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The Dispersion of Total Suspended Solids in Seawater Following Submersion of Dredged Material in the Vung Ang Port

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Abstract

Dredging plays a crucial role in port management, but disposing dredged material in the ocean raises environmental concerns. In recent years, this practice has become more prevalent in Vietnam. This study examined the dispersion of total suspended solids (TSS) in seawater from the submersion of dredged material in Vung Ang Port, northern Vietnam, to evaluate the environmental impact. The study utilized MIKE modeling to simulate the dispersion of TSS during the 16 weeks following the submersion of dredged material into the sea. The model was validated with observed data and adjusted to accurately reproduce wave, water flow, and water level fields. The simulation showed that the propagation of TSS had a significant impact within a radius of 16-17km from the submersion location, with the most severe impact occurring within a radius of 2-3km. The TSS concentration is expected to exceed allowable limits, peaking after 4-5 weeks. Seawater occupation will reach maximums of 49.05ha and 140.66ha for depth increases above 0.5m and 0.1m. The submersion will negatively impact the environment. It is essential to regularly monitor TSS in affected areas during and after dredging to evaluate long-term effects and mitigation effectiveness. The significance of conducting additional research on the matter and the crucial insights offered by this study to pertinent management agencies for their decision-making processes are emphasized in the article. The study offers crucial insights for pertinent management agencies.

Keywords

TSS, submersion, port, MIKE, modeling

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Introduction

In recent years, seabed dredging has become an increasingly crucial aspect of port management and operations in Vietnam. The removal of sediment, sand, and other debris from the seabed is crucial for maintaining or deepening navigable channels, which ensures the safe passage of ships and the smooth flow of goods and materials. The Vung Ang port in northern Vietnam is a critical hub for the region, and its dredging and maintenance activities play a crucial role in ensuring its efficient operation. The 2020 Vung Ang shipping channel dredging project was designed to improve navigational safety and accessibility within the port by removing 205,215m^3 of sediment to a depth of -12m, within the turning basin and shipping channel from Km 2+400 to Terminal 2. To minimize the environmental impact of the dredging, the Ha Tinh Provincial People's Committee approved the relocation of the dredged material to an area 38 km away, outside the monitoring zone for environmental recovery. The designated dumping site, located within a 100ha area (1km x 1km), was approved by Decision No. 7827/UBND-GT1 dated November 22, 2019 (**Figure 1**). The proper implementation of this dredging project contributed to the continued success and development of the Vung Ang port.

One of the primary reasons for the need for seabed dredging in Vung Ang port is the increase in shipping traffic. With the rise in global trade and commerce, there has been a corresponding increase in the volume of ships entering and leaving ports around the world. In order to meet this demand, seabed dredging is necessary to deepen the navigable channels and to ensure that they are capable of accommodating larger ships (Prumm & Gregorio, 2016; Samsami *et al.*, 2022).

Another factor that contributes to the need for seabed dredging in Vung Ang port is sedimentation. The accumulation of sediment, sand, and other debris in the waterways can reduce the depth of the channel and make it difficult for ships to navigate. This sedimentation can also cause the formation of shoals and other navigational hazards, which pose a risk to shipping operations in the port. To mitigate this risk, regular dredging is necessary to remove the accumulated sediment and to maintain the depth and navigability of the channels (Yuwei *et al.*, 2022). Maintenance of navigable channels is another key reason for the need for seabed dredging in Vung Ang port. Dredging helps to remove the accumulated sediment and debris, which ensures that the channels remain free from navigational hazards and remain navigable (Kamal & Nahla, 2018; Vinh & Lan, 2018). Regular maintenance dredging also helps to ensure that the channels remain clear and free from obstructions, which is crucial for the safety and efficiency of shipping operations in the port (Ren *et al*, 1996; Rydningen *et al.*, 2015). Due to the impacts of climate change, Vietnam is considered one of the countries most affected by global warming and sea level rise (Tran Anh & Taniguchi, 2014; Tran-Anh *et al.*, 2022; Tran-Anh *et al.*, 2023). Therefore, it is increasingly important to thoroughly study the harmful effects of materials sinking in the sea.

The dumping of dredged material in the ocean is a common practice in many ports and harbors around the world, including in Vietnam. This process involves the disposal of sediment, sand, and other debris that has been removed from the sea floor during dredging operations. The importance of dumping dredged material in the ocean is linked to several key factors, including the need for safe and efficient navigation, the protection of the marine environment, and the management of waste from dredging operations (Bortali *et al*., 2023). In recent years, mounting concern has arisen over the environmental consequences of seabed dredging and subsequent dumping of dredged material into the ocean. A major focal point of this concern revolves around the dispersion of total suspended solids (TSS) in the water column, which can have adverse effects on aquatic ecosystems and human well-being. Despite the significance of this issue, the available literature on the subject is severely limited, emphasizing the critical need for further research. To provide clarity and insight into this issue, a noteworthy study by Tran Dinh Lan *et al*. (2020) explored the dispersion of TSS in the East Sea subsequent to the dumping of dredged material from the Port of Hai Phong. The findings revealed a substantial increase in TSS concentrations in the vicinity of the dumping site, with elevated levels persisting for an extended period. Additionally, the study underscored the influential role played by the

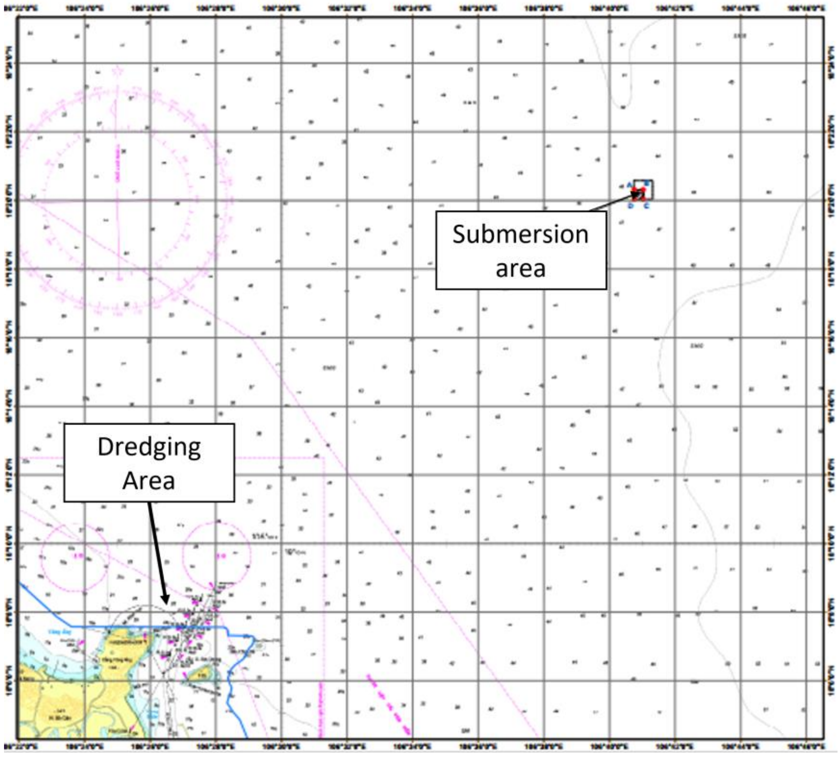

Figure 1. Map of the study area, the small black rectangle indicates the dumping site for dredged material

size and direction of water currents in the dispersion of TSS, enhancing our understanding of the complex dynamics at play. Similarly, Kim *et al*. (2018) conducted a study on the dispersion of TSS resulting from the dumping of dredged material in the East China Sea. Their findings demonstrated a significant rise in TSS concentrations in the water column immediately after the dumping, with the highest concentrations observed closest to the dumping site. As time elapsed, TSS concentrations gradually decreased as the material dispersed away from the site, providing valuable insights into the temporal aspects of TSS dispersion. Considering the limited research available on this critical issue, both studies have contributed significantly to the understanding of TSS dispersion resulting from dredged material dumping in marine environments. Their findings emphasize the importance of investigating similar scenarios, such as the Vung Ang port dredging project, to evaluate potential environmental impacts and inform responsible decision-makers regarding dredged material disposal. As a result, further research in this area is of paramount importance in promoting sustainable practices and safeguarding the delicate balance of maintaining marine ecosystems and human health.

The significance of this study lies in its investigation of the dispersion of TSS resulting from the submersion of dredged material in the Vung Ang Port. The study utilized the MIKE modeling system and observed data to simulate the TSS submersion process, offering crucial insights into the extent and severity of pollution propagation at the dredging and submersion locations. By highlighting the environmental concerns related to dredged material disposal and the significant impacts of disposal on marine ecosystems and water quality, the study offers valuable information for relevant management agencies to make informed decisions about port dredging practices and the implementation of effective environmental conservation measures.

Materials and Methods

Sampling

On June 15, 2019, four mud and seawater samples were collected within the scope of the discharge flow, ranging from Km1+050 to buoy PN14 before docks 3 and 4. The discharge flow covered a total length of approximately 3.75km and had 83 cross-sections along its path, with cross-sections 59-73 located in the ship's turning basin before Dock 2. To ensure accurate analysis, the samples were collected at a depth of -11m, with each sample weighing 200g and a reserve of 10 kg. To guarantee a fair and unbiased selection of sample sites, all four sample sites were randomly picked on the grid map (**Figure 2**), ensuring representation of the entire flow path and allowing for an assessment of the uniformity of potentially polluted areas.

TSS dispersion model

In order to accurately model the processes of sediment transport, erosion, and deposition of non-cohesive sediment in both marine and freshwater environments, we employed the state-of-the-art simulation tool, MIKE 21MT (DHI, 2017). The MIKE model is a widely used numerical modeling tool for simulating hydrodynamic and water quality processes in aquatic environments. In the context of studying sediment dispersion, the MIKE model assumes steady-state or quasi-steady-state flow conditions, uniform sediment properties, and a uniform bed. It may neglect small-scale turbulence effects and sediment-fluid interactions, while assuming constant physical characteristics of the study area. These simplifications enable efficient simulations while aiming to represent real-world conditions as accurately as possible. Calibration and validation against real data are essential for assessing the model's accuracy and reliability. MIKE 21MT can be dynamically linked to the hydrodynamic and wave modules of the Mike program, utilizing either a finite element or rectangular finite difference calculation mesh with the option to perform the simulations in either 3D or 2D. The hydrodynamic foundation of the module is based on the MIKE 21HD FM and MIKE 3HD FM models. Given the significance of wave impact on the erosion process, wave parameters were taken into consideration and were obtained from the frequency-domain wave calculation module Mike21SW. The sediment transport equation utilized in Mike is outlined in Teisson (1991):

$$\frac{\partial c^i}{\partial t}+\frac{\partial uc^i}{\partial x}+\frac{\partial vc^i}{\partial y}+\frac{\partial wc^i}{\partial z}-\frac{\partial w_s c^i}{\partial z}=$$

$$\frac{\partial}{\partial x}\left(\frac{\upsilon_{Tx}}{\delta_{Tx}^i}\frac{\partial c^i}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\upsilon_{Ty}}{\delta_{Ty}^i}\frac{\partial c^i}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{\upsilon_{Tz}}{\delta_{Tz}^i}\frac{\partial c^i}{\partial z}\right)+S^i$$

where t is the time; u, v, and w are the velocity components of the flow; c_i is the concentration component of the sediment i; wis is the sedimentation velocity; δ_{Tx}^{i} is the Schmidt number; υ_{Tx} is the viscosity coefficient; and S_i is the source term coefficient. The process of non-cohesive sediment transport is solved by the algorithm of the particle transport calculation module.

The modeling domain and boundaries of the 3D coastal model

To ensure the accuracy of the tidal simulation in the Central Vietnam region, the model's domain covered not only the project area but also included the East Sea area outside, taking into account the tidal propagation from the various estuaries (**Figure 3**). The finite element grid was applied, with finer grids in shallow areas and coarser grids in deep areas. The smallest grid cell size was 100m in nearshore areas where erosion and deposition occur and the largest was 4km in the middle of the East Sea. The nested domain encompassed the coastal region of the Vung Ang port area, with the Formosa-Ha Tinh plant as its central point. The nested domain extended in both the northern and southern directions to capture the space that had the potential to transmit pollutants and maintain the integrity of the boundaries.

Using the finite element method, the computational mesh was constructed using 36,948 grid nodes and the grid resolution was optimized to suit the area of interest. The grid resolution varied from coarse to fine, with a minimum grid size of 40m and a maximum grid size of approximately 3000m in the deep-water oceanic regions. The numerical simulations were conducted in three vertical layers.

Hydro-dynamic boundaries

In order to predict the tidal water levels at the coastal inlets in the East Sea, a numerical modeling approach was employed using the

Figure 2. Sampling location of mud and seawater

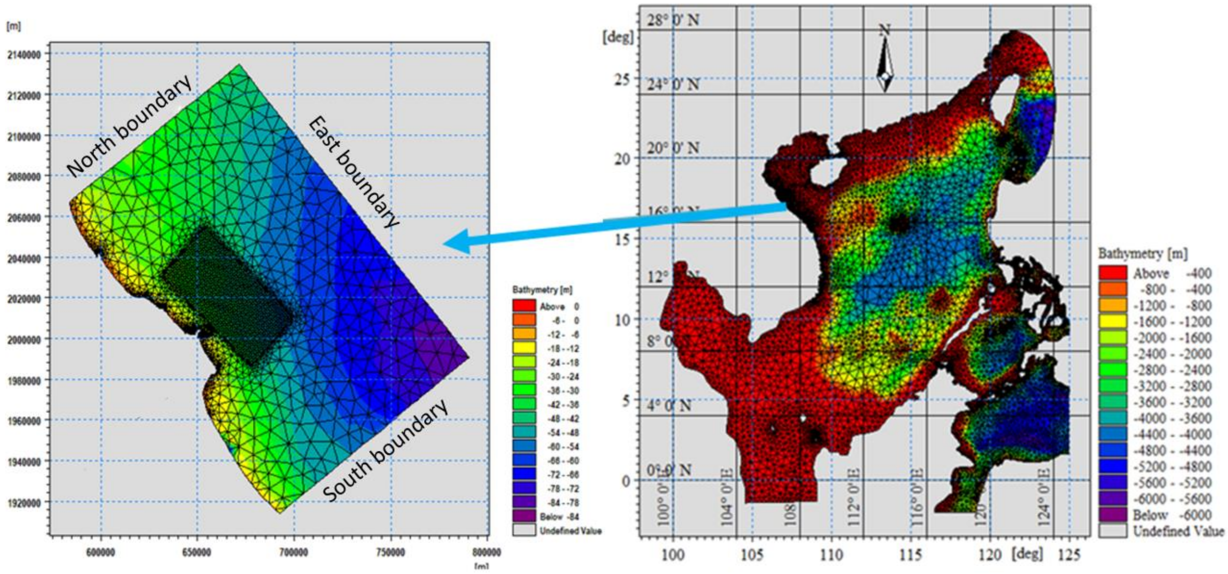

Figure 3. Computation grids for the East Sea (right) and the Vung Ang port (left)

advanced Mike21 Tidal tool. The surface boundary conditions, including wind and pressure data, taken from the ERA5 reanalysis dataset, were analyzed using a 3-hour time step to capture the variability of these parameters. At the detailed scale of the nested domain, the flow and water level boundary conditions were represented by the MIKE 3HD FM model, which consisted of the flux components along the boundary elements obtained from a comprehensive analysis of the East Sea.

The computational boundary of the Quyen River was defined by collecting the average monthly volume data from a hydrometric station in the region. This data was then used to accurately represent the river's influence on the coastal water levels.

The wave parameters along the boundaries were obtained from the results of the MIKE 21 SW wave model, which was used to simulate the wave conditions in the East Sea. These wave parameters were then incorporated into the overall tidal model in order to capture the effects of waves on the tidal water level at the coastal inlets.

Mud and sand condition

The results of a sediment analysis conducted on four samples collected from the layer of sediments in the dredging area provided the initial conditions for the material input for the dispersion process. The mud sample analysis, conducted within 7 days after sampling by the Institute of Environmental Technology (IETVN), was used as the basis for this division. The mud was observed to spread, while the sand was observed to sink. The total volume of dredged material was 180,568m^3. For the simulation, the mud source was modeled with a concentration of 1050 kg m^{-3} and a velocity of 0.015 m s^{-1}, with a yield stress of 0.02 N m^{-2} (contributing to dispersion). On the other hand, the sand source was modeled with a concentration of 2650 kg m^{-3}, a velocity of 0.3 m/s, and a yield stress of 0.5 N m^{-2}. The concentrations of both mud and sand remained constant throughout the sinking process.

The mud source was modeled using two parameters, concentration and flow rate, where the total mud volume was calculated as the product of flow rate and concentration. The flow rate was determined by the ship's load, leading to different values for each ship. The total sinking time was set at 10 minutes, with the flow rate remaining constant during this period. When the submersion process was not occurring, the flow rate was set to zero.

The study employed a 3D model, and the source point was set at 4.0m below the average water level for all types of ships used in the sinking process. The model did not include the effects of bonding, coagulation, or aggregation.

Initial conditions

In this model, the initial conditions were considered as zero for all wave and flow parameters. For the sand transport model, the TSS background parameters were collected from the coast and project area shore locations and were averaged. The average value was chosen as the background condition for the TSS transport model.

Topography, meteorology, wave, and flow data

Geospatial data for this study were sourced from multiple sources, namely the General Bathymetric Chart of the Oceans (GBECO), the Institute of Mechanics (VAST), the Naval Command, and ETOPO5. The GBECO data were collected for the entire East Sea and coastal areas, while surveying data from the Institute of Mechanics (VAST) were collected during the evaluation of waste discharge from the Formosa plant into the sea in 2017. The Naval Command also collected survey data from the coastal areas with scales ranging from 1/25,000 to 1/1,000,000, and areas lacking data were supplemented with ETOPO 5 geospatial data. All the geospatial data were transformed into the national elevation system. The latest surveying data of the project were used to extract geospatial data for the port area.

For meteorological and hydrological data, wind and pressure data were obtained from the National Oceanic and Atmospheric Administration (NOAA), while hydrological and oceanographic data were collected from both NOAA and the European Centre for Medium-Range Weather Forecasts (ECMWF). The average monthly water flow of the Quyen River was also considered in this study.

Water level data were measured at the national coastal hydrological stations, including the Ha Tinh, Vung Ang, and Quang Binh stations, from 2014 to 2015, and were collected by the National Data Center. The wave and flow data, and water quality were collected in two monitoring periods carried out by the Institute of Mechanics in August and December 2017 as part of the Formosa Factory Pollution Transmission Assessment Project, and were utilized to adjust and validate the hydrodynamic model and TSS transmission.

Configuration of MIKE model

The MIKE model was meticulously established, incorporating a comprehensive set of parameters to accurately simulate the system. The key parameters utilized in the model included: Wind friction (Zch) = 0.00255; Eddy viscosity = 0.4; Convergence index (CFL) = 0.8; Breaking wave coefficient (γ) = 0.8; Horizontal diffusion coefficient = 1.0; Angle of internal friction of sediment (φ) = 30 degrees; and Roughness height = 0.15.

Scenarios

Drawing from historical data on prevailing wind patterns, we conducted the simulation during the specific period of May 11, 2020, to August 9, 2020. This time frame was chosen to align with the planned dredging and submersion of seabed sediment, which was scheduled before the storm season.

Results and Discussion

Validation of the MIKE model

The validation and verification process of the MIKE model simulation was conducted in a step-by-step manner, starting with the outer domain in the East Sea and progressing to the inner domain. Through a careful comparison of the simulation results with observation data, the configuration of the MIKE model was iteratively refined until the biases reached convergence states. The best simulation results, obtained from the optimum configuration, are illustrated below.

Simulation for the outer domain

The calibration of the MIKE model was performed by optimizing the model parameters to achieve the best agreement between the simulated results and the measured data. The verification procedure was implemented in a systematic manner, starting with the hydrodynamic model in the East Sea, followed by a more localized assessment on a nested domain (**Figure 3**).

The adjustment and verification of the flow and wave models for the East Sea were conducted using water level measurement data from a Vietnamese coastal station (N18.109063°, E106.435906°) and flow measurement data from the designated research location. The testing and model adjustment method proposed by Tran Anh Quan *et al*. (2021) was applied. The model parameters were initially set to their default values and were gradually refined to best fit the characteristics of the study area. To evaluate the accuracy of the models, the flow and wave model predictions were compared with the measured flow data collected during the periods of August 17-26, 2017 and December 9-18, 2017 at two sites, B1 and B3. The measurement data were recorded with a temporal resolution of 10 minutes. **Figure 4 (a, b)** presents a comparison between the simulation results and the observed data for wave height and direction in the East Sea. The comparison was evaluated using the Nash-Sutcliffe index, yielding a value of 0.65 for wave height and 0.63 for wave direction, demonstrating a good agreement between the simulation and observations. However, the simulation results exhibited limitations in capturing the finer details of the wave fields, particularly in reproducing the small-scale fluctuations and accurately predicting the extremes of wave direction.

In order to calibrate the water level, the observed data obtained from eight coastal monitoring stations (Hon Dau, Hon Ngu, Con Co, Thuan An, Son Tra, Qui Nhon, Nha Trang, and Vung Tau) were utilized. This process involved iteratively adjusting the model parameters within an acceptable range to achieve a close match with the observed water level data. The results of the adjustment showed that the water levels reconstructed through the use of the MIKE model were highly correlated with the observational data from all the tidal stations, as illustrated in **Figure 5**. The Nash value between the simulated and observed water levels at the Hon Dau station for the period of August 2014 was 7.12, indicating a strong correlation between the two.

The MIKE model was further evaluated for its accuracy in simulating the velocity and

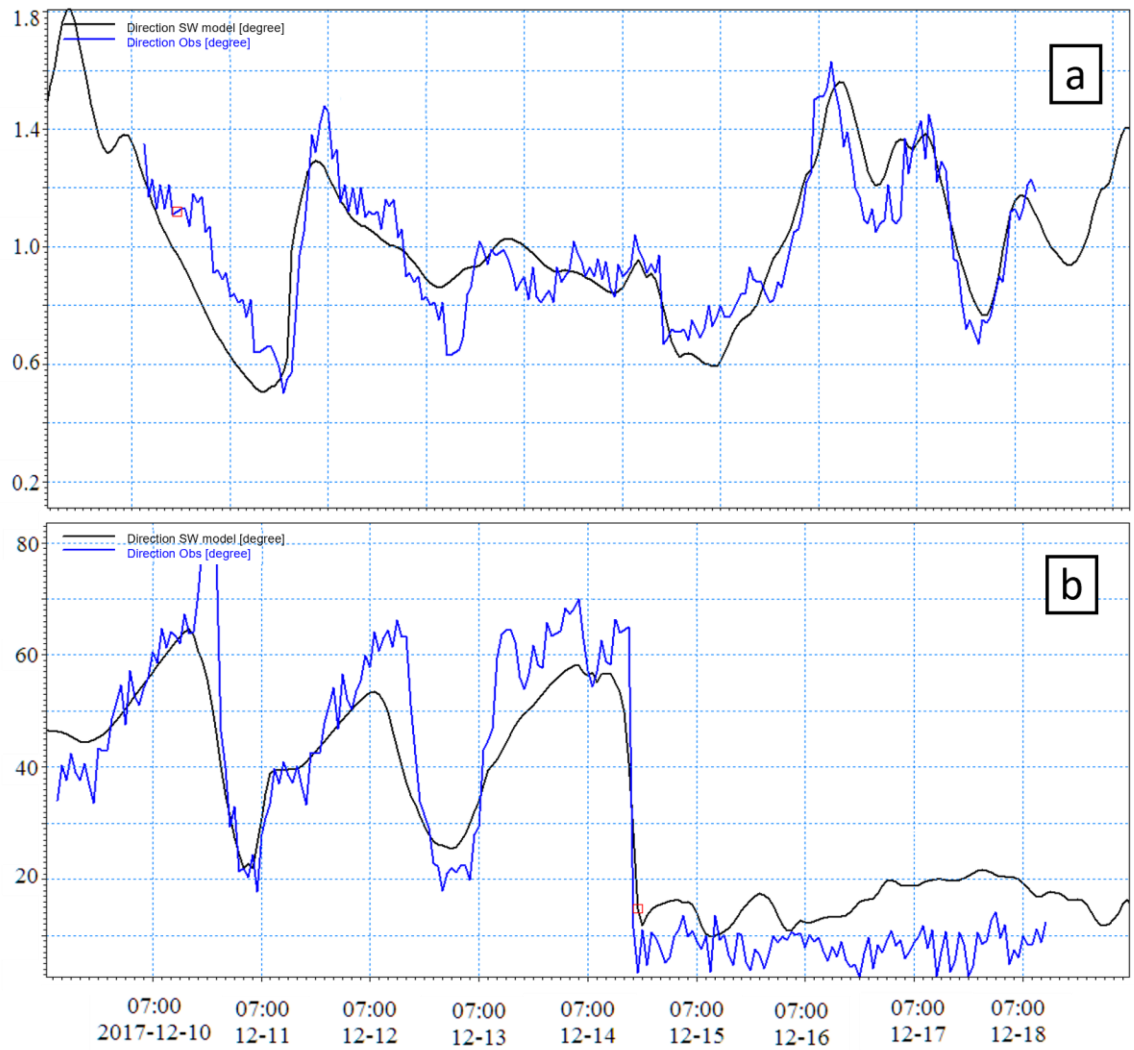

Figure 4. Simulated (black) and observed (blue) data for (a) wave height and (b) wave direction for the East Sea domain

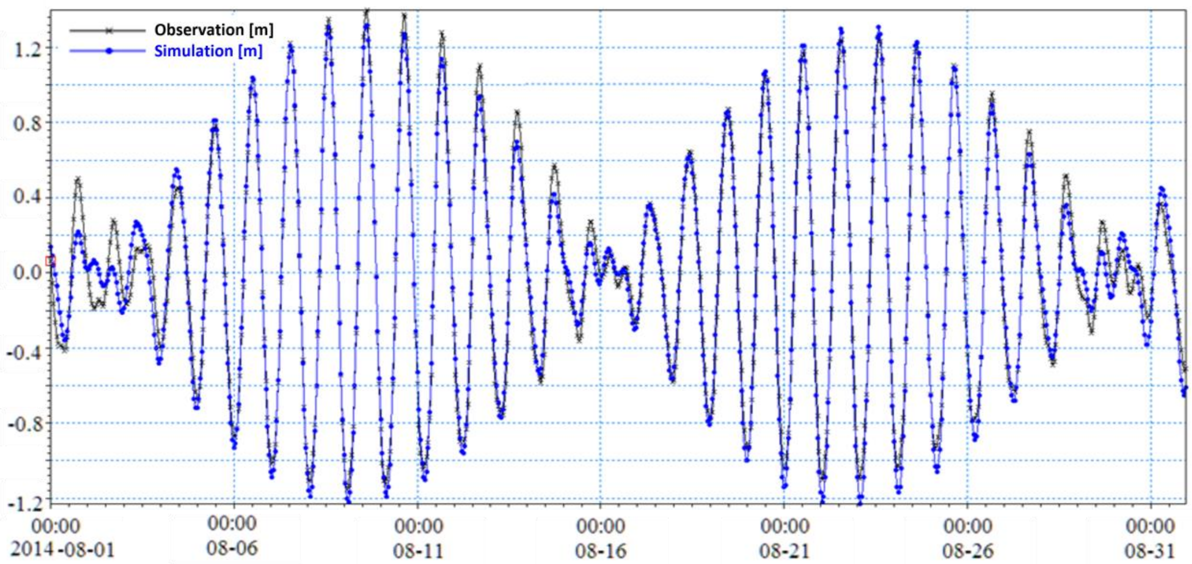

Figure 5. Water level at the Hon Dau hydrology station by the MIKE model (black) and observations (blue)

Table 1. Comparison of the Nash index values between simulated and observed water flow across different ocean depth layers

Index	Surface layer (5th layer)	4th layer	3rd layer	2nd layer	Bottom layer (1st layer)
Velocity	0.7	0.7	0.7	0.7	0.7
Direction	0.4	0.66	0.65	0.53	0.3

direction of water flow by comparing the simulated results to observed data at five ocean depth layers. **Table 1** presents the NASH index values between the simulated and observed water flow across different ocean depth layers. The simulation results revealed that the flow velocity was accurately modeled, with a correlation coefficient greater than 0.7 at all depths. However, the flow direction was less accurately modeled with NASH index values ranging from 0.3 to 0.66. Particularly, the surface and bottom layers displayed the weakest correlations, with NASH values of 0.4 and 0.3, respectively. Although the intermediate layers showed improved accuracy with NASH indices higher than 0.5, the discrepancies in flow direction modeling at the surface and bottom layers are noteworthy limitations. Simulating the dynamic process of wave movement in the bottom layers of the sea poses significant challenges, particularly due to the limited availability of in-situ observations. Consequently, this scarcity of data may lead to a lack of confidence in the simulation results, particularly for the deep sea layers. However, the validation for the outer domain showed good performance, indicating its suitability for extracting input data for simulations in the nested domain. Similarly, Tran Anh Quan *et al*. (2021) found a similar performance of the MIKE model in simulating water flow and wave direction in Nghi Son port. In addition, their study also found that MIKE had lower accuracy at the surface and bottom layers of the sea, consistent with the current study's findings. Overall, the MIKE model effectively represents the velocity and direction of water flow in the outer domain, making it a valuable tool for future simulations.

Validation of the nested domain

The wave model was calibrated based on the stationary conditions across the entire East Sea, resulting in satisfactory outcomes. Subsequently, the wave data were extracted as inputs for the boundary conditions of the coastal region, which were then refined through additional calibration using actual measurements taken during the North East monsoon and South West monsoon phases in August 2017 and December 2017 at locations B1 and B3. The wind data on the sea surface were re-analyzed with a time step of three hours. The results of the detailed calibration are illustrated in **Figure 6**, which compares the simulated wave height produced by the MIKE model with the measured values recorded during August 2017. The simulation results for the wave field in the refined domain showed a marked improvement compared to the broader domain across the entire East Sea, as evidenced by the Nash values of 0.8 for wave height, 0.65 for wave direction, and 0.65 for wave period. The simulation results displayed good consistency with the measured values and had low error margins.

The water level and surface flow velocity data collected from September 27 to October 5, 2015 at the Quang Binh station were employed to assess the model results. **Figures 7(a) and 7(b)** demonstrate the comparisons between the measured values and the simulated values after calibration for both water level and surface flow velocity. The modeling validation results demonstrated that the parameters in the calibration stage were appropriately adjusted to the real conditions of the research area, as indicated by the high NASH indices for water level, flow direction, and velocity, with values of 0.81, 0.77, and 0.72, respectively.

The calibration of the wave model based on stationary conditions across the entire East Sea yielded satisfactory outcomes, providing valuable input data for the boundary conditions of the coastal region. Subsequent calibration using actual measurements during monsoon phases at specific locations further refined the model. The results of the detailed calibration

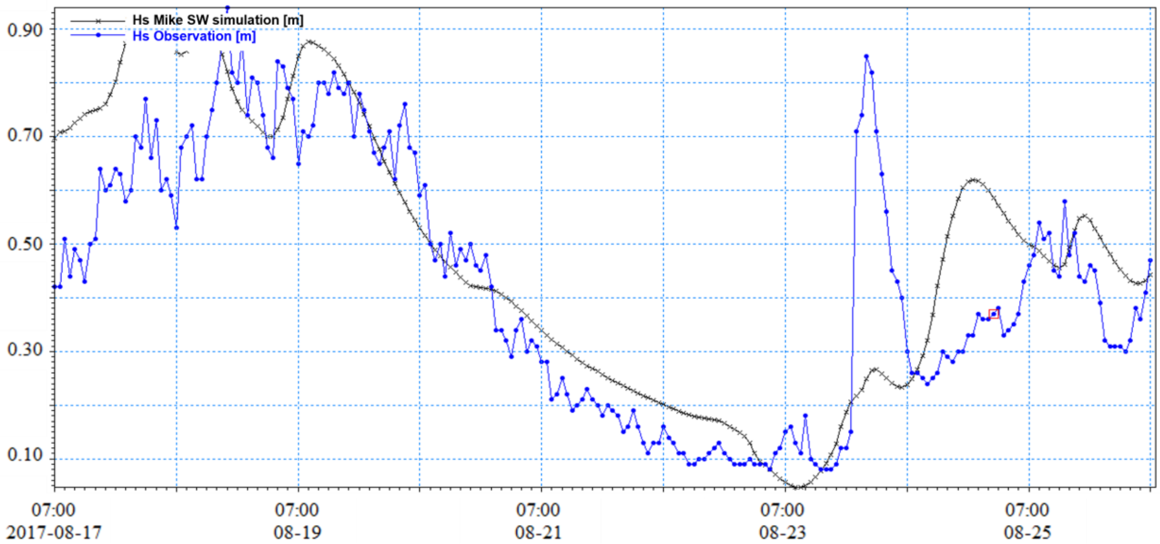

Figure 6. Simulated (black) and observed (blue) wave height for the nested domain

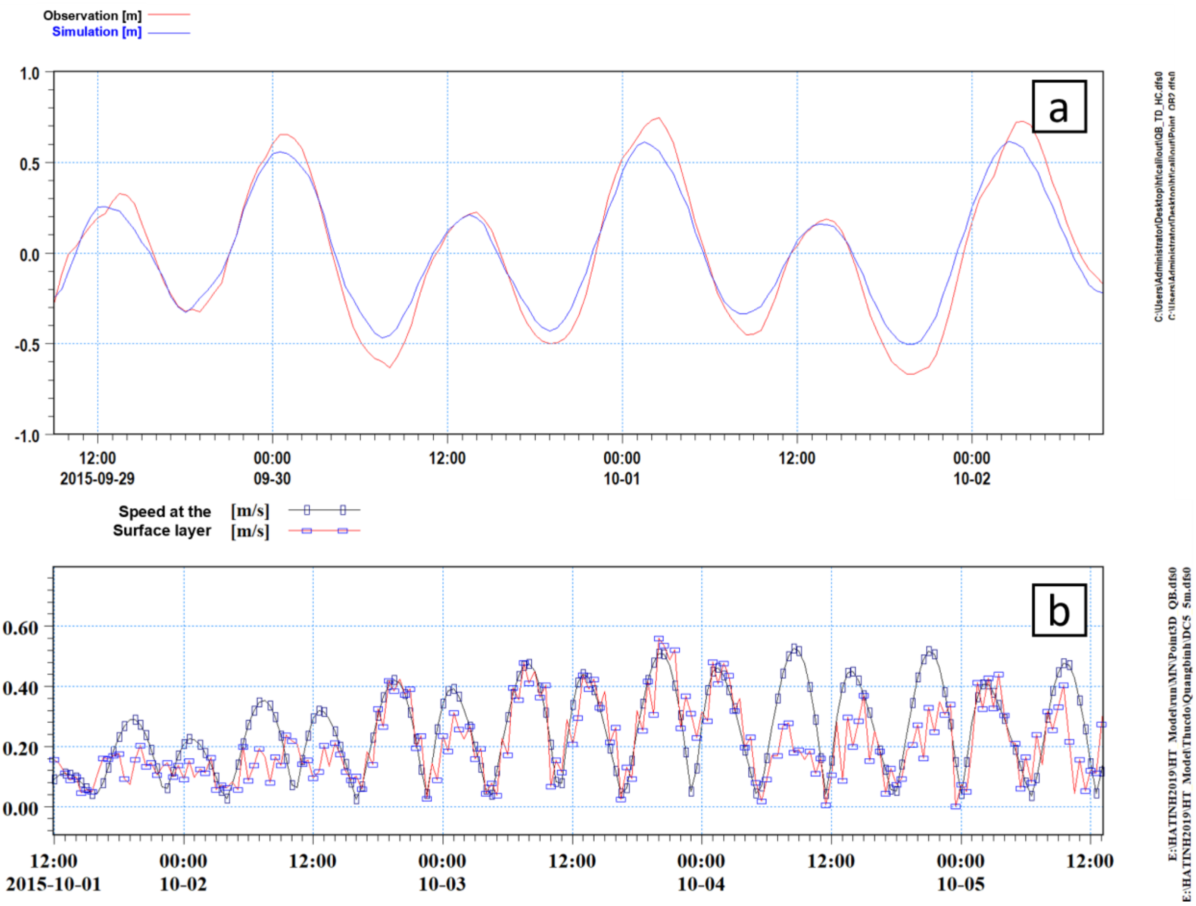

Figure 7. Comparison of the simulated (blue) and measured (red) results for (a) water level and (b) surface velocity at the Quang Binh station

demonstrated a significant improvement in the simulation of the wave field within the refined domain compared to the broader East Sea area, with high NASH values for wave height, direction, and period, which indicated good consistency with the measured data and low error margins. Additionally, the calibration of water level and surface flow velocity using data from the Quang Binh station showcased appropriate adjustments to match the real conditions of the research area, resulting in high Nash indices for these parameters. The overall success of the model calibration and validation process highlights its reliability in accurately representing the physical behavior of water flow, wave field, water level, and surface flow velocity, making it a good tool for future simulations.

Characteristics of dredged material

The sediment in the port area displayed considerable variation in composition and structure, owing to its size, transport dynamic regime, terrain, and pre-existing mineral composition. Analysis of four sediment samples collected from the dredged area revealed that, on average, coarse sand (with a mean grain diameter of Md= 0.2 ÷ 0.2mm) constituted 8%, fine sand (Md = 0.02 ÷ 0.2mm) accounted for about 33%, silt (Md = 0.002 ÷ 0.2mm) constituted approximately 29%, while the remaining material was silt (with a mean grain diameter of Md <0.002mm) that accounted for about 30% (**Table 2**). Therefore, the dominant components of the dredged material were silt, fine sand, and very fine sand, which collectively comprised over 90% of the sediment. These findings are consistent with the literature, which suggests that the dominant components of dredged material are fine sand, silt, and clay, with varying proportions depending on the location and characteristics of the port area sediment (e.g., Vu Thanh Ca *et al*., 2023; Tran Anh Quan *et al*., 2021). The morphology of the sediment layers in the dredged area displayed heterogeneity and dynamic characteristics. The composition of the samples varied significantly based on the distance from the sampling location to the shore, as well as the sea bed morphology. These observations imply that the dispersion of total suspended solids (TSS) in seawater during submersion is primarily influenced by fine particles. The interplay between these factors underscores the complex nature of sediment distribution and its impact on TSS dispersion in the marine environment.

Dispersion of TSS in seawater

The extent and magnitude of coastal occupation resulting from submersion operations were assessed by calculating the propagation of total suspended solids (TSS) in seawater, aligning with the planned operation time from May 11, 2020 to August 9, 2020. Throughout the simulation, we utilized historical data on prevailing wind direction, which showed a consistent dominance of the southeast monsoon. This approach ensured that the simulation accurately represented real-world conditions and factors that influence the wind patterns in the area. Simulation results were obtained for cross-sections CS1 and CS2 (**Figure 8**) at three layers: surface, middle, and bottom. **Figure 9(a)** shows the largest spatial distribution of TSS in each layer during the submergence phase. The propagation of TSS had a significant impact within a relatively wide range, up to 16-17km from the dredging location, with a concentration of 0.01-0.03 kg m^{-3}. The most severe impact occurred within a radius of 2-3km around the dredging location, where the TSS concentration in the environment was higher than the allowable limit of 0.05 kg m^{-3} according to QCVN 10-MT:2015/BTNMT (MONRE, 2015). The pollution dispersion reached its peak after 4-5

Table 2. The percentage composition of grain size in sediment samples taken from the dredged area

Sample No.	Composition of sediment (%)			
	Coarse sand (0.2-2mm)	Fine sand (0.02-0.2mm)	Mud (0.002-0.02mm)	Silt (<0.002mm)
1	13.72	57.54	12.20	16.54
2	0.63	20.93	36.42	42.02
3	0.20	17.58	42.34	39.88
4	37.24	52.62	4.42	5.72

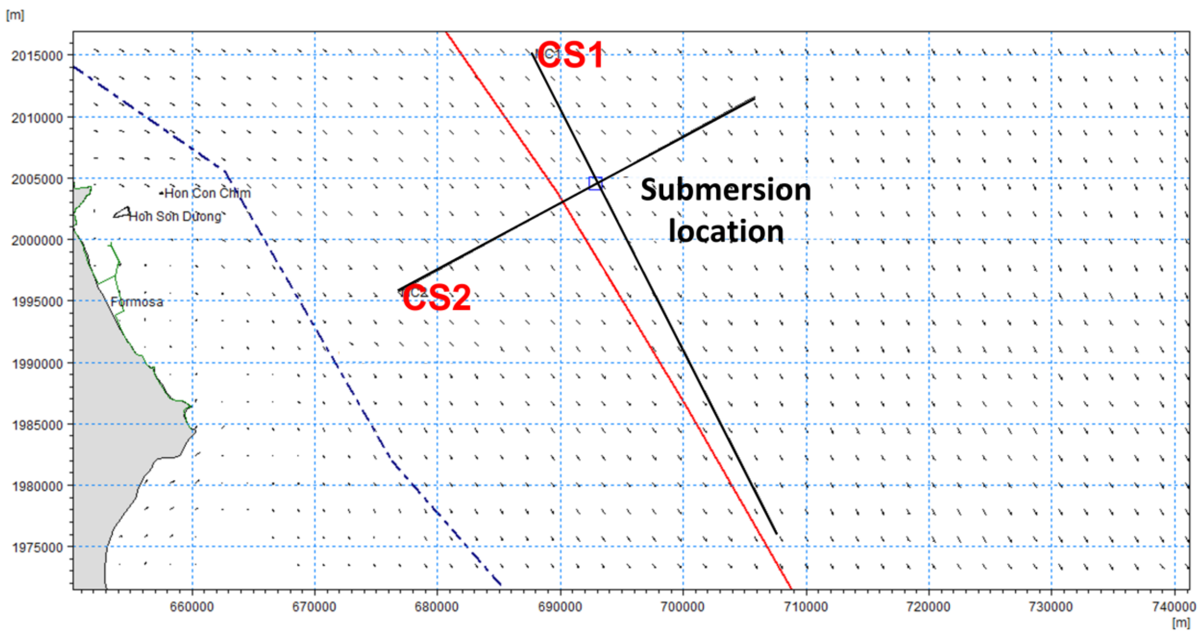

Figure 8. Location of the CS1 and CS2 Cross sections to tracking the TSS propagation process throughout the entire sinking process

weeks. **Figure 9 (b, c)** illustrates the pollution dispersion after two weeks of submergence, where the most severe impact, with TSS concentrations higher than 0.05 kg m^{-3}, could reach a depth of -20 to -25m. At the seafloor, the initial settling of the TSS concentration was at 0.01-0.03 kg/m^3. Previous researchers, such as Vu Duy Vinh & Tran Dinh Lan (2018) and Tran Dinh Lan *et al*. (2020), have also documented notable environmental consequences resulting from dredging activities in coastal regions, aligning with the current study's results.

Simulation of the sedimentation and seawater occupation process during the 16-week submergence operation is shown in **Figure 10 (a, b)**, assuming a fixed location for the site. The simulation results show that the water depth in the area with submerged material increased over time, reaching a maximum of about 0.5m for both cross sections CS1 and CS2. The degree of seawater occupation reached a maximum of 49.05ha for the area with a water depth increase above 0.5m, and extended to 140.66ha for the area with a water depth increase above 0.1m. However, these impacts were only temporary. Over time, the dynamic processes of the ocean dispersed all of the submerged material and restored the initial environment.

Conclusions

This study used the MIKE modeling system to investigate the dispersion of total suspended solids (TSS) in seawater resulting from the submersion of dredged material in the Vung Ang Port. The validation results showed that the model, after adjustment, could accurately reproduce the fields of wave, water flow, and water level in both the outer and inner domains, with higher simulation accuracy in the latter. Simulation accuracy was over 0.6 for most fields, as measured by the NASH index. However, the model faced challenges when reproducing wave direction and the movement of waves in the deep sea layers.

The sediment exhibited significant variation in composition and structure, influenced by factors such as size, transport dynamic regime, terrain, and pre-existing mineral composition. The morphology of the sediment layers in the dredged area was heterogeneous and not static. Analysis of the surface sediment samples from the dredged area revealed that the dominant components were clay, silt, fine sand, and very fine sand, making up over 90% of the sediment. Coarse sand constituted around 8% of the sediment.

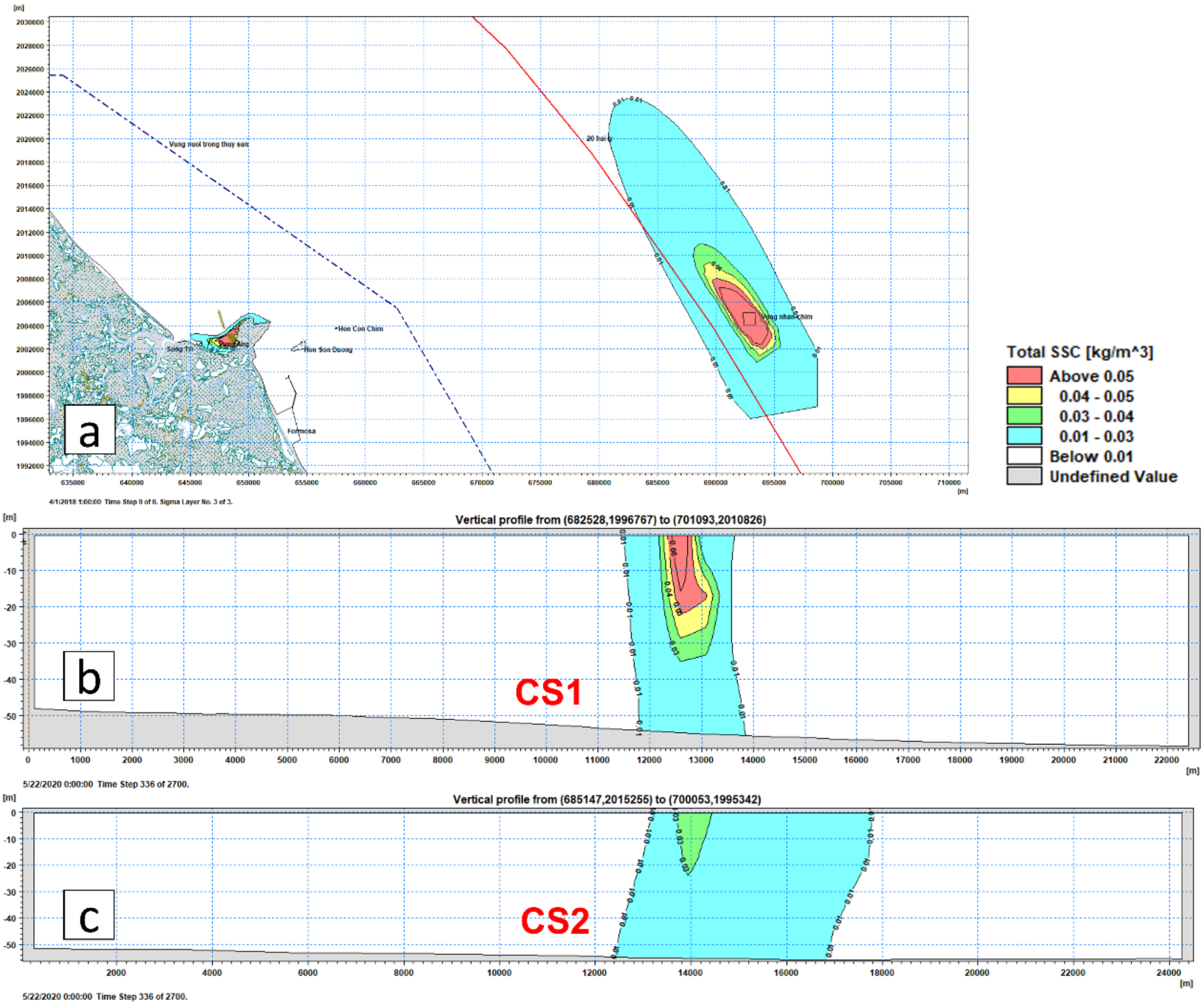

Figure 9. Distribution of TSS during the process of sinking dredged material in the ocean. Panel (a) displays the maximum spatial distribution of TSS in the surface layer of the ocean, while panels (b) and (c) illustrate the depth-wise distribution of TSS in seawater for cross-sections (b) CS1 and (c) CS2, respectively, after two weeks of submergence.

The simulation of the submersion of dredged material in the ocean showed that the propagation of TSS had a significant impact across a relatively wide range, up to 16-17km from the dredging location, with a concentration of 0.01-0.03 kg m^{-3}. The most severe impact occurred within a radius of 2-3km around the dredging location, where the TSS concentration in the environment was higher than the allowable limit according to QCVN 10-MT:2015/BTNMT. The pollution dispersion reached its peak after 4-5 weeks. The degree of seawater occupation reached a maximum of 49.05ha for the area with a water depth increase above 0.5m, and extended to 140.66ha for the area with a water depth increase above 0.1m.

The findings of this study indicate that the submersion of dredged material into the sea has the potential to negatively impact the marine environment, potentially leading to natural hazards. Further in-depth studies are necessary to comprehensively investigate the long-term effects of TSS on the environment. Additionally, thorough research is essential to develop effective mitigation methods aimed at minimizing adverse consequences. Revising regulations to implement better management practices is crucial in ensuring sustainable and environmentally responsible dredging operations. By prioritizing research, mitigation, and regulatory improvements, we can work towards a more balanced and ecologically sound

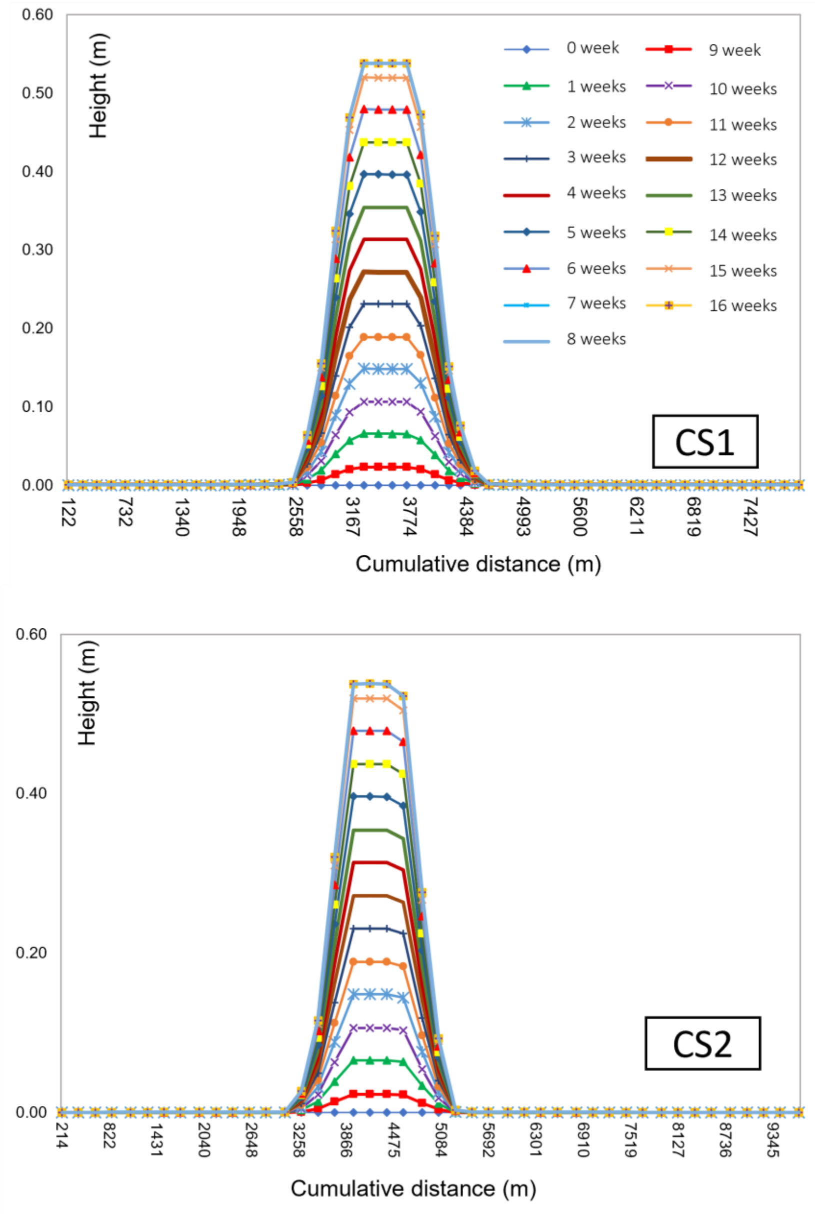

Figure 10. Degree of seawater occupation during the 16-week submergence operation for cross-sections (a) CS1 and (b) CS2

approach to managing dredging activities in marine ecosystems.

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