GIS AND REMOTE SENSING FOR GEOHAZARD ASSESSMENT AND ENVIRONMENTAL IMPACT EVALUATION OF MINING ACTIVITIES AT QUY HOP, NGHE AN, VIETNAM

QuocPhi Nguyen[1], Phuong Nguyen[1], ThiHoa Nguyen[2] and TienPhu Nguyen[3]

[1]Department of Environmental Sciences, Hanoi University of Mining and Geology, Vietnam
Email: nguyenquocphi@humg.edu.vn
[2]Department of Mining Environmental Engineering, Hanoi University of Mining and Geology, Vietnam
Email: hoa.mdc.bn@gmail.com
[3]Geological Division for Radioactive and Rare Elements, General Dept. of Geology and Minerals of Vietnam
Email: quocphu56@gmail.com

ABSTRACT

Satellite remote sensing data and Geographic Information Systems (GIS) offer excellent tools for geohazard assessment and environmental impact evaluation. The study aims to identify the environmental impacts of mining activities with a case study at a mining hub of Nghe An province, Vietnam. The study area is subject to rapid and increasing changes in land-use/land-cover that resulting from natural and human activities such as landslide, flash floods, construction projects of houses and roads, and especially mineral exploration activities, resulting from major environmental impacts. The hazard analysis was carried out with three major hazard types, which are landslide in mining sites and transport routes, debris flow potential by tailings dam collapse and stream blockage, and heavy metals leaching from waste rocks and dump sites. Landslide hazard was evaluated using 87 landslides using likelihood ratio model. Analytical Hierarchy Process (AHP) model was used to evaluate the potential of debris flow due to the scare information of historical data and heavy metals leaching from waste rocks and dump sites was analysed using dispersion model in Water Quality Analysis Simulation Program (WASP) on GIS environment. Initial results show spots which high prone to environmental hazards and provide very useful information for decision making and policy planning with mining sites in study area.

1. INTRODUCTION

Mining and mining activities remain the world's most intensive, primary industrial activity undertaken with severe environmental impact. The environment at mining site is diverse, with the physical environment being affected at every phase, from prospecting, exploration, operation, extraction, closure and post-closure. Mining impact increases with subsequent phases of development. At the prospecting and exploration phases, the impact is relatively small and limited to the immediate physical environment through, for example, clearing of trees, vegetation, habitats, wildlife displacement. Other disruptions include road construction, camps, pits, holes and shafts. At the operation phase, the impact increases with the loss of topsoil, soil erosion, landform changes, slope failure, landslide, cave-ins, and changes in water flow and water quality. Environmental impact on people health increases at the extraction phase with air pollution through sulphur, carbon and nitrogen compounds, toxic metal particles, gases, dust and acid deposition. Ore washing is a primary source of water and air pollution, and subsequent acid rain. The impact varies between mining sites, mining methods, equipment in use and mineral types. At the closure and even post-closure phases, the environmental and social impact is not only limited to air pollution, contaminated land and acid water, but also to ecosystems and human health (EAMIMOIM, 2011; GFDRR, 2013).

2. ENVIRONMENTAL IMPACT IDENTIFICATION AT QUY HOP, NGHE AN

Nghe An is located in the North Central Coastal region of Vietnam. The province has a wide range of mineral resources and possesses some of the largest deposits of minerals in Vietnam including limestone for cement production (4 billion tons), white limestone (over 900 million tons), clay for cement material (1.2 billion ton), basalt rocks (260 million m^3), granite (150 million), marble (300 million m^3), metal ores with tin (42 thousand tons), iron (1.8 million tons), manganese (over 3 million tons), lead, zinc, titan, rare earth and gemstones. Although the mining industry has contributed greatly to the province's economic, mining operation has caused many fatalities and injuries, and also the environment was greatly impacted. Statistical data in over 10 years, from 2001 to 2012, show that there are 59 people died or injured directly related to mining activities. One of recent accident is on April 1st, 2011 at Len Co mine, where the rocks were collapsed to a working bench making 18 deaths and other 6 injures.

Quy Hop with an area of 942 km², is a rural district of Nghe An and becomes the mining hub of the province. The district has big potential in construction stones and metallic ores, especially tin ores with reserves of 36,000 tons of SnO_2 and some 50,000 of primary Sn. Prospecting and mining for mineral in Quy Hop have shown direct impact on the environment in different ways, at each phase and in different type of mining. In study area, most of the mines are surface mining due to the presence of ore deposits is at the surface or close to the surface.

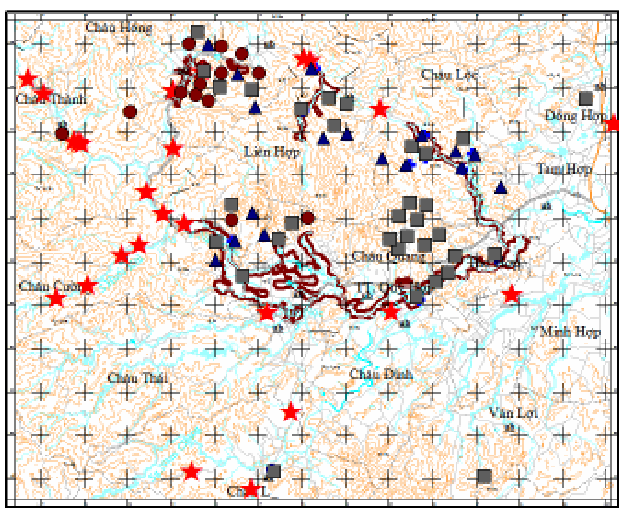


Figure 1. Mining sites at Quy Hop, Nghe An

The operation of rock quarries posed risks of ground movement, vibration, explosion and flying rock, rockfall, landslides that would affect a number of roads and surrounding communities. The exploiting and refining industry of tin, lead and zinc was intensive in the area, and also the illegal mining activities have caused the contamination of soil, groundwater and surface water by chemicals from mining processes. Moreover, high risk from mining site was observed at closed mines in the form of erosion, landslide from the waste dump site, formation of sinkholes, and loss of biodiversity in long term (Nguyen and Nguyen, 2013). Table 1 summary the observation hazards and their impact on surrounding environment in study area.

Table 1. Environmental hazards associated with mining activities in study area

Environmental hazard	Impact	Affected components
Collapse of working benches	Slope stability (rock fall or slide)	Ground movement
Collapse of tailings dam	Stream blockage, debris flow	Groundwater, surface water, soil
Vibration and explosion at mining site	Noise and flying rock	Air, soil
Dusts from mining processes and waste rocks	Dust and chemical additives	Air, soil
Overtopping of tailings dam	Heavy metals leaching	Groundwater, surface water, soil
Waste water leakage	Heavy metals leaching	Groundwater, surface water, soil
Tailing pond ground not leak-proof	Heavy metals leaching	Groundwater
Ore processing without waste water treatment	Heavy metals leaching	Surface water

3. HAZARD ANALYSIS OF MINING ACTIVITIES

Many types of environmental hazard can be identified from mining activities at Quy Hop, Nghe An. However, extensive field surveys show that, the mining operation in study area has cause three major hazard types, which are landslide in mining sites and transport routes, debris flow potential by tailings dam collapse and stream blockage, and heavy metals leaching from waste rocks and dump sites.

3.1 Landslide hazard in mining sites and transport routes

For landslide hazard, the inventory data composed of 87 landslides, in which, 63 slides at mining sites and 24 slides along the routes for ore transportation. The data is sufficient for statistical analyse and the likelihood ratio model has been used to adapt this task. It is common to assume that landslide occurrence is determined by landslide-related factors, and that future landslides will occur under the same conditions as past landslides (Guzzetti et al., 1999). Using this assumption, the relationship between landslides occurring in an area and the landslide-related factors can be distinguished from the relationship between landslides not occurring in an area and the landslide-related factors.

Likelihood ratio method can be expressed as a frequency ratio that represents the quantitative relationship between landslide occurrences and different causative parameters. The likelihood ratio is defined as follow:

$$w_{ij} = \frac{f_{ij}^*}{\bar{f}_{ij}^*} = \frac{A_{ij}^*}{A^*} \times \frac{A - A^*}{A_{ij} - A_{ij}^*} \quad (1)$$

Where: w_{ij} - likelihood ratio of class i of parameter j;

f_{ij}^* - frequency of observed landslides in class i of parameter j;

$\bar{f}_{ij}^*$ - frequency of non-observed landslides in class i of parameter j.

Therefore, the greater the ratio above unity, the stronger the relationship between landslide occurrence and the given factor's attribute, and the lower the ratio below unity, the lesser the relationship between landslide occurrence and the given factor's attribute.

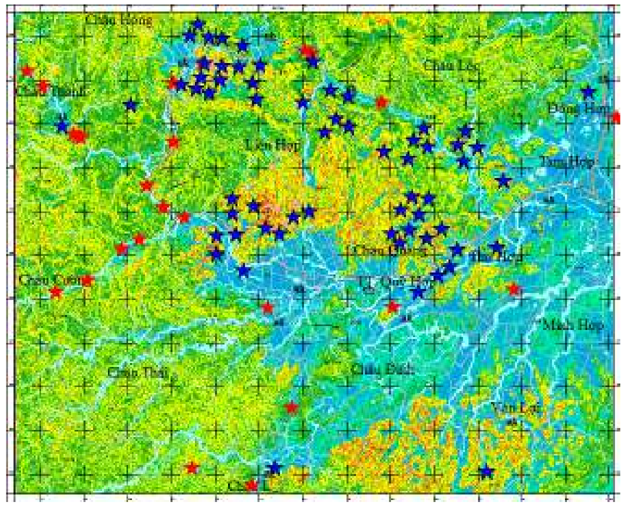


Figure 2. Landslide hazard related to mining activities in study area

3.2 Debris flow potential by tailings dam collapse and stream blockage

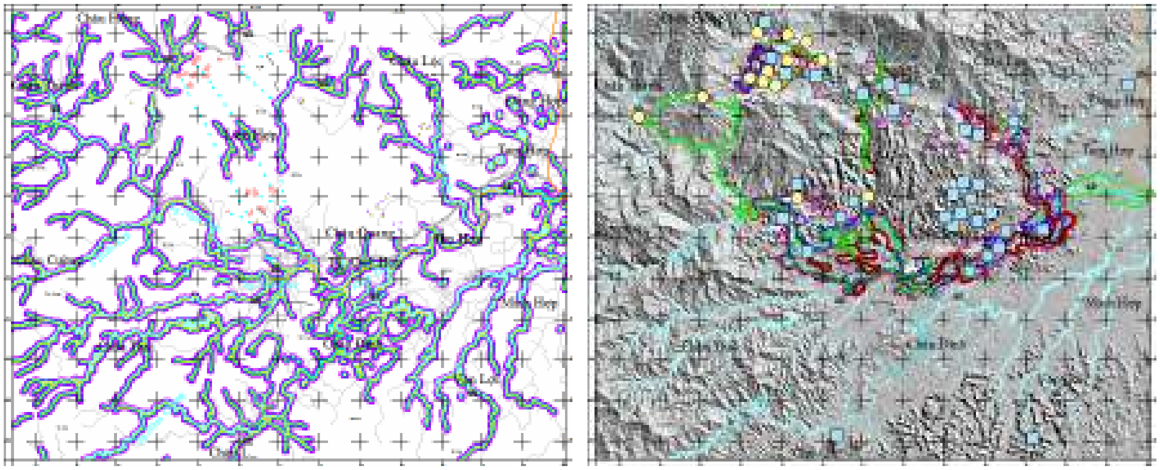
Most of debris flows were triggered by stream blockage in a high rainfall period, and they are characterised by flow with relatively high velocity and short occurrence period which make it more unpredictable. Due to its suddenness, debris flows can hardly be predicted and thus make it difficult to warn people for evacuation (Nguyen et al., 2013). There are several debris flows by the collapse of tailings dam and stream blockage related to mining activities in study area, however, the exact location are very difficult to define as historical information was not proper collected. Therefore, a heuristic approach, Analytical Hierarchy Process (AHP) was used to evaluate the potential of debris flow in study area.

In AHP analysis, weights are given by scores collected from experts, and then, the relative weight of each variable must be determined by the mathematical mean method. The pair-wise comparison of variables, the summation weights matrix, and the average weights matrix of each variable are alternately calculated (Saaty, 1980).

The relative importance of independent variables can be expressed by the weight from AHP analyse, highlighting the causal factors that are most strongly related to the occurrence of debris flow by expert judgments. In study area, among the variables, natural slope angle, land cover types, erosion potential, and vertical terrain roughness receive much attention from experts. These variables represent positive, high coefficient of weights and have to be considered as triggering factors.

3.3 Heavy metals leaching from waste rocks and dump sites

Metal concentrations in impacted surface waters can still drain even after mine closure and the exposure of metallic mining wastes, especially sulphidic ores, in oxidative weathering conditions may cause long-term production of ARD and the resultant long-term mobility of metals. The heavy metals leaching from waste rocks and dump sites was examined by using results of dispersion model in Water Quality Analysis Simulation Program (WASP) of US Environmental Protection Agency (EPA) for GIS analyse. The dispersion model is analogous to Fick's first law of diffusion and was tested with different dispersion exchange coefficients for streams that connected to metallic mines in study area.



(a) *(b)*

Figure 3. Drainage pattern of study area (*a*) and heavy metals from mining activities dispersion (*b*)

4. DISCUSSION AND CONCLUSIONS

There is no uniform definition of hazard and the term is often used in combination with the term risk. In its simple definition, a hazard spot is a source of danger if uncontrolled and risk is the probability of actual exposure to a hazardous event. Generally, mining is regarded as a hazardous activity due to its potential to cause harm in the environment and ecosystem, including human and properties. The problems increase as the fact that the mining sites are mostly located upstream from residential areas has made the situation worse. The environmental hazards compose of the direct impact of mining activities on the environment, such as surface modification, clearing of vegetation, exposing and removing the topsoil, acid mine-water drainage. Besides creating environmental damage, the contamination resulting from leakage of chemicals also affects the health of the local people. Therefore, inadequate understanding of environmental hazards of mining activities is an indication of insufficient hazard awareness and disaster preparedness.

Although there are several environmental hazards related to mining activities, field surveys in Quy Hop, Nghe An show that 3 major hazard types can be identified, which are landslide on working slopes, debris flow by tailings dam collapse or stream blockage, and heavy metals leaching. The result from this study is a step forward in the management of environmental hazard in mining areas and it can provide very useful information for decision making and policy planning at mining sites in the future.

5. REFERENCES

EAMIMOIM (European Association for Mining Industries, Metal Ores and Industrial Minerals), 2011. *Guidelines on sustainable development for the European mining sector*. Euromines, Bruessel.

GFDRR (Global Facility for Disaster Reduction and Recovery), 2012. *Implementing disaster risk reduction strategies*. World Bank, Washington DC.

Guzzetti F., Carrara A., Cardinali M. and Reichenbach P., 1999. Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy. *Geomorphology* 31, 181-216.

Nguyen Q. P., Nguyen Q. L., Nguyen K. L., Do V. N., 2013. Spatial modeling for flash flood potential in Quangngai province. *Proceedings of the Science and Technology Conference*, Hanoi University for Natural Resources and Environment, Hanoi, 157-165.

Nguyen Q. P., Nguyen P., 2013. Geohazards in mining activities of central highlands and central coastal provinces of Vietnam, 2013. *Proceeding of the Conference of Science and Technology Universities*, Dalat, 224-234.

Saaty T.L., 1980. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*. NY, McGraw Hill.