

APPLICATION OF TWO-DIMENSIONAL HYDRODYNAMIC MODEL (MIKE21HD/FM) TO ASSESSING THE IMPACT OF SAND MINING IN THE LO RIVER AREA AND PROPOSING MANAGEMENT SOLUTIONS

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GENERAL INFORMATION

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MIKE 21FM;

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ABSTRACT

Phu Tho is a province with a developed mining industry, making an important contribution to economic development, creating jobs for people. In particular, the industry of exploiting sand as construction materials is also of interest to meet construction needs. However, the sand mining process impacts the environment, landscape and land area in the surrounding area. Therefore, research on application of two-dimensional hydrodynamic model (MIKE21HD/FM) to evaluate the impacts on river banks due to Song Lo sand mining activities, the section through Phu My commune, Phu Ninh district, Phu Tho province is necessary. In particular, sand mining lowers the river bottom, potentially changing basic hydraulic parameters such as water level, flow velocity and flow direction. The results show that after dredging all areas to the design exploitation height, the water level fluctuates from 22.16m to 20.2m. Along the center line from T1 to T10, it can be seen that the water level fluctuates, lower about 0.01m (or 1cm). From there, propose environmental management measures in sand mining, ensuring sustainable economic development goals.

1. INTRODUCTION

The explosion of the global population and urbanization (especially along coastal zones) has ballooned the commodification of sand and sand trade flows in the global system that has inextricably created unintended livelihood and ecosystem ramifications, notably marine biodiversity loss, a decline in marine food resources, water, and air pollution, agricultural

land degradation, and extreme weather events (e.g. coastal flooding) which have all been linked to anthropogenic climate change.

Sand is the 3rd most important natural resource after air and water (Ludacer, 2018), and is the second most exploited resource and the leading traded commodity by weight accounting for about 85% of the annual volume of minerals mined globally (Filho et

al., 2021, UNEP, 2019b). Since the 2000 s, sand has become a scarce but essential natural resource for development; albeit sand extraction has been dotted with myriad socio-economic and ecological costs (Siddique et al., 2020).

Table 1. Some of the leading sand importing and exporting countries by 2020

Country	Share/Volume of Sand (%)		Gross Monetary Value (Million US Dollars)	
	Imports	Exports	Imports	Exports
Canada	10.48	1.88	183	32.8
USA	3.33	20.23*	58.1	353
Germany	4.83	8.77	84.3	153
Netherlands	4.98	9.64	87.0	168
France	2.58	2.98	44.9	52.1
Belgium	8.30	6.30	145	110
Singapore	2.54	0.03	44.3	0.559
China	13.60*	4.67	237	81.5
India	0.53	0.32	9.20	5.65
Japan	5.35	0.47	93.3	8.19
Saudi Arabia	0.22	2.13	3.90	37.2
Mozambique	0.02	1.65	0.369	28.7
Egypt	0.10	2.24	1.7	39.1
Australia	0.11	8.59	2.0	150
Brazil	0.19	0.25	3.25	4.45

(Source: Matovu, Baker, 2024)

Phu Tho is a province with a strongly developed mining industry. Besides stone quarries, soil and sand used for construction materials are also invested in and exploited to meet local construction needs. Reality in recent years has shown that the exploitation of sand mines as construction materials for industrial, transportation, and civil works has brought much efficiency and increasingly attracted the market of Phu Tho province.

Investigating and evaluating material quarries serving civil and industrial construction projects is increasingly receiving more attention. Mineral exploitation for the construction industry makes an important contribution to economic development. In the development process in the new era, industrial parks and construction projects of different scales are being implemented en masse and increasing in number.

However, in addition to economic benefits, sand mining also has negative effects on the environment and people's lives. There is a risk of causing landslides and subsidence, which can lead to the loss of cultivated land and housing. Therefore, it is necessary to assess the impact of sand mining activities on each river section in the province.

Therefore, to build a basis for riverbed sand exploitation planning, the authors used the Mike21HD/FM model to calculate the hydrodynamic regime. However, the story of sand mining and the fear of river bank erosion is not a new story and the consequences it causes never get old.

The research area has a total area of more than 9 ha, including 2 areas as follows:

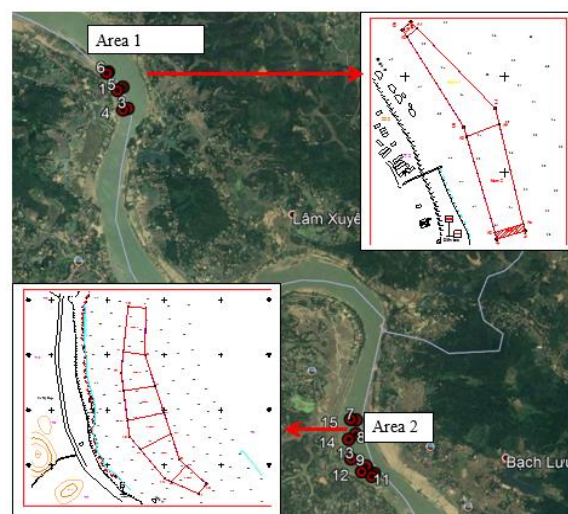


Figure 1. Study location

Area 1 belongs to Phu My commune and Area 2 belongs to Tri District commune. To the northwest of Area 1 is the upstream of Lo River, to the east and northeast is the left dyke of Lo River, about 10-45m from the boundary line between Phu Tho province and Tuyen Quang province, to the south and southeast is the downstream of Lo River. To the north of zone 2 is the upstream of Lo River, about 1,060m from the intersection of the three provinces of Phu Tho, Tuyen Quang, and Vinh Phuc. To the east of Area 2 is the left dyke of Lo River, about 1,060 meters from the boundary between Phu Tho province and Vinh province. Phuc is about 10-26m, the southeast of area 2 is the downstream of Lo River, about 70-90m from the rapids, the southwest of area 2 is about 150-230m from the right dyke of Lo River.

2. METHODOLOGY

2.1. Field survey

Assess the current status of sand mining underway in the study area and its impacts on the surrounding environment and people.

2.2. Collect and process data

Relevant collected documents including:

- Topographic documents include:
 - + Topography in the exploitation area measured in 2020, scale 1/2000.
 - + Topography of the entire river from Vu Quang hydrological station to Viet Tri hydrological station measured in 2012.
- Hydrological documents:
 - + Flow rate, water level, suspended sand and mud at Vu Quang station in 1996, 2018 and Decision 3032/QD-BNN-TCTL dated July 19, 2016.
 - + Water level at Viet Tri station in 1996, 2018 and Decision 3032/QD-BNN-TCTL dated July 19, 2016.
- Sand and mud documents

- + Suspended sand and mud at Vu Quang station.

- + Bottom sand and mud measured at the project.

2.3. Use model Mike21 HD/FM

The flow module is developed by the finite element mesh method. This module is based on the numerical solution of the system of Navier-Stokes equations for 2- or 3-dimensional incompressible fluids combined with the Boussinesq assumption and the hydrostatic pressure assumption.

The one-way model has been thoroughly researched by domestic research units, such as the Vietnam Institute of Water Resources, University of Water Resources, Institute of Planning, Institute of Hydrometeorology and Climate Change. In this research, collect and reuse for the project.

Upper boundary: Is the flow process line at the inlets of the river network:

- + At Hoa Binh hydrological station on Da river
- + At Yen Bai hydrological station on Thao river
- + At Ham Yen hydrological station on Lo river
- + At Na Hang hydrological station on Gam river
- + At Thac Ba on Chay River
- + At the downstream of Lien Son dam on Pho Day river
- + At Buo Waterfall on Cau River
- + At Phu Cuong on Ca Lo river
- + At the downstream of Cau Son dam on Thuong river
- + At Chu on Luc Nam river

+ At Hung Thi on Hoang Long River
 + At the downstream of Day dam on Day river

+ At Vat Lai on Tich River

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The basins in the middle zone join: include 2 types:

a. The flow path of the middle basins at the location of joining the river network is calculated:

+ Area between Hoa Binh - Trung Ha Flv= 1100 km², entering Da river at 32749 m

+ Area between Chu-Luc Nam Flv= 630 km², joining Luc Nam river at 20000 m

+ Luc Nam middle area - Flv intersection = 310 km², joining Luc Nam river at 45,000 m

+ Area between Buoï Waterfall - Flv junction= 2100 km², entering Cau River at 50000 m

+ Area between Cau Son - Flv intersection = 800 km², entering Thuong river at 36118 m

+ Area between Ham Yen - Flv junction = 500 km², entering Lo river (Lo River from Ham Yen to Lo-Gam junction in the model is set as HAM YEN) at 15000 m.

b. The process of drainage water flow from field plots to the intra-field river network or main river network

Therefore, the module includes the equations: equations of continuity, momentum, temperature, salinity and density and they are closed by the turbulence closure scheme. In the three-dimensional case, use the sigma coordinate system.

- Continuity equation

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

- Momentum equation in x and y direction respectively:

$$\frac{\partial u}{\partial t} + \frac{\partial u^2}{\partial x} + \frac{\partial vu}{\partial y} + \frac{\partial wu}{\partial z} = fv - g \frac{\partial \eta}{\partial x} + \frac{\partial u^2}{\partial x} + \frac{1}{\rho_0} \frac{\partial p_a}{\partial x} - \int_z^{\eta} \frac{\partial \rho}{\partial x} dz + Fu + \frac{\partial}{\partial z} \left(vt \frac{\partial u}{\partial z} \right) + uzS \quad (2)$$

In which: t is time; x , y and z are coordinates; η is water level fluctuation; d is the depth; $h = \eta + d$ is the total depth; u , v and w are the velocity components in the x , y and z directions; $f = 2\Omega \sin \phi$ is the Coriolis parameter; g is the gravitational acceleration; ρ is water density; ν_t is vertical turbulent viscosity; p_a is atmospheric pressure; ρ_0 is the standard density; S is the magnitude of the flow due to the source points and (us, vs) is the

velocity of the flow entering the calculation domain. F_u are the horizontal stress terms.

2.4. Procedure for implementing the mathematical model

a. Set up the model

- Collect, edit and digitize topographic and hydrological documents including water level, flow and sand and sediment documents in the study area;

- Build a grid of current terrain and structures to serve hydraulic and erosion calculations;

- Set up boundary conditions for the models;

- Set up initial conditions;

- Determine the current morphological characteristics of sedimentation and erosion to build a set of sedimentation and erosion model parameters;

- Set up basic parameters of flow and sand transport models, including roughness coefficient, turbulence coefficient, diffusion coefficient and friction...

b. Calibrate parameters and test the model

Calibrating parameters and verifying mathematical models is an important and labor-intensive step in model research. The

reliability of the model or in other words the reliability of the calculation results in the next research step depends mainly on this step. A well-tuned and validated model means that the model is capable of accurately simulating hydrodynamic processes under different conditions. The model will be calibrated and tested by comparing calculated data and actual measured data.

c. Calculate necessary scenarios

After the model has been fully set up with terrain conditions, boundaries, suitable grids, verified and assessed for accuracy... as in the above steps, the model is applied to simulate the following cases. Interested in serving calculations and analysis for the project.

3. FINDINGS AND DISCUSSION

3.1. Set up terrain and calculation grid

The topography on the entire route from Vu Quang station to Viet Tri station is established with the number of sections from about 15,000 elements, the grid size ranges from 10-15m in the mining area and from 20-30m in the dump area. rivers, river banks, the purpose of implementing large terrain is to serve the overall model from Vu Quang to Viet Tri to provide boundaries for the detailed model; After calculating, extract results and analyze at points along the route from T1 to T10 as shown in Figure 2.

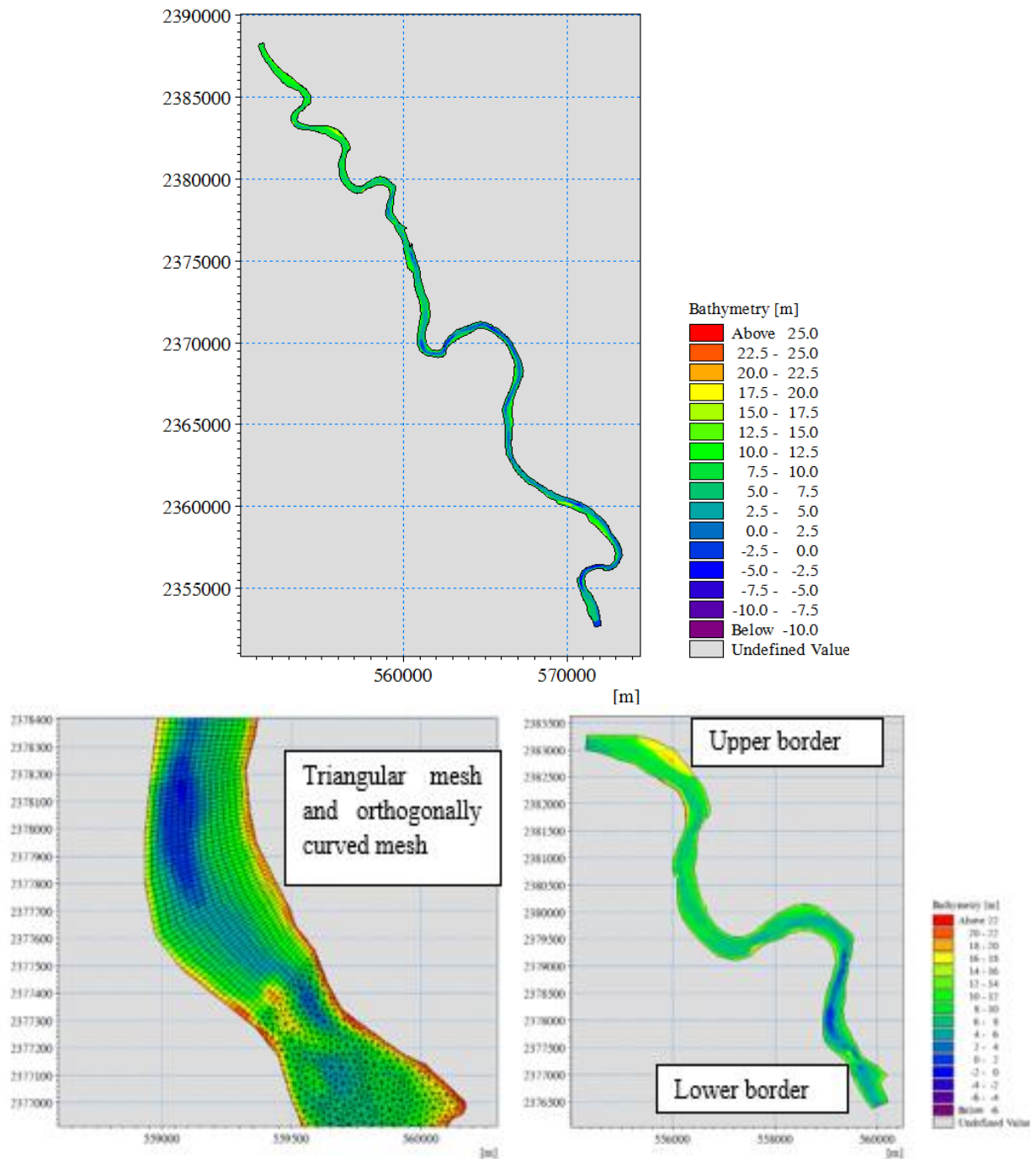


Figure 2. Terrain and calculation grid

3.2. Simulation results of hydrodynamic regime

To evaluate the hydraulic regime including all normal conditions and regular flood conditions, seasonal transition conditions from low water to flood, the project calculated with the 2018 flow and extracted.

At point T1, the water level in 2018 fluctuated low to medium to large from 10.08-12.11-16.82m, flow speed from 0.7-0.92-1.25m/s.

Table 2. The water level and flow speed

Point	Min	Max	Medium
Water level (m)			
T1	10.08	16.82	12.11
	Speed (m/s)		
T5	0.70	1.25	0.92
	Water level (m)		
T5	9.19	16.26	11.39
	Speed (m/s)		
T10	0.50	1.23	0.90
	Water level (m)		
T10	8.02	15.49	10.28
	Speed (m/s)		
T10	0.69	1.46	1.09

Under flow conditions in 2018, the minimum flow at Vu Quang station was 323m³/s, average 1055.9m³/s, maximum 3850m³/s; Suspended sand and sediment flow reaches about 4.4-49g/m³ and reaches a maximum of about 1300g/m³ during floods. The calculation results show that the sedimentation areas dominate and are distributed along both sides of the riverbank, while the erosion areas occur mainly in the mainstream area, notably in the dredged area. mainly tends to sediment at a rate of about 1-1.5m/year.

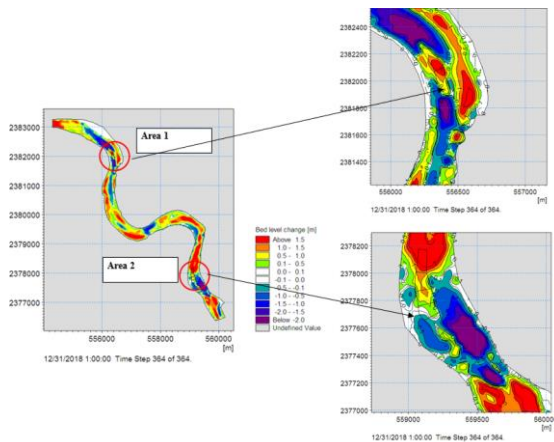


Figure 3. Sediment and erosion zoning on the entire route in 2018

The influence of hydraulic conditions throughout the year will include processes from the influence of low flows, average flows, regular flows, regular flood flows, before and after exploiting changes. Changing the terrain to lower the river bed according to the design documents shows that the hydraulic results are not significantly different, shown by the water level and flow curves throughout the year at points T1, T5 and T10, which are the locations the beginning of the route, the middle of the route, and the end of the river route of the exploitation section, as shown in Figure 4.

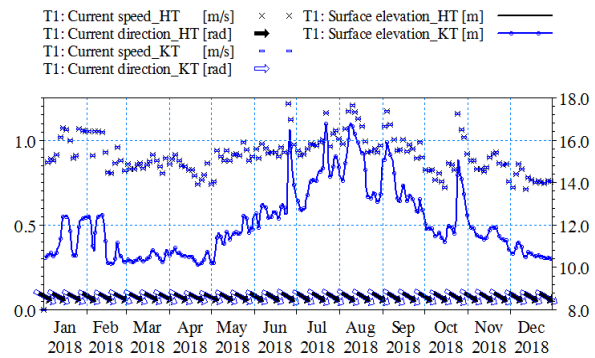


Figure 4. Comparison of water level and flow at point T1 before and after exploitation, hydraulic conditions assessed throughout the year

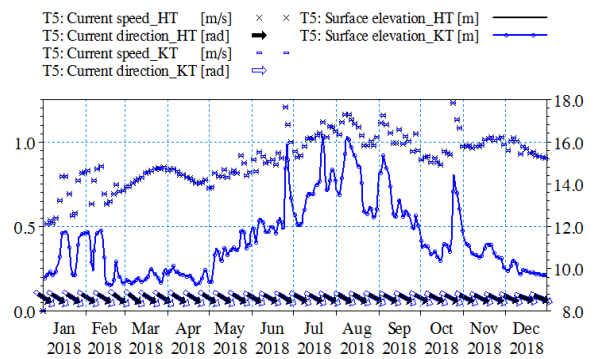


Figure 5. Comparison of water level and flow at point T5 before and after exploitation, hydraulic conditions assessed throughout the year

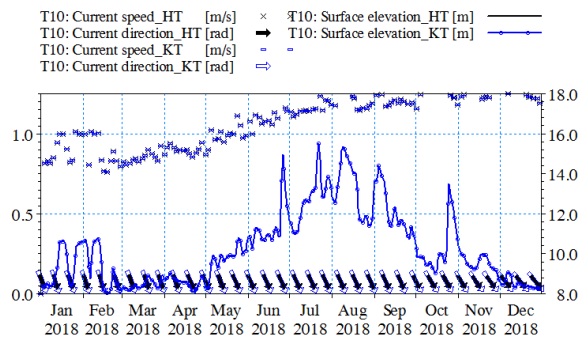


Figure 6. Comparison of water level and flow at point T10 before and after exploitation, hydraulic conditions assessed throughout the year

The calculation results show that

The lowering of the river bottom due to sand mining can change basic hydraulic parameters such as water level, flow velocity and flow direction; The impact is assessed with high flow conditions due to the design flow level $Q_{tk}=10800\text{m}^3/\text{s}$. The results show that under design flood conditions, the vertical water level fluctuates from about 22.17m with current conditions; After dredging all areas to the design exploitation height, the water level fluctuates from 22.16m to 20.2m. Vertically from T1 to T6, it can be seen that the water level has decreased by about 0.01m. (or 1cm). As for the flow, the flow speed is about 1.76-2.46m/s and there is almost no difference between before and after exploitation.

Hydraulic conditions throughout the year will include processes from the effects of low flows, average flows, regular flows, regular flood flows, before and after exploitation, and changes in lower terrain. River bed elevation according to design documents shows that the hydraulic results do not have significant differences, shown by the water level and flow changes throughout the year at points T1 and T5, which are the beginning and end positions of the route. river route of the exploitation section. Under flow conditions in 2018, the minimum flow at Vu Quang station was $323\text{m}^3/\text{s}$, average $1055.9\text{m}^3/\text{s}$, maximum

$3850\text{m}^3/\text{s}$; Suspended sand and sediment flow reaches about $4.4\text{-}49\text{g}/\text{m}^3$ and reaches a maximum of about $1300\text{m}^3/\text{s}$ during floods. The sand and sediment transport calculation model performed in parallel with the hydraulic calculation results in the sedimentation and erosion zoning, showing that the sedimentation areas are dominant and distributed along both sides of the riverbank, while the Erosion occurs mainly in the mainstream area, it is worth noting that the dredged area mainly tends to sediment at a rate of about 1-1.5m/year.

3.3. Impacts of sand mining

The removal and trapping of sand along riverbanks and reservoirs has led to an 80% reduction in water quality in some rivers in Kerala and most rivers around the Western Ghats have experienced reduced water flows (Kondolf et al., 2014). Most sand mining zones in Kerala are located along riverbanks (river sand) and along coastal areas (coastal sand) which highly degrades water quality, and affects the sediment flux that replenishes lowland streams (India Rivers Forum, 2020). Sand mining degrades water quality and affects sediment recharge to lowland streams.

River sand mining has further stressed the natural fluvial processes of rivers leading to extensive vertical accretion, and changes in stream morphology and configuration affecting environmental integrity thus exacerbating the loss of water reservoir storage (Ramkumar et al., 2015); and flooding in plains and deltas; especially around Kochi (Ramkumar et al., 2015). A study by Gupta et al. (2012) observed that the decline in water quality and sediment fluxes in large rivers in India correlates with the increase in sand extraction for the construction of infrastructural projects such as dams.

3.4. Assess impacts on the ecosystem

The initial mining process has negative impacts on the underwater ecological environment that are much more significant than on the terrestrial ecosystem. Sand suction disturbs the quantity and type of benthic organisms. Some species such as those living in the topwater layer, surface water layer (fish, shrimp) and bottom layer (crabs, oysters, mussels...) will disappear or migrate to other places.

Aquatic creatures can be affected by the following causes:

- Turbidity pollution during the process of sucking sand along causes the oxygen content in the water to decrease significantly, and the ability of underwater animals to find prey is also affected due to limited or undetectable food sources. food.

- The concentration of construction vehicles leads to fuels, oils, and greases being scattered or overflowing when there are incidents during the capital construction process, polluting water sources and also causing negative impacts on water systems. underwater ecology.

3.5. Propose measures to minimize impacts

- Arrange a system of marker posts to observe shoreline developments on both sides of the river in the mining area and road signs.

- Invest in mining boundary buoys on the river in the licensed area.

- Only exploit within the licensed boundaries.

- When landslides or subsidence incidents occur, it is necessary to immediately notify the local authorities and take measures to reinforce and embank the river banks before proceeding with further activities.

4. CONCLUSION

To evaluate the impact of sand mining lowering the river bed on the hydraulic regime and sedimentation and erosion in the area of the exploited river section, in the study, modeling and simulation of hydraulic and sedimentation and erosion developments were carried out. Under prescribed design flow conditions, regular annual flow conditions – the Mike21HD/FM model ensures compliance.

Calculation results show that lowering the river bed can change basic hydraulic parameters such as water level, flow velocity and flow direction.

The results show that after dredging all areas to the design exploitation height, the water level fluctuates from 22.16m to 20.2m. Along the center line from T1 to T10, it can be seen that the water level fluctuates. Lower about 0.01m (or 1cm). As for the flow, the flow speed is about 1.76-2.46m/s and there is almost no difference between before and after exploitation.

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