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17 Years of Coastline Changes Observation in the Northern Part of Rupat Island using Landsat 7 ETM + Time Series Imagery (2000-2017); A Case Study of the Country's Border between Indonesia - Malaysia

(Pemerhatian Perubahan Garis Pantai 17 Tahun di Bahagian Utara Pulau Rupat menggunakan Landsat 7 ETM + Imej Siri Masa (2000-2017); Suatu Kajian Kes Sempadan Negara antara Indonesia - Malaysia)

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ABSTRACT

Rupat Island is the outermost part of Indonesia which borders Malaysia. This island is part of Bengkalis Regency, Riau Province, located at 02° 4.911'N-101° 27,191'E. This study uses primary data from field observations and secondary data in Landsat 7ETM+ Time Series image data and other supporting data. The descriptive method is carried out in the form of geological interpretation in the field, determination of validation points and then analysis using GIS/visual interpretation to obtain shoreline changes that occurred in the northern part of Rupat Island from the year 2000 to 2017. Additional data used were sea current and pattern and wind direction and speed. Validation points are used to obtain detailed calculations related to this coastline change: Tanjung Api area to Teluk Rhu and Tanjung Lapin get the measurement results experienced the most accretion occurred in 2013 was 167.21 m, and the most abrasion in 2016 was 72.77 m. The biggest change occurred in 2013 when the accretion occurred at 375.5 Ha, and the most abrasion occurred in 2014 at 50.63 Ha. Meanwhile, for shoreline changes, the minimum annual coastline length in 2004 was 19.04 km, and the normal coastline length in 2015 was 28.26 km. The maximum length of the coastline occurred in 2013 was 36.53 km.

Keywords: Abrasion; accretion; border of Indonesia - Malaysia; geological mapping; coastline changes; Landsat 7 ETM

ABSTRAK

Pulau Rupat adalah bahagian paling luar Indonesia yang bersempadan dengan Malaysia. Pulau ini merupakan sebahagian daripada Kabupaten Bengkalis, Wilayah Riau, terletak pada 02° 4.911'N-101° 27,191'E. Kajian ini menggunakan data primer daripada pemerhatian lapangan dan data sekunder daripada data imej Landsat 7 ETM + Siri Masa dan data sokongan lain. Kaedah deskriptif dijalankan dalam bentuk interpretasi geologi di lapangan, penentuan titik pengesahan dan seterusnya analisis menggunakan GIS/interpretasi visual untuk mendapatkan perubahan garis pantai yang berlaku di bahagian utara Pulau Rupat dari tahun 2000 hingga 2017. Data tambahan yang digunakan ialah arus dan corak laut serta arah dan kelajuan angin. Titik pengesahan digunakan untuk mendapatkan pengiraan terperinci berkaitan perubahan garis pantai ini: Kawasan Tanjung Api ke Teluk Rhu dan Tanjung Lapin mendapat hasil pengukuran yang mengalami penambahan paling banyak, berlaku pada tahun 2013 ialah 167.21 m, dan lelasan paling banyak pada tahun 2016 iaitu 72.77 m. Perubahan terbesar berlaku pada tahun 2013 apabila pertambahan berlaku pada 375.5 ha dan lelasan paling banyak berlaku pada tahun 2014 iaitu 50.63 ha. Manakala bagi perubahan garis pantai, panjang garis pantai tahunan minimum pada tahun 2004 ialah 19.04 km dan panjang garis pantai biasa pada tahun 2015 ialah 28.26 km. Panjang maksimum garis pantai yang berlaku pada tahun 2013 ialah 36.53 km.

Kata kunci: Landsat 7 ETM; lelasan; pemetaan geologi; pertambahan; perubahan garis pantai; Sempadan Indonesia - Malaysia

Introduction

Indonesia is an archipelagic country with a sea area of more than 75%, which reaches 5.8 million square kilometers; there are more than 17,500 islands with the second longest coastline in the world after Canada is 81,000 km (Kausarian et al. 2016; Sui et al. 2020). Coastal areas can be defined as a meeting area between land ecosystems, marine ecosystems and air ecosystems that meet each other in a vulnerable balance (Alesheikh, Ghorbanali & Nouri 2007; Ashton, Murray & Arnault 2001; Yasir et al. 2020; Zhang & Hou 2020; Zhang et al. 2021).

One of the coastal areas in Indonesia is Rupat Island, Bengkalis Regency, Riau Province. Its coastline, which is in contact with the Malacca Strait, has many coastal and marine potential that can be exploited (Kausarian et al. 2017; Rifardi, Isty & Wati 2021; Sandhyavitri, Fatnanta & Husaini 2020). One of the interesting coastal areas is the research location in the northern part of Rupat Island (Figure 1), where this area has a coastline of 40 km with an area of 628.50 km².

This area stretches from Teluk Rhu Village to the Cingam River, which borders Rupat District. The condition of beach has a width of 30 m at low tide or 7 m at high tide and has a beautiful beach with white sand characteristics (Amor et al. 2022; Nasution et al. 2021; Ondara & Purnawan, 2021; Sarah et al. 2022). With its position in the Melaka Strait, this area is vulnerable to the potential for abrasion and accretion. Some factors influenced the coastline changes (Amukti, Adji & Ruslan 2020; Ondara et al. 2020). These factors include natural processes such as erosion, sedimentation (Al-Dubai et al. 2017), sea level rise, loss of biodiversity (Abd Hamid et al. 2023; Lubis et al. 2018; Yun et al. 2022), saltwater intrusion, coastal flooding, economic impacts, as well as human activities like coastal development and climate change (Tew et al. 2022). The impact of coastline changes on Rupat Island can have significant consequences for the environment, local communities, and ecosystems. Areas that have the potential to experience abrasion and accretion are the villages of Tanjung Medang, Teluk Rhu, Tanjung Punak and Kandur, with a critical area length of 13 km with an annual abrasion rate of 5-6 meters. The beach on Rupat Island is a beach that is very prone to abrasion because it is directly opposite the open ocean. This condition causes waves, currents and tides of seawater that occur due to the generation of large enough winds that have the potential to cause coastal abrasion.

Research Background

The coastal area is a transitional area that connects land ecosystems and marine ecosystems, which is located between the border landward to the highest tide and towards the sea as the influence of activities from the land. The beach is an area on the water's edge affected by the highest tides and the lowest low tides (Maulana et al. 2022; Mubarak 2018; Ratri, Mizuno & Martono 2021; Tampubolon 2022). The coastline is the boundary line between land and seawater, where the position is not fixed and can change according to the tides and coastal erosion that occurs. The coastline is one of the important components in determining the boundaries of a country's territory between Indonesia - Malaysia and regional autonomy.

Natural and human factors cause coastline changes. Natural factors include ocean waves, ocean currents, wind, river sedimentation, coastal plant conditions and tectonic and volcanic activities (Daryabor, Tangang & Juneng 2014; Moslim et al. 2021). In comparison, the human factors include the construction of ports and their facilities (e.g., breakwaters), mining, dredging, destruction of coastal vegetation, aquaculture, coastal protection, and coastal reclamation. Due to the dynamic nature of the coastline, it is necessary to monitor it by making a map of shoreline changes regularly.

Abrasion is the process of coastal erosion by the power of ocean waves and destructive ocean currents (Limber & Murray 2011). The strength of the abrasion is determined by the size of the waves hitting the beach. Accretion or sedimentation is the silting or addition of coastal land due to sediment deposition carried by seawater. Tides occur periodically at sea level and are produced by the moon's and sun's gravitational attraction. Generally, high and low tide intervals occur every 12 hours and 25 minutes. Tidal tables are indispensable for structural elevation planning based on the events of the greatest and lowest tides (Liu et al. 2013). The tides at the observation site were separated according to the diurnal (single daily) type, semi-diurnal and mixed.

Changes in the coastline are one form of dynamics of the coastal area that occur continuously (Mohd et al. 2018; Sauti et al. 2021). Changes in the coastline that occur in coastal areas are in the form of erosion of coastal bodies (abrasion) and the addition of coastal bodies (sedimentation or accretion). These processes occur due to the movement of sediments, currents, and waves that interact with the coastal area directly. In addition to these factors, shoreline changes can occur due to anthropogenic factors, such as human activities in the vicinity (Sanjaume & Pardo-Pascual 2005).

Methods

This research is descriptive-quantitative or applied research which includes survey research, namely field observations that produce primary and secondary data. Primary data is data directly obtained from measurements in the field, and secondary data is obtained from related agencies and several references. The initial data is obtained from Landsat 7 ETM + Time Series images as

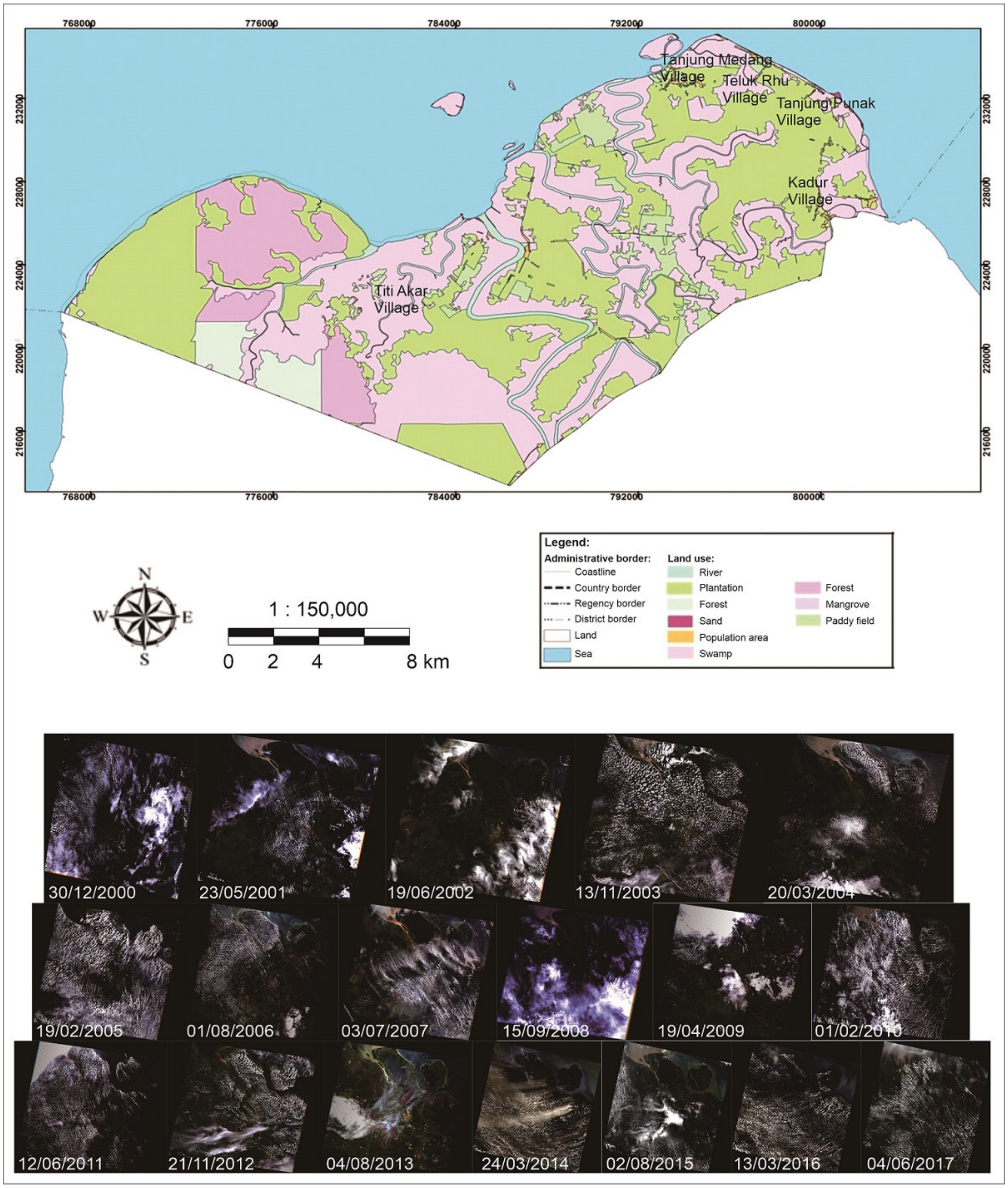
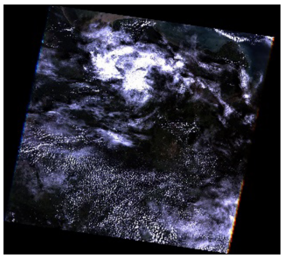
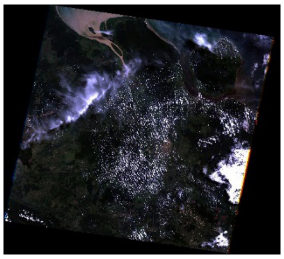
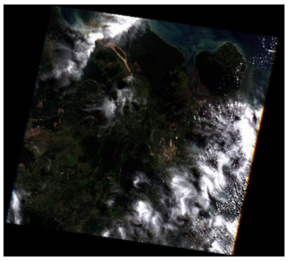
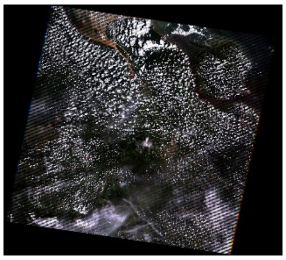
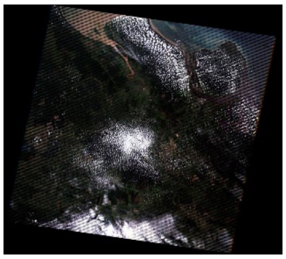


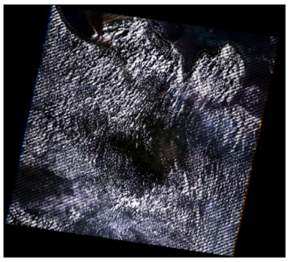
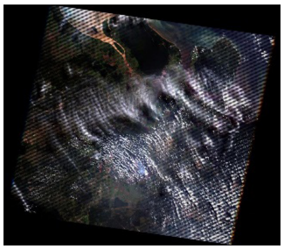
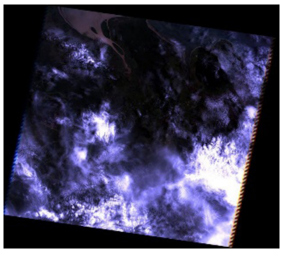
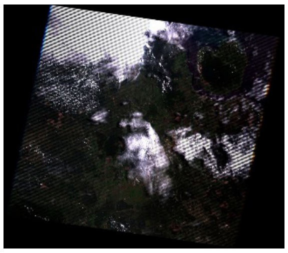
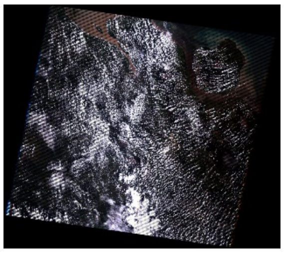
FIGURE 1. Northern Part of Rupat Island as the Research Location and Landsat 7 ETM+ Images used for this research

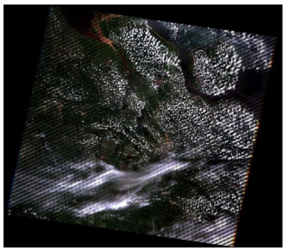
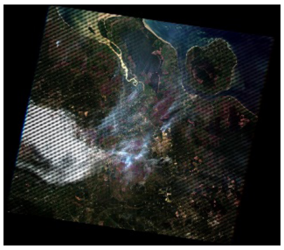
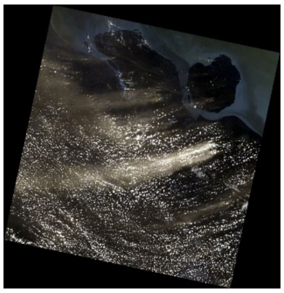
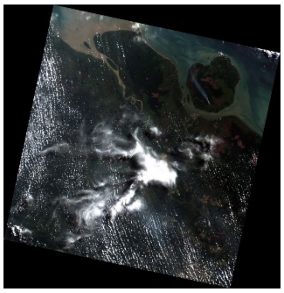
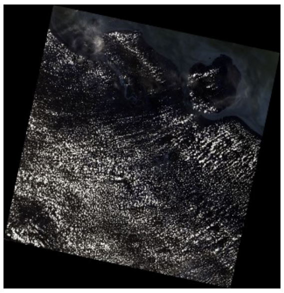
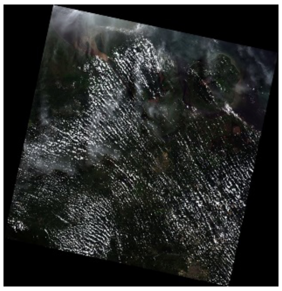
the first reference data in the work of the task so that this initial data will make it easier and further clarify all the shortcomings that exist in this initial data which will then be equipped with direct data searches or survey to a predetermined case study location. The time series data from Landsat 7 ETM + used in this research can be seen in Table 1.

The stages of this field research are the steps carried out directly to collect data by carrying out direct observations and systematically recording the conditions in the field. The tools and materials used in this study are: Digital cameras are used to document observational data, Computers/laptops are used to process image data and GIS analysis, Global positioning system (GPS) to determine land suitability, Landsat Time Series images for 2000-2017, Bengkalis Regency administrative map, North Rupat District administration map, and North Rupat District suitability map.

TABLE 1. Landsat 7 ETM + time series used in this research

Year	Image date taken	Image used
2000	30/12/2000	
2001	23/05/2001	
2002	19/06/2002	
2003	13/11/2003	
2004	20/03/2004	

2005	19/02/2005	
2006	01/08/2006	
2007	03/07/2007	
2008	15/09/2008	
2009	19/04/2009	
2010	01/02/2010	
2011	12/06/2011	

2012	21/11/2012	
2013	04/08/2013	
2014	24/03/2014	
2015	02/08/2015	
2016	13/03/2016	
2017	04/06/2017	

Radiometric correction is a reflectance calibration, and atmospheric correction of DOS (dark of subtraction) is performed on the NIR and red bands. Specifically for the thermal band, radiometric correction is only carried out up to radian calibration with the formula:

$$L\lambda = \frac{Lmax - Lmin}{QCALmax - QCALmin} x(QCAL - QCALmin) + Lmin \rightarrow L\lambda =$$

$$= ML\ x\ QCAL + AL \quad (1) \qquad (1)$$

where $L\lambda$ is the Spectral radiance (Landsat 7); Lmax is the Spectral radiance to QCALmax; Lmin is the Spectral radiance to QCALmin; QCALmax is the Maximum pixel value; QCALmin is the Minimum pixel value; QCAL is the Thermal Band Landsat 7; and AL is the Specific band (additive rescaling)

After the spectral radiance value is obtained, then the DN is converted to reflectance using the following formula (USGS 2013):

$$\rho\lambda = M\rho QCAL + AP \qquad (2)$$

where ρλ is the TOA Reflectance value, without sun angle correction; M_ρ is the Band-specific multiplicative rescaling factor; A_ρ is the Band-specific additive rescaling factor; and Q_{cal} is the Quantised and calibrated standard product pixel values.

After the TOA value is obtained, then it is necessary to change this value to the corrected TOA reflectance value (ρλ*) with the following formula:

$$\rho\lambda * = \frac{\rho\lambda'}{\cos(\theta SZ)}\ or\ \frac{\rho\lambda'}{\sin(\theta SE)} \qquad (3)$$

where $\rho\lambda*$ is the TOA reflectance value (corrected sun elevation); $\rho\lambda$\` is the TOA reflectance value (uncorrected sun elevation); θ_{SE} is the Sun local elevation angle; θ_{SZ} is the Sun local zenith angle; $\theta_{SZ} = 90° - \theta_{SE}$.

After radiometric correction, then atmospheric correction was carried out. The purpose of the atmospheric correction was to reduce the reflectance of the object from the total radiance of the TOA after normalizing the lighting conditions and eliminating atmospheric effects. Usually, the reflectance captured by the satellite, ρ*(λ) or ρTOA, at wavelength λ, is determined by the reflections from the different physical components of the process. Here's how to calculate atmospheric correction:

$$\rho * (\lambda) = \rho a(\lambda) + \rho q(\lambda) + \rho pra(\lambda) + T(\lambda)\rho g(\lambda) + t(\lambda)\rho wc + t(\lambda)\rho BOA(\lambda) \qquad (4)$$

where $\rho_r(\lambda)$ is the Effect of atmospheric scattering caused by air molecules (Rayleigh Scaterring); $\rho_a(\lambda)$ is the Effect of atmospheric scattering caused by aerosols; $\rho_{ra}(\lambda)$ is the influence of atmospheric scattering due to aerosol and Rayleigh interactions; $\rho_g(\lambda)$ is the Reflection of sunlight from the surface of the water; $\rho_{wc}(\lambda)$ is the Reflection of water waves; $\rho_{BOA}(\lambda)$ is the Reflection of the object; reflectance of the actual object; T(λ) is the Direct transmittance of each atmospheric column; t (λ) is the Transmittance spreading from each atmospheric column.

The Data Analysis stage is an analytical activity by comparing, calculating, and considering existing data to produce a systematic and targeted formulation of proposals and draw conclusions about a problem for the final purpose of planning. Qualitative data is in the form of words or letters, not numbers; this stage of qualitative data analysis is obtained through various data collection techniques. This analysis was carried out by field surveys to determine and validate the characteristics of coastline changes that occur in the research area, such as determining observation points used for field validation and adjusting them to the coordinates on the satellite data used, identifying coastline changes based on tidal points, and identifying types lithology (beach sand) found in this research area. The coastline is changing every year. This can occur due to the addition of indentations caused by abrasion and accretion processes on each existing coastline. Changes in the length of the coastline from Rupat Island are recorded by satellite imagery. Areas experiencing abrasion and accretion can be identified by integrating the results of digitized coastline images from different years. The two resulting images are then overlaid to obtain information on changes in the coast. The steps of quantitative data analysis are data in the form of numbers, and quantitative data can be processed or analysed using mathematical calculation techniques and measuring a problem with existing numbers and formulas to get an assessment in the form of more measurable numbers. Furthermore, analysis of shoreline change interpretation using Landsat Time Series imagery using the ENVI method and land use interpretation using visual interpretation using the ArcGIS method and interpretation keys by analysing shoreline changes using GIS (Geographic Information System) and Remote Sensing methods. Hence, shoreline changes in the northern part of Rupat Island were identified. Summary of the methods used in this research can be seen in Figure 2.

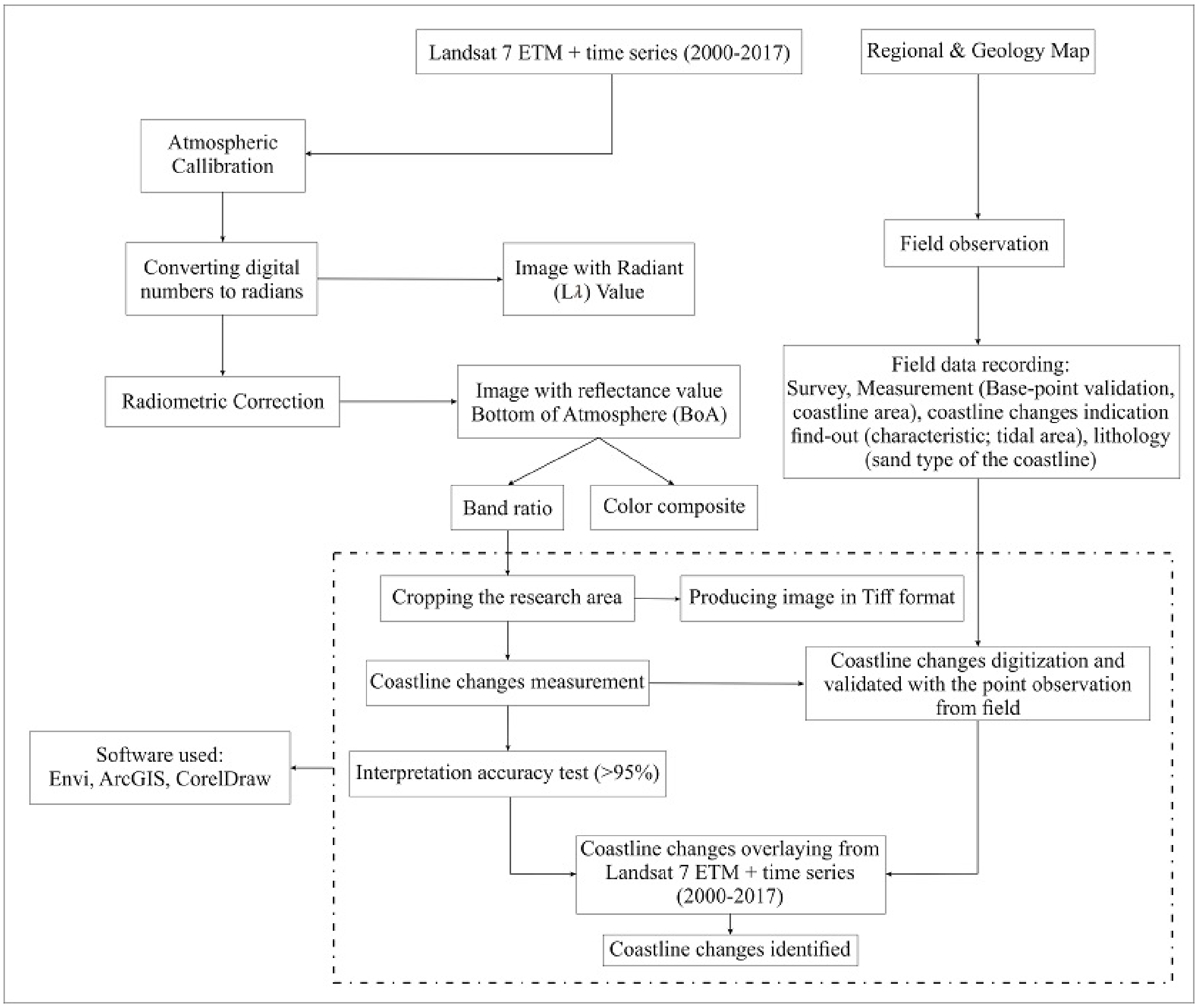


FIGURE 2. Flowchart summary of the methods used in this research

Results and Discussion

FIELD OBSERVATION AND VALIDATION

This result was carried out by field surveys to determine and validate the characteristics of coastline changes that occur in the research area by determining observation points used for field validation and adjusting them to the coordinates on the satellite data used. Based on research results in the northern part of Rupat Island, the validation location of the study was carried out at station 1 in the Tanjung Api area to Teluk Rhu and observation station 2 in the west of northern Rupat, namely in Tanjung Lapin (Figure 3). The coastline of Rupat Island changes every year, influenced by wind, and currents in the Malacca Strait. Coastline changes that occur in Rupat Island start from coordinates 2°07’41.5” N 101°37’ 54.6” E and 2°07’39.2” N 101°39’36.4” E.

SEA CURRENT AND PATTERN

Based on the results of measurements in the northern part of Rupat Island area can be seen in Table 2, which shows the current velocity in the northern part of Rupat Island in 2017 is at coordinates 2°07’41.5” N 101°37’54.6” E and 2°07’39.2” N 101°39’36.4” E, ranges from 0.50 cm/s and 0.60 cm/s and the highest wind direction is on Southeast. This data was taken from the sea current measurement in 2017 by the Board of Meteorological, Climatological, and Geophysical Agency Republic of Indonesia, Regional II Sumatra.

Surface currents around the waters of the Malacca Strait are dominated by currents that are influenced by wind and tidal factors. The movement of water masses (currents) in the waters of the Malacca Strait can be seen in Figure 4, where the direction of the movement of water masses (currents) from January to April is influenced from north to south, in May the current direction is dominated from southeast to north. In June, the wind direction is dominated from the north to the southeast. From July to September, the current direction is dominated from the southeast to the north. In October, the current direction is dominated from the north to the southeast, and in November, the current direction is dominated from the south to the north and north to the southeast. In December, the current direction is dominated from north to south (Figure 4).

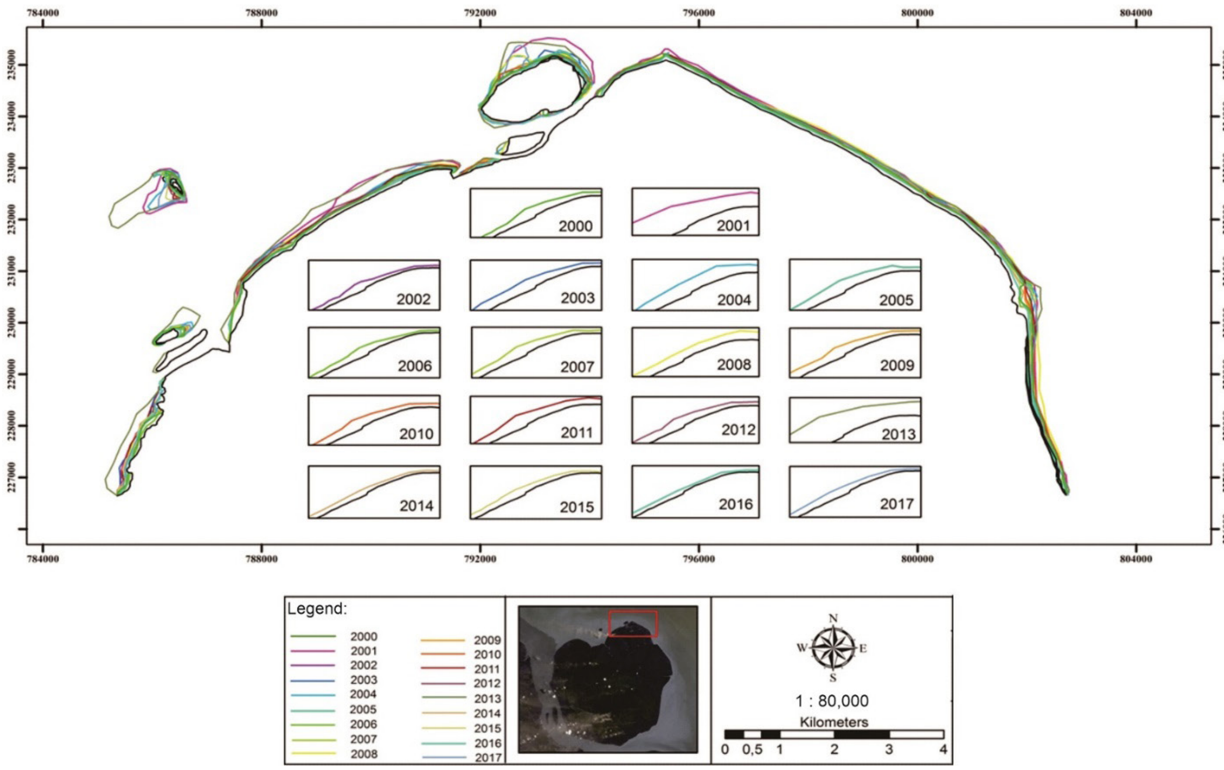


FIGURE 3. Validation point in the Northern Part of Rupat Island

TABLE 2. Current velocity at coordinates 2°07’41.5”N-01°37’54.6”E (a) and 2°07’39.2”N-101°39’36.4”E in 2017*

No.	Month	Current			
		(a)		(b)	
		Direction	Average Velocity (cm/s)	Direction	Average Velocity (cm/s)
1	January	NE	0.58	NE	0.66
2	February	NW	0.62	NW	0.98
3	March	NE	0.46	NE	0.52
4	April	NW	0.44	NW	0.51
5	May	S	0.46	S	0.49
6	June	SE	0.16	SE	0.17
7	July	SE	0.67	SE	0.74
8	August	SE	0.68	SE	0.76
9	September	NW	0.62	NW	0.65
10	October	S	0.58	S	0.76
11	November	S	0.63	S	0.76
12	December	NW	0.64	NW	0.82

*Source: Board of Meteorological, Climatological, and Geophysical Agency Republic of Indonesia, Regional II Sumatra, 2017

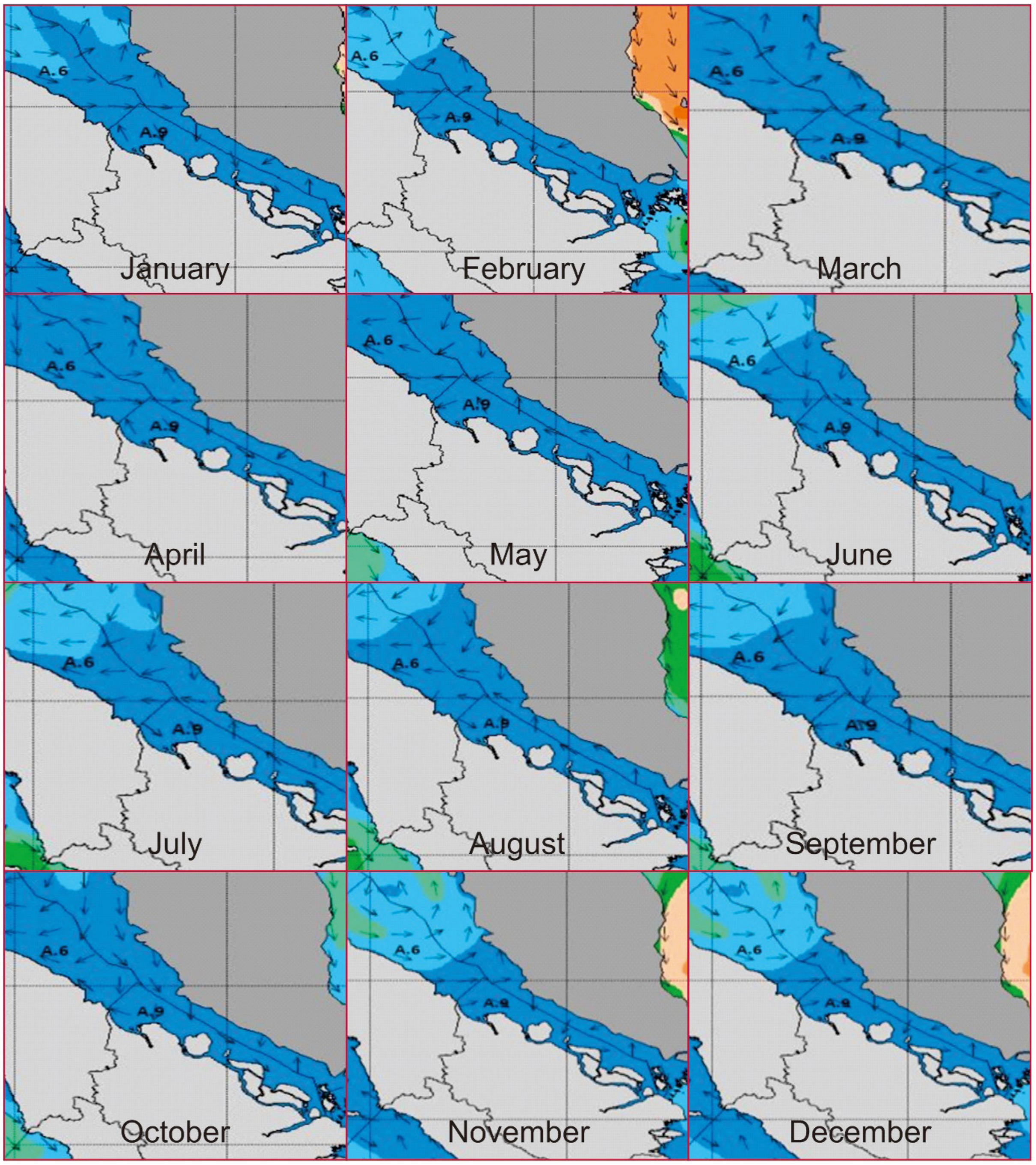


FIGURE 4. Sea Current Pattern in Northern Part of Rupat Island (modified from Board of Meteorological, Climatological, and Geophysical Agency Republic of Indonesia, Regional II Sumatra, 2017)

WIND VELOCITY AND DIRECTION

Based on the daily maximum wind direction data from the Board of Meteorological, Climatological, and Geophysical Agency of The Republic of Indonesia, Regional II Sumatra (BMKG) for the Rupat District area (Table 3), it was found the dominated from the southeast in 2013 with an average annual speed of 4.62 knots, and resulting in a longer coastline change (or known as accretion). This can be seen on the map of abrasion and accretion of changes in the coastline of the northern part of Rupat Island in 2000 and 2013 (Figure 5). In 2014,

TABLE 3. Wind velocity and direction on the northern part of Rupat Island*

No.	Month	Main Direction			Average Velocity (knot)		
		2013	2014	2017	2013	2014	2017
1	January	ESE	NE	NE	5		7
2	February	SSE	E	NE	4	7	4
3	March	ENE	WNW	NE	3.6	8	6
4	April	SE	S	NE	3	0.7	6
5	May	SW	S	W	5.9	0.5	5
6	June	SSW	SW	S	7	7	4
7	July	NE	W	S	0	6.7	4
8	August	E	E	S	0	10	6
9	September	SE	NW	E	5	10	6
10	October	N	NW	E	7	0.6	5
11	November	N	S	NW	0	0.6	4
12	December	NE	E	NW	15	0.6	6

*Source: Board of Meteorological, Climatological, and Geophysical Agency Republic of Indonesia, Regional II Sumatra, 2017

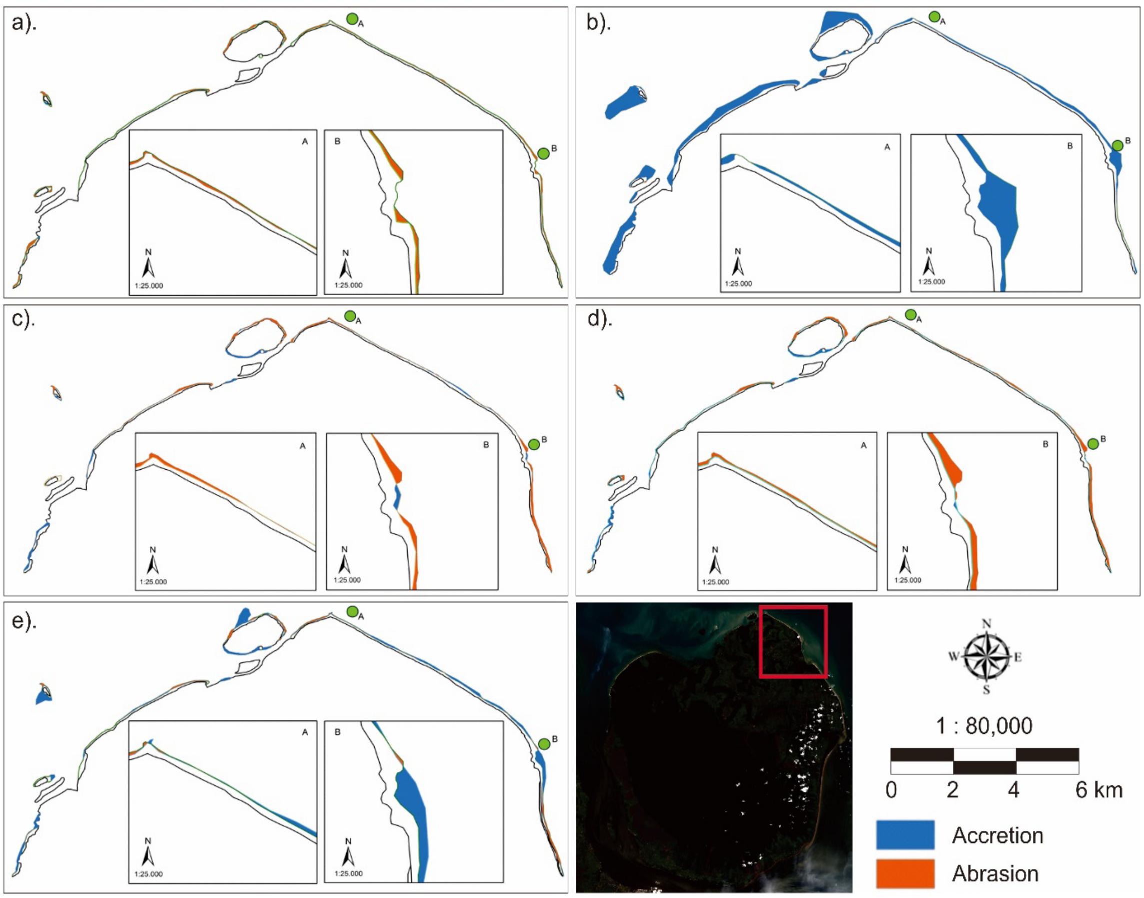


FIGURE 5. Accretion and Abrasion Analysis on Validation Point compared to 2000 as the reference time: a). 2000 and 2006, b). 2000 and 2013, c). 2000 and 2014, d). 2000 and 2016, e). 2000 and 2017

the maximum daily wind direction mostly came from the northeast with an average annual speed of 4.7 knots, which had an impact on changes in the coastline of the northern part of Rupat Island, namely reduction or abrasion; this can be seen in the abrasion and accretion map of the northern part of Rupat Island in 2000 and 2014. then in 2017, the maximum yield wind direction mostly came from the northeast, with an average annual speed until August of 5.14 knots per year. The impact of wind direction and speed in that year made changes in the coastline that occurred is an increase or accretion. This can be seen on the northern accretion and abrasion map in 2000 and 2017 (Figure 5).

MAPPING AND CALCULATION OF COASTLINE CHANGES

From the results of the validation location for the coastline changes in the research area, abrasion occurred in 2006, 2014, and 2016 and accretion occurred in 2013 and 2017 (Table 4). Table 4 shows that the length of the shoreline change at the validation location points, which experienced the most accretion occurred in 2013, was 167.21 m, and was at the validation location point b. And the most abrasion in 2016 was 72.77 m at the point of validation b. The validation map can be seen in Figure 5.

The length of the coastline digitised in the northern part of Rupat Island from 2000 to 2017 was measured from the coordinates of 2°02’57.5”N 101°43’16.0’E in Tanjung Lapin, Putri Sembilan Village, to the coordinates of 2°02 ‘53.0”N 101°33’53.6”E at Apel Beach, Suka Damai Village (Figure 6) and the length of the digitised line can be seen in Table 5. The coastline that is formed every year is changing. This can occur due to the addition of curves indentation caused by abrasion and accretion processes in each existing coastline. Changes in the coastline in the northern part of Rupat Island are influenced by the sea currents of the Malacca Strait because it is directly opposite the Malacca Strait (Syamsul Rizal et al. 2012). The coastline of the northern part of Rupat Island is very easy to change, influenced by wind and currents in the Malacca Strait. Coastline changes that occur in the northern part of Rupat Island, which is affected by current velocity, are measured at coordinates 2°07’41.5” N 101°37’54.6” E and 2°07’39.2” N 101°39’36.4” E, on average the average is 0.50 cm/s and 0.60 cm/s. The average wind direction is from north to south.

Table 5 shows the change in the length of the coastline in the northern part of Rupat Island as recorded by satellite imagery. Areas experiencing abrasion and accretion can be identified by integrating the digitised results of coastline images from different years. Two image results are then overlaid to obtain information on changes in the coast. The coastline data acquisition was obtained from a visual interpretation with a coastline overlay in 2000 as the research reference year until 2017. The results from the overlay of shoreline changes for the last 17 years can be seen in Figure 6. The annual coastline length from the overlay results from 2000 to 2017 shows that the minimum yearly coastline length that occurred in 2004 was 19.04 km, and the normal coastline length in 2015 was 28.26 km. The maximum coastline length in 2013 was 36.53 km (Table 5).

The area of the northern part of Rupat Island which experienced the most abrasion and accretion (Table 5) occurred in 2013 in the form of accretion which occurred as much as 375.5 Ha, and the most abrasion occurred in 2014, as much as 50.63 ha. On average, the northern part of Rupat Island has experienced an abrasion of 14.34 ha and an accretion of 80.58 ha from 2000 to 2017. The average length of coastline change by accretion occurred the most in 2013, 239.13 m, and the average length of abrasion that most occurred in 2016 was 60.67 m. Changes in the length of the coastline compared to 2000, the minimum coastline length occurred in 2004 was 19.04 km, the normal line length occurred in 2015 was 28.26 km, and the maximum coastline length occurred in 2013 was 36.53 km.

Changes in the length of the coastline digitised in the northern part of Rupat Island from 2000 to 2017 can be seen in Table 5. Changes in the coastline in the northern part of Rupat Island are often caused by current velocity from the Malacca strait and wind speed. The current velocity in the study area at coordinates 2°07’41.5”N-101°37’54.6”E and 2°07’39.2”N-101°39’36.4”E an average of 0.50 cm/s and 0.60 cm/s, and the average wind direction is from north to south. Changes in the coastline at the research point experienced the most changes, namely in 2002, 2006, 2012, 2013, 2014, 2015, 2016 and 2017, where changes in that year experienced abrasion and some experienced accretion.

TABLE 4. Length of coastline change at validation point location

Year	Point A		Point B	
	Abrasion (m)	Accretion (m)	Abrasion (m)	Accretion (m)
2000	0	0	0	0
2001	0	71.28	0	105.19
2002	21.39	0	0	0
2003	0	0	0	0
2004	0	38.03	0	120.04
2005	0	21.27	0	84.04
2006	20.05	0	51.84	0
2007	0	0	0	86.36
2008	0	28.75	0	101.44
2009	0	0	66.33	0
2010	0	20.19	0	47.89
2011	0	35.30	0	66.50
2012	12.76	0	46.77	0
2013	0	21.70	0	167.21
2014	23.30	0	45.30	38.84
2015	13.96	0	47.39	0
2016	19.09	0	72.77	0
2017	8.99	5.84	18.16	88.19

TABLE 5. Accretion and abrasion per year, from Tanjung Lapin (Putri Sembilan Village) to Apel Beach (Suka Damai Village), northern part of Rupat Island

No.	Year	Coastline length (km)	Addition/Accretion		Reduction/Abrasion	
			Area (ha)	Length (m)	Area (ha)	Length (km)
1	2000*	27,33	0	0	0	0
2	2000 - 2001	31,57	276,21	142,81	0,11	18,90
3	2000 - 2002	27,26	12,79	28,54	8,75	28,89
4	2000 - 2003	29,21	39,60	174,70	2,02	18,68
5	2000 - 2004	19,45	142,30	124,76	0,260	18,40
6	2000 - 2005	29,12	63,93	43,28	0,22	9,48
7	2000 - 2006	25,98	1,37	29,31	41,79	41,39
8	2000 - 2007	27,86	29,12	46,25	4,06	25,94
9	2000 - 2008	30,09	159,57	87,45	5,35	36,85
10	2000 - 2009	27,04	37,03	52,91	16,12	40,13
11	2000 - 2010	27,9	59,35	47,34	2,92	33,6
12	2000 - 2011	27,31	74,2	84,16	2,04	38,40
13	2000 - 2012	26,7	22,17	50,81	13,94	48,20
14	2000 - 2013	36,53	375,5	239,13	0,68	17,86
15	2000 - 2014	26,08	27,06	39,53	50,63	51,12
16	2000 - 2015	28,26	21,96	69,12	14,96	44,20
17	2000 - 2016	29,07	21,45	40,81	73,51	60,67
18	2000 - 2017	31,13	86,88	86,50	20,82	46,59

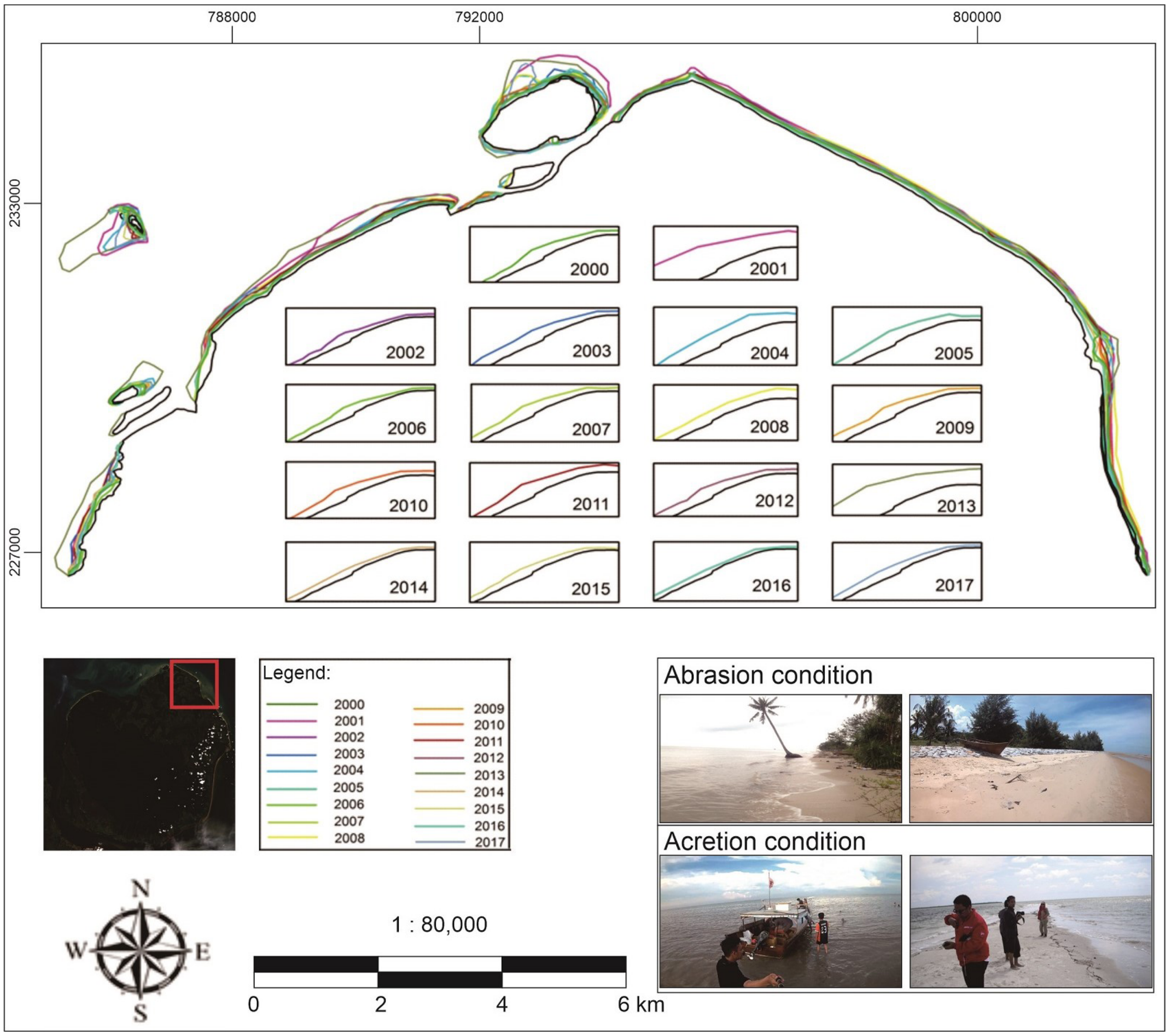


FIGURE 6. Coastline changes in the northern part of Rupat Island from 2000 to 2017

CONLUSION

Changes in the coastline in the northern part of Rupat Island occurred in the range of 2000 to 2017, indicating the occurrence of Accretion and Abrasion. Both have an impact on land use and land cover. Abrasion that occurs impacts community land use, especially on the coast, such as community plantation land, which is decreasing yearly. Community plantation land has an impact, such as rubber plantation land, the abrasion that occurs makes rubber income decline due to seawater entering the plantation. Therefore, it is necessary to deal with changes in the coastline, such as making canals or breakwaters according to standards on the northern shores of Rupat Island so that the abrasion does not become severe.

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REFERENCES

Abd Hamid, M., Md Sah, A.S.R., Idris, I., Mohd Nor, S.A., Abdul Ghaffar, M., Casey Ngo, S.P. & Mod Husin, S. 2023. The diversity and distribution of fish at the port and urbanized areas of Pulau Pinang Strait, Malaysia. *Sains Malaysiana* 52(4): 1047-1058. https://doi.org/10.17576/jsm-2023-5204-02

Al-Dubai, T.A., Antoni, S., Al-Zubieri, A.G. & Majeed, J. 2017. Composition and characteristic of the surficial sediments in the southern corniche of Jeddah, Red Sea Coast. *Journal of Geoscience, Engineering, Environment, and Technology* 2: 1. https://doi.org/10.24273/jgeet.2017.2.1.19

Alesheikh, A.A., Ghorbanali, A. & Nouri, N. 2007. Coastline change detection using remote sensing. *International Journal of Environmental Science and Technology* 4: 61-66. https://doi.org/10.1007/BF03325962

Amor, G., Hanif, M., Yulfa, A., Hidayat, R.A. & Indrayani, P. 2022. Spatial modeling of tidal flood due to the fishpond to tidal waves in Bengkalis, Indonesia. In *Proceedings of the International Conference on Radioscience, Equatorial Atmospheric Science and Environment and Humanosphere Science, 2021, Springer Proceedings in Physics 275*, edited by Yulihastin, E., Abadi, P., Sitompul, P. & Harjupa, W. Singapore: Springer. https://doi.org/10.1007/978-981-19-0308-3_72

Amukti, R., Adji, A.S. & Ruslan, S. 2020. Analysis of shoreline shift using satellite imagery near Makassar City. *Journal of Geoscience, Engineering, Environment, and Technology* 5(3): 133-138. https://doi.org/10.25299/jgeet.2020.5.3.5111

Ashton, A., Murray, A.B. & Arnault, O. 2001. Formation of coastline features by large-scale instabilities induced by high-angle waves. *Nature* 414: 296-300. https://doi.org/10.1038/35104541

Daryabor, F., Tangang, F. & Juneng, L. 2014. Simulation of southwest monsoon current circulation and temperature in the east coast of Peninsular Malaysia. *Sains Malaysiana* 43(3): 389-398.

Kausarian, H., Sri Sumantyo, J.T., Kuze, H., Aminuddin, J. & Waqar, M.M. 2017. Analysis of polarimetric decomposition, backscattering coefficient, and sample properties for identification and layer thickness estimation of silica sand distribution using L-band synthetic aperture radar. *Canadian Journal of Remote Sensing* 43(2): 95-108. https://doi.org/10.1080/07038992.2017.1286935

Kausarian, H., Sumantyo, J.T.S., Kuze, H., Karya, D. & Panggabean, G.F. 2016. Silica sand identification using ALOS PALSAR full polarimetry on the northern coastline of Rupat Island, Indonesia. *International Journal on Advanced Science Engineering and Information Technology* 6(5): 568-573. https://doi.org/10.18517/ijaseit.6.5.92

Limber, P.W. & Murray, A.B. 2011. Beach and sea-cliff dynamics as a driver of long-term rocky coastline evolution and stability. *Geology* 39(12): 1147-1150. https://doi.org/10.1130/G32315.1

Liu, Y., Huang, H., Qiu, Z. & Fan, J. 2013. Detecting coastline change from satellite images based on beach slope estimation in a tidal flat. *International Journal of Applied Earth Observation and Geoinformation* 23: 165-176. https://doi.org/10.1016/j.jag.2012.12.005

Lubis, M.Z., Anurogo, W., Hanafi, A., Kausarian, H., Taki, H.M. & Antoni, S. 2018. Distribution of benthic habitat using Landsat-7 Imagery in shallow waters of Sekupang, Batam Island, Indonesia. *Biodiversitas* 19(3): 1117-1122. https://doi.org/10.13057/biodiv/d190346

Maulana, L., Syamsunasir, S., Suwarno, P. & Aris, T. 2022. Global warming and its impact on mangrove land degradation on the north coast of Bengkalis Island, Riau Province. *Journal of Agriculture* 1(02): 31-39. https://doi.org/10.47709/joa.v1i02.1574

Mohd, F.A., Maulud, K.N.A., Begum, R.A., Selamat, S.N. & Karim, O.A. 2018. Impact of shoreline changes to Pahang coastal area by using geospatial technology. *Sains Malaysiana* 47(5): 991-997. https://doi.org/10.17576/jsm-2018-4705-14

Moslim, N.H., Mokhtar, N.A., Zubairi, Y.Z. & Hussin, A.G. 2021. Understanding the behaviour of wind direction in Malaysia during monsoon seasons using replicated functional relationship in von mises distribution. *Sains Malaysiana* 50(7): 2035-2045. https://doi.org/10.17576/jsm-2021-5007-18

Mubarak, M. 2018. Coastline changes in North Bengkalis Island, Indonesia: Satellite imagery analysis and observation. *Journal of Degraded and Mining Lands Management* 5(2): 1127-1132. https://doi.org/10.15243/jdmlm.2018.052.1127

Nasution, S., Effendi, I., Nedi, S. & Mardalisa, M. 2021. Species diversity of marine bivalves from the Strait of Rupat Island Riau Province, Indonesia. *IOP Conference Series: Earth and Environmental Science* 934: 012071. https://doi.org/10.1088/1755-1315/934/1/012071

Ondara, K. & Purnawan, S. 2021. Numerical models of hydrodynamics and marine debris in the Malacca Strait. *IOP Conference Series: Earth and Environmental Science* 869: 012053. https://doi.org/10.1088/1755-1315/869/1/012053

Ondara, K., Dhiauddin, R., Wisha, U.J. & Rahmawan, G.A. 2020. Hydrodynamics features and coastal vulnerability of Sayung sub-district, Demak, Central Java, Indonesia. *Journal of Geoscience, Engineering, Environment, and Technology* 5(1): 32-39. https://doi.org/10.25299/jgeet.2020.5.1.3996

Ratri, D.A.R., Mizuno, K. & Martono, D.N. 2021. The effectiveness of breakwaters decreasing the peat shoreline change in Bengkalis Island. *IOP Conference Series: Earth and Environmental Science* 802(1): 012007. https://doi.org/10.1088/1755-1315/802/1/012007

Rifardi, Isty, H.T. & Wati, R.A. 2021. The geomorphological dynamic of the Rupat Strait on the east coast of Central Sumatera Island, Indonesia. *Journal of Southwest Jiaotong University* 56(1). https://doi.org/10.35741/issn.0258-2724.56.1.8

Sandhyavitri, A., Fatnanta, F. & Husaini, R.R. 2020. Identification and prioritization of coastal vulnerability areas based on coastal vulnerability indexes (CVI) and analytical hierarchy process (AHP). *AIP Conference Proceedings* 2230: 040002. https://doi.org/10.1063/5.0005007

Sanjaume, E. & Pardo-Pascual, J.E. 2005. Erosion by human impact on the Valencian coastline (E of Spain). *Journal of Coastal Research* SPEC. ISSUE 49(Coastal Erosion): 76-82.

Sarah, S., Aris, T., Wiranto, S. & Purwanto, P. 2022. Government's efforts to minimize the threat of coastline changes on the north coast of Bengkalis Island. *Jurnal Pamator: Jurnal Ilmiah Universitas Trunojoyo* 15(1): 113-124. https://doi.org/10.21107/pamator.v15i1.14260

Sauti, N.S., Daud, M.E., Kaamin, M. & Remali, N. 2021. Geospatial technology in potential analysis and mapping of tsunami risk at West Coast Peninsular Malaysia. *Sains Malaysiana* 50(4): 929-943. https://doi.org/10.17576/jsm-2021-5004-05

Syamsul Rizal, Damm, P., A. Wahid, M., Sundermann, J., Yopi Ilhamsyah, Taufiq Iskandar & Muhammad. 2012. General circulation in the Malacca Strait and Andaman Sea: A numerical model study. *American Journal of Environmental Sciences* 8(5): 479-488.

Sui, L., Wang, J., Yang, X. & Wang, Z. 2020. Spatial-temporal characteristics of coastline changes in Indonesia from 1990 to 2018. *Sustainability (Switzerland)* 12(8): 32-42. https://doi.org/10.3390/SU12083242

Tampubolon, H. 2022. Shoreline change cause of abrasion in Bantan district Bengkalis Island as the outstanding beach area. *Proceedings of the Second International Conference of Construction, Infrastructure, and Materials*. *Lecture Notes in Civil Engineering* 216, edited by Lie, H.A., Sutrisna, M., Prasetijo, J., Hadikumuso, B.H. & Putranto, L.S. Singapore: Springer. https://doi.org/10.1007/978-981-16-7949-0_4

Tew, Y.L., Tan, M.L., Samat, N., Mahamud, M.A. & Chun, K.P. 2022. Analysis of the relationship between climate change and land use change using the ESA CCI land cover maps in Sungai Kelantan Basin, Malaysia. *Sains Malaysiana* 51(2): 437-449. https://doi.org/10.17576/jsm-2022-5102-09

Yasir, M., Sheng, H., Fan, H., Nazir, S., Niang, A.J., Salauddin, M. & Khan, S. 2020. Automatic coastline extraction and changes analysis using remote sensing and GIS technology. *IEEE Access* 8: 180156-180170. https://doi.org/10.1109/ACCESS.2020.3027881

Yun, W.Y., Yeok, F.S., Youshao, W., Lu, D., Limi, M. & Lai, G.T. 2022. Spatiotemporal dispersal study of mangrove *Avicennia marina* and *Rhizophora apiculata* propagules. *Sains Malaysiana* 51(8): 2351-2364. https://doi.org/10.17576/jsm-2022-5108-02

Zhang, Y. & Hou, X. 2020. Characteristics of coastline changes on Southeast Asia Islands from 2000 to 2015. *Remote Sensing* 12(3): 519. https://doi.org/10.3390/rs12030519

Zhang, Y., Li, D., Fan, C., Xu, H. & Hou, X. 2021. Southeast Asia Island coastline changes and driving forces from 1990 to 2015. *Ocean and Coastal Management* 215: 105967. https://doi.org/10.1016/j.ocecoaman.2021.105967

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