УДК 504.75

Vu Thi Lan Anh

Doctor of Philosophy (PhD)

Faculty of Environment
Hanoi University of Mining and Geology, Vietnam

Nguyen Phuong Dong

PhD in Geography

Faculty of Environment
Hanoi University of Mining and Geology, Vietnam

ENVIRONMENTAL IMPACT ASSESSMENT OF SAND MINING ACTIVITIES IN THE TRA LY RIVER

Abstract: *River sand mining plays an important role in supplying construction materials for socio-economic development; however, it also poses various environmental risks and negative impacts. This study was conducted to assess the current environmental conditions in the Tra Ly River sand mining area and to predict potential environmental impacts that may arise during mining operations, thereby proposing appropriate mitigation measures. The research methods included field surveys, sampling and analysis of surface water, sediment, and air quality; estimation of emissions generated from mining and transportation activities; and application of the MIKE 21 model to simulate oil spill dispersion under potential spill scenarios. The results indicate that the baseline environmental quality within the study area remains generally good. Surface water, sediment, and air quality parameters were all found to comply with current Vietnamese environmental standards. Nevertheless, sand mining* *activities may increase dust and exhaust emissions, generate domestic wastewater, and pose environmental risks such as oil spills, fire and explosion incidents, and riverbank erosion. Oil spill simulation results show that under the influence of the Northeast monsoon, the oil slick tends to spread southward, potentially affecting mangrove forests and other sensitive coastal ecosystems.*

Keywords: *River sand mining; Tra Ly River; oil spill; MIKE 21; riverbank erosion.*

1. INTRODUCTION

Sand is one of the most important mineral resources for socio-economic development, particularly in the construction and infrastructure sectors. According to the United Nations Environment Programme (UNEP), global consumption of sand and gravel has reached approximately 50 billion tonnes annually, making it the second most exploited natural resource after water. Population growth, rapid urbanization, and increasing infrastructure development demands have transformed sand into a strategic raw material for the construction industry, which contributes approximately 13% of global GDP and consumes tens of billions of tonnes of construction materials each year (UNEP, 2019).

In Vietnam, the demand for construction sand has continuously increased to meet the requirements of industrialization, modernization, and infrastructure development. Sand is an indispensable material for transportation infrastructure, irrigation systems, residential buildings, urban areas, industrial parks, seaports, and especially national key projects such as the North–South Expressway. The growing demand for construction materials has accelerated sand mining activities across major river systems, with riverbed sand mining becoming the primary source of supply for the construction market.

However, despite its economic benefits, river sand mining also generates numerous adverse impacts on the natural environment and local communities.

Unsustainable extraction practices can alter hydrodynamic regimes, accelerate riverbank erosion, reduce aquatic biodiversity, and negatively affect water quality, riparian land resources, and the safety of infrastructure facilities. Previous studies have indicated that excessive sand mining is one of the major factors disrupting sediment balance within river basins, leading to ecosystem degradation and increasing the risk of natural hazards in downstream areas (Kondolf et al., 2018; UNEP, 2019).

The Tra Ly River is one of the major distributaries of the Red River Delta and plays an important role in regional economic development, inland waterway transportation, and the supply of construction materials. In recent years, sand mining activities along the Tra Ly River have intensified to meet the growing infrastructure and construction demands of Thai Binh Province and surrounding areas. This situation highlights the need for a comprehensive assessment of the environmental impacts associated with sand mining activities. Such an assessment provides a scientific basis for proposing appropriate management and mitigation measures, thereby contributing to efficient resource utilization, environmental protection, and sustainable development within the study area.

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted along the Tra Ly River, Hung Yen Province, Vietnam. The research period extended from June 2025 to January 2026.

2.2. Research methods

2.2.1. Field survey method

Field surveys were conducted throughout the study area to identify surrounding environmental receptors and sensitive components that could potentially be affected during the preparation and operation phases of the sand mining project. In addition, environmental sampling locations were determined to provide a basis for measuring baseline environmental parameters.

Figure 1. Field survey activities in the study area

2.2.2. Sampling and analytical methods

Surface water sampling and analysis

Surface water samples were collected at upstream, mining-zone, and downstream locations, as well as along the survey cross-sections, to evaluate variations in water quality resulting from sand mining activities.

Sampling procedures were carried out in accordance with TCVN 6663-6:2018 (ISO 5667-6:2014), which provides guidance for sampling water from rivers and streams. Sample preservation and handling followed TCVN 6663-3:2016 (ISO 5667-3:2012). Water samples were collected at depths of approximately 0.3–0.5 m below the water surface using specialized sampling equipment and stored in pre-cleaned polyethylene bottles.

Field parameters, including temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), and turbidity, were measured directly using a portable multi-parameter monitoring device.

After collection, samples were preserved at approximately 4°C and transported to the laboratory as quickly as possible to minimize changes in their chemical composition. Analytical results were compared with the requirements of QCVN 08-MT:2023/BTNMT on surface water quality to assess the impacts of sand mining activities on the aquatic environment.

Sediment sampling and analysis

Sediment samples were collected from riverbank areas affected by mining activities and from exploratory borehole cores. Prior to analysis, impurities such as plant roots and coarse gravel were removed. The samples were then sealed in polyethylene bags and transported to the laboratory.

The analyzed parameters included heavy metal concentrations, namely arsenic (As), lead (Pb), cadmium (Cd), copper (Cu), and zinc (Zn). Analytical procedures followed the applicable Vietnamese Standards (TCVN) for soil quality and environmental analysis. The results were compared with QCVN 43:2017/BTNMT on soil quality to evaluate the extent of soil degradation or contamination within the study area.

Ambient air sampling and analysis

Ambient air quality was assessed within the mining area and at material stockpiling sites. Monitoring locations were established based on the prevailing directions of dust and gaseous pollutant dispersion in the study area.

Dust and gaseous pollutants were sampled using ambient air sampling equipment operated at a constant flow rate. The sampling inlet was positioned approximately 1.5 m above ground level, corresponding to the average human breathing zone. The sampling duration was 60 minutes per sample.

2.2.3. MIKE 21 modeling method

To assess the extent of environmental impacts and predict the dispersion of oil in the event of an oil spill within the study area, the MIKE 21 modeling system was employed. MIKE 21 is an integrated numerical modeling platform capable of simultaneously simulating hydrodynamic processes, wave dynamics, advection–dispersion processes, and oil spill transport in aquatic environments (DHI, 2024).

The input data for the model included bathymetric data, tidal water levels at open boundaries, upstream river discharge, time-varying wind data, bed roughness coefficients, and turbulent diffusion parameters. The model was calibrated and validated using observed water level and flow velocity data to ensure the reliability and accuracy of the simulation results.

This modeling approach is considered an effective tool for rapidly simulating the temporal and spatial evolution of oil spills on the water surface. Oil spill input parameters included oil type, spill volume, oil density, kinematic viscosity, volatile fraction content, and the time and location of the spill event.

The simulations were conducted for periods ranging from 24 to 168 hours following the spill event in order to determine the oil slick trajectory, affected area, time required for the oil to reach environmentally sensitive zones, and the potential for oil contamination of shorelines and aquaculture areas.

3. RESULTS AND DISCUSSION

3.1. Environmental baseline conditions of the study area

3.1.1. Sediment quality assessment

The concentrations of heavy metals measured in sediment samples collected from the study area were all within the permissible limits specified in QCVN 43:2017/BTNMT. No evidence of soil or sediment contamination associated with industrial activities or mining operations was detected prior to project implementation. The results indicate that the environmental quality of the study area remains relatively stable and has not been significantly affected by anthropogenic pollution sources.

Table 1. Heavy metal concentrations in sediment samples collected from the project area

No	Parameter	Unit	TT1	TT2	TT3	TT4	TT5	TT6	QCVN 43:2017/BTNMT
1	Arsenic (As)	mg/kg	0.18	0.17	0.19	0.20	0.19	0.16	41.6
2	Zinc (Zn)	mg/kg	70.8	71.8	67.8	66.6	55.1	60.6	271
3	Lead (Pb)	mg/kg	<8.3	<8.3	<8.3	<8.3	<8.3	<8.3	112

4	Cadmium (Cd)	mg/kg	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	4.2
5	Copper (Cu)	mg/kg	23.9	23.3	23.8	23.24	23.4	23.1	108

The analytical results show that arsenic concentrations ranged from 0.16 to 0.20 mg/kg, representing less than 0.5% of the regulatory threshold. Zinc concentrations varied between 55.11 and 71.78 mg/kg, corresponding to approximately 20–26% of the permissible limit. Copper concentrations ranged from 23.06 to 23.91 mg/kg, accounting for approximately 21–22% of the standard value. Lead and cadmium concentrations were below the analytical detection limits and substantially lower than the regulatory thresholds.

Overall, the sediment quality within the study area can be considered good, with no indication of heavy metal accumulation or contamination. These baseline conditions provide a reliable reference for future environmental monitoring and impact assessment during the operation of the sand mining project.

3.1.2. Surface water quality assessment

The study area is located along the Tra Ly River, one of the major distributaries of the Red River system. The river plays a significant role in supplying water for agricultural production, aquaculture, inland waterway transportation, and domestic activities. The hydrological regime of the river is influenced by upstream discharge, tidal fluctuations in the estuarine zone, and seasonal variations.

The analytical results of surface water samples collected prior to project implementation indicate that all measured parameters complied with the requirements of QCVN 08-MT:2023/BTNMT for surface water quality in Table 2.

Table 2. Surface water quality in the study area

Parameter	Unit	Samples				QCVN 08-MT:2023/BTNMT
		NM01	NM02	NM03	NM04	
pH	-	7.77	7.66	7.50	7.49	6.0–8.5
DO	mg/L	6.75	6.50	6.57	6.40	≥ 5.0
TSS	mg/L	41	32	20	11	≤ 100
Salinity	‰	0.81	0.45	0.48	0.45	-
Ammonium (NH_4^+)	mg/L	<0.03	<0.03	<0.03	<0.03	<0.03
Nitrate (NO_3^-)	mg/L	0.96	1.28	1.30	1.25	-
Total Iron (Fe)	mg/L	<0.06	<0.06	<0.06	<0.06	0.5
Oil and Grease	mg/L	ND	ND	ND	ND	5.0
Coliform	MPN/100 mL	820	610	810	600	≤ 5,000

The pH values ranged from 7.49 to 7.77, indicating neutral to slightly alkaline conditions that are favorable for aquatic ecosystems. Dissolved oxygen (DO) concentrations varied between 6.40 and 6.75 mg/L, exceeding the regulatory threshold and reflecting well-oxygenated conditions suitable for aquatic organisms.

Suspended solids (TSS) concentrations ranged from 11 to 41 mg/L, substantially lower than the allowable limit of 100 mg/L. Low TSS concentrations suggest limited sediment disturbance and favorable water transparency conditions. Ammonium concentrations remained below the analytical detection limit (<0.03 mg/L) at all monitoring locations, indicating the absence of significant organic pollution sources. Nitrate concentrations ranged from 0.96 to 1.30 mg/L and were within acceptable levels for natural surface waters.

No oil and grease contamination was detected in any of the collected samples. Coliform densities ranged from 600 to 820 MPN/100 mL, considerably lower than the regulatory limit, suggesting minimal microbiological contamination.

Overall, the results demonstrate that the surface water quality in the study area remains good and has not been significantly affected by anthropogenic activities prior to the commencement of the project.

3.1.3. Ambient air quality assessment

Emission sources within the study area are primarily associated with local transportation activities, residential areas, and agricultural production. In the absence of large-scale industrial facilities or concentrated mining operations, ambient air quality remains relatively good.

Table 3. Ambient air quality monitoring results

Parameter	Unit	Result	QCVN 05:2023/BTNMT
Noise	dBA	62.5	70
Temperature	°C	33.7	-
Relative Humidity	%	74.6	-
Wind Speed	m/s	0.8	-
TSP	µg/Nm³	114	300
CO	µg/Nm³	<9,000	30,000
SO_2	µg/Nm³	96	350
NO_2	µg/Nm³	78	200

The monitored concentrations of total suspended particulates (TSP), carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) were all below the limits prescribed by QCVN 05:2023/BTNMT. Noise levels were also within the allowable threshold for ambient environments.

These findings indicate that the air environment in the project area has not experienced significant degradation. The absence of major industrial emission sources and the relatively open riverine environment contribute to effective atmospheric dispersion of pollutants.

Biodiversity status

The Tra Ly River ecosystem supports a diverse range of biological resources characteristic of estuarine and wetland environments. The area provides habitat for numerous fish species, crustaceans, plankton communities, waterbirds, and mangrove vegetation. These ecosystems play a vital role in maintaining ecological balance, supporting fisheries resources, and providing feeding and breeding grounds for many aquatic and terrestrial species.

In addition, adjacent aquaculture areas and mangrove forests represent environmentally sensitive receptors that may be affected by future mining activities. Therefore, the conservation of these ecosystems should be considered a priority in environmental management and monitoring programs associated with the project.

Figure 2. Mangrove forest ecosystem

3.2. Environmental impact assessment of sand mining activities

3.2.1. Impacts on air quality

Emissions from dredging operations

The project utilizes cable-operated clamshell dredgers with bucket capacities ranging from 1.2 to 2.3 m^3 powered by diesel oil (DO) containing 0.25% sulfur. Pollutant emission loads generated by dredging equipment were estimated using emission factors recommended by the World Health Organization (WHO) in combination with the fuel consumption rate of 4,208 L per working shift. A diesel density of 0.85 kg/L was assumed for the calculations.

The dispersion of gaseous pollutants and particulate matter in the atmosphere was simulated using the Pasquill–Gifford Gaussian dispersion model. Pollutant concentrations at ground level were estimated as a function of emission rate, wind speed, atmospheric stability conditions, and distance from the emission source.

Based on local meteorological data, average wind speeds were approximately 3.7 m/s during summer and 3.5 m/s during winter. Therefore, a representative wind speed of 3.0 m/s was selected for dispersion calculations under atmospheric stability class B (moderately unstable conditions).

The predicted concentrations of sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matter at distances ranging from 30 to 200 m from the dredging source were substantially lower than the limits specified in QCVN 05:2023/BTNMT. The results indicate that emissions generated by dredging activities are unlikely to cause significant deterioration of ambient air quality under normal operating conditions.

Emissions from sand transportation activities

Transportation of dredged sand from the extraction site to the storage area is carried out using twelve barges with a loading capacity of approximately 600 tonnes each. The maximum transportation distance is approximately 4 km, and each round trip requires approximately one hour. Under normal operating conditions, each vessel completes approximately twelve trips per day.

Emission loads associated with transportation activities were estimated using WHO emission factors according to the following relationship:

Emission Load = Emission Factor × Transportation Distance × Number of Vessel Trips per Hour

The estimated emission rates of SO_2, NO_x, CO, total suspended particulates (TSP), and volatile organic compounds (VOCs) were relatively low and are not expected to result in significant adverse impacts on regional air quality. Owing to the open river environment and effective atmospheric dispersion conditions, pollutant concentrations are anticipated to remain well below applicable environmental standards.

3.2.2. Impacts associated with wastewater generation

Approximately 70 workers are involved in dredging and transportation activities. Domestic wastewater generated by workers mainly contains suspended solids (SS), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), nitrogen compounds, phosphorus compounds, and pathogenic microorganisms.

Assuming a daily water consumption rate of 50 L per worker, the total water demand is estimated at 3.5 m³/day. Since wastewater generation is assumed to be equivalent to water consumption, the domestic wastewater flow rate is estimated at approximately 3.5 m³/day.

$$C_{SH} = \frac{A \times 1.000 \times n}{q} \left(\frac{mg}{l} \right)$$

Where:

– A: Pollutant load generated per person per day (g/person/day);

– n: Number of workers involved in the project;

– q: Total domestic wastewater generated per day (m³/day).

Based on the above assumptions, the concentrations of pollutants in untreated domestic wastewater generated by workers engaged in dredging and sand transportation activities were estimated as presented in the following table:

Table 6. Estimated pollutant concentrations in untreated domestic wastewater generated by workers involved in dredging and sand transportation activities

No.	Pollutant parameter	Unit	Estimated concentration	QCVN 14:2025/BTNMT
1	SS	mg/L	1,200–1,300	60
2	BOD_5	mg/L	1,100–1,200	35
3	NH_4^+-N	mg/L	160–210	8
4	P	mg/L	22–44	6

As shown in Table 6, the concentrations of pollutants in untreated domestic wastewater are significantly higher than the limits specified in QCVN 14:2025/BTNMT. Suspended solids (SS) exceed the regulatory limit by approximately 20–22 times, while BOD_5 concentrations are 31–34 times higher than the permissible value. Ammonium nitrogen (NH_4^+-N) exceeds the standard by 20–26 times, and total phosphorus (TP) concentrations are approximately 3.7–7.3 times above the regulatory threshold. These results indicate that untreated domestic wastewater generated during project activities could adversely affect receiving water bodies if discharged directly into the environment. Therefore, appropriate collection, treatment, and disposal measures must be implemented to ensure compliance with environmental regulations and to minimize potential impacts on water quality.

3.2.3. Potential environmental incidents

Oil spill risk

Oil spills represent one of the most significant environmental risks associated with sand mining operations. Such incidents may result from collisions involving dredging vessels, transportation barges, or other navigation-related accidents (UNEP, 2022; ITOPF, 2023).

To evaluate the potential impacts of an oil spill, a worst-case scenario was simulated assuming continuous release of the entire diesel inventory over a 24-hour period at the mining site. Following release, the spilled oil was transported and dispersed under the combined influence of hydrodynamic currents, waves, and wind forcing. The simulation was extended for an additional three days, resulting in a total simulation period of four consecutive days.

The Northeast Monsoon scenario was selected because it represents the most environmentally unfavorable condition, promoting oil transport toward the southern mangrove ecosystem, which constitutes a highly sensitive ecological receptor.

A diesel density of 0.89 kg/L was assumed. Based on the estimated fuel inventory, the spill source term corresponded to approximately 38.44 kg/h during the first 24 hours and was incorporated into the MIKE 21 Oil Spill Model.

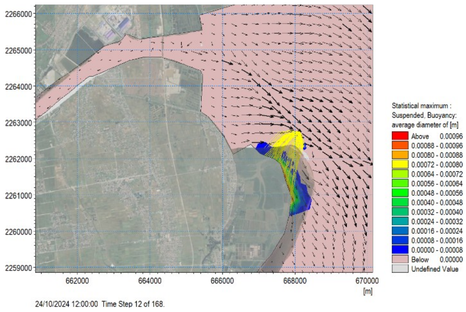

Figure 3. Oil spill extent and trajectory across the affected areas over a 12-hour period

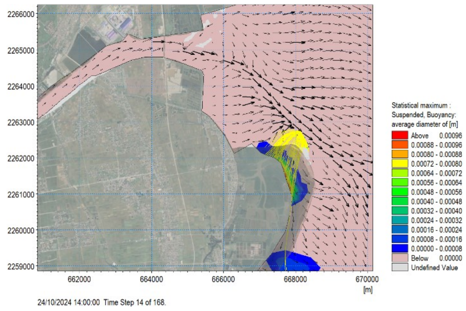

Figure 4. Oil spill extent and trajectory across the affected areas over a 14-hour period

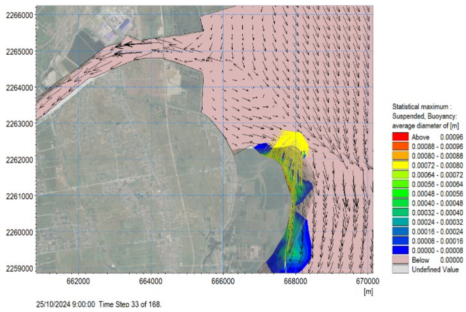

Figure 5. Oil spill extent and trajectory across the affected areas over a 33-hour period

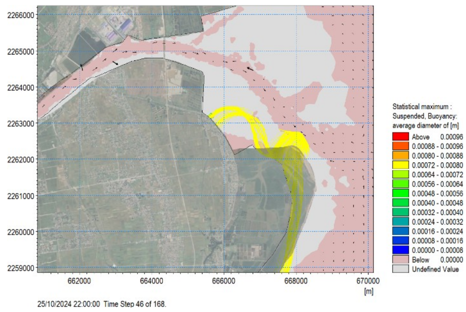

Figure 6. Oil spill extent and trajectory across the affected areas over a 46-hour period

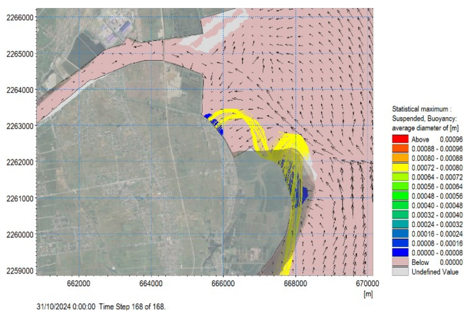

Figure 7. Oil spill extent and trajectory across the affected areas over a 168-hour period

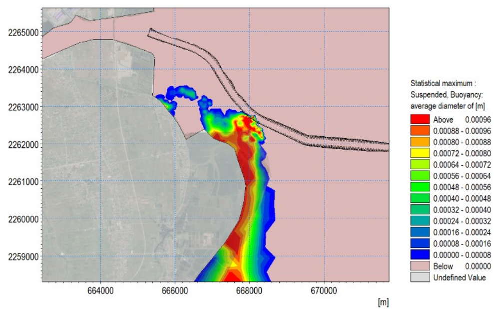

Figure 8. Maximum oil spill extent during the entire simulation period

Simulation results indicate that the oil slick initially spreads rapidly from the release location and subsequently migrates predominantly southward under the influence of coastal currents and prevailing monsoon winds. Portions of the oil slick may periodically move northward due to tidal reversals; however, the overall transport pattern remains strongly directed toward the southern coastal zone.

The maximum affected area occurs approximately 168 hours after the spill event. Mangrove forests and adjacent coastal ecosystems are identified as the most vulnerable receptors due to their ecological sensitivity and limited capacity for natural recovery following hydrocarbon contamination.

Fire and explosion hazards

Diesel fuel stored onboard dredging vessels and barges constitutes a potential fire and explosion hazard. Improper fuel handling, equipment malfunction, or negligence involving ignition sources may result in accidents threatening both human safety and project assets.

Although the probability of occurrence is relatively low, the potential consequences may be severe. Therefore, strict compliance with fire prevention regulations, emergency preparedness plans, and regular safety training programs is required throughout project implementation.

Riverbank erosion risk

From a hydrodynamic perspective, sand extraction removes substantial quantities of sediment from the riverbed, creating dredging pits that are significantly deeper than the natural channel morphology. These morphological alterations modify flow velocity distributions and increase bed shear stress and bank toe erosion.

Progressive erosion at the bank toe reduces slope stability and may trigger bank failure through sliding or mass collapse mechanisms. Previous studies have demonstrated that dredging pits located near riverbanks substantially increase the likelihood of bank instability compared with natural conditions.

Furthermore, excessive sand extraction disrupts the sediment balance of the river system. When sediment removal exceeds the natural replenishment capacity of the river, channel incision occurs, creating so-called “hungry water” conditions. Under such circumstances, the flow acquires additional erosive capacity and extracts sediment from both the riverbed and banks in an attempt to re-establish equilibrium. This process may persist for years after mining activities cease and can substantially increase erosion rates over a broad spatial scale.

3.4. Discussion

The findings indicate that the baseline environmental quality of the Tra Ly River remains relatively good compared with other sand-mining regions in Vietnam. Similar observations were reported by Nguyen et al. (2019) in Hai Phong coastal waters and by Yen et al. (2022) in estuarine areas of southern Vietnam. However, despite the current compliance with environmental standards, long-term sand extraction may alter sediment dynamics and increase riverbank instability if extraction rates exceed natural replenishment capacity. These findings are consistent with those reported by Kondolf et al. (2018) and Nguyen et al. (2024), who identified excessive sand mining as a major driver of channel incision and geomorphological degradation in tropical river systems.

4. CONCLUSIONS

This study assessed baseline environmental conditions and evaluated the potential environmental impacts associated with sand mining activities in the Tra Ly River. Monitoring results indicated that surface water quality, sediment quality, and ambient air quality within the study area complied with current Vietnamese environmental standards prior to project implementation.

Heavy metal concentrations in sediment samples were substantially lower than regulatory thresholds. Surface water quality parameters, including pH, dissolved oxygen, suspended solids, ammonium, nitrate, oil and grease, and coliform bacteria, all satisfied environmental quality requirements. Similarly, ambient air quality monitoring revealed no evidence of significant pollution.

The MIKE 21 oil spill simulation demonstrated that accidental oil spills constitute one of the primary environmental risks associated with the project. Under the influence of hydrodynamic currents and the Northeast Monsoon, spilled oil is likely to migrate southward and affect mangrove ecosystems and other environmentally sensitive coastal areas.

In addition, sand mining activities may alter riverbed morphology, increase bank toe erosion, and elevate the risk of riverbank failure if extraction activities are not adequately controlled with respect to location, depth, and extraction intensity.

ACKNOWLEDGEMENTS

The authors thank the HUMG project "Research on the impact of sand mining activities in the Tra Ly River area, Hung Yen Province using the MIKE21SW – HD – MT model" under Project Code: T26-38.

REFERENCES:

1. Bui, Q. T., et al. (2020). Assessment of the impacts of sand mining activities on river channel morphology and riverbank erosion in the Red River system. *Journal of Water Resources and Environmental Engineering Science* (in Vietnamese).
2. DHI. (2024). *MIKE 21 Flow Model FM: Hydrodynamic and Transport Module Scientific Documentation*. Danish Hydraulic Institute, Denmark.
3. Hoang, V. H. (2002). *Wastewater Treatment*.
4. International Tanker Owners Pollution Federation (ITOPF). (2023). *Oil Tanker Spill Statistics 2023*.
5. Kondolf, G. M., Rubin, Z. K., & Minear, J. T. (2018). Dams, river channel incision, and the sustainability of river-dependent sand mining. *Science*, 361(6405), 705–706. https://doi.org/10.1126/science.aav9719
6. Ministry of Construction of Vietnam. (2021). *Construction Materials Development Plan for the Period 2021–2030, with a Vision to 2050*. Hanoi, Vietnam (in Vietnamese).

7. Ministry of Natural Resources and Environment of Vietnam (MONRE). (2023). *National State of the Environment Report, 2021–2023*. Hanoi, Vietnam (in Vietnamese).
8. Nguyen, B. Q., Kantoush, S. A., & Sumi, T. (2024). Quantifying the consequences of unsustainable sand mining and cascade dams in a tropical river basin. *Scientific Reports*, 14, 1178. https://doi.org/10.1038/s41598-024-51405-z
9. Nguyen, M. H., Khanh, D. G., Vinh, V. D., & Lan, T. D. (2019). Impact of sand mining on sediment transport and morphological change of Hai Phong coastal area. *Vietnam Journal of Marine Science and Technology*, 19(3B), 127–138. https://doi.org/10.15625/1859-3097/19/3B/14517
10. Pham, N. T., Tran, A. D., Tanim, A. H., Nhan, T. T., & Tien, N. A. (2025). Sediment transport and morphodynamic changes due to upstream variation and sea level rise in the Western Mekong Delta, Vietnam. *Ocean Dynamics*, 75, 71–89.
11. United Nations Environment Programme (UNEP). (2019). *Sand and Sustainability: Finding New Solutions for Environmental Governance of Global Sand Resources*. Geneva, Switzerland.
12. United Nations Environment Programme (UNEP). (2022). *Sand and Sustainability: 10 Strategic Actions to Avert a Crisis*. Nairobi, Kenya.
13. Vu, T. H., Backhaus, L., Binh, D. V., Kantoush, S. A., & Stamm, J. (2025). Applying deep learning for boat detection and numerical modeling to assess sand mining impacts on river morphology: A case study in the Vietnamese Mekong Delta. *Geomorphology*, 490, 110010. https://doi.org/10.1016/j.geomorph.2025.110010
14. Vu, V. L., Bui, D. T., Tran, Q. V., Vu, M. C., & Ngo, T. M. (2025). Utilisation of the MIKE 3 model for simulating sediment transport in coastal areas of Nam Dinh Province affected by sand mining. *Vietnam Journal of Science, Technology and Engineering*, 67(2), 45–55.

15. World Bank. (2021). *The Hidden Environmental Cost of River Sand Mining*. Washington, DC, USA.
16. World Health Organization (WHO). (1993). *Assessment of Sources of Air, Water, and Land Pollution*.
17. Yen, B. T., Nguyen, T. V., & colleagues. (2022). Drastic variations in estuarine morphodynamics in Southern Vietnam: Investigating riverbed sand mining impact through hydrodynamic modelling and field controls. *Journal of Hydrology*, 608, 127572. https://doi.org/10.1016/j.jhydrol.2022.127572
18. Zhang, H., Nguyen, P. T., & co-authors. (2025). Assessing the multidimensional impacts of riverbed sand mining on geomorphological change and water transfer rate: A comprehensive investigation of Central Vietnam's Vu Gia–Thu Bon River system. *Journal of Hydrology*, 654, 132853. https://doi.org/10.1016/j.jhydrol.2025.132853