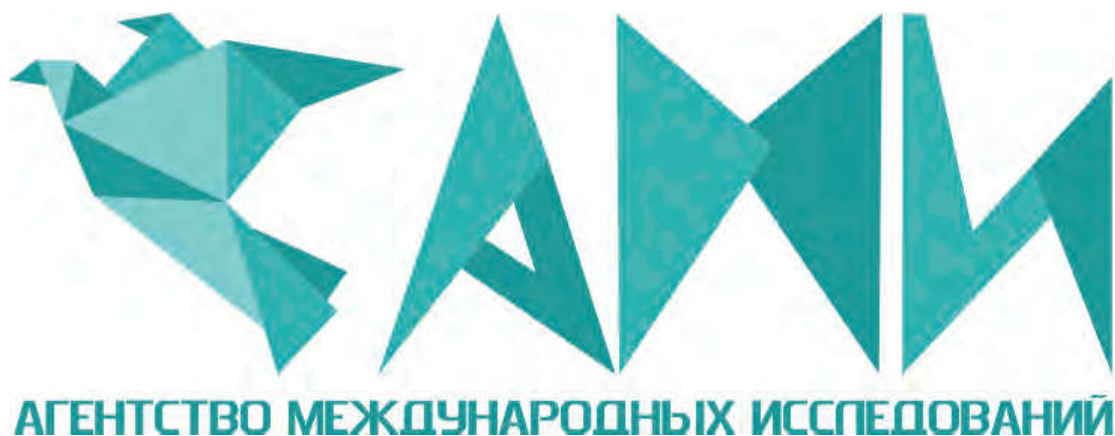




**СТРАТЕГИИ УСПЕХА:
ИННОВАЦИОННЫЕ МЕТОДЫ,
ТЕХНОЛОГИИ И ПРАКТИКИ В НАУКЕ
ДЛЯ ДОСТИЖЕНИЯ
ГЛОБАЛЬНОГО ПРОГРЕССА**

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по итогам
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ASSESSMENT AND ZONING OF ECO - ENVIROMENTAL SESSITIVITY IN HALONG CITY, QUANG NINH PROVINCE

Abstract

Economic development activities such as tourism, services, industry, and especially mineral exploitation activities are creating great pressure on the ecological environment in Ha Long City, Quang Ninh province. Therefore, the assessment and zoning of ecological sensitivity is an important basis for adjusting human activities towards the goal of sustainable use of natural resources and ecological services of Ha Long city. The ecological sensitivity of Ha Long City is assessed through three groups of influencing factors: (i) The group of natural factors including elevation, slope, vegetation cover (NDVI), Precipitation, (ii) The group of Society - economics factors consist of land use, Distances from primary mines, Distances from primary traffic roads and Distances from natural heritage and nature reserves, (ii) The group of human health risk factors consist of Population density and Natural disasters (Risk of landslides). Each factor has spatially shown on the map according to 5 corresponding levels of ecological sensitivity (1 - non - sensitive, 2 - less sensitive, 3 - moderately sensitive, 4 - highly sensitive, and 5 - extremely highly sensitivity). The Analytic Hierarchy Process (AHP) is applied to determine the importance of each factor. The synthetic ecologically sensitive zoning map is built based on weight overlay component maps. Research results have identified 4263 ha of area with highly level of ecological sensitivity (2,8 %), concentrated mainly in nature reserves and mineral exploitation activities area; 83136ha of area has a moderately sensitive (54,61 %), concentrated in mountainous areas, where the terrain is fragmented and forest cover is large; 63978 ha of area has an mildly sensitive level (42,02 %), and non sensitive areas is 0,57 %. Based on these, suggestions for protection - utilization balance were developed.

Keywords

Eco - environmental sensitivity, Quang Ninh, AHP

1. INTRODUCTION

Ecological sensitivity is the response of an ecosystem to environmental change due to the impact of natural systems such as the environment (soil, water, air), topography, land cover and human activities. Research on ecologically sensitive zoning is important in

developing economic development planning and environmental protection planning in each locality. In the US, to address high development requirements while still ensuring sustainability, New Jersey state planning has classified land across the state into 5 main categories including: urban areas with the main criterion being population density of over 1,000 people / square mile; suburbs with the main criterion being contiguity with urban areas; fringe areas with the main criterion of being adjacent to urban areas but without investment in infrastructure; Rural areas include agricultural land, forest land and bare land...; Environmentally sensitive areas include protected species habitats, high - quality wetlands, domestic water sources, high - yield forests, with many native trees... [7]. Europe is one of the world's leading regions in environmental zoning. Specifically, the study uses the AHP multi - criteria analysis method combined with GIS to assess the environmental sensitivity of land degradation and land use in the Mediterranean region (MEDALUS) based on 4 indicators: soil, climate, vegetation and management measures. Areas are divided into three levels: endangered, vulnerable and at risk [2]. Yilmaz et al. (2020) used geographic information system and AHP analytical hierarchy method to classify ecological sensitivity in Denizli of Türkiye. Indicators used to assess ecological sensitivity include: terrain, slope, geomorphology, transportation system, residential area, vegetation and land cover. The research result is a map that stratifies the level of ecological sensitivity into 5 levels: Not sensitive, moderately low sensitive, moderately sensitive, highly sensitive and very sensitive [5]. In Asia, Tag Yuping (2024), Qiang Niu (2018), Xiaoyan Dai (2011) use GIS, remote sensing and multi - criteria analysis methods to evaluate ecological sensitivity based on topographic and elevation, slope, water surface, standardized vegetation index, species richness and flood risk. The research result is a map that stratifies the level of ecological sensitivity according to 5 levels: Not sensitive, moderately low sensitive, moderately sensitive, highly sensitive and very sensitive [15,16,18].

In 2016, Leman and his colleagues performed an assessment of environmentally sensitive areas for land use planning in Langkawi, Malaysia. The Langkawi environmental sensitivity assessment study also used a multi - criteria assessment model and GIS. The set of indicators used in the study includes indicators on natural disaster risks (slope, vegetation, rainfall, seismicity...), indicators on heritage value and indicators on life support. (water source). Research classifies environmental sensitivity into four levels: high, medium, low and non - sensitive [13].

Anh Kim Nguyen et al. (2016) used GIS and remote sensing combined with AHP to zone ecological vulnerability in Thua Thien Hue. In this paper, an assessment framework composed by 16 variables with six of them constructed from Landsat 8 data is proposed to evaluate eco - environmental vulnerability in the Thua Thien – Hue Province. The 16 variables were organized following a hierarchical structure into four groups, including meteorologyhydrology, society - economics, land resource, and topography. An eco - environmental vulnerability map is assorted into six vulnerability levels consisting of potential, slight, light, medium, heavy, and very heavy vulnerabilities, representing 14 %, 27 %, 17 %, 26 %, 13 %, 3 % of the study area, respectively [1].

In Vietnam, ecologically sensitive zoning is mainly assessed for sea and island areas when there are oil spills. Studies by Le Viet Thang, 2021, Dao Nguyen Khoi, 2019, Nguyen Van Phuoc, 2019, Dinh Ba Phu, 2017, Nguyen Ngoc Son, 2015 use the ESI environmental sensitivity index to classify environmentally sensitive zones for each area when oil spills occurred in Thanh Hoa, Thai Binh, Binh Dinh provinces [3, 4, 14, 15, 11]. Huynh Cong Luc, 2017, using GIS and analytical hierarchy method (AHP) combined with weighted linear combination (WLC) analysis, built an environmental sensitivity map of Con Dao district. The results of the above studies show the effectiveness and reliability of using GIS technology and multi - criteria analysis methods in assessing and zoning ecological sensitivity. Ecological sensitivity is closely related to natural factors (topography, geomorphology, slope, cover,...) and human activities (transportation system, population,...) [9].

Ha Long City is located in the center of Quang Ninh province, with a developed economy mainly based on tourism, mining and some other industrial activities. Therefore, sustainable economic development that ensures the preservation of the environmental landscape, especially the natural heritage of Ha Long Bay, is extremely necessary and needs proper attention. Zoning ecologically sensitive map is useful information for managers to establish early warning systems on ecological safety and is important data in building economic development planning of Ha Long city.

2. MATERIALS AND METHODOLOGY

2.1. The study area

The research area is Ha Long city, Quang Ninh province with diverse terrain including high hills and mountains in the east, northeast and gradually lower to the south, coastal areas, islands with 1969 large and small islands with a system of islands. Forest and marine ecosystems are rich and diverse (Figure 1).

2.2. Materials

From the analysis of previous studies and typical characteristics of the research area, 10 ecological sensitivity assessment indicators are proposed including: Elevation, slope, vegetation cover index (NDVI), distance from main roads, distance from mineral exploitation areas and land use. Environmental quality factors were not selected as evaluation criteria due to continuous variability. The database for building a map of indicators is summarized in Table 1.

Table 1. Data sources

Group indicators	Indicators	Reference	Data Feature
Natural factors	Elevation, slope	https:// search.asf.alaska.edu (Alos Pansar, 2011)	AP _ 18811 _ FBD _ F0400 _ RT2 Digital Elevation Model (30 m resolution)
	NDVI (Normalized difference vegetation	https:// earthexplorer.usgs.gov (USGS, 2023)	LC08 _ L2SP _ 126045 _ 20231207 _ 20231209 _ 02 _ T1 Digital Elevation

	index)		Model (30 m resolution)
	Precipitation	https://chrsdata.eng.uci.edu	Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks
Society - economics	Land use, Mining areas, traffic roads, Natural heritage and nature reserves	Department of Natural Resources and Environment of Quang Ninh province, 2023	Digital vector data
Human health risk factors	Population	Department of Natural Resources and Environment of Quang Ninh province, 2023	Digital vector data
	Landslides	[6]	Digital vector data

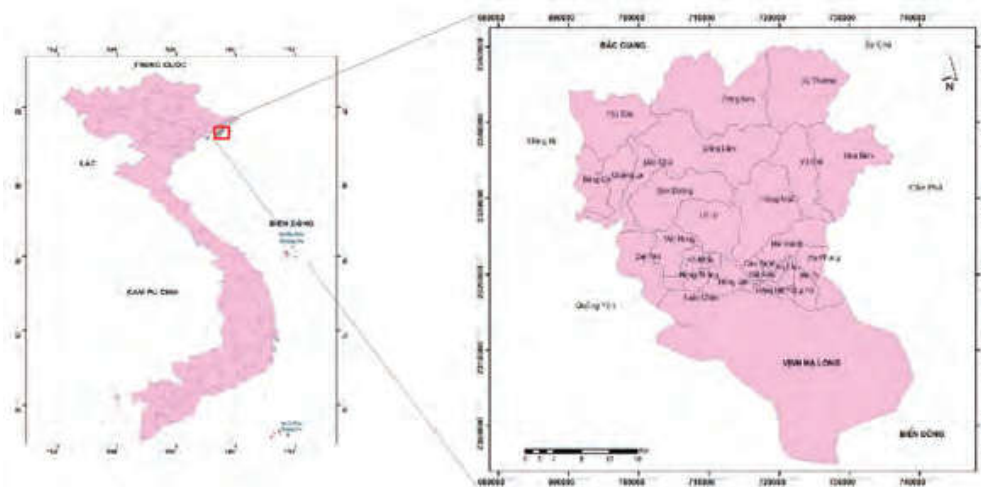


Figure 1. Location of the study area

2.3. Methodology

The research method sequence is carried out according to the following steps:

Step 1. Determine indicators for ecological sensitivity analysis

Step 2. Determine the weight of each indicator according to the AHP method

Step3. Build an ecologically sensitive zoning map by overlaying single - indicator maps according to the weights determined above.

AHP method

The AHP method is used to determine the weight for each evaluation indicator according to the opinions of experts in the field of environment. Expert assessment scores are given according to the scale proposed by Saaty in 1990 (Table 2).

The weight represents the importance of each indicator determined by the formula:

$$w_i = \frac{\sum_{j=1}^n a_{ij}}{\sum_{i=1}^n \sum_{j=1}^n a_{ij}}$$

Where:

a_{ij} : is the evaluation score according to expert opinion

n: Number of indicator

The ecologically sensitive zoning map is built on the basis of overlapping single - indicator maps according to the following weights:

$$W_i = w_i \cdot u_i$$

Where:

- w_i is the weight of each criterion determined by the AHP method

- u_i is weight with a value from 1 to 5 corresponding to 1 - non sensitive, 2 - mildly sensitive, 3 - moderately sensitive, 4 - highly sensitive and 5 - extremely sensitive for each criterion.

Table 2. Saaty's (1990) relative importance scale

Level of Importance	Definition	Explanation
1	Equal importance	Two actions contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed

The consistency ratio (CR) is used to evaluate the consistency of experts' opinions during the scoring process. It is suggested that the value of CR should be less than 0.1 had a reasonable consistency (Saaty, 1980).

To determine weight for each class of variables, variables and group variables, pair - wise comparisons were used to establish the judgment matrix. The resulting matrix was then normalized to obtain final weights. Finally, CR was calculated by the "Row Average" method (Saaty, 1980). Table 3 gives the local weights of indicators and global weights for group indicators.

Table 3. Weightings of group indicators and indicators used for the calculation of eco - environmental sensitivity for the Ha Long city

Group Indicators	Global weight (Wi)	Indicators	Local weight (wi)
Natural	0,345	Elevation (m)	0,528
		Slope (°)	0,276
		NDVI index	0,134
		Precipitation (mm)	0,062
Society - economics	0,441	Distances from mines (km)	0,177
		Distances from primary traffic roads (km)	0,073
		Land use	0,322
		Distances from natural heritage and nature reserves	0,428
Human health risk factors	0,214	Population density (People / km ²)	0,667
		Landslides	0,333

3. Results and discussion

Based on the analysis of authors Luong Van Duc (2018), Leman (2015), Qiang Niu (2018), Yilmaz (2020), Huang (2017), the level of ecological sensitivity depends on natural factors. such as altitude, slope, land use purpose, natural hazards, transportation system, water surface and vegetation [10,13,16,12,8]. Ha Long is a tourist city but also an area with strongly developed mineral mining activities. Currently, 22 / 33 communes and wards of Ha Long city have mineral mining activities, of which 18 communes / wards exploit coal, causing significant impacts on the local ecological environment. Therefore, in this study we add indicators related to the area of mineral exploitation areas. Specifically, 6 indicators evaluate the ecological sensitivity of Ha Long city area including: altitude, slope, vegetation cover index (NDVI), distance near main roads, distance near the area Mineral exploitation and land use.

- Elevation: Altitude: Ha Long has a wide range of altitudes from 0m to 1065m above sea level, the high level of geographical fragmentation leads to the differentiation of plant

species at different altitudes. The higher you go, the more sensitive plant species become, while nature's ability to recover decreases.

- Slope: The steeper the slope, the higher the risk of disasters such as landslides, flash floods, and erosion. Therefore, the degree of ecological sensitivity will be proportional to the slope.

- Normalized difference vegetation index NDVI: NDVI index reflects the proportion of land covered by vegetation. The NDVI index value ranges from 0 to 1. The closer it is to 1, the higher the vegetation coverage and vice versa. According to Xiaoyan (2011) vegetation affects the vulnerability of the ecological environment. Accordingly, ecological sensitivity will increase as vegetation increases [1].

- Precipitation: Precipitation is a vital variable for eco - environmental sensitivity assessment because it represents the climate conditions of the region. Areas with high precipitation allow plants to thrive. Therefore, the higher the precipitation, the greater the ecological sensitivity.

- Distances from primary traffic roads:

Areas near main traffic routes are often invested and developed to fit the general landscape. Therefore, these areas have lower ecological sensitivity, meaning that areas further away from main transportation systems have higher ecological sensitivity.

- Distances from mines

Ha Long city concentrates large - scale coal mines of Quang Ninh province such as Ha Tu, Ha Lam, Hon Gai, Nui Beo. Mining destroys vegetation, changes terrain and greatly impacts the natural environment, especially the gas environment. Therefore, the closer the area is to the mining area, the higher the level of ecological sensitivity.

- Land use: Land used for different purposes has different ecological sensitivities. In particular, bare land and unused land are assessed as not sensitive to environmental changes, agricultural land is assessed as less sensitive; Residential land, tourist land and industrial land are assessed as moderately sensitive; Forest land and water surface are assessed as highly sensitive and water surface used for aquaculture and domestic purposes is assessed as highly sensitive [10].

- Distribution of natural heritage and nature reserves: Ha Long City has the world natural heritage of Ha Long Bay and Dong Son - Ky Thuong Nature Reserve. This is the place to store, protect and maintain biodiversity, the natural resources of Ha Long City need to be strictly protected and managed. In particular, the core area of the heritage, the reserve has a very high ecological and environmental sensitivity.

- Population density: Humans are vulnerable to natural disasters such as storms, floods, landslides,... Areas with high population density are more vulnerable to natural disasters.

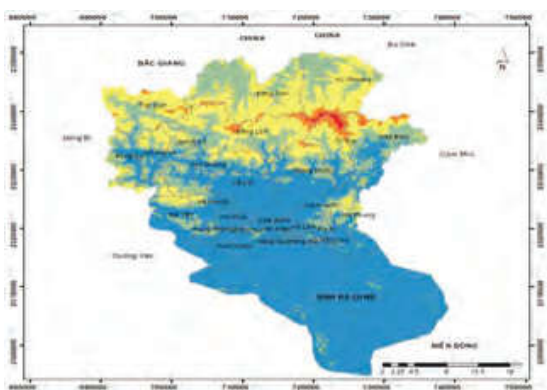
- Landslides: Ha Long City has a very complex geological development history, with a diversity of endogenous and exogenous geological processes such as uplift, downfall, subsidence, displacement, fracturing and splitting of the Earth's crust, creating folds, faults, landslides, mountainous islands or basins, elevated sea terraces, and stepped plains submerged under the Bay. In addition, Ha Long City also has thousands of limestone mountains with fractured structures, and mineral exploitation areas with a very high risk of landslides. Ha Long City has a very complex geological development history, with a diversity of endogenous and exogenous geological processes such as uplift,

downfall, subsidence, displacement, fracturing and splitting of the Earth's crust, creating folds, faults, landslides, mountainous islands or basins, elevated sea terraces, and stepped plains submerged under the Bay. In addition, Ha Long City also has thousands of limestone mountains with fractured structures, and mineral exploitation areas with a very high risk of landslides. Therefore, in areas with a high risk of landslides, the ecological environment is more strongly affected.

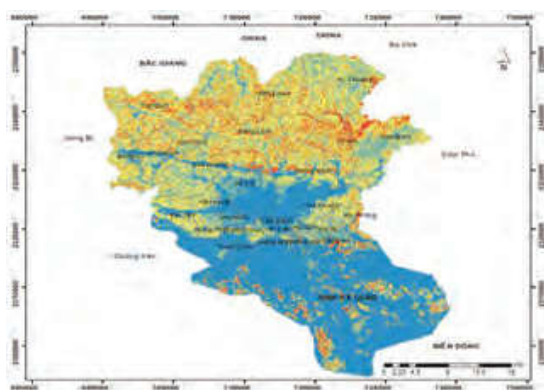
The indicators considered in the study were scored to obtain ecological sensitivity analysis and maps (Table 4).

**Table 4. Grading system of indicators
for assessing eco - environmental sensitivity**

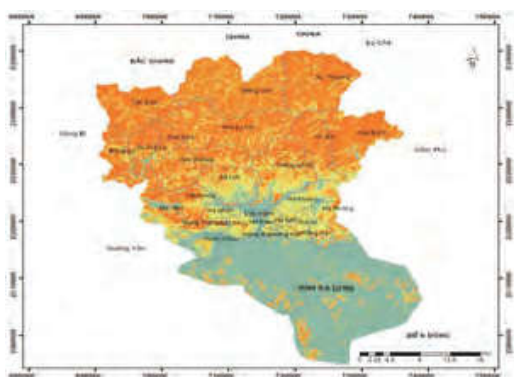
Group Indicators	Indicators	Non - sensitive	Mildly sensitive	Moderately sensitive	Highly sensitive	Extremely highly sensitive
Natural	Elevation (m)	0 - 50	50 - 200	200 - 500	500 - 800	>800
	Slope (°)	0 - 5	5 - 15	15 - 25	25 - 35	>35
	NDVI index	<0,02	0,02 - 0,2	0,2 - 0,3	0,3 - 0,5	>0,5
	Precipitation (mm)	<120	120 - 150	150 - 180	180 - 200	>200
Society - economics	Distances from mines (km)	>3	2 - 3	1 - 2	0.5 - 1	0 - 0.5
	Distances from primary traffic roads (km)	0 - 1	1 - 2	2 - 3	3 - 4	>4
	Land use	Vacant land, unused land	Agricultural land	Residential land, industrial land, tourist land	Forest land, sea surface, irrigation water	Water surface for domestic use and aquaculture water
	Distribution of natural heritage and nature reserves	Other areas	Fringe area	Buffer	Reserve	Core area
Human health risk factors	Population density (People / km ²)	<1000	1000 - 2000	2000 - 3000	3000 - 4000	>4000
	Landslides	Other areas	Buffer 500m	Buffer 200m	Buffer 100m	Buffer 50m



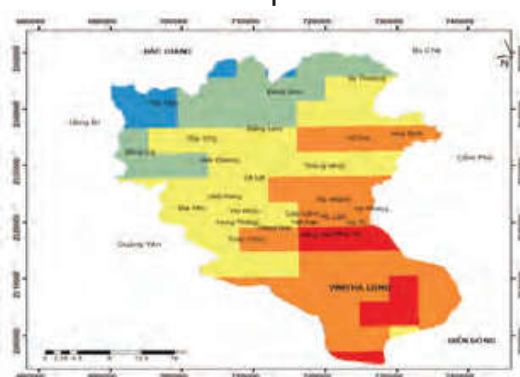
Elevation



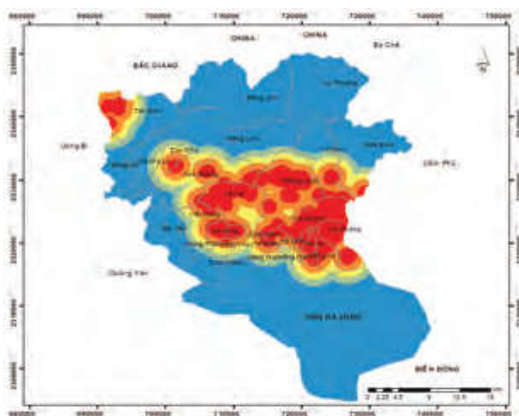
Slope



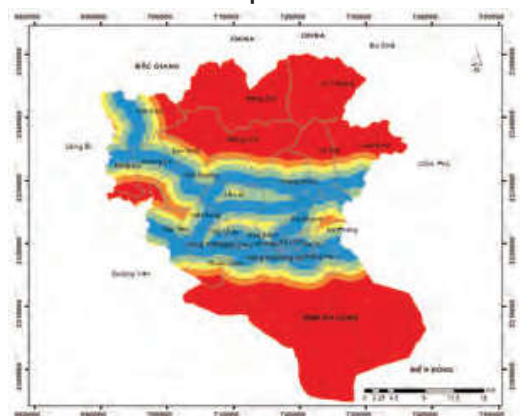
NDVI index



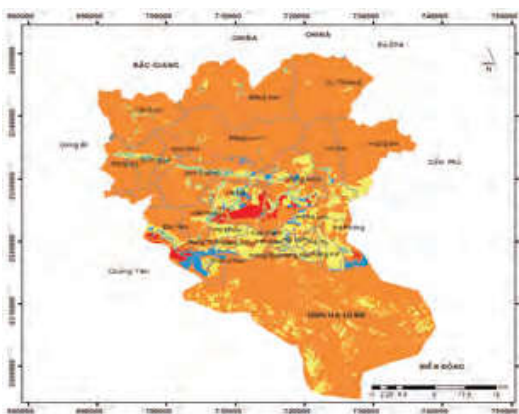
Precipitation



Distances from mines



Distances from primary traffic roads



Land use



Distribution of natural heritage and
nature reserves

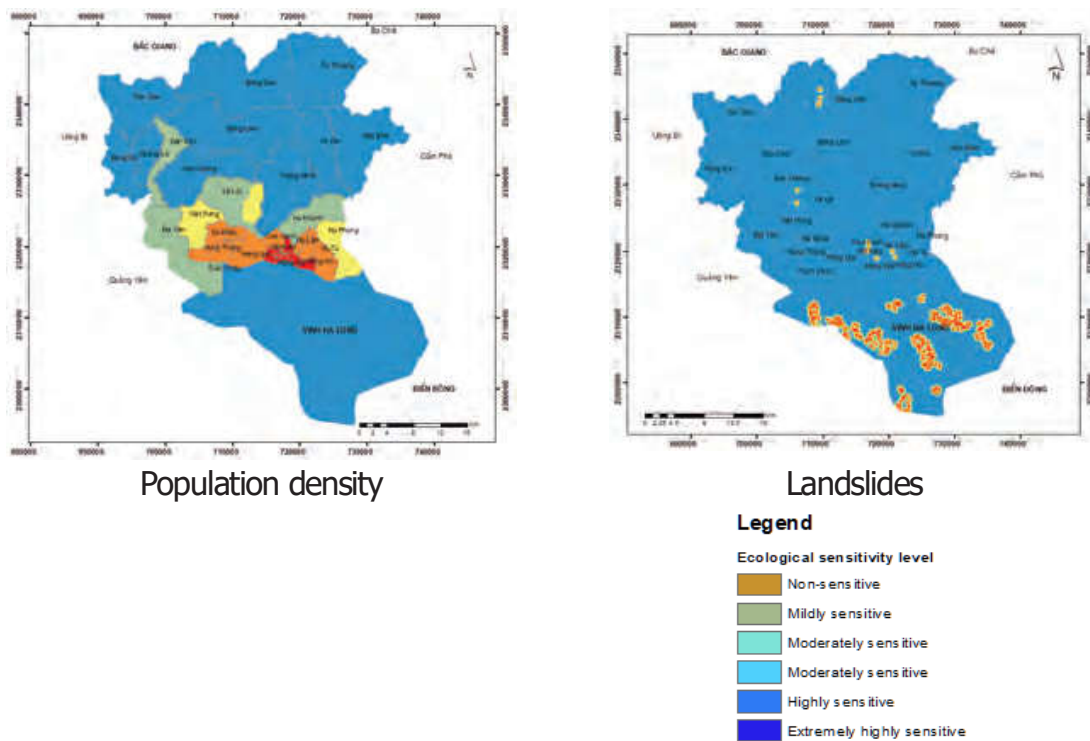


Figure 2. Zoning map of eco - environmental sensitivity Indicators

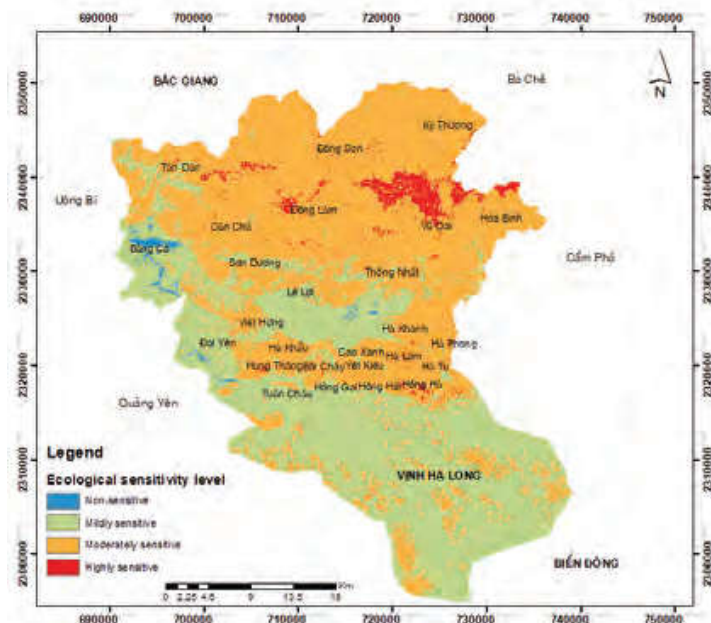


Figure 3. Ecological sensitivity map of Ha Long city

The resulting ecologically sensitive zoning map classified into four levels is shown in table 5 and figure 3.

The ecological sensitivity zoning map is built on the basis of overlapping the synthesis maps (natural factors group, socio - economic factors group and human health risk factors group) according to the weights determined in the table 3. From the results of the

assessment of ecologically sensitive zoning in Ha Long city, it shows that the highly sensitive area (4263 hectares) is concentrated mainly in nature reserves and mineral exploitation activities area such as Dong Son, Ky Thuong, Dong Lam, Ha Lam, Ha Tu, corresponding to 2,8 % of the study area. The moderately sensitivity area (83136 hectares) is mainly forests and land for tourism development, including islands outside the bay, corresponding to 54,61 % of the study area. The area with low ecological sensitivity accounts for 42.02 %, mainly the bay area and the communes on the outskirts of the city. Vacant and unused land areas are less sensitive or unaffected by environmental changes.

Table 5. Areal distribution of Ha Long city ecological sensitivity levels

Ecological sensitivity level	Area (ha)	Rate (%)
Non - sensitive	868	0.57
Mildly sensitive	63978	42.02
Moderately sensitive	83136	54.61
Highly sensitive	4263	2.80
Sum	152245	100

From the results of ecologically sensitive zoning, Ha Long city can orient appropriate economic development for each region as follows:

- For areas with high ecological sensitivity such as Dong Son, Ky Thuong, Dong Lam, Ha Tu, Ha Lam,... especially coal mining areas located near the world heritage site of Ha Long Bay, need to give solutions to strictly control the environment such as: (1) Regularly take periodic samples to quickly assess environmental quality, (2) Research and evaluate the scope of impact of mining activities on the surrounding environment, (3) Establish a perimeter Protect the safety of Ha Long Bay.

- For areas assessed at the moderately ecological sensitivity level such as Hoa Binh, Ky Thuong, Dong Son, Dong Lam..., there is a large concentration of planted forests, production forests, and protective forests. Therefore, economic development planning needs to ensure the maintenance of the region's general ecosystem, especially sloping land areas, to limit widespread land and forest loss.

- Areas with midly sensitivity are mainly vacant and unused land that need attention for economic development. However, most of the city's unused land is located in the Ha Long Bay relic complex. Therefore, economic development activities in this area need to ensure compliance with regulations on heritage protection.

4. CONCLUSION

Research results show that Ha Long city belongs to an area with average ecological sensitivity. Areas with high ecological sensitivity are concentrated mainly in areas with forests and mineral exploitation such as Ha Lam, Ha Tu, Thong Nhat, Ha Phong, Son Duong,..., accounting for 2,80 %; Areas with moderaely ecological sensitivity account for 54.61 %, concentrated in mountainous areas, where the terrain is fragmented and forest

cover is large. The area with low ecological sensitivity accounts for 42.02 %, mainly the bay area and the communes on the outskirts of the city. The ecologically sensitive zoning map is an important basis that needs to be integrated in the process of building economic development planning and environmental protection of Ha Long city. The city's ecological sensitivity will change according to the city's environmental impact and economic development activities, especially mineral exploitation and tourism development. Therefore, it is necessary to consider appropriate economic development solutions for areas assessed to have high ecological sensitivity.

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