JME

Journal of Mining & Environment,
Vol.7, No.2, 2016, 185-193.

Semi-quantitative environmental impact assessment and sustainability level determination of coal mining using a mathematical model

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Received 28 January 2015; received in revised form 8 October 2015; accepted 18 October 2015
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Abstract

Environmental impact assessment (EIA) has led to the dominance of planners on the natural environment of the regions, providing the possibility of continuously monitoring and controlling the status quo by management staff. In this regard, a new semi-quantitative model is presented for the EIA of the Eastern Alborz Coal Mining complex using the matrix method, and determining the corresponding impacting factors and environmental components. For this purpose, the expert opinions are used to gather the preliminary data and score the parameters involved. The effect of each impacting factor involved on each environmental component is determined by quantifying the qualitative comments. According to the results obtained, the components air quality, human health and safety, and ecology and soil of the area undergo the most environmental damages from the mining activities. Then the EIA results obtained are used to assess the sustainability of the complex using the Phillips mathematical model. The results obtained indicate that the sustainability of this complex is weak, and, therefore, the preventive environmental measures with a preference must be recommended to reduce the environmental damages to its components.

Keywords: *Environmental Impact Assessment (EIA), Sustainable Development, Phillips Mathematical Model, Eastern Alborz Coal Mines.*

1. Introduction

Sustainable development in the mining industry was considered by the researchers in the early 1990s after the communities such as the Rio Conference in 1992 [1]. Von Below [2] stated that the continuous exploration of minerals, technological innovations, and environmental remediation were in line with the sustainable development of mining. Allan [3] also had a similar opinion, stating that mining was sustainable when the rates of use of minerals did not exceed in comparison to the total discovered new resources and recoverable materials. Using a case study of high-life mines, Learmont [4] indicated that mining could be considered as a sustainable activity.

Another major issue is related to the sustainable development, exploitation and utilization of non-renewable resources. Crowson [5] claimed that if a mine is considered from an aspect of resource exhaustion only, then no operation is sustainable. Worrall et al. [6] also believed that all of the mineral resources were limited and non-renewable over time. Therefore, mining operations are inherently unsustainable due to the limited resources of the earth. According to Richards [7], no single mine can last forever. It is a fact that the mineral developments would end someday, and this would make the integration of the sustainability considerations into the mining process highly appropriate. However, mining is sustainable when it is conducted in a manner that balances the economic, environmental, and social considerations.

According to the "Mining, minerals and sustainable development" (MMSD) project undertaken in 2002, the goal of sustainable developments in mining maximizes the welfare of the present generation such that the benefits and costs are fairly distributed without compromising the ability of the future generations to meet their own needs [8]. Basu and Kumar [9] stated that achieving sustainable developments in mining required good governance, as the foundation of sustainable development and interaction with project stakeholders. According to Eggert [10], the environmental protection, social justice, and economic growth are crucial to achieve a sustainable development of mining. Villas Boas et al. [11] believed that sustainability was not the same concept as the sustainable development, although these terms are used interchangeably. The former is a characteristic of healthy social and environmental systems, and refers to their ability to withstand externally imposed shocks, and return to normal functioning. Sustainability, defined in this way, is not a characteristic of minerals, which are non-renewable. To the contrary, sustainable development necessitates the integration of environmental policies and development strategies so as to meet the current and future human needs, improve the quality of life, and protect the environment. By this definition, minerals are clearly a part of sustainable developments. According to McCullough and Lund [12], the mining industry has worked towards reducing its operational risks and maintaining its social license to extract the resources through a variety of strategies. These are focused around the concept of sustainable developments by the creation of sustainable livelihoods (employment, community development, and infrastructure), resource optimization, and minimization of environmental and social impacts after mine closures.

A major weakness associated with the sustainability interpretation is that this term is often used interchangeable with 'environmental management' and 'environmental protection'. Therefore, many assessments have focused on environmental protection with a little mention of the socio-economic issues. However, environmental impact assessment (EIA) is a tool that can be used to assess all issues related to sustainable developments.

The underground projects are like the EIA ones, and several studies have been conducted in this regard so far [13-16]. Among the underground projects, environmental impacts of coal mining are more than those of the other mines, either in the mining problems or the consequences of mining. Environmental pollution in coal mining including the surface and underground water contamination, change in soil properties, change in plant and animal ecology, air pollution, damages arising from processing and coal washing facilities, noise, waste, and drainage acid has caused coal mining to be considered as a serious threat to the environment. Thus all the desired or adverse socio-economic effects and environmental impacts should be identified and considered in coal mining. Assessment of these effects can be very effective in preventing the destruction of nature, and also at reducing the adverse environmental effects [17].

The Eastern Alborz Coal Mines are located in the Alborz mountain range, and mining operations are ongoing under the Eastern Alborz Coal Company in the three regions of Tazareh, Takht, and Razi. The aim of this work was to assess the sustainability of this complex through the environmental impact assessment of coal mining. For this purpose, first, the important impacting factors and environmental components were determined, and then the environmental impacts were evaluated quantitatively using the matrix method. Afterward, the level and nature of the sustainability of this complex were studied using the quantitative results obtained for the mathematical model of sustainability. This model can define what sustainability is, the parameters and constraints of the key components, and the conditions under which sustainability or unsustainability can occur. It was developed to define the principles of a sustainable development and the possibility of its application in quantitative EIAs to determine the level and nature of sustainable development of projects [18, 19].

2. Algorithm of EIA

In this study, an EIA was conducted through the following steps:

- Determining the impacting factors and environmental components. The definitions and magnitudes of sixteen overall factors introduced as "Impacting factors" are listed in Table 1. Then the issues on which influence of a mining activity is probable are defined as "Environmental components" (Table 2). In this assessment method, it is necessary to introduce destructively and usefully the effective parameters at first. For the severely destructive parameters, the factor score is between 0 and 10; zero means it is ineffective, and 10 shows the most critical condition. Some factors like the economic and cultural issues have a score between -10 and 10. The negative sign shows their positive effect.

- Defining the possible scenarios to cover the issues related to each impacting factor, as a guide to evaluate the magnitude of each factor (in this section, tables were not presented due to their extension, and just the final scores of the impacting factors were reported in Table 1).
- Data collection: In the present study, the environmental data was collected based on the final opinion of the committee of mining environment consisting of five experts in this field.
- Matrix formation: Environmental assessments are often performed using the matrix methods, in which one dimension of the matrix is “impacting factors” and the other one is the “environmental components”, which are affected by the impacting factors. The next step in this algorithm was to designate the influence of “impacting factors” on “environmental components”. The effect of each impacting factor on each environmental component was expressed by the six statements None (N), Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH), and as numerical values of 0, 1, 2, 3, 4, and 5, respectively. As a result, a table was assembled, showing the effect level of each factor on the components (Table 3).
- Normalization: To obtain the normalized vector, the column vector elements were added together, and then each one of the elements was divided by the whole. Due to the considered range for the levels of impacting factors, the obtained values were multiplied by 10. The results obtained are presented in Table 3.
- EIA: Matrix C was obtained by multiplying matrix F (the impacting factor values) by matrix M (the weighted value of each impacting factor on each environmental component). The total numbers in each column of matrix C represent the amount of effect on each environmental component. The results obtained are shown in Table 4. The components of matrix C are depicted in a column graph (Figure 1), which describes the percentage environmental damage for each environmental component separately.

According to the results shown in Figure 1, the percentage environmental damage for the components air quality, human health and safety, ecology, and soil with scores of 49.05, 33.64, 31.26, and 24.08, respectively, were more significant. Therefore, the preventive environmental measures with a preference must be recommended to reduce the environmental damage of these components. In contrast, the social issues and surface constructions are the least important components in EIA of this complex. The results obtained for this research work were evaluated by five safety and environmental engineers of Eastern Alborz Coal Mines. They confirmed this assessment method for a suitable prediction of the consequences of the environmental components.

Table 1. Extent of each impacting factor value.

Impacting factors	Definition	Magnitude	Score
1. Changing the usage of the area	The usage of the lands before mining activities	0 - 10	2
2. Exposition of the mining area	The view and visibility of the mining area.	0 - 10	0
3. Interference with surface water	The relationship between mining activities and surface water.	0 – 10	4
4. Interference with underground water	The relationship between mining activities and underground water table.	0 – 10	3
5. Increase in the traffic of the area	Influence of mining on the traffic situation of the area	0 – 10	10
6. Dust emission	Dust emission in each part of mine. - Drilling machines. - Explosion. - Loading. - Movement of the tracks on the road (from mine to dump or mill). - The dust produced by wind from the ore and waste dumps.	0 – 10	5.8

Table 1. Continued.

7. Toxic pollutants and substance emissions to air	Concentration of pollutants in mine air (ppm)	0 – 10	10
8. Noise pollution	- The noise level at the work environment caused by devices and machines in qualitative and quantitative form. - Noise level caused by firing.	0 – 10	5.5
9. Land vibration	Intensity of underground vibration in the main underground facilities installations, refreshing place of the workers or the cross point of the shafts with the mine level (mm/s). The intensity of vibration on the surface with regard to the distance to the surface facilities.	0 - 10	1
10. Domestic employment	Domestic employment rate in mining unit	-10 to 10	-10
11. Population control	Influence of mining on the population of the area Population of the mining unit before and after the mining operation The type of influence of mining activities on the change in population	-10 to 10	2
12. Social and cultural development	Condition of the social and cultural institutes before and after the mining operation, in the fields below: Educational, health and help, cultural, and artistic institutes. Sport institutes. Amusement and economic institutes. Conditions of urban facilities before and after the start of the mining operation in the fields below: Water facilities, heating facilities, availability of the electricity, access roads, receiving the TV channels, and phone connections.	-10 to 10	-4.66
13. Instability of the established spaces	Stability condition of the surface and underground excavation in the mine	0 - 10	2
14. Subsidence	The subsidence condition in the mining area	0 - 10	3
15. Environmental arrangements	Green space construction, existence of R&D in the mining unit, taking the Environmental ISO, assembling the health, security, and environmental manuals. Dust controlling unit, lessening the noise level. Recycling the gangue dam water, refining the industrial and sanitary waste water of the mining unit.	-10 to 10	-4
16. Light	Illumination (Lux) in the work area.	0 - 10	2.5

Table 2. Considered environmental components for suggested algorithm.

1	Human health and immunity
2	Social issues
3	Surface water
4	Underground water
5	Air quality
6	Area usage
7	Ecology
8	Surface constructions
9	Underground constructions
10	Area landscape
11	Quietness
12	Economic issues
13	Soil of the area

Table 3. Weighted values of effect of each impacting factor on each designed environmental component for coal mining.

Impacting factors	Environmental components												
	Human health and immunity	Social issues	Surface water	Underground water	Air quality	Area usage	Ecology	Surface constructions	Underground constructions	Area landscape	Quietness	Economic issues	Soil of the area
Changing the usage of the area	M	L	M	M	L	H	M	VL	VL	H	H	H	H
	0.60	0.61	1.30	1.25	0.95	1.11	0.88	0.56	0.56	1.29	1.25	0.75	1.67
Exposition of the mining area	N	N	N	N	N	M	N	N	N	H	H	N	N
	0.00	0.00	0.00	0.00	0.00	0.83	0.00	0.00	0.00	1.29	1.25	0.00	0.00
Interference with surface water	M	N	H	H	N	M	H	VL	N	H	N	VL	H
	0.60	0.00	1.74	1.67	0.00	0.83	1.18	0.56	0.00	1.29	0.00	0.19	1.67
Interference with underground water	M	N	H	H	N	VL	H	N	M	N	N	VL	M
	0.60	0.00	1.74	1.67	0.00	0.28	1.18	0.00	1.67	0.00	0.00	0.19	1.25
Increase in the traffic of the area	H	H	N	N	H	VL	M	N	N	M	H	M	L
	0.80	1.21	0.00	0.00	1.90	0.28	0.88	0.00	0.00	0.97	1.25	0.57	0.83
Dust emission	VH	L	L	N	VH	M	L	N	N	L	N	H	VL
	1.00	0.61	0.87	0.00	2.38	0.83	0.59	0.00	0.00	0.65	0.00	0.75	0.42
Toxic pollutants and substances emission to air	VH	N	N	VL	VH	L	H	N	N	N	N	VH	N
	1.00	0.00	0.00	0.42	2.38	0.56	1.18	0.00	0.00	0.00	0.00	0.94	0.00
Noise pollution	H	M	N	N	N	L	L	N	N	N	VH	L	N
	0.80	0.91	0.00	0.00	0.00	0.56	0.59	0.00	0.00	0.00	1.56	0.38	0.00
Land vibration	VH	L	N	N	N	L	M	H	VH	N	L	L	N
	1.00	0.61	0.00	0.00	0.00	0.56	0.88	2.22	2.78	0.00	0.63	0.38	0.00
Domestic employment	N	H	N	N	N	N	N	N	N	N	N	H	N
	0.00	1.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00
Population control	L	VH	N	N	N	M	N	L	N	L	H	VH	N
	0.40	1.52	0.00	0.00	0.00	0.83	0.00	1.11	0.00	0.65	1.25	0.94	0.00
Social and cultural development	L	VH	N	N	N	H	L	M	N	H	H	H	N
	0.40	1.52	0.00	0.00	0.00	1.11	0.59	1.67	0.00	1.29	1.25	0.75	0.00
Instability of the established spaces	H	N	L	M	N	N	N	L	M	N	N	VH	M
	0.80	0.00	0.87	1.25	0.00	0.00	0.00	1.11	1.67	0.00	0.00	0.94	1.25
Subsidence	N	M	M	H	N	H	L	VH	H	M	N	VH	M
	0.00	0.91	1.30	1.67	0.00	1.11	0.59	2.78	2.22	0.97	0.00	0.94	1.25
Environmental arrangements	VH	M	VH	VH	VH	H	VH	N	N	VH	VH	VH	H
	1.00	0.91	2.17	2.08	2.38	1.11	1.47	0.00	0.00	1.61	1.56	0.94	1.67
Light	VH	N	N	N	N	N	N	N	L	N	N	M	N
	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.11	0.00	0.00	0.57	0.00
Total	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

Table 4. Final scoring for each environmental component in Eastern Alborz coal mines.

Impacting factors	Human health and immunity	Social issues	Surface water	Underground water	Air quality	Area usage	Ecology	Surface constructions	Underground constructions	Area landscape	Quietness	Economic issues	Soil of the area
	Environmental components												
Changing the usage of the area	1.20	1.21	2.61	2.50	1.90	2.22	1.76	1.11	1.11	2.58	2.50	1.51	3.33
Exposition of the mining area	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interference with surface water	2.40	0.00	6.96	6.67	0.00	3.33	4.71	2.22	0.00	5.16	0.00	0.75	6.67
Interference with underground water	1.80	0.00	5.22	5.00	0.00	0.83	3.53	0.00	5.00	0.00	0.00	0.57	3.75
Increase in the traffic of the area	8.00	12.12	0.00	0.00	19.05	2.78	8.82	0.00	0.00	9.68	12.50	5.66	8.33
Dust emission	5.80	3.52	5.04	0.00	13.81	4.83	3.41	0.00	0.00	3.74	0.00	4.38	2.42
Toxic pollutants and substances emission to air	10.00	0.00	0.00	4.17	23.81	5.56	11.76	0.00	0.00	0.00	0.00	9.43	0.00
Noise pollution	4.40	5.00	0.00	0.00	0.00	3.06	3.24	0.00	0.00	0.00	8.59	2.08	0.00
Land vibration	1.00	0.61	0.00	0.00	0.00	0.56	0.88	2.22	2.78	0.00	0.63	0.38	0.00
Domestic employment	0.00	-12.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-7.55	0.00
Population control	0.80	3.03	0.00	0.00	0.00	1.67	0.00	2.22	0.00	1.29	2.50	1.89	0.00
Social and cultural development	-1.86	-7.06	0.00	0.00	0.00	-5.18	-2.74	-7.77	0.00	-6.01	-5.83	-3.52	0.00
Instability of the established spaces	1.60	0.00	1.74	2.50	0.00	0.00	0.00	2.22	3.33	0.00	0.00	1.89	2.50
Subsidence	0.00	2.73	3.91	5.00	0.00	3.33	1.76	8.33	6.67	2.90	0.00	2.83	3.75
Environmental arrangements	-4.00	-3.64	-8.70	-8.33	-9.52	-4.44	-5.88	0.00	0.00	-6.45	-6.25	-3.77	-6.67
Light	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.78	0.00	0.00	1.42	0.00
Total	33.64	5.39	16.78	17.50	49.05	18.54	31.26	10.57	21.67	12.89	14.64	17.94	24.08

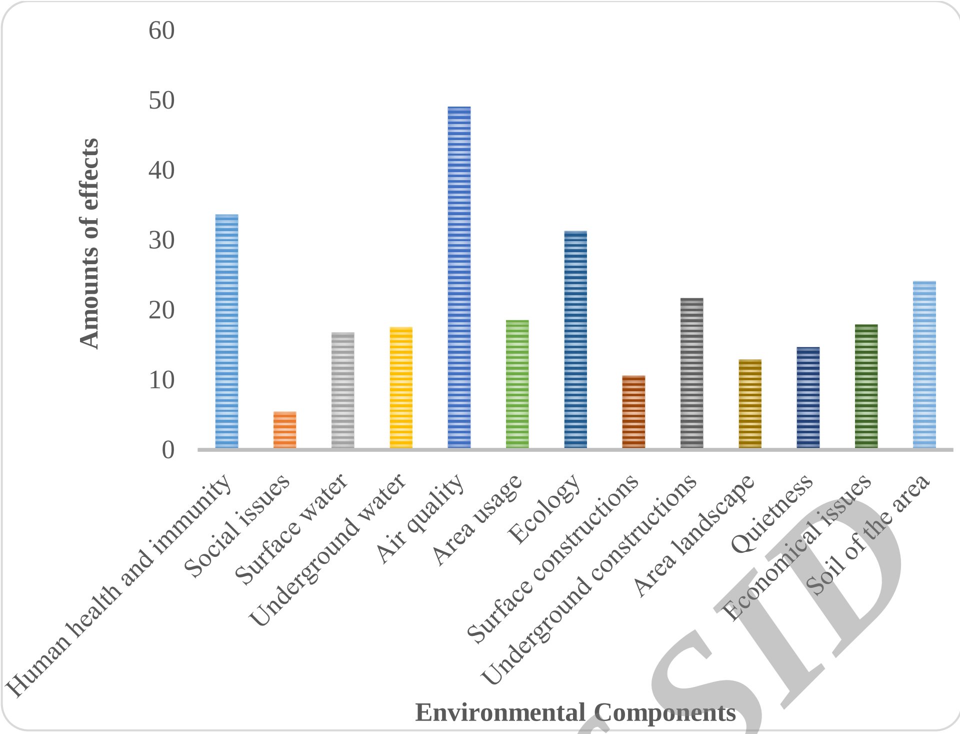

Figure 1. Designed graph for coal mining assessment on the basis of percentage of environmental components according to impacting factors.

3. Mathematical Model of Sustainability

As mentioned earlier, the mathematical model of sustainability for definition of the sustainability, parameters and, constraints of the key components, and the conditions under which sustainability or unsustainability can occur have been developed by Phillips [18, 19]. The utilization steps in this model are as follow:

1) Perform EIA

In this study, the results indicated in the final row of Table 4 (Figure 1) form the basis for the application of the model in the calculation of an indicated level and the nature of sustainable development for the operation of coal mining.

2) Application of model by stating all the project options and determining the environmental and human components

- Determine all project options for evaluation, e.g. project over time (before-during-after) or project alternatives in design or operation phase
- Determine the environmental components (E) to be used in the calculations.

All the studied environmental components along with the corresponding symbols are shown in Table 5.

- Determine the human components (H_{NI}) to be used in the calculations. Table 6 shows the environmental components and relevant symbols.

- Determine maximum scores of environmental and human components.

In this method, the maximum score is 100 per environmental and human components. The respective total scores for the components E and H_{NI} are presented in Table 7.

Table 5. Environmental components.

Air quality	A_1
Quietness	A_2
Ecology	B_1
Surface water	H_1
Underground water	H_2
Area usage	L_1
Surface constructions	L_2
Underground constructions	L_3
Area landscape	L_4
Soil of the area	L_5

Table 6. Human components.

Human health and immunity	H_{NI1}
Social issues	H_{NI2}
Economic issues	H_{NI3}

Table 7. Maximum Scores of E and H_{NI} components.

E and H_{NI} Components	Value
A_{max}	200
B_{max}	100
H_{max}	200
L_{max}	500
E_{max}	1000
$H_{NI\ max}$	300

3) Calculate E for the project options.

$$E = \frac{[(\sum A_{max} - \sum A) + (\sum B_{max} - \sum B) + (\sum H_{max} - \sum H) + (\sum L_{max} - \sum L)]}{(\sum A_{max} + \sum B_{max} + \sum H_{max} + \sum L_{max})} \tag{1}$$

$$E = \frac{[(\sum A_{max} - (A_1 + A_2)) + (\sum B_{ax} - B_1) + (\sum H_{max} - (H_1 + H_2)) + (\sum L_{max} - (L_1 + L_2 + L_3 + L_4 + L_5))]}{(\sum A_{max} + \sum B_{max} + \sum H_{max} + \sum L_{max})}$$

$$E = \frac{[(200 - (49.05 + 14.64)) + (100 - 31.26) + (200 - (16.78 + 17.50)) + (500 - (18.54 + 10.57 + 21.67 + 12.89 + 24.08))]}{200 + 100 + 200 + 500}$$

$$E = 0.78302$$

4) Calculate HNI for the project options.

$$H_{NI} = \frac{[(H_{NI1} + H_{NI2}) + (H_{NI3max} - H_{NI3})]}{\sum H_{NImax}}$$

$$H_{NI} = \frac{(33.64 + 5.39) + (100 - 17.94)}{300}$$

$$H_{NI} = 0.40363$$

5) Determine whether the project option is sustainable.

- State values obtained for E and H_{NI}.
- If the value obtained for E is greater than that for H_{NI}, then it is sustainable:

$E > H_{NI} \leftrightarrow S > 0$

- And if the value obtained for E is less than/equal to that for H_{NI}, then it is unsustainable:

$E \leq H_{NI} \leftrightarrow S \leq 0$

As the calculated value for E is greater than that for H_{NI}, the project being evaluated is sustainable.

$E > H_{NI} \leftrightarrow S > 0$

6) If sustainable, calculate the S value for the project option, and determine the level and nature of sustainability using the ranges defined in Table 8.

$S = E - H_{NI}$

Table 8. S value and level ranges.

Range	Sustainability
0.751 – 1.000	Very Strong
0.501 – 0.750	Strong
0.251 – 0.500	Weak
0.001 – 0.250	Very Weak

According to the results obtained in the previous stages, the sustainability was calculated as follows:

$S = E - H_{NI} = 0.38$

By comparison of the calculated value for S and the specified levels in Table 8, the sustainability of the Eastern Alborz Coal Mines is in the weak class of sustainability.

4. Conclusions

Coal mines of the Eastern Alborz Company have significant environmental and human impacts on the area. In this work, a new model was presented for the quantitative environmental impact assessment (EIA) of mining activities using the matrix method. The results obtained for this study can help prioritizing the environmental measures to reduce the negative effects of coal mining. The importance of prioritizing is the time and financial constraints in the simultaneous response and reaction to all the environmental damages.

According to the results obtained, the percentage environmental damage to the components air quality, human health and safety, ecology, and soil of the area are more significant, and so it is recommended that these components are placed in priority in order to allocate the resources and preventive measures. Finally, the results of the environmental assessment were studied to evaluate the sustainability of the project using the Phillips mathematical model. Phillips has indicated the potential value of the model application to an EIA in determining and resolving questions of sustainability or unsustainability. The approach described by him could offer further potential for the evaluation of a project before, during, and after construction, and provide S values to indicate the level and nature of the project over its life cycle. The results of this study indicated the weak sustainability of the Eastern Alborz Coal Mines.

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ارزیابی نیمه کمّی آثار زیست‌محیطی و تعیین سطح پایداری معدنکاری زغال‌سنگ با به‌کارگیری مدل ریاضی

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ارسال ۲۰۱۵/۱/۲۸، پذیرش ۲۰۱۵/۱۰/۱۸

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چکیده:

ارزیابی آثار زیست‌محیطی (EIA) موجب اشراف برنامه‌ریزان بر اوضاع محیط‌زیست طبیعی منطقه شده و امکان پایش و کنترل مداوم وضع موجود را توسط عوامل مدیریتی فراهم می‌کند. در این راستا، مدل نیمه کمّی جدیدی برای ارزیابی اثرات زیست‌محیطی معادن زغال‌سنگ البرز شرقی با استفاده از روش ماتریس و از طریق تعیین فاکتورهای مؤثر و مؤلفه‌های زیست‌محیطی ارائه‌شده است. بدین منظور، از نظرات کارشناسی افراد خبره برای جمع‌آوری داده‌های اولیه و امتیازدهی هر یک از پارامترها استفاده‌شده و با کمّی‌سازی نظرات کیفی، میزان تأثیر هر یک از پارامترها و تأثیر کلی روی هر مؤلفه زیست‌محیطی تعیین شده است. طبق نتایج به‌دست‌آمده، مؤلفه‌های کیفیت هوا، سلامتی و ایمنی انسان، اکولوژی و خاک منطقه، متحمل بیشترین درصد آسیب زیست‌محیطی از فعالیت‌های معدنکاری شده‌اند. در ادامه، نتایج ارزیابی آثار زیست‌محیطی برای ارزیابی پایداری این مجموعه با مدل ریاضی فیلیپس استفاده‌شده است. خروجی مدل بیانگر ضعیف بودن سطح پایداری این مجموعه است و می‌بایست انجام فعالیت‌های پیشگیرانه زیست‌محیطی با اولویت برای مؤلفه‌های آسیب‌دیده پیشنهاد شود.

کلمات کلیدی: ارزیابی آثار زیست‌محیطی، توسعه پایدار، مدل ریاضی فیلیپس، معادن زغال‌سنگ البرز شرقی.