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ARTICLE

Zoning Marine Disposal for Dredged Material Management: A Case Study in Vietnam

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ABSTRACT

The fast growth of Hai Phong ports in the two last decades requires not only their upgrading facilities but also expanding port area and dredging their shipping channels (existing and new ones) that generate a huge amount of unused dredged materials. While all existing dumping sites in sea waters and on land get over capacity, looking for new dumping sites in sea waters is an urgent need. This study is to zone coastal waters of Hai Phong for suitable dumping sites meeting sustainable coastal management. Multi-criteria overlay analysis on GIS platform was employed with the criteria of natural conditions, environment and socio-economics for zoning coastal waters of Hai Phong. These criteria were detailed into eight sub-criteria and then developed to eight GIS weighted thematic sub-layers of bottom depth, litho-hydrodynamics, ecosystems, distribution of benthos, distance to residential areas and tourist sites, distance to aquaculture area, distance to ecosystems and distance to conservation areas. Analysis results show the highly suitable zone for dredged material dumping in South, South West Hai Phong at depth below 15m to the deeper areas. Disposals of dredged materials in the zone would minimize impacts on the environment, ecology and socio-economics in surrounding waters and coastal areas.

1. Introduction

Shipping channel material dredging that is vital to many harbors worldwide to maintain their operation normally generates some amount of dredged materials. These materials disposed on mainland, islands or in open waters can make not only benefits (reuse, recycle, etc.) to socio-economic development [13] but also negative impacts on the environment [5,13,16]. For many years, environmental impacts of dredged material disposal sites, particularly in marine waters have been studied and assessed for all environmental components as sediment, water and biological issues [1,4,9]. To mitigate environmental impacts of dumping in sea waters, London Convention 1972 (Annex III) issued eight general criteria on characteristics of dumping sites, dumped materials and potentially impacted ecosystems to determine dumping area and sites. Following these general criteria, some nations have developed their adapted criteria. For example, the United States in 1992 issued Ocean Dumping

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Act with detail regulations on management, dumping materials and conditions, and criteria for disposal sites [2]. Australia [14] and Ireland issued Sea Dumping Acts with their specific criteria for dumping sites . Vietnam recently mentioned a marine dumping regulation in the Law on Resources and Environment of Seas and Islands.

Hai Phong sea ports designed by the Government of Vietnam as the main gate and taking an important role for socio-economic development in North Vietnam are located close to the high ecological conservation areas of Cat Ba Biosphere Reserve listed by MAB (Man and the Biosphere)/UNESCO (2004) and Ha Long Bay Natural Heritage recognized by UNESCO (1994), and next to the famous touristic area of Do Son that remarkably contributes to economic growth of Hai Phong. The channels of Hai Phong sea ports are also considered as the main route for the development of the maritime industry in North Vietnam. However, these channels are in sedimentation and dredged every year. According to the Northern Maritime Safety Corporation of Vietnam, the needs of sandy and muddy dredging annually to maintain the channels are up to 2.5-3 million tons with minimum cost estimated around 40-50 billion VND (Vietnamese currency). Recently, Hai Phong sea ports have been expanded seaward with the construction of a new harbor namely Lach Huyen International Gateway Port that will be able to receive ships of 100,000 DWT (dead weight tonnage). It is obvious that the development of Hai Phong ports needs to dredge a huge amount of sediments for construction stage and shipping channel maintenance annually. However, a serious raising problem is where to dispose the dredged materials, while all selected sites inland and in coastal areas are in over capacity. To tackle the problem, some sites in offshore waters were proposed but minimal environmental impacts when disposal of dredged materials, especially on the areas of high ecological values as Cat Ba Biosphere Reserve and Ha Long Bay Heritage. This study is based on multiple criteria overlay analysis using geographic information system (GIS) to zone areas suitable for disposing dredged materials to meet the goal of sustainable management of sea port area.

2. Materials and Methods

2.1 Study Area

The study area is in Hai Phong coastal zone bordering with the districts of Hai An, Do Son and Kien Thuy in the North, Cat Hai district (with Cat Ba Biosphere Reserve and close to Ha Long Bay Natural Heritage) in the East, the Gulf of Tonkin in the South and the West. There are six large rivers discharging in the study area (Figure 1), being strongly influenced by the rainy season and dominated by tide with the highest amplitude over 4m. Seabed is fairly flat with a depth up to 30m. The area is affected by waves with their height of 0.5 to 0.9m average, reaching a maximum of 5.6m and the direction changes seasonally. Surface sediments on sea bottom are mainly small grey-brown and greenish-grey silt [15].

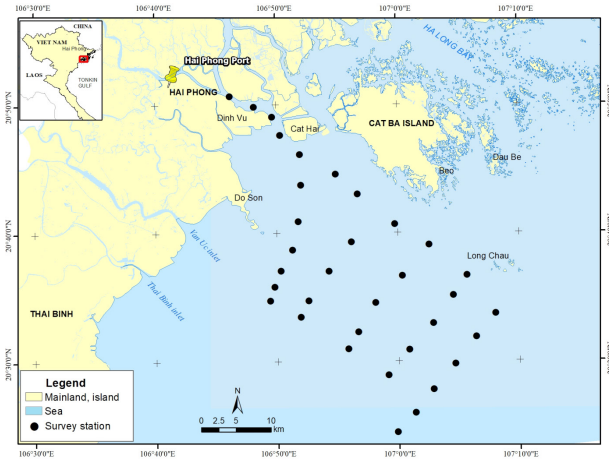

Figure 1. Study area and survey stations

Source: Project DT.MT.2015.721

Surrounding the study area, the ports and maritime activities of Hai Phong have been developed in Bach Dang and Cam estuaries and recently expanded seaward to construct new international port of Lach Huyen associated with the economic zone of Dinh Vu - Cat Hai. The total goods throughput of Hai Phong ports was increased by 25 times for 32 years, 50.1 million tons in 2012 compared to 2 million tons in 1980. From 2000 to 2013, the number of ships entering the port increased by 1.5 times. The growth rate of goods through the ports reached 15-20% per year. As such, the amount of dredged materials in Hai Phong seaport area also ranged from 650 m^3 to 2000 m^3 (2011-2016) (Table 1).

Hai Phong shipping channel system includes 8 sections of total 91.4km long with four main channels of 43km (Lach Huyen, Ha Nam, Bach Dang, Song Cam). All the channels have been in heavy sedimentation. In addition to economic concerning activities, Do Son marine tourist area visited by millions tourists annually is located in the Northwest. Marine fishing that greatly contributes to the Hai Phong gross domestic production takes place in three major fishing grounds as Cat Ba, coastal Thai Binh estuary to Quang Ninh and offshore Long Chau - Ba Lat [7]. Aquaculture with large potential areas stretches from Cat Hai, Tien Lang, Kien Thuy, Do Son, Duong Kinh

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Table 1. The mass of sediment dredging for maintenance and construction of seaport channels in Hai Phong during 2011-2016

The mass	2011	2012	2013	2014	**2015**	**2016**
Dredging for maintenance and construction of jetties (m^3)	840.000	645.000	875.500	797.320	798.800	300.700
Dredging for maintenance of Hai Phong channels (m^3)	985.884	1.262.000	679.984	1.022.299	1.112.419	119.699
Dredging for maintenance of Pha Rung channel (m^3)	164.634	99.727	51.849	57.297	60.104	221.561
Total (m^3)	1.990.518	2.006.727	1.607.333	1.876.916	1.971.323	641.960

Source: Project ĐT.MT.2015.721

and Hai An. Over the past ten years, the area of brackish aquaculture ponds annually has expanded slightly, while the area of marine culture, including intertidal culture (clams, etc.) and cage culture tends to highly increase, especially in Cat Hai district.

In East and Southeast study area is the Cat Ba island conservation with Cat Ba National Park and Cat Ba Biosphere Reserve including four marine ecosystems of mangroves, tidal flats, corals, and soft bottom. In which, coral ecosystem with a total of 177 species is limitedly distributed in Southeast Cat Ba islands and Long Chau islands, relatively far from the area with marine activity. Mangrove ecosystems with a total of 31 species, spread out nearly 18 thousand hectares, mainly in the coastal communes of Phu Long, Cat Hai, Bang La and the river mouths of Bach Dang, Cam, Lach Tray, Van Uc, Thai Binh. It is quite diverse in species of the ecosystem [15]. Tidal flat ecosystem is spatially distributed along the coast of the islands and tidal zones from Cat Ba to Thai Binh estuary. It is diverse in species but distributed uneven and highly dependent on bottom materials (sand, gravel, reef and mud, sandy mud) [15]. Of the ecosystem, benthic communities with 340 species belonging to 186 genera, 84 families have been recorded. The ecosystem of soft bottom (including water mass) is largest but less biologically diverse than others. About 400 species and subspecies of phytoplankton, 131 species of zooplankton, 196 species of marine fish have been found. The bio-diversity index (H') of the soft bottom ecosystem ranged from 0 (zero) to 2.72, averaging 1.72, indicating a low bio-diversity in the area.

2.2 Materials

Data on natural condition, marine environment and ecosystems were mainly resulted from the Hai Phong city-level project "Study on scientific basics for planning dredged material disposal sites in the Hai Phong coastal area" coded DT-MT.2015.721 in the period 2015-2017 and the VAST project coded KHCBBI.01/18-20 implemented in 2018-2020. GIS layers on natural condition were referred to the simulation outcomes using litho-hydrodynamic numerical modeling recently [17].

Socio- economic data and documents were collected from statistic books of Hai Phong city, socio-economic annual reports of the city (including land use maps) and the project reports of Lach Huyen International Gateway Port. Besides, data and information were also contributed by interviews of relevant agencies as Hai Phong Maritime Administration, Hai Phong Department of Natural Resources and Environment, local authorities of coastal and island districts.

2.3 Methods

Zoning dredged material disposal to minimize environmental impacts for port and maritime sustainable management will follow the approach of sustainable development.

In overall, multi-criteria overlay analysis (MCOA) on GIS platform (ARCGIS 10.1) is the main method to employ to zone disposing dredged materials from ports and shipping channels in Hai Phong. To do this MCOA, a database of a 1/50,000 base map and GIS layers of natural condition, environment and ecosystem, and socio-economics was established based on data collected from the projects and other books, reports. After making the layers in GIS platform, they were assigned with weights aggregated from Delphi analysis and then overlaid to get results of zoning maps (Figure 2).

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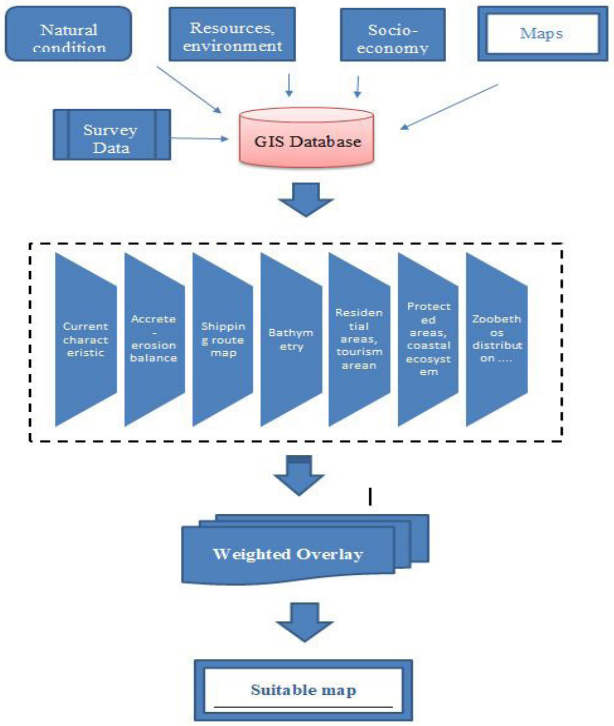

Figure 2. Multi-criteria GIS overlay analysis for zoning marine area of dredged material disposal

Note:
Data on environmental and ecological characteristics was collected in sampling and observing stations at three layers (surface, middle and bottom) of water columns covering the whole study area (Figure 1) for two seasons (dry and rainy) in 2015-2017 and 2018-2019 supplementation. Sampling and analyzing environmental and ecological parameters followed the methods issued in the National Regulations of the Ministry of Natural Resources and Environment of Vietnam (MONRE) [10],[11]. Data on the characteristics of marine and coastal ecosystems were gathered via surveys employing published professional methods [8]. Relevant data on socio- economics were selected from related year books and reports and put in sheets of Microsoft Office Excel 2007. After that, collected data were managed in the GIS database.

Development of criteria: following three poles (social, economic and environmental) of sustainable development approach, three relevant criteria (environmental, social and economic) were established. Based on its characteristics, each was detailed into sub-criteria with specific values. The values were determined by reference to some similar studies and the analysis of relevant current status characteristics of the study area done by the projects DT-MT.2015.721 and KHCBBI.01/18-20.

Making GIS layers and weight assignment: based on 1/50,000 base map of the study area, collected data divided into three groups of environment (including natural condition and ecological features) and socio-economics were input in GIS software to produce thematic normalized layers. Data on the environment were used in GIS platform to develop spatial thematic layers, including: litho-hydrodynamic layers (currents and accretion-erosion) that were referred to previous study[17] , bathymetry layer, layers of protected areas and coastal ecosystems, and benthic distribution layers. Data on socio-economics were employed for developing spatial thematic layers on shipping channels, residential areas and tourist sites. Each GIS thematic layer was attributed with sub-criterion values.

To assign weights to the layers and their criteria and attributes (weight assignment as follows: 1- low, 2- medium, 3- high), the Delphi method [6] was applied with 35 expert respondents. The weight was determined through a comparative evaluation of attribute pairs of the relevant factors regarding the likelihood suitability of pixels. The evaluation process of weight determination was performed according to Saaty matrix [12]. The importance of input layers and their attributes was determined by applying a 9-point Saaty pair matrix.

Spatial analysis for zoning of disposal areas: multi-criteria analytical GIS overlay was the integration of the normalized layers on the suitability levels for dredging materials and weighted overlaying. The overlaying model (Figure 2) resulted in a new layer showing the suitability for disposing with suitable values in the range 0-1. The zone with values close to 1 (one) would meet all conditions of natural characteristics, socio-economics and environment and ecology, being the most suitable for minimal impact dumping dredged materials, and vice versa, the zones with values closer to 0 (zero) would not match.

3. Results and Discussions

3.1 Potential Environment Impacts of Disposing Dredged Materials in Hai Phong Port Waters

On environmental quality of Hai Phong port area, all monitoring parameters of front waters required by the Government of Vietnam have met national technical regulations although in some ports, water has been locally polluted by oil (according to the project DT-MT.2015.721).

Dredged material dumping in the coastal waters of Hai Phong ports would have potentially environmental and ecological impacts. One of the obvious and foreseeable direct impacts is the impact on the benthic fauna at the dumping sites, changing or destroying the benthic fauna and flora at the sites, although in this area the benthic

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fauna and flora are quite poor. The impacts on water and sediment environment quality and socio-economics are also difficult to avoid. These key impacts are summarized as follows.

Impacts of increasing water turbidity at disposal sites and surrounding areas: when dumping dredged materials (composed of over 80% muddy clay according to the project DT-MT.2015.721) marine water at the sites and surrounding areas will be increasingly turbid. The increasing of water turbidity potentially impacts on benthos at the sites and adjacent ecosystems, tourist beaches, aquaculture and nursery grounds, fisheries. Besides, the dumping for years can have cumulative environment impacts of sedimentary pollutants that meet at present national technical regulations.

Impacts of dumping dredged materials on socio-economics are much related to increasing cost of material transport from dredging sites to disposal sites. To minimize the impacts on valuable ecosystems in the conservation areas of Cat Ba Biosphere Reserve and Ha Long Bay Natural Heritage, the dumping zones and sites must be far enough from the dredging sites. This makes transport cost increased (cost of VND 8,424 for 1 cubic meter of dredged materials per 1 km maritime transport according to Hai Phong People Committee Decision). Besides, increasing shipping density in shipping channels in the port areas will make the increase of maritime incidents.

3.2 Development of Criteria

Three criteria were identified according to the principles of sustainable use of natural resources and environmental protection, including economic, environmental and social criteria. The combination of economics and society generated a socio-economic criteria. These criteria were developed and then consulted with experts, scientists, managers, within the framework of the project DT.MT.2015.721 and KHCBBI.01/18-20 (Table 2).

3.2.1 Environmental Criteria

To develop the criteria, the following basic issues were taken into account: natural condition (two first criteria), environmental issues and ecological features:

Criterion of seafloor topography (bathymetry): the dumping area should be located in a region stable, minor affected by currents and waves, and no sedimentation. This was to prevent dumping materials from diffusing back the water environment.

Criterion of litho-hydrodynamics: this included the parameters of currents, waves, sediment transportation and changes in bottom topography. Changes in bottom topography is normally resulted from litho-hydrodynamic conditions of the area [17]. These results showed that the suitable dumping site was placed with the smallest topographic changes under all meteorological conditions, including monsoons and typhoons. The hydrodynamic criteria were quantified digitally as an input to the GIS multi-criteria overlay analysis.

Criterion of dispersing suspended sediment: for suspended matter from the dumping sites not affecting the sensitive areas of ecology and socio-economics of Hai Phong as Cat Ba islands, Long Chau islands, Do Son beaches, the dumping sites should be located in the zones as far as possible from those islands and beaches. However, this criterion was difficult to be quantitative. As such, a numerical model simulation on the influence of suspended matter to the surrounding sea was referred [17].

Criteria of distances to marine ecosystems and marine conservation areas (corals, sea grass, mangroves and other tidal wetlands): the simulation results of suspended matter dispersion [17] and some works [3] indicated that the ecosystems, marine conservation areas could be impacted by dredged materials at the dumping sites within 5km distance. Therefore, dumping in the zones in a distance of 5-10km (and farther) from the ecosystems and the conservation areas was relatively safe.

Criterion of benthic distribution: a biodiversity index (H') was used to set up a criterion for benthic distribution. Based on the classification of bio-diversity index for environmental quality, the areas with H'<1 (less biodiversity) indicating bad environment were suitable for dredged material dumping (not much impacting on benthos and the environment). The areas with H' ranged from 1-3 were relatively suitable for the dumping. Whereas, the areas with H' greater than 3 were not suitable for dumping.

Criteria for distribution of fishing grounds and nursery grounds: fishing and nursery grounds are negatively impacted by pollutant dispersion in sea water. In the area, pollutants from dredged materials could seriously impact on the grounds within a distance of less than or equal to 5km from the dumping zones [17]. Therefore, a distance of 5-10 km and the farther could be relevant to dumping areas.

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Table 2. Combination of criteria system used for determining the suitable dumping sites

Criteria	Sub-criteria	Attributes	Data sources
Natural condition and Environment	Bottom depth	<6m	Topographic map, nautical chart (base maps)
		6-20m	
		20-30m	
		>30m	
	Litho-hydro dynamics	Erosion	Numerical model [11]
		Sedimentation	
	Marine ecosystems (corals, sea grasses, mangroves, beaches, tidal flats, underwater soft bottom)	<5,000m	Project research results
		5,000-10,000m	
		>10,000m	
	Distribution of benthos	H'<1	Project research results
		1<H'<3	
		H'>3	
Socio-Economics	Distance to residential areas, touristic sites (beaches)	<5,000m	Administrative maps (base maps)
		5,000-10,000m	
		>10,000m	
	Distance to shipping channels	<5,000m	Nautical charts (base maps)
		5,000-10,000m	
		>10,000m	
	Distance to aquaculture area	<5,000m	Land use maps
		5,000-10,000m	
		>10,000m	
	Distance to conservation areas, underwater planned structures and facilities	<5,000m	Land use maps
		5,000-10,000m	
		>10,000m	

Source: project ĐT.MT.2015.721

3.2.2 Social-economic criteria

To minimize the impacts of dredged material disposal on the city socio-economic development, the dumping area should be: (1) far away from residential areas and coastal tourist areas; (2) not on areas to be planned for underwater structures such as optical fiber systems, electrical cables, power lines, gas pipes, sewage pipes; (3) certain safe distance from the shipping channels to prevent dredged materials from their re-settlement on the channels.

Criterion of coastal residential areas: residential areas would be directly affected by dumping and the most concern when conducting any socio-economic development activity. The environmental impacts of dredged material dumping must be minimum in these areas. This means dumping areas should be as far as possible. A distance of at least 10km [3] was taken for the criterion.

Tourist beach criterion: beaches in tourism use include Do Son, Cat Co 1, 2, 3, Cat Dua, Van Boi and Tung Thu (Cat Ba islands). The environmental impacts of the dredging materials from dumping areas on beaches must be minimal. This means dumping areas should be as far as possible. A distance of at least 10km [3] was taken for the criterion.

Criterion of aquaculture area: dredged material dumping might negatively impact on aquaculture area adjacent to disposal sites, decreasing aquaculture productivity and yield. A distance of 5km and farther from the disposal sites [17] should be kept.

Criteria of socio-economic development planning (underwater planned structures and facilities): the dumping area cannot be in an area that already exists or is planned for underground infrastructure such as fiber optic cable, electric cable, gas pipeline, wastewater pipe ... In terms of economics, the distance from dumping area to dredging site is a major concern. Disposal sites closed to dredging areas are more convenient and economical for dredged material transportation. Furthermore, the transport of dredged materials to dumping sites will generate more emissions, noises and busier shipping. Therefore, it is not only of saving the cost of transporting but also of environmental protection and maritime safety. According to the project DT.MT.2015.721 and other works [3], the suitable distance of 10km from the dumping site should be taken into account.

3.3 Zoning Dredged Material Disposal to Minimize Environmental Impacts

3.3.1 Weight Assignment

Weight assignment was made for criteria, sub-criteria and their attributes. The 9-point pair matrix resulted in the values of the criteria, sub-criteria and attributes (Tables 3,4,5).

Table 3. Importance of criteria in dumping site selection

No.	Criteria	Weight
1	Natural condition	0.36
2	Environment	0.33
3	Socio-economics	0.31

Table 3 presents three key criteria that were weighted in the total weight being 1 (one). Among the three criteria, the criteria of natural condition was most important, followed by the environmental criteria and the socio-economic criteria. Weighting detail criteria (sub-criteria) was done in the same way as for the three key criteria. Of the natural condition, the sub-criterion of litho-hydrodynamic was more important than the remain one. Similarly, the sub-criterion of ecosystems and the

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distance to conservation area were more weighted than others (Table 4). The weights of attributes (Table 5) show the more importance of farther distances from impacted objects (shipping channels, aquaculture areas, conservation areas, residential areas, etc.). For benthos, the bottom area with H' less than 1 was the most suitable for dumping.

Table 4. The weights of the sub-criteria

Criteria	Sub-criteria	Weight
Natural condition	Bottom depth (m)	0.4
	Litho-hydrodynamics	0,6
Environment	Ecosystems	0.65
	Distribution of benthos	0.35
Socio-economics	Distance to conservation areas (m)	0.39
	Distance to residential areas, touristic spots (m)	0.30
	Distance to shipping channels (m)	0.15
	Distance to aquaculture area (m)	0.16

Table 5. The weights of the attributes of each sub-criterion

Sub-criteria	Attributes	Weight
Bottom depth	<6m	0.0445
	6 - < 20m	0.1034
	20 - < 30m	0.2646
	≥30m	0.5874
Litho-hydrodynamics	Accretion	0.9000
	Erosion	0.1000
Distance to residential areas, tourist sites	<5,000m	0.0581
	5,000-10,000m	0.2067
	>10,000m	0.7352
Distance to shipping channels	<5,000m	0.0581
	5,000-10,000m	0.2067
	>10,000m	0.7352
Distance to aquaculture area	<5,000m	0.0581
	5,000-10,000m	0.2067
	>10,000m	0.7352
Distance to conservation areas	<5,000m	0.0581
	5,000-10,000m	0.2067
	>10,000m	0.7352
Ecosystems (beaches, mangroves, corals and tidal wetlands)	<5,000m	0.0581
	5,000-10,000m	0.2067
	>10,000m	0.7352
Distribution of benthos	H' <1	0.7352
	1<H'<3	0.2067
	H>3	0.0581

3.3.2 Zoning Dredged Material Disposal

Zoning of suitable dumping area was performed through a weighted overlay of thematic layers of the criteria in Arc GIS 10.1.The GIS thematic layer of environmental criteria included four sub-layers of bottom depth, litho-hydrodynamics, ecosystems and benthic distribution. The GIS thematic layer of socio-economics was composed of four sub-layers of distance to residential areas, tourist sites, distance to shipping channels, distance to aquaculture area and distance to conservation areas. GIS thematic sub-layers of criteria with their weighted attributes were built in GIS database and then overlaid following multi-criteria GIS overlay analysis model (Figure 2). A new layer outcome showed one zone (green) at the range of above 0.5 to 0.65, being highly suitable for the dumping and the another zone (red and yellow) of under 0.5, being low suitable or not matching criteria for the dumping. Also, from the outcome of the MCOA (Figure 3), it shows that deep-sea areas (below 15m deep to the deeper), offshore to the South, Southwest have a higher suitability (values above 0.5) than other zones.

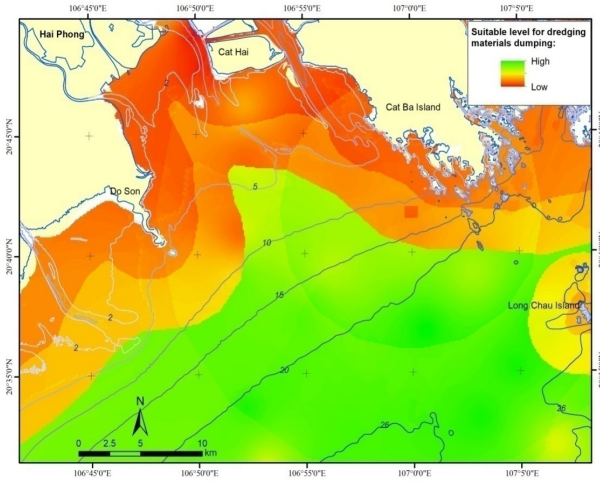

Figure 3. Zones of suitability for dredged material dumping

3.4 Discussions

Considering that being dredged from the shipping channels in Hai Phong, the environmental quality of dredged materials meeting the permissible limits issued by the Ministry of Natural Resources and Environment of Vietnam, the effects of turbidity and sedimentation by the dredged material dumping in coastal waters of Hai Phong ports are accepted when the dumping takes place in the highly suitable zone. The dispersion and sedimentation

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of dredged materials dumped into coastal waters can generally degrade marine and coastal ecosystems, pollute the waters used for economic activities such as tourism, aquaculture and fishing ... Therefore, the environmental impacts from disposal sites in the zone, when put into operation, will be focused on turbidity. Some recent studies in the study area found the existence of the maximum turbidity zone of the Cam River - Bach Dang estuary (EMT) with the maximum turbidity concentrated in the area of the saline intrusion and decreasing when salinity increases (1-15‰) [18], and could be spatially distributed up to 15km seaward from the coast during the low tide in the rainy season [18]. Thus, the area suitable for dumping is outside of the maximum turbidity zone and in the area with the sedimentation rate reaching about 10-20mm/ year [17]. It can be seen that the dredged material dumping at sites in this zone is quite suitable for the development trend of the bottom topography as well as ecological and environmental. The results of the 3-dimensional numerical model (3D) of the project DT.MT.2015.721 [3] also showed that, in the rainy and dry seasons, the turbid area from the depth below 15m to 25m for dumping would be expected to have a minor impact on the coastal area of Cat Ba islands in sea bad conditions that occur during the S, SW directional waves. The predicted cases with other wind and wave directions hardly affect the coastal areas of Cat Ba-Long Chau islands, Cat Hai coastal areas and Do Son beaches. Thus, the turbid waters caused by the dredged material disposals in the area are suitable because dredged material dispersion is only in a narrow range due to the diversion of the tidal currents. This turbid area in some cases has a minor impact on the coastal waters of Cat Ba with the concentration of suspended sediment increasing below 10mg/l in the bottom layer, not significantly in the upper layers.

The proposed appropriate zone for dredged material dumping will meet the increasingly urgent need of Hai Phong city. However, this area is located quite far from the dredging areas. This can increase the cost of transporting dredged materials from the dredging area to dumping sites. Transportation cost incurred for $1m^3$ of dredged materials per 1km is estimated at VND 8,424 - this price applies to the transportation distance from km 6 onwards. Although this increases the cost of channel dredging, it may still be much lower than the environmental costs and losses incurring if dumping closer to shore. Therefore, it is not possible to place disposal sites closer as it may cause unpredictable impacts, especially impacts on the Cat Ba Biosphere Reserve and the coral areas surrounding Long Chau island.

4. Conclusions

Eight sub-criteria of sustainable development criteria of socio-economics and the environment developed and weighted included bottom depth, litho-hydrodynamics, ecosystems, distribution of benthos, distance to residential areas and tourist sites, distance to aquaculture area, distance to ecosystems and distance to conservation areas. These sub-criteria were developed in GIS platform and then analyzed using multi-criteria GIS overlay model. The analysis results show that the zone below 15m deep, to the South and Southwest is highly suitable than others for dredged material disposing. In the zone, the factors of topographical depth, low biodiversity, medium to relatively high sedimentation rate, minor negative impacts on important ecosystems meet criteria for sustainable management of coastal area of Hai Phong. The dumping of the dredged materials offshore in this zone may incur costs for the maintenance and dredging of shipping channels in Hai Phong. This issue requires further research in costs - benefits with the integration of environmental - ecological factors to ensure rational use of resources and environmental protection in coastal areas.

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