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Study of Waves, Currents and Coastline Changes in North Rupat Sub-District, Bengkalis Regency, Riau

Studi Gelombang, Arus, dan Perubahan Garis Pantai di Kecamatan Rupat Utara, Kabupaten Bengkalis Riau

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ABSTRACT

The Malacca Strait, between the island of Sumatra and the Malaysian Peninsula, is classified as an international strait. One of the Indonesian islands in the Malacca Strait is Rupat Island, which is the outermost small island of the Indonesian territory and has a sub-district directly facing the Malacca Strait, namely North Rupat Sub-district resulting in the phenomenon of shoreline change in this area. The location that became the research object is the coastal waters of the North Rupat District. The research aimed to investigate the coastline changes in Rupat Utara over the past 20 years and analyze the physical oceanographic factors affecting the area. The research method used in the research is survey methods. Primary data collected were wave, tidal, and sediment data. Sediment sampling was carried out using a sediment grab at the research stations, with each station being sampled three times. The sediment samples were collected at intervals of 50 meters between sampling points at each station. The results of the analysis of changes in the coastline of North Rupat District carried out using DSAS, and it can be seen that in the period 2003 to 2023, there was a change in the coastline, which was dominated by the accretion process with the highest accretion value at 252.80 m, the lowest abrasion value was -111.29 m, and an EPR value of 2.20 m/year. The current velocity and wave height in these waters are categorized as low. The sediment fraction in this area falls into the sand and mud categories.

Keywords: Currents, Waves, Coastline Changes, Sediment

ABSTRAK

Perairan Selat Malaka merupakan selat yang berada di antara Pulau Sumatera dan juga Semenanjung Malaysia tergolong dalam kategori selat internasional. Salah satu pulau di Indonesia yang berada di selat malaka adalah pulau Rupat yang menjadi pulau kecil terluar dari wilayah Negara Indonesia dan memiliki kecamatan yang berhadapan langsung dengan Selat Malaka, yakni Kecamatan Rupat Utara dan mengakibatkan terjadinya fenomena perubahan garis pantai pada wilayah ini. Lokasi yang menjadi objek penelitian adalah pesisir Pantai Kecamatan Rupat Utara. Adapun tujuan penelitian adalah untuk menyelidiki perubahan garis pantai yang terjadi di Kecamatan Rupat Utara selama 20 tahun dan faktor-faktor fisika oseanografi. Metode penelitian yang digunakan dalam penelitian ini adalah metode survei. Data primer yang dikumpulkan berupa data gelombang, pasang surut, dan sedimen. Untuk pengambilan sedimen dilakukan menggunakan *sediment grab* pada stasiun penelitian dan dilakukan pengulangan sebanyak 3 kali dengan jarak pengambilan sampel pada tiap stasiun sejauh 50 meter. Hasil analisis perubahan garis pantai Kecamatan Rupat Utara yang dilakukan menggunakan DSAS, dapat diketahui bahwa dalam kurun waktu 2003 hingga 2023 terjadi perubahan garis pantai yang didominasi oleh proses akresi dengan nilai akresi tertinggi pada 252,80 meter, nilai abrasi terendah adalah -111,29 meter, dan nilai EPR 2,20 m/tahun. Kecepatan arus dan gelombang pada perairan ini termasuk ke dalam kategori rendah. Fraksi sedimen yang ada pada wilayah ini termasuk ke dalam kategori pasir dan lumpur.

Kata Kunci: Arus, Gelombang, Perubahan Garis Pantai, Sedimen

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INTRODUCTION

Rupat Island is the outermost small island of Indonesia, located in the Malacca Strait. One of the sub-districts on Rupat Island is the North Rupat Sub-district. North Rupat Sub-district directly faces the Malacca Strait. Coastline changes in this area generally occur due to two natural phenomena, namely abrasion and accretion. Abrasion is the phenomenon of coastal erosion caused by the force of seawater (Ervianto, 2021). This phenomenon typically occurs due to natural factors such as wave impact, tidal changes, and alterations in current patterns (Rinjani et al., 2022).

In addition to abrasion, changes in the coastline can also occur due to sedimentation processes. Sedimentation is the phenomenon of the transfer of materials resulting from erosion through various methods, which are then deposited in a basin (Purnomo et al., 2021). Both phenomena are common in coastal areas and are generally caused by water dynamics. One of the factors that greatly influence the occurrence of these phenomena is currents. Ocean currents are the continuous movement of water masses horizontally or vertically (Darmanto et al., 2016). Many important components in the water are highly dependent on ocean currents, both in terms of direction and speed. One example is microorganisms like phytoplankton and various other types of plankton that move according to the direction of the currents (Aramita et al., 2015). Another example of a component dependent on currents is the distribution of nutrients and substrates or sediments (Girsang & Rifardi, 2014).

In addition to water currents, other physical factors that influence coastline changes include ocean waves. Ocean waves are the oscillatory movement of the sea surface that forms a sinusoidal curve (Ayunarita et al., 2017). Ocean waves carry energy that then affects changes in the coastline, particularly in abrasion (Nabilla et al., 2021). One model commonly used to simulate current movement patterns is the hydrodynamic model, utilizing numerical modeling methods.

Several studies have been conducted on coastline changes and current circulation patterns, such as Analisis Perubahan Garis Pantai Menggunakan Data Remote Sensing Sistem Informasi Geografi (Puspita et al., 2021) and Analisis Kerentanan Pantai Pulau Rupat Provinsi Riau Berdasarkan Metode Indeks Kerentanan Pantai (Husaini & Darfia, 2021). Research on current characteristics and coastline changes in the North Rupat Sub-district is still limited; therefore, the author is interested in conducting this study.

MATERIALS AND METHOD

The research was conducted in the waters of North Rupat Sub-district (Figure 1). The research method used was the survey method, which involved observation and direct data collection in the field. Sampling was carried out at four station points: Station 1, located in Tanjung Medang village; Station 2, located in Teluk Rhu village; Station 3, located in Tanjung Punak village; and Station 4, located in Kadur village.

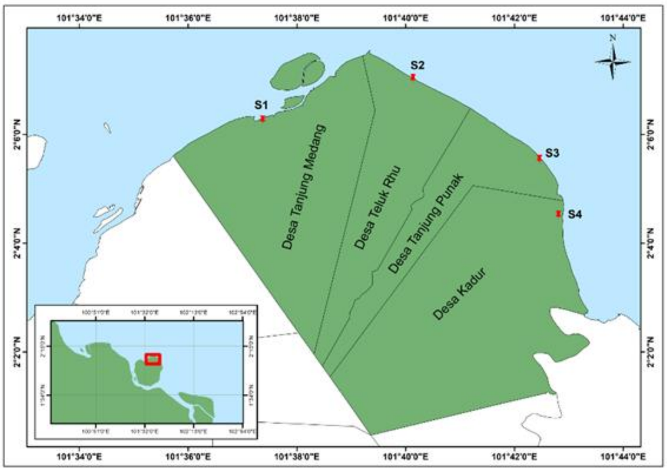

Figure 1. Map of locations and research stations

The coastline change analysis was conducted using ArcGIS software with the DSAS (Digital Shoreline Analysis System) extension. This coastline change analysis also utilized Landsat 8 satellite imagery, with data from 2003 to 2023. The composite bands used for this study were bands 2, 3, and 4 to obtain the natural color of the satellite imagery.

Sediment data collection was conducted at the research stations with three repetitions at each station, and the distance between repetitions was 50 m. The collected sediment samples were then processed using the Rifardi (2001) method. The modeling of current circulation patterns was carried out using Mike 21 software, which, in the process, requires wind data, bathymetry data, coastline data, and tidal data. The wind data was obtained from the BMKG website and was then processed using Mike 21 to be incorporated during the model creation.

Bathymetry data was obtained from the DEMNAS website and processed using Global Mapper and QGIS software. Global Mapper was used to generate contours from the downloaded bathymetry data and to convert the data format to add it when defining the model boundaries (mesh boundary). QGIS displayed vertices on the bathymetry data after the contours were generated. The processed bathymetry data was then used to create the model boundaries.

Coastline data was obtained by digitizing the coastline using Google Earth Pro software and the Add Path tool. Coastline digitization was carried out using this software due to its high resolution and ease of digitizing the coastline. The digitized coastline data was then converted into a different format using Global Mapper to include it when creating the model boundaries. Tidal data was obtained from the field and compared with tidal data acquired using the NaoTide software. The data was compared using the MRE (Mean Relative Error) formula from Melisa et al. (2020). The tidal data was then processed using Mike 21 with the Time Series: Blank module to be used when creating the current circulation model. The tidal data was also used to determine the type of tide using the formula from Fadilah et al. (2014).

The analysis using Mike 21 software involves creating model boundaries (mesh boundary) using the previously processed coastline and bathymetry data. After the model boundaries are defined, the current circulation model uses the Flow Model (FM) module in Mike 21, utilizing the established model boundaries, wind data, and processed tidal data. Wave data was collected at the research location. The data gathered includes wave height, wave period, wavelength, and wave energy. These data were obtained by measuring the peak and trough points of the waves at specific times using a scaled pole and then calculated using the Triatmojo (1999) equation.

RESULT AND DISCUSSION

Waves

The wave data obtained during the primary data collection can be seen in Table 1.

Table 1. Wave data

Stasiun	Wave Height (m)	Wave Period (s)	Wave Lenght (m)	Wave Speed (m/s)	Wave Energy (J)
1	0,55	3,28	16,78	5,12	689,92
2	0,25	4,05	25,58	6,32	313,60
3	0,30	3,84	23,00	5,99	376,32
4	0,35	2,76	11,88	4,30	439,04

Based on Table 1, the wave height on the North Rupat coast is categorized as very low (<0,5 m) at stations 2, 3, and 4 and low (0,5 – 1 m) at station 1. The average wave period is 3,48 sec, highest at station 2 (4,05 sec) and the lowest at station 4 (2,76 s). The average wavelength is 19,31 m, with the longest at station 2 (25,58 m) and the shortest at station 4 (11,8 m). The average wave speed is 4,43 m/s, the highest at station 2 (6,32 m/s) and the lowest at station 4 (4,30 m/s). The average wave energy is 454,72 J, with the highest at station 1 (689,92 J) and the lowest at station 2 (313,60 J).

At the research location, the range of wave energy is from 313,60 J to 689,92 J. This is consistent with the study conducted by Akbar et al. (2020), which explained that the potential wave energy in the Malacca Strait ranges from 391,17 J to 25.035,95 J. The wave height at the research stations ranges from 0,25 m to 0,55 m and is categorized as low. This low wave height is directly related to the low wave energy values.

Tidal

The tidal data obtained during the data collection was used to verify the data acquired using the Naotide software. The comparison between the field tidal data and the data obtained using Naotide can be seen in Figure 2.

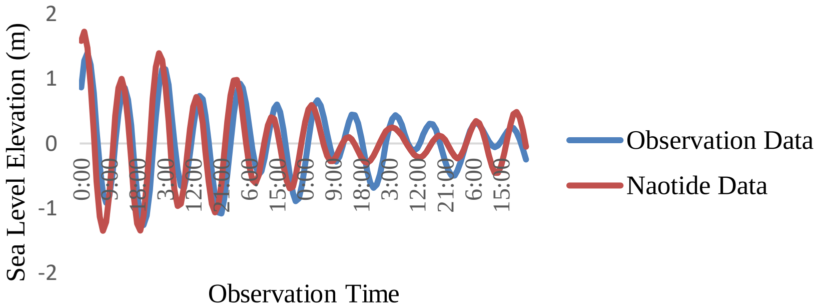

Figure 2. Graph of comparison between field tidal data and naotide data

The verification results between the observation data and the data generated by Naotide show that the comparison of both has an accuracy of 97%, meaning that the Naotide data can be used to simulate current direction and speed using the Mike 21 software. The tidal type occurring in the North Rupat Sub-district waters falls under the semidiurnal tides category. This can be determined by the Formzahl value, which is 0,227186.

Wind

The wind data is presented using a wind rose plot, as shown in Figure 3. The figure shows that the wind predominantly blows to the north, with a speed range of 8,909 to 10,182 m/s.

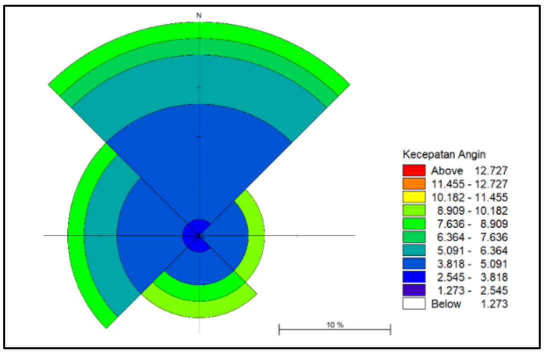

Figure 3. Wind Data Using Rose Plot

Tide current model

The tide current model was created using Mike 21 software with processed tidal elevation, wind, and bathymetry data. The simulation results show that the current moves from the southeast toward the northwest during low and high tides, and the current moves from the northwest toward the southeast. The simulation results for the current direction and speed can be seen in Figure 4.

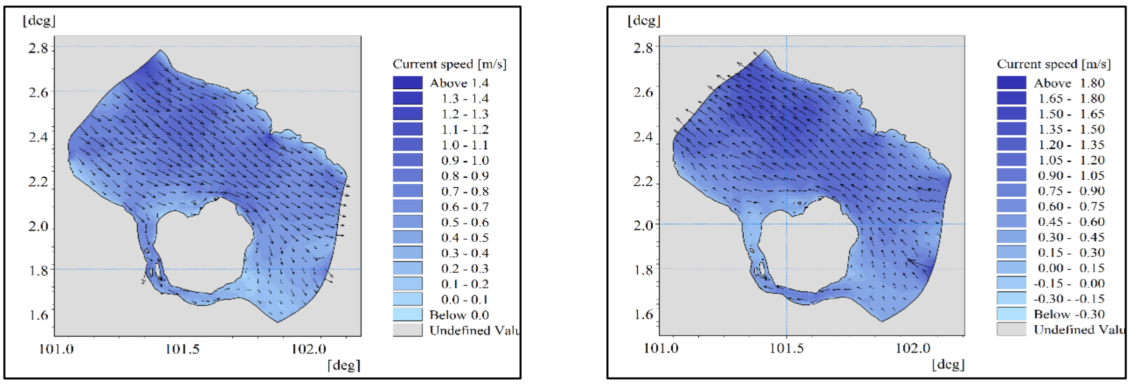

Figure 4. Simulation results of the sea current during (a) High Tide and (b) Low Tide

The simulation results show that the lowest current speed in the waters of North Rupat Sub-district during low tide ranges from 0,38 to 0,82 m/s. Meanwhile, during high tide, the highest current speed ranges from 0,36 to 0,95 m/s. The direction and speed of the current at each station can be seen in Table 2.

Table 2. Average sea current speed per station

Stasiun	Y (*Latitude*)	X (*Longitude*)	Average sea current speed (m/second)
1	2.128819	101.631662	0,37
2	2.126933	101.662111	0,43
3	2.106993	101.698757	0,55
4	2.061724	101.723008	0,22

Based on the simulation results using Mike 21, it was found that the current moves from the southeast toward the northwest during low tide and from the northwest toward the southeast during high tide. This is consistent with the study conducted by Haditiar et al. (2019), which explains that ocean currents in the Malacca Strait move toward the Andaman Sea, located to the northwest of the Malacca Strait. The current speed at the research stations, ranging from 0,22 m/s to 0,55 m/s, is also consistent with the research conducted by Usman et al. (2016), which states that the average current speed in the coastal waters of North Rupat Sub-district is 0,13 m/s.

Sediment

The results of the sediment fraction analysis in the coastal waters of North Rupat Sub-district can be seen in Table 3. The results show that the sediment type at stations 1 and 2 is predominantly sand, while at stations 3 and 4, it is generally dominated by silt. The percentage of gravel at station 1 ranges from 0,10-0,19%, station 2 from 0,14-0,24%, station 3 from 3,60-7,60%, and station 4 from 16,09-29,78%. The percentage of sand at station 1 ranges from 80,07-86,61%, at station 2 from 80,57-91,94%, at station 3 from 16,66 to 26,23%, and at station 4 from 11,48-19,26%. The percentage of silt at station 1 ranges from 13,20-19,83%, station 2 from 7,93-19,27%, station 3 from 68,21-75,74%, and station 4 from 58,05-72,41%.

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Table 3. Percentage of Sediment Fractions

Station	Repetition	Sediment Fractions			Sediment Type
		Gravel (%)	Sand (%)	Mud (%)	
	1	0,10	80,07	19,83	Sand
1	2	0,19	86,61	13,20	Sand
	3	0,14	81,99	17,88	Sand
	1	0,14	91,94	7,93	Sand
2	2	0,24	82,13	17,62	Sand
	3	0,16	80,57	19,27	Sand
	1	5,56	26,23	68,21	Sandy Mud
3	2	7,60	16,66	75,74	Mud
	3	3,60	22,80	73,60	Sandy Mud
	1	21,29	19,26	59,45	Gravelly Mud
4	2	16,09	11,48	72,43	Gravelly Mud
	3	29,78	12,17	58,05	Gravelly Mud

Based on the research conducted in the physical oceanography laboratory, the sediment in the coastal waters of the North Rupat Sub-district falls into the categories of sand and silt. According to Dianawati & Sentosa (2016), sediment grain size can describe the sediment's resistance to weathering and abrasion processes, particularly sand particles, which are an important factor in the coastal abrasion process. The location of the North Rupat Sub-district, which directly faces the Malacca Strait, can also be a factor in the distribution of sediment particles, especially at stations 1 and 2, which are directly impacted by wave action during high tide, resulting in a predominance of sand particles in these areas. Meanwhile, at stations 3 and 4, the current generally moves parallel to the coastline and transports many silt particles.

Coastline change

The coastline change analysis on the North Rupat Sub-district coast was conducted using the NSM and EPR methods, with a distance of 30 meters between transects. The satellite imagery used for this analysis spans from 2003 to 2023. The results of the coastline change analysis can be seen in Figure 5.

The analysis results from 2003 to 2023 using the DSAS analysis showed that the program created 1,757 transect lines along the coastline, with 1174 indicating accretion events and 583 transects showing erosion events. The highest accretion value was 252,8 meters, and the lowest erosion value was -111,29 meters. The results of the coastline change analysis at each station can be seen in Table 4.

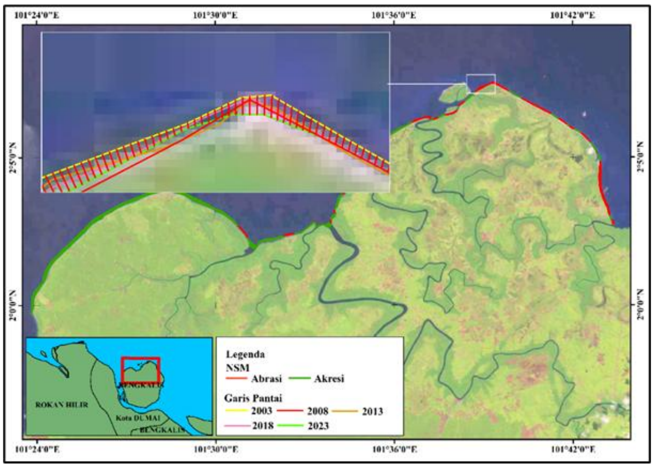

Figure 5. Coastline Change from 2003 to 2023

Table 4. NSM values at each station from 2003 to 2023

Station	Highest NSM Value (m)	Lowest NSM Value (m)	Number of Erosion Transects	Number of Accretion Transects	EPR (m/year)
1	93,87	-111,29	141	119	-0,23
2	24,11	-85,66	111	30	-0,99
3	74,7	-33,94	74	68	0,25
4	85,4	-99,83	126	20	-2,79

The results of the coastline change analysis in the North Rupat Sub-district show the occurrence of both erosion and accretion processes along the coast. The accretion process dominated the analysis of coastline changes from 2003 to 2023. The highest and lowest NSM values were 252,80 meters and -111,29 meters, respectively, with an EPR value of 2,20 m per year.

The analysis also showed that from 2003 to 2008, the coastline of North Rupat Sub-district was dominated by the erosion process, while from 2008 to 2013, the coastline changes were dominated by the accretion process. Similarly, from 2013 to 2018, the coastline changes were dominated by accretion, and from 2018 to 2023, the coastline of the North Rupat Sub-district was again dominated by the erosion process.

Based on the research findings, it can be concluded that the processes of accretion and erosion on the coastal beach of North Rupat Sub-district are caused by the interaction of hydro-oceanographic factors. Erosion on the coastal beach occurs due to the movement of currents relatively parallel to the coastline. Currents that run parallel to the coastline generally lead to erosion due to sediment transport. The coastal beaches of the North Rupat Sub-district also fall into the moderate and low categories in the coastal vulnerability index (Husaini & Darfia, 2021). The reduction of coastal vegetation, such as mangroves, can also contribute to the occurrence of erosion processes along the coast of the North Rupat Sub-district (Puspita et al., 2021).

Accretion generally occurs near river mouths and regions with low wave and storm energy levels (Istiqomah et al., 2016). The accretion process in the coastal region can occur due to sedimentation processes and anthropogenic (human activity) influences in coastal management (Fairuzia et al., 2023). Sedimentation can occur due to large amounts of freshwater runoff, which is caused by prolonged rainfall, as well as sediment transport from rivers.

The relationship between currents, waves, and coastline changes

Currents and ocean waves are closely related, where currents can be generated by wind movement and ocean waves striking the sea at an oblique angle, thus having a coastal erosive effect (Apriansyah et al., 2019). The observations show that both currents and waves fall into the moderate and low categories. The current velocity ranges from 0,36 m/s to 0,95 m/s, while wave heights range from 0,25 to 0,55 m. The relatively low currents and waves are suspected to be due to the gentle topography of the coastal area in the North Rupat Sub-district. One of the factors that can influence the processes of erosion and accretion is ocean currents and waves. Waves are formed by the movement of water masses, which are also generated by wind perpendicular to the coastline. The stronger the wind, the larger the waves created.

Ocean waves carry energy, which is then released when they reach the shore through wave impact. Waves approaching the shore at an angle create longshore currents, which play a crucial role in sediment distribution patterns along the coast and lead to erosion and accretion processes. Other factors can trigger erosion in certain areas, such as the lack of protective vegetation and the absence of wave breakers (Putra, 2019).

The relationship between sedimentation and coastline changes

The sedimentation process is the process of shallowing or extending the beach area caused by seawater accumulation and natural deposition (Halim et al., 2016). The grain size can explain the resistance of sediment to weathering, erosion, abrasion processes, and the sedimentation process itself (Girsang & Rifardi, 2014). The sediment distribution is influenced by physical factors such as currents and waves, particularly for suspended sediment types like mud (Purnawan et al., 2012). High sedimentation rates can cause the coastal area to become more gradual or sloping.

Sediment type is one of the important factors in the sedimentation process and changes in coastlines (Hidayati et al., 2016). Several characteristics of sediment that influence the sedimentation process include sediment composition, sediment size, and the distribution of sediment grains (Agnestasia et al., 2020). At the research stations, the dominant sediment types are sand and mud, with each sediment fraction found at all research stations.

CONCLUSION

The changes in the coastline of Rupat Utara District from 2003 to 2023 were dominated by the accretion process, with the highest accretion value recorded at 252,80 meters, the lowest abrasion value at -111,29 m, and an EPR value of 2,20 m/year. The coastline changes from 2003 to 2008 were dominated by abrasion, with the lowest abrasion value at -397,69 m, the highest accretion at 1319,57 m, and an EPR value of -6,98 m/year. The current velocity in the coastal waters of Rupat Utara District is categorized as low, ranging from 0,36 m/s to 0,95 m/s. The wave height in this coastal area is also categorized as very low to low. The sediment fractions in this area are generally classified as mud and sand.

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