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Modeling of Water Surface Elevation Using MIKE 21 Based on Rupat Strait Bathymetric Data

Pemodelan Elevasi Muka Air Menggunakan MIKE 21 Berdasarkan Data Batimetri Selat Rupat

Alianisa Ahmad*[1], Mubarak[1], Afrizal Tanjung[1], Rifardi[1], Ilham Ilahi[1]
[1]Department of Marine Science, Faculty of Fisheries and Marine, Universitas Riau, Pekanbaru 28293 Indonesia
*Correspondent Author: alianisa.ahmad0585@student.unri.ac.id

ABSTRACT

The Rupat Strait, a strategically crucial marine channel separating Sumatra Island from Rupat Island, exhibits complex hydrodynamic characteristics influenced by tidal propagation from the adjacent Malacca Strait. As a vital shipping corridor, the strait's navigational safety is fundamentally governed by its bathymetric profile and tidal regime. This study implements an integrated methodological framework combining in situ bathymetric surveys with MIKE 21 hydrodynamic modeling to assess morphological dynamics quantitatively. Systematic validation of model outputs against field measurements revealed significant spatial variations in seafloor topography, including pronounced shallowing (>6.6 m) and substantial deepening (≤17 m) at distinct locations. Concurrent analysis of tidal data demonstrated extreme water level fluctuations, ranging from -2.36 m during the lowest astronomical tides to +6.28 m during peak tidal surges. These geomorphological alterations appear correlated with anthropogenic pressures, particularly intensive shipping traffic and coastal zone modifications, suggesting a coupled natural-anthropogenic forcing mechanism governing the strait's evolving morphodynamics. The findings highlight the critical need for ongoing monitoring to ensure maritime safety and sustainable coastal management in this rapidly changing marine environment.

Keywords: Rupat Strait, Elevation, Bathymetry, MIKE 21

ABSTRAK

Selat Rupat merupakan jalur laut strategis yang memisahkan Pulau Sumatra dari Pulau Rupat, menunjukkan karakteristik hidrodinamik yang kompleks yang dipengaruhi oleh perambatan pasang surut dari Selat Malaka yang berdekatan. Sebagai koridor pelayaran yang vital, keselamatan navigasi selat ini pada dasarnya diatur oleh profil batimetri dan rezim pasang surutnya. Studi ini menerapkan kerangka metodologi terpadu yang menggabungkan survei batimetri in situ dengan pemodelan hidrodinamik MIKE 21 untuk menilai dinamika morfologi secara kuantitatif. Validasi sistematis keluaran model terhadap pengukuran lapangan mengungkapkan variasi spasial yang signifikan dalam topografi dasar laut, termasuk pendangkalan yang jelas (>6,6 m) dan pendalaman yang substansial (≤17 m) di lokasi yang berbeda. Analisis serentak data pasang surut menunjukkan fluktuasi muka air yang ekstrem, berkisar dari -2,36 m selama pasang surut astronomis terendah hingga +6,28 m selama gelombang pasang puncak. Perubahan geomorfologi ini tampaknya berkorelasi dengan tekanan antropogenik, khususnya lalu lintas pelayaran intensif dan modifikasi zona pesisir, yang menunjukkan adanya mekanisme pemaksaan alami-antropogenik yang mengatur morfodinamika selat yang terus berkembang. Temuan ini menyoroti kebutuhan kritis untuk pemantauan berkelanjutan guna memastikan keselamatan maritim dan pengelolaan pesisir berkelanjutan di lingkungan laut yang berubah cepat ini.

Kata Kunci: Selat Rupat, Elevasi, Batimetri, MIKE 21

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INTRODUCTION

The Rupat Strait is a strait that separates the island of Sumatra and Rupat Island, which is the administrative area of Bengkalis Regency and is located at 2°1'42.87"- 1°42'13.37"N and 101°21'9.31"- 101°42'17.79"E (Ginting, 2021). The eastern coast of Sumatra Island, directly opposite the Rupat Strait, has a length of around 84 KM; various industrial and tourism activities occur along the coast. These activities include the industrial activities of the Pertamina RU II Dumai Refinery, the Dumai Industrial Area, palm oil refineries, traditional to modern fishing, ecotourism, and marine tourism, as well as coastal environmental conservation activities in the mangrove ecosystem (Larasati et al., 2015). The Rupat Strait is also an active shipping lane; the shipping activities of tankers and cargo ships are pretty high, making the Rupat Strait an international shipping lane leading to the Malacca Strait.

The increasingly intensive development around the Rupat Strait, including converting mangrove land into fishponds and settlements, has put significant ecological pressure on the coastal ecosystem. In addition, large-scale industrial activities and shipping traffic around Dumai Port also affect the dynamics of the waters, especially in terms of variations in sea level elevation. This phenomenon is closely related to the seabed topography (bathymetry) characteristics, which play an important role in the movement of water masses (Anugrah, 2021). Thus, using numerical models such as MIKE 21 is crucial in producing more accurate and representative water level elevation simulations (Hapsari et al., 2022), so that they can support sustainable planning for managing the Rupat Strait coastal area.

Measuring sea depth or bathymetry is a primary data needed in a pier's planning and construction process. Bathymetry plays an important role in determining the feasibility of a pier, because the depth of the water will affect the type of ship that can dock and the shipping route of the ship that will sail or dock. In addition, tides are included in the hydrooceanographic factors that also affect environmental conditions around the pier (Hanifah et al., 2016). Coastal environmental observations have a broad scope, with various activities occurring. Hydrodynamic modeling to maintain coastal conditions makes it very easy to examine significant areas. Therefore, monitoring the bathymetric conditions and water elevation variations in the Rupat Strait is essential to assess coastal dynamics. Additionally, this monitoring must account for the influence of monsoon wind seasons, which play a critical role in hydrodynamic and sediment transport processes in global coastal and marine systems.

MATERIALS AND METHODS

The research was conducted in the Rupat Strait in November 2024. The quantitative method determines the error value of field data and modeling results. Furthermore, the data results are described descriptively (Hapsari et al., 2022). The results of the water elevation modeling will be corrected using field tidal observation values at the observation station located at the Dumai branch of Pelindo Port (101 ° 26' 36.25" E, 01 ° 41' 05.05" N). Figure 1 illustrates the bathymetric observation stations strategically positioned to monitor both coastal and mid-strait conditions in the Rupat Strait. Their locations were selected by the stations established by Rifardi (2021), enabling a comprehensive assessment of bathymetric variations across the strait's waters and ensuring consistency in subsequent hydrodynamic modeling.

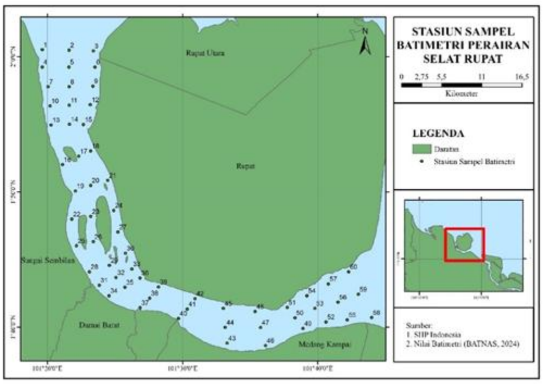

Figure 1. bathymetric observation station

This study uses primary and secondary data (Amirullah et al., 2014). Primary data in the form of tidal data from field measurements for three days are used to verify the model. Secondary data includes coastlines from

Google Earth Pro and bathymetry data from the site tanahair.indonesia.go.id, both used as input in the modeling. In addition, the modeling results in the form of current speed-direction and tides are also used, each to describe the simulation results and support the verification process of observation data.

Coastline and bathymetry data are processed to make them into a mesh boundary or research area to be input into Mike 21 (Prihantono et al., 2018). Other inputs, such as current speed and direction, are also adjusted for Mike 21. Furthermore, the model running process is carried out to obtain the elevation results of the Rupat Strait waters

RESULT AND DISCUSSION

Bathymetry

The results of bathymetric mapping using station points used by Rifardi (2021), extracted from BATNAS data owned by BIG (2024), show that there is shallowing and deepening in several parts of the Rupat Strait. Figure 2 is the result of bathymetric mapping using survey data carried out by Rifardi (2021), and Figure 3 is the result of mapping using BATNAS data, which is used as input for modeling currents in the Rupat Strait waters.

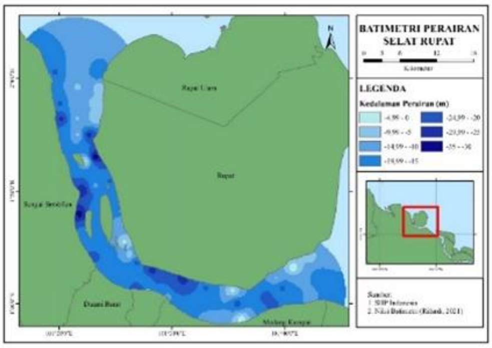

Figure 2. Bathymetric map of the Rupat Strait waters
(source: Rifardi, 2021)

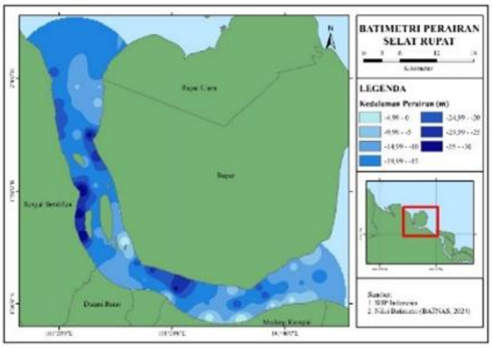

Figure 3. Bathymetric map of the Rupat Strait waters
(source: BIG, 2024)

Table 1. Comparison of bathymetric values in 2024 and 2021

No	X	Y	Rifardi (2021)	BIG (2024)	Δ	No Stasiun	X	Y	Rifardi (2021)	BIG (2024)	Δ
1	101.33	2.01	-20.6	-21.1	0. 5	31	101.40	1.72	-15.5	-15	-0.5
2	101.36	2.01	-11.2	-12.3	1.1	32	101.42	1.73	-15.3	-14	-1.3
3	101.39	2.01	-19.7	-19.7	0	33	101.44	1.74	-7.8	-6.1	-1.7
4	101.33	1.99	-16.7	-19.3	2.6	34	101.41	1.71	-15.5	-10.3	-5.2
5	101.36	1.99	-9.2	-9.3	0.1	35	101.43	1.72	-16	-14.9	-1.1
6	101.39	1.99	-8.2	-9.8	1.6	36	101.45	1.73	-20.9	-22.1	1.2
7	101.33	1.96	-20.6	-21.8	1.2	37	101.45	1.69	-22.4	-13.7	-8.7
8	101.36	1.96	-10	-13.5	3.5	38	101.46	1.70	-16.7	-14.8	-1.9
9	101.39	1.96	-8	-8.6	0.6	39	101.47	1.72	-27	-26.7	-0.3
10	101.34	1.94	-26.3	-24.4	-1.9	40	101.49	1.68	-13.8	-5.5	-8.3
11	101.36	1.94	-9.5	-15.3	5.8	41	101.51	1.69	-21.1	-31.2	10.1
12	101.39	1.94	-6.5	-9.9	3.4	42	101.52	1.70	-27.5	-29.4	1.9
13	101.34	1.92	-19.2	-20.7	1.5	43	101.55	1.65	-11.7	-3	-8.7
14	101.36	1.92	-9.4	-11.1	1.7	44	101.55	1.67	-19	-15.2	-3.8
15	101.38	1.92	-26.5	-31.7	5.2	45	101.55	1.69	-20.2	-18.6	-1.6
16	101.35	1.87	-19.2	-15.3	-3.9	46	101.60	1.64	-3	-1.2	-1.8
17	101.37	1.88	-4.5	-9.8	5.3	47	101.60	1.67	-21.8	-23.3	1.5
18	101.39	1.88	-32.1	-29.6	-2.5	48	101.59	1.69	-4	-6.9	2.9
19	101.37	1.83	-29	-36.6	7.6	49	101.65	1.67	-21.9	-4	-17.9
20	101.39	1.84	-14.1	-13.9	-0.2	50	101.64	1.68	-22.9	-22.7	-0.2
21	101.41	1.85	-20.1	-19.1	-1	51	101.63	1.69	-16.2	-21	4.8
22	101.36	1.80	-31.5	-32.8	1.3	52	101.68	1.67	-19.1	-3.6	-15.5
23	101.39	1.80	-15.6	-15.5	-0.1	53	101.66	1.69	-20.9	-19.8	-1.1
24	101.42	1.81	-16.7	-14.2	-2.5	54	101.65	1.71	-9.8	-12	2.2
25	101.37	1.77	-17.8	-34.8	17	55	101.70	1.68	-13.1	-5.9	-7.2
26	101.39	1.77	-15.8	-12.5	-3.3	56	101.69	1.70	-14.6	-15.5	0.9
27	101.42	1.78	-13.8	-12.4	-1.4	57	101.68	1.72	-2.4	-9.3	6.9
28	101.39	1.73	-23.3	-16.7	-6.6	58	101.73	1.68	-17.2	-14.1	-3.1
29	101.41	1.74	-18	-18	0	59	101.72	1.71	-17.7	-17.7	0
30	101.43	1.76	-4.4	-1.1	-3.3	60	101.70	1.73	-8.8	-6.8	-2

Data visualization done in the observation year shows the occurrence of sediment shallowing and deepening periodically. It appears in several different areas of the Rupat Strait in the northern part of the Rupat Strait waters, showing a deepening of the waters since 2021. The waters are also being deepened in the Rupat Strait around the coastal area of the Sungai Sembilan sub-district. Shallowing of the waters is seen in the coastal area of Medang Kampai sub-district, which is suspected to be a tourism area, and the occurrence of shallowing can be due to coastal filling activities to build coastal ecotourism areas. Comparison of bathymetry values in 2024 and 2021 (Table 1).

The data in Table 1 show the shallowing or deepening of the waters that occur in the Rupat Strait waters, which can be caused by the rate of sedimentation originating from the river mouth to anthropogenic activities (Ananda et al., 2020) that take place around the Rupat Strait coast. It can be seen that there is a shallowing of the waters up to 6.6 m and a deepening of the waters up to 17 m. A more detailed analysis of the observation stations reveals distinct bathymetric trends. Stations along the Dumai coast exhibit progressive shallowing, whereas those in the mid-strait and along the Rupat coast demonstrate consistent deepening patterns across successive sampling points. According to Rifardi (2021), the central part of the Rupat Strait is also characterized by weak sediment transport flows, resulting in bathymetric changes due to high sedimentation rates. This condition is supported by the formation of clusters of small islands in the area, and it is suspected that new islands will still form there because the current from the Malacca Strait flows in and out of the Rupat Strait during high and low tides. Water currents from two different directions form a meeting in the middle of the Rupat Strait during high tide and reverse direction during low tide. Weak water currents and varying sediment fraction values can cause weak sediment transport.

Elevation

Water elevation is influenced by various factors, both natural and anthropogenic. Natural factors can be climate change, causing melting of polar ice and thermal expansion of seawater, El Niño and La Niña phenomena affecting sea surface temperature and rainfall, and tides due to gravitational forces between the Earth, moon, and sun (Bisyri et al., 2020). In addition, wind and rainfall can create waves and increase the volume of seawater, while tectonic activities such as plate movement or volcanic eruptions can significantly change elevation. Coastal morphology and bathymetry also affect the interaction of waves and currents with land, impacting sea level elevation (Zahro & Zahrina, 2024). These factors interact and cause variations in water elevation at various locations and times. Water elevation from ebb to tide during the West Monsoon season for 2022-2023 can be seen in Figure 4, and for the period 2023-2024 can be seen in Figure 5. while the water level from high to low tide during the West Season for 2022-2023 can be seen in Figure 5, and the period 2023-2024 can be seen in Figure 6.

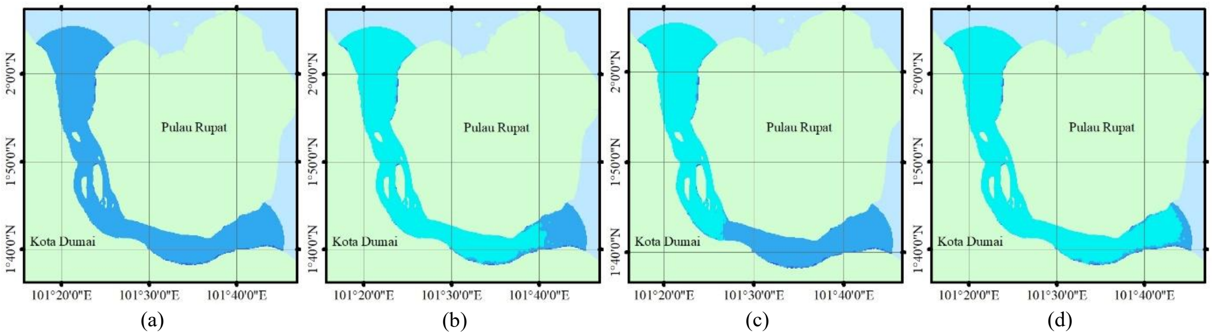

Figure 4. Water elevation from ebb to tide during the west monsoon (a), First transitional season (b), East monsoon (c), and Second transitional season (d) for the period 2022-2023

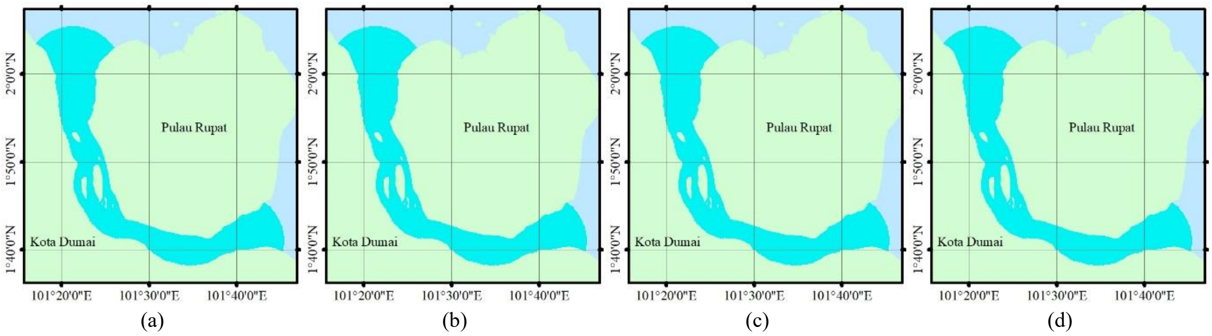

Figure 5. Water elevation from ebb to tide during the west monsoon (a), First transitional season (b), East monsoon (c), and Second transitional season (d) for the period 2023-2024

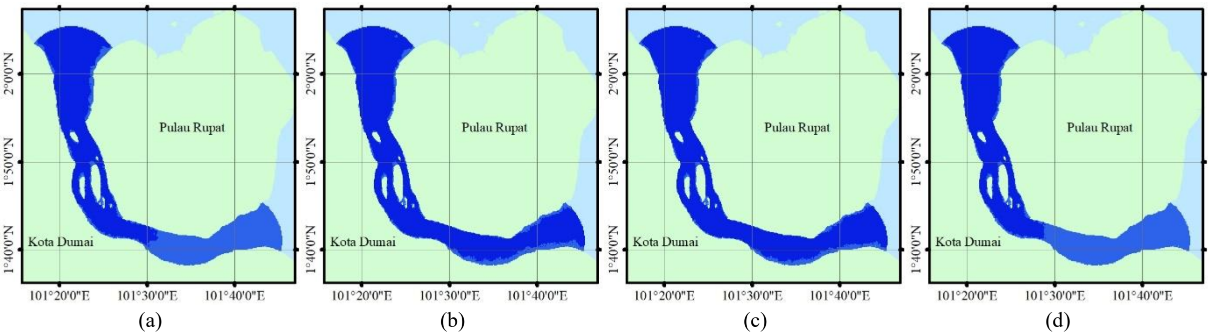

Figure 6. **Water elevation from tide to ebb during the west monsoon (a), First transitional season (b), East monsoon (c), and Second transitional season (d) for the period 2022-2023.**

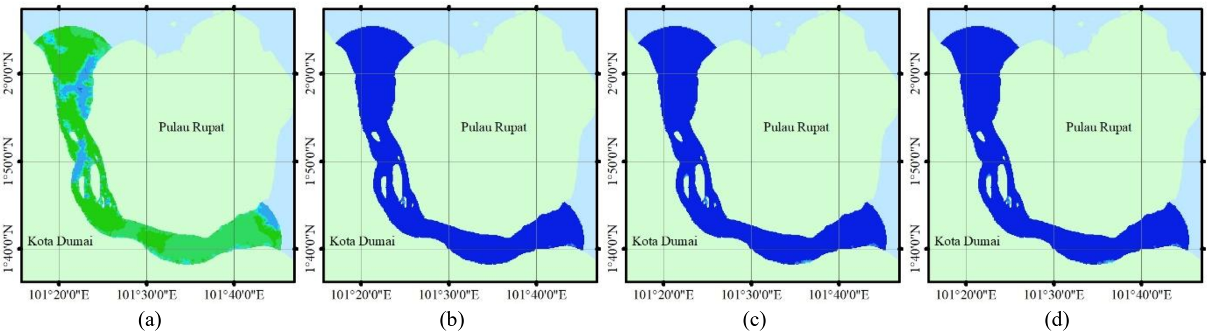

Figure 7. Water elevation from tide to ebb during the west monsoon (a), First transitional season (b), East monsoon (c), and Second transitional season (d) for the period 2023-2024

Based on modeling results, the highest sea level elevation increase can be seen in 2023-2024, with a value of 6.28 meters during the high tide phase towards low tide, accompanied by a decrease of 1.31 meters in 2022-2023. This significant variation can trigger tidal flooding, seawater intrusion, and abrasion in coastal areas (Pamuttu et al., 2018). In contrast to the west season, the transition season I (west to east transition) shows stability with the highest elevation of 2.39 meters (2023-2024, low tide to high tide) and a decrease of 2.36 meters (high tide to low tide), in a narrow range of 1.49–2.44 meters (low tide) and -2.36 to -1.40 meters (high tide). A similar pattern is seen in the east season, which is characterized by the Australian-Asian monsoon and calm sea conditions, with a maximum elevation of 1.81 meters and a decrease of 2.26 meters (2023-2024), and an elevation range similar to transition season I. Meanwhile, transition season II (east to west transition) recorded the highest increase of 2.6 meters and a decrease of 2.35 meters (2023-2024), remaining in a stable range like the previous season. Overall, only the west season showed extreme fluctuations, while the other three seasons were relatively consistent, indicating a lower risk to coastal areas other than during the west season.

CONCLUSION

Comparison of bathymetric data in 2021 and 2024 shows changes in the morphology of the Rupat Strait waters in the form of shallowing of up to 6.6 m and deepening of up to 17 m. This change is caused by sedimentation from river mouths and anthropogenic activities. Weak currents in the middle of the strait also contribute to sediment accumulation, trigger the formation of small islands, and show ongoing sediment dynamics in the area. The highest elevation increase is with a value of 6.28 m. The decrease in the elevation of the Rupat Strait waters experienced the lowest decrease of up to 2.36 m in the transition season I period 2023-2024, the high tide phase towards low tide. The average value of the Rupat Strait waters was 0.6 m during the observation period.

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