DOI: 10.31276/VJSTE.2024.0068

Utilisation of the MIKE 3 model for simulating sediment transport in coastal areas of Nam Dinh province affected by sand mining

Van Lan Vu[1] , Dac Thuyet Bui[1], Quoc Viet Tran[1*], Minh Cat Vu[2], Tra Mai Ngo[3]

[1]Hanoi University of Natural Resources and Environment, 41A Phu Dien Street, Phu Dien Ward, Bac Tu Liem District, Hanoi, Vietnam
[2]Van Lang University, 45 Nguyen Khac Nhu Street, Co Giang Ward, District 1, Ho Chi Minh City, Vietnam
[3]Institute of Physics, Vietnam Academy of Science and Technology, 18 Hoang Quoc Viet Street, Nghia Do Ward, Cau Giay District, Hanoi, Vietnam

Received 22 July 2024; revised 27 September 2024; accepted 7 October 2024

Abstract:

The application of mathematical models in assessing the environmental impact of sand mining projects plays a crucial role in forecasting and managing the effects of mining activities on the environment. Mathematical models can predict turbidity propagation, pollutant dispersion, and the impact of mining activities on environmental factors such as water quality and ecosystems, thereby providing a solid scientific basis for analysing and reporting environmental impacts. This study utilised the MIKE 3 model to simulate sediment propagation from sand dredging activities under monsoon conditions in the coastal area of Nam Dinh province. The results reveal the trend of turbidity propagation and the distribution of turbidity concentrations at various water depths. At the surface layer, sediment concentration is the lowest compared to the middle and bottom layers, with a range of approximately 0.6 km where turbidity exceeds 0.5 kg/m³ (the permissible limit according to Vietnamese standard TCVN 10-MT:2015/BTNMT). Meanwhile, sediment concentrations in areas adjacent to the mouths of the Ninh Co river and the Day river are within the permissible limits.

Keywords: **coastal zone, environment, MIKE 3, sand mining, turbidity.**

Classification numbers: **4.4, 5.3**

1. Introduction

Dredging is an essential operation to ensure safe navigation for vessels at ports and harbours [1]. It also plays a critical role in maintaining harbour operations, such as the import and export of goods. However, dredging at sea can have detrimental effects on the marine environment and its ecosystems by increasing turbidity levels and causing fine sediments to settle over a wide area. This can affect a large zone surrounding the mining site. The dredged material may smother seabed habitats, coral reefs, and fish spawning sites, and disrupt fish navigation [2]. Additionally, dredging alters seabed topography at both extraction and disposal sites, potentially changing local flow patterns. Consequently, it is vital to monitor, control, and assess the environmental impacts of dredging activities [3].

In Vietnam, due to the scarcity of sand for construction projects, sand mining activities in river and coastal areas have increased. These activities often cause significant changes in the marine environment by increasing water turbidity through the release of organic and inorganic particles from the seabed during the extraction process [4, 5]. This not only affects the growth of marine organisms but also impacts tourism, fisheries, maritime transportation, and coastal morphology [6]. Therefore, applying models to simulate turbidity dispersion from dredging activities is crucial for understanding the propagation of pollutants in the marine environment. Computational models can predict changes in turbidity over time and space, aiding managers in planning and implementing measures to mitigate negative environmental impacts [7].

Nam Dinh province, located in the southern part of the Red river delta, holds a strategically important position in socio-economic development. One of Nam Dinh's strengths lies in its abundant marine sand resources of relatively good quality, which are distributed along the coastal areas of Giao Thuy, Hai Hau and Nghia Hung districts and are used as filling and construction materials [8]. These coastal areas are currently being exploited to supply construction materials for both local and national projects. Therefore, using mathematical modelling tools to simulate the dispersion of turbidity from sand mining activities is essential for

---

[*] *Corresponding author: Email: tqviet@hunre.edu.vn*

assessing the impact of these activities on the environment and surrounding ecosystems [9].

Mathematical models have proven highly beneficial in assessing the environmental impacts of sand mining activities [10-12]. They provide a scientific basis for environmental impact assessments of coastal sand mining projects. In some studies, mathematical models have been applied to simulate, evaluate, and forecast environmental factors based on socio-economic development activities. For instance, in a study by Q.T. Doan, et al. (2019) [3], the MIKE model was employed to simulate turbidity propagation from dredging and dumping activities in the Quy Nhon seaport area. Similarly, the study by D.S. Maren, et al. (2015) [4] investigated the effects of channel deepening and dredging on sediment concentrations in estuaries, offering a detailed analysis of sediment transport dynamics and the resulting environmental impacts. To assess the impact of dredging on the marine environment, prior research has primarily utilised 2D and 3D models. These models are grounded in field data and undergo calibration and validation to realistically simulate physical processes such as sediment dispersion and the movement of dredged material near the coast [13-15]. In this study, the MIKE 3 model is used to calculate and simulate the impact of coastal sand mining activities on turbidity dispersion, based on observational data from the Nam Dinh sand dredging project.

According to the Circular No.14/2024/TT-BTNMT on Technical Regulations for Exploration and Classification of Reserves and Resources of Marine Sand Mines, it is required to build flow models and suspended sediment dispersion models caused by sand mining activities, specifically utilising a 3D model. Therefore, applying the MIKE 3 modelling suite is essential for evaluating the impact of sand mining activities on the marine environment.

2. Materials and methods

2.1. Study area

The sand mining area is located in the coastal region of Nghia Hung district, Nam Dinh province, approximately 1.1 km from Con Mo (Con Xanh) in Nam Dien commune, about 6.5 km south of the Day river mouth, and about 10.5 km north of the Ninh Co river mouth. The mining area covers approximately 100 hectares, with a width of 500 metres and a length of 2 kilometres. The mining capacity is about 276,970 cubic metres per year, averaging around 1,108 cubic metres per day (Fig. 1) [10].

The study selected a typical year for simulation, from 1 January 2021 to 30 December 2021, divided into two periods corresponding to the Northeast monsoon and the Southwest monsoon. This division aims to assess the impact

Fig. 1. The location of the study area.

of seasonal wind regimes and hydrodynamic characteristics including tides, waves, ocean currents, river flows, and sediment transport on the turbidity dispersion process in the study area.

2.2. Methods

The research methodology is demonstrated through the following steps:

Data collection: Gather input data for the model, including topographical data, wind data, water levels, and sediment waves.

Model setup and calibration: Establish, calibrate, and validate the model.

Hydraulic simulation: Simulate seasonal hydraulic conditions using the hydrodynamic (HD) and spectral wave (SW) modules. The results of the hydraulic simulation will serve as input parameters for simulating turbidity dispersion. The research framework is illustrated in the diagram below (Fig. 2).

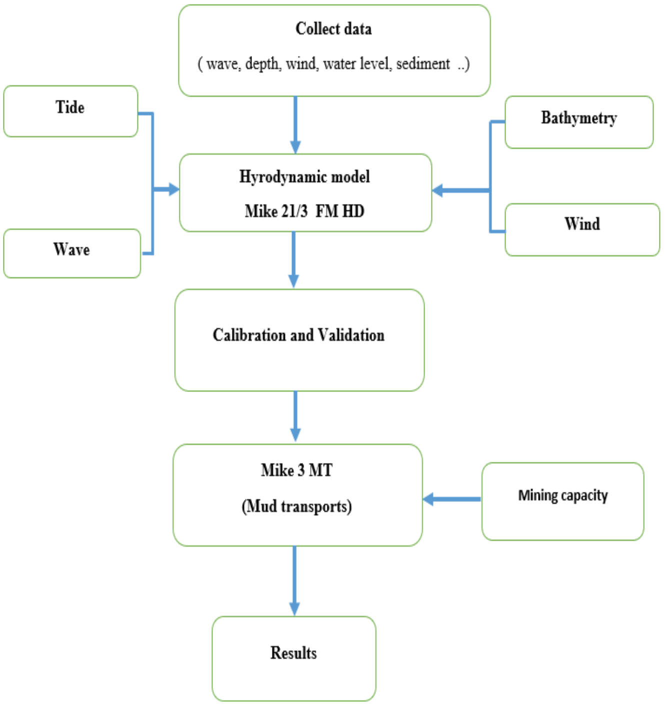

Fig. 2. Study approach flowchart.

The MIKE 3 hydraulic model is a 3D numerical modelling software developed by the Danish Hydraulic Institute (DHI). It is used for calculations in areas with complex terrain such as oceans, coastal zones, river mouths, seaports, rivers, and lakes. The model can simulate detailed impacts from various factors, including hydrodynamic conditions, terrain, currents, turbidity, and geology. It also accounts for the effects of density stratification, temperature, salinity, and interactions between atmospheric and marine factors (pressure, waves, and surface winds). The theoretical basis of the model is built on the shallow water equations, as follows:

The model is based on the solution of the three-dimensional incompressible Reynolds-averaged Navier-Stokes equations, subject to the assumptions of Boussinesq and hydrostatic pressure. The local continuity equation is written as [16]:

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

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

$$\frac{\partial u}{\partial t}+\frac{\partial u^2}{\partial x}+\frac{\partial vu}{\partial y}+\frac{\partial wu}{\partial z}=fv-g\frac{\partial \eta}{\partial x}-\frac{1}{\rho_0}\frac{\partial p_a}{\partial x}- \\ \frac{g}{\rho_0}\int_z^\eta \frac{\partial \rho}{\partial x}dz-\frac{1}{\rho_0 h}\left(\frac{\partial s_{xx}}{\partial x}+\frac{\partial s_{xy}}{\partial y}\right)+F_u\frac{\partial}{\partial z}\left(v_t\frac{\partial u}{\partial z}\right)+u_s \tag{2}$$

$$\frac{\partial u}{\partial t}+\frac{\partial u^2}{\partial x}+\frac{\partial vu}{\partial y}+\frac{\partial wu}{\partial z}=fv-g\frac{\partial \eta}{\partial x}-\frac{1}{\rho_0}\frac{\partial p_a}{\partial x}- \\ \frac{g}{\rho_0}\int_z^\eta \frac{\partial \rho}{\partial x}dz-\frac{1}{\rho_0 h}\left(\frac{\partial s_{xx}}{\partial x}+\frac{\partial s_{xy}}{\partial y}\right)+F_u\frac{\partial}{\partial z}\left(v_t\frac{\partial u}{\partial z}\right)+u_s \tag{3}$$

$$\frac{\partial v}{\partial t}+\frac{\partial v^2}{\partial y}+\frac{\partial uv}{\partial x}+\frac{\partial wv}{\partial z}=-fu-g\frac{\partial \eta}{\partial y}-\frac{1}{\rho_0}\frac{\partial p_a}{\partial y}- \\ \frac{g}{\rho_0}\int_z^\eta \frac{\partial \rho}{\partial y}dz-\frac{1}{\rho_0 h}\left(\frac{\partial s_{yx}}{\partial x}+\frac{\partial s_{yy}}{\partial y}\right)+F_v\frac{\partial}{\partial z}\left(v_t\frac{\partial v}{\partial z}\right)+v_s s \tag{4}$$

where t is the time; x, y, and z are 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 directions; $u = 2\Omega\sin\Phi$ is the Coriolis parameter (Ω is the angular rate of revolution and Φ 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; v_t is the vertical turbulent (or eddy) viscosity; P_a is the atmospheric pressure of the discharge due to point sources, and (v_s, u_s) is the velocity by which the water is discharged into the ambient water.

Data collection: The bathymetric data for the study area includes a 1:5,000 scale map inherited from an environmental impact assessment survey project, combined with deep-water topographic data at a 1:10,000 scale surveyed between

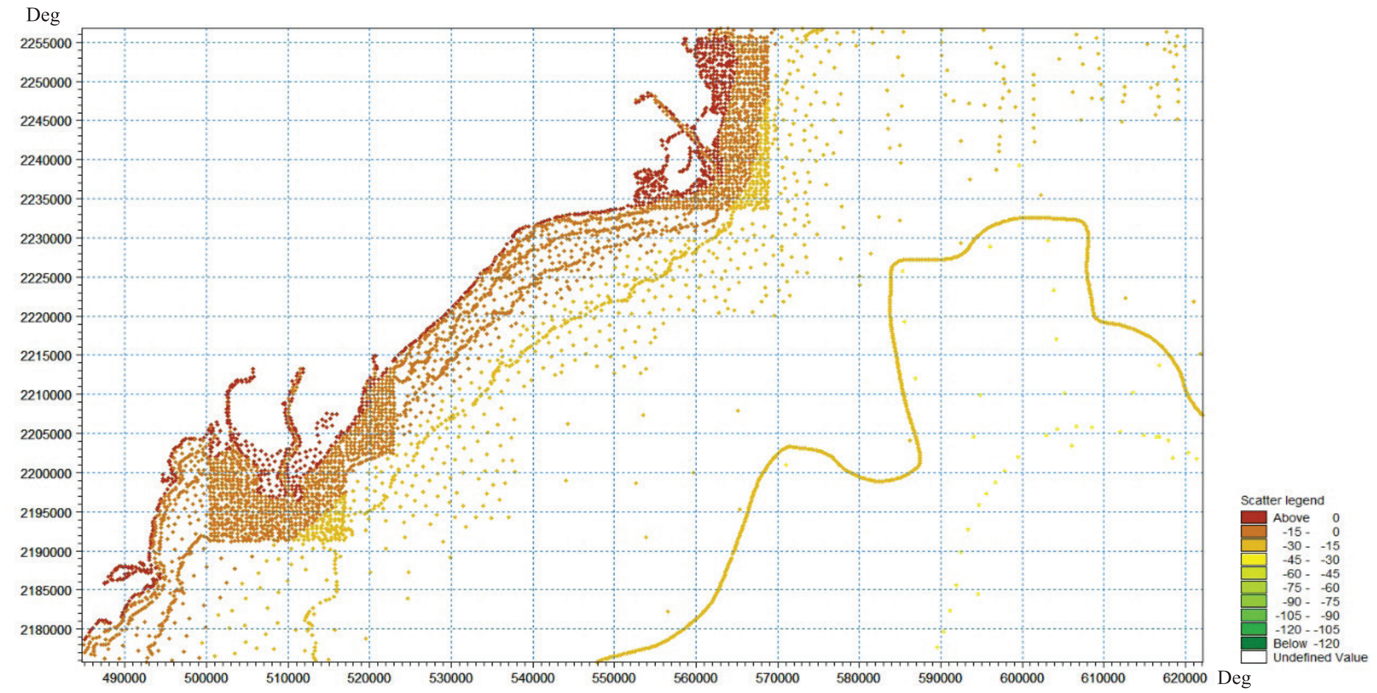

Fig. 3. The bathymetry data in the study area.

2007 and 2015. This data was provided by the Department of Cartography, Vietnam Ministry of Natural Resources and Environment, and has been adjusted and synchronised to the same elevation system for calculation purposes (Fig. 3).

Water level and river flow: The study utilised actual measurement data on water levels, currents, and suspended sediment from Van Ly station, Nam Dinh (20°1’46.07”N; 106°16’45.72”E), obtained from the project “Study on coastal dynamics changes and propose reasonable resource utilisation solutions for the coastal areas of northern and central Vietnam” (Code: NDT.30.RU/17) [17]. River flow data was collected from the Phu Le hydrological station on the Ninh Co river and the Nhu Tan station on the Day river in 2018 and 2021. Water level, flow, and wind data from 2018 were used for model calibration and validation, while data from 2021 were used for simulations according to sand mining scenarios.

Wave data: Offshore wave data near Nam Dinh were extracted from the results of the WAVEWATCH III model for a point located at coordinates 106°15’ E, 20°00’ N, covering the period from 1 January 2018 to 30 December 2021 (Fig. 4).

Wind data: The study used extreme wind data recorded at Hon Dau station between 2018 and 2021.

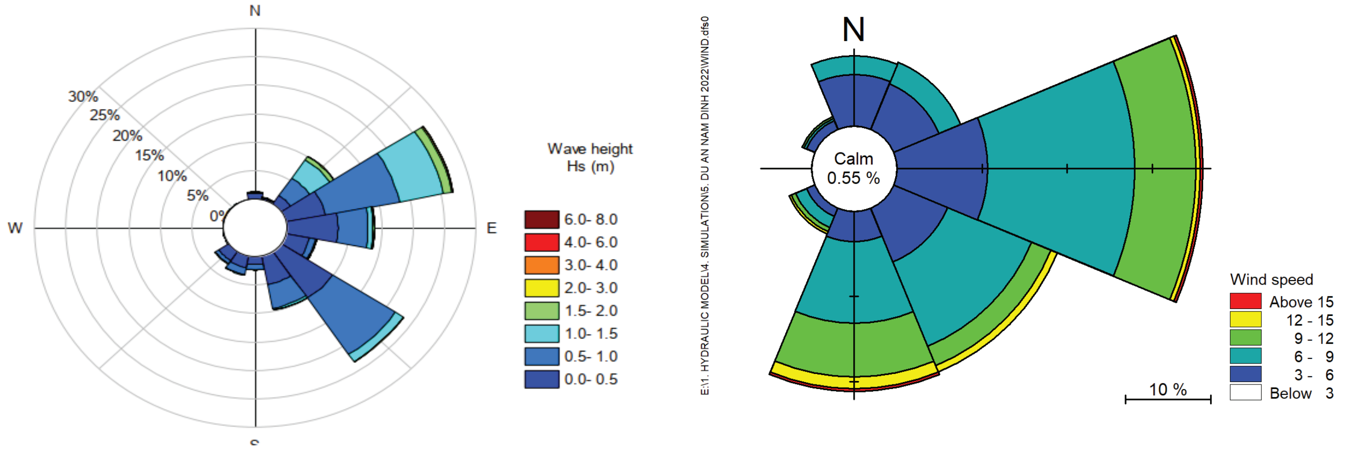

Fig. 4. Distribution of wave height and wave direction.

Sediment data: Sediment data and concentrations at the mouths of the Ninh Co and Day rivers were obtained from the survey data of the sand mining project. The analysis results of sand particle sizes are presented below (Table 1) [17].

Table 1. Sediment grain size distribution.

No.	Sediment grain size (mm)	Ratio (%)
1	0.25-0.5	3.5
2	0.1-0.25	66.6
3	0.05-0.1	24.7
4	0.01-0.05	5.3
5	0.005-0.01	7.4
6	D<0.005	3.08

2.3. Model setup

The computational domain of the model includes the coastal area of Nam Dinh province, extending approximately 41 km in length and 15 km from the coast to offshore. The grid for the study area consists of a total of 4,436 grid cells and 2,492 grid nodes, utilising a structured grid combined with orthogonal grids to optimise simulation time.

The model's boundary inputs include the sea boundary and the river boundary. The sea boundary consists of global tidal water levels obtained from the MIKE 21 Toolbox, while the river boundary includes discharge and suspended sediment concentrations at the mouths of the Ninh Co river and the Day river, extracted from the MIKE 11 hydrological model of the Red river - Thai Binh river system (Fig. 5).

2.4. Calibration and validation model

Calibration was performed by adjusting bed resistance, with a Manning number of 30, 32, and 35 $m^{1/3}$/s. The finite-volume model has been successfully tested in several basic, idealised simulations, where computed results were compared with analytical solutions. This study used the Nash coefficient for the calibration and validation model:

$$\text{Nash} = 1 - \frac{\sum (Xo,i - Xs,i)^2}{\sum (Xo,i - \overline{Xo})^2} \tag{5}$$

where Xo,i is the observed value, Xs,i is the computed value, and $\overline{Xo}$ is the average observed value.

Due to the lack of coastal oceanographic observation stations in the study area, survey data from Van Ly station in Nam Dinh was used for model calibration and validation (Fig. 5 and Table 2). Data from Van Ly station (20°1'46.07"N; 106°16'45.72"E), collected between 28 October 2018 and 5 November 2018, was used to calibrate the model. Subsequently, a time series from 14 November 2018 to 26 November 2018 was used for hydraulic model validation.

Table 2. Calibration and validation results.

No.	Manning number coefficient ($m^{1/3}$ /s)	Nash
1	28	0.94
2	32	0.82
3	35	0.80
4	Validation	0.93
5	Suspended sediment	0.65

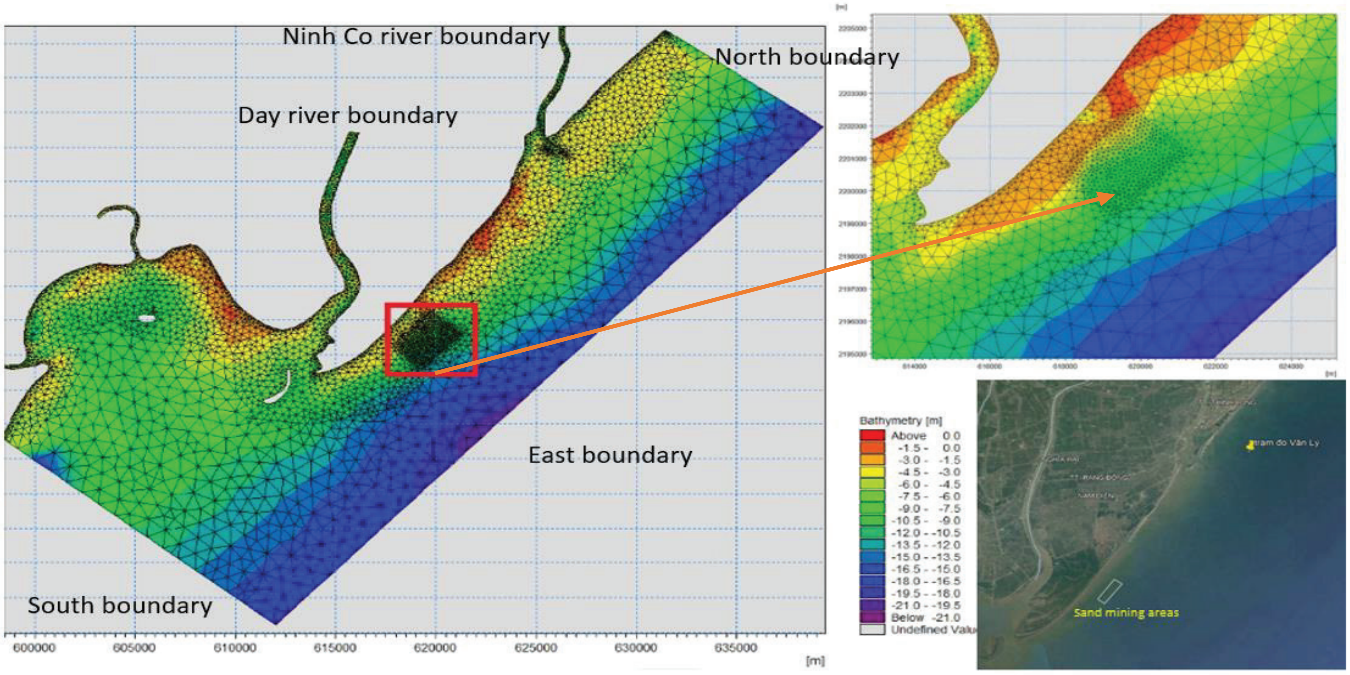

Fig. 5. The grid for the research area.

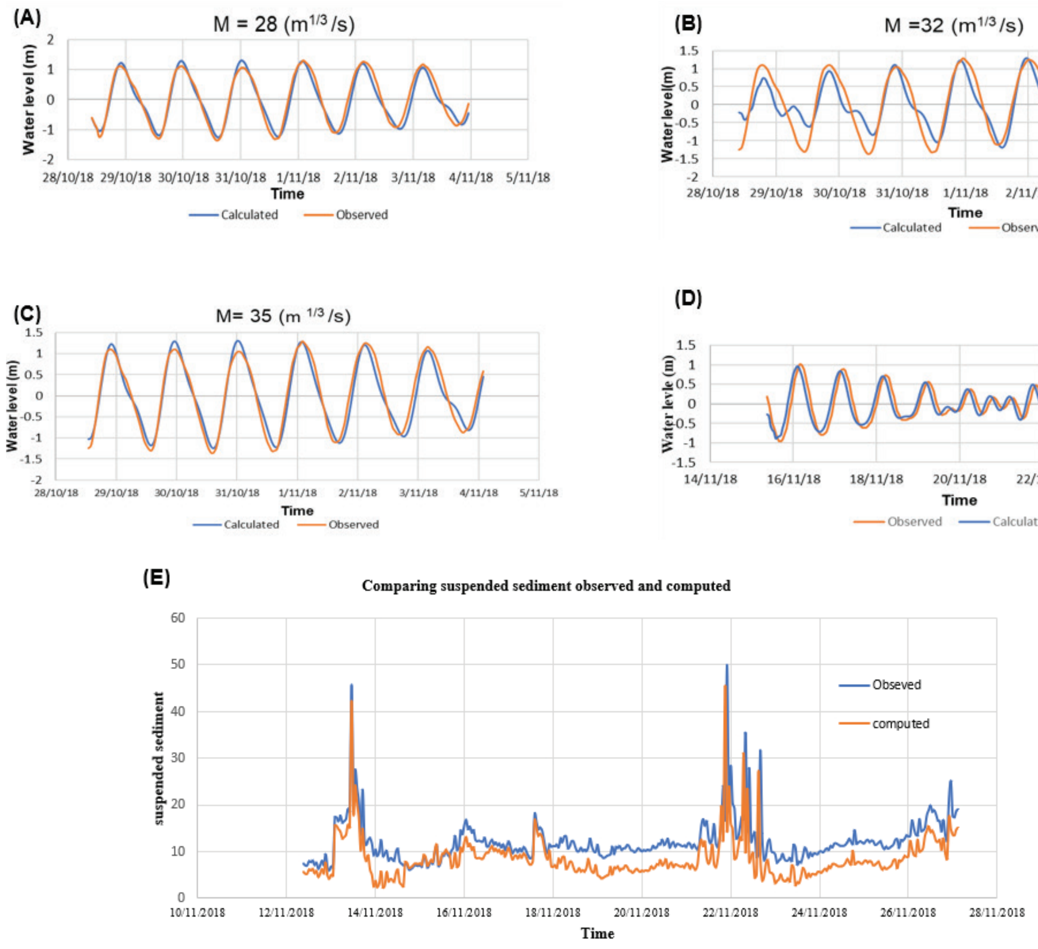

Fig. 6. Comparison of observed and computed water levels during calibration (A, B, C) and validation (D, E). Comparison of suspended sediment concentration.

The calculated and observed water levels demonstrated good agreement in terms of vibration amplitude, absolute value, and tidal phases during both calibration and validation (Fig. 6). The NSE value for calibration and validation of water levels at Van Ly station ranged from 0.80 to 0.94. Based on the calibration of the model's roughness coefficient, a Manning number of 28 yielded the best Nash coefficient result. Therefore, this value was selected for hydraulic model validation. In summary, the model's parameter set meets the accuracy requirements and can be used for simulating turbidity dispersion scenarios.

3. Results and discussion

The scenarios tested in the mud transport module are as follows:

Scenario 1 (S1): Simulation of turbidity dispersion during the Northeast monsoon season. This scenario used wind direction data from 1 January 2021 to 30 March 2021, recorded at Hon Dau station. The simulation time step was 30 seconds, with 250,000 iterations and an average extraction capacity of 14,204 m^3/day.

Scenario 2 (S2): Simulation of turbidity dispersion during the Southeast monsoon season. This scenario used wind direction data from 1 July 2021 to 30 September 2021, recorded at Hon Dau station. The simulation time step was 30 seconds, with 250,000 iterations and an average extraction capacity of 14,204 m^3/day.

3.1. Scenario 1 results

The model results indicated that the flow field in the study area was significantly influenced by topography, river flow, wind, and wave fields (Fig. 7). The flow field exhibited substantial fluctuations in both direction and speed, suggesting that sedimentation processes would vary under different conditions. The study decoupled the hydrodynamic module and the mud transport module in the 3D model to simulate sedimentation in the submerged zone separately.

The hydraulic simulation results demonstrated that flow direction in the dredged area generally moves from north to south, while flow directions near the river mouths vary significantly due to river currents. Streamflow velocity ranged from 0.25 to 0.65 m/s in the dredged area, with tidal flow velocities reaching up to 0.65 m/s during high tide (Figs. 7A, 7B).

The hydraulic results influenced the diffusion of total suspended solids (TSS) in the 3D MT model. The findings indicated that the highest concentration of sediment in the dredged areas was 0.15 kg/m³, below the acceptable limit of 0.5 kg/m³, set by Vietnam National Technical Regulation QCVN 10-MT:2015/BTNMT (Figs. 8A, 8B). During low tide, sediment concentration dropped to 0.045 kg/m³, spreading over an area of 6 km², while at high tide, the concentration exceeded 0.075 kg/m³ over an area of 8 km² (Figs. 8C, 8D). Despite these fluctuations, concentrations

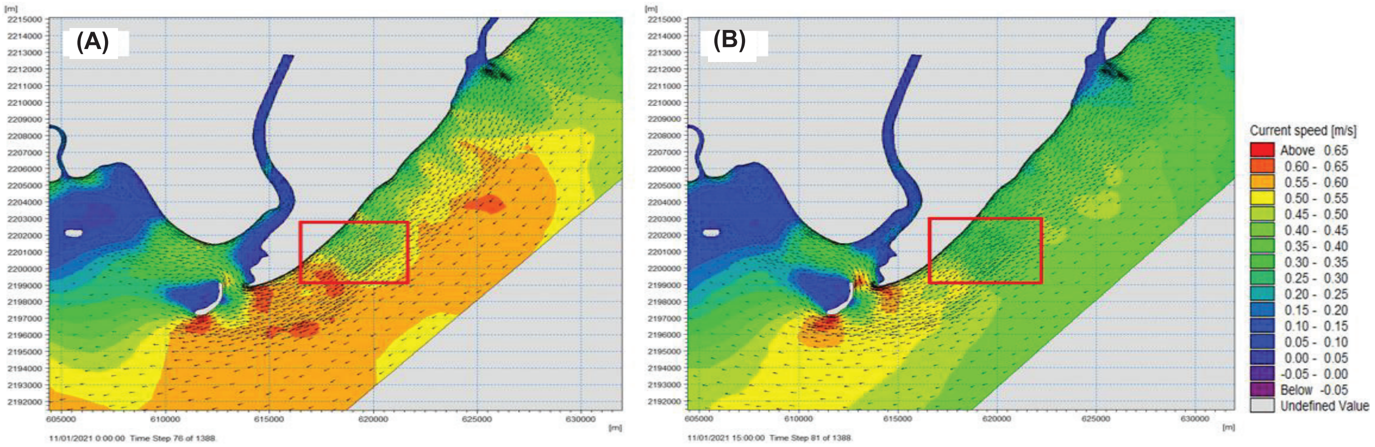

Fig. 7. Flow field results in the dredging area: (A) Low tide; **(B)** High tide.

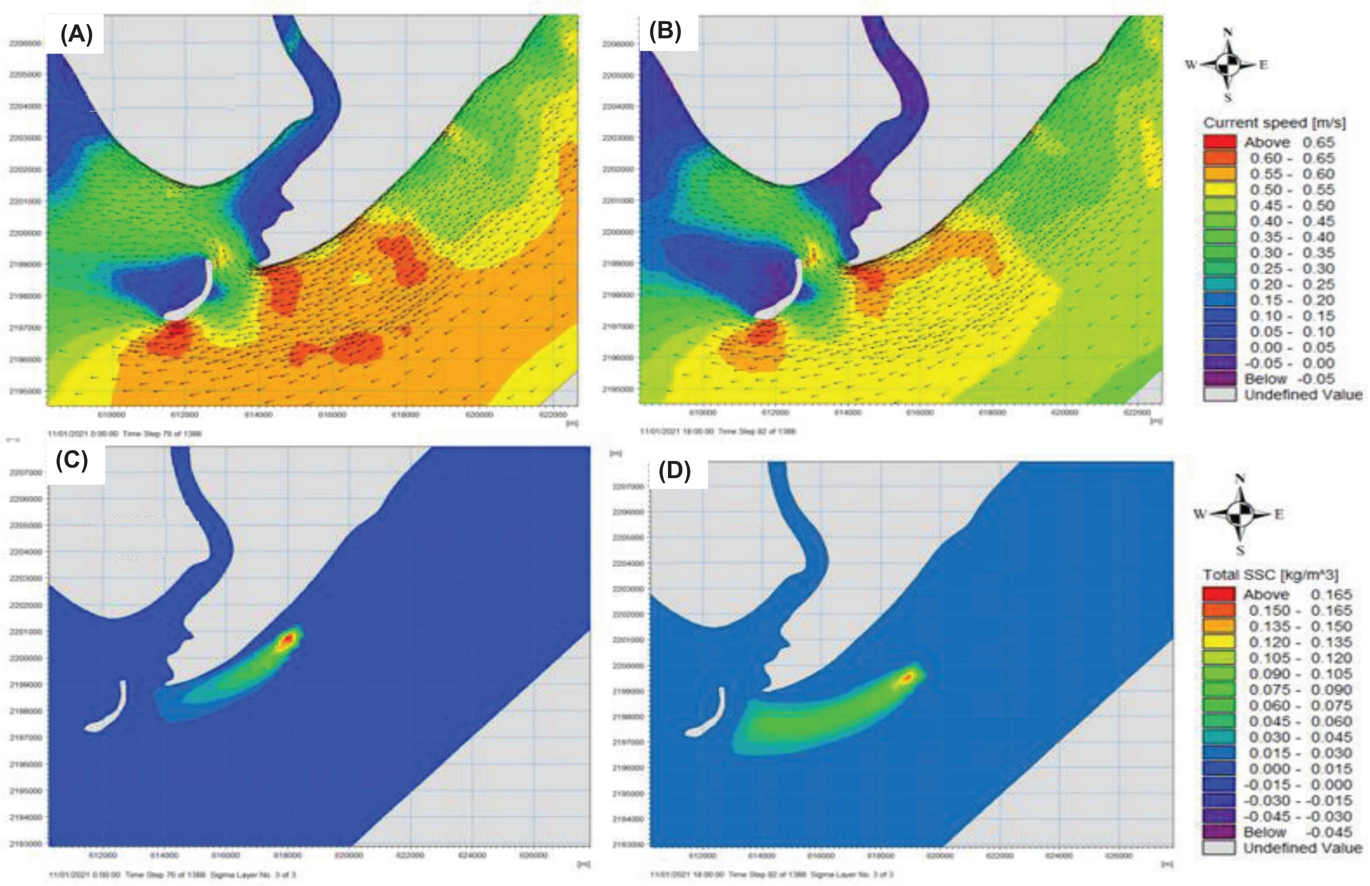

Fig. 8. Simulation results of Scenario 1: (A) Low tide streamflow; **(B)** High tide streamflow. Distribution of suspended sediment concentration (SSC): **(C)** Low tide; **(D)** High tide.

remained well below the regulatory threshold, indicating that dredged materials in this area were unlikely to cause excessive suspended material concentrations.

The hydraulic results influenced the diffusion of total suspended solids (TSS) in the 3D MT model. The findings indicated that the highest concentration of sediment in the dredged areas was 0.15 kg/m^3, below the acceptable limit of 0.5 kg/m^3, set by QCVN 10-MT:2015/BTNMT (Figs. 8A, 8B). During low tide, sediment concentration dropped to 0.045 kg/m^3, spreading over an area of 6 km^2, while at high tide, the concentration exceeded 0.075 kg/m^3 over an area of 8 km^2 (Figs. 8C, 8D). Despite these fluctuations, concentrations remained well below the regulatory threshold, indicating that dredged materials in this area were unlikely to cause excessive suspended material concentrations.

The turbidity dispersion process was significantly influenced by coastal currents, particularly the seasonal variations in wind patterns. During the Northeast monsoon season, current speeds increased compared to the Southwest monsoon, causing turbidity dispersion during the Northeast monsoon to expand further. This resulted in the Day river estuary being more affected by the turbidity dispersion process than the Ninh Co river estuary.

After one month of mining in the northern nearshore area of the Day river mouth, surface layer turbidity concentrations reached approximately 0.05 kg/m^3. In the mining area, the maximum turbidity concentration reached 0.28 kg/m^3, with an influence radius of 0.3 km along the coastline (Fig. 9A). After two months, the area influenced by turbidity concentrations >0.05 kg/m^3 expanded, with an influence radius of approximately 2.5 km. The maximum turbidity concentration in the mining area reached 0.33 kg/m^3, gradually decreasing southward, remaining below the acceptable limit. However, after three months, the maximum turbidity concentration at the extraction site reached 0.96 kg/m^3, exceeding the regulatory limit set by QCVN 10-MT:2015/BTNMT (Figs. 9B, 9C).

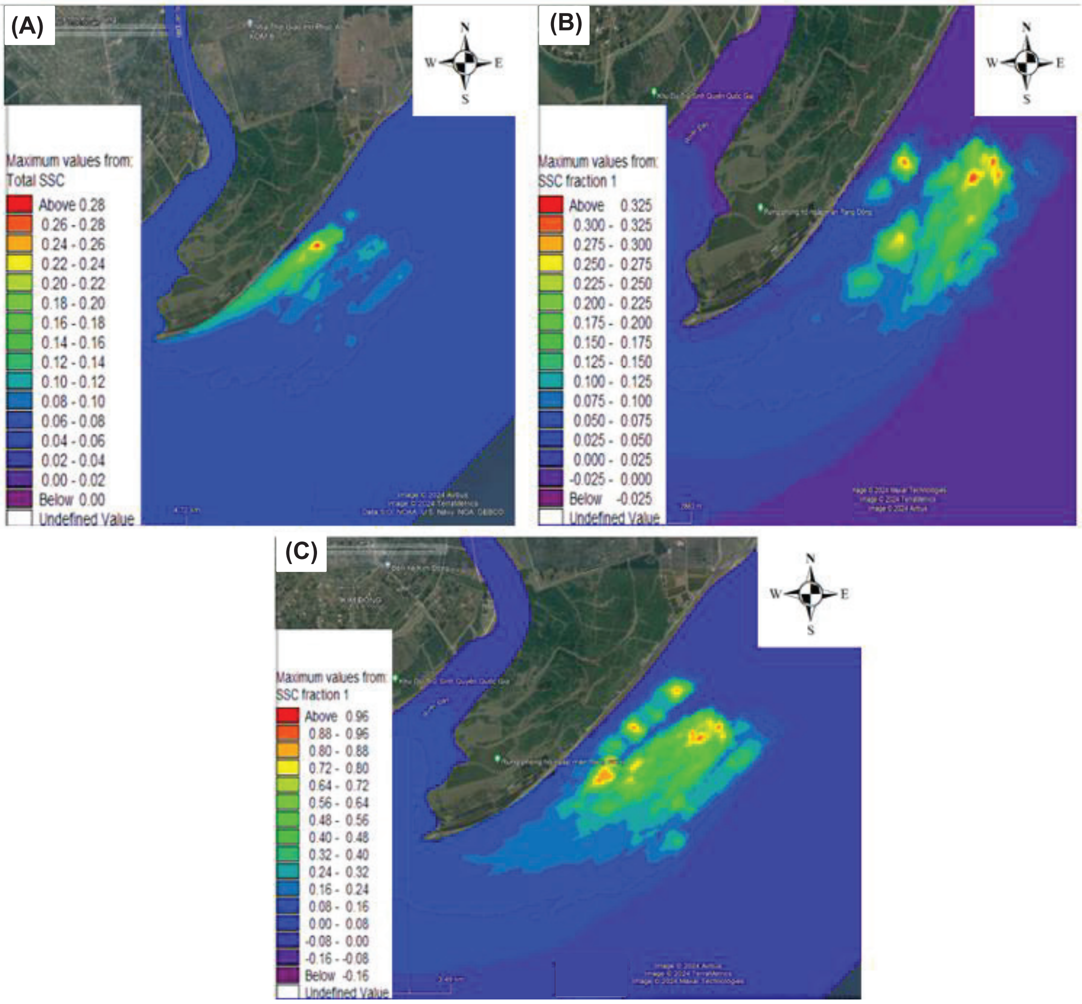

Fig. 9. Maximum turbidity field during the Northeast monsoon: (A) After 1 month, **(B)** After 2 months, **(C)** After 3 months of mining.

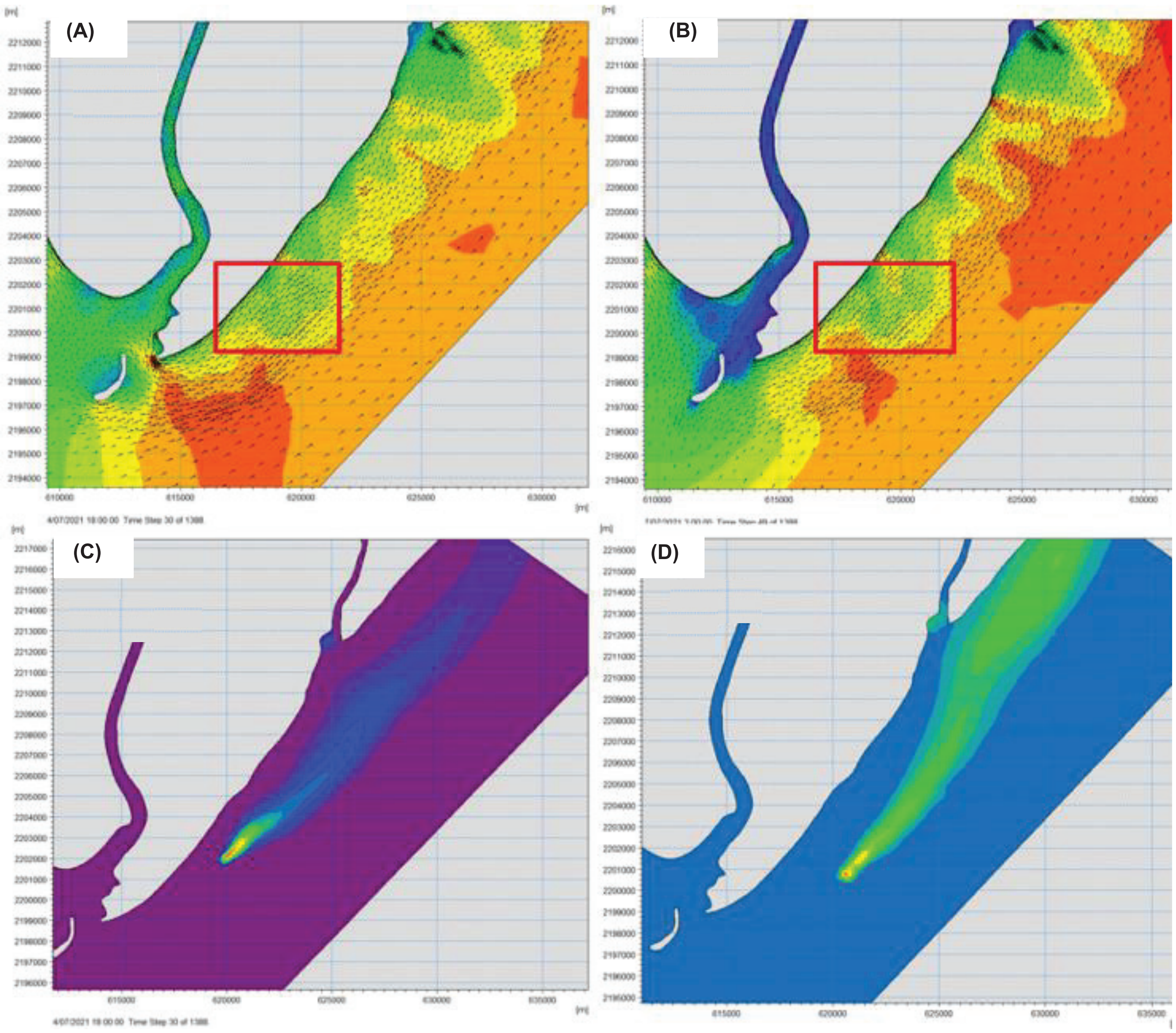

Fig. 10. Simulation results of S2. Streamflow field during **(A)** low tide, **(B)** high tide. Distribution of suspended sediment concentration (SSC) during **(C)** low tide, **(D)** high tide.

3.2. Scenario 2 results

During the Southeast monsoon season, the maximum flow velocity in the mining area reached 0.35 m/s, while the average flow velocity was 0.31 m/s. Simulation results for the wave regime indicated that the maximum wave height reached 1.7 m, while the average wave height was 0.56 m (Fig. 10).

The simulation results indicate that turbidity concentration tends to move from the south to the north of the sand mining area due to the influence of coastal currents during the Southwest monsoon season. In the mining area, the maximum sediment concentration reaches approximately 0.04 kg/m³, which is below the allowable limit set by TCVN 10-MT:2015/BTNMT. Meanwhile, in the coastal area of the Ninh Co river mouth, sediment concentration gradually decreases, ranging from approximately 0.008 to 0.024 kg/m³ (Fig. 11).

From the simulation results during the Southwest monsoon season, it was observed that areas where turbidity exceeds the threshold of 0.05 kg/m³ extend along the coastline from the mining site to the mouth of the Ninh Co river. After 1 month of sand mining in the extraction

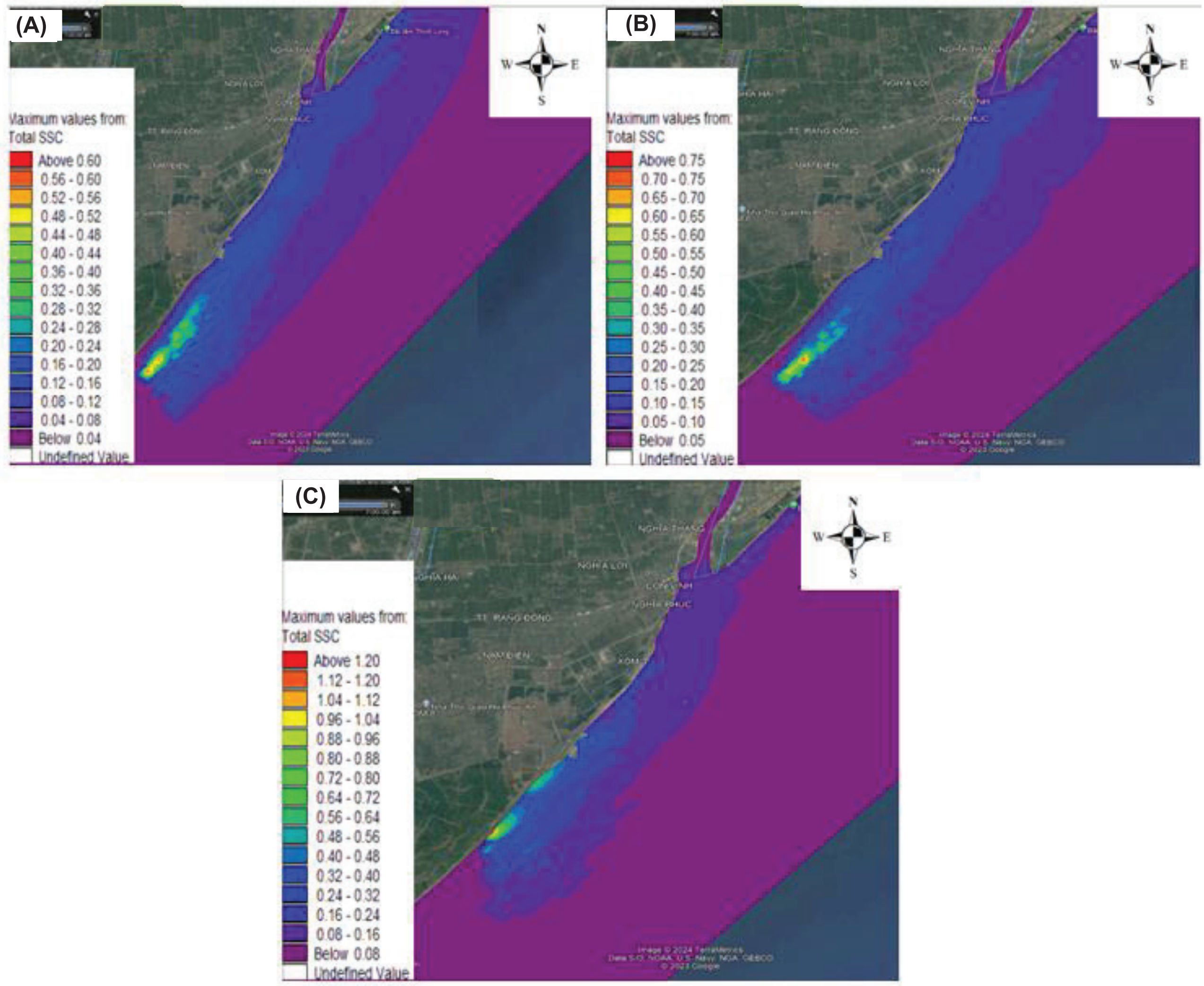

Fig. 11. The maximum turbidity field in the research area during the Northeast monsoon season: (A) After 1 month of mining; **(B)** After 2 months of mining; **(C)** After 3 months of mining.

area, the maximum turbidity concentration reached 0.6 kg/m^3 with an influence radius of approximately 0.3 km. Due to the combined effects of currents and monsoonal winds, turbidity tends to move northward from the mining area. Consequently, the coastal area near the mouth of the Ninh Co river experienced the highest turbidity concentration, reaching 0.2 kg/m^3, while the coastal area near Thinh Long town had a maximum turbidity concentration of about 0.1 kg/m^3. The area near the mouth of the Day river was minimally affected by turbidity dispersion from sand mining activities. After 2 months of mining, the maximum turbidity reached 0.86 kg/m^3 with an influence radius of 0.5 km. Turbidity dispersion primarily occurred along the coastline, driven by nearshore currents, with turbidity exceeding the threshold of 0.05 kg/m^3 from the mining area to the mouth of the Ninh Co river. After 3 months of mining, the maximum turbidity concentration in the coastal area of the mining site reached 0.96 kg/m^3, while turbidity at the mouth of the Ninh Co river and Thinh Long town was approximately 0.32 kg/m^3.

During the Northeast monsoon season, the flow rate of small rivers is minimal, and suspended sediment transport to the river mouths (Ninh Co river, Day river) is negligible, almost approaching zero (Fig. 12). Turbidity distribution seems to be minimally affected by sediment sources from the rivers. Conversely, during the Southwest monsoon season, the flow rate of rivers increases significantly, and the sediment load transported to the sea is higher, leading to increased turbidity, particularly from the mining site to the mouth of the Ninh Co river, and in coastal areas.

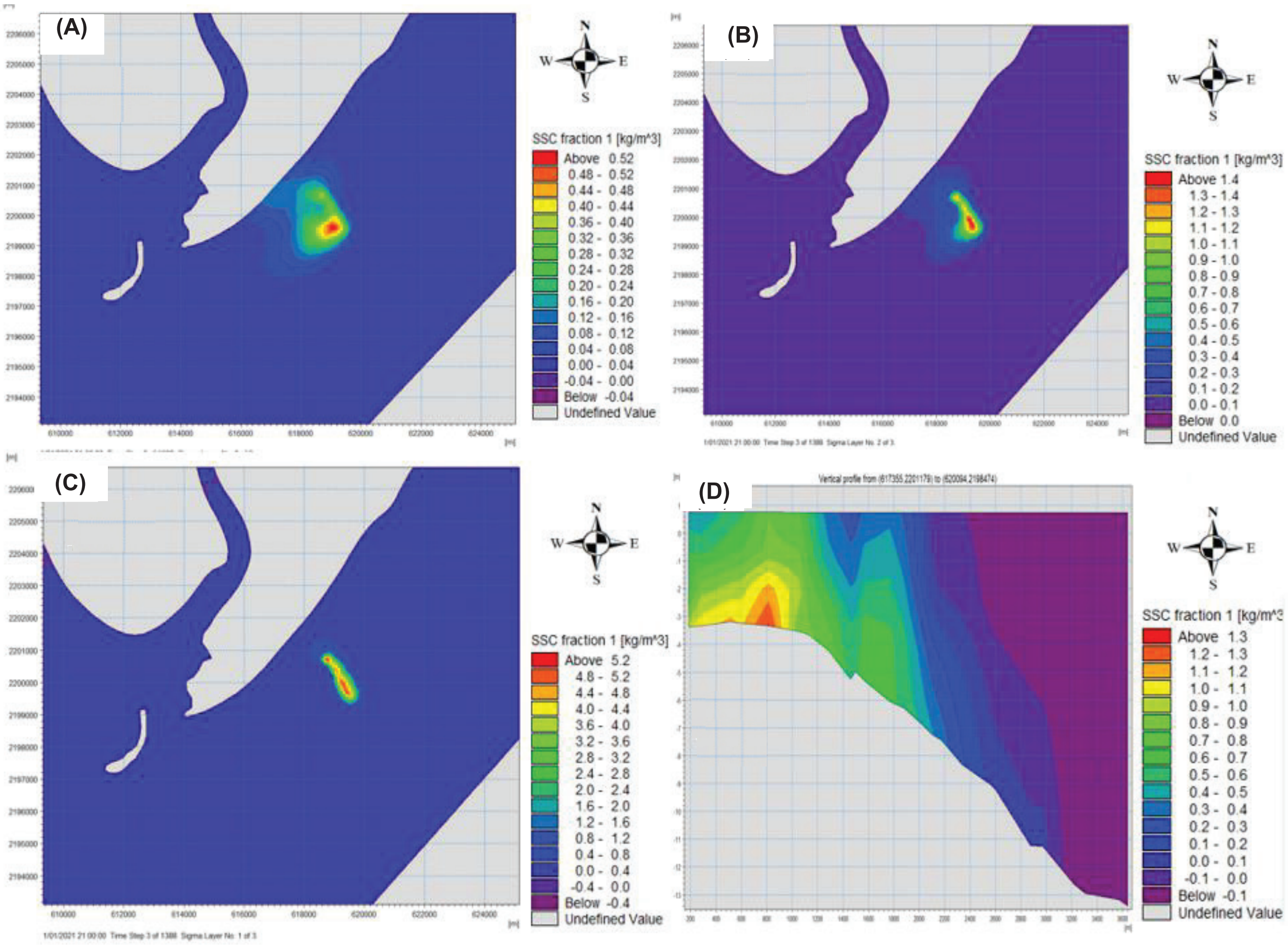

Fig. 12. Turbidity dispersion by depth: (A) Surface layer, **(B)** Middle layer, **(C)** Bottom layer, **(D)** Along the cross-section.

One of the advantages of the MIKE 3 model compared to the MIKE 21 tool is its ability to calculate hydrodynamic regimes and turbidity dispersion processes across different water depths, as well as assess turbidity across cross-sections. In contrast, the MIKE 21 tool calculates only average values. Therefore, the MIKE 3 model provides detailed information on the impact of turbidity across three-dimensional cross-sections [9, 10].

The results of turbidity propagation by depth from sand mining activities show that turbidity tends to increase gradually from the surface to the bottom layer. At the bottom layer, turbidity concentration ranges from approximately 1.4 to 5.2 kg/m^3 with an influence range of about 0.6 km. In the middle layer, turbidity concentration ranges from 0.32 to 1.3 kg/m^3 with an influence range of about 0.8 km. At the surface layer, turbidity ranges from 0.14 to 0.52 kg/m^3 with an influence range of about 2 km.

4. Conclusions and recommendations

The research results provide a scientific basis for assessing the impact of sand mining activities on the marine environment in the coastal area of Nam Dinh province. The findings indicate that the trend of turbidity propagation depends on the flow regime and wind conditions during the monsoon periods. During the Northeast monsoon, the current flow causes turbidity propagation from sand mining activities to affect the coastal area and the mouth of the Day river. Conversely, during the Southwest monsoon, turbidity propagation moves northward, impacting the mining site and the mouth of the Ninh Co river.

Turbidity levels at the mouth of the Ninh Co river during the Southwest monsoon season were higher compared to the Northeast monsoon season due to the combined effects of increased river flow during the flood season and coastal currents, which transported turbidity from the mining area to the river mouth. Therefore, it is recommended that the mining project focuses operations during the Northeast monsoon season to minimise the impact of sediment turbidity on the marine environment in the study area.

With a mining volume of 14,204 m^3/day, turbidity concentration remains within permissible limits according to TCVN 10-MT:2015/BTNMT for the first 1 to 2 months. However, after 3 months, turbidity concentration at the mining site exceeds the allowable limit. The simulation results using the MIKE 3 model also show that sediment concentration decreases from the bottom layer to the surface layer. At the bottom and middle layers, sediment concentration exceeds the regulatory threshold, while at the surface layer, it decreases and remains below the permissible limit according to TCVN 10-MT:2015/BTNMT.

The area with turbidity exceeding 0.5 kg/m^3 is concentrated around the mining area with an influence radius of approximately 2 km, while surrounding areas remain within permissible limits according to TCVN 10-MT:2015/BTNMT. Nevertheless, it is recommended that the sand mining project consider reducing the mining volume to mitigate the impact on the marine environment in the study area.

CRediT author statement

Van Lan Vu: Conceptualisation, Funding acquisition, Resources; Dac Thuyet Bui: Software, Visualisation; Quoc Viet Tran: Investigation, Writing original draft; Minh Cat Vu: Project administration, Writing - Reviewing and Editing; Tra Mai Ngo: Data curation, Methodology, Supervision, Validation, Formal analysis.

COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

REFERENCES

[1] S.G. Bolam, H.L. Rees (2003), “Minimizing impacts of maintenance dredged material disposal in the coastal environment: A habitat approach”, *Environment Management*, **32**, pp.171-188, DOI: 10.1007/s00267-003-2998-2.

[2] P.L.A. Erftemeijer, B. Riegl, B.W. Hoeksema, et al. (2012), “Environmental impacts of dredging and other sediment disturbances on corals”, *Mar. Pollut. Bull.*, **64**, pp.1737-1765, DOI: 10.1016/j.marpolbul.2012.05.008.

[3] Q.T. Doan, J. Kandasamy, C.D. Nguyen (2019), “Quantitative assessment of the environment impacts of dredging and dumping activities at sea”, *Applied Sciences*, **9**, pp.1-20, DOI: 10.3390/app9081703.

[4] D.S. Maren, T. Kessel, K. Cronin, et al. (2015), “The impact of channel deepening and dredging on estuarine”, *Continental Shelf Research*, **95**, pp.1-14, DOI: 10.1016/j.csr.2014.12.010.

[5] S. Davies, H. Mirfenderesk, R. Tomlinson, et al. (2009), “Hydrodynamic, water quality and sediment transportmodeling of estuarine and coastal waters on the Gold Coast Australia”, *Proc. J. Coast. Res.*, **56**, pp.937-941.

[6] A.N. Menendez, N.D. Badano, M.F. Lopolito, et al. (2013), “Water quality assessment for a coastal zone through numerical modeling”, *J. Appl. Water Eng. Res.*, **1**, pp.6-18, DOI: 10.1080/23249676.2013.827892.

[7] Department of Natural Resources and Environment of Nam Dinh Province (2022), *EIA Report of The Project: Exploitation of Sand Minerals for Common Construction Materials at Lot 14 in The Coastal Area of Nghia Hung District, Nam Dinh Province* (in Vietnamese).

[8] Ministry of Natural Resources and Environment (2024), *Circular No. 14/2024/TT-BTNMT of August 30, 2024, Providing Technical Regulations on Exploration and Classification of Reserves and Resources of Sea Sand Mines* (in Vietnamese).

[9] Danish Hydraulic Institute Software (2007), *MIKE 21 & MIKE 3 Flow Model FM Hydrodynamic Module User Guide*.

[10] Danish Hydraulic Institute Software (2011a), *Mud Transport Model. User Guide. MIKE 21/3.*

[11] Danish Hydraulic Institute Software (2014), *MIKE 3 Environmental Hydraulics Advection - Dispersion Module Scientific Documentation.*

[12] V.C. Ho, N.A. Tran, B.T. Nguyen (2020), “Application of the MIKE 3 model to simulate salinity intrusion in the Ninh Co river under climate change and sea-level rise conditions”, *Journal of Science and Technology in Water Resources*, **58**, pp.1-31 (in Vietnamese).

[13] Nam Dinh Provincial People’s Committee (2022), *EIA Report on The Project of Exploiting Sand for Filling Material at Lot 18 in The Coastal Area of Nghia Hung District, Nam Dinh Province* (in Vietnamese).

[14] M.H. Le (2018), “Application of a mathematical model to assess the impact of sand mining on the morphological evolution of the Tien river section from Tan Chau to Hong Ngu”, *Journal of Meteorology and Hydrology*, **23**, pp.56-67 (in Vietnamese).

[15] T.B. Nguyen, T.K. Tran, T.T.A. Tran, et al. (2023), “Assessment of the impact of sand mining on the bed evolution of the Tien river section flowing through Vinh Long province”, *Journal of Meteorology and Hydrology*, **12**, pp.24-34 DOI: 10.36335/VNJHM.2023 (in Vietnamese).

[16] Danish Hydraulic Institute Software (2011b), *MIKE 21 & MIKE 3 Flow Model FM Hydrodynamic Module*, 14pp.

[17] T.H. Nguyen (2017), “Study on coastal dynamics and proposed solutions for the rational use of coastal resources in northern and central Vietnam”, *Journal of Meteorology and Hydrology*, **23**, pp.1-14 (in Vietnamese).