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Environmental Assessment of Coastal Sand Mining Using Proposed DPSIR Criteria: A Case of Hai Phong

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ABSTRACT

The environmental impact of coastal sand mining activities in Hai Phong city was assessed using ten proposed sustainable criteria for socio-economic development, and ecological and environmental protection. These ten criteria were developed by the analysis of the Dynamics-Pressure-State-Impact-Response (DPSIR) framework, including one driver and pressure criterion (D and P), seven status and impact criteria (S and I), and two response criteria (R). Each criterion is quantified according to five specific evaluation criteria corresponding to the evaluation score from 1 to 5. The results of the ten criterion application for environmental impact assessment of coastal mining Hai Phong by weighting show that the areas with economic activities, benthic biodiversity, and coastal ecosystems are most negatively impacted (score 4/5 and 3.5/5). Other subjects suffer low to moderate impacts (score 1/5 to 3/5). The environmental impact of sand mining (2015-2020) is generally moderate (score ranging from 2/5 to 3/5). The set of adjusted criteria can be applied to similar activities in coastal provinces and cities in Vietnam.

1. Introduction

Environmental assessment is by law required for all development projects in Vietnam, including coastal and marine projects such as sand minings that take place frequently in estuaries along the coast of Vietnam [1]. Coastal sand mining directly has impacts on ecosystems and water quality at mining sites and surrounding areas. In many cases, these impacts are seriously negative on benthic fauna and flora [1-8]. Potential environmental impacts

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on ecosystems and environmental qualities need criteria to rate their levels that often serve coastal sustainable management [9,10]. For specific activities such as coastal sand mining, the proposed criteria focus on assessing their impact on marine ecosystems and water quality at the extraction sites. For years, the criteria have been developed and used over the world [9-13] and in Vietnam for many fields, including environmental assessment as indicators [9,11-14]. In the marine environmental study towards sustainable development in Vietnam, criteria, indicators and indices are developed for assessing the quality of marine environments, marine ecosystems and human activities, and natural processes that affect the marine environment and ecology [9,11,15,16]. A quantitative approach to assessing the impact of sand mining activities in the coastal area of Hai Phong follows the DPSIR (Driver-Pressure-State-Impact-Response) framework that is commonly applied in environmental fields [9,14,17,18]. Accordingly, the criteria for assessing the environmental impact of these activities on the environment and ecosystems in the coastal area are researched, proposed and applied in specific conditions and in the period 2015-2020.

The coastal area of Hai Phong is typical to study the interaction between human development activities and the natural environment due to the diversity of development activities as well as the natural value exploitation versus its conservation. The pressures on marine resources and the environment in this coastal area have questioned effective and reasonable management, exploitation, and use to serve development needs while still ensuring environmental protection goals. In the current issues related to resource management and the environment in Hai Phong, the problem of sustainable management of sand mining activities in the coastal area has emerged. This study focuses on proposing criteria and using these ones for the environmental assessment of coastal sand mining to serve sustainable management in coastal Hai Phong.

2. Methods and Materials

2.1 Study Area

Located in the coastal area of Vietnam's Northeast region, Hai Phong city is a place with many favorable conditions for socio-economic development. Key economic sectors of coastal Hai Phong include maritime shipping and ports with the largest seaport system in the North and the gateway to the sea of the Northern provinces of Vietnam, marine tourism with sand beaches and land and sea sceneries and urbanization associated, aquaculture and agriculture, mining of constructional materials including sands. Coastal Hai Phong is also known for its rich marine resources, many endemic species, and high economic value living resources and high biodiversity, particularly in Cat Ba Biosphere Reserve listed by UNESCO (2004). In recent years, due to fast and intensive economic development, the demand for the exploitation and use of natural resources is increasing, especially the demand for materials of construction to expand coastal areas and urbanization.

The study area in coastal Hai Phong is bordering with the mainland crossing the ecosystems of tidal flats and beaches in the North, Cat Ba Biosphere Reserve and Ha Long Natural Heritage that possess valuable marine ecosystems like corals and mangroves in the East, open waters with low biodiversity of the soft bottom ecosystem of the Tonkin Gulf in the South, and coastal Thai Binh province with the ecosystems of mangroves and tidal flats in the West. Two main seasons including a dry one (October to April) and a rainy one (May to September) within a year control hydrometeorological conditions of the area. Also, in the rainy season, the area is directly or indirectly attacked by one to three typhoons that often make some sudden changes to the coastline, intertidal zone and seabed, etc. There are 5 rivers (Bach Dang, Cam, Lach Tray, Van Uc, and Thai Binh) discharging water and sediments into the area through their river mouths. Diurnal tide with a tidal range of about 4 m and tidal currents dominate the coastal waters of Hai Phong. Seabed and intertidal zone in the area are mostly flat and covered with sandy and muddy sediments at depths ranging from 0 m to 15 m [1]. The study area annually receives tens of million cubic meters of mud and sand from the rivers. The sedimentation over a long time has formed sand mines in the area outside the river mouths of Nam Trieu, Lach Tray, and Van Uc-Thai Binh [1].

In the 2015-2020 Master Plan for Hai Phong socio-economic development, the coastal reclamation for urbanization, tourist resort construction, and new seaport facility development associated with industrial zones, the amount of sand for landfill leveling was estimated at 251 million cubic meters and increasing in the period 2020-2030 [1]. The huge demand for landfill sand mining in recent years has also made sand mining intensive in this coastal estuary area. In addition to the economic benefits, these activities can cause many environmental consequences, especially in the coming years when the demand for sand mining is further boosted. According to the City's Adjustment Scheme "*Planning for exploration, exploitation and use of minerals in the city until 2020, with a vision to 2030*", the areas planned to exploit sands for landfill leveling are 8.2 thousand hectares, with reserves of about 142 million m^3. The areas that are permitted to explore and exploit sand as construction materials in Hai Phong city are mainly located outside the estuaries of Van Uc and Nam Trieu-Lach Tray, South Cat Hai district, along the coast of Do Son peninsular. As of August 2019, 22 sand mining licenses were issued (of 18 enterprises) and are still valid. The total area licensed for sand mining in Hai Phong city is 1953.1 ha with a total exploiting reserve of approximately 81.5 million m^3. The sand mining licensed projects are concentrated mainly in the Southeast estuaries of Van Uc, Lach Tray, Lach Huyen and Nam Trieu-Bach Dang (Figure 1). These sand mining projects vary in size. The area of sand mines averages about 90.1 ha, the largest at 99.9 ha and the smallest at 8.6 ha. These sand mines have different reserves with the largest of 5.2 million m^3, the smallest of about 0.8 million m^3 and the average of 3.88 million m^3. The average depth after mining these sand mines increases to 4.3 m at the sand mining sites, a maximum of 7.2 m and a minimum of 2.1 m. The mining period of the licensed mines is from 7 to 29 years. So far, the annual exploitation volume of licensed projects totals 9.3 million m^3. The annual exploitation duration of sand mines lasts about 150-200 days, commonly about 180 days and 8 hours per day. The relative position analysis of these sites shows their locations to sensitive areas as follows: To Van Uc river mouth, the nearest is 2.7 km from the mangrove forest, and some mining parts overlap with the clam culturing areas; to Cat Ba Biosphere Reserve, the nearest is about 4 km.

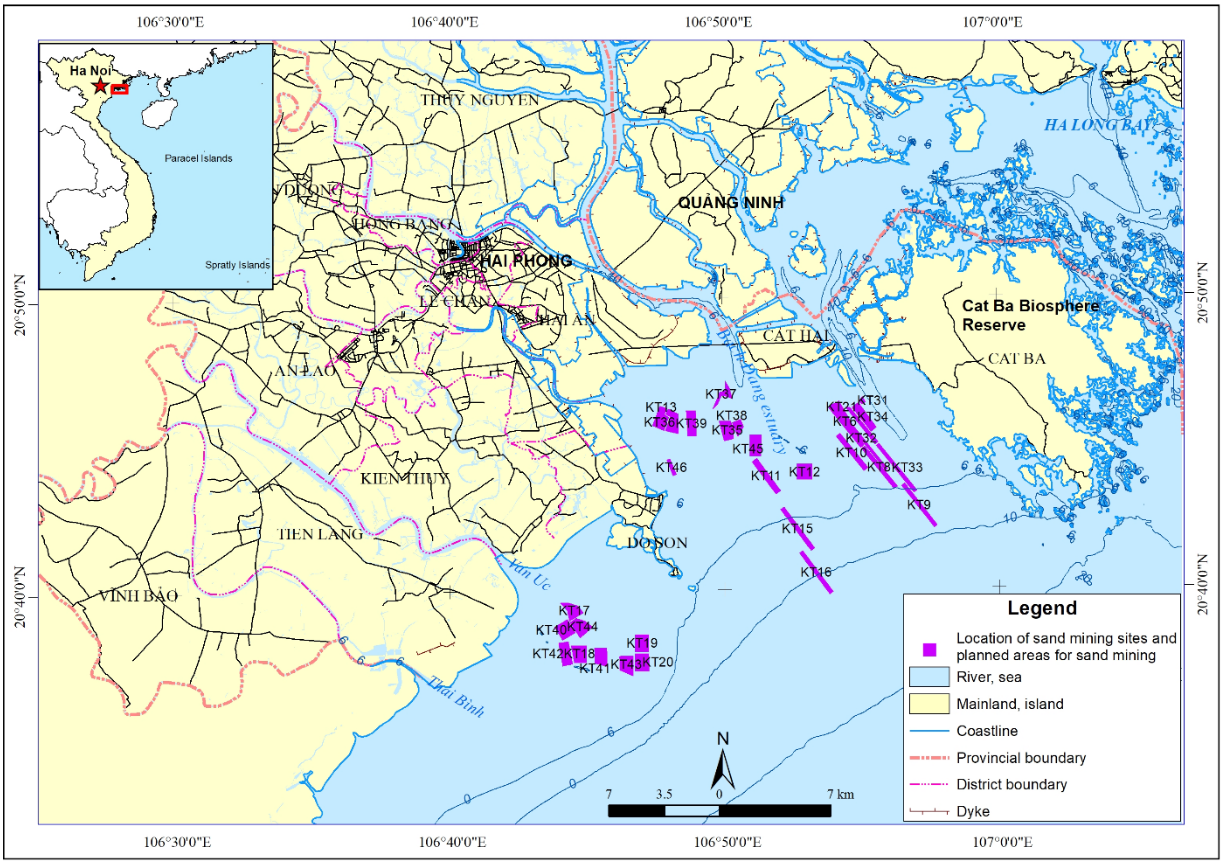

Figure 1. Sites and planned areas for sand mining in coastal Hai Phong.

2.2 Methods

The two basic methods employed in this study include the DPSIR framework analysis and the Delphi matrix. The DPSIR has been applied in many studies around the world in different fields and is effective in analyzing and evaluating effects and interactions with each other among the elements in the framework [9,15,18]. In this study, driving forces are the factors promoting coastal sand mining, leading to changes in the coastal marine environment. These factors may include the ones that directly or indirectly trigger mining sands. These factors can be economic, social or natural ones that have positive or negative effects, causing changes in the quality of the marine environment and impacts on the marine ecosystem. For example, the increasing sand demand of Hai Phong city for landfill leveling and construction in coastal urbanization and seaport expansion is a direct factor triggering sand mining activities, and the global need for sand as minerals for industries and for construction materials belongs to indirect factors related to sand mining. From a local perspective, the driving force behind increasing sand mining projects comes from the city's socio-economic development needs, especially in the field of leveling and infrastructure construction. Besides, the impetus comes from the increasing demand for sand for leveling and construction in the world. The driving force causes pressure on the coastal resources of Hai Phong through the increase in the opening of sand mines and the increase in illegal and over-exploiting activities. Through the assessment of the current status of the study area, environmental and socio-economic issues in sand mining places determine the environmental impacts of the activities, analyze, evaluate, and propose solutions to minimize negative impacts, promoting positive factors to meet the goal of sustainable development in coastal areas.

The Delphi matrix method [19] is mainly applied when developing and analyzing the criteria to assess the impact of sand mining on the coastal environment of Hai Phong. The criteria went through three steps. The first step involved a group of experts conducting the study in the period 2015-2020 (8 experts), the second step was conducted with a questionnaire after synthesizing and classifying criteria according to the results of the first step and consulting experts in the fields of environment, ecology, oceanography, environmental and resource management (35 people). The third step took place with the results of the second step by qualitative analysis (expert opinion) and quantitative analysis (expert consensus level), and 50 consulting experts. The criteria were classified following three pillars of sustainable development and associated with a rating scale from 1 to 5 points showing the importance of each selected criterion. Then the criteria were gathered, statistically processed, and selected based on the consensus level according to the parameter standard description in statistical analysis. Ten selected criteria were used to assess the impact of sand mining activities on the environment and ecosystems in the coastal area of Hai Phong. To evaluate the reliability of the statistical evaluation, crossbach's alpha coefficient was used.

Besides, the biodiversity index or Shannon-Wiener index (H') is employed to measure sand mining's impact on the soft-bottom ecosystem. The biodiversity index is a way to measure the diversity of species in a community. The index H' is calculated as follows [20,21]:

$$H' = \sum_{i=1}^{s} Pi\ lnPi$$

where P_i is the proportion of individuals found in the i^{th} species and ln denotes natural logarithm.

Values of Shannon index for real communities are often found to fall between 1.5 and 3.5. The higher the value of H', the higher the diversity of species in a particular community.

2.3 Materials

Materials used for the study are mainly from the results of the scientific research project at Hai Phong city level "Research to assess the impact of sand mining activities on the environment of coastal estuaries in Hai Phong" implemented by the Institute of Marine Environment and Resources, 2017-2019. In addition, other information and documents of environmental impact assessment reports of Hai Phong coastal sand mining projects, the project "General assessment of the current status of coastal areas of Hai Phong city" (2013) and the project "Solutions for environmental contrasts in coastal areas" (2009-2013) were used.

3. Results and Discussions

3.1 DPSIR Analysis of Sand Mining Activities to the Environment

The DPSIR framework for analyzing the environmental impact of sand mining activities in the Hai Phong coast (Figure 2) shows the main aspects of each component in the framework and the relationship between the components.

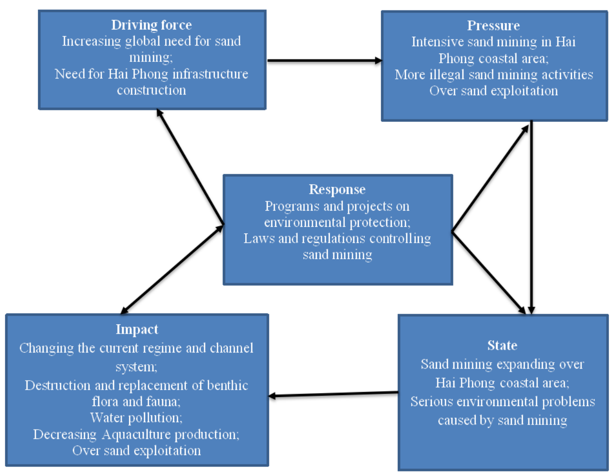

Figure 2. Applying the DPSIR to assess the impact of sand mining on the environment in the coastal Hai Phong.

In addition to the environmental and ecological impacts in the area, the impact of sand mining on socio-economic activities in this coastal area is also a prominent issue recently, which is the conflict between sand mining with shellfish farming. Sand extraction actors directly conflict with clam farmers because of the overlap in marine and intertidal exploiting areas. These are the most obvious and serious consequences of sand mining even though most mining projects have been licensed. However, the issues of zoning, planning, and allocating land and water surface to shellfish farming households have not been implemented yet.

3.2 Proposed Criteria to Assess the Impact of Sand Mining Activities on the Environment

Based on the DPSIR analysis, synthesizing relevant documents and consulting experts on the appropriateness, ten criteria to evaluate the impact of sand mining activities on the environment in the Hai Phong coastal area have been proposed and classified into 3 groups: 1) Criteria of driver and pressure of sand mining activities; 2) Criteria of current status and impacts of sand mining activities; 3) Criteria for the response.

Criteria of driver and pressure

Criterion 1: Local demand for sand mining shows the driving forces and pressures on sand mining. This criterion is evaluated with five levels based on the output/year in comparison with the mining plan. Mining production is divided into five grades (no sand mining, mining less than 30% of the output plan, mining 30%-50% of the output plan, mining > 50%-70% of the output plan, and mining over 70% of the output plan), corresponding to five impact levels (1—no impact to 5—very high impact) respectively.

Criteria of the status and the impacts of sand mining

Criterion 2: The seabed topography in the sand mining area is used to evaluate the natural compensation possibility of seabed topography after sand mining. This is related to current conditions, waves, seabed morphology [22], and the capacity to backfill the bottom topography with sand (or other materials). Then for the comprehensive result of the compensation capacity, the bathymetry changing is an indicator. As such, the depth of sand mining is taken into account and divided into five grades (deeper 30 m, 30 to > 20 m, 20 to > 10 m, 10 to 6 m, and < 6 m) corresponding to five impact levels (1—no impact to 5—very high impact) respectively.

Criterion 3: Suspended sediment dispersion in the water environment is to assess the dispersion of suspended sediments from mining sites to the surrounding environment with its values. Spreading suspended particles to highly significant subjects (natural and socio-economic) will have negative impacts on them. The higher concentration of suspended sediment is above the allowable limit (issued in Vietnam Regulations for Environmental Protection—QCVN), the more serious the negative impacts on the subjects. As such, the impacting dispersion includes five categories (not spreading to protected areas, important ecosystems, breeding grounds, spawning grounds, tourist areas, aquaculture; dispersing to conservation areas, important ecosystems, breeding grounds, spawning grounds, tourist areas, aquaculture but not exceeding the allowable limit; dispersing to conservation areas, ecosystems, breeding grounds, spawning grounds, tourist areas, aquaculture is approximately the allowable limit; dispersing to conservation areas, ecosystems, breeding grounds, spawning grounds, tourist areas, aquaculture with concentrations up to 3 times exceeding the allowable limit; dispersing to conservation areas, ecosystems, breeding grounds, spawning grounds, tourist areas, aquaculture with concentrations higher than 3 times exceeding the allowable limit). These categories correspond with five impact levels (1—no impact to 5—very high impact) respectively.

Criterion 4: Distance from the location of sand mining to socio-economic entities is to assess varying degrees of sand mining impacts on coastal residential areas, tourist beaches, historical and cultural sites, and aquaculture areas. The impacts may include coastal water pollution, changing the current regime and channel system, and over-sand exploitation leading to erosion at tourist beaches and coastal resident areas, decreasing coastal aquaculture production (shellfish farming). The degree of impact largely depends on the distance between the sand mining activities and the socio-economic groups. Generally, sand mining makes more serious adverse impacts on socio-economic groups when it takes place closer to the groups. Then five different recommended distances relevant to five impact levels (1—no impact to 5—very high impact) respectively include farther 15 km, 15 to > 10 km, 10 to > 5 km, 5-1 km, and < 1 km.

Criterion 5: Biodiversity of benthic fauna uses the biodiversity index (H') measured before and after sand mining takes place to assess the impacts on benthic organisms as a basis for assessing the impact on the soft bottom ecosystem. The changes in the seabed environment cause changes in benthic fauna and flora. Therefore, the difference between H' before and after mining indicates the impact levels. Based on the biodiversity baseline in the study area, five H' value intervals recommended relevant to five impact levels (1—no impact to 5—very high impact) respectively include > 5, 5 to > 3, 3 to > 2, 2-1, and < 1.

Criterion 6: Distance from the location of sand

mining to the coastal ecosystem and the national park is for assessment of sand mining that causes increased turbidity and re-dispersal of deposited pollutants. The further away from sand mining activities take place, the less the impact of these activities. Similar to Criterion 4, five recommended distances relevant to five impact levels (1—no impact to 5—very high impact) respectively include father 15 km, 15 to > 10 km, 10 to > 5 km, 5-1 km, and < 1 km.

Criterion 7: Distance from the location of sand mining to fishing grounds and nursery grounds is applied to assess the impacts of sand mining activities on these grounds. This criterion can be merged with Criterion 6 in some marine areas with the grounds merging with the coastal ecosystem. The further away sand mining takes place, the less the impact of these activities. Similar to Criterion 4, five distances relevant to five impact levels (1—no impact to 5—very high impact) respectively include father 15 km, 15 to > 10 km, 10 to > 5 km, 5-1 km, and < 1 km.

Criterion 8*: *Quality* of *seawater environment is used to periodically assess its environmental status in and around areas with sand mining activities. The impact levels in score range from 1 to 5 for each indicator according to the water pollution classification under Circular No. 17/2011/TT-BTNMT (Vietnam Regulations for Environmental Protection—QCVN). The average combined results of each evaluated parameter show the criterion impact levels (Table 1).

Table 1. Indicators for assessing the impact levels related to sea water quality.

Water quality indicators	**Content**	**Negative impact level (score 1-5)**
Total suspended solids (TSS) (mg/L)	Less than the allowable limit according to QCVN	1
	Approximate allowable limit according to QCVN	2
	1-3 times higher than the allowable limit	3
	>3-5 times higher than the allowable limit	4
	>5 times higher than the allowable limit	5
Dissolved Oxygen (DO) (mg/L)	Within the allowable limit according to QCVN	1
	Not within the allowable limit	5
COD ($KMnO_4$) (mg/L)	Less than the allowable limit according to QCVN	1
	Approximate allowable limit according to QCVN	2
	1-3 times higher than the allowable limit	3
	>3-5 times higher than the allowable limit	4
	>5 times higher than the allowable limit	5
Ammonium (NH_4^+) (mg/L)	Less than the allowable limit according to QCVN	1
	Approximate allowable limit according to QCVN	2
	1-3 times higher than the allowable limit	3
	>3-5 times higher than the allowable limit	4
	>5 times higher than the allowable limit	5
Phosphate (PO_4) (mg/L)	Less than the allowable limit according to QCVN	1
	Approximate allowable limit according to QCVN	2
	1-3 times higher than the allowable limit	3
	>3-5 times higher than the allowable limit	4
	>5 times higher than the allowable limit	5
Arsenic (As) (mg/L)	Less than the allowable limit according to QCVN	1
	Approximate allowable limit according to QCVN	2
	1-3 times higher than the allowable limit	3
	>3-5 times higher than the allowable limit	4
	>5 times higher than the allowable limit	5
Quality of sea water environment	(Average of water quality indicators)	(ranges from 1-5)

Criteria of response

Criterion 9: Effectiveness of policy on sand mining management involves assessing the role of state and local management of sand mining activities that negatively impact the natural environment, socio-economic, and ecosystem. The effectiveness of policies including laws and regulations issued by governments (central and local) related to coastal sand mining possibly decreases the negative impacts and vice versa. Assessment of real impact and possible impact on the environment supports policymakers to judge the efficiency of the policy periodically. The more effective the environmental policy is, the lower the impact of these activities. This positive criterion is in contrast to the criteria of drivers and pressures. The criterion ranges from "very effective" to "ineffective" (very highly effective, highly effective, averagely effective, low effective, and ineffective) corresponding with 5 points (1—very effective, 5—ineffective) of impact levels.

Criterion 10: Marine environmental protection programs and projects implemented in the city are to evaluate the effectiveness of environmental protection programs and projects in mitigating the negative impacts of sand mining activities in Hai Phong city. Similar to Criterion 9, this is a positive criterion, in contrast to the criteria of drivers and pressures. The environmental assessment after completing the programs and projects in a stage and environmental monitoring onward will show the levels of negative impacts from no more impact to no reduced impact. Therefore, the criterion of 5 impact reduction levels (no more impact, reduced to the required level, reduced but not meeting the required level, a bit reduced, not reduced) after completion of programs or projects is in 5 points (1—no more impact, 5—not reduced impact) respectively.

3.3 Assessment of Coastal Mining Impacts on the Environment

An environmental impact assessment of sand mining activities in the coastal waters of Hai Phong with 10 proposed criteria was applied for 30 project areas of sand mining (Figure 1). Criterion 6 and Criterion 7 got the same points because the breeding and spawning grounds are located in the ecosystems of the estuary, coral, and mangroves in the study area.

The overall assessment for the entire study area was made based on the average of the evaluation results for all 30 areas. Criteria from 1 to 8 had evaluation scores calculated with data collected in the period 2015-2020. Criteria 9 and 10 were scored by relevant experts who come from environmental agencies of Hai Phong, research institutions and universities located in Hai Phong (e.g. Institute of Marine Environment and Resources, IMER; Research Institute of Marine Fisheries, RIMF; Vietnam Maritime University, VMU; Hai Phong University, etc.), and others having much experiences and information on environmental issues caused by human activities in coastal and marine areas including sand mining. Scores ranged from 1 to 5, corresponding to the impact level from the lowest to the highest (Table 2).

Assessing results show that the impact of coastal sand mining is strongest in areas with economic activities, on biodiversity and benthic organisms (rated score of 4), and coastal ecosystems (rated score of 3.5). The other subjects were affected only at a low to moderate level (rated score from 1 to 3). The trend in environmental impact level shows a decrease from shallow waters close to the coastline (including sandy tidal flats) with dense socio-economic activities and valuable ecosystems like mangroves to deeper ones with low biodiversity (Figure 3A). Also, the low impact level is in the area farther from highly valuable ecosystems like corals, seagrass in Cat Ba Biosphere Reserve (Northeast), and mangroves in Van Uc river mouth (Southwest) (Figure 3B). The overall assessment of the environmental impact of sand mining activities in the study area in the period 2015-2020 is average (rated score of 3).

The results of the environmental impact assessment of sand mining activities in Hai Phong coast are relatively consistent with the evaluations in the "Report on the current state of the coastal area of Hai Phong city" issued by the Sea and Island Division under Hai Phong Department of Natural Resources and Environment (2020) on two groups of criteria: Protection, restoration, and management of ecosystems; Waste management and pollution reduction. Crossbach's alpha coefficient value approaches 0.7. Frequently, Crossbach's alpha benchmark value at 0.7 and higher indicates a reliable measure (Delphi matrix). A coefficient value close to 0.7 is minimally acceptable but not ideal. This study on coastal environmental assessment with proposed DPSIR criteria is a new effort to qualify the impact of sand mining on the environment in Hai Phong particularly and in Vietnam generally. Therefore, the coefficient value near 0.7 can be accepted and indicates sufficiently minimal consistency in data collection for the employed method of Delphi matrix. This also presents the potential to apply the DPSIR criteria for environmental assessment in other fields and regions.

Table 2. Criterion scoring of environmental impact assessment of sand mining activities in coastal waters of Hai Phong (averaging of 50 interviewees).

Mining sites	Criteria														Average score
	1	**2**	**3**	**4**	**5**	**6&7**	**8_TSS**	**8_DO**	**8_COD**	**8_NH4**	**8_PO4**	**8_As**	**9**	**10**	
KT6	2	5	1	4	4	4	3	1	3	1	1	1			2,6
KT8	2	5	1	4	4	3	3	1	3	1	1	1			2,5
KT9	2	4	1	4	4	3	1	1	3	1	1	1			2,3
KT10	2	5	1	4	4	3	3	1	3	1	1	1			2,5
KT11	2	5	1	3	4	3	3	1	3	1	1	1			2,4
KT12	2	5	1	3	4	3	3	1	3	1	1	1			2,4
KT13	2	5	1	4	4	4	3	1	3	3	1	1			2.7
KT15	2	4	1	3	4	3	2	1	3	1	1	1			2.3
KT16	2	3	1	3	4	2	1	1	3	1	1	1			2.1
KT17	2	5	1	4	4	4	3	1	3	3	1	1			2.7
KT19	2	5	1	4	4	3	3	1	3	3	1	1			2.6
KT20	2	5	1	3	4	3	3	1	3	3	1	1			2.6
KT32	3	5	1	4	4	3	3	1	3	1	1	1			2.6
KT33	2	5	1	4	4	4	3	1	3	1	1	1			2.6
KT35	2	5	1	4	4	3	3	1	3	3	1	1	3 (Scored by experts and interviewers)	3 (Scored by experts and interviewers)	2.6
KT39	2	5	1	4	4	4	3	1	3	3	1	1			2.7
KT40	2	5	1	4	4	4	3	1	3	3	1	1			2.7
KT42	3	5	1	4	4	4	3	1	3	3	1	1			2.8
KT43	3	5	1	3	4	3	3	1	3	3	1	1			2.6
KT44	3	5	1	4	4	4	3	1	3	3	1	1			2.8
KT45	2	5	1	4	4	3	3	1	3	3	1	1			2.6
KT31	3	5	1	4	4	4	3	1	3	3	1	1			2.8
KT21	3	5	1	4	4	4	3	1	3	1	1	1			2.6
KT18	3	5	1	4	4	4	3	1	3	3	1	1			2.8
KT34	2	5	1	4	4	4	3	1	3	1	1	1			2.6
KT36	3	5	1	4	4	4	3	1	3	3	1	1			2.8
KT37	3	5	1	4	4	4	3	1	3	3	1	1			2.8
KT38	3	5	1	4	4	3	3	1	3	3	1	1			2.7
KT41	2	5	1	3	4	3	3	1	3	3	1	1			2.6
KT46	4	5	1	4	4	4	3	1	3	3	1	1			2.9
Averaged score	***2***	***5***	***1***	***4***	***4***	***3.5***	***3***	***1***	***3***	***3***	***1***	***1***	***3***	***3***	

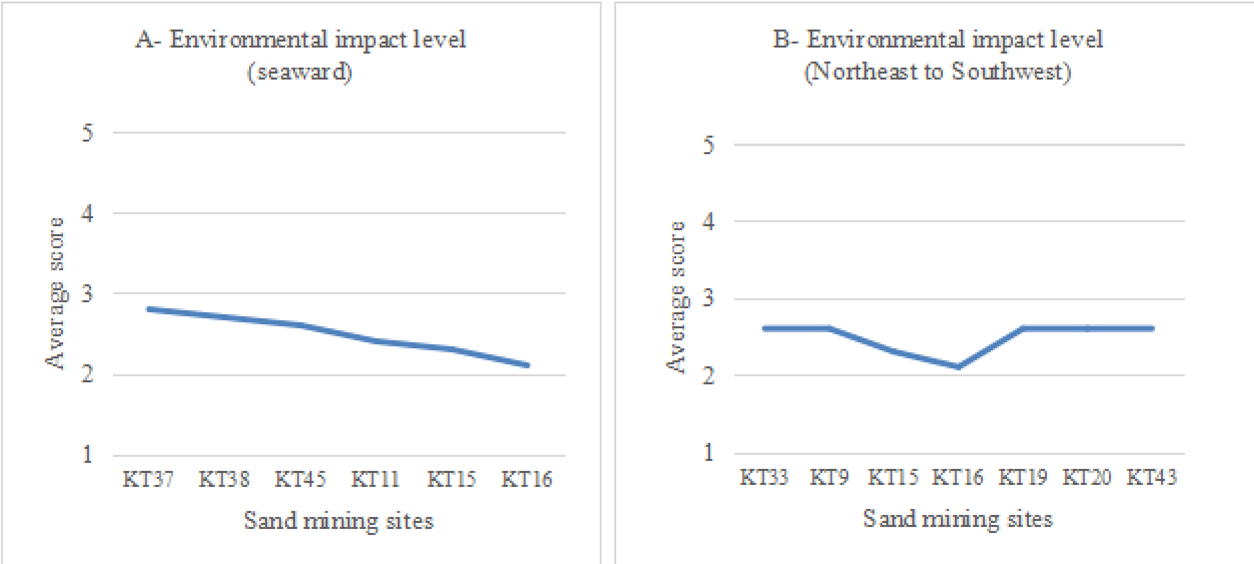

Figure 3. Trends in environmental impact level of sand mining by average scores: A- from coast to open sea; B- along the coast at the depth from 6 m to 10 m.

4. Conclusions

The environmental impact of sand mining activities in the Hai Phong coastal area was fair with a rated score ranging from 2 to 3 among mining sites and stronger (rated score from 3.5 to 4) on the coastal areas of dense economic activities, high biodiversity and benthic organisms, and coastal ecosystems in the stage from 2015 to 2020. Ten proposed criteria are well involved in the management and planning of socio-economic development, conservation, and environmental protection in Hai Phong coastal areas. These criteria can also be applied to assess the environmental impact of similar activities on the coastal areas in cities and provinces in Vietnam with their adjustment. However, to have more reliable assessment results, it is necessary to collect data sets and systematic information, covering both space and time in the area and activities to be assessed. This is also the current limitation when using the criteria in environmental and ecological assessment, especially in coastal and marine areas.

Author Contributions

Tran Dinh Lan conducted the study and wrote this paper. Do Thi Thu Huong developed and analyzed multi-criteria and maps. Do Gia Khanh collected data and statistical analysis of socio-economic data. Nguyen Van Thao analyzed physical and environmental data.

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The written consent was obtained from all participants prior to the study.

Conflict of Interest

There is no conflict of interest.

References

[1] Khanh, D.G., 2022. Study on environmental effects of sand mining and shipping channel dredging in Hai Phong coastal waters [PhD thesis]. Hanoi, Vietnam: Graduate University of Science and Technology.

[2] Pitchaiah, P.S., 2017. Impacts of sand mining on environment—A review. SSRG International Journal of Geoinformatics and Geological Science. 4(1), 1-5.

[3] Mensah, J.V., 1997. Causes and effect of coastal sand mining in Ghana. Singapore Journal of Tropical Geography. 18, 69-88.

[4] Bayram, A., Onsoy, H., 2015. Sand and gravel mining impact on the surface water quality: A case study from the city of Tirebolu (Giresun Province, NE Turkey). Environmental Earth Science. 73, 1997-2011.

[5] Hurme, A.K., Pullen, E.J., 1988. Biological effects of marine sand mining and fill placement for beach replenishment: Lessons for other uses. Marine Mining. 7(2), 123-136.

[6] Boyd, S.E., Limpenny, D.S., Rees, H.L., et al., 2005. The effects of marine sand and gravel extraction on

the macrobenthos at a commercial dredging site (results 6 years post-dredging). ICES Journal of Marine Science. 62, 145-162.

[7] Desprez, M., Pearce, B., Le Bot, S., 2010. The biological impact of overflowing sands around a marine aggregate extraction site: Dieppe (eastern English Channel). ICES Journal of Marine Science. 67, 270-277.

[8] Kowalska, A., Sobczyk, W., 2014. Negative and positive effects of the exploitation of gravelsand. Inzynieria Mineralna. 15(1), 105-109.

[9] Lan, T.D., Olsson, E.G.A., Alpokay, S., 2014. Environmental stresses and resource use in coastal urban and peri-urban regions DPSIR approach to SECOA's 17 case studies. Sapienza Università Editrice Digilab: Rome, Italy.

[10] Kaikkonen, L., Venesjärvi, R., Nygård, H., et al., 2018. Assessing the impacts of seabed mineral extraction in the deep sea and coastal marine environments: Current methods and recommendations for environmental risk assessment. Marine Pollution Bulletin. 135, 1183-1197.
DOI: https://doi.org/10.1016/j.marpolbul.2018.08.055

[11] Lan, T.D., 2007. Research in rational use of natural resources in the Northeastern coastal region of Vietnam based on environmental indicators [PhD thesis]. Hanoi: University of Natural Sciences, Hanoi National University.

[12] European Environment Agency (EEA), 1999. Environmental Indicator: Typology and Overview. Available from: https://www.isprambiente.gov.it/files/biodiversita/Smeets_Environmental_indicators_1999.pdf

[13] Merino-Saum, A., Halla, P., Superti, V., et al., 2020. Indicators for urban sustainability: Key lessons from a systematic analysis of 67 measurement initiatives. Ecological Indicators. 119, 106879.
DOI: https://doi.org/10.1016/j.ecolind.2020.106879

[14] Khanh, D.G., Huong, D.T.T., Vinh, V.D., et al., 2019. Zoning marine disposal for dredged material management: A case study in Vietnam. Sustainable Marine Structures. 1(2), 19-27.
DOI: https://doi.org/10.36956/sms.v1i2.141

[15] Huong, D.T.T., Ha, N.T.T., Khanh, D.G., et al., 2022. Sustainability assessment of coastal ecosystems: DPSIR analysis for beaches at the Northeast Coast of Vietnam. Environment, Development and Sustainability. 24, 5032-5051.

[16] Lan, T.D., 2009. Assessment of some marine using sustainable utilization indicators in Hai Phong—Quang Ninh coastal area, Vietnam. Aquatic Ecosystem Health & Management. 12(3), 243-248.

[17] Lan, T.D., Chien, H.T., 2021. Proposition of economic valuation index for sustainable ecosystem management: An island case study in Vietnam. Modern Environmental Science and Engineering. 6(11), 1196-1204.

[18] Wang, C., Qu, A., Wang, P., et al., 2013. Estuarine ecosystem health assessment based on the DPSIR framework: A case of the Yangtze Estuary, China. Journal of Coastal Research. 165, 1236-1241.
DOI: https://doi.org/10.2112/si65-209.1

[19] Harold, A., Limestone, M.T., (editors), 2002. The delphi method techniques and applications. Portland State University and New Jersey Institute of Technology: USA. pp. 618.

[20] Shannon, C.E., Weaver, W., 1949. The mathematical theory of communication. University of Illinois Press: Urbana, IL.

[21] Pielou, E.C., 1975. Ecological diversity. Wiley Interscience: New York.

[22] Mielck, F., Hass, H.C., Michaelis, R., et al., 2019. Morphological changes due to marine aggregate extraction for beach nourishment in the German Bight (SE North Sea). Geo-Marine Letters. 39, 47-58.
DOI: https://doi.org/10.1007/s00367-018-0556-4