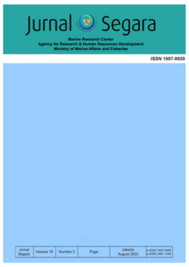

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MODELING THE POSSIBLE IMPACTS OF DREDGING ACTIVITIES IN THE FISHERY PORT OF CAROCOK, PESISIR SELATAN REGENCY, WEST SUMATRA: HYDRO-GEO-OCEANOGRAPHICAL APPROACHES

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ABSTRACT

Carocok Fishery Port (PPP Carocok) is a supporting facility for capturing fishery in the Pesisir Selatan Regency. Thus, bathymetry monitoring the shipping lane and the port pool dredging is crucial to bolster fishery activities. This study aims to model the possible impact when massive dredging is applied based on geological and oceanographical approaches. The bottom sediment sampled in the field was analyzed using a granulometric method. A direct bathymetry survey was also done using a single beam echosounder and tide gauge deployment. Hydrodynamic modeling was employed to predict the changes in water motion characteristics if dredging is applied-a scenario applying bathymetry profile after dredging was applied in the simulation. The bathymetry contour within Carocok Bay was relatively declivous, categorized as shallow water with a depth ranging from -2.5 to -15 m. The sediment type in the study area consisted of sand, sandy clay, clayey sand, silty sand, and mixed textures. The tidal current motions (ranging from 0 to 0.053 m/s) are the primary factor transporting the water mass within the port pool, which also impacts sediment transport in the semi-enclosed water area. The sediment characteristics showed that the sediment is deposited in low-energy conditions. It is modeled that the dredging plan in the PPP Carocok will not cause any significant changes, including bathymetry alteration and water environment. Therefore, the port pool is still appropriate to espouse fishery activities in the Carocok Port without dredging.

Keywords: Sedimentation, harbor dredging, marine geology, hydro-oceanographic.

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INTRODUCTION

Coastal development is proliferating around the world. The coastline has been extensively extended, with changes in port development, seabed mining, beach tourism, and land reclamation (Rosa & De Freitas, 2021; Wenger *et al*., 2018; Zhou *et al*., 2021). Efforts to expand coastal development and port facilities to accommodate higher shipping demand and large capacity vessels require extensive regional dredging services. The dredged sediments may be processed and used in reclamation projects to create new land for development purposes (Sandirasegaran & Manap, 2016). Sediment dredging is necessary to maintain the navigational infrastructure at fishing ports and wharves (Gustavson *et al*., 2008).

Over the last few decades, construction stakeholders have received attention to many issues regarding dredging and reclamation activities (Smith, 2019). Dredging and reclamation work without proper environmental management can cause long-term environmental impacts, affecting the marine environment and the fishing industry (Feola *et al*., 2016). The fishing port is aimed to support capture fisheries activities. One type of port is (Fish Landing Base) which is included in type D (Massiseng, 2019).

The Fishery Port (PPP) Carocok is the potential to be expanded because many ships are moored with the large-scaled fish-catching. On the other hand, the obstacle in PPP Carocok is the condition of several inadequate facilities. Therefore, the port authority is obliged to maintain the shipping channel pool and control the use of shipping lanes. Maintenance requirements must ensure sailing safety, environmental sustainability, water layout, and irrigation system. Dredging is necessary to maintain the desired depth and width of the shipping lane (Risky, 2021).

Dredging activities in coastal waters, especially in ports and canals, produce large amounts of sediment that must be disposed of. Thus, the management of these sediments is of great concern worldwide. Dredging according to the process of removing, transporting, and final disposal of sediment present in the navigation channel becomes essential for maintaining waterway transportation routes (Méar *et al*., 2018; Rosa & de-Freitas, 2021). Several studies in the world have conducted research related to dredging activities in coastal areas and ports. They only focus on the management of sediment from scrapings, the impact on the surrounding biotic environment and water quality pollution for the ecosystem (Lankester *et al*., 2015; Zheng *et al*. 2019; Zhou *et al*. 2021). However, there has been no research related to risk management of dredging activities from a hydro-geo-oceanographic perspective to determine the impact of these activities.

Thus, both techniques for dredging and removing dredged sediments threaten the functioning of marine ecological systems (Rosa & de-Freitas, 2021). This research proposes something new, namely a systematic impact assessment that helps in decision making and risk management of dredging activities. Therefore, research on risk management of dredging activities at PPP Carocok, Pesisir Selatan Regency, needs to be carried out to analyze the environmental impacts and port structure systematically caused by dredging activities. The selection of different techniques for the disposal of sediment dredged from port activities is a significant consideration in determining the risk management of these activities so that they will not cause environmental impacts in the future. Therefore, this study examines the changes that possibly occur if dredging is applied in the waterways of PPP Carocok based on geological and oceanographical perspectives.

METHODOLOGY

Studi Area

Carocok Tarusan coastal fishing port is one of three fishing ports in West Sumatra Province. The Carocok Tarusan Coastal Fishing Port (PPP) was built in 1997 as the Fish Landing Base (PPI) with an area of 2.19 hectares. The coastal fishing port of Carocok Tarusan is located in the District of Koto XI Tarusan, Pesisir Selatan Regency, West Sumatra Province and geographically is positioned at coordinates 0.59° - 1.17° South Latitude, and 100.34° - 100.64° East Longitude (Figure 1).

The Carocok Tarusan Coastal Fishing Port has the main task of carrying out some operational, technical activities, and technical support services in the coastal fishing port sector. Some of the existing facilities at PPP Carocok are docks, harbor pools, roads, and sheet piles. At the same time, other functional facilities include Fish Auction Place, fuel, clean water installations, a fish processing building, and several shops to support port activities.

Sediment Data Analyses and Mapping

Sediment analysis of 25 sediment samples scattered around the location of the planned dredging activity was carried out (Figure 1). The granulometric characteristic analyzes the sediment grain size to determine its characteristics and environment. This analysis was conducted to determine the level of resistance of sediment grains to exogenic processes, such as weathering, erosion, and abrasion from the provenance, as well as their transport and deposition processes (Rifardi *et al*., 1998).

Bottom sediment specimens were sampled using a grab sampler in the surrounding site. A granulometry analysis was performed to determine the resistance of

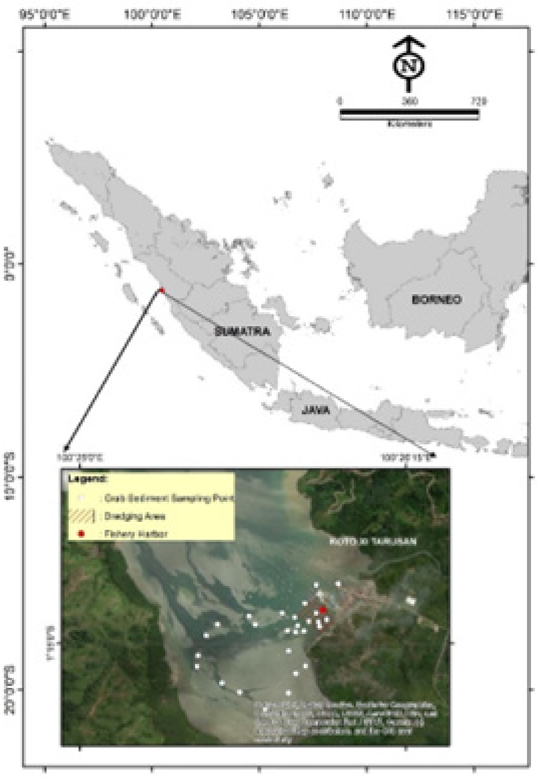

Figure 1. Research location and sediment sampling points.

the sediment fraction toward exogenic processes such as weathering, erosion, and abrasion from its provenance, the transport mechanism, and deposition regimes (Korwa *et al*., 2013). The grain size distribution was determined using the granulometric method (Hubbard & Pocock, 1972). Separation of grain size was carried out with a sieve of size: >2; 1.4; 1; 0.5; 0.250; 0.150; 0.090; 0.063; and <0.063 mm classified based on the Wentworth classification (1922). Then, the determination of sediment type was based on the classification of the Shepard Triangle Diagram in 1954 (Dyer, 1986). On the other hand, we used a statistical approach from each sediment group to interpret sediment distribution, transport, and deposition mechanisms. Statistical parameters used in sediment analysis include the mean, sorting, skewness, and kurtosis as follows:

Empirical mean (X_a)

The empirical mean parameter is used to determine the size of the sediment concentration. The average grain size reflects the characteristics of depositional energy by water or wind in transporting sediment. The empirical mean calculation uses the following statistical equation (Blott *et al*., 2006):

$$X_{a}=\frac{\sum f m_m}{100} \qquad \text{........ 1)}$$

where,

Xa = empirical mean

f = frequency

mm = mid-point for each class (mm)

Sortation (σ_a)

Sorting can show grain size limits or grain size diversity, type and characteristics as well as the length of sedimentation time of a sediment population (Folk & Ward, 1957). Statistical equations and classification of sorting classes based on the sorting equation made by Blott *et al*. (2006):

$$\sigma_a = \sqrt{\frac{\sum f(m_m - X_a)^2}{100}} \qquad \text{........ 2)}$$

where,

σ_a = sortation value

f = frequency

M_m = mid-point for each class (mm)

X_a = empirical mean

Skewness (Sk_a)

The skewness value is the deviation of the grain size distribution from the normal distribution. Skewness grouping is referred from Folk & Ward (1957). Statistical equations and classification of skewness based on the equations made by Blott *et al*. (2006):

$$Sk_a = \frac{\sum f(m_m - X_a)^2}{100{\sigma_a}^3} \qquad \text{........ 3)}$$

where,
Sk_a = skewness value
f = frequency
m_m = mid-point for each class (mm)
X_a = empirical mean
σ_a = sortation

Kurtosis (K_a)

Kurtosis shows the peak or flatness of the distribution in comparison to the normal distribution. This measure is not often used to measure the particle size distribution in rivers with gravel bottoms. The formula is as follows:

$$K_a = \frac{\sum f(m_m - X_a)^4}{100\sigma_a{}^4} \quad \text{...... 4)}$$

where,
K_a = kurtosis value
f = frequency
m_m = mid-point for each class (mm)
X_a = empirical mean
σ_a = sortation

Bathymetry Analysis

The bathymetric analysis was used to determine the value of the depth of the harbor pool in TPI Carocok Tarusan. The depth of the harbor pool was obtained by conducting bathymetric surveys through sounding activities with the acoustic method using the Echosounder Echotrack CVM Teledyne Odom Hydrographic single beam. The results of bathymetry data were processed and processed spatially to get an overview of the bottom of the waters. The sounding distance was made at intervals of 25 m and 50 m for each lane and perpendicular to the shoreline. The pattern of the housing line interval will determine the quality of the recorded depth value (Purwanto, 2015). The depth position was detected using GPS, which records the position of each depth value recorded by the transducer in absolute and real-time (Rahmawan *et al*., 2019). Before taking bathymetry measurements to ensure depth accuracy, the transducer was checked using the bar-check method by placing an iron plate under the transducer at several depths (Wulandari & Cahyono, 2020).

A tidal analysis was used to correct the value of the measurement depth with the seawater conditions at the time of measurement. Tidal data measured by the tide gauge was carried out for 16 days around the port area of PPP Carocok. The selection of tide monitoring locations represented the study area and was safe from wave disturbances (Ondara & Husrin, 2018). The tidal data obtained were processed to obtain harmonic constituents and Mean Sea Level (MSL) using the admiralty method (Rahmawan *et al*., 2017). The bathymetry data were then corrected for the draft transducer and tides at the study site. The calculation was done using the formula as follows:

$$D = D_t - r_t \quad \text{...... 5)}$$

$$r_t = TWL_t - MSL \quad \text{...... 6)}$$

where,
D = the real depth
R_t = tidal correction during the survey

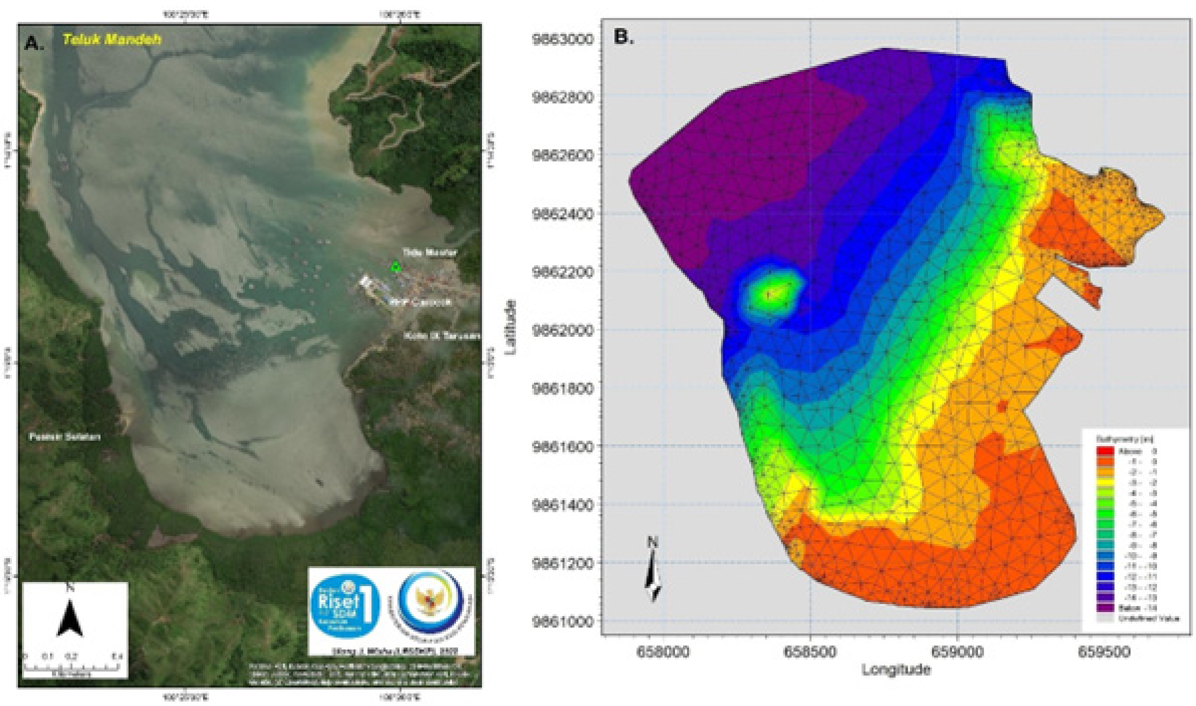

Figure 2. Tide master deployment location within the PPP Carocok harbor.

TWL_t = surface elevation during the survey
MSL = mean sea level

Tidal Measurement and Hydrodynamic Model Development

Several measurement instruments have been installed at the study site as a basis for knowing the pattern of tidal current circulation. In this case, the instrument used was Tide Master, installed in the PPP Carocok area. The installation locations of the tools are presented in Figure 2a. The instrument was installed for approximately 15 days of measurement to represent the conditions of full moon tides and new low tides.

The hydrodynamic model uses a flexible mesh in the two-dimensional hydrodynamic model as part of the flow model. The flow model is simulated based on the continuity equation and two horizontal momentum equations for the x and y components (Zhao *et al*., 1994) as follows:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=S \qquad \text{7)}$$

$$\frac{\partial u}{\partial t}+\frac{\partial u^2}{\partial x}+\frac{\partial vu}{\partial y}+\frac{\partial wu}{\partial z} = fv - g\frac{\partial \eta}{\partial x} - \frac{1}{\rho_o}\frac{\partial P_a}{\partial x} - \frac{g}{\rho_o}\int_z^{\eta}\frac{\partial \rho}{\partial x}dz - \frac{1}{\rho_o h}\left(\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y}\right) + Fu + \frac{\partial}{\partial z}\left(vt\frac{\partial u}{\partial z}\right) + U_s S \qquad \text{8)}$$

$$\frac{\partial v}{\partial t}+\frac{\partial v^2}{\partial y}+\frac{\partial uv}{\partial x}+\frac{\partial wv}{\partial z} = -fu - g\frac{\partial \eta}{\partial y} - \frac{1}{\rho_o}\frac{\partial P_a}{\partial y} - \frac{g}{\rho_o}\int_z^{\eta}\frac{\partial \rho}{\partial y}dz - \frac{1}{\rho_o h}\left(\frac{\partial S_{yx}}{\partial x} + \frac{\partial S_{yy}}{\partial y}\right) + Fv + \frac{\partial}{\partial z}\left(vt\frac{\partial v}{\partial z}\right) + V_s S \qquad \text{9)}$$

where,
t = time
x, y, z = cartesian coordinates
η = water level
d = water depth
u, v, w = velocity component in the x, y, and z direction
f = 2Ωsinφ (Coriolis parameter)
g = specific gravity
ρ = density
$S_{xx}, S_{xy}, S_{yx}, S_{yy}$ = radiation component of tensor stress
vt = vertical turbulent (eddy viscosity)
Pa = atmosphere pressure
ρo = reference density
S = the magnitude of discharge from the source
(U_s V_s) = acceleration of water release

The stage of making flexible mesh is crucial as the basis for the hydrodynamic model domain. The flexible mesh consists of bathymetric data, shorelines, and model boundary conditions. Bathymetric measurement data were used to build the basis of the hydrodynamic model obtained by conducting a field survey. At the same time, the coastline data are on-screen digitized from Google Earth images. The model boundary conditions consisted of tidal forecast time series data gained using the NAO99b model. The flexible mesh used in the simulation is presented in Figure 2b. In addition, wind data sourced from the Meteorology, Climatology, and Geophysics Agency (BMKG) were also applied in the simulation as time series data.

The current pattern simulation was carried out for 15 days, representing the tidal and full moon periods. Simulations were repeated with the dredging scenario so the changes could be well-compared and identified. The model settings are presented in Table 1.

RESULTS AND DISCUSSION

Sediment characteristics

Sedimentary texture parameters such as mean (Mz), standard deviation (σ1), skewness (Ski) and kurtosis (Ka) are generally used to reconstruct the depositional environment of sediments (Amaral & Pryor, 1977). The relationship between sediment grain size parameters and sediment transport/depositional mechanisms has been used by modern research in-depth and in the division of depositional environments (Malvarez *et al*., 2001) (Table 2).

The value of the mean size indicates that the study area is included in the very fine sand group, which was deposited under low energy conditions. The sample mean varies from 1.60 - 5.47Φ with a mean of 3.25Φ (Figure 3A). All samples generally fall into the category of mean fine sand to very fine sand because they have a mean value of more than 2Φ. The mean size of the sediment is influenced by the source that feeds the sediment, the sediment transport medium, and the energy conditions in the sediment deposition environment (Kumar *et al*., 2010). The value of the mean size indicates that the very fine sand size was deposited in low to very low energy conditions.

Skewness (Ski) measures the asymmetry of a frequency distribution. The skewness value at the research location ranges from 0.68 to – 0.59, with an average skewness value of -0.07 (Figure 3b). The symmetry of the sample is in the very fine skewed to the coarse skewed category. As much as 48% of the sample is in the fine skewed category. Very coarse skewed sediment has a percentage of 20%, while the rest fall into the category of symmetrical (12%), coarse

Table 1. Hydrodynamic modeling set-up applied in the simulation

Parameter	Diterapkan dalam simulasi
Mesh file	Digitasi batimetri dan garis pantai Source: Batimetri In Situ Citra Google Earth
Modul Hidrodinamika	
Solution Technique	Shallow water equations: - Time integration – Low order, fast algorithm - Space discretization: Low order, fast algorithm - Minimum time step: 0.01 sec - Maximum time step: 3600 sec - Critical CFL number: 0.8 Transport equations: - Minimum time step: 0.01 sec - Maximum time step: 3600 sec - Critical CFL number: 0.8
Flood and Dry	Drying depth: 0.005 m Flooding depth: 0.05 m Wetting depth: 0.1 m
Density	Density type: Barotropic Reference temperature: 10°C Reference salinity: 32 PSU
Eddy viscosity	Smangorinsky formulation: 0.28 Eddy parameters: min $1.8e^{-006}$ m^2/s^2, max 10^7 m^2/s^2
Bed resistance Wind forcing Boundary conditions (BC)	Manning number: 32 [m^(1/3)/s] Varying in time, constant in domain: Data angin BMKG Peramalan pasang surut pada koordinat sebagai berikut: Carocok Simulation: BC1: 100,42869 E -1,2396 S BC2: 100,42443 E -1,2401 S BC3: 100,42058 E -1,2420 S Specified level – varying in time, constant along boundary

skewed (4%), and very fine skewed (16%). Negatively skewness (28.00%) of sediment indicates sediment deposition in a robust energy environment, while as much as 72.00% is included in the positive skewness of sediment, which indicates sediment deposition in a protected environment with low energy (Rajasekhara *et al*., 2008).

The value of the slope (skewness) in 25 samples of the bottom sediment of the PPP Carocok waters showed different variations in values in the range of -0.82 - 0.89. So based on the slope of the study area, there are five types of classification of the level of sedimentation of sediment grains, namely fine skewed, symmetrical skewed, very fine skewed, very rough skewed, and rough skewed. This state indicates that the sediment has undergone a transportation process and settled in the water area. The slope value obtained from the calculation results shows differences in sediment texture between stations.

The difference in the slope value illustrates that the strength of the energy working in the waters is not dominantly the same (Putra & Nugroho, 2017). The skewness condition in general in the research area is positively skewed, which indicates that the conditions at the location are on a fine-sized substrate, namely silt to mud where it is found in Surbakti (2010 , that the skewness at the river estuary is in the average range. Symmetrical average, fine, to very fine. The statistical value of sediment in the form of kurtosis, according to Setiady & Darlan (2016), is a description of the sorting relationship between the middle and the bottom and only shows sediment criteria through graphs. Based on the results of statistical calculations of sediment kurtosis values in the study area, there are two types of kurtosis graphs: very pointed and very pointed.

The standard deviation graph (σ1) measures sediment sorting and shows fluctuations in kinetic energy. Sorting has an inverse relationship with the

Table 2. Statistics of sediment grainsizes of PPP Carocok waters

Sample ID			Grain statistical parameters (ϕ)			
	Sorting	Classification	Skewness	Classification	Kurtosis Classification	
CR-01	1.22	Poorly Sorted	0.35	Very fine skewed	0.94	Mesokurtic
CR-02	1.20	Poorly Sorted	0.68	Very fine skewed	1.12	Leptokurtic
CR-03	1.07	Poorly Sorted	0.24	Fine skewed	0.88	Platykurtic
CR-04	1.28	Poorly Sorted	0.22	Fine skewed	0.84	Platykurtic
CR-05	1.23	Poorly Sorted	0.24	Fine skewed	1.10	Mesokurtic
CR-06	1.30	Poorly Sorted	0.23	Fine skewed	0.90	Platykurtic
CR-07	1.39	Poorly Sorted	0.38	Very fine skewed	1.24	Leptokurtic
CR-08	1.50	Poorly Sorted	0.18	Fine skewed	0.82	Platykurtic
CR-09	1.48	Poorly Sorted	0.25	Fine skewed	0.84	Platykurtic
CR-10	1.36	Poorly Sorted	-0.54	Very coarse skewed	0.78	Platykurtic
CR-11	1.34	Poorly Sorted	-0.45	Very coarse skewed	0.86	Platykurtic
CR-12	0.89	Moderately sorted	-0.43	Very coarse skewed	0.91	Mesokurtic
CR-13	0.86	Moderately sorted	-0.24	Coarse skewed	0.91	Mesokurtic
CR-14	1.31	Poorly Sorted	-0.59	Very coarse skewed	1.02	Mesokurtic
CR-15	1.33	Poorly Sorted	0.25	Fine skewed	0.98	Mesokurtic
CR-16	1.02	Poorly Sorted	-0.08	Symmetrical	1.10	Mesokurtic
CR-17	0.51	Moderately well sorted	-0.34	Very coarse skewed	2.25	Very leptokurtic
CR-18	1.42	Poorly Sorted	0.05	Symmetrical	0.92	Mesokurtic
CR-19	1.41	Poorly Sorted	0.13	Fine skewed	0.72	Platykurtic
CR-20	1.40	Poorly Sorted	0.27	Fine skewed	0.93	Mesokurtic
CR-21	1.29	Poorly Sorted	0.06	Symmetrical	0.78	Platykurtic
CR-22	1.41	Poorly Sorted	0.30	Fine skewed	0.72	Platykurtic
CR-23	1.50	Poorly Sorted	0.21	Fine skewed	0.53	Very platykurtic
CR-24	1.52	Poorly Sorted	0.31	Very fine skewed	0.72	Platykurtic
CR-25	1.28	Poorly Sorted	0.10	Fine skewed	0.90	Mesokurtic

standard deviation. The standard deviation indicates a difference in the kinetic energy associated with the sediment depositional mode (Ganesh *et al*., 2013). Variation in sorting value is one of the parameters to observe differences in turbulence in water and variability in the velocity of sediment deposition currents (Venkatramanan, 2011). The sorting value of 25 bottom sediment samples from PPP Carocok waters ranged between 0.51Φ - 1.52Φ with an average of 1.26Φ.

In general, the sediment sorting characteristics of the study area are categorized as poorly sorted, with almost 88.00% dominating (Figure 4a). The value of sediment sorting at the study site is included in poor sorting. Prandle (2000) explained that sediments with poorly sorted granulometry were caused by the size of particles that accumulated randomly. Sediment samples also own this condition in the waters of PPP Carocok, which are dominated by the moderately sorted to poorly sorted categories (Figure 5).

Sedimentary grain sorting conditions are badly influenced by the strength of currents and volatile waves, meaning that the strength is not the same every time,

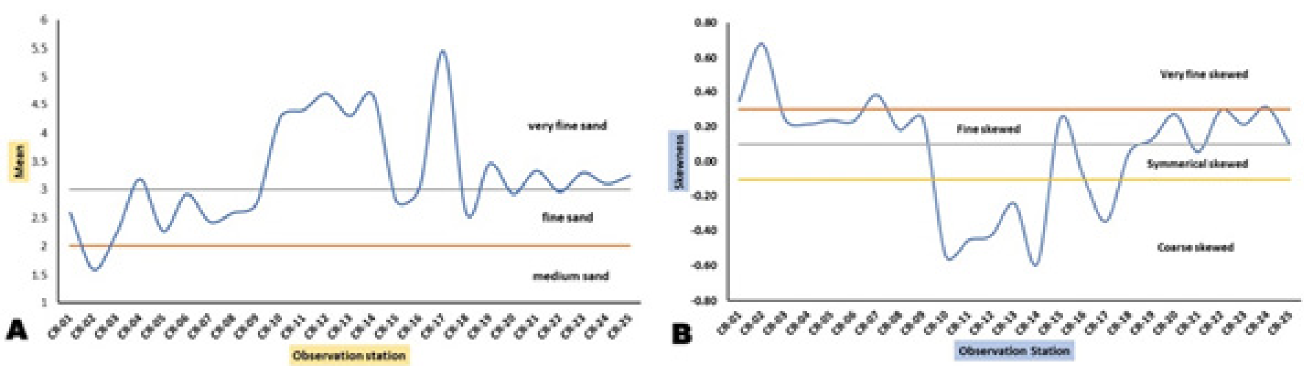

Figure 3. Graph of mean (A) and Skeweness (B) of bottom sediment in the PPP Carocok.

so the deposited sediment grains differ very strikingly (Rifardi *et al*.,1998). In addition to these conditions, the process of a meeting between river and ocean currents causes a gradation of depositional current energy, causing a fluctuating current energy condition, and the grain size of the sediment is not properly sorted.

The kurtosis chart is a quantitative measure used for the onset of a normal distribution. The kurtosis graph values in the sediment samples ranged from 0.53 – 2.25, with an average kurtosis of 0.95 (Figure 4b). In general, the sediment kurtosis value in the study area is as much as 36.00% in the mesokurtic category, while the rest are in the leptokurtic and platykurtic categories. Excessively high or low kurtosis values indicate that part of the sediment has reached a sorted (sorted) process elsewhere with a high-energy depositional environment (Deepthi *et al*., 2018). The variation in kurtosis values reflects the flow characteristics of the sedimentary depositional media.

The grain size data were based on 25 samples from the waters around PPP Carocok, XI Koto Tarusan. Sediment samples showed variations in the value and percentage of sediment grain size. The analysis results of the percentage of sediment grain size were then classified based on the 1954 Shepard Triangle Diagram, so it could be easier to interpret the grouping of sediment types. Generally, the study area's seabed sediments are dominated by clay to sand sizes (Figure 5). The naming of sediment types is based on the classification in the 1954 Shepard Triangle Diagram.

In general, based on the percentage of sediment

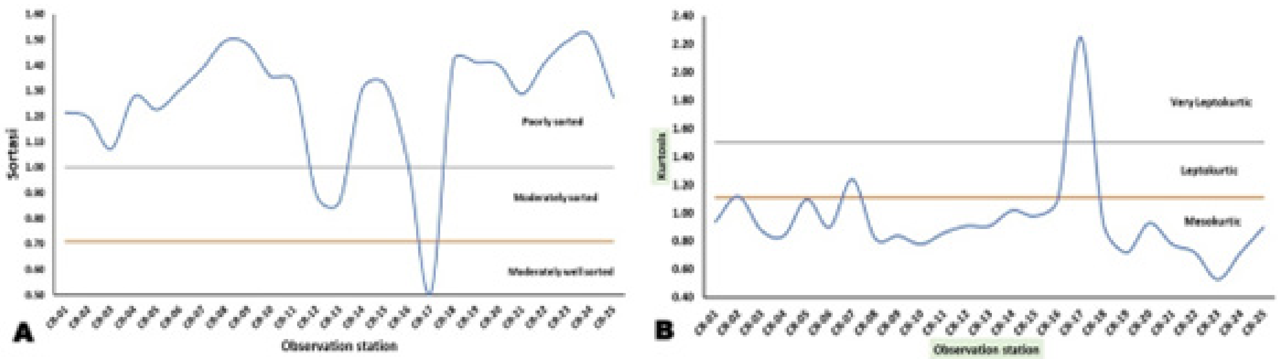

Figure 4. Graph of sortation (A) and kurtosis (B) of bottom sediment in the PPP Carocok.

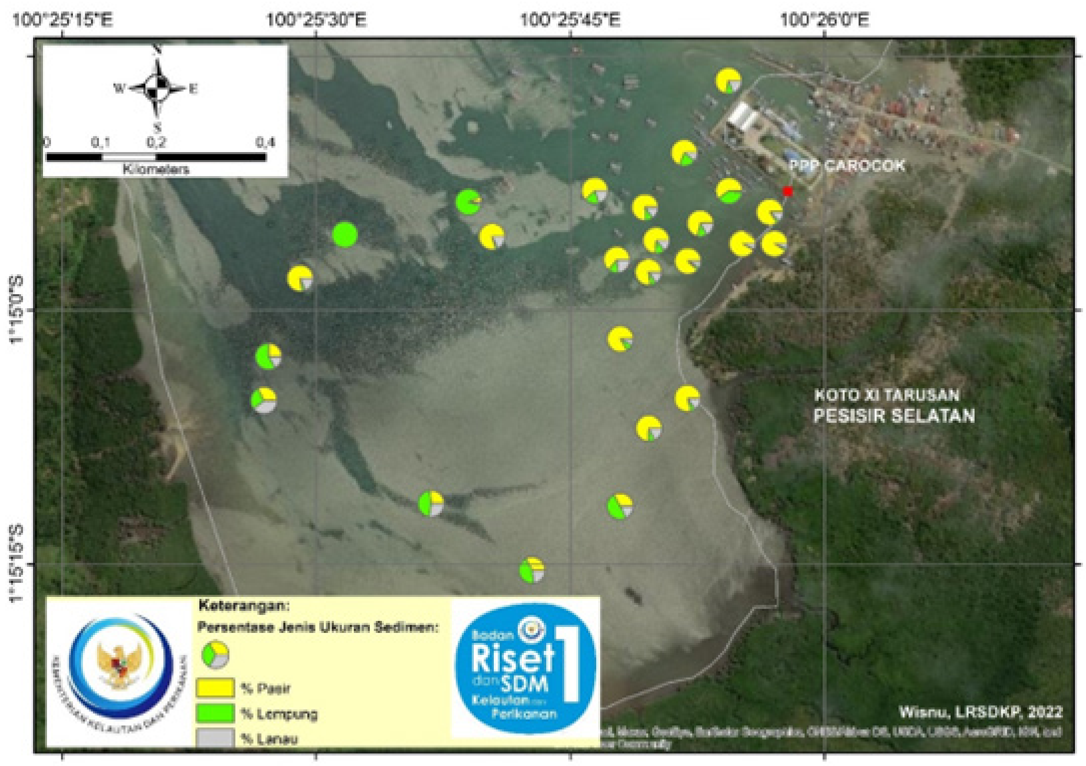

Figure 5. Grain size distribution percentage of sediment sampled within PPP Carocok.

grain size, the sediment types in Carocok PPP waters were divided into four types of sediment based on percentage of sediment grain size: sand, sandy clay, clayey sand, silty sand, and mixed texture (mixing). The predominance of sandy to silt-sand types was scattered in the eastern part of the bay morphology or adjacent to the location of the dredging plan. Groups of sandy clay and clay mixed with silty sand sediment types were scattered in the western part of the bottom of the waters of the study area. The western part of the research area is an area that has hilly morphology and no river flow.

Bathymetry profiles

From the results of tidal calculations using the Tide Master instrument, which is installed near the tourist port pier, the tidal constituent values are obtained as follows.

Measurements were carried out for 16 days, and the average tidal value in Tarusan was 0.93 meters, represented by the S0 component. The M2 and N2 constituents are the components of the double tide, with the most dominant M2 amplitude value of 0.4 m. This indicates that the moon's declination influences the tidal component at the study site. In addition, the value of the single tidal component K1 shows that the moon's declination on the water mass has a more significant influence than the effect of the sun's declination on the earth (Aziz *et al.*, 2013). Tidal events at the location occurred twice a day. This state is shown by the tidal measurement chart, where there are two-times high and low tide fluctuations with different heights at different times in a day. In addition, in calculations using the Formzahl number, which is used to determine the type of tidal waters (Rampongan, 2013) of 0.925, this value is included in the mixed tide with prevailing semidiurnal category. The tidal range is 2.14 m.

The maximum depth around the pier pool was about 7 meters (Figure 7). A red line borders the dock pool area. The contours of the wharf pond are relatively sloping, and the overall water area around the harbor to the mouth of the bay is a shallow water type with a maximum depth of 16 meters. In terms of oceanography, shallow waters have a depth of up to 200 m, and shallow water areas generally have very high dynamics of change (Setyawan *et al.*, 2014).

Table 3. Tidal constituent amplitude and phase lag analyzed using a least square method

Tidal constituents	Amplitude (m)	Phase lag (°)
M2	0.4	55.97
S2	0.05	175.42
N2	0.1	33.02
K2	0.16	191.99
K1	0.27	167.91
O1	0.08	232.64
P1	0.19	30.33
M4	0.02	211.37
MS4	0.01	117
S0	0.93	

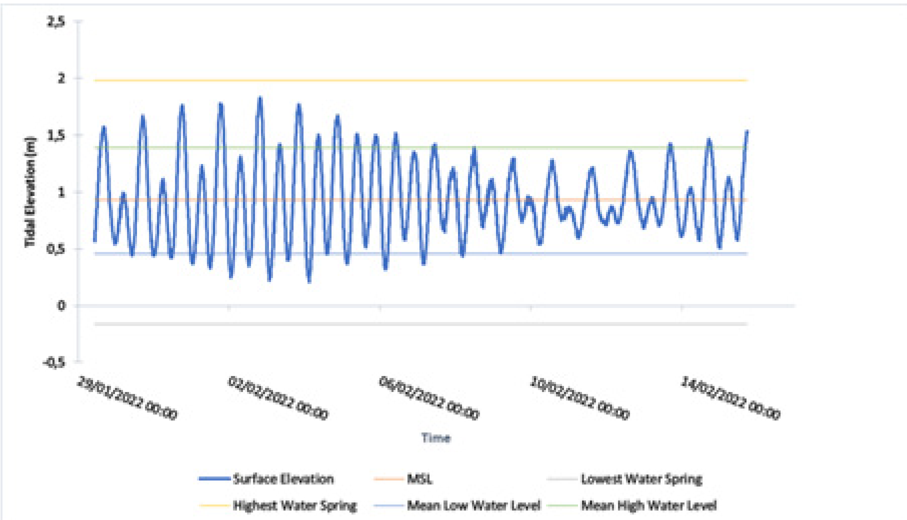

Figure 6. Significant elevation of tides in the Carocok Bay.

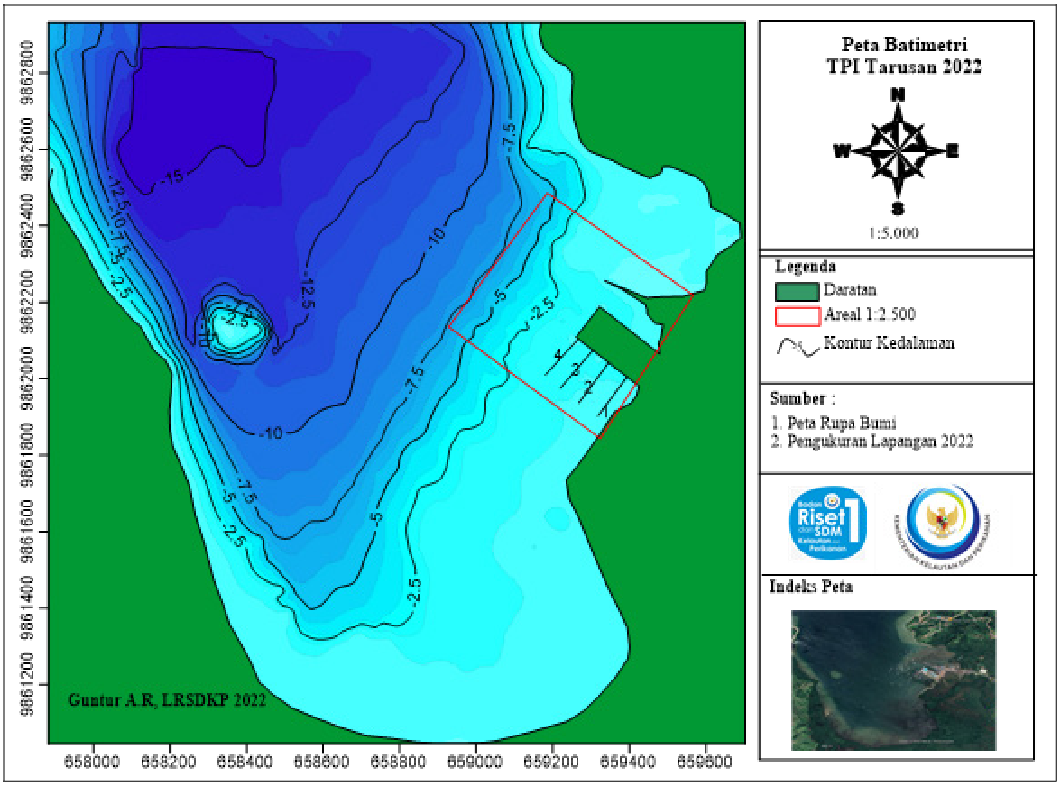

Figure 7. Bathymetry contour of Carocok Bay.

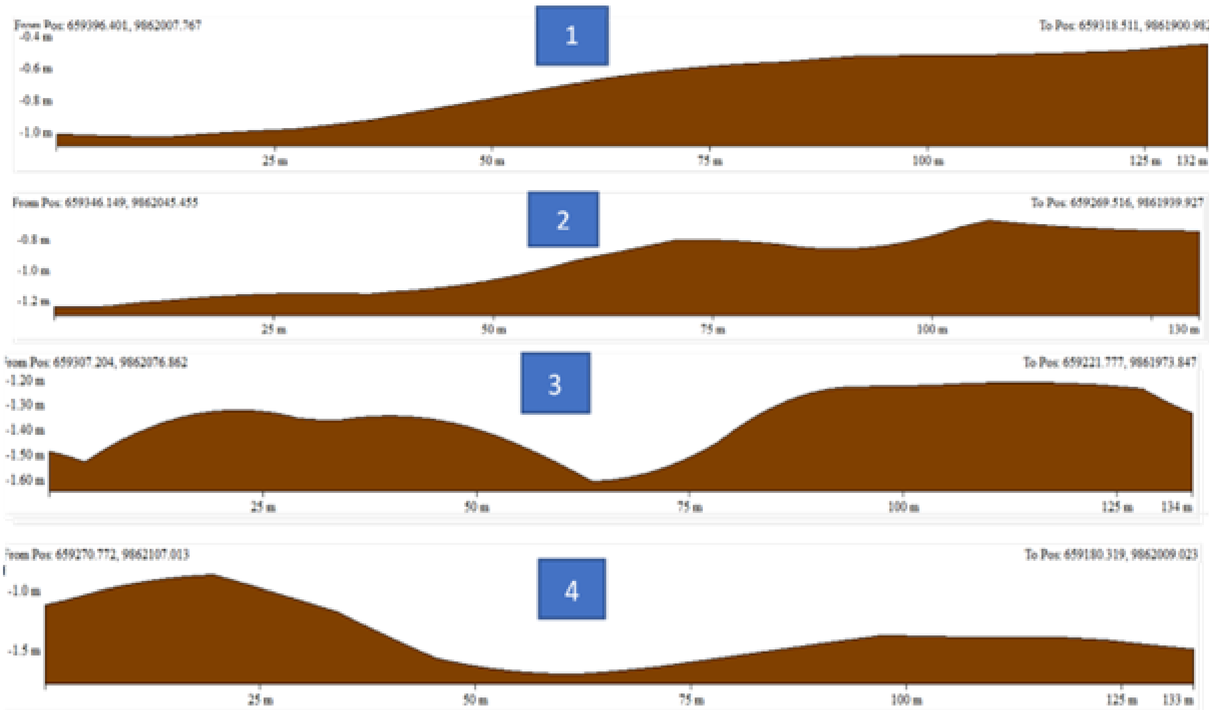

Figure 8. . Cross-section of the expected area for dredging in the PPP Carocok. The cross-section lines are referred to Figure 8.

Depth conditions are increasing towards the mouth of the bay. On the east side, a depth of 5 m can be found from the coastline to 30 - 50 m westward. On the south side, the water depth is very gentle, averaging 5 meters. From the pier up to 240 m to the bay, it has a very gentle slope with a maximum slope of 2.5˚. A slope is a measure of the slope caused by differences in altitude and is expressed in degrees (Febrianto *et al*., 2016). The slope of water becomes a parameter of some damage caused by aquatic phenomena (Narany *et al*. 2014; Syahrul *et al*., 2020).

In certain parts, coral areas have a depth of less than 1 meter. Sedimentation also occurs in certain parts, which are marked by the presence of several ships that ran aground and shallow areas in some parts of the waters. Currents along the coast caused by breaking waves and forming an angle to the shoreline will bring sediment driven by waves to the beach. The sediment partially settles and will form spits (Dewi & Ismanto, 2015).

The transverse profile of the southwest part of the pier can be seen by dividing the cross-section into four sections, as shown in the picture above. The results of the transverse profile can be seen in Figure 8. The transverse profile is at a depth of 0.5 to 1.6 meters, with a different profile shape in each cross-section. Profile 1 has the shallowest sea area with a depth of +- 0.5 meters, where mangroves near the mainland overgrow the area. Mangroves maintain coastal stability against erosion/abrasion hazards (Erwin *et al*., 2021). Natural sedimentation can be caused by the presence of mangroves (Widagdo & Sugiri, 2014). Sedimentation will cause siltation in the harbor pond area. Fluctuations in changes in the bottom of the water can be seen in profile two, where the conditions experience a difference in depth at 50 meters from the edge of the pier, then the depth decreases and then rises again at 75 meters. This is different from the situation in profile two, where the depth at the pier's edge is around 1.2 meters. Then the depth is reduced to less than 1 meter in the area. While in profile 4, the depth ranges from 0.8 to 1.5 meters. Tidal and current conditions affect the depth of the waters. The amount of sediment carried through the mouth of the river will affect changes in the bottom morphology profile through the sedimentation process.

Figure 9 shows a 3D simulation of the seabed condition of the PPP Carocok. The green color is the land area, while the blue color is the sea area. Color gradations to dark colors are areas with high depth values. The light blue color indicates the area with a depth from 0 to 5 m, and the maximum distance to the mouth of the bay is as far as 600 m.

Tidal Current Pattern of Carocok Bay

The RMSE (Root Mean Square Error) value obtained from the comparison of sea level elevation data for simulating ocean currents at PPP Carocok is 0.008 meters. The sea level elevation values between the model data and field data show almost the same magnitude during new conditions and at full moon conditions, but the elevation value in in situ data is approximately 0.1 meters higher (Figure 10). From the validation of the results of this model, it also shows that the developed oceanographic model can represent the actual conditions in nature, so that it can be used as a basis for further analysis.

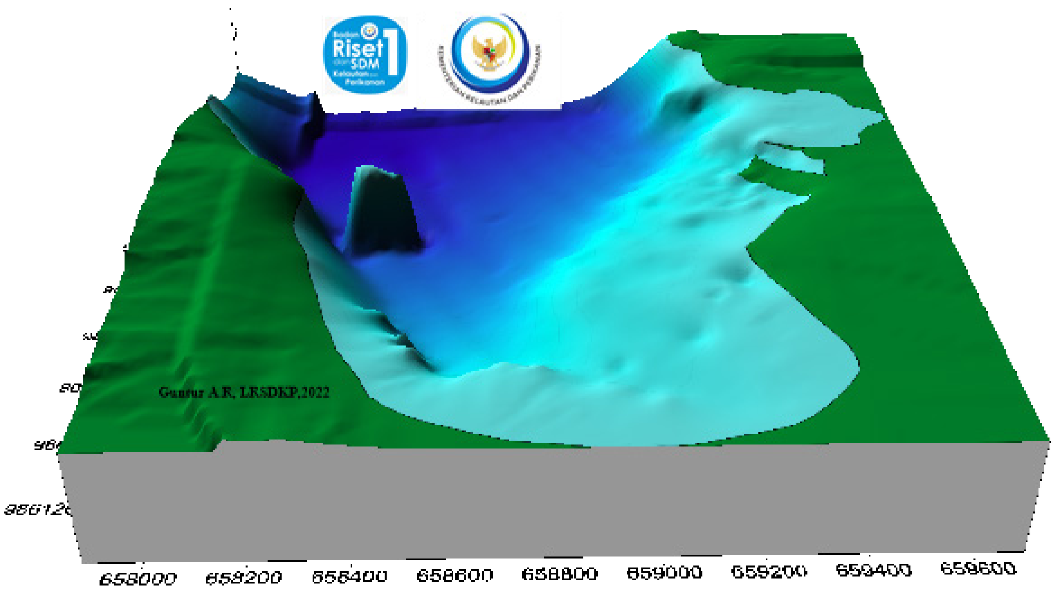

Figure 9. 3D topography of Carocok Bay.

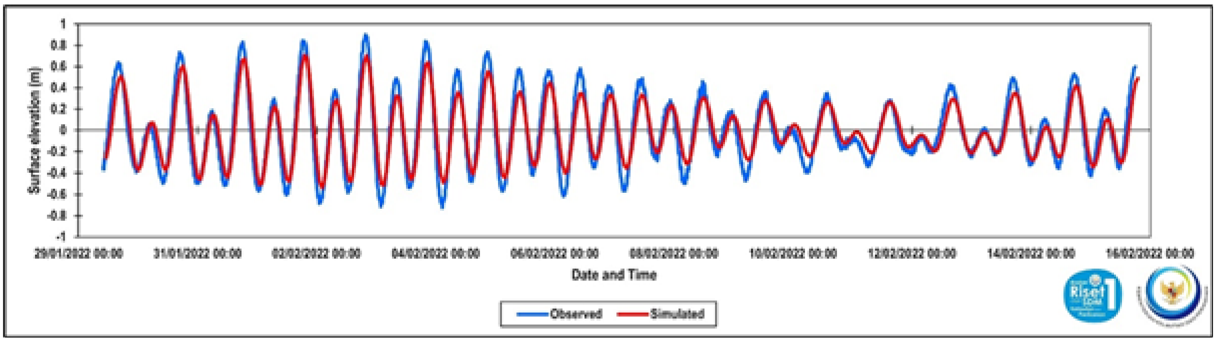

Figure 10. Model validation using tidal data.

The tidal type in the PPP Carocok area is a mixed double daily slope, so that in a day there will be two tidal cycles and two low tide conditions with asymmetrical elevations (Rahmawan *et al.*, 2019). Because there is no current measurement at the study site, the current condition in situ cannot be explained. However, based on previous research by (Wisha *et al.*, 2018) in Mandeh Bay, stated that the velocity of the surface current is stronger which gradually decreases towards the bottom of the waters ranging from 0.1-0.3 m/s.

The tidal elevation which is quite significantly different between the spring and neap conditions also explains the different current speeds as well. At high tide conditions, the current direction moved towards the southeast with a speed of 0-0.053 m/s. The maximum current velocity was found to the north and south of the port at speeds of 0.04-0.05 m/s (Figure 11a). This can be hypothesized that sediment input from the mouth of Carocok Bay and some river mouths will tend to move/ displace from the coastal area and be transported well and indicate possible coastal erosion.

At low tide conditions, the current velocity ranged from 0-0.012 m/s with the dominant current moving to the northwest (Figure 11b). The maximum current speed was found in the southern area of the port with current speeds ranging from 0.01-0.012 m/s and in the north of the port with speeds reaching 0.012 m/s. In general, the direction of the current in the near-coastal area tends to turn along the coast before finally moving dominantly out of the bay.

During the neap high tidal condition (Figure 11c), the dominant direction of current movement was quite different from the current pattern in spring conditions. Interestingly, the current velocity during neap condition moved to the west as it approached the shoreline, which ranged from 0-0.029 m/s. Areas with a robust current velocity were in the south and north of PPP Carocok with speeds approaching 0.03 m/s. In addition, the different current patterns during spring and neap low tides indicate different sediment transport mechanisms (Qarnain *et al.*, 2014).

The similar pattern of current movement with spring low tidal conditions was detected. At the neap low tide, the dominant current direction moved to the northwest where there is a change in the direction of the current near the coast indicating the shifting phase of tidal conditions has not yet fully occurred (Figure 11d). This can also be caused by the increase in longshore currents that occur in the bay so that the current direction turns and changes according to the shoreline pattern (Wisha *et al.*, 2018). The current velocity was approximately the same as the spring phase, ranging from 0 to 0.012 m/s. A strong current profile was found in the south and north of PPP Carocok (yellow-red color) with speeds reaching 0.01 and 0.012 m/s, respectively.

Regarding the distribution of sediment particles, the bottom sediment will have a wider and more random spatial distribution in the Carocok area (Andutta *et al.*, 2019). In the next subsection, the prediction of the impact of dredging the bottom of the water on changes in current characteristics around the port will be discussed.

Estimated Hydro-oceanography alteration after dredging

Prediction results at PPP Carocok show a decrease in post-dredging current velocity, ranging from 0.004-0.006 m/s (Figure 12a). However, the direction of the current does not change significantly, only about 10-15 degrees of change will occur (Figure 12b). Although not very significant, the decrease in flow velocity after dredging can support the process of entering/outgoing ships to the port. So that the dredging process can be carried out, but if it is seen that the dredging plan area in PPP Carocok is not an area with high levels of resuspension and sedimentation, then the dredging process will only have a bad impact on the aquatic environment around the port.

Given the semi-enclosed bay area with a weak current profile, the sediment transport process is also low. If there is a change in the morphological profile of the bottom waters because of dredging, an imbalance of the abrasion and accretion mechanism is likely to occur

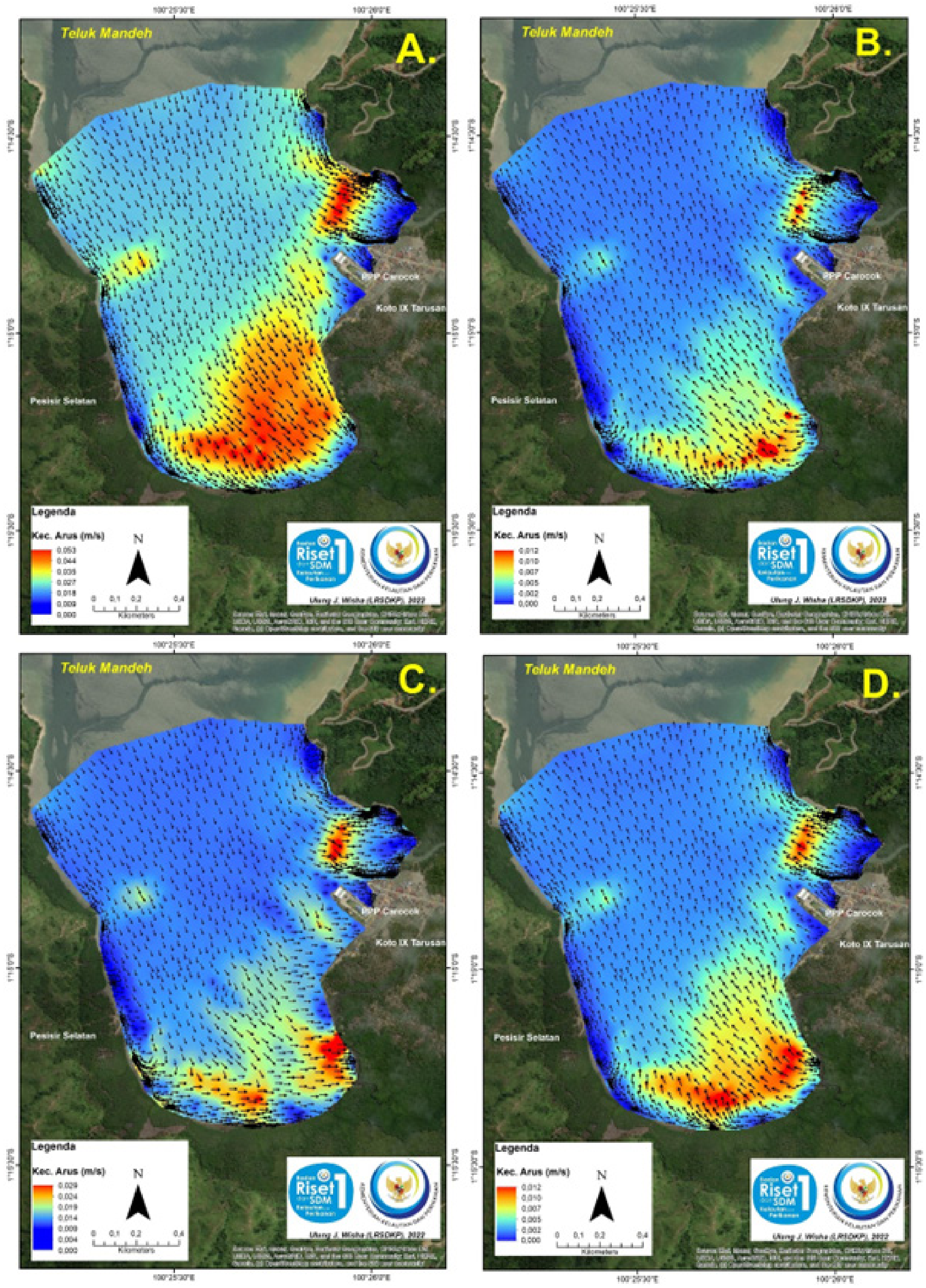

Figure 11. Tidal current pattern in the Carocok Bay during spring high tides (a), spring low tides (b), neap high tides (c), and neap low tides (d).

in other areas around the bay. The pool port dredging plan should consider the environmental changes and impacts that will occur. Based on the prediction that dredging does not have a significant positive impact, then the plan needs to be reviewed whether it is very crucial to do or not.

Risk Management Analysis

The process of sediment deposition in PPP Carocok waters can be estimated based on data from granulometric analysis and sediment statistics. Sediment grain size characteristics are used to interpret the distribution and mechanism of sediment transport and deposition in an area (Korwa *et al*., 2013). In general, the sediment type in the study area is dominated by fine grain size particles, namely silt and coarse (sand). Based on the grain size of the sediment, it is described that the water conditions at PPP Carocok when the sediment settles are influenced by the speed of a strong current characterized by coarse particle size, while a weak current characterizes the fine particle size.

Grain size indicates the magnitude/strength of the currents and waves acting in the depositional

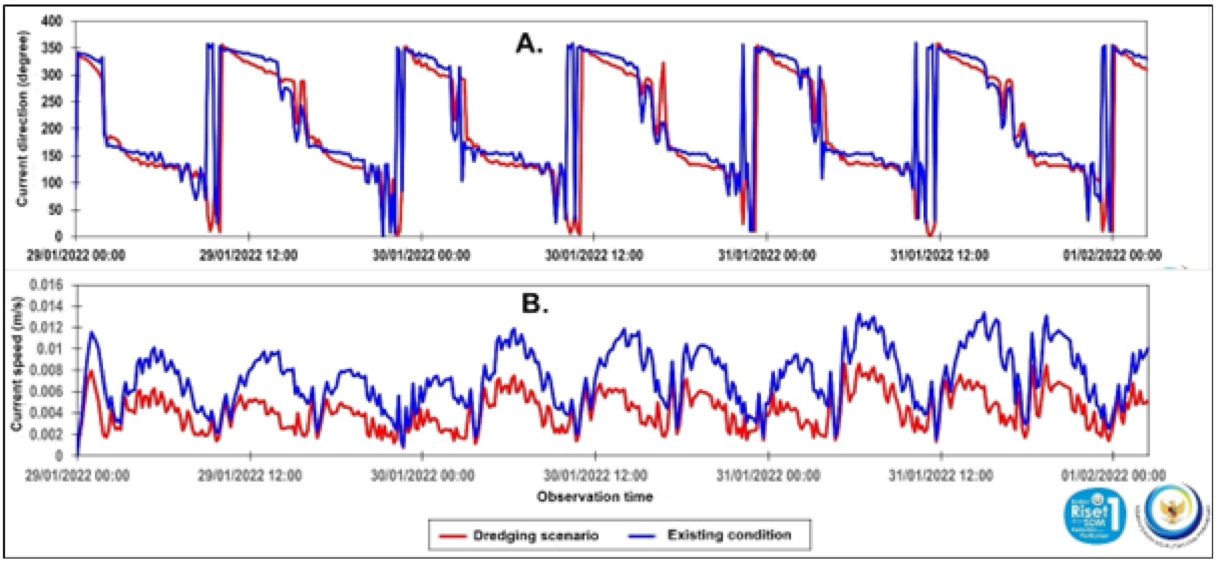

Figure 12. The current feature's alteration with dredging scenario, current direction (a) and current magnitude (b).

environment (Rifardi *et al*., 1998). The sorting value indicates the deposition type, the depositional currents' characteristics, and the deposition time speed (Solahuddin *et al*., 2006). Sediment scattered and deposited in the waters of the study area shows that the sediment has a short time to settle, as indicated by the high value of sorting (sorted poor to moderate), indicating a small uniformity of sediment grains.

The grain size of the sediment in the study area is in the couarse to a fine fraction, so it can be interpreted that the sediment transport mechanism is in the form of bedload and suspension (suspension). The bedload transport mechanism occurs in the coarse fraction through the movement of traction current transport in the form of rolling, sliding, creep, and saltation. Suspension load works to transport fine sediment (clay, silt to very fine sand) in the form of a suspension that is transported quite far and deep before finally settling with a weakened current velocity (Nugroho & Basit, 2014).

The condition of the sea waters of PPP Carocok is strongly influenced by the presence of river estuaries, where river mouths are strongly influenced by river discharge and tides. During tidal conditions, the energy of the river current that meets sea water will weaken in the estuary, so that river sediment is mixed with sea sediment with a coarse sediment fraction. However, when conditions recede, and the river current weakens in the estuary (around PPP Carocok), only the fine fraction of clay to silt size will be deposited.

In contrast to the western part of the study area, fine silt and sandy clay sediments tend to be deposited (Figure 13). The condition of the distribution of finer grain sizes in the east and west (around the PPP Carocok dredging site) has the potential to impact the erosion process in the area around the port (Bayhaqi & Dungga, 2015). In this case, erosion occurs around the river mouth and mangroves.

The coarse-sized sediments indicate that the currents and waves in this area are relatively strong. The coarse fraction is scattered in the eastern part of the study area around the PPP Carocok dredging plan (Figure 14). Generally, the coarse fraction (sand) is deposited in open areas associated with the high seas, while fine sediments are deposited in currents and waves with weak and calm energy, namely in the western part and closed morphology. In the western part, which is protected from the mouth of the bay and is not influenced by river mouths and the morphology of the depth is more profound than in the eastern part, clay-silt-sand sediments dominate it. This is because it is located further from the open ocean and protected from the influence of strong currents, and much organic matter and detritus carried by river water accumulate in these waters, significantly when the current weakens due to the presence of mangrove areas.

The PPP Caroock area has an extensive mangrove area. This condition reduces the speed of currents and waves so that only fine-sized fractions are deposited near the area (the western part). Differences in the density of mangrove vegetation will cause differences in current velocity due to the ability of mangrove roots to accumulate or trap sediment (Hidayat & Rozamuri, 2016). According to (Kennish, 2002), mangrove roots can accumulate sediment, trapping litter and playing a role in soil formation. Furthermore, Fitriana, (2014) added that the mangrove ecosystem has strong roots and can reduce the influence of waves and retain mud or fine sediment so that mangrove land can become

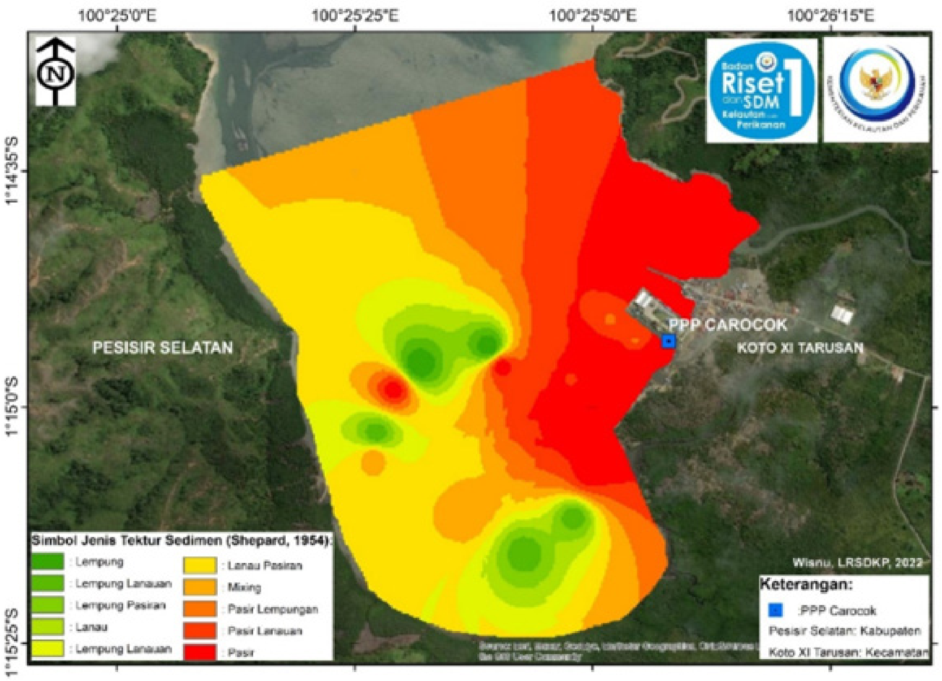

Figure 13. The current feature's alteration with dredging scenario, current direction (a) and current magnitude (b).

wider and accelerate the formation of soil or sediment deposits for mangroves to grow.

CONCLUSION

The bathymetry condition of the PPP Carocok port pool is included in the shallow water category (maximum 16m). The characteristics of the current pattern are highly dependent on tidal conditions as the primary driver of water mass transfer, and these conditions affect the sediment transport process in semi-enclosed areas. The highest current velocity is in the north and south of PPP Carocok. This can be the basis for anticipating the process of scouring the surrounding sediment. The domination of the bottom waters of the dredged site is sand, while the central and western parts of the bay are silty sand and mixed sediments. The bottom sediment statistics of the waters indicate that the bottom sediments of the PPP Carocok waters were deposited in a weak energy condition because they are in a protected environment. Energy fluctuations of sediment deposition occur in the middle and mouth of the bay. The integrated hydro-geo-oceanographic modeling interprets that the Carocok port pool's dredging activity does not significantly change the bathymetric conditions or environmental balance around the PPP Carocok. Research on water quality before and after dredging needs to be carried out to determine the risk of water quality degradation at PPP Carocok.

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