Analysis of coastline changes using Sentinel 2A imagery in the coastal area of West Pandeglang, Banten

Asshobirul Huda*, *James* Parlindungan Panjaitan, and *Syamsul* Bahri Agus

Department of Marine Science and Technology, IPB University, Bogor 16128, Indonesia

Abstract. Coastline changes on the west coast of the Pandeglang Regency are caused by hydrooceanographic parameters and human activities. These changes can be observed through remote sensing. This study aimed to identify and map these changes. The shoreline of the Sentinel 2A satellite image was extracted using the *Tasseled Cap* method. The shoreline was then calculated using the *Digital Shoreline Analysis System* (DSAS) method, and field data were collected using *Ground Control Points* (GCP). The analysis of shoreline changes indicated the dominance of abrasion over accretion. The most significant abrasion occurred in Sidamukti Village at a rate of 26.65 metres per year, while the largest accretion occurred in Sukajadi Village at a rate of 24.92 metres per year. A comparison of the categories of coastline changes can indicate areas that are susceptible to large waves. This information can be used to provide both experience and knowledge to the people of the Pandeglang Regency. The study of coastline changes is an important reference for the development of coastal areas, harbors, tourism, and cultivation.

1 Introduction

This coastline represents an imaginary line between land and sea, which continuously changes in shape and position owing to the dynamics of environmental conditions [1]. The coastline undergoes constant alterations because of perpendicular currents, waves, and sediment movement parallel to the coastal area. Coastline changes are primarily driven by various hydro-oceanographic parameters, including currents, tidal waves, and winds, which can influence sediment dynamics along the shoreline, leading to processes known as abrasion and accretion [2].

Changes in coastlines can be attributed to various factors, including natural disasters such as tsunamis [3]. On December 22, 2018, a tsunami struck several coastal areas of the Banten Province, triggered by the eruption of Mount Krakatoa near the Sunda Strait. The tsunami resulted in a significant loss of life, with 426 people reporting dead, 7,202 injured, and 23 missing [4]. This natural disaster had a profound impact on specific areas, including the Panimbang District, Pagelaran District, Sukaresmi District, Labuan District, and Carita

* Corresponding author: asshobirulhuda@apps.ipb.ac.id

District. The tsunami brought about numerous changes across various domains, including coastal alterations due to beach erosion and deposition of coastal substrates [5].

One method for obtaining information about coastline changes is through the use of remote sensing techniques. Remote sensing data uses comprehensive (synoptic) observations. Remote sensing technology has developed rapidly, and has been widely used in various fields of human life. One such application is the identification and study of coastlines, and we can effectively distinguish and identify the boundaries between bodies of water and land, including their respective coastlines [6].

The study of coastline changes is important as a reference for the development of coastal areas, harbors, tourism, and cultivation [7]. Comparative analysis of the conditions before and after specific events can help identify areas susceptible to large waves and those most affected by tsunamis, thereby serving as a valuable source of knowledge and experience for the people of the Pandeglang Regency. To assess the impact of tsunamis, it is crucial to investigate changes in the coastline within the Pandeglang Regency.

Spatial analysis was employed to determine the status of coastline changes, as well as land use and land cover in the coastal areas of the Pandeglang Regency, as a means of sustaining continuous monitoring. The findings of this study can offer essential insights and serve as the foundation for devising strategies and management plans for the coastal regions of the Pandeglang Regency. Understanding coastline changes has several advantages, including enhancing navigation interests [8], managing coastal resources, preserving coastal ecosystems, facilitating sustainable development and planning of coastal areas [9], and mitigating the effects of coastline changes to prevent significant losses [10]. This study aimed to identify and map changes in coastlines on the west coast of the Pandeglang Regency, Banten.

2 Location, tools and materials research

This study was conducted in April 2023 in the coastal areas of Panimbang District, Pagelaran District, Sukaresmi District, Labuan District, and Carita District in Pandeglang, Banten (**Fig. 1**). Documentation and geomorphological survey results were provided in. Data processing and analysis were performed at the Marine Remote Sensing Laboratory, Department of Marine Science and Technology, Faculty of Fisheries and Marine Sciences, Bogor Agricultural Institute. The tools employed in this research included a Personal Computer (PC), QGIS 3.14, Envi 5.2, ODV (Ocean Data View) 4.7, and ArcGIS 10.4 for data visualization and analysis. WRPlot, Microsoft Excel, and Microsoft Word were used for spatial data processing, numerical data processing, and thesis writing, respectively. In the field observations, we utilized the Global Position System (GPS) and cameras to capture Ground Control Points (GCP), along with writing materials. The materials used in this study encompassed Sentinel-2A image, wind, bathymetry, and tidal current data.

2.1 Field data collection

The primary data used in this study consisted of Sentinel-2A satellite images. The secondary data employed included current, wind, wave, bathymetry, and tidal data. Field data were collected using Ground Control Points (GCP) and on-site observations conducted at locations where coastline changes were observed.

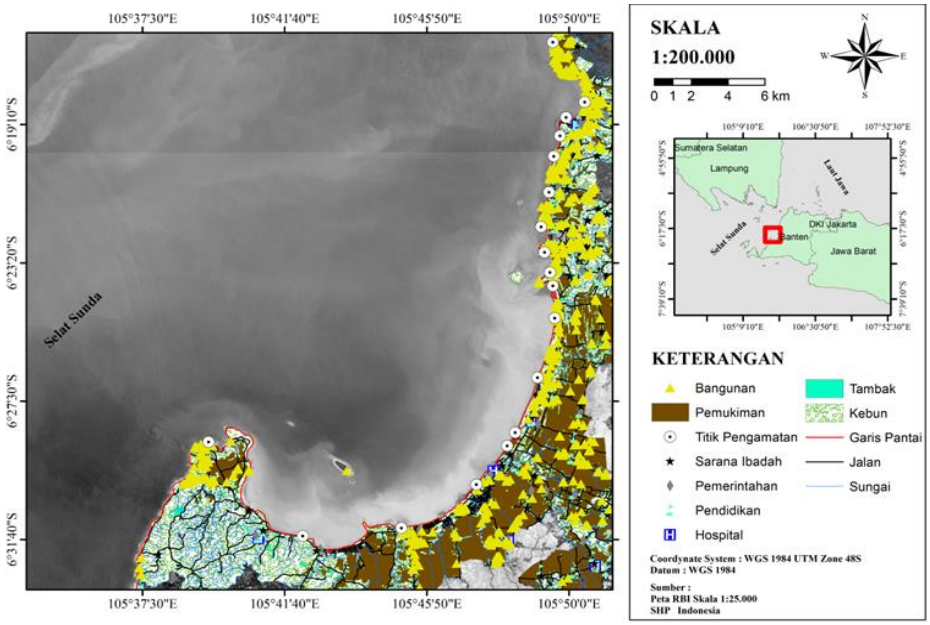


Fig. 1. Research Location Map.

2.2 Shoreline extraction

The research process begins with the initial step of defining the image area of interest (AOI) to focus on the specific study location. Subsequently, the image was processed using the shoreline extraction technique outlined in [11]. This technique involves the application of a *Normalized Difference Vegetation Index* (NDVI) algorithm, which utilizes a composite of the *red band* and *near-infrared* (NIR) to assess the level of *greenness* and classify vegetation areas. The *Tasseled Cap* transformation, as reported by [11], demonstrated an accuracy rate of 97%.

$$\mathrm{NDVI} = \frac{\mathrm{NIR-Red}}{\mathrm{NIR+Red}}$$

The subsequent step involves the application of shoreline extraction transformation to assess the *brightness*, *greenness*, and *wetness*. This transformation relies on a composite of specific bands, including *blue, green, red, Near Infrared* (NIR), *Short Wave Infrared-1* (SWIR-1), and *Short Wave Infrared*-2 (SWIR-2) *bands*. The formulas for these three *Tasseled Cap* components are based on [12].

The results of NDVI, *brightness, greenness and wetness* were used to classify the images into land and sea classes. *Unsupervised classification* is a classification in which classes are formed using a *category creation technique for land and sea*. The classes or clusters formed in this classification are highly dependent on the data itself, namely, grouping pixels based on their similarity or spectral similarity into 10 land cover classes so that separate classes are obtained between land and sea [13].

Next, a pixel-based classification method is employed, utilizing a *supervised classification* algorithm to differentiate between land and sea, based on input un*supervised classification* layers generated from corrected images. In the land-sea classification stage, the land class is assigned a value of 0, while the sea is designated as 10, as per [14]. Subsequently, the shoreline delineation process transforms the boundary between land and sea into an

interpretable coastline. The final stage involved overlaying the coastlines for 2017, 2018, 2019, 2020, 2021, and 2022.

2.3 Tidal correction

The coastline data for 2017, 2018, 2019, 2020, 2021, and 2022, prior to overlay, were adjusted for tidal variations to minimize errors stemming from disparities in tidal conditions during image acquisition. In this study, the sea-level height difference during image capture was calculated relative to the *Mean Sea Level* (MSL), and the resultant shoreline shift was quantified, as illustrated in **Fig. 3**. The final step involves overlaying the coastlines from 2017 to 2022, which are subsequently employed in the *Digital Shoreline Analysis System* (DSAS) analysis.

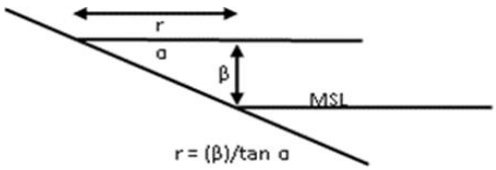


Fig. 2. Scheme of tidal correction process.

2.4 DSAS analytical

The DSAS method is a software application used to calculate coastline changes. It was developed by the *Environmental Systems Research Institute* (ESRI) and the *United States Geological Survey* (USGS), and is part of the *Geographic Information System* (GIS) software suite. The DSAS is capable of calculating the rate of change statistics for the time series of shoreline vector data. The methodology was initiated by determining the distance at the coastline change point using a single transect (ST) created with the buffer tool. Subsequently, the combined baseline and shoreline data were processed using the DSAS method, resulting in transect lines perpendicular to the sea (seaward) and landward.

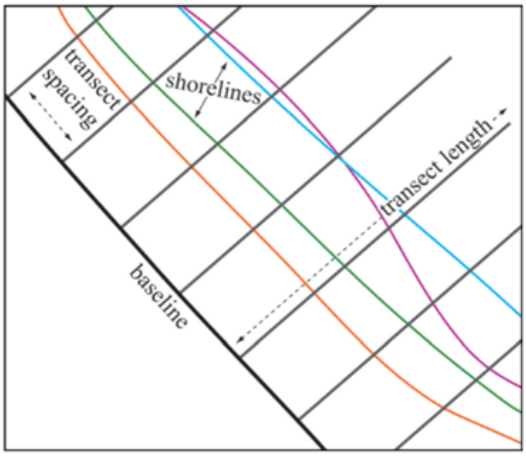


Fig. 3. Illustration of parameter creation DSAS.

This stage was employed to establish transects and determine the extent of shoreline changes. The outcomes of this process are referred to as *Net Shoreline Movement* (NSM). Subsequently, the next step involves calculating the annual average changes, which is

referred to as the *End Point Rate* (EPR). The measurement of coastline change rates utilizes *End Point Rate* (EPR) calculations in meters per year, as well as *Net Shoreline Movement* (NSM) in meters.

The rate of change determined was subsequently classified as either abrasion or accretion, depending on the yearly changes in the coastline. Litbang PU Pengairan applies a weighting system based on four classes: light, medium, heavy, and very heavy, in accordance with field conditions. This study specifically evaluated the types of abrasion and accretion damage, and the details are presented in **Table 1.**

Table 1. Coastline changes category.

No.	Coastline Changes (m/year)	Category
1	< -10	Very Heavy Abrasion
2	-9.99 – -5	Heavy Abrasion
3	-4.99 – -2	Medium Abrasion
4	-1.99 – 0	Mild Abrasion
5	0 – 2	Mild Accretion
6	2 – 5	Medium Accretion
7	5 – 10	Heavy Accretion
8	> 10	Very Heavy Accretion

2.5 Bathymetry data

Bathymetry data obtained from National Bathymetry are stored in raster format, specifically as *. tif files. Subsequently, these data were imported into ArcMap 10.4 software and mapped using the bilinear interpolation method. The bathymetric values are then segmented into multiple depth contours. The bilinear interpolation method calculates new pixel values based on the average of the four neighboring pixels. Additionally, bathymetry data were employed to create transverse profiles of the water depth at each observation location.

2.6 Current data

The current data is in .nc format, which can be processed using the Ocean Data View (ODV). The current data contain information in the form of time, longitude, latitude, u and v components, as well as z components. Wind data include u and v wind direction components and station positions. Subsequently, the data were converted into. txt format and corrections were performed using Microsoft Excel.

2.7 Wind data

Wind direction and speed data are presented in. nc format and comprises grid values based on latitude and longitude, representing the zonal (u) and meridional (v) wind speed components. To process the wind direction and speed, WRPLOT software was used to generate wind graphs for a year. Furthermore, the current data were processed using QGIS 3.14 software to visualize the speed and direction of currents during the west and east seasons at the research location.

2.8 Tidal data

The tidal data were saved in the *. txt format and was subsequently processed using Microsoft Excel using the Admiralty method. The Admiralty method is a tidal calculation approach that allows for the determination of two harmonic constants, amplitude (A) and phase difference (go), enabling the analysis of tidal types.

3 Results and discussion

The West Coast of Pandeglang Regency in Banten, particularly in five sub-districts – Panimbang District, Pagelaran District, Sukaresmi District, Labuan District, and Carita District–serves as a natural tourist destination, featuring mangrove forests, fishing communities, river estuaries, and pond areas (**Fig. 4**). In general, the geomorphological types on the west coast of the Pandeglang Regency consist of sandy and rocky beaches, as depicted in the figure.

(a) (b)

Fig. 4. Sandy beach in Carita village (a), and Rocky beach in Sukarame village (b).

3.1 Wind conditions

The pattern of wind direction and speed on the West Coast of Pandeglang for the time period from 2017 to 2022 is presented in the form of a wind rose. The dominant wind is from the north at 34%, from the northeast at 20.4%, from the east at 20.4%, and from the west at 6.6%. For wind speeds on the coast, the dominant ones come from the north and east, ranging between 0.5 – 5.7 m/s as in (**Fig. 5**). The hand of the wind rose shows the direction from which the wind is blowing, while the color shows the wind speed class (m/s). The study area on the West Coast of Pandeglang over a period of six years showed that the winds that blow most often come from the north and east (**Fig. 6**). Wind has a huge influence on the process of coastline changes that occur because it is one of the main factors generating waves in the sea. The wind speed influences the height of the generated waves, whereas the wind direction influences the direction of wave movement [15].

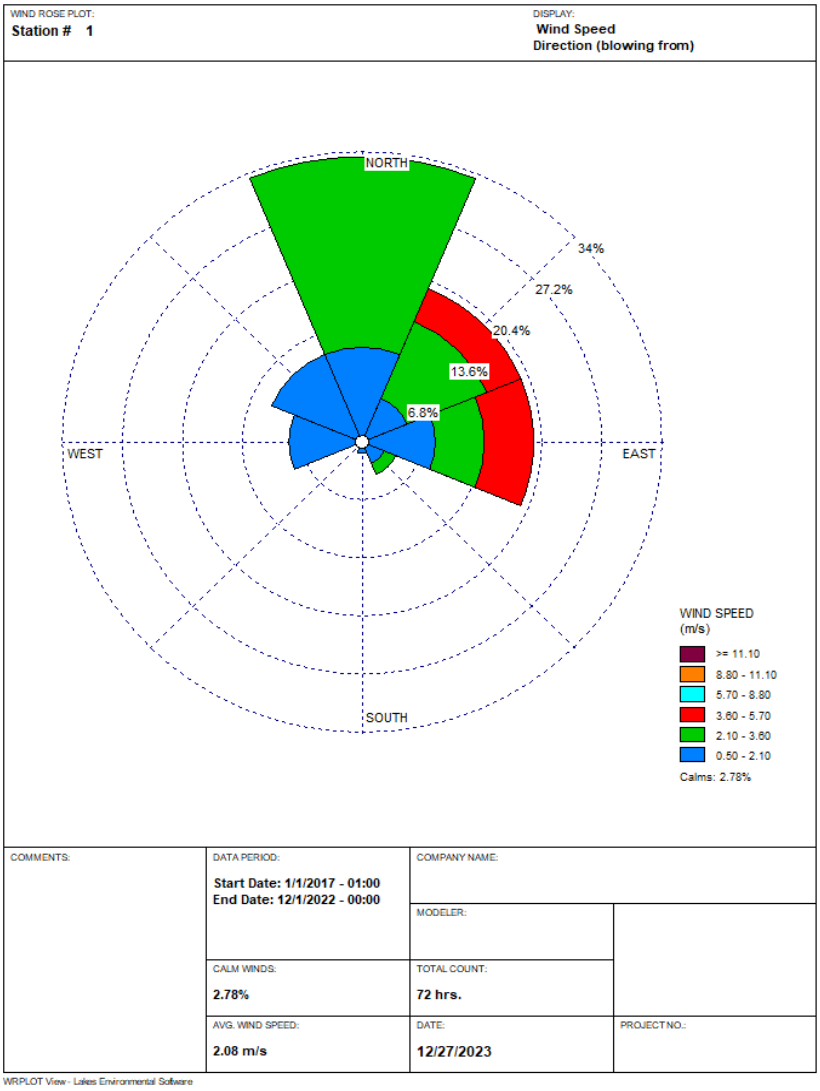


Fig. 5. *Wind rose* at 2017 – 2022 years.

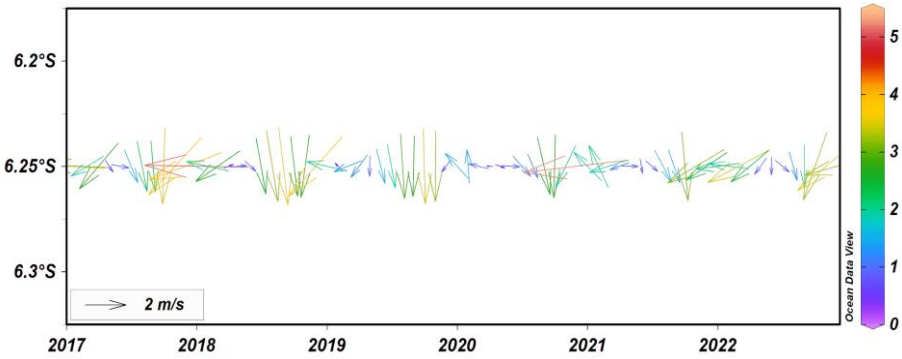
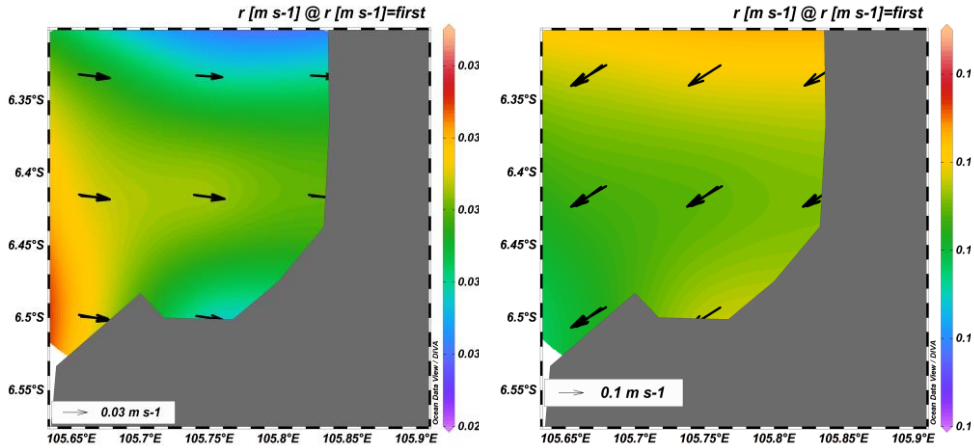


Fig. 6. Stick Plot Wind Conditions.

3.2 Currents conditions

The results of the analysis of data on the direction and average speed of currents in 2017–2022 in the waters of the west coast of Pandeglang Regency show that the movement of the current direction in the west season moves towards the east, whereas in the east season, the current moves towards the west (**Fig. 7**). The speed of water currents during the West season ranges from 0.03 – 0.038 m/s, while in the East season, it ranges from 0.09 – 0.14 m/s (Figure 7). The dominant current direction was parallel to the coastline (longshore current). Currents that run parallel to the coast can have a significant impact on changes in the coastline because they can transport sediment along the coastline [16]. When movement and deposition of sediment occur, it causes a reduction in sediment (abrasion) or an addition of sediment (accretion) in a coastal area.



(a) (b)

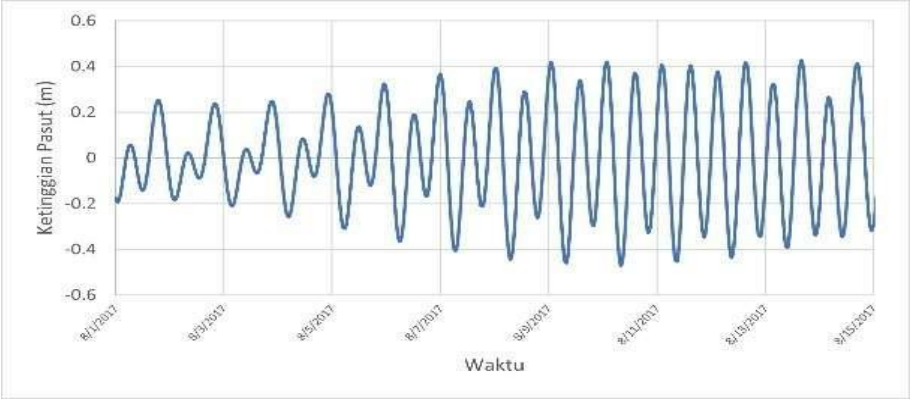
Fig. 7. Distribution of west season currents (a), and east season (b).

3.3 Tidal conditions

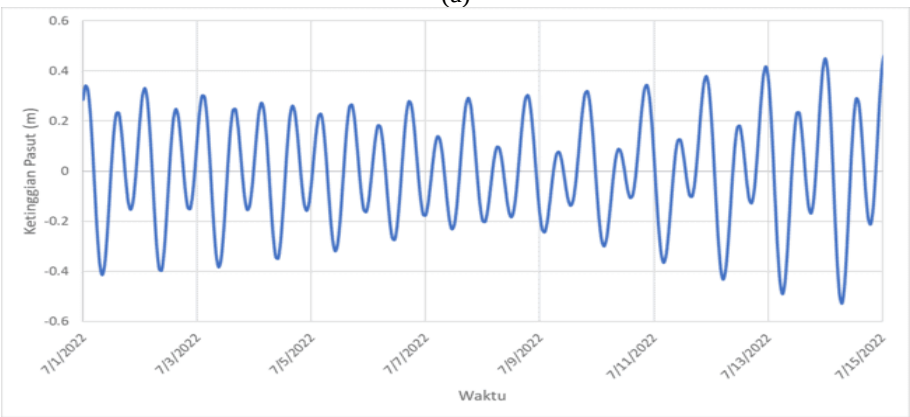
Tides refer to the periodic rise and fall of sea level. Tidal height values were used for tidal corrections to ensure that the coastline aligned with the mean sea level (MSL). **Fig. 8** illustrates the tidal height values for 15 days in August 2017, with the highest tidal value reaching 0.427 m and the lowest ebb value at -0.47 m. In August 2022, the highest tidal value was 0.465 m and the lowest ebb value was -0.537 m, as presented in. Tides can significantly impact coastlines by altering sedimentation patterns and causing shallowing at river mouths, which in turn leads to changes in coastline positions [17].

3.4 Bathymetry

The waters surrounding the West Coast of Pandeglang exhibit a gradually sloping bathymetric contour at depths of less than 10 m. The areas on the West Coast of Pandeglang, namely the Panimbang, Pagelaran, Sukaresmi, Labuan, and Carita Districts, are situated within the lowlands. The topography of the west coast of Pandeglang is characterized by sloping terrain with a sandy beach substrate. This can be observed by the variations in water depth coloration along the coastline (**Fig. 9**). Beaches with gentle slopes and shallow waters are more susceptible to sediment particle movement than steep beaches, as discussed in [18].



(a)



(b)

Fig. 8. Tidal Conditions in Coastal West, Pandeglang.

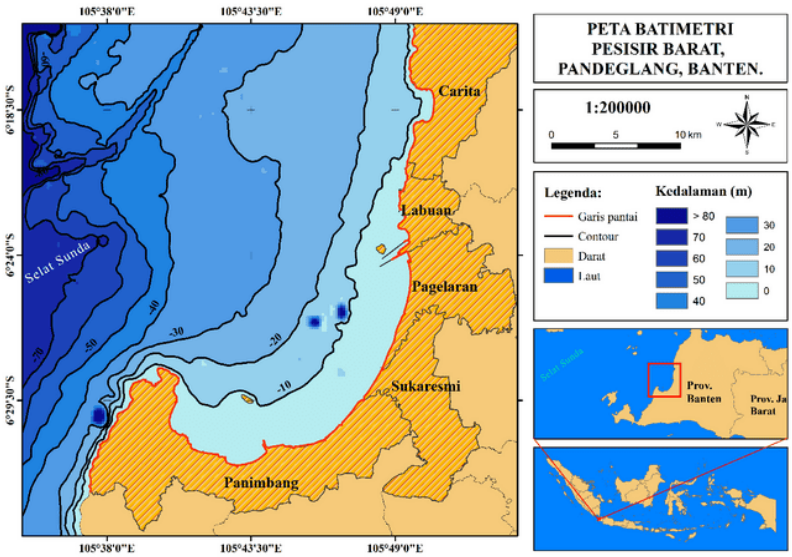


Fig. 9. Map of Bathymetric Conditions of West Coast, Pandeglang.

3.5 Shoreline extraction

The satellite image used in this Sentinel-2A image, has undergone basic geometric correction and had a resolution of 10 m. The shoreline extraction results obtained through the tasseled cap method using the shoreline extraction technique generated various extraction data including *wetness*, *greenness*, *brightness*, and NDVI, as illustrated in **Fig. 10**. These extraction results yielded multiple classes that allowed for differentiation between land areas and water bodies.

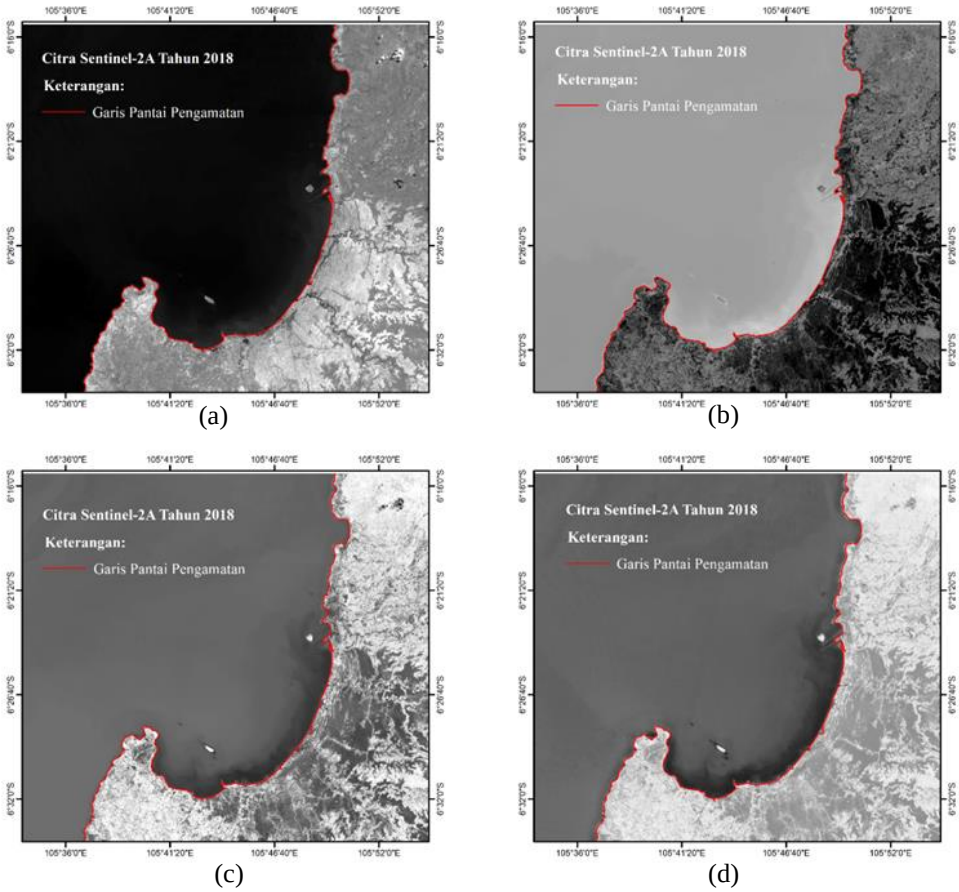


Fig. 10. Transformation *Shoreline Extraction* (a) *wetness* (b) *greenness* (c) *brightness* dan (d) NDVI.

The data extraction results for *wetness*, *greenness*, *brightness*, and NDVI yielded multiple values. The subsequent transformation involved utilizing the *Category creation for land and sea* to generate an un*supervised classification*. These results were further categorized into 10 land cover classes, allowing for the distinction between land and sea, as depicted in **Fig. 11**.

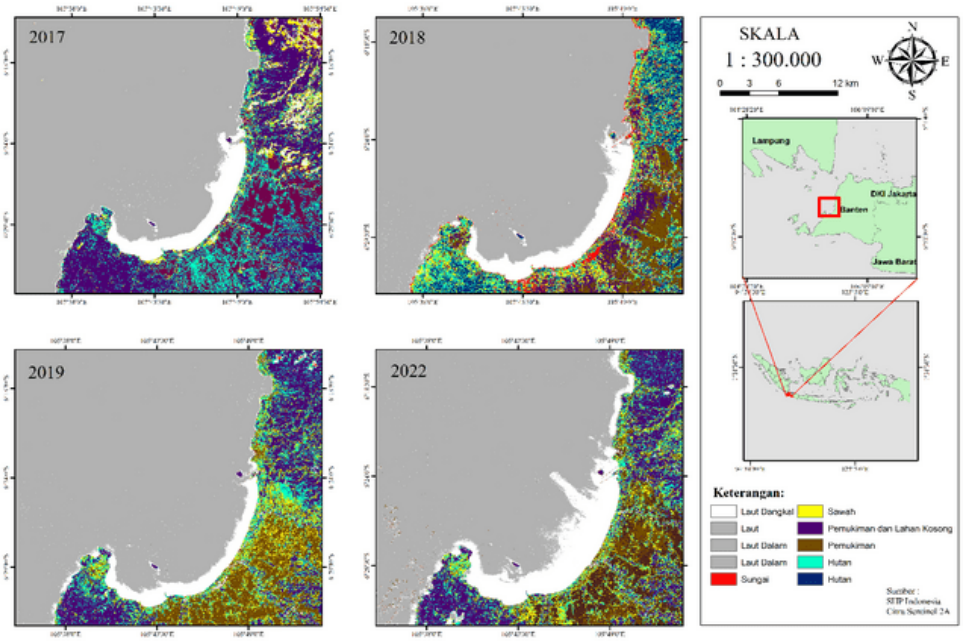


Fig. 11. The Result *Unsupervised Classification.*

The following classification results, utilizing the" classify land and sea' technique, are reclassified into two classes, resulting in a land class and a sea class, as shown in **Fig. 12**. The *supervised classification* technique is an analytical method that can identify pixels within each class and represent various patterns formed by these classes, as discussed in [19].

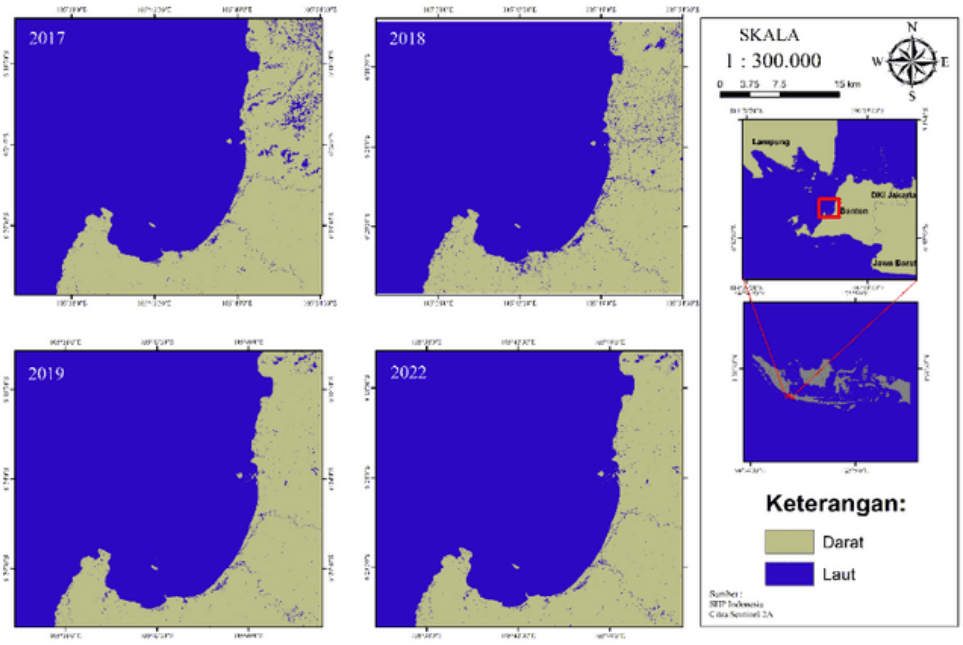


Fig. 12. The Result *Classify Land and Sea.*

The raster data results were subsequently converted into vector data using the 'shorelines features' technique, enabling the extraction of shoreline features technique, enabling the extraction of shoreline features. The coastline extraction process was conducted for each image from 2017 to 2022. The coastline results were adjusted to account for tidal variation. The corrected coastline extraction results are shown in **Fig. 13**.

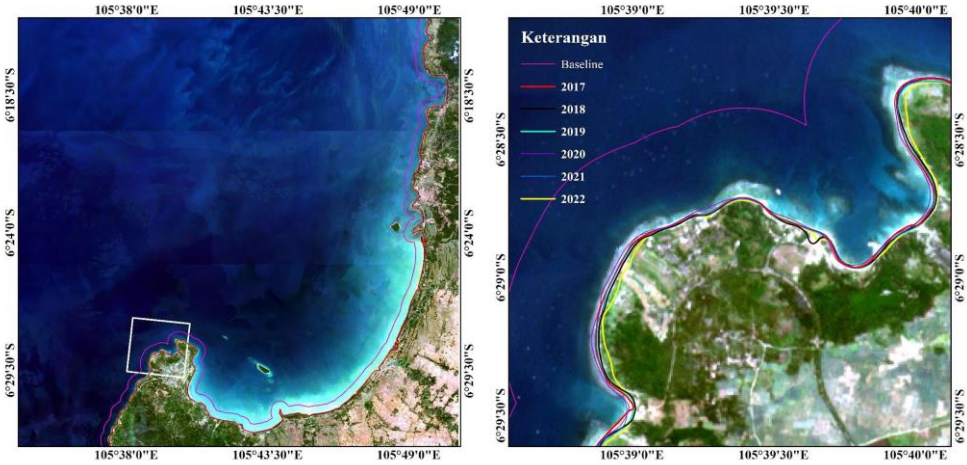


Fig. 13. The Result *Shoreline Extraction.*

3.6 Coastline changes

The shoreline changes were derived by overlaying the shoreline extraction results from 2017 to 2022. These results were categorized into two components: *Net Shoreline Movement* (NSM) and *End Point Rate* (EPR). *Net Shoreline Movement* represents the distance between the oldest and newest coastlines, whereas the *End Point Rate* is the outcome of calculating the annual average change [11]. The outcomes of the DSAS process for the study area were distributed across multiple villages, as depicted in **Fig. 14**. The analysis was conducted on a per-village basis to determine the average coastline change distances and identify areas where the changes were most pronounced.

The results of the analysis of the distance changes along the coastline are shown in **Table 2**. Sukarame Village experienced changes in the form of a maximum abrasion of 13.51 m/year, and a maximum accretion of 0 m/year because it did not have a number of transects. The coastline changes that occur in Sukarame Village are dominantly abrasion and are included in the very heavy category. Sukajadi Village experienced changes in the form of a maximum abrasion of 4.2 m/year, and accretion of 24.92 m/year. The coastline changes that occurred in Sukajadi Village were predominantly accretions and were included in the very severe category. Carita Village experienced changes in the form of maximum abrasion of 3.1 m/year, and maximum accretion of 10.83 m/year. The coastline changes that occur in Carita Village are predominantly accretions and are included in the very severe category.

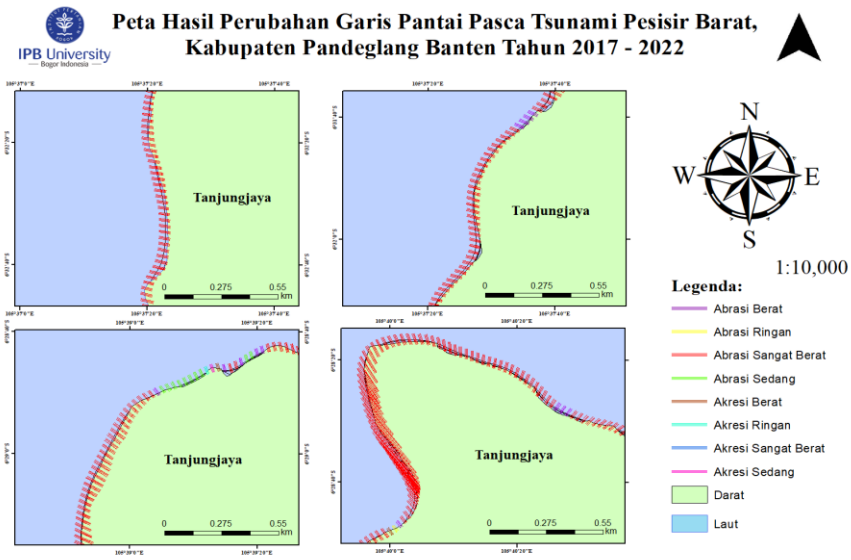


Fig. 14. Coastline Changes That Occurred in Tanjungjaya Village.

Table 2. Coastline changes 2017-2022 years.

Village	Coastline Changes (m) 2017 – 2022 years				Average Coastline Change (m/year)			
	Abrasion		Accretion		Abrasion		Accretion	
	Max	Min	Max	Min	Max	Min	Max	Min
Sukarame	-67.54	-10.24	N/A	N/A	-13.51	-2.08	N/A	N/A
Sukajadi	-21	-10.37	124.57	14.9	-4.2	-2.11	24.92	2.87
Carita	-15.51	-10.96	54.16	11.5	-3.1	-2.23	10.83	2.34
Banjarmasin	-43.32	-10.63	N/A	N/A	-8.66	-2.16	N/A	N/A
Pejamben	-77.13	-10.26	N/A	N/A	-15.43	-2.09	N/A	N/A
Caringin	-28.58	-10.39	69.33	11.72	-5.72	-2.11	13.87	2.34
Teluk	-97.59	-10.13	N/A	N/A	-19.52	-2.06	N/A	N/A
Cigondang	-84.01	-10.79	29.29	29.29	-16.8	-2.2	5.86	5.86
Sukamaju	-59.49	-10.99	38.52	12.39	-11.9	-2.24	7.7	2.52
Margasana	-16.8	-11.39	N/A	N/A	-3.36	-2.32	N/A	N/A
Margagiri	-41.24	-10.32	102.64	14.18	-8.25	-2.10	20.52	2.89
Tegalpapak	-90.61	-10.36	26.04	11.99	-18.1	-2.11	5.21	2.40
Cibungur	-125.23	-12.78	N/A	N/A	-25.05	-2.60	N/A	N/A
Sidamukti	-133.25	-12.09	48.1	38.51	-26.65	-2.46	9.62	7.70
Panimbang jaya	-53.43	-10.59	24.52	10.94	-10.69	-2.16	4.9	2.23
Mekarjaya	-110.72	-11.21	39.89	10.45	-22.14	-2.28	7.98	2.13
Citeureup	-34.79	-12.31	66.04	10.95	-6.96	-2.50	13.21	2.23
Tanjungjaya	-131.22	-10.54	39.78	10.74	-26.24	-2.14	7.96	2.18

Note : Abrasion and Accretion = Shoreline Changes, N/A = Number of Transects 0.

Banjarmasin Village experienced changes in the form of a maximum abrasion of 8.66 m/year, and maximum accretion of 0 m/year because it did not have a number of transects. The coastline changes that occur in Banjarmasin Village are predominantly abrasion and fall into the heavy to very heavy categories. Pejamben Village experienced changes in the form of maximum abrasion of 15.43 m/year, and maximum accretion of 0 m/year because it did not have a number of transects. The coastline changes that occur in Pejamben Village are predominantly abrasion, and are included in the very heavy category. Caringin Village experienced changes in the form of maximum abrasion of 5.72 m/year, and maximum accretion of 13.87 m/year. The coastline changes that occurred in Caringin Village were predominantly accretions and were included in the very severe category.

Teluk Village experienced changes in the form of maximum abrasion of 19.52 m/year, and maximum accretion of 0 m/year because it did not have a number of transects. The coastline changes that occur in Teluk Village are predominantly abrasion and are included in the very heavy category. Cigondang Village experienced changes in the form of a maximum abrasion of 16.8 m/year, and accretion of 5.86 m/year. The coastline changes that occur in Cigondang Village are predominantly abrasion, and are included in the very heavy category. Sukamaju Village experienced changes in the form of a maximum abrasion of 11.9 m/year, and accretion of 7.7 m/year. The coastline changes that occur in Sukamaju Village are predominantly abrasion and are included in the very heavy category. Margasana Village experienced changes in the form of a maximum abrasion of 3.36 m/year, and maximum accretion of 0 m/year because it did not have a number of transects. The coastline changes that occur in Margasana Village are predominantly abrasion and fall into the mild-to-moderate category. Margagiri Village experienced changes in the form of a maximum abrasion of 8.25 m/year, and maximum accretion of 20.52 m/year. The coastline changes that occurred in Margagiri Village were predominantly accreted and were included in the very severe category. Tegalpapak Village experienced changes in the form of a maximum abrasion of 18.1 m/year, and accretion of 5.21 m/year. The coastline changes that occur in Tegalpapak Village are predominantly abrasion and are included in the very heavy category.

Cibungur Village experienced changes in the form of a maximum abrasion of 25.05 m/year, and a maximum accretion of 0 m/year because it did not have a number of transects. The coastline changes that occur in Cibungur Village are predominantly abrasion and are included in the very heavy category. Sidamukti Village experienced changes in the form of a maximum abrasion of 26.65 m/year, and accretion of 9.62 m/year. The coastline changes that occur in Sidamukti Village are dominantly abrasion and are included in the very heavy category. Panimbangjaya Village experienced changes in the form of a maximum abrasion of 10.69 m/year, and accretion of 4.9 m/year. The changes in the coastline that occurred in Panimbangjaya Village were predominantly abrasion and were included in the very heavy category.

Mekarjaya Village experienced changes in the form of maximum abrasion of 22.14 m/year, and maximum accretion of 7.98 m/year. The coastline changes that occur in Mekarjaya Village are predominantly abrasion and are included in the very heavy category. Citeureup Village experienced changes in the form of a maximum abrasion of 6.96 m/year, and maximum accretion of 13.21 m/year. The coastline changes that occurred in Citeureup Village were predominantly accretions and were included in the very severe category. Tanjungjaya Village experienced changes in the form of a maximum abrasion of 26.24 m/year, and accretion of 7.96 m/year. The coastline changes that occur in Tanjungjaya Village are predominantly abrasion and are included in the very heavy category. The largest change in coastline in the form of abrasion occurred in Sidamukti Village (26.65 m/year. The largest value of change in the form of accretion occurred in Sukajadi Village, at 24.92 m/year.

The results that occur in coastline changes are dominated more by abrasion than by accretion. Significant differences occur because of factors that influence abrasion and accretion, namely currents, wind, waves, tides, relatively shallow bathymetric conditions, and gentle land slopes. Abrasion is thought to be the result of waves crashing towards the coast, causing beach erosion in the village area, while the accretion that occurred in the 2017-2022 period is thought to be due to the presence of river basins that carry mud and spread across the coastal area, resulting in additional material. and the existence of jetties that can hold the sediment material carried by currents and settle [20]. Another factor that causes abrasion and accretion is large-scale natural phenomena in a short period of time, such as the natural tsunami disaster in 2018.

4 Conclusion

The coastline on the west coast, Pandeglang Regency, and Banten experienced more abrasion than accretion did. Villages that experienced coastline changes in the moderate abrasion category were Sukajadi Village, Carita Village, and Margasana Village. Villages that experienced changes in the coastline in the heavy abrasion category were Banjarmasin, Caringin, Margagiri, and Citeureup. The villages of Sukarame, Penjamben, Teluk, Cigondang, Sukamaju, Tegalpapak, Cibungur, Sidamukti, Panimbangjaya, Mekarjaya, and Tanjungjaya. Meanwhile, the village that experienced changes in the coastline in the moderate accretion category was Panimbangjaya. Villages that experienced changes in the coastline in the heavy accretion category were Tanjungjaya, Mekarjaya, Sidamukti, Tegalpapak, Sukamaju, and Cigondang. Villages that experienced changes in coastlines in the very heavy accretion category were Citeureup, Margagiri, Caringin, Carita, and Sukajadi. Relatively shallow bathymetric conditions, currents, wind, waves, tides, and the natural disaster phenomenon of the tsunami in 2018 were factors that changed the coastline. A comparison of categories of coastline changes can describe areas that are prone to being hit by large waves so that they can be used as experience and knowledge for the people of the Pandeglang Regency. Research on changes in coastlines is important as a reference for the development of coastal areas and ports, tourism, fishing, and cultivation activities.

References

1. N.N. Salghuna, S.A. Bharathvaj, Aquat Procedia. **4**, 317–324 (2015)
2. D. Reeve, A. Chadwick, C. Fleming, *Coastal Engineering Processes, Theory and Design Practice* (CRC Taylor, Francis Group, 2018)
3. N. Hidayati, R.W. Paluphi, M.A. Asadi, H.S. Purnawali, J. Ilmu-ilmu Perairan. **6**, 31-43 (2017)
4. W. Hendriyono, M. Wibowo, A.l. Hakim, D.C. Istiyanto, Earth and Planetary Science. **14**, 166-178 (2015)
5. D. Fitriana, N. Oktaviani, I.U. Khasanah, J. Meteorologi Klimatologi dan Geofisika. **6**, 38-48 (2019)
6. A. Emily. Himmelstoss, E. Rachel. Henderson, Meredith, Kratzmann, S. Amy, Farris, J. Geological Survey. **10**, 1-4 (2018)
7. Y. Sulistriani, *Perubahan daratan pantai dan penutupan lahan pasca tsunami secara spasial dan temporal di pantai Pangandaran, Kabupaten Ciamis Jawa Barat* (Institut Pertanian Bogor, Bogor, 2019)

8. K.H. Ekosafitri, E. Rustiadi, F. Yulianda, J. Regional and Rural Development Planning. **6**, 38-48 (2019)
9. M.S. Suhana, I.W. Nurjaya, N. Metta, N. Natih, J. Teknologi Perikanan dan Kelautan. **7**, 19-24 (2016)
10. A. Arifin, M. Awaluddin, F.J. Amarrohman, J. Geodesi Undip. **1**, 156–165 (2019)
11. N.M.N. Natih, R.A. Pasaribu, M.S. Sangadji, E.E. Kusumanigrum, J. earth and environmental science. **429**, 1-5 (2020)
12. H. Daruwedho, B. Sasmito, A.F. Janu, J. Geodesi Undip. **5**,147-158 (2016)
13. R. Rahmat, M. Masita, R. Nur, J. Chart Datum **5**, 155-168 (2019)
14. P. Aryastana, I.M. Ardhanta, N.K.A. Agustini, J. Fondasi. **6**, 100-111 (2017)
15. A. Suo,H. Ma, F. Li, B. Wei, Y. Lin, J. Zhao, J. Image and Video Processing. **84**, 1-12 (2018)
16. A.W. Dwinanto, N.P. Purba, S.A. Harahap, M.L. Syamsudin, J. Perikanan dan Kelautan **3**, 152-160 (2017)
17. N. Anggraini, S. Marpaung, M. Hartuti, J. Penginderaan Jauh dan Pengolahan Data Citra Digital. **14**, 65-78. (2017)
18. Darmiati, I.W. Nurjaya, A.S. Atmadipoera, J. Ilmu dan Teknol Kelaut Trop. **12**, 211–222 (2020)
19. M.N. Khafidlin, B. Sasmito, P. Yudo, J. Geodesi Undip. **7**, 152-158 (2016)
20. S.H. Nugroho, Oseana. **38**, 63-74 (2014)