Environmental hazard mapping using GIS and AHP – A case study of Dong Trieu District in Quang Ninh Province, Vietnam

To cite this article: N K Anh *et al* 2014 *IOP Conf. Ser.: Earth Environ. Sci.* **18** 012045

View the article online for updates and enhancements.

Related content

Environmental hazard mapping using GIS and AHP - A case study of Dong Trieu District in Quang Ninh Province, Vietnam

N K Anh[1,5], V Phonekeo[2], V C My[3], **N D Duong[1] and P T Dat[4]**

[1] Researcher, *Institute of Geography, Vietnam Academy of Science and Technology*, 18 Hoang Quoc Viet Rd., Cau Giay, Hanoi, Vietnam
[2] Senior Researcher, *Geoinformatics Center, Asian Institute of Technology*, 58 Moo 9, Phaholyothin Road Km 42, Khlong Luang, Pathumthani, Thailand
[3] Researcher, *Mine surveying Department, Hanoi University of Mining and Geology, Vietnam*
[4] Researcher, *Center for Agricultural Research and Ecological Studies, Hanoi University of Agriculture,* Trauquy, Gialam, Hanoi, Vietnam

E-mail: kimanh.nguyen2010@hotmail.com

Abstract. In recent years, Vietnamese economy has been growing up rapidly and caused serious environmental quality plunging, especially in industrial and mining areas. It brings an enormous threat to a socially sustainable development and the health of human beings. Environmental quality assessment and protection are complex and dynamic processes, since it involves spatial information from multi-sector, multi-region and multi-field sources and needs complicated data processing. Therefore, an effective environmental protection information system is needed, in which considerable factors hidden in the complex relationships will become clear and visible. In this paper, the authors present the methodology which was used to generate environmental hazard maps which are applied to the integration of Analytic Hierarchy Process (AHP) and Geographical Information system (GIS). We demonstrate the results that were obtained from the study area in Dong Trieu district. This research study has contributed an overall perspective of environmental quality and identified the devastated areas where the administration urgently needs to establish an appropriate policy to improve and protect the environment.

1. Introduction

Fast developing economy and population growth has severe impacts on environment and natural resources. Outstandingly, environmental recession is getting more and more complicated. Identifying and assessing pressing areas full of features, which need to be indicated. It is also challenging for researchers to estimate the overall environmental quality with adequate technology. Several methods have been applied for environmental vulnerability assessment. One of them is the combination of an Analytical Hierarchy (AHP) process method with GIS for solving spatial planning problems. It has received considerable attention among multidisciplinary decision makers and has demonstrated its value in various studies related to natural and environmental management. AHP was used in most of the studies to determine weight at each level. AHP is considered prevalent and effective method [1,2]. This method can alleviate subjective conception of human thinking by depicting interval judgment instead of giving the results in the form of an exact numeric value.

---

[5] To whom any correspondence should be addressed.

Quang Ninh is one of the most dynamic provinces as a whole, in particular due to coal mining and mineral exploitation. It is widely known that Ha Long bay is famous as one of the natural wonders in the world which was even recognized by UNESCO. However, operations of open-pit coal mines and many other mines have severe impacts on soil, water, plants, animals and atmosphere here. A map of the environmental status in Quang Ninh province was generated based on Multi-Criteria analysis. However, the weight of factors has not been calculated clearly and mainly depends on perception and skill of experts. Moreover, the results contain limitations regarding the environmental status. By these pressing real factual, assessment of environmental quality and forecast of the future trends are urgent tasks.

2. Objectives of the study
The main objective of the study is to develop a model for environmental risk zoning based on the Analysis Hierarchy Process (AHP) and a multi-criteria approach.
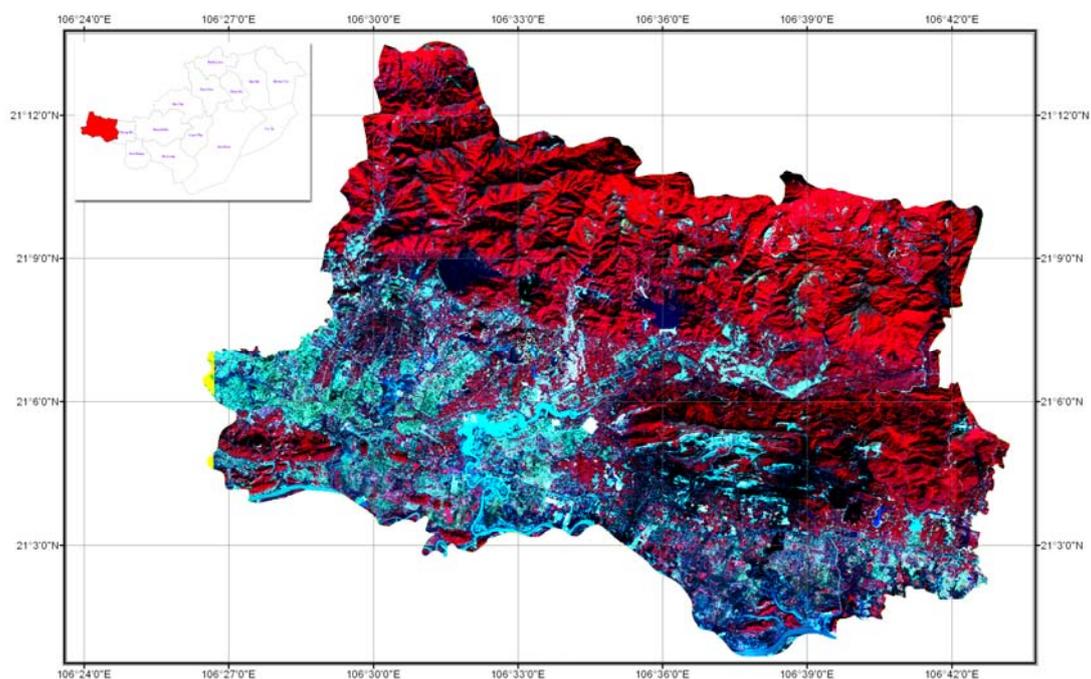
Figure 1. Study area.

2. Materials and method

2.1. Study area
Dong Trieu is a district of Quang Ninh province in the north eastern region of Vietnam, located between 21° 01' - 21° 13'N and 106° 26' 0"-106° 43' 0"E with an area of 397 km^2. The climate is monsoon and tropical, annual average temperature, moisture and rainfall are about 23.4 ^{o}C, 81% and 1,809 mm respectively. The population density is approximately 390 people/km^{-2} of which the majority works in the coal mining industry.

2.2. Data
Table 2.1 shows the data used in this study. Satellite images and topographic maps, covering the study area, were used for analysis and land cover classification.

Table 1. List of used data.

| No	Data	Date	Source of data	Description
1.	District Boundary	2003	MONRE	Quang Ninh province and Dong Trieu district
2.	Points survey	2010	DPA[b]	Surveyed data points of environmental components
3.	Topographic map	2007	MONRE[a]	Quang Ninh province and Dong Trieu district, scale 1:50.000
4.	DEM	2011	ASTER GDEM	Resolution 30 x 30m
5	SPOT 5	2010	NRSC[c]	Resolution 10 x 10m, projection system WGS-84 UTM zone 48 North

[a]Ministry of Natural Resources and Environment
[b]Department of Provincial Administration
[c]National Remote Sensing Center
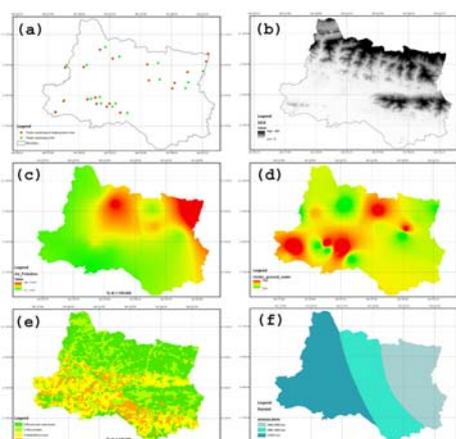
Figure 2. GIS layers in the study: (a) surveyed points, (b) DEM, (c) air quality, (d) underground water, (e) land use and (f) rainfall.
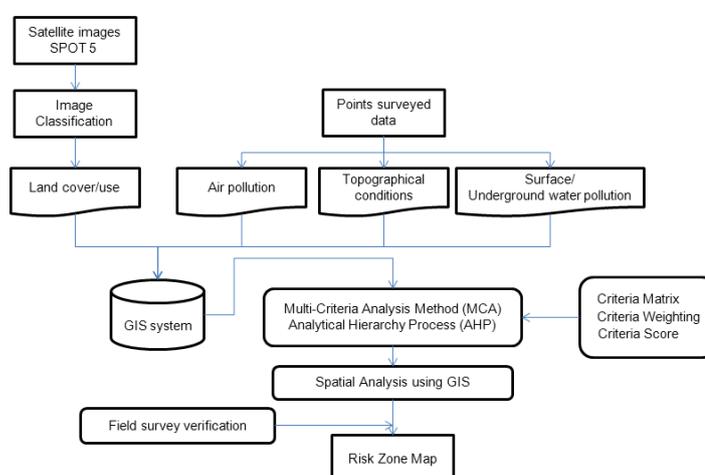
Figure 3. Flowchart of the methodology.

2.3. Methodology
A flow chart of the methodology for modelling environmental risk zoning is shown in Figure 3. Criteria and indicators were evaluated by applying GIS techniques on remote sensing data, coupled with the physical-environment, climate, and topographical factors, in association with environmental risk incidence locations. In the methodology the AHP was applied together with GIS. After classification of the SPOT 5 satellite data, the land cover map was obtained.

The data from field survey such as air pollution, surface underground water pollution and topographical conditions of the terrain in the study area were converted to vector format and applied to GIS processing. The matrix for criteria calculation was defined, followed by criteria weighting and scoring. The outputs from these calculations are used in the Multi-Criteria Analysis Method (MCA) and AHP as well. The obtained results were used in spatial analysis using GIS. The data from field visit also were used for verification of the results, and finally the final output risk zone map was generated. In the process of AHP for this study, there are several steps that were followed, which are prioritization, decomposition, checking for consistency, interpolated pollution and synthesis as described below:

2.3.1. Prioritization. The relative importance of all decision elements is captured and revealed through pair-wise comparison. This method involves pair-wise comparisons to create a ratio matrix. The

matrix of pair-wise comparison values, in order must be satisfied using the equation $A_w = \lambda_{max}\, w$, where $A = \{a_{ij}\}$ is a reciprocal square matrix to find the priority vector (vector w).

For numerical computation, Saaty developed an approximation method where the weights were determined by normalizing the eigenvector associated with the largest eigenvalue (λ_{max}) of the reciprocal matrix and the largest eigenvalue is shown in Equation (1);

$$\lambda_{max} = \frac{\sum_{i=1}^{n} i \left[\sum_{j=1}^{n} (a_{ij} w_j)/w_i \right]}{n} \;,\; w_i = \sum_{j=1}^{n} a_{ij}^* / n \;,\; a_{ij}^* = a_{ij} / \sum_{i=1}^{n} a_{ij} \tag{1}$$

Here, $a_{ij} = s_i/s_j$, where s_i and s_j are the weights and $a_{ji} = 1/\,a_{ij}$. The degree of inconsistency in the square matrix A was measured using a Consistency Index (CI), where $CI = (\lambda_{max} - n)/(\,n - 1)$. [3] compared the estimated DI with the same index derived from a randomly generated square matrix, called a Random Consistency Index (RCI) as shown in Table 2. The ratio of CI and RCI for the same order matrix was called a Consistency Ratio (CR). The judgment consistency of an expert was then determined. A CR of ≤ 0.10 was considered to be acceptable.

Table 2.2. Random Consistency Index (RCI) [3].

n	1	2	3	4	5	6	7	8	9
RCI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45

2.3.2. Decomposition. A complex problem is decomposed into a hierarchy of interrelated decision elements. A hierarchical structure is established to interrelate and chain all decision elements of the hierarchy from the top level down [3]. The global objective (DF/DHF risk zones) was placed at the top of the hierarchical structure. The lower level of the hierarchical structure consisted of more detailed elements, which interrelated to the criteria in the next higher level.

2.3.3. Checking for consistency. The values of CI, CR and λ_{max} of the main criteria were 0.034, 0.031 and 5.317 respectively. The value of CR for the sub-criteria of location of environmental risk affected air and underground pollution, rainfall, land use and elevation were 0.008; 0.008; 0.008, 0.012 and 0.026, respectively. As a result, all the weights are acceptable. On the basic of weights assigned to the criteria and analysis performed, it can be seen that the significant factors were air condition, underground water, rainfall, land cover and elevation respectively.

2.3.4. Interpolated pollution. For air pollution, surface of multi-criteria was interpolate based on the K_t index, where K_t was calculated by equation 2

$$K_i = \frac{N_i}{N_{SVN}} \tag{2}$$

Where K is Index of air quality, N is measured concentrations of substances gases, dust or noise intensity, N_{SVN} is the concentration of the standard allows gases, dust or noise intensity. K allows determining degree exceeds the allowed standard Vietnam (SVN) for each given indicator. Calculated K_t index includes CO, SO_2, NO_2, CO_2 dust and noise by equation:

$$K_t = K_{bui} + K_{on} + K_{SO_2} + K_{NO_2} + K_{CO} + K_{CO_2} \tag{3}$$

Where: $K_{bui}, K_{on}, K_{SO_2}, K_{NO_2}, K_{CO}, K_{CO_2}$ are quality index of criteria which is put into assessment and calculated by equation 3. The index of air quality around can be calculated using equation 4

$$K_t = \sum_{i=1}^{n} Ki \qquad\qquad (4)$$

Several criteria were input into underground assessment including Hg, Pb, Fe, BOD, pH, Arsenic, oil. There are several steps that are taken in order to create surface of underground pollution. Firstly, interpolation and classification are conducted for each above physical parameters; there are four level of pollution including low, medium, high and very high based on concentration of each criteria. Finally, layers of criteria are weighted and output is only one surface of underground water.

2.3.5. Synthesis. To identify environmental risk zoning, a weighted linear combination (WLC) method, which is one of the most often used techniques for tracking spatial multi-attribute decision-making (MADM) is used. WLC is used to assess the weightings for factors, and to map the risks in the various zones. It is based on the concept of weighted average. The relative weights are assigned to each attribute. The weights of the main-criteria are multiplied by the weights of sub-criteria within the same hierarchical level and summing of the products over all attributes to obtain total scores (*Ri*) by the following formula;

$$R_i = \sum k W_k r_{ik} \qquad\qquad (5)$$

Where, w_k and r_{ik} are vectors of priorities of the main and sub-criteria, respectively.

To create the environmental risk zoning index (ERZI) map, the normalized weights of the main criteria are multiplied with the normalized weights of the sub-criteria, each generating a single a resultant layer as shown in equation 6, which is modified from equation 5. By performing union operation, these resultant layers were overlay to a single layer. Hence generating one layer for each criterion;

$$ERZI = \sum (F_{LC} B_1 + F_{UW} B_2 + F_A B_3 + F_E B_4 + F_R B_5) / \sum W_1 \qquad (6)$$

Where F is weight factor of Land cover (LC), rainfall (R), Underground water (UW), Elevation (E), Air (A), B_i is class weight of sub-criteria. The value of ERZI had no quantitative meaning other than to describe in relative terms the study area.

3. Results and discussions

Relying on the proposed method above the environmental risk was divided into four levels which are low, medium, high and very high, shown in figure 4. The pie chart in figure 4 illustrates the distribution of percentage of environmental risk degrees. According to figure 4, on an overall perspective, high and very high risk areas occupied 50%, approximately 196 km^2, moderate high risk accounted for 27% estimated for 106 km^2 and medium and low risk contributed about 23% almost 90.4 km^2. In addition, it can be seen clearly in figure 4 that the high and very high environmental risk incidence were found in agriculture and built up areas with elevation from 100 to 300 m and
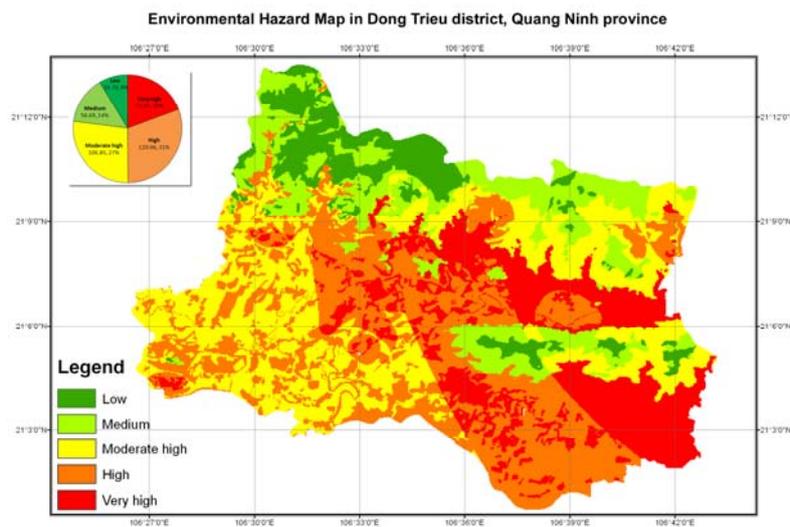
Figure 4. Result environmental risk map of the study area
with five risk degrees in percentage.

rain fall fluctuated from 1600 to 2000 mm. Another reason for this is the existence of many coal mining exploitation sites operating in these areas, hence it has drastic impact on environment. The remainder were low and medium risk areas which are located at the North and East side. It is easy to explain: These areas are forest or contain grassland and elevation is greater than 500m.

4. Conclusions
The integration of AHP and GIS in the analysis of the environmental hazards in the study area can be an efficient tool to obtain the weights of all factors that can impact environment. Then, these results can be applied to comprehensive index method to quantify the environmental quality so as to reflect the environmental impacts caused by fast social-economic development clearly and directly. The approach discussed in this study has been well utilized in the development of a model for environmental risk zoning. The results obtained in this study indicate this approach is practicable and also effective.

5. Acknowledgements

References
[1]   Li ZW, Zeng G M, Zhang H, Yang B and Jiao S 2007 The integrated eco-environment
           assessment of the red soil hilly region based on GIS/A case study in Changsha
           City, China *Ecol. Model* 202 540–546
[2]   Lu L 2009 A fuzzy analytic hierarchy process (FAHP) approach to eco- environmental
           vulnerability assessment for danjiangkou reservoir area, China
[3]   Satty T L 1977 A scaling method for priorities in hierarchical structures. *J. Math.*
           Psychol. 15 234–281