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Article

The properties of Sediment transport mechanism in River Mouth of Rupat Strait

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Abstract: The Rupat Strait, a part of the Malacca Strait, is recognized as semi-closed waters and shows a high activity; thus, discovering the transport sediment mechanism of the strait as consequence of ambient and anthropogenic forces is essential. Hydrodynamic and sediment transport modelling was constructed using the 2-Dimensional Explicit method which is averaged over depth. The results show that the dispersion of sediment at high tide is longer than that at low tide. This follows hydrodynamic model in which current velocity at high tide is greater than the ocean current at the low tide. The previous sediment observation supports the results of transport sediment modelling, indicating that the anthropogenic factors are highly associated with the sedimentation in the Rupat strait.

Keywords: River mouth, Rupat Strait; sediment transport; tidal current

1. Introduction

The Rupat Strait constitutes a part of the Mallaca strait and is known as semi-closed waters, with fluctuating currents controlled by the monsoons. The sediments in the Rupat Strait are dominated by fine and very fine sediments with a muddy beach type and well sorted and fine sediments transported by tides [1]. Fine sediment transport plays an important role in the formation of coastal morphology especially in intertidal zone. This is a zone where the freshwater meets saltwater; therefore, the river stream runs slowly and deposits the suspended sediment supplied from the upstream basin into the bottom, resulting in a shallow bathymetry. The silting speed is highly dependent on the competition between the forces of the sea (tides), wave, wind, and river discharge. These driving forces sometimes interact with each other to provide sediment transport dynamics that contribute to resuspension and advection properties [2]. The tidal flow also affects the small-scale ripples of the suspended load sediment transport, both indirectly and directly [3]. The mouth of the estuary with sediment dominated by mud will have an important cross-shore chenier dynamics effect [4].

Due to large of human activities, the Rupat Strait suffers a high sedimentation. For example, Mesjid River, one of the rivers located in the strait, shows a large drainage due to rapidly developed and becomes the center of residents, industries and agriculture [5,6]. Human activities and ambient forces greatly contribute to the geomorphology and water quality of the Rupat Strait. Hence, environmental aspects related to sediment transport driven by anthropogenic activities and ambient forcing becomes the most important issue. The research is needed to uncover the sediment processes, transport and related environmental aspects of the strait.

The dynamics study of the Rupat strait has been reported by researchers and mostly published national journals (non-English). However, these reported studies seem to be partially discussed. Studies using modeling show that in the western monsoon, the significant wave heights of the Rupat Strait ranged from 0.12 to 0.90 m / s, and the velocity of the highest current ranged from 0.18 to 0.78 m /s. In general, during springtide, the Malacca strait flows into the Rupat Strait [6]. The bathymetry

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measurement results show that in the mouth of the river around the Rupat strait sandbar is formed, indicating that sediment transport due to the monsoon effect is quite strong. Sediment supply indicated by the value of suspended sediment at the mouth of the river was very high, reaching up to 354.61 mg / l and 926 tonnes/day of sediment from the river and deposited at a rate of 0.024 m / year in the front area river mouth [5,7,8]. Another study shows that the sediment sampling with a gravity core in front of the river mouth and at the border with the Malacca strait shows that the mouth of the river generally consists of fine sand while the area close to the Malacca strait has sediment from fine sand and sand. It was found that organic matter was also more abundant in the waters near the mouth of the river [1,5]. In this paper, we show the distribution of transports sediment based on the generating force with the variation in input as a representation of the anthropogenic effects.

2. Materials and Methods

The research was carried out in the Rupat strait waters with a research focus on the Dumai river estuary and the Mesjid river estuary. The study area is depicted in Figure1a. Measurements for one month in November 2020 with measured parameters are sea-level elevation, ocean currents, and sediment content in seawater. The analysis of TSS samples was carried out using the gravimetric method SNI 06-6989.3-2004, with 100 mL of seawater samples filtered using a vacuum pump and filter paper with a pore size of 0.45 μm. The results of the screening were then weighed and the TSS concentration was calculated. The hydrodynamic model and a simple disperse were simulated by entering the tide and discharge data of the Dumai and Mesjid rivers. Simulations were carried out in various scenarios of input and concentration from the two rivers. In the simulation of the distribution model of sediment suspension, 3 (three) model scenarios were carried out, namely: scenario 1 with a concentration input of 0.1kg/m^3, scenario 2 with a concentration input of 0.5 kg/ m^3, scenario 3 with a concentration input of 1kg m^3. The sediment material included fine silt with a sediment velocity of 0.009 cm / sec with a grain size of 10 μm [7].

Hydrodynamic modelling was constructed using the 2-Dimensional Explicit method which is averaged over depth (depth-averaged). The governing equation was represented by the mass conservation equation (the continuity equation) and the momentum equation. Hydrodynamic modelling simulations were carried out for 15 days to obtain the conditional of tidal patterns. The tidal data obtained from the Indonesian Navy's Hydrooseanographic Service and processed by using tide harmonic analysis. The validation of the model and data comparison was performed using the RMSE.

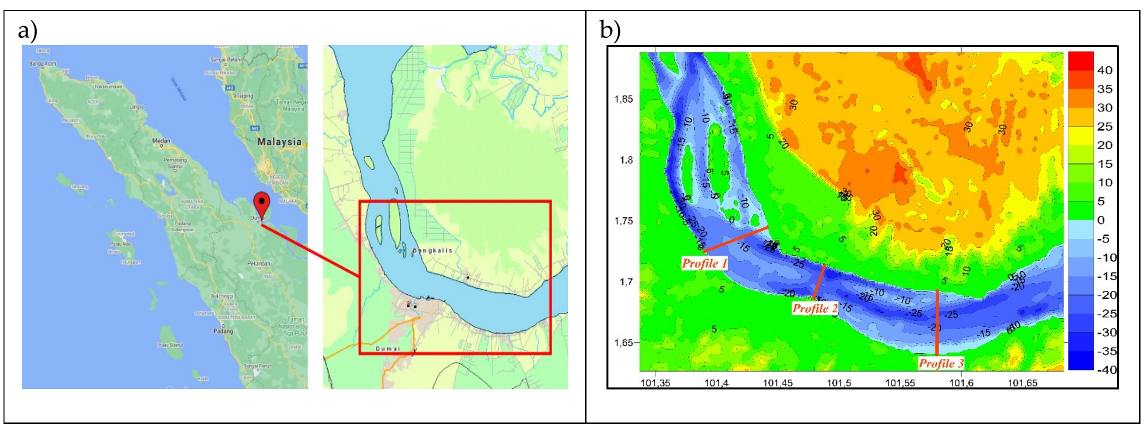

Figure 1. (**a**) The research location in the Rupat strait with coordinates around (N781930.04, E184415.80) ; (**b**) The bottom topography of Rupat strait shows present study site and the depth is expressed in meter.

The sediment transport model followed a two-dimensional system, in which the vertical direction concentration is assumed to be uniform. We use the Mud Transport (MT) module which

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is applied for sediment transport using clay or clay as a base material which specialized for non-cohesive modelling. The equation can be written as follow [10],

$$\frac{\partial C}{\partial t}+U\frac{\partial C}{\partial x}+V\frac{\partial C}{\partial y}=\frac{\partial}{\partial x}\left(D_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_y\frac{\partial C}{\partial y}\right)+\alpha_1 C+\alpha_2 \quad (1)$$

where C is sediment concentration, U and V are zonal and meridional velocity respectively, D_x and D_y are dispersion coefficient in x (zonal) and y (meridional) direction respectively, α_1 is decay coefficient and α_2 is a sediment source.

3. Results

3.1. Morphology and Hydrodynamics of the Rupat Strait

Water depth in the Rupat Strait varied, ranging from -5 to -40 m. According to Girsang and Rifardi [7], the depth of the eastern Rupat strait ranged between 0.4 - 24.8 m, as depicted in Figure-2. Based on the shape of the topography, several ridges were formed in the Rupat strait, and the deepest depths were generally observed in the middle of the strait. Regarding the tide chart, it can be seen that the tides in the Rupat strait occurred two times a day or semi-diurnal, where the highest tide reached 1.26 meters, while the lowest was -1.37 meters. Based on the calculation, tidal type in Rupat strait waters obtained a Formzhal Number value of 0.21, demonstrating that it is a mixed tidal type that tends to double a day. This means that in one day there are two times the tide rises and two times down. Meanwhile, the height of the first tide is different from the height of the second tide. The comparison between tidal measurement and hydrodynamics model is presented in Figure-2.

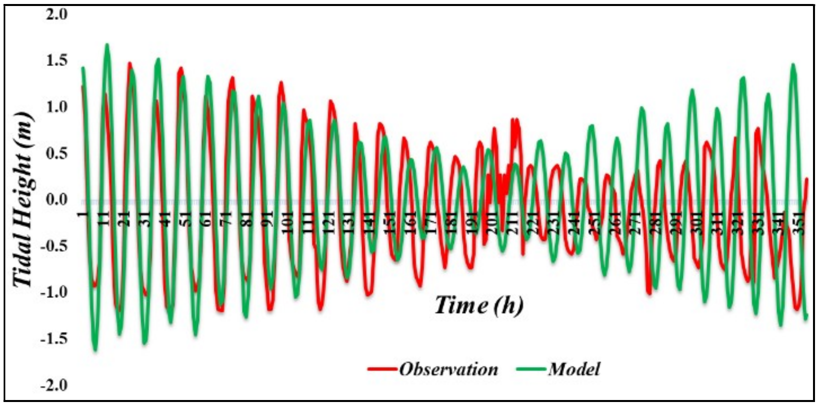

Figure 2. Tidal elevation in Rupat Strait. The observation follows 1-hour intervals for 15 days. The green color represents the resulting tidal elevation from the model and the red color is the tidal elevation from observation.

According to observation, we found variation of the amplitude of the tidal components. *So* component possesses the amplitude of 136.2 cm and phase difference of 0 cm from MSL, while *M2* component has the amplitude of 77.9 cm and phase difference of -196 cm. In addition, *S2* has the amplitude of 18.6 cm and phase of 34cm, and *N2* has the amplitude of 61.9 cm and phase of -101. Furthermore, *K2* shows the amplitude of 4.3 cm and the phase of 34 cm, while *K1* has the amplitude 5.5 m and the phase 317 cm. Futhermore, *O1* has the amplitude of 17.6 cm and the phase of -79 cm. *P1* has the amplitude of 1.8 cm and the phase of 317 cm, while *M4* has the amplitude of 5.5 cm and the phase of -459 cm. *MS4* has the amplitude of 6.5 cm and the phase of -192 cm. The verification revealed that RMSE error value between the tidal data acquired from the model and the field observations reached 4.21%. The percentage showed a higher accuracy compared to the research conducted by Syafutra et al. 2014 with a verification value of 6,389%. In short, we performed better validation to compare the hydrodynamics model and fields measurement. The ocean current obtained by hydrodynamic models is depicted in Figure 3. This shows that the current flows from

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west to east during high tide, and in the low ride the direction of the ocean currents change from east to west.

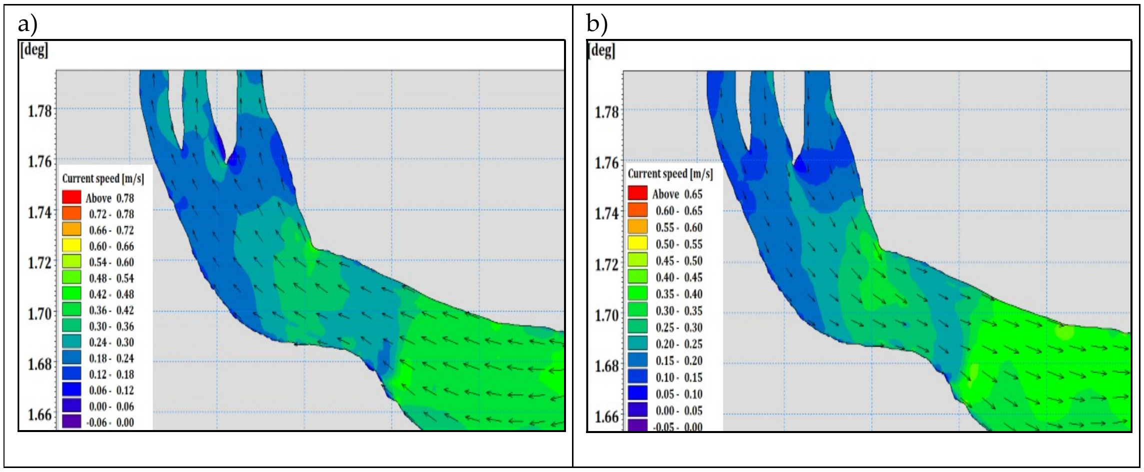

Figure 3. (**a**) Ocean currents at spring-tide from the hydrodynamic model show the dominant flow in the Malacca strait coming from the east; (**b**) The currents at neap-tide from the hydrodynamic model shows the dominant flow coming from the west to the east.

3.2. The Sediment Transport

The results of sediment transport modelling can be seen in Figures 4, explaining the model during high tide and low tide conditions. In the sediment transport simulation, the sediment source is assumed only from the Dumai river and the Mesjid river which are carried by the ocean currents, while other sediment sources such as seabed mortars (due to the resuspension process) and industrial activities and ports around the estuary are ignored. The simulation results show that the distribution of sediment in the Rupat strait waters is influenced by the current pattern generated by the tides. Tidal currents are effective when working in estuary, bay mouth or strait areas that are protected by the border island. Sediment concentration during low tide tends to be higher than during high tide. This closely relates to the fact that at low tide the suspended sediments in the estuary are dominated by suspended sediments from the river.

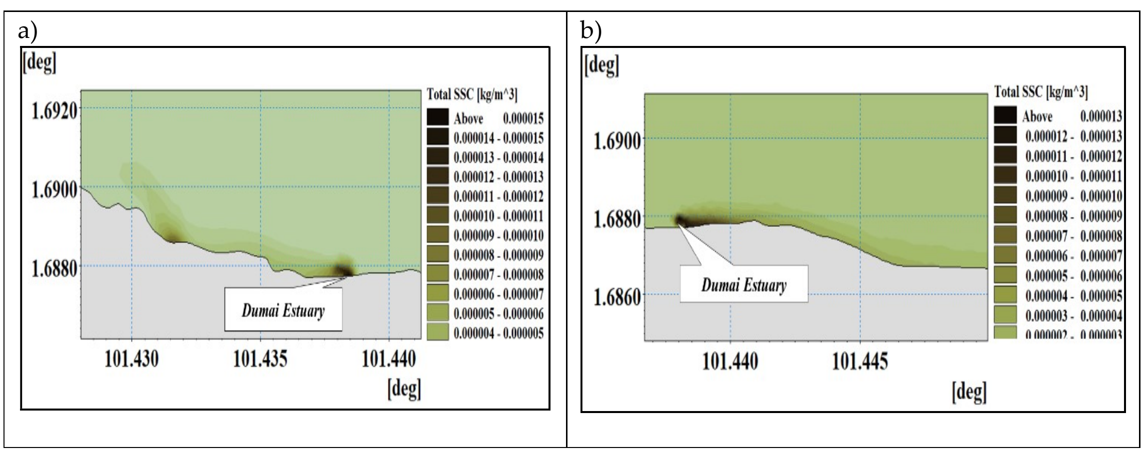

Figure 4. (**a**) Transportation of suspended sediment during spring tide at the mouth of the Dumai River for the first scenario with 0.1 kg / m³ sediment input; (**b**) Transportation of suspended sediment during spring tide at the mouth of the Dumai River for the first scenario with 0.1 kg / m³ sediment input.

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The sediment transports at the mouth of the Dumai river and the Mesjid river are located in the west and middle of Rupat strait. According to the hydrodynamic model, this region has a weaker current speed than the eastern part. For the Dumai river, the average speed is around 0.5m/s, while the speed for Mesjid river reaches about 0.2 m/s. The dispersion of sediment at high tide is longer than that at low tide. This supports finding in hydrodynamic model showing that at high tide the current speed is greater than the ocean current at the low tide. It can be inferred that the dispersion due to advection is quite dominant.

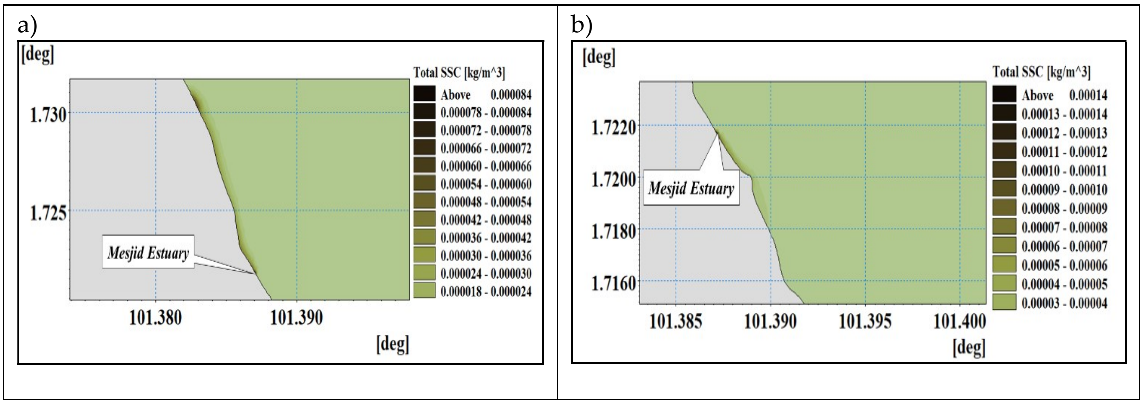

Figure 5. (**a**) Transportation of suspended sediment during spring tide at the mouth of the Mesjid River for the first scenario with 0.1 kg / m^3 sediment input ; (**b**) Transportation of suspended sediment during spring tide at the mouth of the Mesjid River for the first scenario with 0.1 kg / m^3 sediment input.

4. Discussion

In general, the dominant currents in the Rupat strait are bidirectional, in which they flow from the west to the east during high tide, but flow at contrary direction during low tide. Because the Rupat strait is quite narrow, the water mass influence from the Malacca strait should be quite dominant, but the monsoon system shows dominant effects [9,11]. The south-west (SW) where the wind flows from the south-west to the north-east is monsoon active from June through September. The north-east (NE) monsoon where the winds are directed from the north and northeast to the south-west is active from December through February. During SW the water mass of Malaca strait affects by Andaman sea and during NW the watermass affects by South China Sea. The general pattern of surface ocean current flow is continuous from southwest to northwest throughout the year, except June and August, when the currents are very weak and sometimes reversed to the south-east [9,10]. In this study, it is still unclear regarding the effect of water mass from the Malacca strait. Considering that input of the model uses only tidal data, the surface current by monsoon winds does not appear. For future research, the effect of the water mass of the Malacca strait needs to be considered since its flow direction is similar throughout the year.

The Rupat strait connects two bustling industrial areas, i.e. the city of Dumai and Rupat island, in which there are many activities of the oil industry, palm oil industry and trading. This activity provides sediment input and worsens the water quality in the well-supplied Rupat strait waters from the river or ship traffic. Key environmental indicators based on dissolved oxygen concentration (DO) and BOD in Rupat strait indicated light to medium pollution. On the other hand, concentration of oil in surface waters was higher compared to the oil content in sediment either in river estuary or in the port of Dumai [12,13]. The accumulation of these materials results in solid material via coagulation process, then they are deposited on the bottom of the waters as seabed sediments. Figure 4 and Figure 5 suggest that that the advection process in a sediment transport is dominant, thus sediment deposition follows the flow pattern. Consequently, in accordance with the current pattern, the sediment deposition is concentrated in the west part of the Rupat strait where the upper

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layer consists of mostly fine sediment as a result of the coagulation of material in water bodies due to the presence of pollutants.

The measurement results show that in the western part of the Rupat strait, the sediment consists of a small part of gravel, dominant sand and fine sediments in the moderately well sorted and well sorted category [14]. The results of sediment analysis demonstrated that the sediment fraction at the PT CPI oil port (which is the most densely populated area in the western part of the Rupat strait) is sandy mud with mud content ranging from 48,17–74,75% [13]. On the contrary, the surface sediment of the Rupat strait waters is characterized by fine sand to coarse silt sediments, and dominated by the basic character of sand. The proportion of surface sedimentary sand is more than 50% terrigenous sediment, while suspended sediment content is greater than 100 ppm [1,7]. Data from observations are in accordance with the results of transport sediment modelling in the Rupat strait, in which the fine sediment becomes more concentrated in the west part. This indicates that the anthropogenic effect greatly affect sedimentation in the Rupat strait.

Sediment transport at the mouth of the Dumai river at high tide (see figure 4) indicates onshore movement at strong level. Several studies reported that onshore movement of sediment in the mouth of the estuary could be fingerprinted by presence of suspended sediment fluxes and bedload transport [15]. In addition, sediment transport models also showed that the sediment dynamics at the mouth of the estuary are constructed by tidal pumping, especially for semi-closed waters [16]. For dominant wind-induced current, the sediment transport at the mouth of the estuary is usually dominated by eddying circulation [17]. For monsoon-dominated estuaries, tidal and wave effects (usually, large waves occur at the NW monsoon) generate a cheniers effect (is a beach ridge, resting on silty or clayey deposits) where a body of wave-reworked is able to stabilize mud-dominated coastlines [4]. As presented in Figure 4 and Figure 5, sediment transport at high tide and low tide is asymmetrical. The existence of asymmetries in sediment transport is not only related to the tide–wind interaction, but also related to the intratidal asymmetries in sediment concentration that can be generated by current-topography interaction [2]. Although sediment transport modelling provides us with an understanding of the sediment transport mechanism either due to ambient or anthropogenic forces, intensive monitoring of sediment transport is necessary and this is the target of future research.

5. Conclusions

Discovery of the sediment transport mechanism in the Rupat strait using hydrodynamic models and depth-averaged integrated approach is reported. The research focused on sediment transport generated by tidal currents. The tides in the Rupat strait were recorded as semi-diurnal (two times a day), in which the highest and lowest tide reached 1.26 m and -1.37 m, respectively. The current flow from west to east occurred during high tide, and during low tide the direction of the ocean currents changed from east to west. The dispersion of sediment at high tide was longer than that at low tide. These findings were in agreement with hydrodynamic model showing that current speed was higher at high tide than that at low tide. This also suggested that the dispersion due to advection was dominant. In short, our findings in field observation successfully confirmed the results of transport sediment modelling which indicated that the anthropogenic effect was essential factor responsible for sedimentation in the Rupat strait.

Author Contributions: MM analyzed data and wrote the manuscript; AN created the hydrodynamics and sediment transport model, RR analyzed sediment transport model, AS analyzed data and output model.

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Conflicts of Interest: The authors declare no conflict of interest.

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