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RISK REGIONAL ZONATION OF ENVIRONMENTAL POLLUTION ON THE PORT OF HAI PHONG, VIETNAM AND THE SURROUNDING AREA

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Abstract. The Port of Hai Phong has been recognized as the largest seaport in the north of Vietnam. The extension and the growth of international trade in this port have resulted in corresponding rapid growth in amount of goods, as well as the impacts on the marine environment. For years, the port operations and maritime activities in Hai Phong have caused significant damage to water quality and subsequently to marine life and ecosystems, as well as human health. This study illustrates an approach to zone the environmental risk of pollution on coastal and marine areas on the basis of three criteria: the level of pollution (or the risk of pollution), the extent of pollution impact, and the vulnerability of risk receptors. The result showed that the Port of Hai Phong and the surrounding area were comprised of four zones: very high, high, medium, and low degrees of risk; in those zones, factors that may cause maritime hazard, such as meteorological conditions, hydrology, topography, geology, ship life, maritime density, transport categories, and risk management factors are all taken into consideration. The risk map, thus, provided a basis for the implementation of control measures as a part of the environmental risk prevention and management.

1 INTRODUCTION

The Port of Hai Phong has been recognized as the largest seaport in the north of Vietnam by cargo volume, which offers advanced facilities, complete and safe infrastructure suitable for multi-modal transportation, and international trade. The Port of Hai Phong consists of different main branches, including Chua Ve Terminal, Hoang Dieu Port, Dinh Vu Port, Tan Vu Port. Main services of the Port are: 1) cargo handling, bagging/packing, tallying and warehousing; 2) Tug assistance and maritime salvages to ocean vessels; 3) Cargo transit and

container transshipment services; 4) Transport agent and forwarding; 5) Logistics services of container transport by Hai Phong - Lao Cai rail-way route; 6) On-land and by-waterway transport; and 7) Ship agent and maritime brokerage. Cargo throughput at the Port in 2015 was 23,748,843 (MT), and 14,407,703 TEUs.

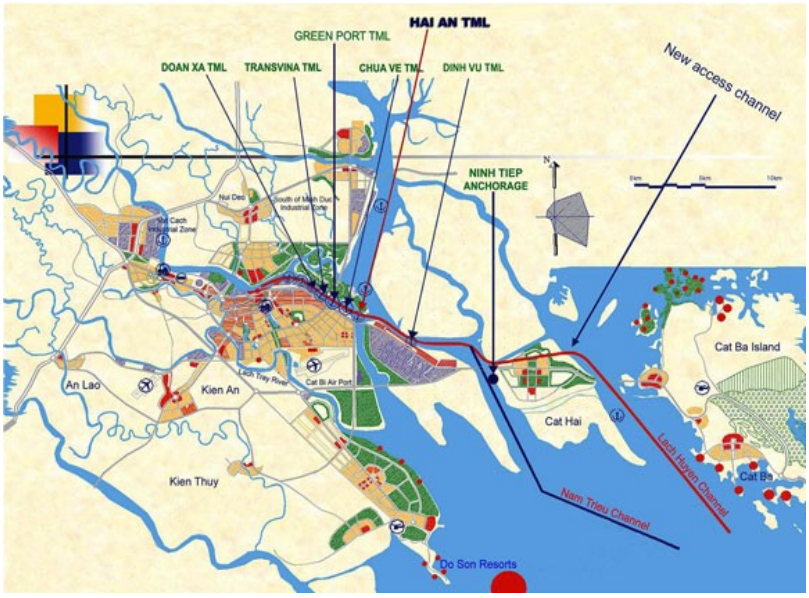

Figure 1: Container terminals in Hai Phong Area

The Vietnamese government is planning to upgrade the Port of Hai Phong. Lach Huyen Port is being built as a general port, and container port. It will be the main wharf area of the Port of Hai Phong, and be capable to receive ships of 50,000 to 80,000 DWT by 2020. Dinh Vu area is being dredged and renovated to be able to receive ships of 20,000 to 30,000 DWT (Figure 1). Another port will be built in Yen Hung as a specialized wharf that can accommodate 30,000 to 40,000 DWT vessels. In addition, there is Nam Do Son wharf used for national security. This extension and the growth of international trade in the Port of Hai Phong have resulted in corresponding rapid growth in amount of goods being shipped by sea, as well as the impacts on the marine environment. For many years, the port operations and maritime activities in Hai Phong have caused significant damage to water quality and subsequently to marine life and ecosystems, as well as human health.

Regional environmental risk assessment (ERA) can be defined as a risk assessment which deals with a spatial scale that contains multiple habitats with multiple sources of many stressors affecting multiple endpoints. The characteristics of the landscape also affect the estimated risk [1]. The regional ERA is more complex than the general ERA because all risk receptors, risk sources, risk exposure, uncertainty, and especially spatial heterogeneity, are taken into account. The regional ERA results in a risk zoning map to help risk analysts and scientists explore the spatial nature of pollutant concentrations, exposure, and effects. Moreover, it also constitutes a very powerful tool to communicate the outcome of complex ERA [1]. Indicators used to display risks are often indices or quotients like the toxicity exposure ratios, hazard quotient, and risk quotient. Regional risk zonation of environmental pollution is useful for the protection of marine resources and the development of sea-based

economic sectors. However, the number of studies on environmental risk as a complex system of multiple factors and effects caused by regional environmental risks on the marine and coastal areas is still limited [3].

This study presents an approach to carry out regional risk zonation of marine pollution on the Port of Hai Phong and the surrounding area. Comprehensive risk index values were calculated and a quantitative risk zoning map can be obtained on the basis of risk index system. The quantitative risk zoning map provides a basis to implement control measures as a part of the environmental risk prevention and management for the largest seaport in the north of Vietnam.

2 MATERIALS AND METHODS

2.1 Computational grid

To assess the environmental risk, the research region should first be divided into smaller units. Rectangular/square grids, administrative grids, industrial parks, or industrial development zones have been used as units in previous studies [2]. In this study, the rectangular grid was applied as the zonation unit, because it has been proved to be an appropriate mesh in dealing with regional environmental risk caused by complex pollution from multi-sources, multi-paths and multi-objects [5].

According to Vietnamese regulation on zoning of environmentally polluted risk on sea and islands (henceforth, Vietnamese regulation) [7], the grid division must be based on the geography and geomorphology of the land shorelines, the dynamic regime, the coastal and marine ecosystems, and the socioeconomic activities. Lengths of coastal grids and marine grids do not exceed 03 nautical miles and 12 nautical miles, respectively.

2.2 Comprehensive risk index (I_g)

The environmental pollution risk on each grid (I_g) comprises three criteria (Table 1), namely the risk of pollution (I_p), the extent of pollution impact (I_i), and the vulnerability of risk receptors (I_v).

Table 1: Zonation index system

Comprehensive index	Criteria	Primary index
Environmental pollution risk (I_g)	The risk of pollution	I_p
	+ *Maritime risk factors*	I_f
	+ *Maritime risk management,*	I_m
	+ *Status of marine water quality*	I_s
	Extent of pollution impact	I_i
	Vulnerability	I_v
	+ *Likelihood of harm to human health*	I_h
	+ *Likelihood of harm to marine ecosystems*	I_e
	+ *Likelihood of harm to sea use activities*	I_u

Source: Vietnamese regulation on zoning of environmentally polluted risk on sea and islands

The environmental pollution risk index is defined by Formula (1).

$$I_g = (2I_p + I_i + 3I_v)/6 \quad (1)$$

where:

"I_g" = the comprehensive risk index on each grid.

"I_p", "I_i", and "I_v" = the indices of the risk of pollution (or the level of pollution), the extent of pollution impact, and the vulnerability of risk receptors respectively.

The comprehensive risk index (I_g) is divided into 4 categories: very high risk area where $I_g > 2.6$; high risk area where $2 \leq I_g \leq 2.6$, medium risk area where $1.5 \leq I_g < 2.0$, and low risk area where $I_g < 1.5$.

2.3 The risk of pollution (I_p)

The risk of pollution (I_p) was accessed and ranked according to maritime risk factors (I_f), maritime risk management (I_m), and the status of marine water quality (I_s).

$$I_p = (I_f + I_m + I_s)/3 \quad (2)$$

Factors that may cause maritime hazard such as meteorological conditions, hydrology, topography, geology, ship life, maritime density, transport categories, and risk management factors such as maritime assistance, depth assurance, and plans, measures and manpower responding to the risk of environmental pollution, are all taken into consideration. All of the above indices have different component indices that are quantified by scoring from 1 to 4. The scoring method is presented in a study by Giang et al. [8]. In this study, all component indices of the index "I_p" were ranked according to practical conditions in each zonation unit.

2.4 The extent of pollution impact (I_i)

This index is given from 1 to 4 depending on the impact of pollution in the calculated grid on adjacent grids. Detailed guideline for scoring of this index is showed in the Vietnamese regulation [7]. In this study, this index was determined based on the results of a hydrodynamic model developed for these areas. A 2D tidal current – wave was developed for this area by applying the DELFT3D model. Based on the flow regime and rate, we determined the value of "I_i".

2.5 The vulnerability of risk receptors (I_v)

The vulnerability is determined by the mean of three indicators, including the likelihood of harm to human health (I_h), to marine ecosystems (I_e), and to sea use activities (I_u). The scoring method is presented in the Vietnamese regulation [7]. In this study, component indices of the vulnerability index (I_h, I_e, I_u) were scored depending on actual natural and socio-economic characteristics in each zonation unit and by the judgment of a panel of experts.

$$I_v = (I_h + I_e + I_u)/3 \quad (2)$$

2.6 Risk zonation map

The results of the comprehensive risk indices were mapped by using GIS tool and then a risk zonation map of environmental pollution was obtained.

3 RESULTS AND DISCUSSION

3.1 Computational grid

Computational grids are presented in Figure 2.

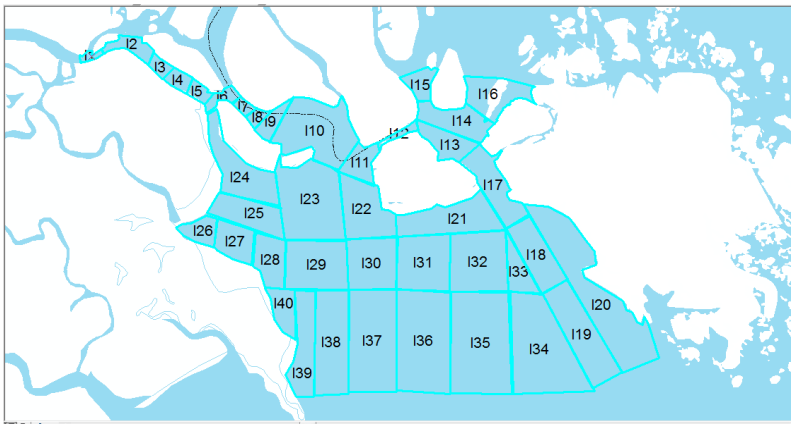

Figure 2: Computational grids

The study area was divided into 40 rectangular grids. The minimum grid size was 0.55 km^2 and the maximum grid size was 22.17 km^2. The total calculated domain (along the coastline) was about 310 km^2. Small grids were concentrated in the seaport waters or access channels, where there are many maritime activities. Larger grids were located in offshore waters.

3.2 Comprehensive risk index and risk zonation map

Table 1 shows the calculated results of the component and comprehensive risk indices. Based on these results, a risk zonation map of environmental pollution has been conducted and is shown in Figure 3. The Port of Hai Phong and the surrounding area comprised four zones according to very high, high, medium, and low risk degrees of marine pollution.

The red areas in the Figure 3 are very high risk zones, which make up 6% of the study area. These areas were located at Cam River Channel (from Hoang Dieu Port to Tan Vu Terminal) and in Ha Nam Channel. The comprehensive risk score ranged from 2.6 to 2.7. High risk values appeared around Hoang Dieu Port and Chua Ve Terminal, as these were densely populated residential areas with many marine uses, resulting in very high risk of pollution to human health, and the marine environment. Moreover, these areas are narrow but there are many ships passing by. Besides, the water environment here is also receiving domestic waste water from Hai Phong City, so the quality of water is rather low. Active and effective risk management measures must be taken in these areas to minimize the environmental pollution to the surrounding area.

The channels of Bach Dang and Lach Huyen, and a part of Van Uc Estuary had high risk of marine pollution (in orange in the Figure 3). Bach Dang and Lach Huyen Channels are the main navigation channels with high density of maritime activities, but their topography is complex; consequently, risk of marine pollution is high. In general, the high-risk areas accounted for 30% of the study area.

The yellow areas are medium risk zones, which make up 28% of the study area. These were estuary areas located outside the maritime access channels leading into the ports,

including Van Uc Estuary, the south of Tan Vu and Dinh Vu Ports. These areas did not have any maritime activity, but were directly affected by the risk of environmental pollution caused by maritime incidents in Hoang Dieu Port, along Bach Dang Channel, or possibly in the Ha Nam Channel. The comprehensive risk index values ranged from 1.5 to 1.9. The south of Tan Vu - Dinh Vu Ports had higher values of comprehensive risk index because it was directly affected by the risk of environmental pollution from the main channel. About 36% of the study area belonged to low risk zones (in green in the Figure 3). This area included the offshore of Hai Phong City. This area did not have any maritime activities, so it was not directly affected by pollution from these activities. Moreover, there was no marine exploitation, no human activity, and no important ecosystems or protected areas in this area.

Table 2: Results of the primary and comprehensive risk indices

Gird	I_f	I_m	I_s	I_p	I_i	I_h	I_e	I_u	I_v	I_g	Risk level
I1	2	1.8	4	**2.6**	**1**	3	2	4	**3.0**	**2.5**	high
I2	2	1.8	4	**2.6**	**2**	3	2	4	**3.0**	**2.7**	very high
I3	1.7	1.8	4	**2.5**	**2**	3	2	4	**3.0**	**2.7**	very high
I4	1.9	1.8	4	**2.6**	**2**	3	2	4	**3.0**	**2.7**	very high
I5	1.9	1.8	4	**2.6**	**2**	3	2	3	**2.7**	**2.5**	very high
I6	2.1	1.8	4	**2.6**	**2**	3	2	3	**2.7**	**2.5**	high
I7	2.1	1.8	4	**2.6**	**2**	3	2	3	**2.7**	**2.5**	high
I8	2.1	1.8	4	**2.6**	**2**	3	2	3	**2.7**	**2.5**	high
I9	2.1	1.8	4	**2.6**	**2**	3	2	3	**2.7**	**2.5**	high
I10	1.9	1.8	4	**2.6**	**3**	3	2	2	**2.3**	**2.5**	high
I11	2.4	1.8	4	**2.7**	**3**	3	2	2	**2.3**	**2.6**	high
I12	2.2	1.8	2	**2.0**	**3**	3	2	3	**2.7**	**2.5**	high
I13	2.4	1.8	2	**2.1**	**3**	3	2	4	**3.0**	**2.7**	very high
I14	1.7	1	1	**1.2**	**2**	1	2	2	**1.7**	**1.6**	high
I15	1.7	1	1	**1.2**	**2**	1	2	2	**1.7**	**1.6**	low
I16	1.7	1	1	**1.2**	**2**	1	2	2	**1.7**	**1.6**	low
I17	2.2	1.8	1	**1.7**	**3**	3	2	4	**3.0**	**2.6**	high
I18	2.3	1.8	1	**1.7**	**3**	3	2	4	**3.0**	**2.6**	high
I19	1.9	1.8	1	**1.6**	**3**	3	2	4	**3.0**	**2.5**	high
I20	1.4	1	1	**1.1**	**3**	3	1	1	**1.7**	**1.7**	medium
I21	1.4	1	1	**1.1**	**3**	3	1	1	**1.7**	**1.7**	medium
I22	1.4	1	4	**2.1**	**3**	3	1	1	**1.7**	**2.0**	high
I23	1.4	1	4	**2.1**	**3**	3	1	1	**1.7**	**2.0**	high
I24	1.4	1	4	**2.1**	**3**	3	1	1	**1.7**	**2.0**	high
I25	1.4	1	4	**2.1**	**3**	3	1	1	**1.7**	**2.0**	high
I26	1.4	1	3	**1.8**	**3**	3	1	1	**1.7**	**1.9**	medium
I27	1.4	1	3	**1.8**	**3**	1	1	1	**1.0**	**1.6**	medium
I28	1.4	1	3	**1.8**	**3**	1	1	1	**1.0**	**1.6**	medium
I29	1.4	1	3	**1.8**	**3**	1	1	1	**1.0**	**1.6**	medium
I30	1.4	1	3	**1.8**	**3**	1	1	1	**1.0**	**1.6**	medium

I31	1.4	1	3	**1.8**	3	1	1	1	**1.0**	**1.6**	medium
I32	1.4	1	2	**1.5**	3	1	1	1	**1.0**	**1.5**	medium
I33	1.4	1	1	**1.1**	3	1	1	1	**1.0**	**1.4**	low
I34	1.4	1	1	**1.1**	3	1	1	1	**1.0**	**1.4**	low
I35	1.4	1	1	**1.1**	3	1	1	1	**1.0**	**1.4**	low
I36	1.4	1	1	**1.1**	3	1	1	1	**1.0**	**1.4**	low
I37	1.4	1	1	**1.1**	3	1	1	1	**1.0**	**1.4**	low
I38	1.4	1	1	**1.1**	3	1	1	1	**1.0**	**1.4**	low
I39	1.4	1	1	**1.1**	3	1	1	1	**1.0**	**1.4**	low
I40	1.4	1	1	**1.1**	3	1	1	1	**1.0**	**1.4**	low

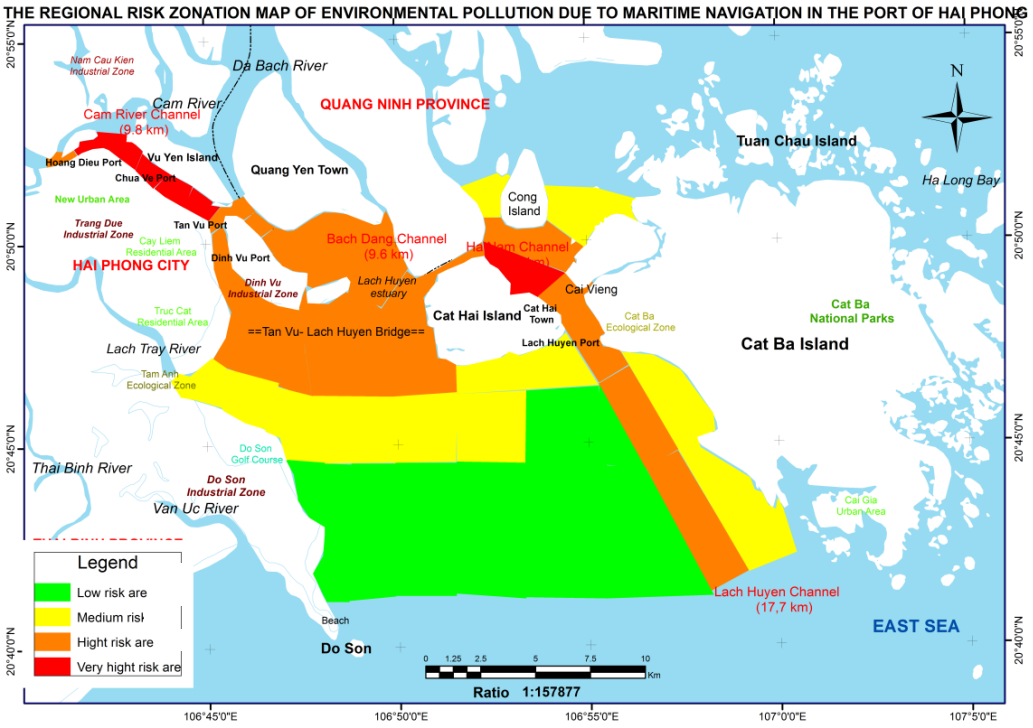

Figure 3: The regional risk zonation map of environmental pollution due to maritime activities in the Port of Hai Phong

3.3. Some recommendation for control measures

As the results of the study, 36% of the study area has high to very high level of environmental pollution risk. These areas located at all main channels, and harbor basins. Some control measures could be specified for the risk areas as the followings:

- The areas from Hoang Dieu Port to Lach Huyen Estuary: These areas have high maritime traffic and many seaports. It also receives all industrial and domestic wastewater from Hai Phong city. Therefore, risk management measures need to focus on two aspects: 1) managing maritime risks and 2) minimizing pollution of land sources. The "I_s" indexes in these areas always at their highest levels, so much attention should be paid to minimize pollution from

the mainland. To do this, domestic and industrial wastewater must be collected, and standardly treated before discharging to the environment. For maritime risk management, the Maritime Administration of Hai Phong need to develop a reasonable ship schedule, invest, manage and well exploit the VTS system, and regularly dredge the channels to ensure the navigation depth.

- The Ha Nam Channel: The risk of environmental pollution in this area is mainly caused by the risk of unsafe navigation. Therefore, maritime safety risk management is the only measure that should be applied to this area. As stated above, reasonable ship schedule, good exploitation of the VTS system, ensuring the navigation depth are some control activities to keep the safe navigation.

4 CONCLUSIONS

The results of the study showed that 64% of the Port of Hai Phong and surrounding area had low to medium risk of environmental pollution with the comprehensive risk value of from 1.4 to 1.9. The medium risk zones were concentrated at Van Uc Estuary, and from the south of Tan Vu - Dinh Vu Ports to the sea. Area with a low risk was offshore area far from the ports. Areas with high level of environmental pollution risk accounted for 30% of the study area and were concentrated in all main channels, and harbor basins. Only 6% of the study area had very high risk level. These areas were located at the Cam River channel (from Hoang Dieu Port to Tan Vu Terminal) and in Ha Nam Channel. These areas need to have active and effective risk management measures to reduce the environmental pollution to the surrounding area.

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