efficient method to monitor and determine the condition of an area over a period of time [7]. In addition, remote sensing data such as satellite imagery from Landsat 8 combined with Geospatial Information System techniques can provide results related to the monitoring and mapping of shoreline changes [8]. One technique of Geospatial Information System that we use is Digital Shoreline Analysis System. According to [9], some researchers utilize the Digital Shoreline Analysis System as a geoprocessing tool to analyze, calculate and monitor shoreline changes using several statistical approaches. These include the Net Shoreline Movement, End Point Rate and Shoreline Change Envelope statistical methods, whose effectiveness is highly dependent on the variability of the data used [8]. The objective of this research is to estimate abrasion based on Net Shoreline Movement (NSM), End Point rate (EPR) and Shoreline Change Envelope (SCE) at Merah Putih Beach, Bangkalan Regency within 12 years.

2. Materials and Method

2.1 Research Location

The study area is the coastal area of Merah Putih Beach, Bangkalan Regency with coordinates between longitudes 112°49.045' E to 112°49.420' E and 7°9.490' S to 7°9.755' S. This area is located in East Sukolilo, Labang District, Bangkalan Regency, East Java as shown in (**Figure 1**). This beach is directly adjacent to the Madura Strait which separates Madura Island and Java Island. The study area of the coastline studied has a length of 675 meters shown in the red box at the research location. The location was selected based on the consideration that the study area has a meandering shoreline profile that tends to cause variations in shoreline stability patterns.

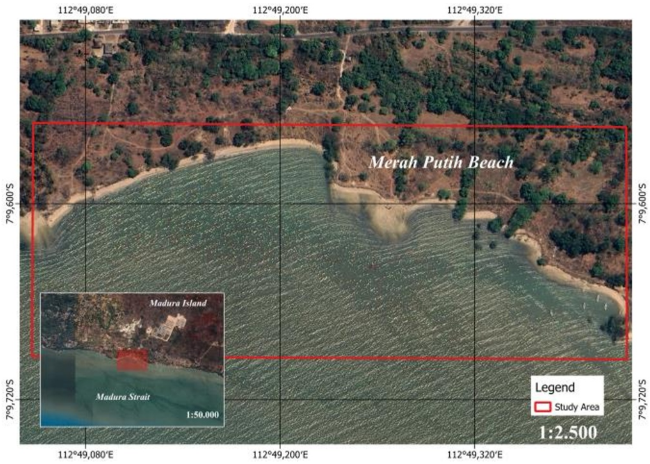

Fig 1. Map of the study area at Merah Putih Beach, Bangkalan Regency

2.2 Landsat Image Data And Tools Used In The Research

This study analyzed a 12-year period (2013-2024) using Landsat 8 OLI Collection 2 (Level-2A) satellite imagery with 30-meter corrected spatial resolution. All of the images used for this study were downloaded from the Google Earth Engine website (https://code.earthengine.google.com/). The complete information for each Landsat satellite image is presented at (**Table 1**).

Table 1. Landsat image data used in the research

Date Acquired	Satellite	Sensor	Spatial Resolution	Access
10/01-31/2013	**Landsat 8**	OLI Collection 2 (Level-2A)	30 Meter	https://code.earthengine.google.com/
10/01-31/2024	**Landsat 8**	OLI Collection 2 (Level-2A)	30 Meter	https://code.earthengine.google.com/

Based on the study of shoreline stability carried out through the analysis stage, several tools are required in processing the shoreline study data. The information for each of the tools used in this study is presented in full in (**Table 2**). The shoreline that has been obtained from each Landsat 8 OLI Collection 2 (Level-2A) satellite image in the 2013 and 2024 periods will then be used as input data for analysis in the Digital Shoreline Analysis System. This study uses a quantitative and statistical approach. The quantitative approach is to use mathematics systematically by utilizing remote sensing technology through image data processing obtained using the NDWI (Normalized Difference Water Index) algorithm, while the statistical approach is to use data analysis obtained from the DSAS (Digital Shoreline Analysis System) method regarding changes in shoreline due to abrasion.

Table 2. Tools used in research

Tools	Version	Usefulness
Google Earth Engine (GEE)	JavaScript API	Download and extract shorelines
Global Mapper	V. 17. 0	Adjust UTM zone projection and smooth line
Digital Shoreline Analysis System	**V6. 0. 168**	**Analyzed shoreline changes**
QGIS	V. 3. 38. 2	Map layout

2.3 Methods

2.3.1 Normalized Difference Water Index (NDWI)

Normalized Difference Water Index is one of the algorithms in remote sensing techniques for monitoring water-related changes in various landscapes in regional arrays. Normalized Difference Water Index is used to identify water bodies by utilizing differences in absorption and reflection properties between water and non-water [10]. In the analysis of shoreline stability, the Normalized Difference Water Index method is used to determine how the condition of the coastline by identifying and extracting the separated coastline. In the Normalized Difference Water Index, there are bands that will be used, namely between the green band (band 3) and near infrared (NIR) indices, where the green band records the reflection of green light while the near infrared represents infrared radiation [11]. The following is the formula for normalized difference water index:

$$\text{NDWI}_{(\text{Green, NIR})} = (\text{Green} - \text{NIR}) / (\text{Green} + \text{NIR}) \quad (1)$$

2.3.2 Digital Shoreline Analysis System (DSAS)

Digital shoreline analysis system is software that maintains the calculation of shoreline changes and provides position transformation over time. DSAS has been an important component of the Coastal Change Hazards (US Geological Survey) project [12]. This software uses a geodatabase as data input and outputs a classification of shoreline changes [13]. The geodatabase used as input data uses coastlines that have been extracted using Google Earth Engine with the NDWI (Normalized Difference Water Index) algorithm. horeline data extracted from different time periods, namely 2013 and 2024, will be analyzed using the Digital Shoreline Analysis System to obtain calculations on shoreline changes over an 12-year period. Shorelines from different periods will be merged into one part in the attribute table used as the shoreline, while the shoreline with the initial year period will be used as the baseline which is set to the default parameters set. The shoreline is then cast transects to determine the maximum search distance, transects spacing and smoothing distance. The calculation of the change distance of each shoreline is analyzed using statistical analysis, namely Net Shoreline Movement, End Point Rate and Shoreline Change Envelope [13]. The following is the formula for the digital shoreline analysis system:

$$\text{NSM} = \textit{distance (m) between oldest and youngest shorelines} \quad (2)$$

$$\text{EPR} = \frac{NSM}{time\ between\ oldest\ and\ most\ recent\ shoreline} \quad (3)$$

$$\text{SCE} = \textit{greatest distance (m) between all shorelines} \quad (4)$$

NSM (Net Shoreline Movement) is a calculation that measures the shoreline between the oldest and newest shoreline in each transect, EPR (End Point Rate) is a calculation that measures the end point rate by dividing the difference between two shorelines with different years. While SCE (Shoreline Change Envelope) is a calculation that measures the distance on the shoreline. Calculations on SCE and NSM are used to characterize shoreline change, while EPR is used to determine the rate of shoreline change [14]. The computational calculations will result in positive (+) or negative (-) values. A positive (+) value indicates that the coast is advancing or accretion, while a negative (-) value indicates that the coast is retreating or abrasion [13]. The calculation results using the Digital Shoreline Analysis System statistical approach are then classified by (**Table 3**) [15].

Table 3. Shoreline classification based on DSAS Statistic

Category	Rate of Shoreline Change (m/year)	Shoreline Classification
1	> - 2	Very High Abrasion
2	> - 1 and < - 2	High Abrasion
3	> 0 and < - 1	Moderate Abrasion
4	0	Stable
5	> 0 and < + 1	Moderate Accrection
6	> + 1 and < + 2	High Accrection
7	< + 2	Very High Accrection

3 Result and Discussion

3.1 Shoreline Extract 2013 and 2024

Several studies using the Digital Shoreline Analysis System method show that the method used can produce accurate data in describing the profile of shoreline changes that occur in a particular area. However, the Digital Shoreline Analysis System method still has weaknesses, one of which is that it cannot extract the coastline automatically. This can be solved by automatically extracting the shoreline using the Normalized Difference Water Index algorithm. The algorithm is used because it can distinguish water bodies from non-water bodies (land), can produce shoreline extracts automatically, and get accurate shoreline data by minimizing the subjectivity that occurs in manual digitization.

The coastline extraction results are located at Merah Putih Beach, precisely in Bangkalan Regency. The image used in the coastline extraction process is Landsat 8 OLI collection (level 2A) satellite image with a recording time span of 2013 and 2024. The satellite image was obtained through the Google Earth Engine website using the Normalized Difference Water Index algorithm. According to [16] ,NDWI (Normalized Difference Water Index) is a simple algorithm proposed by [11]. NDWI is used in remote sensing image processing for water resources assessment with Band 3 (green) and Band 5 (infrared/NIR). Where Band 3 (green) is a reflection value of the band that records the reflection of green light, Band 5 (infrared/NIR) is a reflection value that represents infrared radiation. (**Figure 3**) is the result of coastline extraction in 2013 and 2024, where the green color indicates 2013 while the purple color indicates 2024.

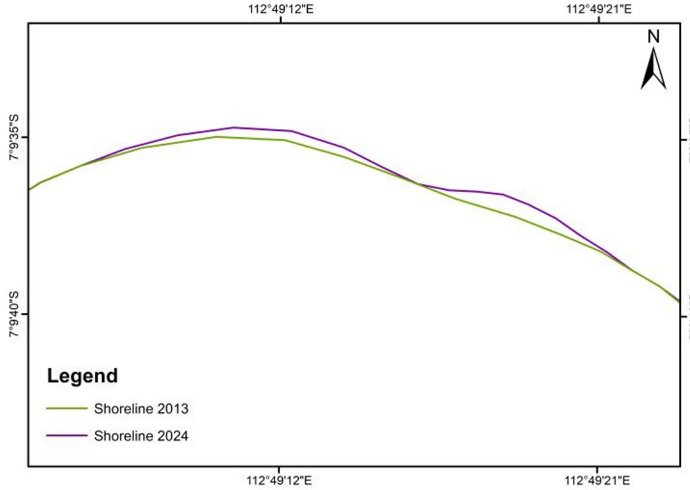

Fig 2. Shoreline Extract 2013 and 2024

3.2 Segments of Shoreline 2013-2024

The entire coastal segment of Merah Putih Beach over the period of 675 meters between 2013 and 2024 shows a division into two segments, segment A and segment B (**Figure 3**). The 2013 coastline is shown in purple and the 2024 coastline is shown in green. The division of segments in this analysis shows the dynamics of changes that occur in each part of the coastline. Segment A is shown in the red box located on the west coast with a shoreline profile condition that tends to be stable. Meanwhile, segment B is shown in the blue box located on the east coast with a shoreline profile condition that tends to be more open than segment A. The difference of each segment can be used to determine the condition of shoreline change because it has a significant role in determining the level of shoreline stability.

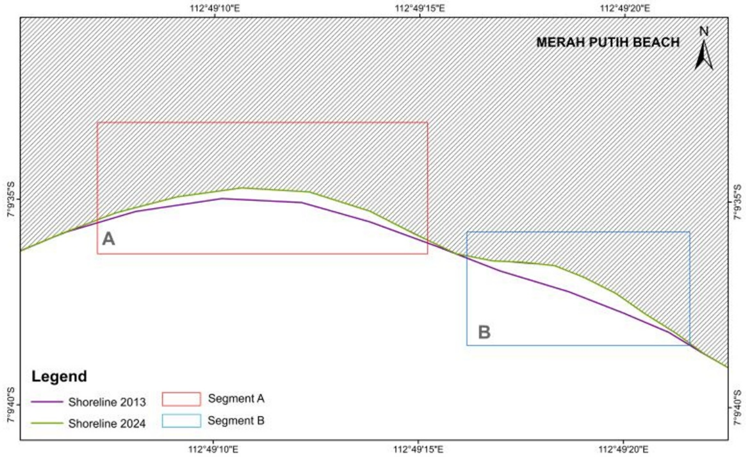

Fig 3. Segments of Shoreline 2013 and 2024

3.3 Long Term Shoreline Change 2013-2024

The obtained results of the Digital Shoreline Analysis System methods by using shoreline data for the period 2013 and 2024 (**Figure 4**). This method calculates shoreline changes that occur within a 12-year time frame. This analysis was conducted on the 675 meter-long Merah

Putih coastline with an interval between transects of 15 meters and resulted in 42 transects. The study location in this research was divided into two segments based on differences in the morphological shape of the coastline where segment A was in the western part and segment B was in the eastern part. Segment A in this study includes transects number 6 to 25, while segment B includes transects number 26 to 38. Some transects are not included in the segment because in these transects no phenomenon occurs which is characterized by small statistical calculation results.

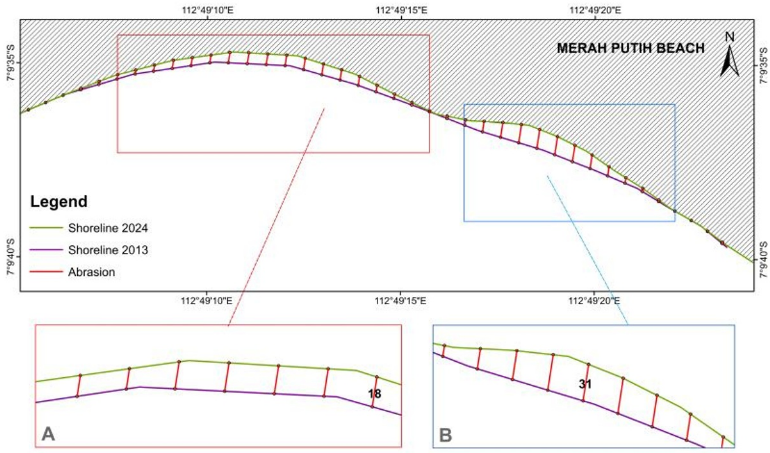

Fig 4. Long Term Shoreline Change 2013-2024.

Calculations of statistics obtained from the Digital Shoreline Analysis System method include Net Shoreline Movement, Endpoint Rate, and Shoreline Change Envelope [14]. The calculation results can be viewed at (**Table 4**) which shows the phenomena that occur and the value of shoreline change in each segment for the period 2013 to 2024. The data presented only displays the largest and smallest values of all statistical calculations on both segments. The results show that the phenomenon that occurs in both segments is abrasion characterized by the retreat of the shoreline towards land but with a varying distance of change ranging from 0.59 meters to 14.99 meters. The highest shoreline change in segment A occurred at transect ID 18 by 9.09 meters and EPR value of 0.83 meters/year, while the lowest change occurred at transect ID 25 by 0.59 meters and EPR value of 0.05 meters/year. Shoreline alteration in segment B has the highest value where the highest value is in transect ID 31 as far as 14.99 meters with an EPR of 1.37 meters/year with the lowest value being in transect ID 38 as far as 1.16 meters and an EPR value of 0.11 meters/year. Shoreline changes at Merah Putih Beach, Bangkalan Regency during the period 2013 to 2024 showed abrasion with an average shoreline distance of 14.99 meters and with an average rate of 1.37 m / year in coastal areas which resulted in reduced land area. Coastal abrasion is affected by hydro-oseanographic factors such as wind which causes an increase in wave height and wave strength that hits the coastal area [17].

Table 4. End Point Rate, Shoreline Change Envelope and Net Shoreline Movement of Shoreline 2013-2024

Segments	Transects ID	EPR (m/year)	SCE (m)	NSM (m)	Remaks
		Value	Value	Value	
A	**18**	**-0,83**	**9,09**	**-9,09**	Abrasion
	25	-0,05	0,59	-0,59	
B	**31**	**-1,37**	**14,99**	**-14,99**	Abrasion
	38	-0,11	1,16	-1,16	

Graphical classification of shoreline change in segment A and segment B based on EPR values. The EPR (End Point Rate) was calculated using shoreline change distance data with the time interval occurring between the old (oldest) year shoreline and the new (newest) year shoreline [18]. These results were obtained by calculating the average value of shoreline change of all transects included in each segment. Then the value obtained is reviewed based on (**Table 3**) to determine the category of shoreline change. Segment A and segment B are -0.511 meters/year and -0.768 meters/year, these two segments are included in the moderate abrasion category. Segment B has a higher value which indicates that this segment or the eastern study area has a high rate of shoreline alteration when compared to the western part. This also answers the division of segments according to the morphology of the shoreline shape where the two segments have different shoreline stability values.

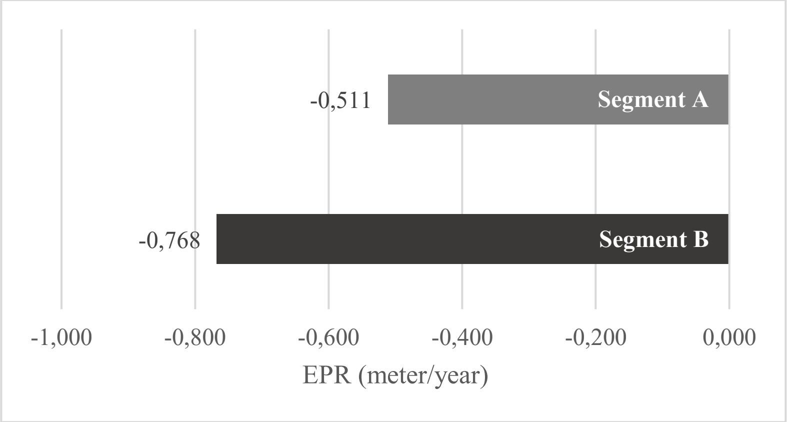

Fig 5. Classification of Rate Shoreline Change by Segment.

4 Conclusions

Research on shoreline stability analysis with remote sensing techniques, namely Landsat 8 satellite images processed using the NDWI algorithm. The results of the NDWI algorithm are in the form of shoreline extract data which is then analyzed using the Digital Shoreline Analysis System method to estimate abrasion based on Net Shoreline Movement (NSM), End Point rate (EPR) and Shoreline Change Envelope (SCE) at Merah Putih Beach, Bangkalan Regency in a period of 12 years. Based on the results of the research study using the Digital Shoreline Analysis System, there are 2 segments, namely segment A and segment B with a total of 42 transects. Changes in the coastline at Merah Putih Beach, Bangkalan

Regency during the period 2013 to 2024 showed abrasion which was marked by the retreat of the coastline towards the mainland with an average shoreline distance of 14.99 meters and with an average rate of 1.37 m / year in coastal areas which resulted in reduced land area. In addition, the values that have been reviewed based on the classification of coastlines in DSAS statistics show that the two segments with values of 0.511 meters / year and -0.768 meters / year are included in the moderate abrasion category. So it can be concluded that the beach during the 12-year period experienced a stable condition with a significant beach dynamics profile.

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