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INVESTIGATING IMPACT OF SEA SAND MINING IN TUNDA ISLAND WATERS, INDONESIA BASED ON MIKE 21 MODELLING

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ABSTRACT

In Indonesia, sea sand mining was introduced in the late 1970s, and one of the sites is Banten Province, Indonesia. Sea sand mining in Banten waters began in 2003 after the issuance of a permit by the Regent of Serang Regency, namely Decree No. 540/Kep.68/Huk/2003, which was updated by the Regional Regulation of Serang Regency No. 2 of 2013 on the Zoning Plan for Coastal and Small Island Areas in Serang Regency for 2013-2033. Studies related to marine sand mining in Banten, Indonesia are required in accordance with the principle of ecosystem sustainability. The objective of this study is to analyze the impact of sea sand mining on the ecological quality of coral reefs and hydro-oceanographic hue on Tunda Island. The survey method was used to determine the coral reef cover, while the hydrodynamic aspects were carried out by simulating bathymetric data, tidal and wave patterns. In addition, a simulation of sediment distribution was performed to determine the effects of sea sand mining using MIKE 12 sand transport module. The percentage of coral cover in the west, east and south of Tunda Island was 66.00%, 39.67% and 28.15%, respectively. The maximum sea depth around the study site reached 70 m, while it is relatively shallow in the mining area. In the last 14 years, the prevailing wave height ranged from 0.5-0.75 m or 49.02%, and 0.25-0.50 m or 36.69%. In addition, the concentration of TSS was relatively high, ranging from 40 mg/l to 60 mg/l. From the results, the most commonly observed impact of sea sand mining off Tunda Island was the high concentration of TSS. This can be prevented by rotating TSHD vessels, especially in the areas adjacent to Tunda Island.

How to Cite

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INTRODUCTION

Mining is one of the industrial sectors that contribute to economic development in Indonesia (Suseno, 2019). Based on Statistics Indonesia (2021) data, the value of exports in mining and other sectors reached USD 14,041.5 million, accounting for 14.47% of Indonesia's total export revenue in June 2021. This sector not only increases government revenue but also provides new business opportunities that contribute positively to improving the welfare of society (Tonts et al., 2012). From an economic perspective, the availability of jobs and business opportunities, as well as the increase in community income, are some of the benefits for communities surrounding the mining industry.
According to Presidential Decree No. 33 of 2002 on the Control and Supervision of Sea Sand Concessions, sea sand is a mineral found in Indonesian waters that does not contain Class A and/or Group B elements in economically significant quantities in mining operations. Sea sand mining is the physical movement of sediments from the seafloor to a location, beginning with dredging and then continuing with the transportation and collection of other materials at various locations (Todd et al., 2015; Miller et al., 2018). The annual increase in demand for marine sand is influenced by anthropogenic factors such as urbanization and technological developments. Urbanization leads to an increase in population, which requires the need for supporting facilities such as roads, buildings, bridges, and housing (Drucker et al., 2004; Trop, 2017). Meanwhile, technological developments provide the opportunity to explore mining materials such as sea sand, which enables dredging at the extraction site (Fumbuka, 2017).
In Indonesia, sea sand mining was introduced in the late 1970s, and one of the sites is Banten Province, Indonesia. According to Saraswati (2005), the coastal and marine areas in Serang District have potential reserves of mineable marine sand of 3.7 billion m^3. The seabed sediments in the northern coastal waters generally consist of sand mixed with mud or biotic shell remains and the weathering of coral (Prihantono et al., 2016). One of the areas where marine sand is mined is Tunda Island waters. Tunda Island is administratively located in Tirtayasa District with a geographical location at latitude 5° 48' 43" and longitude 106° 16' 47" east and an area of 289.79 ha.
Mining of marine sand in Banten waters started in 2003 after the issuance of a permit by the Regent of Serang Regency, namely Decree No. 540/Kep.68/Huk/2003, which was updated by the Regional Decree of Serang Regency No. 2 of 2013 on the Zoning Plan for Coastal and Small Island Areas in Serang Regency for 2013-2033. The utilized area is about 43.92% of the total mining area in Banten in 2019 or an area of 54,677 hectares (BPS, 2019). Husrin et al. (2014) stated that marine sand mining provides more income to the community and local government by collecting taxes.
In 2019, there were 28 companies engaged in sea sand mining in Banten province (BPS, 2019). The existence of mining activities in residential areas potentially affects the socioeconomic and physical conditions of the surrounding area, both positively and negatively.
In particular, the negative impact that has occurred on Tunda Island is a change in environmental quality. Syahrial et al. (2020) found that the environmental quality of mangrove vegetation in Tunda Island, Serang, Banten was about 73.74% and had changed by 26.26% from its ideal condition. In addition, the average value of mangrove diversity was 1.20, indicating that the diversity of mangrove forests is low and the condition of vegetation is also not good so most species are not able to adapt to the environment and are suspected to be disturbed.
The environmental pollution caused by sand mining is the increasing turbidity of water bodies. Teng et al. (2007) pointed out that high turbidity levels affect the growth of natural food such as plankton by reducing sunlight and water productivity. Water turbidity is closely related to total suspended solids (TSS) which consist of fine sand, silt, and microorganisms (Budianto and Hariyanto, 2017; Jiang et al., 2021). An increase in the concentration of TSS in the water bodies can affect the quality of the ecosystem, resulting in the loss of microbiology, organisms, and fish resources (Jiang et al., 2021; Saberioon et al., 2020).
Sea sand mining in Tunda Island has negative impacts in the form of ecological degradation in coastal and marine areas (Wahyudi et al., 2018). Meanwhile, the existence of economic factors has brought more benefits to improve the welfare of the community (Emas et al., 2018).
The main problem in managing marine sand mining is the potential degradation of marine ecology. Massive marine sand mining can cause impacts such as a decline in ecosystem services and coastal and marine carrying capacity. In the management of marine sand mining in the waters of Tunda Island, hydro-oceanographic data is one aspect that can be used to assess the extent of impacts. Therefore, the management is planned and carried out in an environmentally friendly way. One of the factors to be considered is that the location of sea sand mining must be supported by oceanographic data on water quality, waves, currents, tides, and bathymetry.
This means that a study of marine sand mining in accordance with the principle of sustainability is required. Therefore, this study aims to analyze the impact of sea sand mining on the ecological aspects, especially on the total suspended solids (TSS) and hydro-oceanographic hue on Tunda Island, taking into account aspects of bathymetry, tides, currents and wave patterns.

MATERIALS AND METHODS

This study was carried out for 6 months starting from July to December 2021 in the waters of Tunda Island, Serang Regency - Banten Province. The location was selected based on the Sea Sand Mining Business Permit Area (WIUP), as seen in Figure 1.

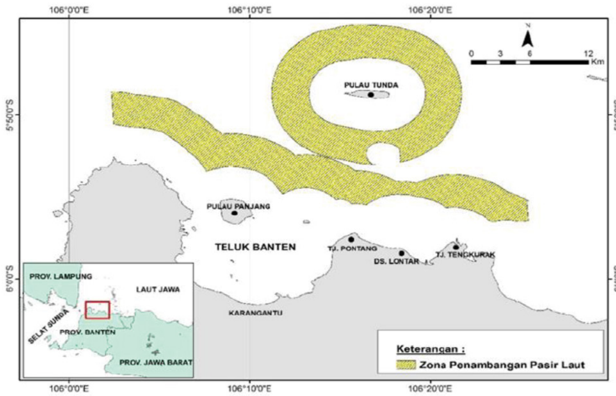

Fig 1. Sampling location

To determine coral reef cover, the intercept transect method was used. This observational method was conducted to determine the percentage of live corals and other components of the benthic community. It was used to study the benthic community based on the morphological characteristics of the life forms and the living coral species.

The hydrodynamic aspects were carried out by collecting samples in the field and simulating bathymetric data, tidal, current and wave patterns using MIKE 21 software. Two data sources were used, namely, primary data obtained at the study site and secondary data provided by a third party, as well as the results of previous related studies. In addition, data processing was performed using MIKE 21 Hydrodynamic and ECO Lab module.

To determine the effects of lake sand mining on the morphology of the waters in Banten Bay, a simulation of sediment distribution was performed using MIKE 21 sand transport module. This module allows the calculation of transport capacity, rate of change in the base layer, and can also indicate morphological changes due to sediment displacement. Bottom friction in water bodies is not modeled by the advection-dispersion approach but adds two important effects, namely the deviation of the direction of shear stress and the effect of slop on the bottom of the water body. Modeling of incohesive suspended sediment in a fluid can be explained by the transport equation for volumetric sediment concentration. The model of Van-Rijn (1997) was used to model sediment transport. The numerical equation used for the sediment modulus is as follows:

$$S_{bl} = 0.053\,\frac{T^{2.1}}{D^{0.3}}\sqrt{(s-1)g\,d_{50}^{3}} \quad (1)$$

$$S_{sl} = f\,c_a\,V\,h \quad (2)$$

$$(n-1)\frac{\partial z}{\partial t} = \frac{\partial S_x}{\partial_x} + \frac{\partial S_y}{\partial_y} - \Delta S \quad (3)$$

Remarks:

S_{bl}: bed load,
S_{sl}: suspended load,
T: non-dimensional transport depends on the critical frictional speed and the frictional speed,
D: non-dimensional particle parameters,
s: sediment relative density,
c_a: basic volumetric concentration,
f: correction factor for suspended sediment bed fall based on bed load,
n: porosity of the sediment bed,
z: sediment bed thickness,
S_x and S_y: total transport in x and y directions,
ΔS: sink and source of sediment.

RESULTS

The substrate cover category obtained according to English et al. (1997) consisted of abiotic, algae, dead and hard coral, other fauna, as well as soft coral. The abiotic categories found comprise rubble, rock and sand, while the highest and lowest hard coral cover was found in the west and south of Tunda Island, respectively.

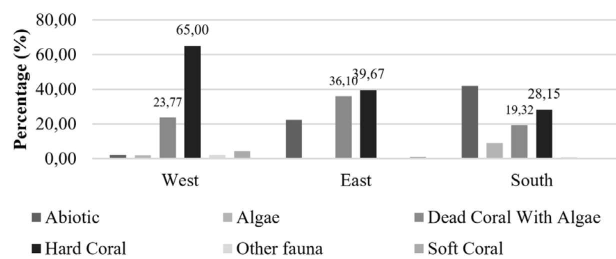

Fig 2. Substrate cover at Tunda Island

The percentage of coral cover in the west, east and south was 65.00%, 39.67%, and 28.15%, respectively. Additionally, dead coral covered with algae was also found with a percentage of 23.77% in the west, 36.10% in the east, and 19.32% in the south.

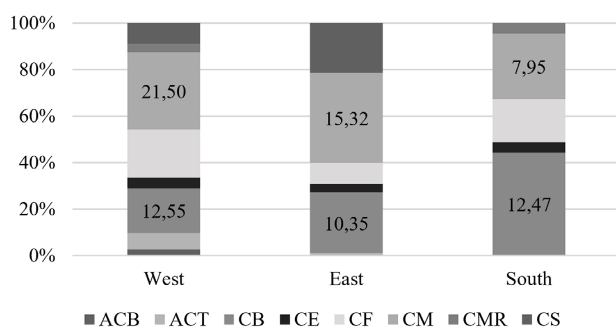

Fig 3. Coral growth forms in Tunda Island waters

Based on Figure 3, 8 forms of coral reefs were found on Tunda Island, namely Acropora Coral Branching (ACB), Acropora Coral Tabulate (ACT), Coral Branching (CB), Coral Encrusting (CE), Coral Foliose (CF), Coral Massive (CM), Coral Mushroom (CMR) and Coral Submassive (CS). At the western and eastern observation sites, Coral Massive was more dominant than the other growth forms, accounting for 21.50% and 15.32%, respectively. In the Strait of Tunda Island, the dominant growth form is coral branching with 12.47%.

Banten Bay is located in the west of Java Island in the northern part of Serang City and is bounded by Tanjung Piatu in the west and Tanjung Pontang in the east. Bathymetrically, these waters are relatively shallow and have depths of 2-35 m (Rustam et al., 2018). Most depths are around 10 meters and up to 35 meters at high seas. The bay, which is open to the Java Sea, has an estuarine span of about 16 km and an area of about 120 km^2. It is surrounded by several small islands, which provide a barrier to large amounts of energy entering the waters of the inner bay and also limit hydrodynamics (Wisha et al., 2015; Doloksaribu et al., 2020). In addition, the bay and its surroundings are part of the lowlands dominated by beach sand. The topography is highly variable due to the influence of coastal erosion and sedimentation by surrounding rivers. Morphologically, the marine area has similarities with the north coast of Java Island, which has a gentle slope (Rahadian, 2013).

Tides are the process of rising and falling sea levels periodically due to the attractive force of celestial bodies, especially the sun and moon on the mass of seawater on earth. The gravitational attraction pulls sea water towards the moon and sun, culminating in two gravitational tidal bulges in the sea (Hasriyanti, 2015). Aside from the technical purposes for planning coastal structures and navigation, tides are also one of the important parameters in environmental impact studies due to activities in coastal waters (Kim and Yoo, 2020; Kim and Grigalunas, 2009). For example, when a water current character is strongly influenced by tides, the pollutant that enters the water has a more predictable movement. Tidal data was obtained from PUSHIDROSAL Suralaya Station which is the closest to the studied site.

Based on Table 1, the component amplitude of double tides or semidiurnal tides was more dominant than for single tides or diurnal tides. The total amplitude of double tides consisting of S2, M2, N2, and K2 reached 52.94%, while in single tides, comprising K1, O1, and P1, the percentage was smaller, namely 43.14%. The rest were shallow tidal waters of M4 and MS4 which had a relatively small percentage of 3.92%. Quantitatively, the tidal type was determined by calculating the ratio between the amplitudes of the main single tidal elements (K1+O1) and that of the main double tidal elements (M2+S2), known as the Formzhal number. The results were included in the mixed category of semidiurnal tides with a Formzhal number of 0.82.

Based on the obtained constant, the tides can be determined using several equations as shown in Table 2.

Tidal range is based on mean sea level (MSL) and lowest astronomical tide (LAT). Based on the calculation results, the tidal range at the spring tide of mean high water (MHWS) was 0.82 m for the LAT reference and 0.22 m for the MSL reference.

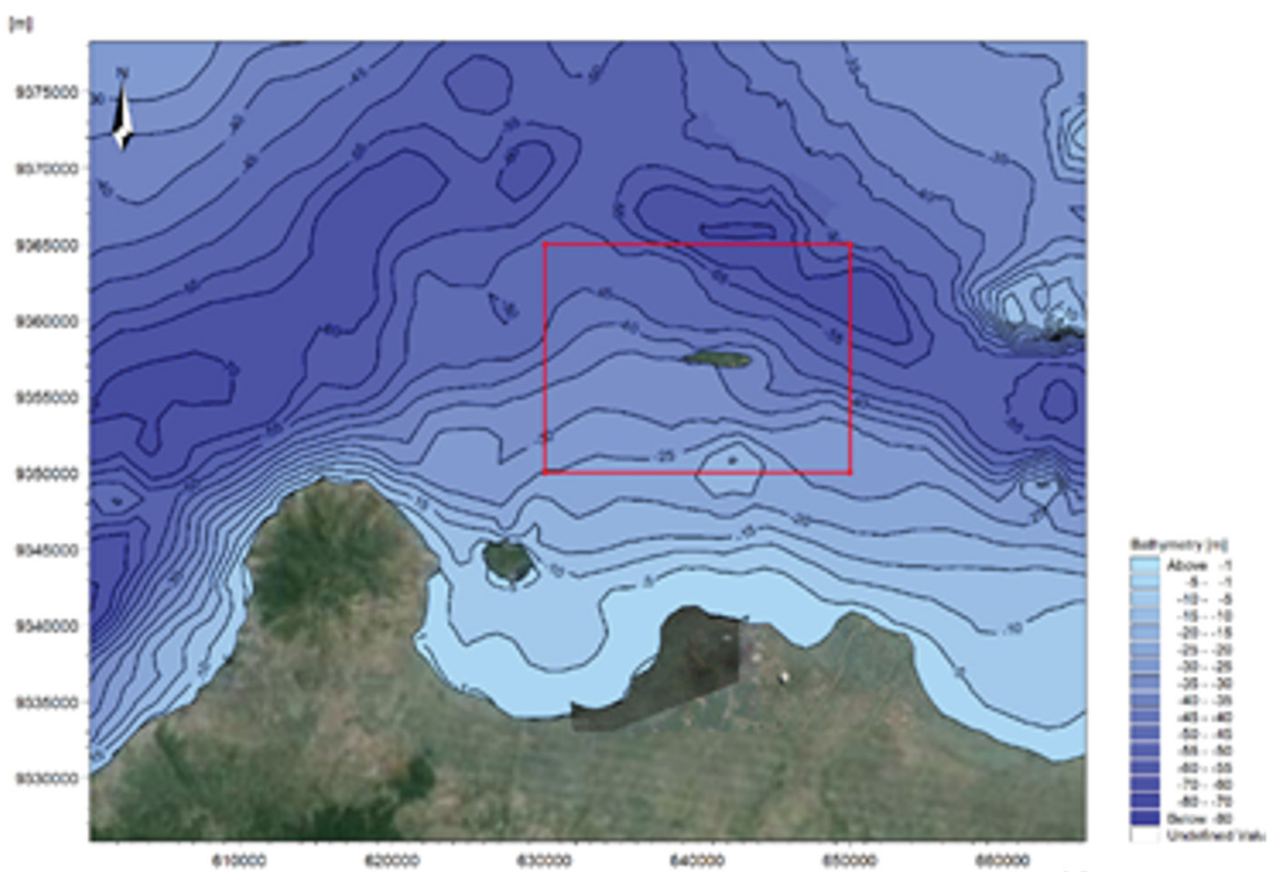

Fig 4. Depth of water around the sand mining site

Table 1. The tidal harmonic constant of Suralaya Station

	Tide constant									
	S0	M2	S2	K1	O1	N2	K2	P1	M4	MS4
Amplitude (m)	0.60	0.12	0.10	0.12	0.06	0.02	0.03	0.04	0.01	0.01
Phase difference (°)		161	78	201	214	155	78	201	264	210

Table 2. Important tidal elevations in mixed mainly semidiurnal tides

Water level design	Symbol	Calculation	Reference	
			LAT (m)	MSL (m)
Highest Astronomical Tide	HAT	Z0+(all constituents)	1.11	0.51
Higher High Water Level	HHWL	Z0+(M2+S2+K2+K1+O1+P1)	1.07	0.47
High Water Spring	HWS	Z0+(M2+S2+K1+O1)	1.00	0.40
Mean High Water Spring	MHWS	Z0+(M2+S2) or Z0+(K1+O1)	0.82	0.22
Mean High Water Level	MHWL	Z0+(M2+K1+O1)	0.90	0.30
Mean Sea Level	MSL	Z0	0.60	0.00
Mean Low Water Level	MLWL	Z0−(M2+K1+O1)	0.30	-0.30
Mean Low Water Spring	MLWS	Z0−(M2+S2) or Z0-(K1+O1)	0.38	-0.22
Chart Datum Level	CDL	Z0−(M2+S2+K1+O1)	0.20	-0.40
Lower Low Water Level	LLWL	Z0−(M2+S2+K2+K1+O1+P1)	0.13	-0.47
Lowest Astronomical Tide	LAT	Z0−(all constituents)	0.09	-0.51

On the other hand, the low tide level at low tide (MLWS) for each reference obtained values of 0.38 m and -0.22 m, respectively. The tidal range values of neap tide at mean high tide (MHWL) for the LAT reference were 0.9 m and 0.3 m for the MSL reference, while for low tide at low tide (MLWL) the LAT and MSL references obtained 0.3 m and -0.3 m, respectively. The tidal range, or the distance between the highest and lowest tides, based on all components, was 1.02 m.

Wave data were obtained based on results from Wavewatch-III, a third-generation wave model developed by the Marine Modeling and Analysis Branch (MMAB) of the Environmental Modeling Center (EMC), National Centers for Environmental Prediction (NCEP). Worldwide, the wave data of the model are disseminated through the website http://polar.ncep.noaa.gov/waves/, while in Indonesian waters they can be obtained through INA-COAP (Indonesia-Consortium of Oceanic and Atmospheric Prediction). The wave data used are from the last 14 years, i.e. 2006-2019, in terms of significant wave height, average period, and wave direction.

The wave height and period between 2006-2019 are shown in Figure 5, while a statistical description based on the image can be found in Table 3. In general, the highest wave heights occurred in the western season from December to February and then decreased in the transition season I from March to May. However, as we enter the eastern season (June-August), wave heights decrease. They increase again during the transition season II (September-November) and then decrease during the transition season I.

In the western season, the wave height is highest in January. The average value was 0.59 m, and the lowest and highest values were 0.15 m and 1.48 m, respectively. In February, the average wave height decreased slightly to 0.48 m with a range of 0.2-1.42 m. The lowest wave height during the western season occurred in December when the average value was 0.48 m with a range of 0.14 m to 1.36 m. In the transition season I, the lowest average wave height occurred in April at 0.38 m, while the highest occurred in May at 0.48 m, and the highest waves for the two months were 1.05 m and 1.12 m, respectively. In the eastern season, the highest wave peak occurred in August when the average wave height was 0.63 m, while the minimum and maximum waves were 0.24-1.29 m, respectively. In transition season II, the average wave height was 0.4-0.56 m, while the highest was 1.14-1.25 m.

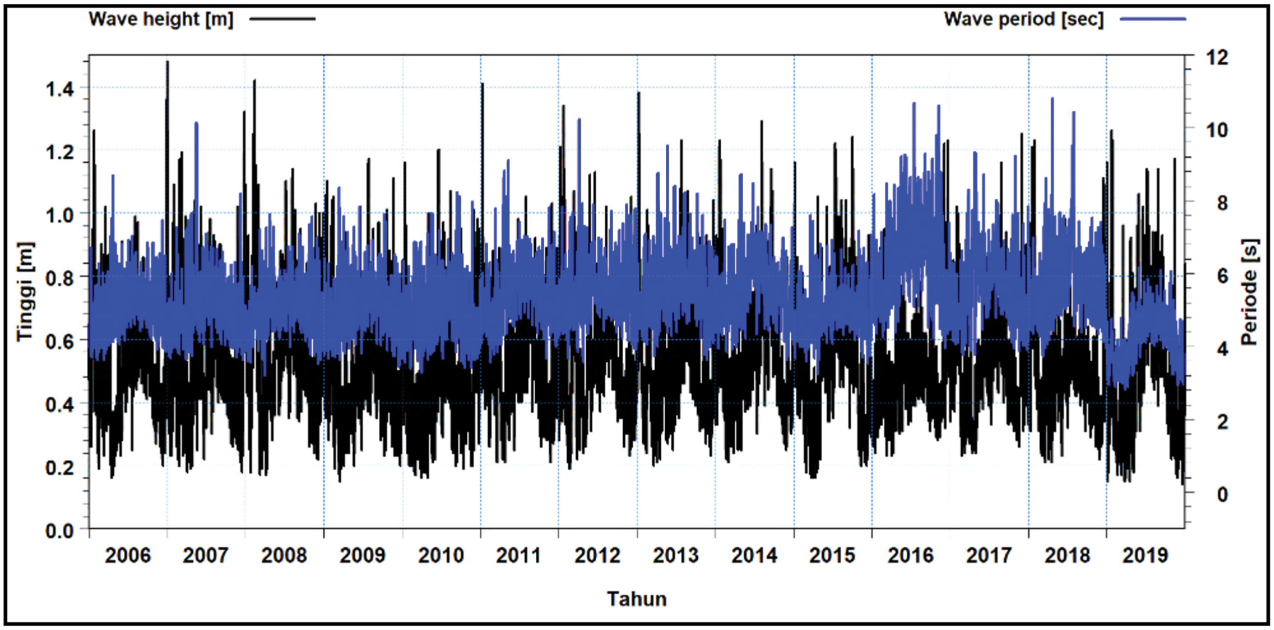

Fig 5. Daily significant wave heights and periods during 2006-2019

The character of the wave period in the last 14 years has been slightly different from the significant wave heights, with the highest wave period occurring in the eastern season (June-August) and the lowest in the western season (December-January). The average range of wave period in the eastern season was between 5.62 seconds and 5.75 seconds, while in the western season it was 4.77-4.90 seconds. In transition seasons I and II, the average wave period was not significantly different, ranging from 5.10-5.63 seconds and 5.25-5.59 seconds, respectively.

Aside from the general statistical description of wave height and period in the study area, an analysis was also carried out on the percentage of height and direction of wave arrival. The aim was to identify the range and direction wherein waves often occur. The percentage of height, period, and direction of wave arrival for the last 14 years, namely 2006-2019, is presented in Figure 6. The dominant wave height ranges from 0.5-0.75 m or 49.02% and 0.25-0.50 m or 36.69%.

Table 3. Description of statistically significant wave heights and periods between 2006-2019

Season	Month	Wave height (m)				Period (seconds)			
		Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
	Jan	0.59	0.22	0.15	1.48	4.77	0.67	2.94	8.18
	Feb	0.48	0.20	0.17	1.42	4.90	0.79	2.90	7.55
	Mar	0.42	0.17	0.15	1.19	5.10	1.00	2.82	8.63
I switch	April	0.38	0.14	0.15	1.05	5.53	1.19	2.89	10.81
	May	0.48	0.15	0.18	1.12	5.63	0.96	3.21	10.14
	Jun	0.54	0.15	0.22	1.20	5.70	0.90	3.71	9.27
East	Jul	0.60	0.15	0.25	1.23	5.75	0.88	3.68	10.67
	August	0.63	0.15	0.24	1.29	5.62	0.73	4.04	8.65
	Sep	0.56	0.14	0.20	1.14	5.59	0.76	3.85	9.29
Transition II	Oct	0.48	0.13	0.19	1.24	5.43	0.82	3.24	9.80
	November	0.40	0.14	0.16	1.25	5.25	1.02	2.93	10.61
West	Dec	0.48	0.20	0.14	1.36	4.84	0.84	2.95	8.20

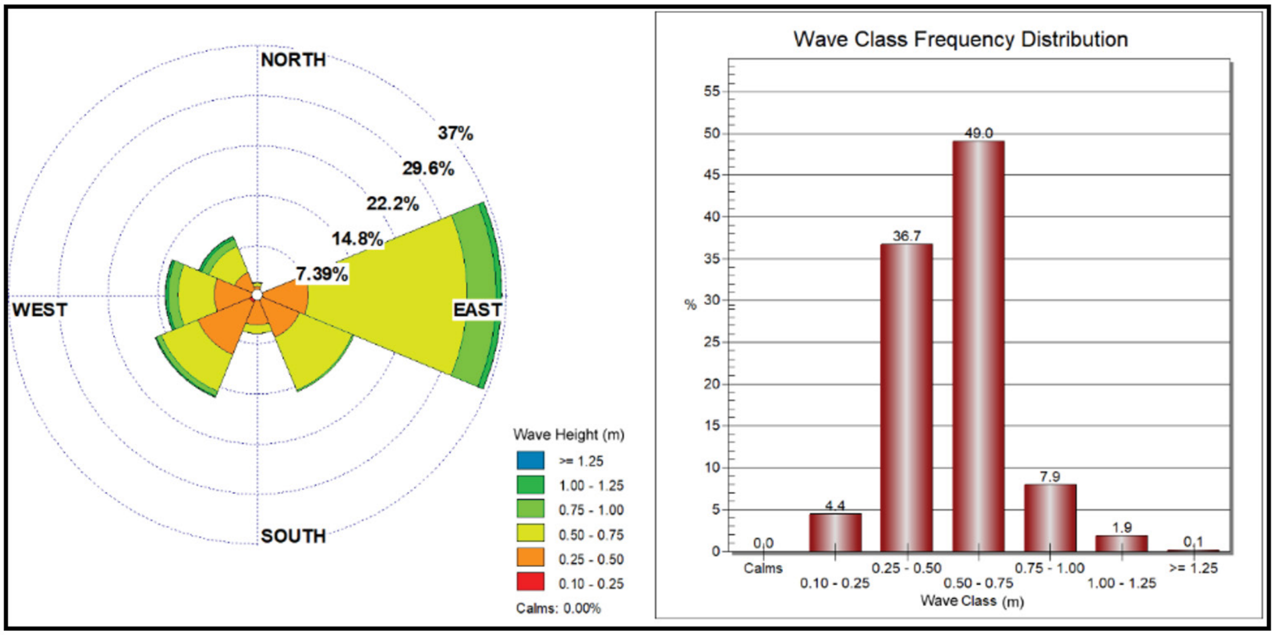

Fig 6. The wave characteristics were significant during 2006-2019; Waverose (left); Distribution of high-frequency waves (right)

For the direction of arrival, the dominant waves come from the east at 36.22%, followed by the southwest at 16.44%, southeast at 15.57%, and west at 13.68%. The percentage of wave occurrence from other directions was small, namely not higher than 10%, respectively.

The significant wave height was more dominant from the east with a range of 0.5 - 0.75 meters with a percentage of 23.44%, then followed by the southwest, west, and northwest with the respective percentages of 16.44%, 13.58% and 9.46%. The waves from the east and west show that the season has a significant effect, and one of the effects of wave formation is the wind. According to Triatmodjo (1999), monsoons are wind patterns that blow periodically for at least 3 months with opposite wind patterns and directions every half year. The monsoon wind phenomenon, which is supported by the location of Indonesia's territory on the equator and geographical conditions consisting of 70% of water areas, causes a great wind energy potential (Dida et al., 2016).

DISCUSSION

The effects of lake sand mining on the sediment morphology of the waters around Tunda Island were simulated for 15 days during the western season (January) and the eastern season (August). The TSS source does not follow the path of the TSHD vessel during mining due to overflow losses but is placed around the waters only at the dredge site. As water is displaced from the hopper during TSHD operations, the material is stirred up and introduced into the water body via the overflow. A water body denser than the surrounding water sinks toward the seafloor due to the input of this silt, which can have a high initial momentum (Spearman et al., 2011). Garel et al. (2009) and Tang et al. (2011) found that during dredging operations, both the screening process and the overflow of material from the hopper create turbidity plumes at the surface. Mechanical crushing of bottom sediment by the head of the pipe creates a second source of turbidity with a much smaller number of suspended solids. Large increases in suspended sediment concentrations often last only a short time and are localized near the dredging vessel in operation.

Sea sand mining in the Tunda Islands uses suction pipes that cause the material to pass through the suction pipes on the drag head and into the hopper without first being washed through the exhaust pipe and chute, thereby controlling the distribution of the material over the entire bottom surface of the hopper. After it is deposited along the ship channel, the seawater slowly flows back to the sea through the existing exhaust pipes. Therefore, during mining activities with a TSHD suction vessel, turbidity of seawater at the surface is relatively low because the mud that is drawn in with the sand is also accommodated in the hopper, so it is less likely to cause turbidity of the surface waters.

Water depth is one of the most important parameters in the study of the aquatic environment (Zhou et al., 2017). When the water has a shallow depth, the dilution of pollutants generally takes longer than in deeper waters. The shape of the bottom topography also affects the pattern of water circulation. The proposed sand mining site is located on the high seas, which are part of the Java Sea. The closest land to the mining area is Tunda Island. Because water depth is an important factor in dilution and flow patterns, the water depth around the proposed mining site must be considered during construction and sand dredging operations.

The distribution of maximum concentration in the west monsoon is influenced by the prevailing flow pattern moving eastward. The concentration tends to increase in the center of the output with a value of 260 mg/l. The TSS concentration of the model results is high, compared to the quality standard of the Government of the Republic of Indonesia with Regulation No. 22 of 2021 on the implementation of environmental protection and management of marine biota (coral reef), estimated at 20 mg/L. This high concentration is far from the coast of Tunda Island. Where the distribution of TSS is farther from the discharge source, the concentration decreases with increasing distribution distance. In addition, the maximum simulation results of the western monsoon show that there is no distribution of TSS in the Banten Bay area. The concentration is relatively high with a value of 60 mg/l to 80 mg/l around the area of Tunda Island, which is located on the high seas, causing the wide distribution of TSS.

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ISTRAŽIVANJE UTJECAJA VAĐENJA MORSKOG PIJESKA U VODAMA OTOKA TUNDA U INDONEZIJI NA TEMELJU MODELIRANJA MIKE 21

SAŽETAK

U Indoneziji je vađenje morskog pijeska uvedeno kasnih 1970-ih, a jedna od za to važnih lokacija je provincija Banten, Indonezija. Vađenje morskog pijeska u vodama Bantena započelo je 2003. godine nakon što je uprava u Serangu izdala dozvolu, točnije Odlukom br. 540/Kep.68/Huk/2003 koja je ažurirana Regionalnom uredbom Seranga br. 2 iz 2013. godine o Planu prostornog uređenja za obalna i mala otočna područja u pokrajini Serang za 2013.-2033. Istraživanja povezana s aktivnostima vađenja morskog pijeska u Bantenu u Indoneziji potrebna su u skladu s načelom održivosti ekosustava. Ova studija ima za cilj analizirati utjecaj vađenja morskog pijeska na ekologiju koraljnog grebena i hidrooceanografiju otoka Tunda. Napravljena je identifikacija pokrova koraljnog grebena, dok su hidrodinamički aspekti provedeni simulacijom batimetrijskih podataka, uzoraka plime i valova. Osim toga, provedena je simulacija distribucije sedimenta kako bi se odredio utjecaj eksploatacije morskog pijeska korištenjem modula za transport pijeska MIKE 21. Postotak koraljnog pokrivača na zapadu, istoku i jugu otoka Tunda bio je 66,00%, 39,67%, odnosno 28,15%. Najveća dubina mora oko lokacije istraživanja dosegla je 70 m, dok je u području vađenja pijeska ona relativno plitka. U posljednjih 14 godina dominantna visina valova kretala se od 0,5-0,75 m ili 49,02% i 0,25-0,50 m ili 36,69%. Nadalje, koncentracija TSS bila je relativno visoka s vrijednošću od 40 mg/l do 60 mg/l. Na temelju rezultata, najveći identificirani utjecaj vađenja morskog pijeska na otoku Tunda bila je visoka koncentracija TSS-a. To se može spriječiti rotiranjem plovila TSHD, posebno u područjima uz otok Tunda.

Ključne riječi: Ekologija, Mike 21, vađenje morskog pijeska, otok Tunda

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