Fuzzy Multi-Attribute Decision Model for the Optimal Mine Closure Option to Contribute to Sustainable Development in Binh Duong Province, Vietnam

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Abstract

Binh Duong is the leading industry development province of Vietnam. In particular, quarries in Di An, Phu Giao and Tan Dong Hiep districts have contributed significantly to the demand for construction and transportation in the locality and vicinity. The quarries in Binh Duong province are exploited by the open-pit mining method. The mining depth is from 100m to 150 m. The mine surface area is hundreds of hectares. At the end of the quarries will leave huge pits. The current regulations of Vietnam on mine closure are mainly aimed at ensuring the stability of the physical and chemical factors of the mine, while the land use after the mine closure is permanent. Binh Duong province has a rapid urbanization rate, the use of land after mining here is very important and has a significant influence on the sustainable development of the region. Depending on the occupied area of the mine or mine cluster, there are many options to close the mine after mining based on the required technical, economic, social and environmental criteria. The paper uses fuzzy multi-attribute decision model to calculate the optimal solution selection. The selected option is to use the mine lake for tourism, entertainment and water storage at Nui Nho mine, Di An city, Binh Duong province with the highest total score of economic, social and environmental criteria.

Keywords: *mine closure, fuzzy multi-attribute decision, sustainable development*

1. Introduction

Mining closure is rated as one of the top risk activities of mining, its importance is increasingly recognized, more stringently required mine closure regulations have been introduced since 1990s [19, 23]. Mining closures can cause negative impacts such as job loss, tax revenue deficit, impact on infrastructure development, reduced demand for local goods and services, and especially environmental landscape [1, 6]. The development opportunities that mines can offer to local communities after mine closure should be carefully studied. If managed properly, the mine closure transition can provide significant opportunities in line with the Sustainable Development Goals (SDGs), such as resettlement, infrastructure development for other purposes creating new economic resources [3, 18].

Around the world, organizations such as the International Council on Mining and Metals (ICMM), the World Bank have reported on the sustainable mine closure framework [13, 15]; Countries with developed mining industries such as the US, Australia, Canada, and South Africa have legalized mine closures and issued detailed manuals. Some of the key themes in these guidelines and standards include integrated closure planning that considers the environmental, financial, physical, and socioeconomic context of a particular site, incorporating the stakeholders including community goals and aspects of social welfare, environmental management based on optimization of protection, land use and infrastructure [14]. Some of the proposed legislation includes the following sustainable land use practices under the statutory framework: i) Closures must begin at the start of the operational phase and continue until the start of the closure phase; ii) The quantification and management of environmental risks must be achieved; iii) Mine Health and Safety regulations must be observed; iv) The identification and quantification of residual environmental impacts must be achieved; v) The land must be restored to its natural state or to a predetermined state as agreed by the government to include the concept of sustainable development; vi) Mining operations must be effectively and cost-effectively closed.

Binh Duong is a leading industrial province in the country. Along with the economic development and infrastructure construction, the demand for stone construction materials is increasing. Currently, the province has 22 mines, of which 16 are being exploited and 5 are under construction. The total licensed mining area is 778.11 hectares with a total licensed mining capacity of 14,112 million m^3/year. Construction material mines in Binh Duong province are mainly concentrated in the districts: Phu Giao (3 mines) and Bac Tan Uyen (19 mines).

The quarries in Binh Duong have a close relationship: they work together on the same shore, exploit together deep below the self-flowing drainage level, and are connected to regional roads. Around the mine, it is arable land of local people. Open pit mining inevitably causes changes in the surrounding envi-

Fig. 1. Location of mine closure area (Google Map)

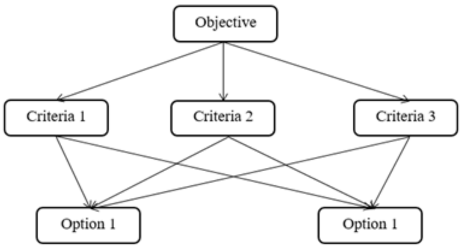

Fig. 2. AHP hierarchical structure diagram

ronment, the extent of which depends on the depth of finish, mining capacity, technology, equipment as well as size, shape and location of the mine [7].

The mining process has changed the landscape, affecting the environment, ecology, and traffic in the area. Currently and a few years from now, the quarries in Binh Duong province will end their exploitation and have to close according to regulations. Vietnam has clear regulations on the contents of mine closures, which are shown in the following documents:

- Law on Minerals No. 60/2010/QH12 approved by the National Assembly of the Socialist Republic of Vietnam, term XII, 8th session, on November 17, 2010;
- Law on Environmental Protection No. 55/2014/QH13 passed by the National Assembly on June 23, 2014;
- Circular No. 45/2016/TT-BTNMT dated December 26, 2016 of the Ministry of Natural Resources and Environment "Regulating on mineral exploration project, mineral mine closure and form of report on mineral activities and samples of documents in the application for a license for mineral activities, the application for approval of mineral reserves, and the application for closure of a mineral mine; order and procedures for mineral mine closure";
- Circular No. 38/2015/TT-BTNMT dated June 30, 2015 of the Ministry of Natural Resources and Environment on environmental renovation and restoration in mineral mining activities;

The regulations on mine closure in Vietnam are determined that after the end of mining, bring the mine to a stable state: leveling, renovating floors, dismantling works, etc., make a plan to close the mine and submit it to the authorities when preparing to end mining. The new mine closure is mainly concerned with the physical stability of the work, not integrating economic and social factors into the mine closure. The site of land use after the mine closure is directly related to society, but it is only oriented to be used as a water reservoir, planting trees without specific instructions on physical and chemical stability, etc. Closing costs have to be taken from the project's funds, but with each different model of land use after mining, the cost of closing the mine will be different, affecting the efficiency of the investor. At that time, it is necessary to consider the lifespan, the end boundary, the different stability assurance solutions to ensure the effective project after the closure. Land use after the closure of mines has not been effective, the orientation to use the premises stated in the environmental impact assessment (EIA) report is often counter-productive, simple, with as little improvement costs as possible, not really suitable with the natural and socio-economic characteristics of the area.

Mines in the same area do not have a link in a common whole, there is no integrated closure model for the most optimal use of the site after closing. Existing studies have only focused on the use of post-closure premises on the basis of the criteria to ensure the set goals, but there are no studies on stability for each model.

That's why choosing an appropriate mine closure model that contributes to the sustainable development of the region is essential and has practical significance, especially with Binh Duong province with rapid urbanization and rapid development of industries.

2. Research methodology

2.1. Research subjects

- Research object: Mine closure and land use after mining.
- Scope of research: Nui Nho mine with an area of 33.9 hectares. This is the place that takes away the most soil and rock in the area, causing a lot of environmental impact
- Location is in Binh Thung quarter, Binh An ward, Di An town, Binh Duong province. The location of mineral mine closure is about 20 km southwest of Ho

Tab. 1. Criteria for selecting the optimal mine closure model

Objective 1: Match the natural features of the mine	Objective 2: Match with regional social characteristics	Objective 3: Ensure environmental targets	Objective 4: Ensure economic efficiency	Objective 5: Technical feasibility
TN1: Mine topography	XH1: Population	MT1: Water environment	HQ1: Benefits for investors	KT1: Technical feasibility
TN2: Surface water	XH2: Social infrastructure	MT2: Water environment	HQ2: Benefits for the community	KT2: Shape and size of mine field
TN3: Groundwater	XH3: Industry	MT3: Earth Environment	HQ3: Local interest	KT3: Current land use status in the surrounding area
TN4: Climate	XH4: Pre-mining land use	MT4: Air environment		KT4: Climate change
TN5: Flora and Fauna	XH5: Entertainment area	MT5: Risk		KT5: Supply of raw materials
TN6: Pit area				
TN7: Geological structure				

Tab. 2. W-weighting for the objectives of option 1. CR ratio = 0.061< 0.1

	Nature	Economy	Society	Environment	Technical feasibility	Weight
Nature	1, 1, 1	1/4, 1/3, 1/2	1/5, 1/4, 1/3	1/5, 1/4, 1/3	1, 2, 3	**0.092**
Economy	2, 3, 4	1, 1, 1	1/3, 1/2, 1	1, 1, 1	2, 3, 4	**0.233**
Society	3, 4, 5	1, 2, 3	1, 1, 1	1, 1, 1	2, 3, 4	**0.312**
Environment	3, 4, 5	1, 1, 1	1, 1, 1	1, 1, 1	3, 4, 5	**0.286**
Technical feasibility	1/3, 1/2, 1	1/4, 1/3, 1/2	1/4, 1/3, 1/2	1/5, 1/4, 1/3	1, 1, 1	**0.077**

Chi Minh City, 10 km northeast of Bien Hoa city, 18 km northwest of Thu Dau Mot city (Figure 1).

2.2. Applicable methods

2.2.1. Method of data collection and field investigation

The collected database includes natural factors, socio-economic conditions, maps such as administrative boundaries, and land use planning maps. These are documents as a basis for fieldwork to comment and evaluate, and as a basis for surveying backlogs, limitations and causes to be overcome.

2.2.2. Matrix and Expert Method

The matrix method lists development activities and environmental factors that may be affected [20]. The matrix table compares each project activity with environmental parameters or components to assess the cause-and-effect relationship [10]. In which, the horizontal axis represents actions, the vertical axis represents environmental factors and marks the level of impact between them. For this method, the knowledge and practical experience of experts in the field of mineral resources and environment are used to analyze and evaluate the impacts.

2.2.3. Multi-Criteria Analysis (MCA) with fuzzy sets

AHP's purpose is to help people organize their thoughts and judgments to make more effective decisions. AHP provides an objective algorithm to deal with the separability of subjectivity and the private preferences of an individual or group in decision making. The diagram of the AHP hierarchy is shown in Figure 2.

The AHP method facilitates computational judgments and preferences by using pairwise comparisons. This is also the best procedure for performing pairwise judgmental comparisons [21]. However, human judgments are completely imprecise, so preferences are not quantifiably determined [9]. Fuzzy theory was developed by Zadeh [26] to overcome incorrect judgments and preferences. Many methods of weighing attributes and alternatives are intelligently implemented using qualitative scales, while the logical determination of priorities is difficult for general decision-makers [25]. Therefore, to perform accurate pairwise judgment comparisons and decision making, fuzzy set theory and AHP method are combined with good results [2]. Later, other methods have been presented that combine these two approaches [4]. Since ambiguity and ambiguity are common features in many decision-making problems, fuzzy analytical hierarchical processing (FAHP) should be able to deal with ambiguity [17].

Supposing that a decision-making board consists of l decision makers (Dt, t = 1,.., l) responsible for evaluating m (Ai, i = 1,…, m) green suppliers based on over n standards (Cj, j = 1,..., n) where the rating of green suppliers is based on each standard and the weights of the standards are represented as linguistic variables [27] and presented as triangular fuzzy numbers. The modeling process is presented in the following steps:

* Step 1: Define a set of criteria to evaluate and group green suppliers. In this study, the criteria used to evaluate and classify green suppliers are divided into two groups: economic criteria and environmental criteria. These criteria were selected based on a review of previous studies presented in Table 1.

* Step 2: Determine the weight for each criterion. In this section, the FAHP method is applied to determine the priority (weight) of the green supplier evaluation criteria. This study applies the extended FAHP method which is considered simple, popular and presented by Chang [4]. The FAHP model is used to determine the weights of the criteria. The model uses a language variable to represent the comparative judgments made by the decision panel.

Set: X = {X1, X2, ..., Xn} is the set of n objects;

G = {g1, g2, ..., m} is the set of m comparison targets.

According to Chang's method, each Xi object corresponds to a comparison object, denoted Gi. Accordingly, each object Xi will be compared with m targets, denoted as follows:

$$M_{gi}^{1}, M_{gi}^{2},\dots M_{gi}^{1};\ M_{gi}^{1}, M_{gi}^{2},\dots M_{gi}^{m}\ \textit{với}\ i = 1,2,\dots m;\ j = 1,2\dots n$$

(In which every value M_{gi}^{j} M_{gi}^{j} is a triangular fuzzy number).

* Step 3: Calculate the value of the composite fuzzy number for the i-th object according to the formula:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad (1)$$

Tab. 3. Overall score evaluation for option 1

Objectives	Objective's Weight	Criteria	Explanation	Criterion weight	Average score of experts	Criteria score	Total score
Objective 1: Match the natural features of the mine	0.092	Mine topography	The mine topography is suitable for the post-mining land use plan	0.36	70	25.2	2.318
		Surface water	Reservoir suitable for post-mining land use	0.17	65	11.05	1.017
		Groundwater	Ground water supplies to the reservoir	0.07	65	4.55	0.419
		Climate	Climate affects post-mining land use purpose	0.21	70	14.7	1.352
		Flora and Fauna	Is the flora and fauna rich?	0.04	50	2	0.184
		Mine scale	Is the size of the mine suitable?	0.08	70	5.6	0.515
		Geological structure	Stable geological structure	0.07	60	4.2	0.386
Objective 2: Match with regional social characteristics	0.312	Population	The population density is high to participate in post-mining land use	0.53	65	34.45	8.027
		Social infrastructure	Favorable traffic conditions, electricity and water networks	0.19	80	15.2	3.542
		Industry	Industrial activities that support the form of post-mining land use	0.12	75	9	2.097
		Pre-mining land use	Is the pre-mining land use suitable for the form of post-mining land use	0.08	70	5.6	1.305
		Entertainment area	The entertainment area around the mine affects the plan	0.08	60	4.8	1.118
Objective 3: Ensure environmental targets	0.286	Water Environment	The form of post-mining land use affects the water source	0.47	70	32.9	10.265
		Water Environment	The form of post-mining land use has an impact on water resources	0.47	70	32.9	10.265
		Earth environment	Does the form of post-mining land use cause pollution to the land environment?	0.17	60	10.2	3.182
		Air environment	The form of post-mining land use has an effect on the surrounding air	0.19	55	10.45	3.260
		Risk	The form of post-mining land use can reduce the possibility of risk	0.17	75	12.75	3.978
Objective 4: Ensure economic efficiency	0.233	Benefits for investors	Cost and profit for investors	0.63	75	47.25	13.514
		Benefits for community	Bringing benefits to investors	0.28	70	19.6	5.606
		Benefits for the local	Tax revenue from the form of land use	0.09	75	6.75	1.931
Objective 5: Technical feasibility	0.077	Technology readiness	construction technology can implement the plan of post-mining land use	0.204	75	15.282	1.177
		The shape and size of the mine field	The shape and size of the field field meets the post-mining land use plan	0.397	60	23.832	1.835
		Current status of land use in the vicinity	Current status of land use in the vicinity considering the possibility of success of the post-mining land use plan	0.107	50	5.340	0.411
		Climate change	Land use plan after exploitation is stable with climate change	0.086	65	5.589	0.430
		Supply of raw materials	Is the supply sufficient for the post-mining land use plan?	0.206	75	15.470	1.191
Total							82.2

Tab. 4. W-weighting for the objectives of option 2. Ratio CR = 0.085< 0.1

	Nature	Economy	Society	Environment	Technical feasibility	Weight
Nature	1, 1, 1	1/3, 1/2, 1	1/4, 1/3, 1/2	1/4, 1/3, 1/2	2, 3, 4	**0.127**
Economy	1, 2, 3	1, 1, 1	1/3, 1/2, 1	1, 1, 1	1, 2, 3	**0.199**
Society	2, 3, 4	1, 2, 3	1, 1, 1	1, 1, 1	2, 3, 4	**0.295**
Environment	2, 3, 4	1, 2, 3	1, 1, 1	1, 1, 1	2, 3, 4	**0.295**
Technical feasibility	1/4, 1/3, 1/2	1/3, 1/2, 1	1/4, 1/3, 1/2	1/4, 1/3, 1/2	1, 1, 1	**0.083**

Calculate by: $\sum_{j=1}^{m} M_{gi}^{j} \sum_{j=1}^{m} M_{gi}^{j}$ perform fuzzy operations the analytical values m for a special matrix given in below, in the final calculation step, the new set (l, m, u) is obtained and used for next step:

$$\sum_{j=1}^{m} M_{gi}^{j} = \{\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\} \quad (2)$$

In which: l is the minimum cut-off value, m is the maximum estimated value, and u is the value higher than the cut-off value to take. Calculate by:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad (3)$$

Performing fuzzy operation of the value $M_{gi}^{j} M_{gi}^{j}$ (j=1,2,3,4,5…,m) we have

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \{\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j,\} \quad (4)$$

And then, calculating the inverse vector in step (8),(9) we get the following:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = [\frac{1}{\sum_{i=1}^{n} l_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} u_i}] \quad (5)$$

* Step 4: Calculate the average ratio.

Suppose a group of users Ut with t = 1, 2, …, k evaluates m choices Ai with i = 1,…, m with h evaluation criteria Cj , j = 1, 2,…, h. Let ( ) with i = 1,…, m, j = 1,…, h and t = 1,…, k be the norm for each choice Ai with user set Ut and criterion Cj . The average rating is calculated as follows:

$$x_{ijt} = \frac{1}{k} \otimes (x_{ij1} \oplus x_{ij2} \oplus \ldots \oplus x_{ijt} \oplus x_{ijk}) \quad (6)$$

In which:

$$e_{ij} = \frac{1}{k} \sum_{t=1}^{k} e_{ijt}, \quad f_{ij} = \frac{1}{k} \sum_{t=1}^{k} f_{ijt}, \quad g_{ij} = \frac{1}{k} \sum_{t=1}^{k} g_{ijt} \quad (7)$$

* Step 5: Calculate the average weight.

Set $Wj_t = (oj_t, pj_t, qj_t)$, $w\, j_t \in R^*$, j = 1,…,h, t = 1,..,k to be the importance determined by the user group with the criterion. The mean importance $w\, j_t = (oj_t, pj_t, qj_t)$ of the Cj criterion as assessed by k user groups is determined as follows:

$$W_j = \frac{1}{k} \otimes (W_{j1} \oplus W_{j2} \oplus \ldots \oplus W_{jk}) \quad (8)$$

In which:

$$o_j = \frac{1}{k} \sum_{t=1}^{k} o_{jt}, \quad p_j = \frac{1}{k} \sum_{t=1}^{k} p_{jt}, \quad q_{ij} = \frac{1}{k} \sum_{t=1}^{k} q_{jt} \quad (9)$$

* Step 6: Calculate the total score of the options according to the criteria with the weight just found. The option with the highest total score will be selected.

3. Research results and discussion

3.1. Result

Based on the SAW method and research results [12], 25 important criteria are proposed to be used to evaluate the weights and are summarized in Table 1. In which: i) Matching characteristics nature of the mine area – 7 criteria; ii) Conformity with regional socio-economic characteristics – 5 criteria; iii) Ensuring environmental criteria – 5 criteria; iv) Ensuring economic efficiency – 3 criteria; v) Technical feasibility – 5 criteria. For details, see Table 1.

3.2. Analyze and propose a plan to improve and restore the environment for Nui Nho quarry

Mining activities cause negative impacts on the environment and health throughout all stages of mining [5, 8, 24]. Mineral mines often cause adverse impacts on the ecological environment [11]. For example, contamination of surface water and groundwater in the project area and its vicinity may be affected by mining activities. To find out the most suitable environmental rehabilitation and restoration plan for the research quarries cluster, the hierarchical process method is used. In fact, on a general level, there is always a change in the ecosystem and landscape before and after mineral extraction [16, 22].

Through information about the characteristics of the mine cluster, the natural socio-economic conditions of the area, refer to the options for mine closure and land use after mining, on the basis of the above criteria, the experience of mine closure in countries around the world, it is possible to propose two options for mine closure and land use after exploitation as follows:

Option 1: Renovating the mining pit into a lake used for tourism, entertainment and water storage. However, this option requires a large investment capital, a long implementation time, but brings economic efficiency.

Option 2: Renovating the mining pit into a water reservoir, enclosed with a fence. This option 2 has low investment capital, fast implementation time but brings lower economic efficiency.

In this study, for option 1, to determine the weight of the principles for the option by means of geometric mean (Geomean) weighting (W) is shown in Table 2.

Integrated assessment based on the weights of principles and criteria combined with scores of experts in minerals, land use management and environmental protection for option 1 – improvement forming a tourist area with a total score of 82.2. For details, see Table 3.

Option 2 is selected to renovate the pit into a water reservoir and closed fence with the weighted principles of calculation in Table 4.

The total score of Option 2 is 74.86, lower than Option 1. For details, see Table 5 .

4. Conclusions

Binh Duong is an industrial province of Vietnam. The construction material mining industry has met a large demand for construction works. The quarries in Binh Duong have been finished and closed according to regulations. With the speed of urbanization and rapid industrial development like Binh Duong, it is necessary to maximize the use of land after mining, contributing to the sustainable development of the mine.

The selection of a suitable model for closing the quarries for deep mining should be based on appropriate objectives in terms of natural, socio-economic, environment, and technical feasibility. The hierarchical process method with fuzzy set is a suitable tool to choose the best plan for mine closure and post-mining land use. Summarizing the research results, it

Tab. 5. General evaluation of option 2

Objectives	Objective's Weight	Criteria	Explanation	Criterion weight	Average score of experts	Criteria score	Total score
Objective 1: Match the natural features of the mine	0.127	Mine topography	The mine topography is suitable for the post-mining land use plan	0.24	75	18	2.286
		Surface water	Reservoir suitable for post-mining land use	0.18	70	12.6	1.600
		Groundwater	Ground water supplies to the reservoir	0.05	65	3.25	0.413
		Climate	Climate affects post-mining land use purpose	0.11	75	8.25	1.048
		Flora and Fauna	Is the flora and fauna rich?	0.04	70	2.8	0.356
		Mine scale	Is the size of the mine suitable?	0.29	70	20.3	2.578
		Geological structure	Stable geological structure	0.09	75	6.75	0.857
Objective 2: Match with regional social characteristics	0.295	Population	The population density is high to participate in post-mining land use	0.53	70	37.1	4.764
		Social infrastructure	Favorable traffic conditions, electricity and water networks	0.19	85	16.15	2.301
		Industry	Industrial activities that support the form of post-mining land use	0.12	65	7.8	1.770
		Pre-mining land use	Is the pre-mining land use suitable for the form of post-mining land use	0.08	75	6	1.770
		Entertainment area	The entertainment area around the mine affects the plan	0.08	75	6	11.092
Objective 3: Ensure environmental targets	0.295	Water Environment	The form of post-mining land use affects the water source	0.47	80	37.6	11.092
		Water Environment	The form of post-mining land use has an impact on water resources	0.17	65	11.05	3.260
		Earth environment	Does the form of post-mining land use cause pollution to the land environment?	0.19	70	13.3	3.924
		Air environment	The form of post-mining land use has an effect on the surrounding air	0.17	75	12.75	3.761
		Risk	The form of post-mining land use can reduce the possibility of risk	0.63	75	47.25	9.403
Objective 4: Ensure economic efficiency	0.199	Benefits for investors	Cost and profit for investors	0.28	80	22.4	4.458
		Benefits for community	Bringing benefits to investors	0.09	75	6.75	1.343
		Benefits for the local	Tax revenue from the form of land use	0.204	85	17.319	1.438
Objective 5: Technical feasibility	0.083	Technology readiness	construction technology can implement the plan of post-mining land use	0.397	75	29.790	2.473
		The shape and size of the mine field	The shape and size of the field meets the post-mining land use plan	0.107	90	9.611	0.798
		Current status of land use in the vicinity	Current status of land use in the vicinity considering the possibility of success of the post-mining land use plan	0.086	75	6.449	0.535
		Climate Change	Land use plan after exploitation is stable with climate change	0.206	90	18.564	1.541
		Supply of raw materials	Is the supply sufficient for the post-mining land use plan?	0.206	75	15.470	1.191
Total							74.86

shows that the plan to renovate the mining pit into a lake using for tourism, entertainment and water storage is the option to close the mine and use the land for Nui Nho mine.

However, besides the achieved results, there are still issues that need to be researched to improve the management of natural resources and environment in mining activities in general and quarries in particular. It is necessary to plan to close the mine early to be proactive and reduce financial costs.

Literatura – References

1. Antwi, E.K.; Owusu-Banahene, W.; Boakye-Danquah, J.; Mensah, R.; Tetteh, J.D.; Nagao, M.; Takeuchi, K. Sustainability Assessment of Mine-Affected Communities in Ghana: Towards Ecosystems and Livelihood Restoration. Sustain. Sci. 2017.
2. Buckley, J. J., "Fuzzy hierarchical analysis", Fuzzy Set and System, 17 (3), PP. 233-247, 1985.
3. Butler, C. R., Hynds, R. E., Gowers, K. H., Lee, D. D. H., Brown, J. M., Crowley, C., ... & Janes, S. M. (2016). Rapid expansion of human epithelial stem cells suitable for airway tissue engineering. American journal of respiratory and critical care medicine, 194(2), 156-168.
4. Chang. (1996), "Applications of the extent analysis method on fuzzy AHP." European Journal of Operational Research, vol. 95, no. 3, pp. 649-655, 1996.
5. S. Fields, The Earth's Open Wounds: Abandoned and Orphaned Mines, Environmental Health Perspectives, Vol. 111, 2003, pp. 154-161, https://doi.org/doi/abs/10.1289/ehp.111-a154.
6. Gupta, S.; Kumar, U. An Analytical Hierarchy Process (AHP)-Guided Decision Model for Underground Mining Method Selection. Int. J. Min. Reclam. Environ. 2012, 26, 324–336.
7. Heikkinen, P. M., Noras, P., Salminen, R., "Environmental techniques for the extractive industries", Mine closure, 2008.
8. M. Hendrychová, M. Kabrna, An Analysis of 200- Year-long Changes in a Landscape Affected by Large-scale Surface Coal Mining: History, Present And Future, Applied Geography, Vol. 74, 2016, pp. 151–159, https://doi.org/10.1016/j.apgeog.2016.07.009.
9. H e r r e r a F., H e r r e r a V.E., 2000 – Linguistic decision analysis; steps for solving decision problems under linguistic information. Fuzzy Sets and Systems, 115, 67–82.
10. S. Hira, P. S. Deshpande, Mining Precise Cause and Effect Rules in Large Time Series Data of Socio-Economic Indicators, Springer Plus, Vol. 5, No. 1, 2016, pp. 1625, https://doi.org/10.1186/s40064-016-3292.
11. P. N. Ho, N. X. Hai, P. T. T. Ha, T. N. Diep. Assessing Soil Quality at Three Typical Construction Material Mining Sites (Limestone Mine, Basalt Mine, and Clay Mine) in Luong Son District, Hoa Binh Province, VNU Journal of Science: Earth and Environmental Sciences, Vol. 32(1S), 2016, pp. 155-163 (in Vietnamese).
12. Nguyen Tri Quang Hung, Vo Truong Nhu Thuy, Nguyen Minh Ky, Study and Proposal of Environmental Improvement and Restoration Plan for Quarry Cluster – A Case Study in Dong Nai Province, VNU Journal of Science: Earth and Environmental Sciences, Vol. 38, No. 2 (2022) 1-12.
13. International Council on Mining and Metals (ICMM): The role of mining in national economies- London, UK (2012).
14. International Council on Mining and Metals 2019 (ICMM), Integrated Mine Closure – Good Practice Guide, 2nd end.
15. International Institute for Environment and Development (IIED). Minerals and Sustainable Development Mining for the Future Appendix B: Mine Closure Working Paper; WBCSD: Geneva, Switzerland, 2002.
16. D. M. McHaina, Environmental Planning Considerations for the Decommissioning, Closure And Reclamation of a Mine Site, International Journal of Surface Mining Reclamation and Environment, Vol 15, 2001, pp. 163-176, https://doi.org/10.1076/ijsm.15.3.163.3412.
17. M i k h a i l o v L., T s v e t i n o v P., 2004 – Evaluation of services using a Fuzzy analytic hierarchy process. Applied Soft Computing, 5, 23–33.
18. Monosky, M., & Keeling, A. (2021). Planning for social and community-engaged closure: A comparison of mine closure plans from Canada's territorial and provincial North. Journal of Environmental Management, 277, 111324.
19. Norouzi Masir, R., Ataei, M., Khalo Kakaei, R., & Mohammadi, S. (2021). Sustainable Development Assessment in Underground Coal mining by Developing a Novel Index. International Journal of Mining and Geo-Engineering, 55(1), 11-17.
20. C. M. Pastakia, A. Jensen, The Rapid Impact Assessment Matrix (RIAM) for EIA, Environmental Impact Assessment Review, Vol. 18, No. 5, 1998, pp. 461-482, https://doi.org/10.1016/S0195-9255(98)00018-3.
21. Saaty, T.L. (1977) A Scaling Method for Priorities in Hierarchical Structures. Journal of Mathematical Psychology, 15, 234-281.
22. J. A. Simmons, W. S. Currie, K. N. Eshleman, K. Kuers, S. Monteleone, T. L. Negley, B. R. Pohland, C. L. Thomas, Forest to Reclaimed Mine Land use Change Leads to Altered Ecosystem Structure and Function, Ecological Applications, Vol. 18, 2008, pp. 104-118, https://doi.org/10.1890/07-1117.1.

23. Tomlins, S. A., Laxman, B., Dhanasekaran, S. M., Helgeson, B. E., Cao, X., Morris, D. S., ... & Chinnaiyan, A. M. (2007). Distinct classes of chromosomal rearrangements create oncogenic ETS gene fusions in prostate cancer. Nature, 448(7153), 595-599.

24. J. M. R. Vega, A. G. Villar, J. S. González, R. B. G. Gutiérrez, J. Á. Martínez, Changes in Land use Due to Mining in the North-Western Mountains of Spain During the Previous 50 Years, Catena, Vol. 149, 2017, pp. 844-856.

25. W a r r e n L., 2004 – Uncertainty in the analytic hierarchy process. Technical Report DSTO-TN-0597, Australian Government Department of Defence. Command and Control, Division Information Sciences Laboratory.

26. Zadeh, L. A., "Fuzzy sets", Information and control, 8, PP. 338–353, 1965.

27. Zadeh, L. A. (1975). Fuzzy logic and approximate reasoning. Synthese 30, 407-425.