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Tidal and Bathymetry Characteristics in Dumai River Estuary in Dumai City, Riau Province

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ABSTRACT

This research was carried out in July 2023 in Muara Sungai Dumai, Dumai City, Riau Province. This study aims to conduct depth mapping analysis using echosounders based on reference corrections to tides. Tidal analysis is performed to determine reference values such as MSL (Mean Sea level) and tidal characteristics. The methods used are survey methods and quantitative analysis. The results showed that the waters of the Dumai River Estuary were mixed tide prevailing semi-diurnal with a formzahl value of 0.29. There is tidal asymmetry with the time to the high tide faster than the time to low tide. The depth ranges from 0.28 to 7.34 m, increasing to 40 m in the Rapat Strait. The weak current and the difference in HHWL values of 3.55 m and MSL 0.14 m affect water level rise due to bathymetric changes at high tide.

Keywords: Bathymetry, Dumai River estuary, Tides

1. INTRODUCTION

The estuary of the Dumai River is a watershed (DAS) whose utilization continues to increase for various activities, and this increase impacts the decline in the quality of the Dumai River. Various activities occur in these waters because they are located in transportation channels, ports, and fisheries trade. The estuary of the Dumai River serves to drain a water discharge more significant than the river discharge, so the estuary must be broad and deep enough (Aristi et al., 2021).

Depth information is vital for several studies of marine resource activities, both in deep and shallow waters (Anzari et al. 2017). However, bathymetric maps for shallow waters are currently limited, including the Dumai River Estuary area. The term bathymetry is defined as the measurement and mapping of the topography of the seabed. Bathymetric information is critical in the marine sector, for example, in determining shipping flows, development planning, suitability for cultivation, etc. The amount of human activity in the estuary causes environmental degradation, so the natural ecosystem becomes disturbed. Rapid land development resulted in rapid siltation. The obstruction of river flow impacts the Dumai River's capacity when accommodating the water flow from the sea when the tide overflows into settlements and causes tidal flooding. In contrast, at low tide, shipping can be hampered.

Technology development runs very rapidly nowadays, and bathymetric measurements can be done using acoustic technology. Bathymetric measurements with acoustic methods are more effective and efficient because they do not damage the environment (Febrianto et al., 2015). Bathymetric mapping requires tidal correction at the location. However, how bathymetric conditions in the Dumai River Estuary are not yet clearly known, so it is necessary to extract data and information related to the area's characteristics, conditions, and oceanographic dynamics.

2. RESEARCH METHOD

Time and Place

This research was carried out in July 2023 at the Dumai River Estuary, Dumai City. Data was analyzed at the Physical Oceanography Laboratory, Faculty of Fisheries and Marine, Universitas Riau.

Method

The survey method was used in this study. The data collected is in the form of primary data and secondary data. The research station was determined by purposive sampling, which considered that the station point could represent all research objects at the Dumai River Estuary. The results of the data obtained are analyzed and then discussed descriptively.

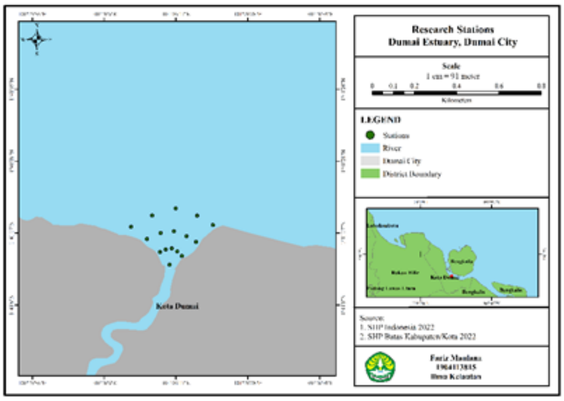

Figure 1. Map of research location

Procedures

Tidal Measurement

Tidal measurements are carried out to determine the mean sea level as a correction and measurement of water depth. The Tide Pole method uses a measuring pole installed at a predetermined location. Determination of the observation location using the sampling area method. Data was measured over 15 days and time intervals of 1 hour.

Tidal secondary data were obtained through Japan's NAOTide (National Astronomical Observatory) model, forecasting the tides' water level elevation (vertical direction). The data was managed using the admiralty method of Microsoft Excel to obtain graphs of sea level rise and tidal harmonic constants. The value of the continuous obtained is used to determine the type of tide by looking at the Formzahl value (Sasongko, 2014).

Depth

Depth measurement using a single beam echosounder Garmin GPS map 585 mounted on a vessel with a subsurface transducer. This tool measures water depth by using a single beam as a sender and receiver of signals. Sounding data is obtained by measuring the time interval between the emission of sound waves and the reception of their reflection (echo) from the bottom of the water. The slumping data is then downloaded from the echosounder and corrected to the value of the sea level position at the time of the gathering (Ali et al., 2017).

Current Speed

Current velocity measurements are made using a current drogue, and travel time is calculated using the equation:

$$v = \frac{s}{t}$$

Brightness

Brightness is measured using a Secchi disk tied with a string. It then calculates the visible pattern until the part is not visible, using the equation:

$$\text{Brightness} = \frac{d1+d2}{2}$$

Temperature and Salinity

Sea surface temperature is measured using a thermometer, and data is detected from the echosounder, while salinity is measured using a hand-refractometer.

Bathymetry

Bathymetric data is obtained through the BATNAS (National Bathymetry) website, which is part of the BIG (Geospatial Information Agency) service on the availability of elevation data in Indonesia.

Data Processing

Data processing begins by analyzing the tides using the Admiralty method. This method calculates two harmonic constants, amplitude and phase difference, in a short period (29 days) (Ichsari et al., 2020). The output produced has nine main components, namely M2, S2, N2, K1, O1, P1, M4, MS4, and K2. In contrast, the elevation value is in the form of MSL (Mean Sea Level), MHWL (Mean High Water Level), HHWL (Highest High Water Level), and LLWL (Lowest Low Water Level). According to Musrifin (2011), the tidal component is used to determine tides based on Formzhal numbers expressed in the formula:

$$F = \frac{(O_1) + (K_1)}{(M_1) + (S_2)}$$

F = Formzahl number
K1 = constant by declination of the moon and sun
O1 = constant by the decline of the moon
M2 = constant by month
S2 = constant by the sun

So from the F value, the type of tide can be determined based on the following classification: $F \leq 0.25$ (semi-diurnal tide), $0.25 \leq F \leq 1.5$ (mixed tide prevailing semi-diurnal); $1.5 \leq F \leq 3.0$ (mixed tide prevailing diurnal); $F > 3.0$ (diurnal tide).

The depth data was corrected by tides, according to Tarigan et al. (2014), using the equation:

$$rt = TWLt - (MSL+Z0)$$

Note:

rt = the amount of reduction (correction) of the depth measurement results in Time t

TWLt = actual sea level position (True Water Level) on Time t

MSL = Average sea level (mean sea level)

Z0 = Depth of ebb receding below MSL

After reduction, the actual depth value is hit by the equation (Masrukhin et al., 2014):

$$D = dT - rt$$

Note:

D = Actual depth

Dt = Transducer corrected depth

rt = reduction of tides

The corrected depth data is interpolated as contour maps using the Kriging method by creating a Countur Map and 3D Surface contained in the Surfer 16 software. The effect of water surface height due to bathymetric changes was carried out through qualitative descriptive analysis. This analysis explains and examines something based on data to obtain conclusions from the phenomenon with existing data.

3. RESULT AND DISCUSSION

Tidal

The results of admiralty processing produce tidal components (Table 1). The results obtained are the amplitude value (A) and phase delay (g°), then from the results of the tidal components obtained tidal elevation values (Table 2).

Table 1. Results of the admiralty harmonic constant

	So	M2	S2	N2	K2	K1	O1	P1	M4	MS4
A cm	0.14	79.1	43.4	20.9	10.0	16.6	20.1	5.5	0.3	0.2
g°		23.5	78.3	43.4	78.3	344.8	6.4	344.8	116.0	236.7

Table 2. Tidal elevation value

Tidal Elevation	Value (cm)
MSL (Mean Sea Level)	0.14
LLWL (Lowest Low Water Level)	36.8
HHWL (Highest High Water Level)	355.1
MHWL (Mean High Water Level)	318.4
MLWL (Mean Low Water Level)	73.5

Based on the results of the Admiralty's calculations, it is known that the value of the Formzahl number F = 0.29 means that the tides in the waters of the Dumai River Estuary are mixed tides prevailing semi-diurnal. Previous research also found the same thing. According to Febrian et al. (2016), the beach of Pangkalan Sesai Village was classified as a mixed tide prevailing semi-diurnal. Tidals in estuaries are tides that propagate from the open sea, so the tidal component changes compared to deep waters such as the Strait of Malacca and the Rapat Strait. Usually, the magnitude increases by a more significant factor when there is a resonance between the tidal period of deep waters and the natural period of inland waters (Fadilah et al., 2014).

Based on the results of measurements made in the field, tidal range data or the average position of high water and low water position is 244.9 cm (2.4 m), with the Mean Low Water Level (MLWL) being 73.5 cm and the Mean High Water Level (MHWL) is 318.4 cm (Figure 2).

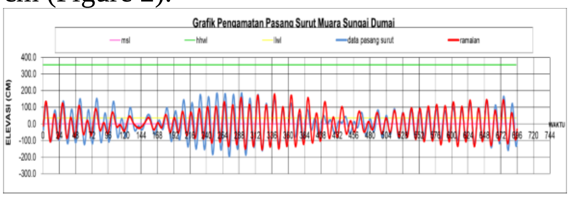

Figure 2. Tidal fluctuations of the Dumai River Estuary

Figure 2 shows the same elevation up and down pattern from the measurement and prediction results. So that tidal measurement data is considered appropriate for use. Based on the data plotted in the graph (Figure 3), it can be seen that the time is asymmetrical when going to the highest tide and heading to the lowest tide, where the highest tide time (3-4 hours) is faster when compared to the time of conditions towards the lowest low tide (7-8 hours). According to Surbakti (2012), asymmetry is characteristic of tidal phenomena that commonly occur in estuary areas because, during high tide, there is an influx of water from the sea and upstream. Hence, the buildup of water masses causes the water level to rise faster. Meanwhile, at low tide, the water level drops longer. According to Gunawan et al. (2021), tidal asymmetry is also due to the influence of reduced depth.

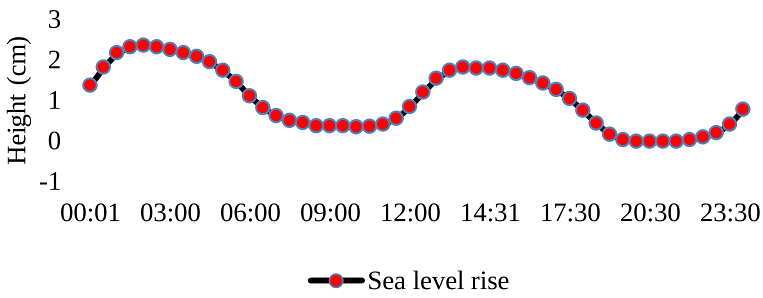

Figure 3. Asymmetric tidal graph

Table 3. Correction of bathymetric data

Station	dT (m)	MSL (cm)	Z0	TWLt	rt (m)	D (m)
1	-2.9	0.14	195.95	75	-1.21	-1.69
2	-4	0.14	195.95	75	-1.21	-2.79
3	-2.3	0.14	195.95	75	-1.21	-1.09
4	-1.5	0.14	195.95	75	-1.21	-0.29
5	-3.1	0.14	195.95	104	-0.92	-2.18
6	-1.2	0.14	195.95	104	-0.92	-0.28
7	-3	0.14	195.95	104	-0.92	-2.08
8	-1.8	0.14	195.95	104	-0.92	-0.88
9	-2.5	0.14	195.95	104	-0.92	-1.58
10	-3.9	0.14	195.95	104	-0.92	-2.98
11	-2.8	0.14	195.95	104	-0.92	-1.88
12	-7.2	0.14	195.95	104	-0.92	-6.28
13	-7.6	0.14	195.95	120	-0.76	-6.84
14	-7.8	0.14	195.95	120	-0.76	-7.04
15	-8.1	0.14	195.95	120	-0.76	-7.34
16	-7.4	0.14	195.95	120	-0.76	-6.64

Note: Dt: Transducer/Echosounder depth; MSL: Mean sea level; Z0: Chart datum level; TWLt: True Water Level at t time; rt: reduction (correction) of tides; D: Actual depth

Correction of Bathymetric Data

Bathymetric data is corrected with MSL (Mean Sea Level) values and reduction of data to the vertical reference Z0 (datum chart) to produce actual depth values (Table 3).

Bathymetry Conditions of Dumai River Estuary

Based on the measurement results and after correction, it is known that the depth ranges from 0.28 - 7.34 m below sea level. The lowest depths in the middle of the estuary are relatively shallower at Stations 4 and 6. Heading to the north part (Rupat Strait), the contour state is more profound at Station 15. Dumai Estuary waters vary from 5 - 40 m, while the eastern part is degraded with depths between 0.4 - 28 m (Mubarak et al., 2022).

The map view results from the visualization of Surfer 16 using 0.5-meter intervals (Figure 4). The contour line pattern on bathymetric maps tends not to be parallel to the coastline at a depth of 0.5 - 2 m, forming a closed curve. As seen in the 3D profile (Figure 4) of the middle of the estuary, there is significant silting at the bottom. This siltation is thought to come from sedimentation from rivers and the sea. Estuaries' current tends to weaken, allegedly due to the confluence of two water periods, so suspended sediments will settle. While at a depth of 3-8 m, the tendency of the contour line pattern parallel to the coastline forms an unbranched and uncut pattern. According to Widuri et al. (2021), bathymetric changes due to the influence of sediment supply from land in the Dumai River Estuary range from 0.0013 – 0.017 m per year or 26.94 tons/year. Expanding industrial land with reclamation and mangrove forests on the coast as sediment traps reduces transport to the sea. This condition will be dangerous for ships passing the Dumai River because the depth is less than 1 meter. According to Rifardi et al. (2020), the rapid development of Dumai and Rupat Island resulted in significant surface soil erosion, eventually transported through rivers and canals.

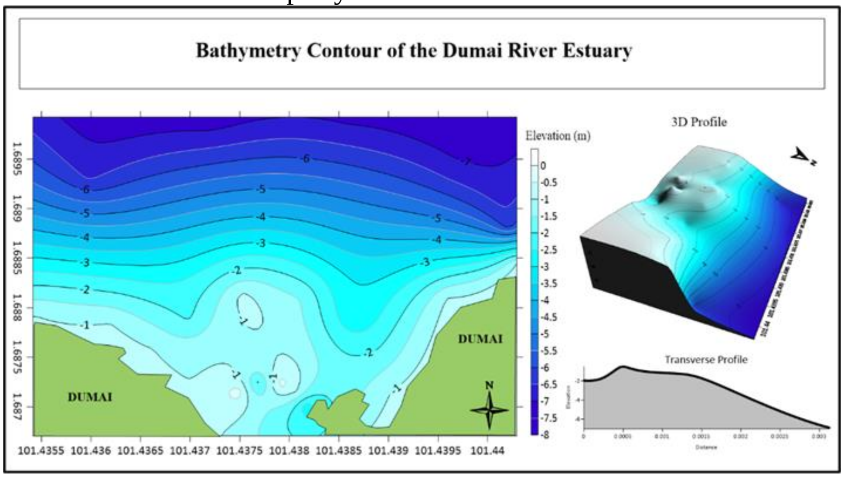

Figure 4. Contours of the depth of the waters of the Dumai River estuary

Bathymetric Conditions of Rupat Strait Waters.

The Dumai River Estuary has slightly different conditions, where this area empties into the waters of the Rupat Strait. These waters have a depth contour of up to 40 m on the part that approaches the mainland of Rupat Island, forms like a trough, and has a bottom that forms a ridge in the middle with a depth of 16 m (Figure 5) and slopes westward. In front of the Dumai River Estuary, there is an increase in depth so that the hill is very steep towards a depth of 16 m, seen on a transverse profile and 10 m contour with tighter intervals.

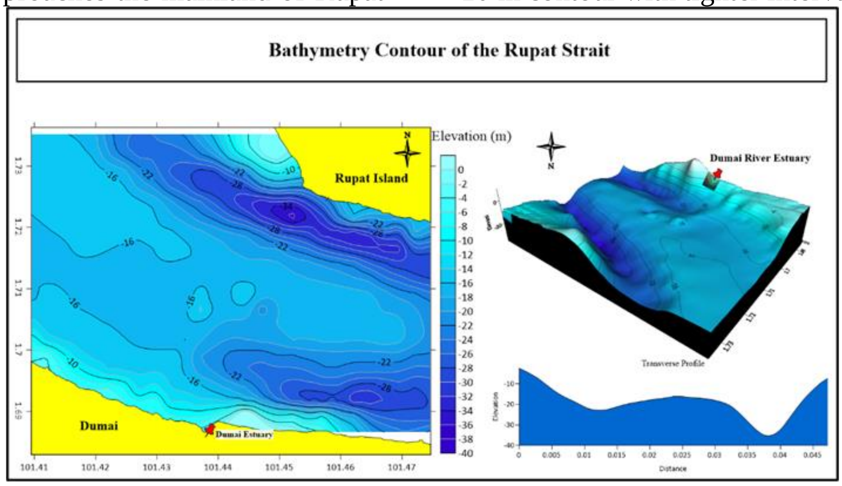

Figure 5. Rupat Strait bathymetry

Bathymetry to the Water Surface Level

Bathymetry of the Dumai River Estuary is known to have a shallow depth, where the condition of this shallow water will affect the height of the sea level that enters the river at high tide. Because the waters are shallow due to sedimentation, the water surface elevation is higher than the actual surface conditions in estuaries or seas. According to Pelling et al. (2013), bathymetric changes cause sea elevation, tidal velocity, and coastal sediment transport capacity changes. In addition to bathymetry, climate change is one of the causes of tidal floods that trigger sea water rise (Nabella et al., 2022). According to Febrian et al. (2016), the sea level in Pangkalan Sesai, Dumai City, experienced an increase of around 19.5-22 cm in the previous 3 and 1 year due to climate change. This phenomenon is often called Pasang Keling and occurs around Pangkalan Sesai.

According to Situmorang (2023), the coast of Dumai City has an average height of 3 meters above sea level with a slope that tends to be flat and predicts a water level rise of 0.973 m in 2040. This is based on calculating the difference between HHWL (Highest water level) and MSL (Mean Sea Level) for 20 years. It can be seen in the results of tidal calculations (Table 2) that it is known that the HHWL elevation is 3.55 m, and the MSL value is 0.14 m. This significant difference is considered to affect puddles that reach land.

Current Pattern and Speed

Current velocity measurements to verify model results have differences with field data. Current speeds in the waters of the Dumai River estuary are 0.07 m/s, 0.17 m/s, 0.2 m/s and 0.21 m/s.

Table 4. Current speed value

Station	Current speed (m/s)	
	Model	Measurement
12	0.04 - 0.08	0.2
13	0.08 - 0.12	0.17
14	0.12 – 0.16	0.07
15	0.08 – 0.12	0.17
16	0.04 – 0.08	0.21

According to Table 4, the highest current speed occurred at station 16 at 0.21 m/s, while the lowest occurred at station 14 at 0.07 m/s. This result differs from the model result because the model data predicts current speed based on predictions from secondary wind data. The wind data obtained was simulated using Mike 21 to describe the speed and direction of currents in the Dumai River Estuary (Figure 6).

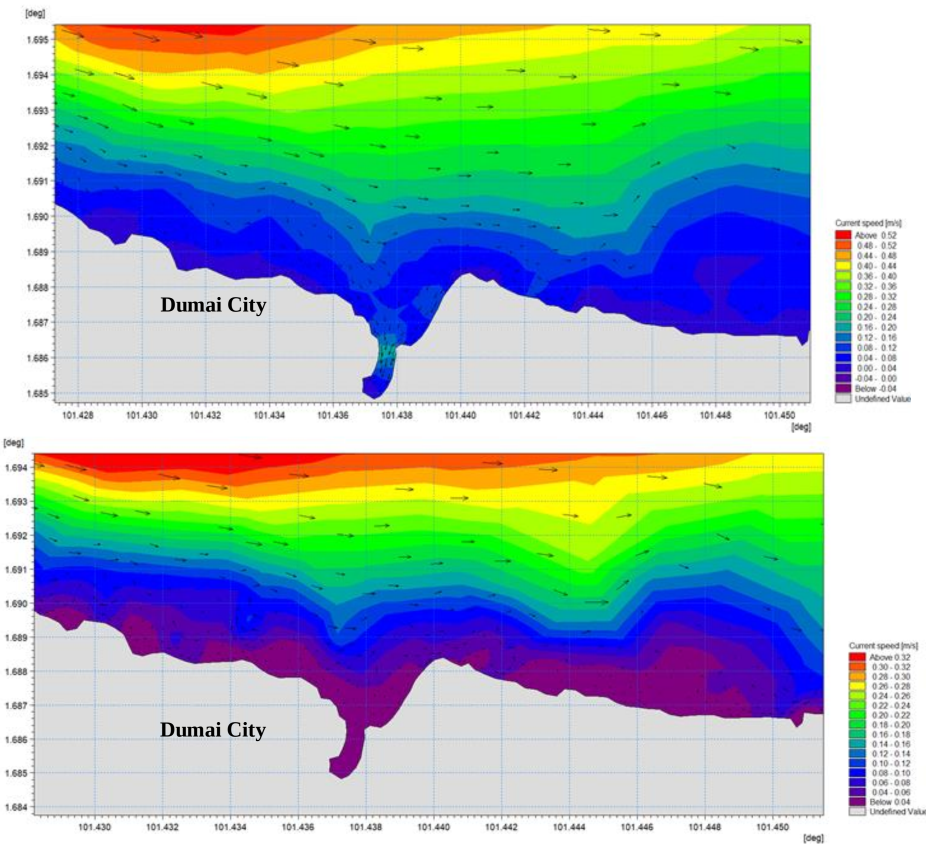

Figure 6. Current pattern of tidal and tidal conditions of Dumai River estuary

Tidal currents dominate the current in the Dumai River Estuary. The depth of the waters also influences current patterns, and the shallower the waters lead to higher elevation and higher current speeds (Isty et al., 2017).

Water Quality Parameters

Water quality parameters observed include temperature, salinity, and brightness, measured at each study station. This is done to describe the condition of the research waters. The results of measuring water quality parameters are presented in Table 5.

Table 5. Water quality measurement

Station	Temperature (°C)	Salinity ‰	Brightness (m)
1	27.3	25	0.72
2	27.2	25	0.55
3	29.1	24	0.87
4	29.3	24	0.5
5	29.8	24	0.45
6	29.5	14	0.45
7	29.3	17	0.5
8	29.5	23	0.52
9	29.5	22	0.55
10	29.5	23	0.65
11	29.5	24	0.52
12	30	25	0.5
13	30	25	0.9
14	29.9	24	0.92
15	29.9	23	0.85
16	29.9	23	0.62

4. CONCLUSION

The waters of the Dumai Estuary are known to have a mixed tide prevailing semidiurnal, characterized by two high tides and two low tides but different heights and periods. In addition, the characteristic of tides in estuaries is the asymmetry of time patterns when receding towards tide, which is faster than tide towards low tide. The analysis and mapping results show that the Dumai River Estuary's water depth ranges from 0.28 – 7.34 mdpl. The depth of these waters is relatively shallow in the middle of the river estuary compared to the depth of the river. The deeper the Rupat Strait gets, the depth ranges from 16 to 40 m. The shallowness of the estuary waters affects the rise in water because the current is relatively weak to the land during high tide conditions.

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