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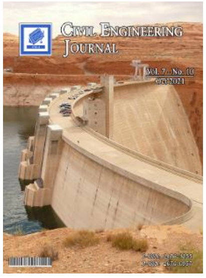

The Impact of Waves and Tidal Currents on the Sediment Transport at the Sea Port

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Abstract

Dredged sediments in estuarine and coastal waters can cause sediment transport and water pollutant in marine environment since the sediments are diffused to waterbodies under the influence of wave and flow regimes. As a result, it increases turbidity and enhances sediment deposition at dump sites. In Vietnam, few authors have studied and assessed the environmental impact of dumping and dredged materials to the port areas. This paper combines a coupled spectral wind-wave, hydrodynamic, and sediment transport models in order to study the impact of tide and wave conditions to regional sediment transport patterns at Vung Ang port area in Vietnam. The results for the currents and waves were evaluated and validated using field data. Wind and wave data for the calculated domain are extracted from the WAVEWATCH-III (wave data) and NOAA global climate change models (wind data). The calibration and validation of the MIKE 21/3 showed a high conformity between the observed and simulated data based on the mean absolute error (MAE), the RMSE-observation standard deviation ratio (RSR) and the Percent bias (PBIAS). The MIKE 21/3 sediment transport simulation results showed that the highest suspended sediment concentrations were 2.5-3 g/m^3 at the dredging position and the increased concentration along the transport route ranged from 1-1.5 g/m^3. The simulation results showed the bed level change of the simulated domain. We found that the suspended sediment diffusion area decreased with the respective depth: Layer 1 (65.5 km^2), Layer 2 (45.7 km^2), and Layer 3 (37.4 km^2). Therefore, the simulation results of the dredged materials activities were significantly affected by the wave and tidal regime on the sediment transport.

Keywords: Vung Ang Port; Dredged Materials; 2D/3D Modeling; Sediment Transport.

1. Introduction

All around the world, seaports play an important role in navigation and economic development of every country. Ports are basically a means of integration into the global economic system. However, sedimentation related to sediment transport and the disposal of sediments from maintenance dredging works has always been one of the main problems at the ports, which interfere with the movement of vessels. Dredging efforts have been carried out for many decades on various rivers around the world [1]. They have been carried out periodically and regularly in order to clear the vessel's channel, roadstead for the port areas [2]. Open water disposal of dredged sediment is a common practice adopted by the major ports in many countries [3-5]. Dredged mud is mainly treated in landfill, marine dumping, and filling. The environmental impact due to the dredging and dumping activities has been studied by scientists in recent

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times. Previous studies of dredge-spoil dumping have demonstrated a range of large to long-term impacts on benthic communities [6-8]. The environmental impact of geomorphic modifications related to dredging activities have been described on the literature [9-11]. However, few authors have evaluated the impact of dumping dredged sediments in the marine environment and estuaries [12-14]. Capturing current regimes and wave influences is important for understanding sediment transport pathways in the region and is relevant for coastal management. The majority of studies in this field focused on assessing the bottom water level and bedmud level changes, and turbidity of spreading and dissipating to pollution water quality within several hours after dredging [15-17]. They used numerical 2D and 3D models to simulate the sediment transport and evaluate the impact of dredging and dumping activities on the marine environment near the port [18-21]. In Vietnam, not many studies have assessed the dumping and dredged materials at the port areas [10]. Because no publications have been carried out at Son Duong - Vung Ang Port (Ha Tinh province, Vietnam) in evaluating the impact of sediment transport from dredging activities, we, therefore, selected it as our case study.

Son Duong - Vung Ang Port is a national general port, a regional hub (class I port) of Vietnam, located in Vung Ang town, Ky Anh town, Ha Tinh province. It is only 9 km from National Highway 1A, only 9 km away and about 230 km far away from Vietnam - Laos border (Mu Gia pass). Currently, the Vung Ang port has two main wharf areas that have started to be put into operation. They are Vung Ang general port area and the port area for transporting coal to serve Vung Ang thermal power plants. Phase 1 construction of the Vung Ang general port started in 1999 and was completed in 2001. It is 185.5 m long, 298 m wide, and 11 m deep with the capable of receiving ships up to 30 thousand DWT. Phase 2 started in 2006 and it will be able to increase the capacity of the Vung Ang port up to 50,000 DWT (Figure 1) [22].

Instead of using 2D and 3D models, this study used a combination of 3 models in the 2D semi-distribution model MIKE 21/3 software including spectral wind-wave model (SW), hydraulic model (HD), and sediment transport (ST). They are based on field data, calibration and validation for realistic assessment of the physical process and fate of the sediments. Numerical simulation of the sediment dispersion was carried out the bed load movement of the dredged material near Vung Ang port. The aims of this study were (1) to simulate the wind-wave propagation from offshore to the study area, (2) to validate the wave height in spectral wind-wave model, (3) to validate and calibrate the hydraulics HD model, (4) to simulate the sediment transport (ST) process model.

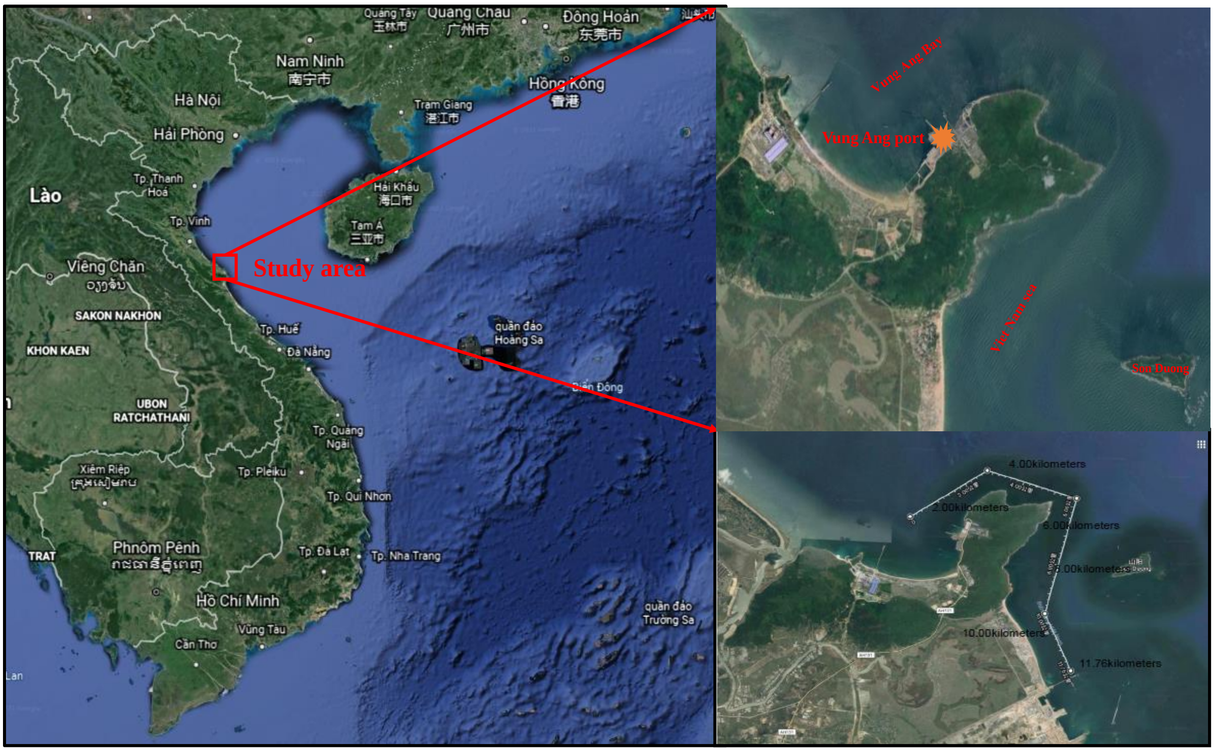

Figure 1. Study area

2. Materials and Methods

The study used a combination of spectral wind-wave, hydrodynamic, and sediment transport models in MIKE 21 software to reproduce the bed load movement of the dredged material near Vung Ang port. The flow diagram of this study methodology is presented in Figure 2.

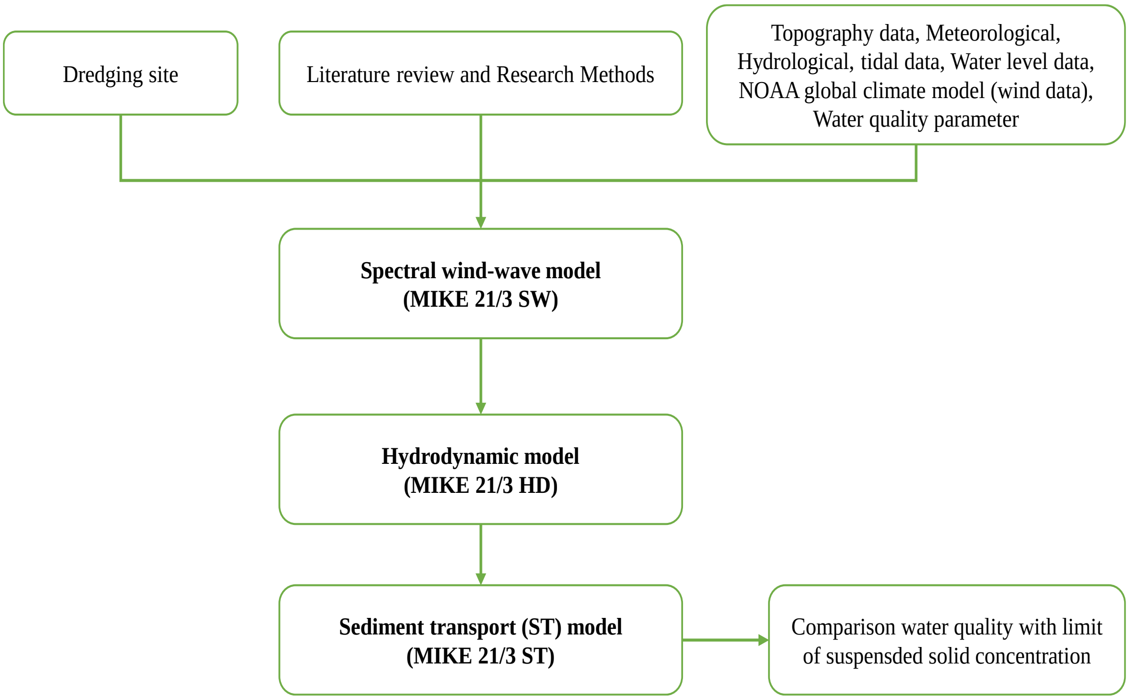

Figure 2. Flowchart of the study

2.1. Description of Study Area

The dredging process is divided into two phases: (1) Phase 1 (from Notice-to-Proceed (NTP) to NTP + 4 = 4 months): the harbor area has a berth length of 250 m and the width of 23.5 m wide; the wharf is 1.82km. The water area covers in front of the wharf, channel and whirlpool. The total volume to be dredged is 2.4 million m^3 but its volume in this phase is 1.4 million m^3. In phase 1, the dredged material is sucked and pumped directly to the storage yard for leveling by floating pipeline system. Therefore, there is no need to assess the impact of the increased amount of suspended sediment on the flow of the dredging construction area; (2) Phase 2 (from NTP+14 to NTP+28 = 15 months): discharge path of cooling water is about 1.8 km. The cooling water intake is 500 m in length. The dredging volume is about 0.4 million m^3. It is estimated that 0.3 million m^3 will be deposited. The total volume of dredging in phase 2 is, therefore, 1.7 million m^3 (including the remaining 1.0 million m^3 of the volume in phase 1). They are transported by barge to pump and dump into the dredged material storage yard ashore (Figure 1).

Bucket-type dredging equipment (8 m^3) is applied to implement dredging and transferring to the transport barge (1000 m^3 barge). It will be used to transport the dredged material to the proposed storage area 12 km away from the dredged area. The dredged material will be pumped to the onshore storage area by a sandblaster with a pipeline of 2.65 km long. The phase 2 uses a crank mesh to minimize the impact of sediment spreading. Specifically, the using crank mesh method reduces the impact of sediment transport when using ships and the risk of increasing turbidity.

2.2. Description of Model

The MIKE 21/3 model is based on a flexible grid approach and has been developed for applications in marine, coastal and estuarine environments. The model is based on numerical solving of three-dimensional Reynolds averaged Navier-Stokes equations with the Boussinesq and hydrostatic pressure. The equations of model system includes continuity equations, momentum, temperature, salinity and density, and it is closed by a entangled diagram [23].

- Continuity equation:

$$\frac{\partial h}{\partial t}+\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=S \tag{1}$$

- The two equations of momentum for the two components x and y, respectively, are:

$$\frac{\partial u}{\partial t}+\frac{\partial u^2}{\partial x}+\frac{\partial vu}{\partial y}+\frac{\partial wu}{\partial z}=fv-g\frac{\partial \eta}{\partial x}-\frac{1}{\rho_o}\frac{\partial p_a}{\partial x}-\frac{g}{\rho_o}\int_z^\eta \frac{\partial \rho}{\partial x}dz-\frac{1}{\rho_o h}\left(\frac{\partial s_{xx}}{\partial x}+\frac{\partial s_{xy}}{\partial y}\right)+F_u+\frac{\partial}{\partial z}\left(\upsilon_t\frac{\partial u}{\partial z}\right)+u_s S \tag{2}$$

$$\frac{\partial v}{\partial t}+\frac{\partial v^2}{\partial y}+\frac{\partial uv}{\partial x}+\frac{\partial wv}{\partial z}=-fu-g\frac{\partial \eta}{\partial y}-\frac{1}{\rho_o}\frac{\partial p_a}{\partial y}-\frac{g}{\rho_o}\int_z^{\eta}\frac{\partial \rho}{\partial y}dz-\frac{1}{\rho_o h}\left(\frac{\partial s_{yx}}{\partial x}+\frac{\partial s_{yy}}{\partial y}\right)+F_v+\frac{\partial}{\partial z}\left(\upsilon_t\frac{\partial u}{\partial z}\right)+v_s S \tag{3}$$

where t is the time; x, y and z are the Cartesian coordinates; η is the surface elevation; d is the still water depth; $h=\eta+d$ is the total water depth; u,v and w are the velocity components in the x, y and z direction; f = 2ΩsinΦ where t is the time; x, y, z are directions in Cartesian coordinate system; is the surface water level; d is the calm water depth; h=η+d is the total depth of the water column; u, v, w are the velocity components in the x, y, z directions; f = 2ΩsinΦ is the Coriolis parameter (Ω is the angular rate of velocity and Φ is the geographic latitude); g is the gravitational acceleration; ρ is the density of water; s_{xx}, s_{xy}, s_{yx} and s_{yy} are components of the radiation stress tensor; υ_t is the vertical turbulence (or eddy) viscosity; p_a is the atmospheric pressure; ρ_o is the reference density of water; S is the magnitude of the discharge due to point source and (u_s,v_s) is the velocity by which the water is discharge into the ambient water [23].

- Transport equations for salt and temperature

The transport of temperature, T, and salinity, s, follow the general transport-diffusion equations as:

$$\frac{\partial T}{\partial t}+\frac{\partial uT}{\partial x}+\frac{\partial vT}{\partial y}+\frac{\partial wT}{\partial y}=F_T+\frac{\partial}{\partial z}\left(D_\upsilon\frac{\partial T}{\partial z}\right)+\widehat{H}+T_s S \tag{4}$$

$$\frac{\partial s}{\partial t}+\frac{\partial us}{\partial x}+\frac{\partial vs}{\partial y}+\frac{\partial ws}{\partial y}=F_s+\frac{\partial}{\partial z}\left(D_\upsilon\frac{\partial s}{\partial z}\right)+\widehat{H}+s_s S \tag{5}$$

where D_υ is the vertical turbulent (eddy) diffusion coefficient. $\widehat{H}$ is a source term due to heat exchange with the atmosphere. T_s and s_s are the temperature and the salinity of the source. F are the horizontal diffusion terms defined by.

- Transport equation for a scalar quantity

The conservation equation for a scalar quantity is given by:

$$\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial vC}{\partial y}+\frac{\partial wC}{\partial z}=F_C+\frac{\partial}{\partial z}\left(D_\upsilon\frac{\partial C}{\partial z}\right)-k_P C+C_s S \tag{6}$$

where C is the concentration of the scalar quantity; k_P is the linear decay rate of the scalar quantity; C_S is the concentration of the scalar quantity at the source and D_v is the vertical diffusion coefficient. F_C is the horizontal diffusion term defined by:

$$F_C=\left[\frac{\partial}{\partial x}\left(D_h\frac{\partial}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_h\frac{\partial}{\partial y}\right)\right]C \tag{7}$$

where D_h is the horizontal diffusion coefficient.

- Simulation of sediment transport

The calculation formula used: SSd = SSg × (1-r)

where SSd is the emission discharge of SS Day (tons/ day); SSg is the exhaust emissions; r is the loss rate.

$r = v_c/v_o$

where Vc is the settling speed of lightning: 0.43; V_o is the speed of water movement: 0.6 (m/day).

$SSg = D_v \times \rho_t \times C_m/10C$

where Dv is the dredged volume (m^3/day); ρ_t is the wet density; C_m is the clay component: 20%.

$D_v = C_p \times G_c/100$

where C_p is the dredging capacity (m^3/day); G_c is the clay particle composition: 50%.

$$\rho_s=\frac{\left(1+\frac{\omega}{100}\right)\rho_w}{\frac{\rho_w}{\rho_s}+\frac{\omega}{S}}$$

where ω is the water composition: 89%; ρ_w is the water density: 1.02 (g/cm^3); ρ_s is the density of particles: 2.68; S is the saturation temperature.

2.3. Model Settings

2.3.1. Hydrodynamic (HD) Model

The computation domain was built with a large grid area from 17°55'N to 18°55'N and 105°40'E to 107°00'E and a small grid area from 18°00'N to 18°10'N and 106°07'E to 106°33'E. The large grid area was built to simulate deep water waves and then to propagate the waves to the study area by the use of MIKE 21 SW wave model. It covers the entire route of transporting dredged sediment, from the dredging area to the receiving location of the dredged material. A grid combines unstructured grid and square grid, in which unstructured mesh size is from 50 to 1000 m and a square grid is established for the area along the sediment transport route from the dredging site to the dumping site with a grid size of 10×10 m (Figure 3).

The boundaries of the study area include: (1) 01 river boundary: the boundary is the river cross-section of Quyen and Vinh rivers; and (2) 03 sea borders: the East Sea, the South Sea and the North Sea. The water layers are divided vertically as follows: the 1st floor from undersea level to 2 m (undersea level); the 2nd floor from 2 m to 4 m; and the 3rd floor over 4 m. The vertical division of the water layer is of great importance to calculate the hydrodynamics and diffusion of suspended sediments based on the topography and depth of the study area. The effect of dividing the upper water layer is greater than others because this layer has a higher flow velocity.

a) Hydrometeorological conditions:

Wind regime: Wind is a factor that disperses pollutants into the air environment, especially during the transportation of raw materials. The extent of pollutant dispersion depends on wind speed and direction. Ha Tinh province is affected by the pronounced monsoon circulation, including the winter monsoon and the summer monsoon. The characteristics of these monsoons are described as follows:

- Winter monsoon: During December, January, February with the prevailing wind direction is the northeast. However, from late March onwards, the wind direction gradually shifts from the northeast to the east.
- Summer monsoon: The summer monsoon usually starts from mid-May and becomes prevalent in June and July. The prevailing wind direction is the southwest and the south.

Hydrological regime: Cua Khau river mouth is formed by the confluence of two rivers, namely Quyen River and Vinh River. The hydrological characteristics of these two rivers are described in Table 1.

Table 1. The hydrological characteristics of Quyen and Vinh rivers

	Quyen River	Vinh River
	The section flowing to Cua Khau area	Confluent from many branches to form a large river
Drainage area	1.2 km^2	0.9 km^2
Length	17.67 km (only for the section flowing to Cua Khau area)	22.87 km
Flow rate	1.67 m/s	1.5 m/s
Total discharge	4,800,000 m^3	about 3,600,000 m^3
Sediment composition on the seabed	Mud (70%) and impurities (30%)	Mud (70%) and impurities (30%)

Oceanographic regime: The northwest wind direction accounts for 5.92% in the year based on the speed levels of Hon Ngu station but it causes 0.53% of wave height (approximately lasts for 2 days or 8 times) with the height ≥ 0.76 m. The tidal regime in Vung Ang and Mui Ron areas is mainly diurnal tide regime.

- Amplitude of fluctuation: The wave was transmitted from the deep-water wave simulation model in the northern, eastern and southern edges of the study area.
- Tidal boundary: It was transmitted and simulated by Prediction Tide Height tool in the study area.
- Wind boundary: Wind was extracted from the model of National Oceanic and Atmospheric Administration (NOAA).
- The time for model stabilization: It was 30 days, until the river flow and the density of sea water (affected by the thermal balance between the sea surface and air) was stable. The data during the last 24 hours was used for analysis. The sediment model would be set up to run for 24 hours after the hydrodynamic model was completed its run.
- Simulation time: 17 consecutive months, of which 15 months for dredging and transporting sediment to the landfill, one month before dredging and one month after the end of the dredging process.

Other parameters: viscous coefficient, roughness coefficient and others are inputted into relevant models through calibration and validation processes.

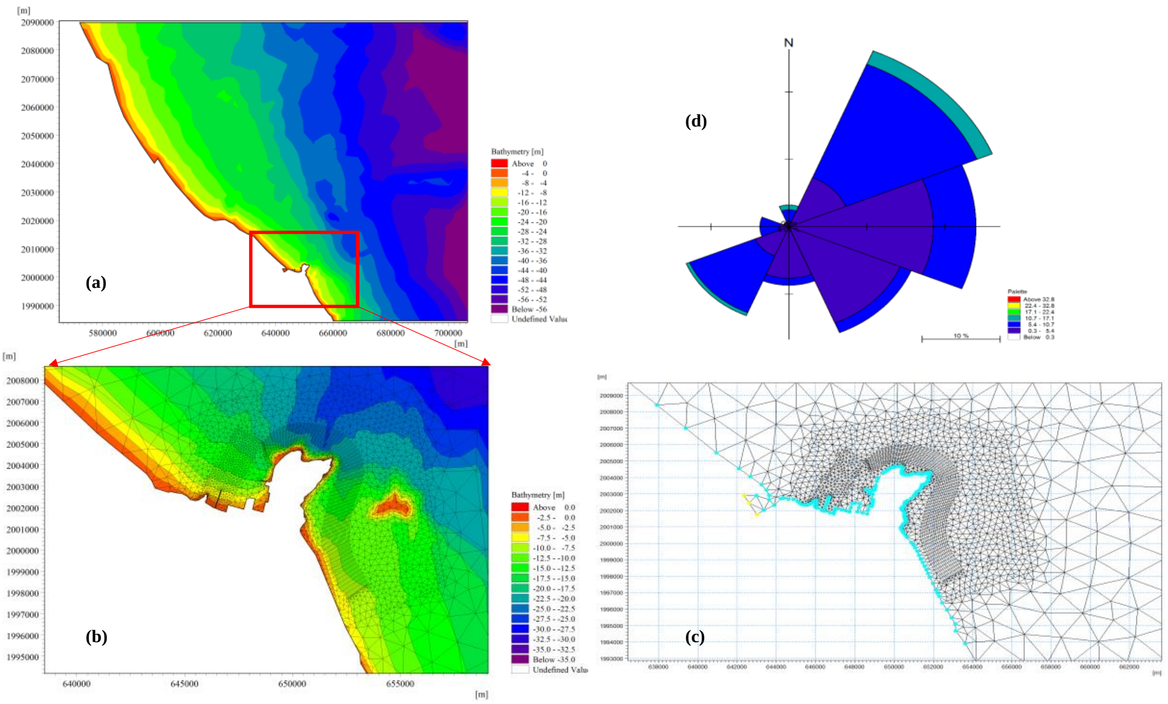

Figure 3. (a) Topography of study area; (b) The mesh of deep-water wave; (c) Mesh of study site; (d) Wind rose in the study area

2.3.2. Diffusion Model of Suspended Sediment

a) Specific conditions for calculation

- Computational domain, meshing and layering vertical division of aquifers were similar to those in the hydrodynamic models.
- Initial condition and boundary values of suspended sediment concentration was calculated as 0 mg/l to evaluate the diffusion range and content of suspended sediment caused by construction activities.
- Diffusion coefficient used the same horizontal and vertical turbulent diffusion coefficients in the hydrodynamic model.
- Grain size distribution of dredged soils: shown in Figure 4 (the preliminary assessment of dredged materials by the research of Vung Ang II - Thermal Power Plant).

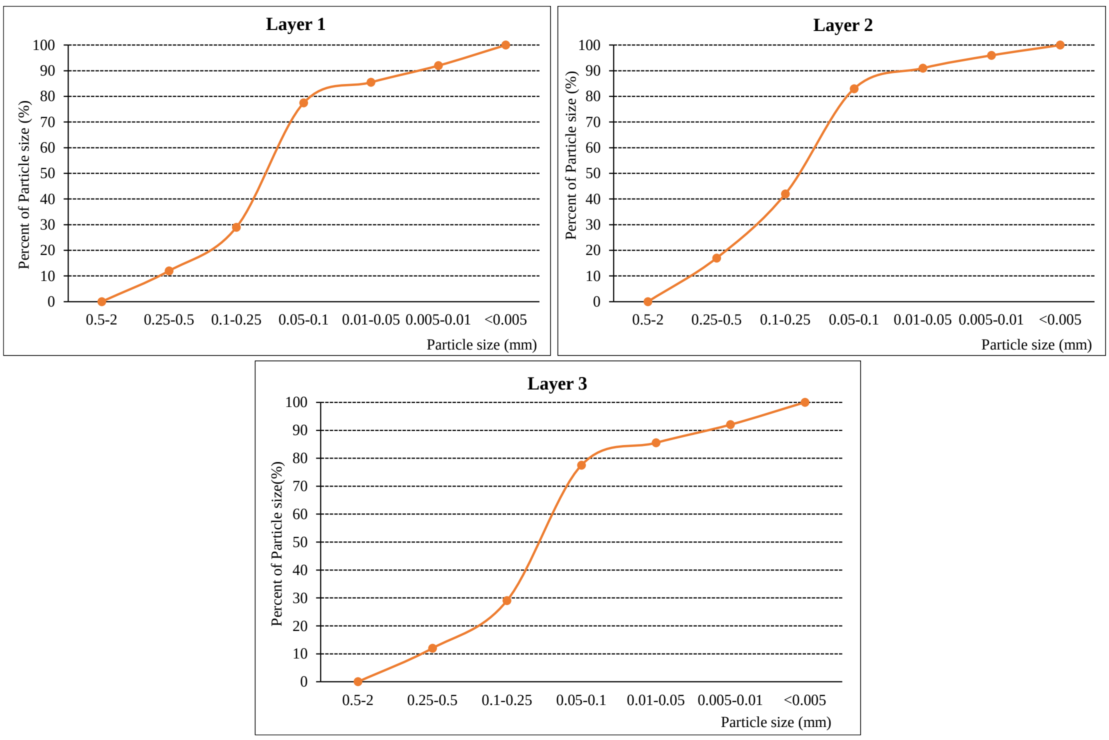

Figure 4. Particle size distribution flowchart of dredged material according to soil layers 1-3

b) Establishment of sediment model

The diffusion depends on the construction method, for example, dredging by vessel, grab dredge, or dumping by barge; it is also affected by the productivity of dredging vessel and grain size of the dredged soil. The document "Guidance on the prediction of sediment diffusion" provided the suitable amount of diffused sand/ mud for each method obtained from the results of experimental construction in Japan. The study used the average value of the sediment mentioned in this Guidance for the model because the stated grain size was not the same size of the dredged soil from the study area. It was used to calculate the amount of sediment generated each day as input data for the sediment model. Table 2 summarizes the amount of sediment diffused and the dredging output per day by each construction method.

Table 2. Amount of Sediment diffused [24]

Construction method		Types of machines	Based on the Guidance		Calculated discharge unit (ton/m^3×10^{-3})	Discharge unit per machine (m^3/day/ machine)	Numbers of machines	Total discharge (m^3/day)	Discharge unit per day (ton/day)	Operating time (hour)
			Productivity (m^3)	Discharge unit (ton/m^3×10^{-3})						
a	Dredging	Grab dredge (GD)	08	5.32	6.46	3800	01	3800	24.531	16
b	Dumping	Barge (HB)	1000	31.58	44.52	950	04	3800	169.176	16

c) Evaluation criteria

Currently, there are not many standards/ guidelines on assessing the impact of construction activities (or human impact) on the environment. This study considered Japanese and Canadian guidelines on water quality standards for the protection of aquatic resources and the aquatic environment [25-27]. Table 3 summarizes the limits for suspended sediment content in water.

Table 3. Limits on suspended sediment content in water

Title of the guideline	Limits on suspended sediment content
Japan's water quality standard for the protection of aquatic resources (Publication 2005) [25]	Activities which affect the terrain but cannot lead to increases in the suspended sediment above 2 mg/l, compared to the current turbidity.
Canadian water quality guidelines to protect aquatic environments [26]	Activities which affect the terrain but cannot lead to increases in the suspended sediment above 5 mg/l, compared to the current turbidity (for a long period).
According to the parameters of water quality in QCVN 10-MT:2015/BTNMT [27]	Concentrations of total suspended solids for aquaculture and aquatic conservation areas; beaches, water sports. The limit value is 50 mg/l.

It can be seen that the Japanese standard (2 mg/l) is higher than that of Canada (5 mg/l). Therefore, this study applied the Japanese one to examine marine organisms which are sensitive to water turbidity, particularly hard coral and applied the Canadian one to examine other marine life. According to the parameters value of coastal water quality in QCVN 10-MT:2015/BTNMT [27], the concentration of total suspended solids in aquaculture and aquatic conservation areas, swimming area or water sports is limited to 50 mg/l. As there are no aquatic conservation areas in the study area, therefore, the limits of suspended solid concentration for Vietnam and Canada were used to assess the impact of dredging activities on the surrounding waters.

3. Results and Discussion

3.1. Calibration and Validation of MIKE 21/3 Model

The MIKE 21/3 model was established for the calculated domain with the hydrometeorological and sediment parameters, only the wind and wave data for the whole calculated area were extracted from the WAVEWATCH-III (wave data) and NOAA global climate change models (wind data).

3.1.1. Calibration and Validation of the HD Model

The hydrodynamic (HD) model was setup for the study area including the estuary and the coastal area. The model was calibrated and validated using the water level data at Con Co station in 2016 and 2017 and the observed data of flow velocity at some locations to ensure that the hydrodynamic model was suitable for the study area. The results of the calibration and verification of the HD model are presented in Figures 5a-5b. The results showed that there was a high degree of conformity in both phase and amplitude of the water level at Con Co station. The evaluation of simulation results was based on the mean absolute error (MAE), the RMSE-observation standard deviation ratio (RSR) and the Percent bias (PBIAS) also known as the coefficient of model efficiency (Nash-Sutcliffe). MAE value ranged from 5.89 to 8.75; The RSR value ranged from 0.24 to 0.37; and PBIAS value ranged from -2.96 to -2.10% (Figures 5a and 5b).

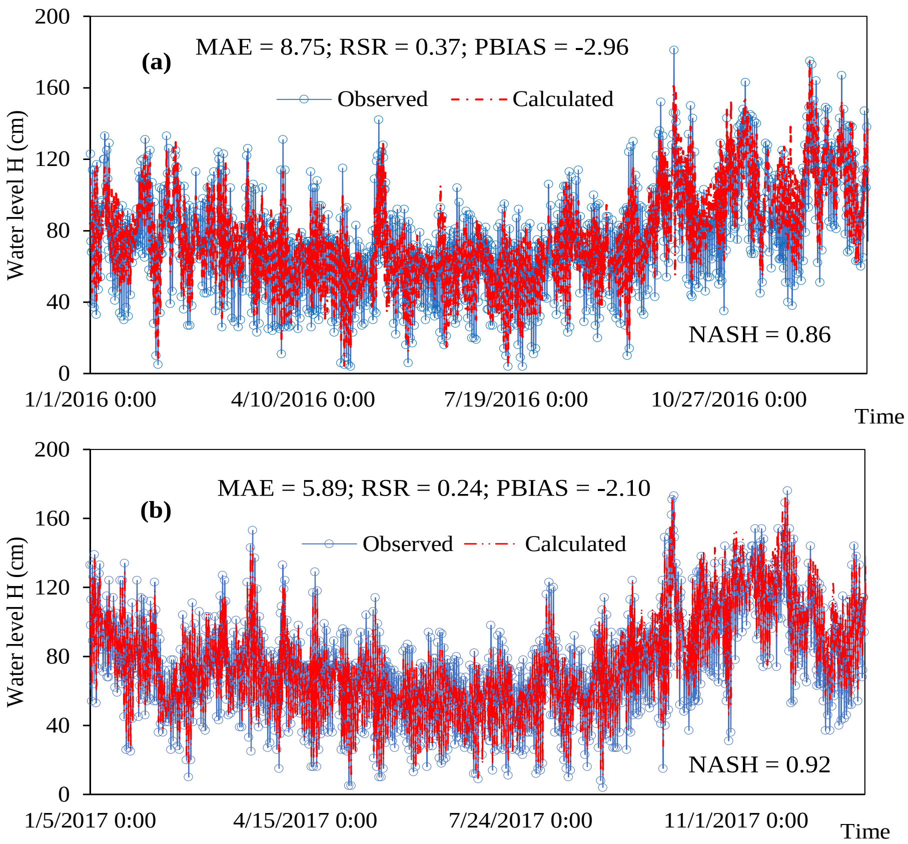

Figure 5. (a) The calibration results of water level in 2016; (b) The validation results of water level in 2017

Figure 6. Location of flow rate measurement at the study site

Table 4. The evaluation results of measured and calculated current velocity error

Current velocity (m/s)	Location 1	Location 2	Location 3	Location 4	Location 5
Observed	0.42	0.436	0.457	0.482	0.405
Calculated	0.345	0.385	0.404	0.415	0.354
Error	0.075	0.051	0.053	0.067	0.051
PBIAS	18%	12%	12%	14%	13%

This study evaluated the flow rate at 5 positions at the study site (Figure 6). Error and PBIAS were used to evaluate the comparison of observed and simulated current velocity at these test positions. Error values range from 0.051 to 0.075; PBIAS values range from 12 to 18% (Table 4).

The MIKE 21/3 model allows the simultaneous operation of wave and sediment models. The hydraulic parameters of the model MIKE 21/3 for the study area (Table 5) shows that the calibration and validation results are quite good (Nash-Sutcliffe ranged from 0.86 to 0.92, PBIAS < 25%). Therefore, it is possible to use the parameters to simulate for the study area.

Table 5. The parameters of the hydrodynamic MIKE 21/3 HD model

No.	Parameters	Value
1	Weight	Barotropic
2	Viscosity coefficient (Eddy)	0.302
3	Roughness coefficient (Manning)	0.045 m
4	Shallow water wave equation	
4.1	Minimum time	0.01 (s)
4.2	Maximum time	30 (s)
4.3	Standard CFL	0.8

3.1.2. The Validation Results of Wave Model

The wave data was taken from the WAVEWATCH III data to test the parameter set of the model. The validation results show that there is a similarity in wave height and wave phase between the measured data and the simulated results, hence the wave model parameters can be used to simulate the study area (Figure 7). The wave model parameters used in the sediment transport model are shown in Table 6.

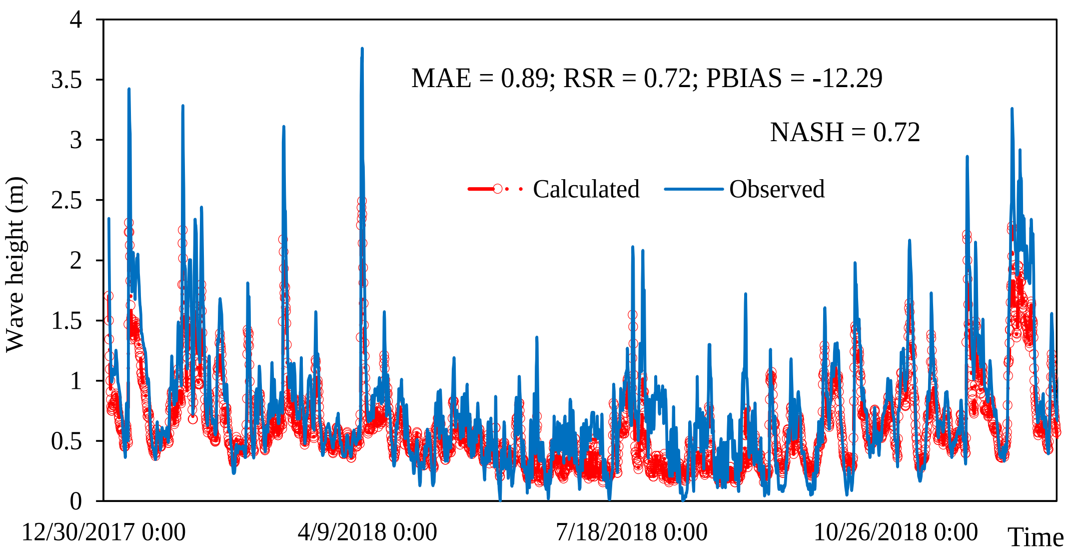

Figure 7. The validation results of wave height

Table 6. The parameter of spectral wind-wave model (MIKE 21/3 SW)

No.	Parameter	Value
1	Number of directions	16
2	Bottom Friction	0.045
3	White Capping	Cdis = 4.5, Delta = 0.45
4	Wind Forcing	Varying in time, constant in domain
5	Energy transfer	0.25
6	Wave Breaking	0.75
7	Initial Conditions	Type of formulas JONSWAP fetch growth expression
8	Boundary Conditions	Choosing two liquid boundaries where there was an exchange of wave energy between the inside and outside of the calculated region

3.1.3. The Validation Results of Sediment Transport (ST) Model

After the establishment of the sediment model for the study area, the real value suspended sediment concentration was used to verify the suitability of simulated sand model for the area (Figure 8). It can be seen that there is a correlation between the observed and simulated process. The parameters of the sediment model are presented in Table 7.

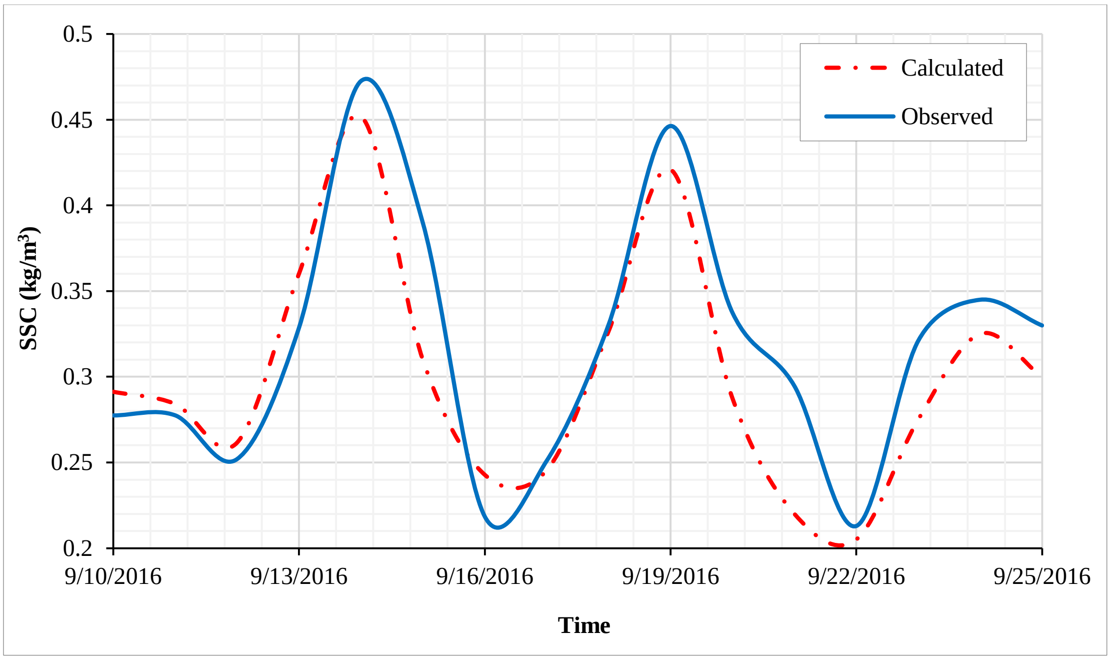

Figure 8. The validation results of sediment transport in model

Table 7. The parameter of sediment transport in MIKE 21/3 ST

Parameter	Value
Time step	720s
Bottom sediments	0.90
Sedimentation of suspended sediments	0.90
Empty factor	0.65
Grain diameter	0.25 mm
Relative density	2.65
Bottom resistance	43 $m^{1/3}/s$
Dispersion coefficient	0.90
Biggest change in the bottom	0.8 m/day
Initial conditions	The concentration of suspended sediment is 0
Thickness of layer 1	2 m
Thickness of layer 2	2 m
Thickness of layer 3	2 m

After testing the hydraulic model, the wave and sediment models in the MIKE 21/3 model, a set of parameters for the study area were established. This set was used for simulating the data of 2018. The simulation results of the models are showed in section 3.2.

3.2. The Simulation Results of the Wave Field

The wave simulation results show that the typical wave height in the study area ranges from 0.15 to 0.6 m from the coastal area to the 10 km offshore area (Figure 9). The dominant wave direction in the simulation area is the Northeast. The study area is a coastal area so the wave regime in the surrounding sea area will affect the propagation of sediment from the dredging process of the study area.

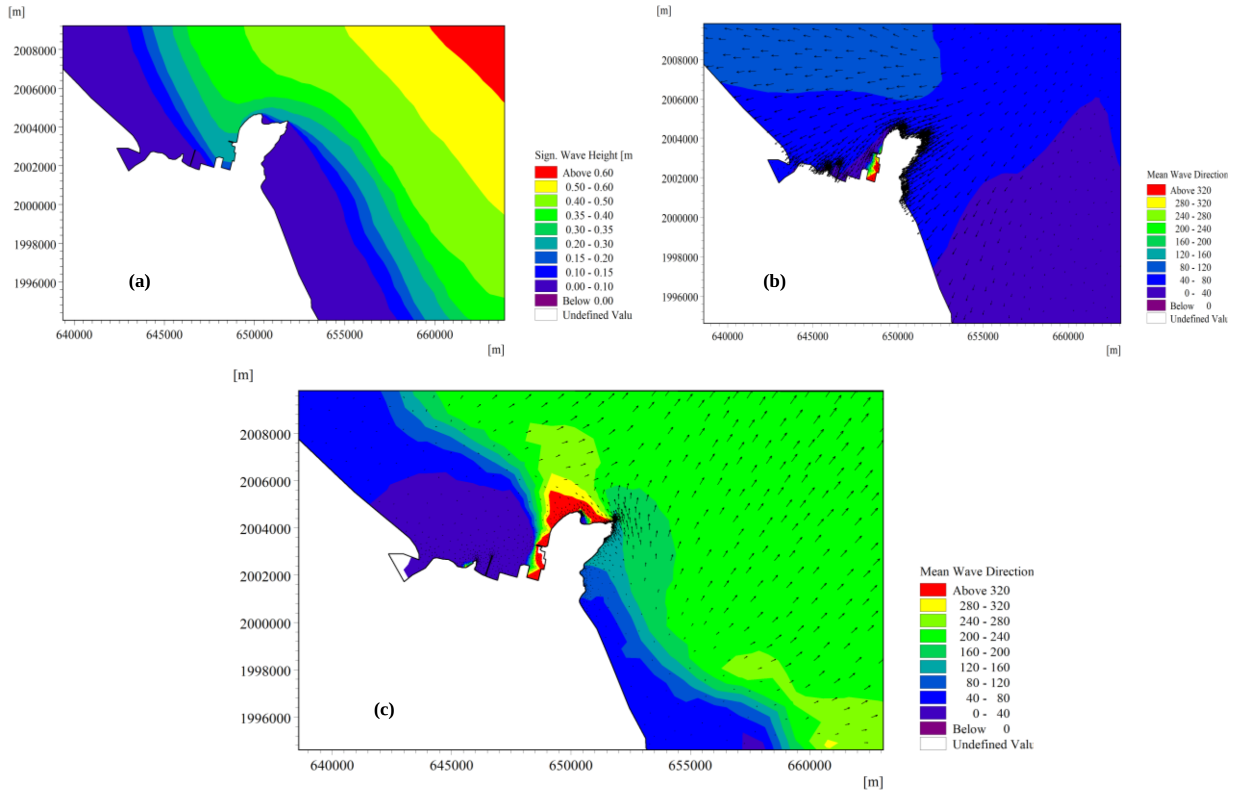

Figure 9. (a) Simulation results of characteristic wave height; (b) Simulation results of average wave direction (February); (c) simulation results of average wave direction (June)

3.3. The Results of Hydrodynamic (HD) Model

The simulation results of the HD model for the study area show the water depth ranging from 10 to 22 m, and tidal flow velocity ranging from 0.04 to 0.2 m/s (Figure 10a-10d). It can be seen that hydraulic factors including flow rate and sea depth have the most influence on the sediment transport process. The results of hydraulic simulations combined with simulation model results of the process of spreading sediment from dredging activities will lead to the conclusions in next section. With the increase of flow velocity, different bottom forms appear. When the flow velocity is weak and the sediment is relatively fine, sand ripples will form.

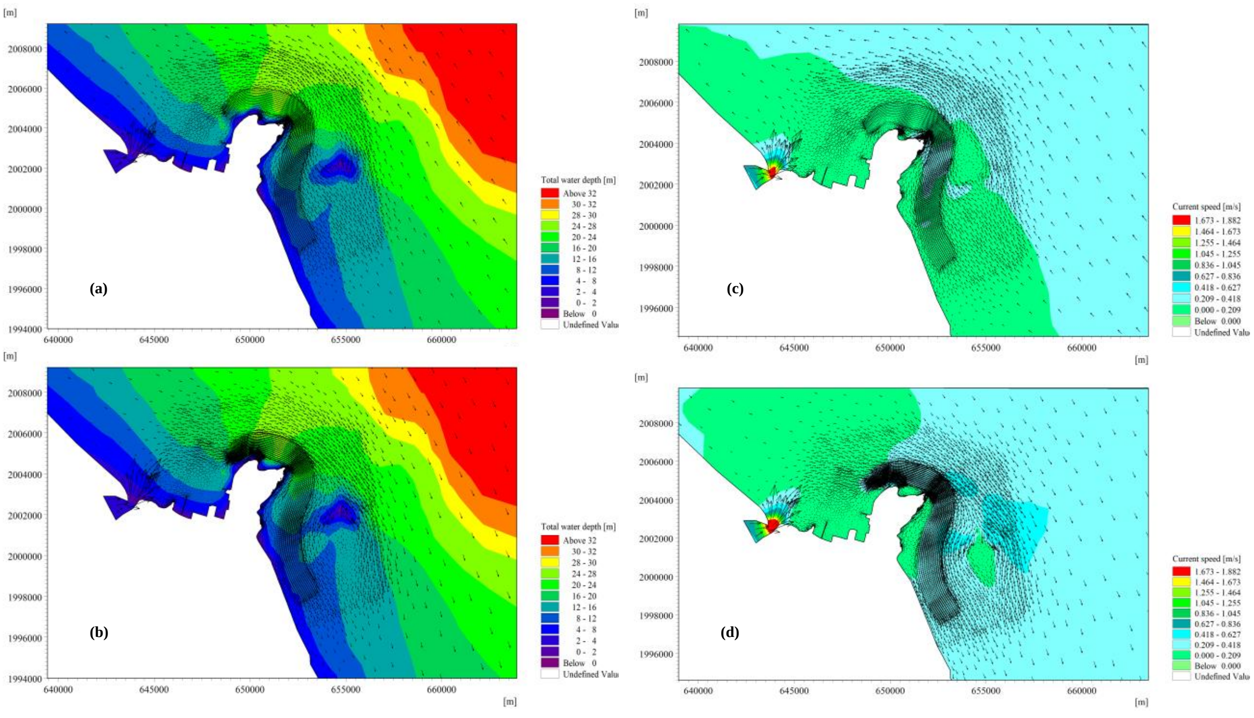

Figure 10. (a, b) The distribution of tidal current at high tide and low tide; (c, d) Tidal current velocity in the study area at high tide and low tide

The dredging area is the coastal area of Ha Tinh, therefore the sediment transport is mainly influenced by the flow regime as well as the wave and wind regime along the coast. MIKE 21/3 integrated model allows to run three models of hydraulics, waves and sediments at the same time; therefore, the simulation results of the model are a combination of the interaction between hydrodynamic factors and diffusion propagation in water. The detailed simulation results of the sediment transport model are showed in section 3.4.

3.4. The Results of Sediment Transport Model

The information analyzed from sand and mud model in the report is simulated with the peak wind direction and wind speed in three consecutive hours in 17 months of the whole dredging process. The results of sediment concentration in the Figure 11a-11c show the trend of spreading suspended sediment through the water. It can be seen that the highest concentrations of suspended sediment are 2.5-3 g/m^3 at the dredging site and the concentration along the transport route increases from 1-1.5 g/m^3.

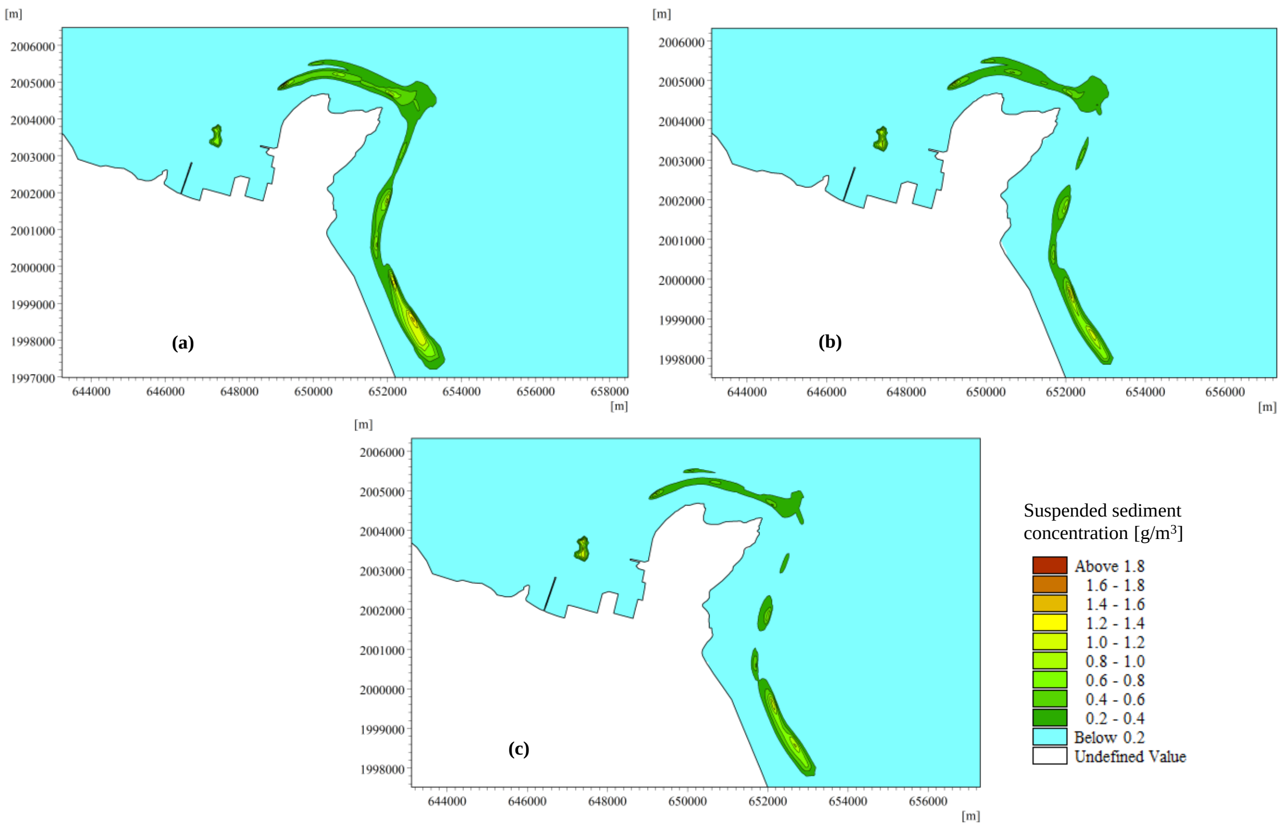

Figure 11. Range of suspended sediment diffusion: (a) 1st water layer; (b) 2nd layer of water; (c) 3rd layer of water

The calculation results of the spreading range of suspended sediment concentrations are presented in Table 8. According to the statistical results, the area of suspended sediment dispersion in layers when dredging construction activities took place indicates that the area of suspended sediment diffusion decreases with the corresponding depth: Layer 1 (65.5 km^2), Layer 2 (45.7 km^2), Layer 3 (37.4 km^2).

Table 8. Statistics of suspended sediment dispersed during dredging process

No.	Layer	Diffusion area suspended sediment (km^2)
1	Layer 1	65.5
2	Layer 2	45.7
3	Layer 3	37.4

To show the results of the suspended sediment dispersed through the water layers, the research examined the results of suspended sediment at some specific locations around the dredging area in Figure 12.

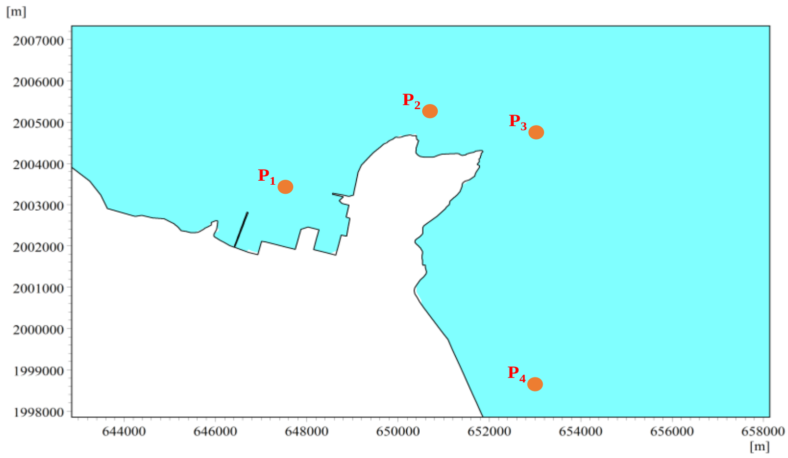

Figure 12. Locations of test suspended sediment

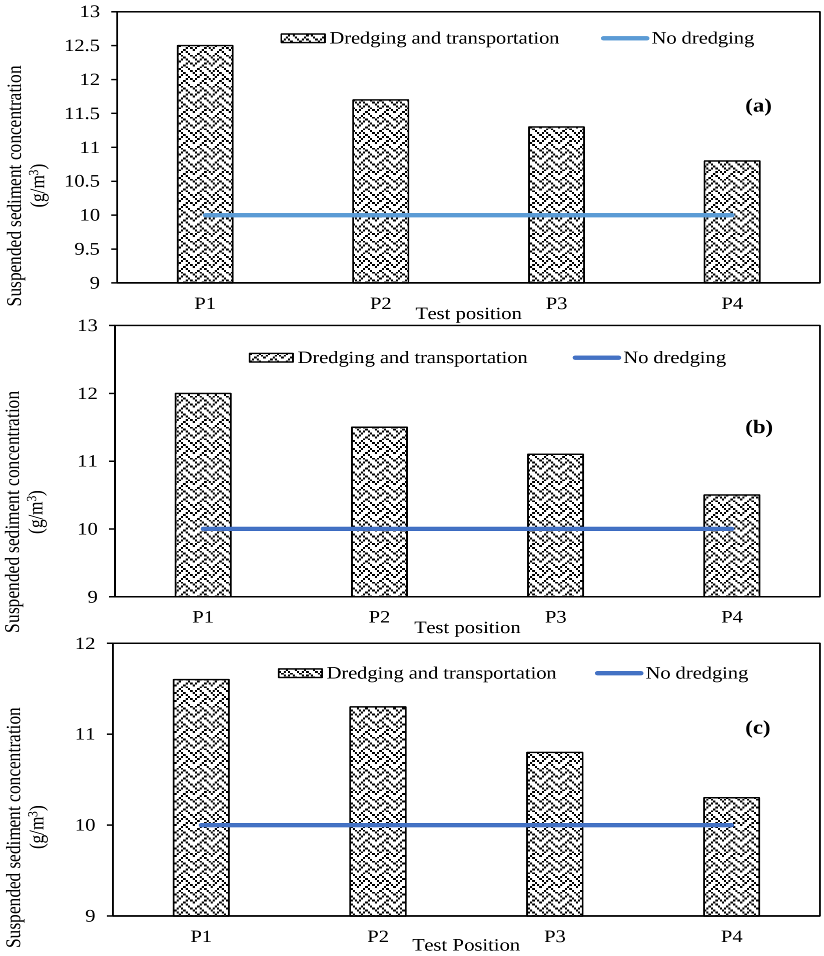

Figure 13. (a) Suspended sediment concentration increases in water - 1st water layer; (b) Increased concentration of suspended sediment in the water - 2nd layer of water; (c) Increased concentration of suspended sediment in water - 3rd layer of water

In the current condition, when dredging has not been constructed, the initial suspended sediment concentration in layers included in the model is 10 g/m^3 for three simulated water layers. The calculation results of the increased concentration of suspended sediment in the model's water source, an increase in sediment concentration at 4 test points was built (Figure 13). The largest increase in suspended sediment concentration can be seen at site P1, which is normal because P1 was the test site at the dredging area of sedimentary materials; P4 had the slightest increase because P4 is the point at the end of the barge transporting the dredged material to the dumping area. Figure 13 shows the increased suspended sediment concentration at the test sites in the 17th month simulation period. It can be seen that at the end of the dredging and transporting process, the concentration of suspended sediment gradually decreases, at P1 it only fluctuates from 1-1.2 g/m^3 and at P4 it is only 0.02-0.08 g/m^3. The model MIKE 21/3 ST also shows the changes in the bed level of the study area. Figure 14 represents the simulation results of the change at the bed level after the dredging and transporting material was delivered to the receiving location.

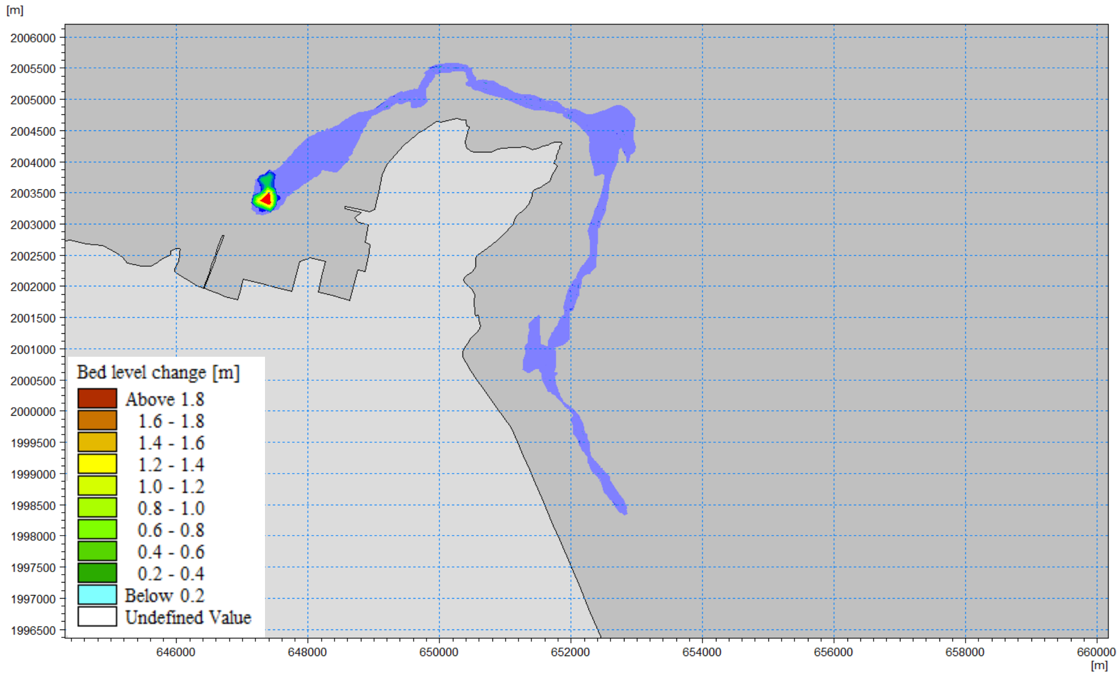

Figure 14. Bed level change after the completion of dredging process

It can be seen that the most significant changes of the bottom occurred at the dredging site, because the dredging process directly affects the sedimentary layers of the area. By contrast, the net only prevented the suspended sediment as much as diffusing happening into the surrounding water. The bed level along the route of transporting dredged material to the receiving place did not change significantly. According to general statistics, there are quite a number of aquatic organisms in the estuaries and coastal areas of Ky Anh district and Ky Anh town such as seaweed; Floating plants; Fish; Mollusks, Crustaceans; and 35 species of zooplankton mainly belonging to the phylum Cladocera and Copepoda. The results of the suspended sediment diffusion from Figures 11a-11c and Table 7 showed the concentrations of the suspended sediment diffusion in the simulated water layers in the study area. It can be seen that the highest concentrations of suspended sediment increased from 2.5-3.0 g/m^3 at the dredging site and the concentration along the transport route increased from 1-1.5 g/m^3. Because the study area does not have any aquatic reserve, the Canadian standard of 5 mg/l increments is applied. Based on the simulation results, there was a good decision to use net and tools in the dredging and transportation process; which will not have a great influence on aquatic life in the coastal estuary of the study area.

4. Discussion

The environmental impacts of the dredging and dumpling activities at sea port have studied in many countries. However, there was few publications related to this problem in Vietnam. Recently, the study on quantitative assessment of the environmental impact of dredging and dumping activities on Quy Nhon port [10] used the 2D models (SW, HD, PT) to simulate the concentration of suspended material for three scenarios. The simulation results were accepted at the dredging position proven by the direction and velocity of wave-wind in the study site. This is the first study applied for Vung Ang port area on the influence of wave regime and tidal current on dredging and dumping activities. However, this study developed a different approach in which a combined 2D semi-distribution model MIKE 21/3 (SW, HD, ST) was used. Wind and wave data for the calculated domain were extracted from the WAVEWATCH-III (wave data) and NOAA global climate change models (wind data). The results of MIKE 21/3 ST showed the changes in the mudbed at the simulated domain. The dredged materials activities were significantly affected by the wave and tidal regime on the sediment transport at Vung Ang port area in Vietnam.

5. Conclusions

In this study, coupled hydrodynamic, wave, and sediment transport models were used to calculate and simulate the influence of wind, wave, fand low regimes on regional sand transport patterns. The results for the currents and waves were evaluated and validated using field data. Wind and wave data were extracted from the WAVEWATCH-III and NOAA accordingly and water level data were collected at Con Co station. The calibration and validation of the MIKE 21/3 (including SW, HD, and ST) showed a high conformity based on the mean absolute error (MAE), the RMSE-observation standard deviation ratio (RSR), the Percent bias (PBIAS), and NSE criteria. Based on the simulation and evaluation results, we found that dredged sediments in estuarine and coastal waters have caused sediment transport in marine environment at Vung Ang port which increased turbidity and enhanced sediment deposition at dump sites. We also found the sediments diffused to the waterbody at the study area were strongly influenced by wave and flow regimes. Specific outcomes are given as follows:

- The SW model was used to evaluate the relative tidal influence and wave forcing on potential sediment transport in the Vung Ang Port area. Wave, wind, and tidal regimes strongly influenced sand transport direction. Median waves predominantly enhanced sand transport in the tidal direction, whereas extreme waves were able to induce directional shifts and full reversals;
- The HD simulation results showed that the water depth ranged from 10 to 22 m, and tidal flow velocity ranged from 0.04 to 0.2 m/s. Hydraulic factors including flow rate and sea depth had the most influence on the sediment transport process;
- The most significant changes of the bottom occurred at the dredging site. The slight increase of sediment concentration did not impact on the sediment quality and the benthic ecosystem in the disposed site.

This study would be beneficial for the management and control of heavy pollution in the marine environment due to sediment transports and the disposal of sediments from maintenance dredging works.

6. Declarations

6.1. Author Contributions

Conceptualization, D.D.T., D.Q.T. and N.C.D.; methodology, D.Q.T., N.C.D.; software, D.Q.T., N.C.D.; validation, D.Q.T., and N.C.D.; formal analysis, D.D.T. and D.Q.T.; investigation, D.Q.T.; resources, D.Q.T.; data curation, D.Q.T. and N.C.D.; writing–original draft preparation, D.D.T., D.Q.T.; writing–review and editing, D.D.T., D.Q.T. and N.C.D.; visualization, D.D.T. and D.Q.T.; supervision, D.D.T. and D.Q.T. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in article.

6.3. Funding and Acknowledgement

The authors gratefully acknowledge the financial support from the National Economics University and the permission to use its facilities to perform the study.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

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