Marine Water Quality Mapping in Rupat Strait with Modelling Hydrodynamics

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Abstract

This research aims to analyze water quality and determine the status of quality standards in the waters of Rupat Strait. The method used in the study is comparative descriptive analysis and literature analysis. Hydrodynamic and water quality models with MIKE 21 Hydrodynamics and ECO Lab modules were used to examine the distribution of water quality parameters in the waters of Rupat Strait. The results showed that the waters of the Rupat Strait have a depth between 2-15 m with a velocity of 0.15-0.3 m/s. DO concentration has an interval of 5-6 mg/L, then BOD concentration has an interval of 0.8-2.4 mg/L, salinity has an interval of 17- 27‰, and temperature has an interval of 26-31^{0}C. Water quality in Rupat Strait is still within the quality standards. The pollution index calculation in Rupat Strait obtained values between 1<IP<5, indicating that Rupat Strait is still classified as lightly polluted.

1. Introduction

Rupat Strait is a small strait in the Malacca Strait and is geographically located between the coast of Dumai City and Rupat Island, Riau Province, which has a length of ±72.4 km and a width of 3.8-8 km. Rupat Island, in general, still has no activities other than agricultural plantation, but anthropogenic activities in Dumai City significantly affect the environmental conditions of the Rupat Strait waters (Nedi et al., 2010). The seas of Rupat Strait are highly affected by anthropogenic activities such as residential, industrial and port activities that will directly result in pressure on the environmental system in Rupat Strait, which can cause damage to aquatic ecosystems (Usman et al., 2016).

One of the environmental problems of Dumai City is the potential pollution of coastal waters caused by various spatial/regional utilization activities. This pollution problem is caused by human activities such as urban and industrial development, logging and residential waste that enters the waters of the Rupat Strait through river flow (Arifin et al., 2019). Significant water quality parameters can be analysed, including Biochemical Oxygen Demand, Dissolved Oxygen, salinity, and temperature.

Numerical modelling can describe the movement of ocean currents in a water column. Hydrodynamic processes influence the movement of ocean currents in the water column and affect water quality parameters, such as those in the Rupat Strait. This can be known through MIKE 21 software with a modelling base system and user interface so that spatial and temporal information about the direction of movement of ocean currents can be obtained, and the quality of seawater in the water column can be described.

2. Methodology

2.1. Time, Place, and Materials

This research was conducted in September 2022. The research location was in the Rupat Strait, Bengkalis Regency, Riau Province (Figure 1).

2.2. Method

The determination of research sample points was carried out using GPS by determining

9 points using a purposive sampling method carried out by observation, where each research station was found to have many anthropogenic activities. Station A is in the Darul Aman Village area, Rupat District, where station A is a community oil palm plantation area and Magruf Umbul Rejo tourist area. Station B is in the Tanjung Kapal area, Rupat District. Station B is the Tanjung Kapal Roro port area, UPT Pelabuhan Rupat District, community shrimp pond area and Parit Joko Beach tourist area. Station C is in the Pergam area of Rupat Subdistrict, a community shrimp pond area, community oil palm plantations, Pergam Harbour and Pergam Tourism Park.

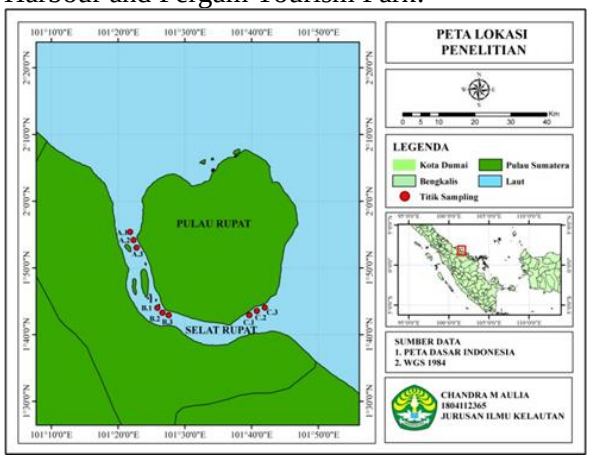

Figure 1. Research Location

2.3. Procedure

The source of research location and determination of coordinates and sampling points are done using Google Earth software. Secondary data preparations, such as bathymetry, will be made using QGis Software. Next is the study area boundary data or Mesh Boundary using MIKE 21 Software using Mesh Generator. Primary data obtained from the field is processed using MIKE 21 Software with the Flow Model (FM) module and the ECO Lab module; the model used is the MIKE 21 WQ Simpling model, including temperature/ salinity.

3. Result and Discussion

Water Quality Parameters

The number of concentrations of water quality parameters can be known by taking water samples from several predetermined location points. Some of these location points consist of the Darul Aman village area as station point A, the Tanjung Kapal area as station point B, and the Pergam area of Rupat District as station point C. Water quality parameters measured in situ include Temperature and Salinity. In contrast, DO (Dissolved Oxygen) and BOD (Biochemical Oxygen Demand) parameters are carried out by taking water samples and then analyzed in the Chemistry Laboratory of the Department of Marine Science, Universitas Riau (Table 1).

Table 1. Water Quality Parameters at Research Station

Station	Longitude	Latitude	Sampling Point	Temperature (^{O}C)	Salinity (ppt)	DO (mg/L)	BOD (mg/L)
A	101.372202°	1.928389°	1	29	26	5,93	1,63
	101.376063°	1.908136°	2	28	25	6,14	2,04
	101.380208°	1.887591°	3	29	27	5,93	1,22
B	101.419934°	1.748409°	1	28	21	5,93	1,22
	101.434147°	1.723430°	2	31	21	5,52	1,63
	101.456270°	1.707635°	3	29	17	5,42	2,04
C	101.637160°	1.692698°	1	26	25	5,32	0,81
	101.674848°	1.706500°	2	26	20	5,51	1,14
	101.706504°	1.722381°	3	26	15	5,57	1,12

Based on Table 1, the measurement results at each station show the comparison is that the salinity value is between 15-27 ppt, the temperature is between 26-31 °C, the maximum BOD is 20 mg/L, and the minimum DO is 5 mg/L. So, it can be said that the water quality at each station is still suitable and qualifies as the quality standard set by the Government Regulation of the Republic of Indonesia Number 22 of 2021.

Bathymetry Modelling of Rupat Strait

To enable the MIKE 21 application to be used for numerical water quality modelling, the first step is to model the bathymetry of the modelling site, Rupat Strait. As shown in Figure 2, the modelling location includes the Rupat

Strait adjacent to the Darul Aman area, which flows into the Pergam area.

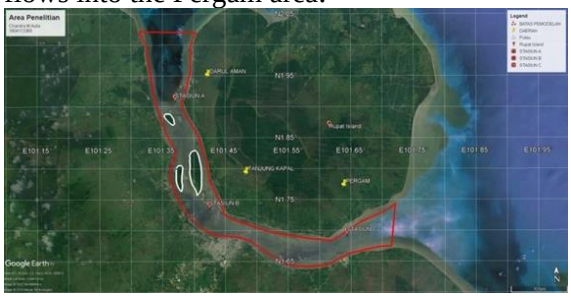

Figure 2. Location and Boundary of Modelling Area

Figure 3 shows the meshing results of the Rupat Strait bathymetry map, which shows that the depth ranges from 2.5 to 35 m with a meshing resolution of 1495 nodes and 2256 elements. This research by Mubarak et al. (2017) states that the seabed bathymetry is built based on data reported on the nautical map of the TNI Army Hydro-Oceanographic Agency, as shown in Figure 4. The bathymetry of the Rupat Strait shows that the depth ranges from 2.5 to 35 m. Regional marine waters with a depth of about 5 m are usually not very far from the shoreline. The water depths around the Rupat Strait trough are relatively steep. The depths of the eastern, southern and northern Rupat waters range from 10 to 20 m, while the depths of the northeastern and east waters range from 30 to 35 m.

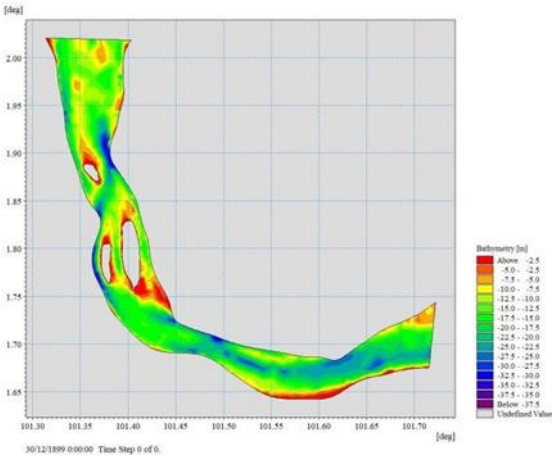

Figure 3. Meshing Bathymetry of Rupat Strait

Hydrodynamics Model Validation

Accuracy testing is done by calibrating tidal data from DISHIDROS-AL with data from hydrodynamic modelling using Mike 21. Model validation in Figure 4 compares model results with tidal data from DISHIDROS-AL. Model validation and data comparison were conducted using RMSE (Mubarak et al., 2020). Figure 4 also shows the location of the highest and lowest tides for one month, which were used as reference in the modelling. The highest tide occurred in the 23rd time step, on 25 September 2022, at 23:00, while the lowest tide occurred in the 5th time step, on 25 September, at 5:00. Verification shows that the RMSE error value between tidal data obtained from the model and field observations reaches 4.21%.

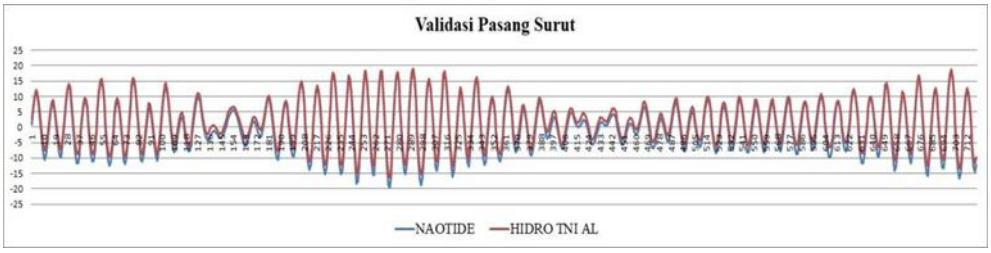

Figure 4. Tidal Data Validation

Based on Figure 4, it can be seen that the Rupat Strait has two high tides and two low tides. This follows research conducted by Mubarak et al. (2017), which states that the Dumai Estuary experiences semidiurnal tides, which means it has two rising and two falling tides daily. Nedi et al. (2010) stated that the Rupat Strait is semi-enclosed because it experiences two high tides and two low tides for 24 hours.

In general, oil pollutants that enter the Rupat Strait only move back and forth without being able to reach the open sea (Malacca Strait). According to the wind rose diagram in Figure 5, the currents generated by wind movements tend to move from the northwest. This is due to the location of the Rupat Strait, which is in the northeastern part of the Malacca Strait. Winds from the northwest often blow the area, so the Rupat Strait ocean currents tend to flow from the northwest because they are affected by the direction and strength of the wind. The Malacca Strait also has stronger ocean

currents eventually entering the Rupat Strait area.

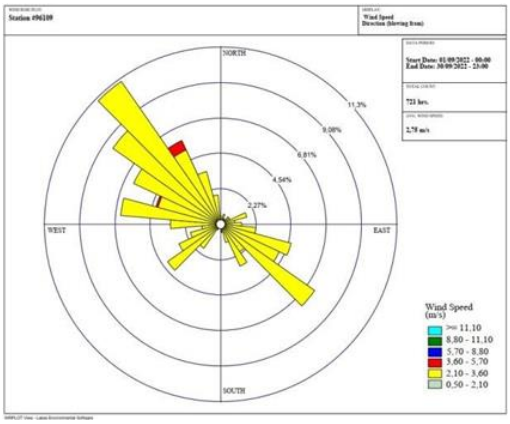

Figure 5. Wind Rose of Rupat Strait Based on ECMWF Data

This is also seen in the hydrodynamics simulation results for Rupat Strait during the highest tide in Figure 7, where the vector in the Rupat Strait waters generally moves from the northwest with wind speeds ranging from 2.10 - 3.60 m/s. Mubarak et al. (2017) mentioned that the current moves from north to south and east during high tide. Conversely, at low tide, the current moves from east to west turns north, and exits in the Malacca Strait, with current speeds generally ranging from 0.2 to 0.45 m/s.

The graphs in Figure 6 and Figure 7 show the tides and current velocities in the Rupat Strait. It can be seen that during the highest tide at time step 657 (28 September 2022, 09:00), the water level can reach 3.1 m, and the current velocity reaches 0.24 m/s.

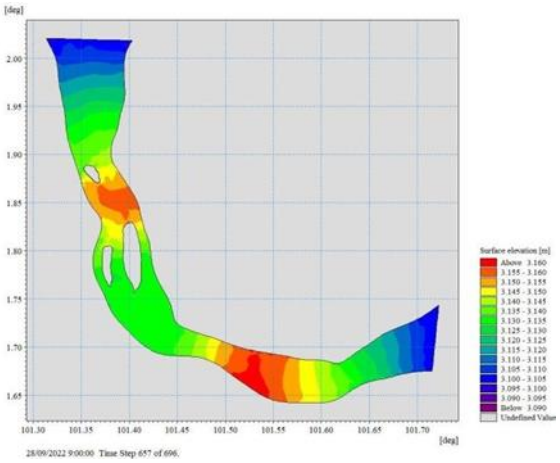

Figure 6. Sea Level at Highest Tide

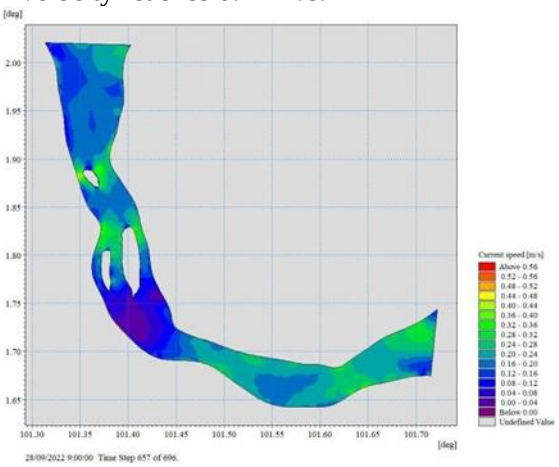

Figure 7. Current Velocity at Highest Tide

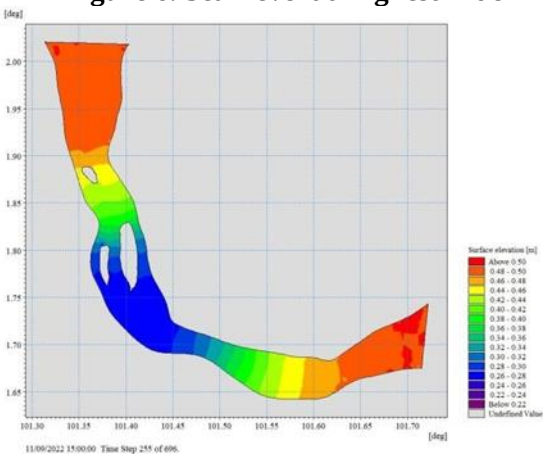

Figure 8. Current Height at Lowest Tide

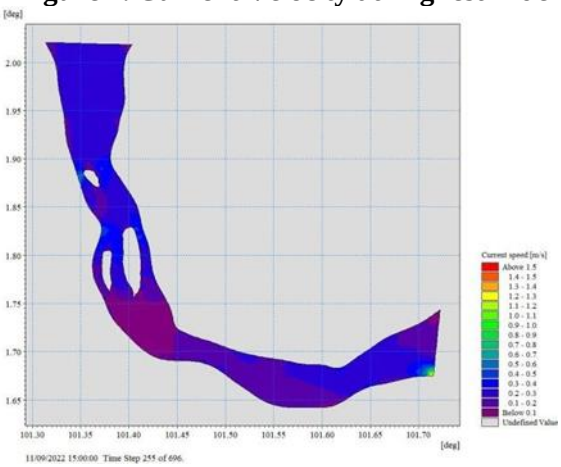

Figure 9. Current Speed at Lowest Tide

While at the lowest tide in Figures 8 and 9 for the 255th time step (11 September 2022, 15:00), the water surface height is 0.28 to 0.5 m with a current velocity of 0.15 m/s. These results show that the sea current height and current velocity are higher at the highest tide than at the lowest tide. This can occur because the volume of seawater around the coastal area increases, so the current speed increases. While at low tide, the volume of seawater around the coastal area decreases, so the current velocity decreases. The results of the hydrodynamics simulation show that during the highest tide, the current pattern moves from the northwest towards the southeast. Conversely, at the lowest tide, the current pattern moves from the southeast towards the

northwest. From the simulation results, it can be concluded that the current pattern in the waters of Rupat Strait moves back and forth following the tidal pattern in these waters.

Water Quality Model Analysis

ECO Lab was used to simulate water quality dispersion in the water body through advection and to model the physical, chemical and biological processes of water quality parameters. This research measured four water quality parameters: Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), temperature, and salinity. Figure 10 and Figure 11 are the ECO Lab simulation results for dissolved oxygen (DO) concentration during the highest and lowest tide periods.

Figure 10 shows the DO distribution during the highest tide, where the DO concentration in the area of station A, which is directly adjacent to the Malacca Strait, reaches 6 mg/L. The DO concentration at station B was recorded at 6.3 mg/L, while at station C, it was 5 mg/L. While at the lowest ebb, almost all areas of the Rupat Strait have relatively similar DO concentration values, between 4.8 and 5 mg/L.

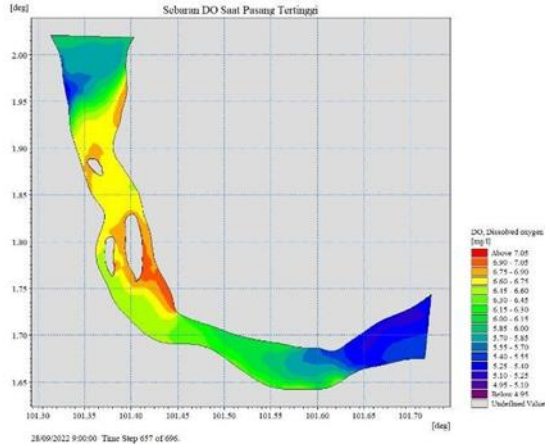

Figure 10. Distribution of DO at the highest tide

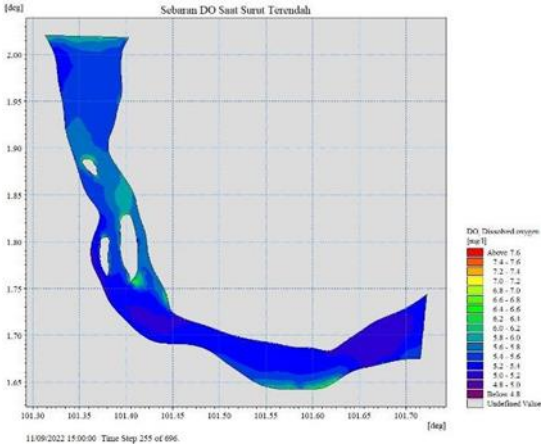

Figure 11. Distribution of DO at lowest tide

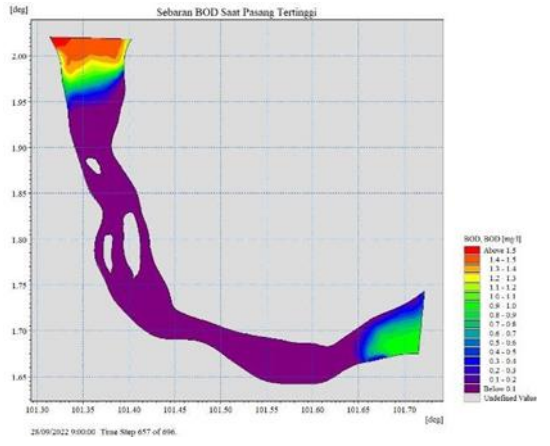

Figure 12. BOD Distribution at Highest Tide

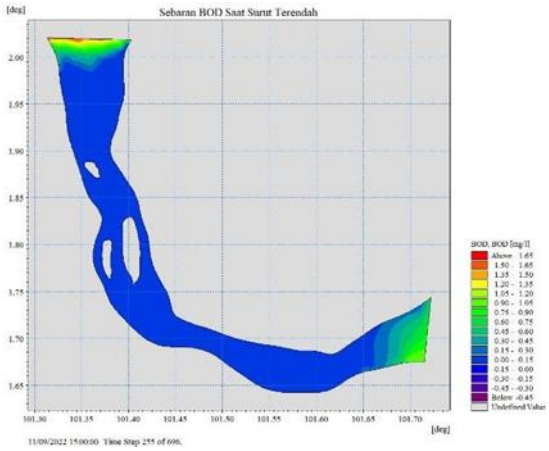

Figure 13. BOD Distribution at Lowest Tide

The distribution of DO in the Rupat Strait at the highest tide is more significant than at low tide due to the more incredible current speed at the highest tide. The distribution of DO at the lowest tide gets the same value because, at that time, the ocean currents circulate through the sea, reducing the amount of seawater containing dissolved oxygen in the estuaries. So that the concentration of oxygen dissolved in estuarine waters decreases and is distributed evenly throughout the area. In addition, the decomposition of inorganic matter at low tide can also reduce the concentration of oxygen dissolved in estuarine waters.

Figure 12 shows the distribution of BOD during the highest tide with relatively similar concentrations at the three stations, which is 0,15 to 0,30 mg/L. Figure 13 shows the distribution of BOD at the lowest ebb with the lowest concentration of 0.44 mg/L. The highest concentration was 1,5 mg/L. Meanwhile, BOD concentrations at stations A, B, and C are in the

same range, namely 0.48 to 0.64 mg/L. The following presents the simulation results of temperature concentration simulation during the highest and lowest tides (Figure 14 and Figure 15).

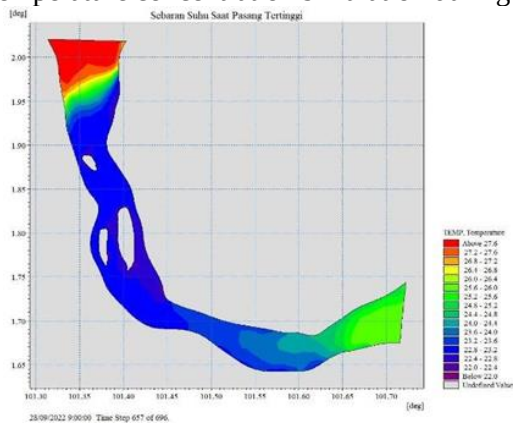

Figure 14. Temperature Distribution at the Highest Tide

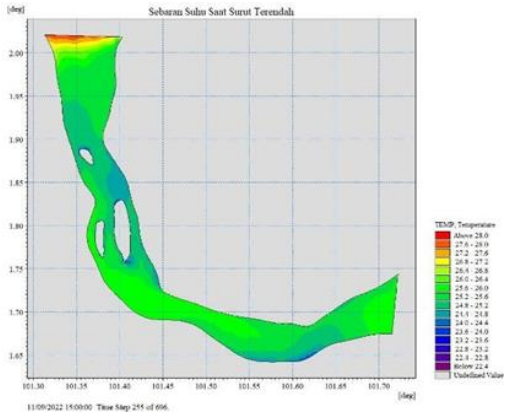

Figure 15. Temperature Distribution at Lowest Tide

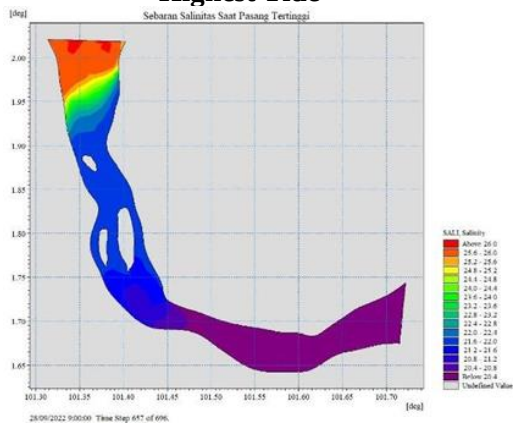

Figure 16. Salinity Distribution at Highest Tide

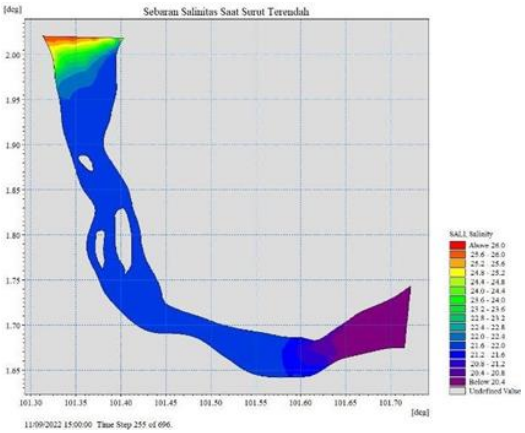

Figure 17. Salinity Distribution at Lowest Tide

Figure 14 shows the temperature distribution during the highest tide with the lowest temperature of 27^0C. The highest temperature is in the Boundary Condition area of 29.9^0C. The area is an area of exit and entry of seawater. The temperature concentration at Station A is 27^0C. Then, the temperature at station B is between 26 - 27^0C. Then, for station C is 27.5^0C. Figure 15 shows the temperature distribution during the lowest low tide conditions with the lowest temperature of 27^0C. The highest temperature is 29.7^0C, which is in the Boundary Condition area. Based on the modelling results, the temperature values at all stations A, B and C are in the same range, namely 28 to 29 mg/L.

The temperature values in both images are quite low because the time taken for the modelled images is the highest and lowest tide, which shows 9:00 and 15:00. This low-temperature value is influenced by weather, seawater flow, and heat radiation. The following presents the results of the salinity concentration simulation during the highest and lowest tides (Figure 16 and Figure 17).

Figure 16 shows the salinity distribution at the high tide with the highest value of 26 ppt. The low salinity was 20,44 ppt. Figure 17 shows the salinity distribution at the lowest low tide with the highest value of 26 ppt. The low salinity was 20,4 ppt. The high rainfall influences the salinity value during the measurement. Precipitation levels are important in reducing salt concentrations and freshwater inflows during field measurements. This also follows the statement (Daroini & Arisandi, 2020) that the high rainfall at the measurement time influenced the low salinity values at both stations.

Pollution Index

Determining water quality status in the Rupat Strait is based on the Pollution Index method. The calculation of pollution index values is based on the Ministry of Environment

Decision No. 115 of 2003, Appendix II, regarding guidelines for determining water quality status. The detailed results of the Pollution Index analysis at the research location are presented in Table 2.

Table 2. Calculation of Pollution Index

Station	Sampling Point	Index Value	Average	Category
A	1	1,77	1,79	Lightly Polluted
	2	1,84		Lightly Polluted
	3	1,77		Lightly Polluted
B	1	1,74	1,61	Lightly Polluted
	2	1,58		Lightly Polluted
	3	1,51		Lightly Polluted
C	1	1,48	1,55	Lightly Polluted
	2	1,55		Lightly Polluted
	3	1,62		Lightly Polluted

Based on the calculation of the Pollution Index (IP) in Table 2, it can be determined that the Rupat Strait waters are lightly polluted, with an IP score ranging from 1.55 to 1.79. With an IP value between 1 and 5, the water quality status is classified as lightly polluted.

4. Conclusion

Hydrodynamics and ECO Lab modelling obtained an RMSE value of 4.487, so the model is considered good enough to predict tides in the Rupat Strait. Tides in the Rupat Strait itself occur twice a day or semidiurnally. Water quality at station A near the Darul Aman area has an average BOD of 1.63 mg/L, DO of 6 mg/L, temperature of 28.6^{o}C, and salinity of 26 ppt. Then, station B, in the Tanjung Kapal area, has an average BOD of 1.63 mg/L, DO of 5,63 mg/L, temperature 29.3^{o}C, and salinity 19.7 ppt. Then, station C in the Pergam area has an average BOD value of 1.03 mg/L, DO of 5.51 mg/L, temperature of 26^{o}C, and salinity of 20 ppt. Based on the calculations of the pollution index, the Rupat Strait is categorized as being lightly polluted.

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