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Detection of Shoreline Changes due to Abrasion and Accretion Using Landsat Imagery – A Case Study in the Coastal Areas of Supiori Regency, Indonesia

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ABSTRACT

Shoreline changes have become a serious problem in all coastal areas worldwide. This study aimed to detect shoreline changes and analyze the shoreline change rate caused by abrasion and accretion in the coastal area of Supiori Regency, Indonesia. Landsat 8/9 imagery was used to determine the position of the coastline in 2013 and 2023. The shoreline movement (Net Shoreline Movement) and the shoreline change rate (End Point Rate) were analyzed using the Digital Shoreline Analysis System installed on ArcMap software. The results of this study indicate that there has been abrasion and accretion where there are several very significant locations. The maximum distance of the shoreline movements due to abrasion and accretion occurred in the Supiori Selatan District as far as -67.15 and 92.86 m, respectively. The average shoreline movement caused by abrasion ranges from -11.37 to -13.59 m and from 9.75 to 15.64 m in the case of accretion. From the comparison of abrasion and accretion, only the Kepulauan Aruri District has a positive value (dominant accretion), while the other four districts have a negative value (dominant abrasion). The shoreline changes rates in the study area caused by abrasion and accretion ranged from -1.22 to -1.46 m/yr and 1.05 to 1.68 m/yr, respectively. Abrasion and accretion in the study area are predominantly caused by natural factors such as waves, currents, and river flows, as well as caused by non-natural factors mainly due to human activities. Information on shoreline changes in the study area is an important aid for stakeholders involved in coastal area management. Therefore, planning, strategies, and mitigation efforts are urgently needed to anticipate increased coastal erosion and possible negative impacts.

Keywords: abrasion, accretion, DSAS, Landsat 8/9, shoreline movement, shoreline change rates.

INTRODUCTION

The coastal area can be defined as a land area directly adjacent to the ocean, where the land boundary includes areas that are inundated with water or not inundated with water that is still influenced by processes from the ocean. Coastal areas are rich in natural resources (Burke et al., 2002) and have high economic value in supporting the lives of coastal communities (Rumahorbo et al., 2020). As the boundary between land and sea, coastal areas have varied shapes and are very dynamic (Cui and Li, 2011; Nath et al., 2021), greatly influenced by waves, ocean currents, tides, storms, and other physical processes in coastal areas (Passeri et al., 2015; Hamuna et al., 2019), as well as sediment supply from rivers (Fan et al., 2018). Thus, the coastal area is an area that is very weak and vulnerable to environmental factors because of its location in the transition zone of land and sea environments (Kaly et al., 2004; Tsai, 2022). One of the dynamic processes of the coastal area is the change in the coastline which is indicated by the forward and backward coastline. Shoreline change is an important phenomenon that needs to be studied in relation to the dynamics of coastal areas and has become an indicator to determine the vulnerability of coastal areas to sea level rise caused by climate change (Thieler and Hammar-Klose, 1999; Pendleton et al., 2010; Marfai, 2014; Rumahorbo et al., 2023). The process of changing the coastline will take place dynamically and continuously, which is marked by the existence of coastal areas that experience land erosion (abrasion) as well as the addition of coastal land area in the sea area (accretion) (Kankara et al., 2015; Armenio et al., 2019; Baig et al., 2020; Rumahorbo et al., 2022). Shoreline changes, especially abrasion, are tentative hazards that can cause damage to coastal areas as well as threaten settlements, the economy, and the activities of people living in coastal villages (Baig et al., 2020; Sam and Gurugnanam, 2022; Liwun et al., 2023).

Various techniques, methods, and technologies have been developed to monitor environmental changes, including shoreline changes in coastal areas. One of the technologies that have been widely used to detect shoreline changes is satellite remote sensing technology. This technology can produce data with very wide spatial coverage in a short time, high resolution; in addition, it is cheaper than conventional monitoring and mapping techniques (Cendrero, 1989; Amukti et al., 2020; Goksel et al., 2020; Rumahorbo et al., 2022). There are many products of remote sensing technology, but Landsat satellite imagery is the more popular, because it is freely available and provides time-series images from earlier times. For example, Mafi-Gholami and Baharlouii (2019) can map shoreline changes in the Northern of the Persian Gulf and Sea of Oman from 1986 to 2016. Sam and Gurugnanam (2022) and Zonkouan et al. (2022) detected shoreline changes on the Indian Peninsula (southern coast) and the Southern Ivory Coast (Lahou-Kpanda) in the period 1980 to 2020, respectively. Likewise, Koulibaly and Ayoade (2021) and Yulianto et al. (2019) were able to identify changes in the coastline in Rufisque, Senegal (period 1978 to 2018) and Pekalongan coastal area, Indonesia (period 1978 to 2017), respectively. Even Kuleli et al. (2011) and Rahman et al. (2011) have used Landsat 1 to Landsat 7 images to detect shoreline changes in coastal Ramsar (Turkey) and along the coastal areas of India-Bangladesh, respectively.

Satellite remote sensing technology combined with a Geographic Information System that is integrated with the Digital Shoreline Analysis System (DSAS) is very helpful in describing the phenomenon of shoreline changes more effectively and automatically, both changes in short and long periods (Thieler et al., 2009). One of the advantages of shoreline change analysis using DSAS is the ease of calculation and the minimum requirement that only two shoreline datasets are needed. DSAS can be used to determine the extent of shoreline movements caused by abrasion and accretion over a certain period (Net Shoreline Movement; NSM), determine the rate of shoreline change over a certain period (End Point Rate; EPR), and can be used to predict shoreline movements in the future (Linear Regression Rate; LRR) (Thieler et al., 2009). Currently, the DSAS method has been widely used to analyze shoreline changes in various countries (Mujabar and Chandrasekar, 2013; Nhan et al., 2018; Nassar et al., 2019; Koulibaly and Ayoade, 2021; Rumahorbo et al., 2022; Sam and Gurugnanam, 2022), because the statistical data produced is very accurate (Thieler et al., 2009).

Understanding shoreline change dynamics is important for monitoring coastal areas and is intended for effective coastal area management. This aligns with the Sustainable Development Goals (SDGs; goal 14), which require accurate and sustainable shoreline information for managing and conserving coastal areas (Tsai, 2022). Therefore, this study aimed to detect and analyze the shoreline changes caused by abrasion and accretion in Supiori Regency, Papua Province (Indonesia), to eliminate damage to coastal areas as well as minimize physical and economic losses. This research is considered necessary because the geographical location of the study area is in the Pacific Ocean's high seas, which is estimated to be very vulnerable and has the potential for coastal disasters due to physical processes in the ocean. In addition, residential areas are more concentrated in coastal villages, so the pressure on coastal areas will increase.

MATERIALS AND METHODS

Study area

Supiori Regency is a division of Biak Numfor Regency in Papua Province, Indonesia. Geographically, Supiori Regency is located at 0°55'-1°31' South Latitude, 134°67'-136°48' East Longitude with an area of approximately 634.24 km^2, which is directly adjacent to the Pacific Ocean in the north, the Yapen Strait in the south, the Aruri

Strait in the west, and Biak Numfor Regency in the east (Badan Pusat Statistik Kabupaten Supiori, 2022). The topography of Supiori Regency consists of hills that form mountain ranges (Supiori Mountains), undulating land, lowlands, and island areas, with altitudes ranging from 0 to 1,030 m above sea level. Wombonda Peak is the highest peak in Supiori Regency and is designated as a Protected Area in the Supiori Nature Reserve. At the same time, flat to sloping areas are mostly located in coastal areas, which are used as development centers, settlements, plantations, and socio-economic activities of the population (Badan Pusat Statistik Kabupaten Supiori, 2022).

The Supiori District comprises five districts: Supiori Timur, Supiori Utara, Supiori Barat, Supiori Selatan, and Kepulauan Aruri (Figure 1). Most of the Supiori Regency area is on Supiori Island, and only part of the Supiori Timur District (eastern part) is on Biak Island, which the Sorendiweri Strait separates. This study area was limited to coastal areas on the mainland, namely Supiori Island and Biak Island, excluding small islands (except Sowek Island and Ineki Beba Island in the Kepulauan Aruri District, which are quite large).

Landsat imagery dataset used

The satellite images that detect and identify shoreline changes in the study area are Landsat 8 and 9 (Path/Row: 104/61) (Table 1). These images are obtained free of charge from the website http://earthexplorer.usgs.go. This study needed several satellite images to determine the coastline for a certain year. One image that was free of cloud cover, covering all study areas, was not obtained. It is assumed that the position of the coastline is the same between the main image and the supporting images because the acquisition date is similar.

Data processing

There are three stages of satellite image processing to determine shoreline changes: satellite image correction, determination and construction of coastlines, as well as development of baselines and transects (Figure 2). Processing and processing of satellite images start from the stages of satellite image correction (geometric and atmospheric correction). The geometric correction aims to correct errors in the geometric position of the image so that it matches the actual position on the Earth's surface. In this study, all Landsat images were geometrically corrected using Ground Control Points obtained in the study area using the WGS 1984 UTM Zone 53S coordinate system. The atmospheric correction aims to perform image recovery to improve its quality. The atmospheric correction process is carried out using the FLAASH Atmospheric Correction module in ENVI 5.1 software to minimize atmospheric

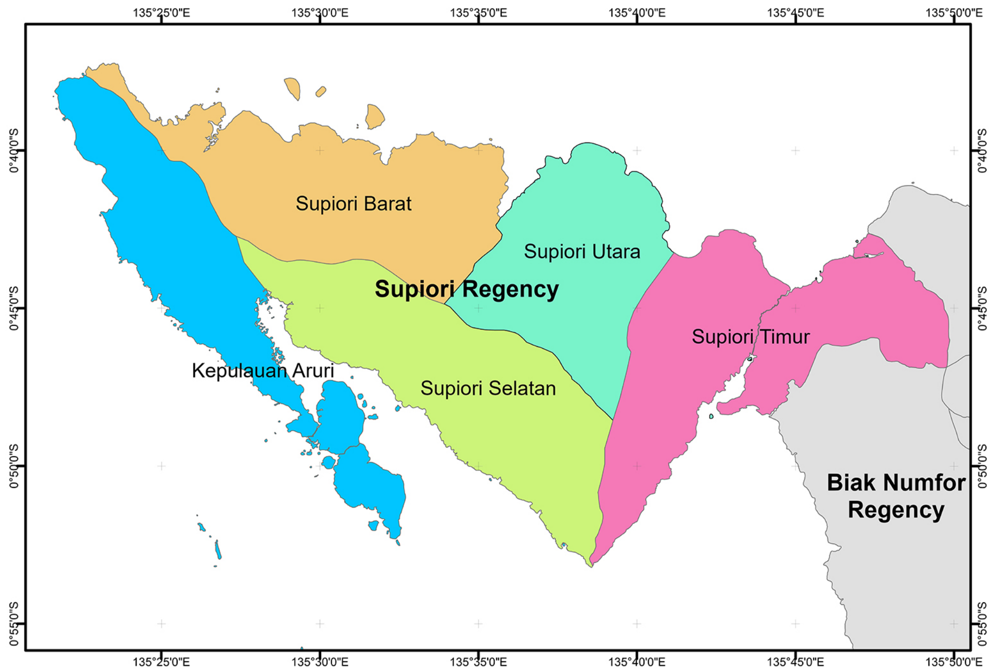

Figure 1. Study area along the coast of Supiori District, Indonesia (Supiori Island and western Biak Island)

Table 1. The Landsat imagery dataset used in this study

Satellite and sensor	Date acquired	Utility
Landsat 8 OLI	01/12/2013	For 2013 coastlines in the Districts of East Supiori. South Supiori and Kepulauan Aruri
	14/10/2013	For 2013 coastlines in the Districts of Supiori Utara and Supiori Barat
	21/04/2013	For 2013 coastlines in the Districts of Supiori Timur. Supiori Utara. dan Supiori Barat coasts covered by clouds in the two previous images
	03/02/2014	For the 2013 coastline in Kepulauan Aruri District covered by clouds in the previous image
	16/03/2023	For 2023 coastlines in the Districts of Supiori Barat. Kepulauan Aruri (northern part). and coastal areas on Supiori Timur and Supiori Utara covered by clouds in the previous image
	12/02/2023	For the 2023 coastline in the Supiori Barat District covered by clouds in the previous image
Landsat 9 OLI-2	25/04/2023	For 2023 coastlines in the Districts of Supiori Timur. Supiori Selatan. Supiori Utara. and Kepulauan Aruri (southern part)

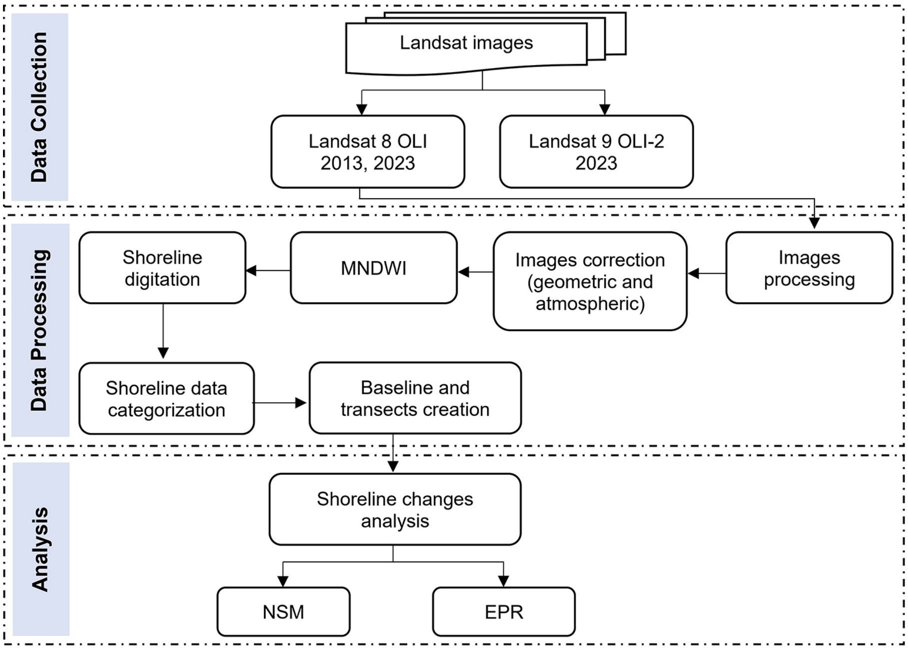

Figure 2. Flowchart of the process of identifying and determining shoreline changes from multitemporal satellite imagery: processing and analysis of satellite imagery

disturbances (Dewi and Trisakti, 2016; Prieto-Amparan et al., 2018; Yerzhanova et al., 2021). Determining the boundary between land and sea is important so that the position of the coastline interpreted from satellite imagery is the same as the actual condition. For this purpose, the Modified Normalized Difference Water Index (MNDWI) is used to provide a clear picture of the position of the coastline on satellite imagery. The MNDWI equation for Landsat 8 OLI and Landsat 9 OLI-2 images is as follows (Ko et al., 2015):

$$MNDWI = \frac{(Green - SWIR\ 1)}{(Green + SWIR\ 1)} \quad (1)$$

The MNDWI imagery produced will be used as a reference in the digitization process to generate the coastline data for 2013 and 2023. Coastline digitization (polyline features) was carried out using ArcMap 10.8.1 software. The next stage is the creation of input parameters in the analysis of shoreline changes, namely shorelines, baselines, and transects. The shorelines used are digitized by adding the necessary attributes. The baseline and transects can be generated automatically using the DSAS 5.0 toolbar installed and integrated with the ArcMap software (Thieler et al., 2009). In this study, the baseline was made by buffering the 2023 coastline as far as 100 m inland, while the transects were made 150 m from the baseline seaward with a distance between transects of 100 m.

Analysis of shoreline changes

This study analyzed the shoreline change rate in the study area using two statistical approaches in DSAS software: Net Shoreline Movement (NSM) and End Point Rate (EPR). NSM measures the distance of change between two shorelines on each transect. Meanwhile, EPR determines the shoreline change rate in each transect over a certain period (Thieler et al., 2009). The similarities between the two statistical approaches are as follows (Thieler et al., 2009):

$$\text{NSM [m]} = \text{Distance between 2013 and 2023 shorelines} \quad (2)$$

$$\text{EPR [m/yr]} = \frac{\text{NSM}}{\text{Time between 2013 and 2023 shorelines}} \quad (3)$$

The shoreline change rate (EPR value) in this study was grouped into five categories according to Thieler and Hammar-Klose (1999) and Pendleton et al. (2010), where this categorization is the basis for determining the level of vulnerability of coastline variables to coastal disaster threats (sea level rise). The range of EPR value categories is shown in Table 2, where positive values indicate accretion and negative values indicate abrasion.

RESULTS

Abrasion and accretion detection

In this study, 2332 transects were generated automatically using DSAS software to detect shoreline changes in the coastal area of Supiori Regency. The number of transects in the Kepulauan Aruri District was higher than in the Supiori Timur, Supiori Barat, Supiori Selatan, and Supiori Utara Districts, namely 804, 588, 474, 334, and 189 transects, respectively. The difference in the number of transects depends on the length of the coastline in each district.

Shoreline changes due to abrasion along the coastal area of Supiori Regency were detected in 868 transects (36.33%), with 164 transects showing statistically significant abrasion. In comparison, accretion was detected in 693 transects (29.01%) with a statistically significant number of transects. Significant accretion of 107 transects (Figure 3). More abrasion was detected in Kepulauan Aruri and Supiori Timur Districts than in other districts, namely 254 and 228 transects, respectively. Likewise, accretion was detected more in the Kepulauan Aruri and Supiori Timur Districts, reaching as many as 307 and 184 transects, respectively. Overall, abrasion was detected in four dominant districts, only in the Kepulauan Aruri District where accretion was dominant.

Regarding the percentage of abrasion and accretion in each district, the percentage of abrasion in Supiori Utara District is higher, around 59.79% of the total transects. Also, the percentage of transects showing statistically significant abrasion is greater than in other districts, namely 35.61% (40 transects). The percentage of accretion is more in the Kepulauan Aruri District, which is around

Table 2. Classification of EPR values (shoreline change rates)

Shoreline changes rates (m/yr)	Classification
EPR < -2	High abrasion
-2 < EPR < -1	Low abrasion
-1 < EPR < 1	Stable
1 < EPR < 2	Low accretion
EPR > 2	High accretion

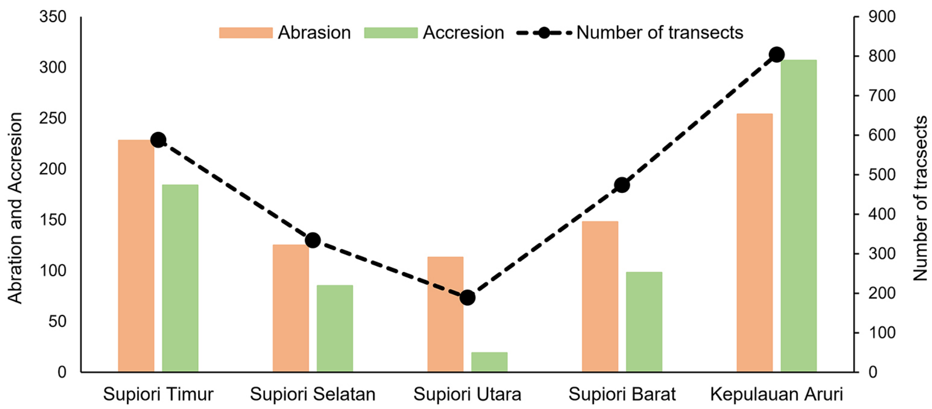

Figure 3. Comparison of the number of abrasion and accretion transects

38.18% of the number of transects in the Kepulauan Aruri District; this shows a statistically significant accretion of around 19.43% or as many as 60 transects (higher than the other four districts).

Shoreline movement

On the basis of the results of NSM analysis in the coastal areas of Supiori Regency in the period 2013 to 2023 presented in Table 3, the highest distances for shoreline movements due to abrasion occurred in Supiori Selatan and Kepulauan Aruri Districts, namely as far as -67.15 and -60.33 m, respectively. The consequences of accretion occurred in the Supiori Selatan District as far as 92.86 m, which is very high compared to the accretion distance in the other four districts. When viewed from the average distance of the shoreline movement due to abrasion and accretion, there is no significant difference in the average distance due to abrasion in all districts, with an average range of abrasion between -11.37 to -13.59 m, where the average highest average abrasion distance in Supiori Selatan District. At the same time, the average distance due to accretion in Supiori Timur District is lower (9.75 m) than in the other four districts (between 13.38 to 15.64 m).

Overall, comparing the average distance of the shoreline movement due to abrasion and accretion along the Supiori Regency's coastal area can be balanced, namely -12.39 and 12.93 m, respectively. However, comparing the average distance between abrasion and accretion in each district shows that only the Kepulauan Aruri District has a positive value (1.95 m), which means that the shoreline movement due to accretion is higher than abrasion. Conversely, in the other four districts, the value is negative, where the effect of abrasion is higher than accretion. The interesting thing that happened in Supiori Utara District is that the average distance of the shoreline movement due to accretion (15.30 m) is higher than due to abrasion (-13.42 m). Still, the overall average distance is negative (-9.28 m), which shows the effect of abrasion on shoreline changes is very dominant. This condition is strongly influenced by the number of transects showing abrasion and accretion in the district, where the number of abrasions transects is very high (113 transects) compared to the number of accretions transects (19 transects).

Shoreline change rates

On the basis of the analysis of the rate of change of coastline in Supiori Regency for 2013 to 2023, the average rate of change of coastline caused by abrasion and accretion is -1.33 and 1.39 m/yr, respectively. In particular, the average rate of shoreline changes due to abrasion ranges from -1.22 to -1.46 m/yr, while that due to accretion ranges from 1.05 to 1.68 m/yr (Table 4). On the basis of the EPR data for each transect, the maximum rates of abrasion and accretion

Table 3. Net shoreline movement (NSM) in each district in Supiori Regency for the period 2013 to 2023

Districts	Abrasion (m)		Accretion (m)		Average distance (m)
	Maximum	Average	Maximum	Average	
Supiori Timur	-39.13	-11.37	43.72	9.75	-1.94
Supiori Selatan	-67.15	-13.59	92.86	14.50	-2.22
Supiori Utara	-28.04	-13.42	38.37	15.30	-9.28
Supiori Barat	-32.55	-13.03	47.99	15.64	-1.61
Kepulauan Aruri	-60.33	-11.87	61.60	13.38	1.95

Table 4. Shoreline changes rates (End Point Rate; EPR) in each district in Supiori Regency for the period 2013 to 2023

Districts	Abrasion (m/yr)		Accretion (m/yr)		Average rate (m/yr)
	Maximum	Average	Maximum	Average	
Supiori Timur	-4.21	-1.22	4.71	1.05	-0.21
Supiori Selatan	-7.23	-1.46	9.99	1.56	-0.24
Supiori Utara	-3.02	-1.45	4.13	1.64	-0.99
Supiori Barat	-3.51	-1.40	5.17	1.68	-0.17
Kepulauan Aruri	-6.50	-1.28	6.63	1.44	0.21

occurred in the Supiori Selatan District, namely -7.23 and 9.99 m/yr, respectively. Overall, based on the average EPR rate, abrasion is more dominant in Supiori Utara District (-0.99 m/yr) than in Supiori Timur, Supiori Selatan, and Supiori Barat Districts (range -0.17 to -0.24 m/yr). The average rate of shoreline changes in the Kepulauan Aruri District is positive (indicating accretion), because accretion is higher than abrasion.

Spatially, the rate of shoreline changes (based on the distribution of EPR values) along the coastal area of Supiori Regency varies greatly depending on the shape and characteristics of the coastal area (Figure 4). This shows that the response of coastal areas is different to various factors that cause different shoreline changes, both abrasion and accretion. Overall, the number of transects showing the categories of high abrasion (EPR<-2), low abrasion (-2<EPR<-1), stable (-1<EPR<1), low accretion (1<EPR<2), and high accretion (EPR>2) was 134, 448, 1398, 277, and 132 transects, respectively. Thus, the rate of shoreline changes based on the classification of EPR values is more dominated by the stable category.

The rate of shoreline changes in the Supiori Barat District varies greatly but is more dominated by the stable category (Figure 4a). The high abrasion category was found only in a few locations,

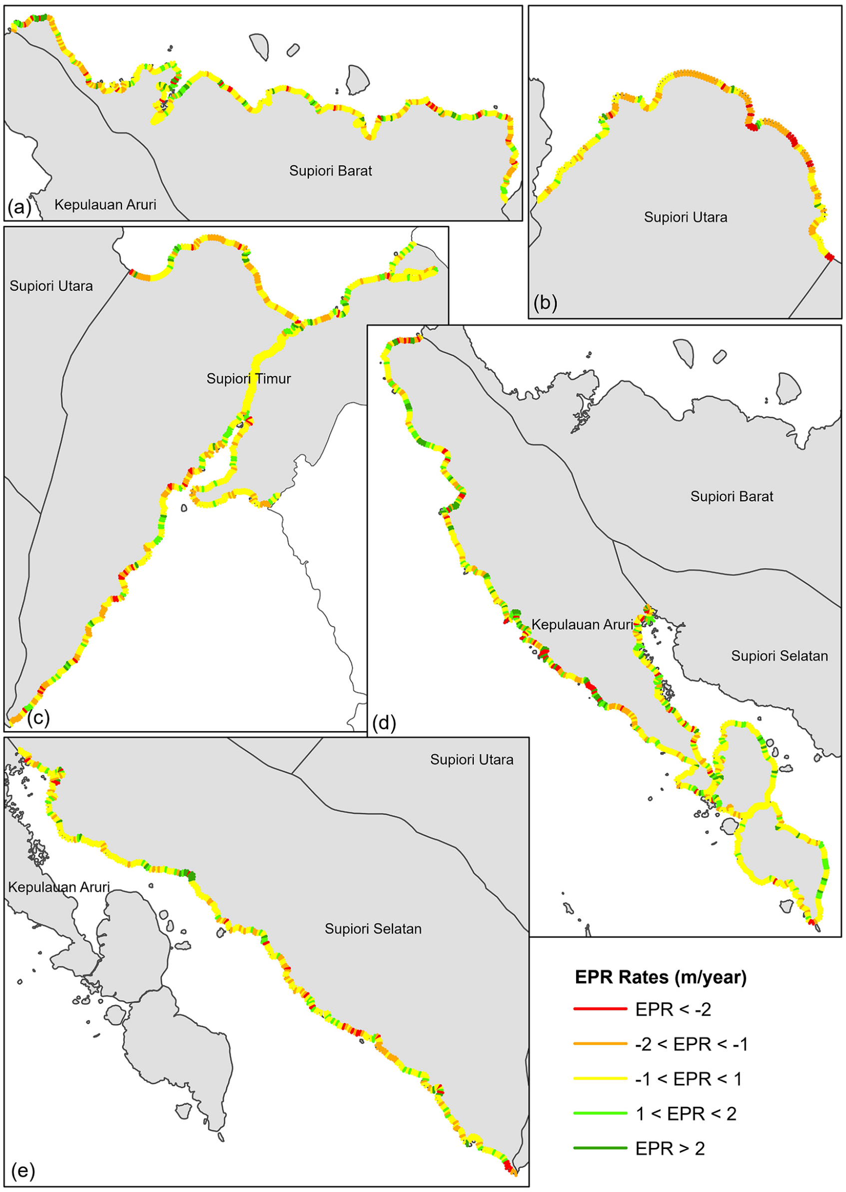

Figure 4. Spatial distribution of EPR rates in Supiori Regency in the period 2013 to 2023: (a) Supiori Barat District, (b) Supiori Utara District, (c) Supiori Timur District, (d) Kepulauan Aruri District, and (d) Supiori Selatan District

while the low abrasion category was mostly found on the border between Supiori Barat District and Kepulauan Aruri District (in the west) and Supiori Utara District (in the east). The categories of low accretion and high accretion are dominant in the western part of the coast of Supiori Barat District. In Supiori Utara District, the stable and low abrasion categories are very dominant, where the dominant stable category is found towards the border with Supiori Barat District and the border with Supiori Timur District, while the low abrasion category is dominant in the central part of the coastal area of Supiori Utara District (Figure 4b). In Figure 4c, it is clear that the stable category is very dominant in the Sorendiweri Strait, which separates Supiori Island and Biak Island (except in the outer part of the strait with varying levels of abrasion and accretion). The northern and southern parts of Biak Island are more dominated by the stable category. In contrast, the southern part of Supiori Island varies greatly (abrasion, stability, and accretion), whereas the stable and low abrasion categories dominate the northern part. In the Kepulauan Aruri District, there is a difference in the rate of change of the coastline between the mainland and the two islands included in this study area (Figure 4d). The stable category is dominant on Sowek Island and Ineki Beba Island in the Kepulauan Aruri District, while it is more varied on the mainland. Stable and low accretion categories are often found in the bay to the border with Supiori Selatan District. As for the abrasion category, both low and high abrasions are mostly found near the border with the Supiori Barat District and in the southern part of the mainland of Supiori Island in the Kepulauan Aruri District. As for the Supiori Selatan District, the stable category is more dominant, although many are found in the central to the south towards the border with Supiori Timur District (Figure 4e).

DISCUSSION

The dynamics of shoreline change is a serious problem in almost all coastal areas. Shoreline change is important in assessing coastal vulnerability (Pendleton et al., 2010). In this context, changes in coastline are used as an indicator of the stability of coastal areas due to climate change and as a capacity for coastal resilience (Koroglu et al., 2019). This study analyzed the degree of shoreline change to determine the trend of shoreline movements caused by abrasion and accretion in the study area. From 2013 to 2023, the coastline in the study area tends to experience abrasion rather than accretion. However, when viewed in terms of the rate of change, most of the coastline is in the stable category. This is greatly influenced by the morphology and protection of coastal areas. The morphology of various coastal areas (such as bays and headlands) will have different responses to various forms of change due to abrasion or accretion (Koroglu et al., 2019). In addition, the morphology of coastal areas in the form of bays has smaller wave heights than headlands or open coastal areas (Dronkers, 2005). In this study, the coastal area in the Sorendiweri Strait, which is protected from waves, is categorized as stable; even a movement in the coastline does not occur in the strait. Likewise, coastal morphology is in the form of a closed bay, where the tendency to change lines due to abrasion rarely occurs, and what actually happens is the buildup or accumulation of sediment carried by run-off flows, causing sedimentation or accretion. Accretion in a coastal area can be affected by the sediment supply from river flow (Hanzu et al., 2015; Hawati et al., 2017; Fan et al., 2018). This starkly contrasts the open coastal morphology, such as in the Supiori Utara District coast (also in the eastern Supiori Timur District), where shoreline changes are dominated by abrasion. The waves can erode the beach if they come perpendicular to the shoreline for a long time. Coastal abrasion will reduce the use value and even eliminate the potential of coastal areas. Abrasion can occur if a beach under review experiences loss or reduction of sediment, where the sediment transported is greater than what was deposited (Triatmodjo, 2012).

Compared with the results of the previously conducted research on shoreline changes in Biak Numfor Regency on Biak Island (see Rumahorbo et al., 2022), the maximum distance of the shoreline movement due to abrasion in this study area is lower (-60.33 m; average -11.37 to -13.59 m) compared to Biak Numfor Regency which reached -83.65 m with a lower average range of -6.65 to -13.16 m. However, the maximum distance due to accretion is higher in this study area which reaches 92.86 m with an average range of 9.75 to 15.64 m, while in Biak Numfor Regency, it only reaches 72.33 m with an average range of 4. 64 to 8.4 m. The rate of shoreline change due to abrasion in the two districts is not significantly different, where in Supiori Regency it ranges from

-1.22 to -1.46 m/yr and in Biak Numfor Regency it ranges from -0.76 to -1.50 m/yr. This study and previous studies show that the two districts experience relatively similar coastline dynamics. This is because the morphology of the coastal areas of the two districts is relatively the same and is located in the vicinity of the Pacific Ocean. Hence, they are very vulnerable to physical processes from the ocean (waves and currents). Also, the characteristics of the same people tend to be concentrated and live around coastal areas, which can increase the pressure on coastal areas.

In general, the processes of abrasion and accretion take place slowly, but if supported by natural and human activities factors, these processes will occur very quickly. Of course, the causes of natural factors cannot be avoided. Still, they can be anticipated through the development of adaptive strategies appropriate to the conditions of coastal areas, such as the construction of breakwaters which can significantly reduce the level of abrasion (Saad et al., 2021). In addition, planting vegetation on the coast is believed to prevent abrasion, because it has a dense root system that can hold sediment particles (Hartati et al., 2016). Coastal vegetation can act as a barrier to sea waves that lead to the beach.

CONCLUSIONS

The study of shoreline changes from multitemporal remote sensing data integrated with a Geographic Information System is a very effective technique for managing, planning, and evaluating coastal areas. In this study, the two techniques helped to identify as well as map the locations of abrasion and accretion in the coastal area of the Supiori Regency. During the data period used, there has been abrasion up to -67.15 m with an average rate of change between -1.22 to -1.46 m/yr, while accretion is as far as 92.86 m with an average rate of change between 1.05 up to 1.68 m/yr. Abrasion and accretion in the study area are predominantly caused by natural factors, such as waves, currents, and river flows, as well as caused by non-natural factors, especially due to human activities. Information on shoreline changes in the study area is an important aid for stakeholders involved in coastal area management.

As a recommendation, it is necessary to carry out planning, strategies, and mitigation efforts to anticipate increased coastal abrasion and even against the possible impacts that can threaten coastal areas. For example, building coastal protection in high abrasion areas and planting coastal vegetation to stabilize the coastline area. In addition, increasing the awareness of communities around coastal areas in protecting and preserving the coastal environment is urgently needed.

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