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Modeling and environmental risk assessment of Eastern Alborz Coal washing plant

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Abstract

Mining operations and mineral-related industries are closely and directly related with the environment. The negative impacts of mining industry on the environment, known as environmental risks, must be controlled and managed in a way to minimize harmful and destructive effects. Environmental risk assessment studies are a suitable step to identify, analyze and rank the risk factors. In this study a hybrid model has been presented to identify the environmental risks caused by coal washing plant in eastern Alborz in the form of 17 risk factors and introducing 8 criteria to assess them. Then their impact has been studied upon 12 environmental factors such as agriculture, ecology and so forth. In this regard, the risks for each of the affected environmental components have been assessed using linear assignment method, which is one of the most important multi- attribute decision-making methods. The results showed that in components of "area usage", "social issues", "surface water" and "underground water", the risks of "exposition of the plant and the tailing area", "tailing discharge considerations", "type of geological formations of the area" and "changing the usage of the area" have been ranked first, respectively and have been introduced as the most critical risks for the above-mentioned components.

Keywords: *Modeling, Risk Assessment, Environmental factors, Coal washing plant, Linear Assessment.*

1. Introduction

Test Mining operations threaten the environment if the monitoring and controlling steps are not implemented completely. The mining operations directly are related to surrounding environment thus mining units should design in such ways, which have the least harmful influences on individuals and environment (Aryafar et al., 2013). Mining and mineral processing plants are among the most important hazardous industries for the environment. In line with the economic benefits of this industry, environmental risks such as air pollution, contamination of groundwater, loss of vegetation in the affected area are inevitable. Hence, environmental risk assessment in industrial plants and mining activities is essential to prevent and control harmful and sometimes irreversible effects. In fact, risk assessment is the cornerstone of project risk management aimed at measuring risks based on different criteria. Ranking of risks is a key component of this process, which enables determination of priority of each risk against other risks, and the decision-maker can therefore plan for allocation of available resources to deal with each risk (Ghosh and Jintanapakanont 2014).

Risk assessment is usually performed using traditional methods such as Fulcher (Folchi, 2003), probability-risk impact matrix (Bertolinia 2009; Rebelo et al. 2014; Favasa and Pratasb 2014), FMEA (Wang et al. 2012), FTA (Laul et al. 2006), integrated risk regionalization method (Guan et al. 2017), quantitative risk assessment (Wu et al. 2017), ETA (Hong et al. 2009; Shahriar et al. 2012) and MADM method (Mirabi et al. 2014). Assessment criteria are limited in these methods and other important criteria have been waived in them. However, these methods are simple and easy to use but do not often give reliable results and may cause systematic error (Chapman and Ward 2003; Ghosh and Jintanapakanont 2014); therefore, the use of more reliable methods is necessary. In this context, Multiple Attribute Decision Making (MADM) is a reliable tool for risk assessment and ranking (Pomerol and Romero 2000; Saaty and Vargas 2006). These methods allow consideration of all the criteria related with different weights, the exchange between them and therefore provide reliable results. Nowadays, MADM methods are used separately or in combination with other decision-making methods to assess and manage risk in many projects but studies show that these methods have not been effectively used in evaluation of environmental risks. Ghaedrahmati and Doulati Ardejani (2012) have evaluated East Alborz coal washing plant using developed Fulcher method as well as development of environmental factors and effective plant factors (risk factors). In this study, the risks associated with twelve environmental components have been evaluated using linear assignment method by presenting a hybrid model in four phases, while taking into account the environmental risks arising from eastern Alborz coal washing plant, affected environmental factors used in Qaedrahmati and Dowlati work and introduction of a set

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of risk assessment criteria (Ghaedrahmati and Doulati Ardejani 2012).

2. MADM methods

Multiple criterion decision making (MCDM) refers to making decisions in the presence of multiple, usually conflicting criteria. The problems of MCDM can be broadly classified into two categories: multiple attribute decision making (MADM) and multiple objective decision making (MODM), depending on whether the problem is a selection problem or a design problem. MODM methods have decision variable values that are determined in a continuous or integer domain, with either an infinitive or a large number of choices, the best of which should satisfy the decision maker's constraints and preference priorities. MADM methods, on the other hand, are generally discrete, with a limited number of predetermined alternatives. MADM is an approach employed to solve problems involving selection from among a finite number of alternatives. An MADM method specifies how attribute information is to be processed in order to arrive at a choice. MADM methods require both inter- and intra-attribute comparisons, and involve appropriate explicit tradeoffs (Rao 2007). These methods are used to choose the most appropriate options from among *m* available options. A distinctive feature of these methods is typical existence of a few countable predetermined options. The best option in a multi-attribute model is the one satisfying the most preferred value of each available trait (Hwang and Yoon 1981). The basis of modeling is formation of contingency table (Hamidi et al. 2012). Linear assignment is one of the most important multi-attribute decision-making methods (Hamidi et al. 2012). Similar to other multi- attribute decision-making methods, the performance of options should be first evaluated in terms of criteria (attribute). Therefore, the decision matrix is developed as follows: $X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \cdots & \cdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}$

where x_{ij} stands for performance of option i (i=1, 2, …., n) in relation to criterion j (j=1, 2, …., n). After development of decision matrix and assignment of the relative importance of criteria, the linear assignment method is implemented as follows.

3. Linear Assignment Method

Linear assignment is one of the most important multi-attribute decision-making techniques. In this method, the given options of a problem are ranked in terms of their scores from each criterion and the final ranking will be determined by a linear compensation process (Hwang and Yoon 1981). In this technique, based on simplex effect of solution space, the optimal solution is extracted under a convex simplex space taking into account all the arrangements implicitly (Hwang and Yoon 1981). In addition, the compensatory nature of criteria is achieved by exchange between ranks and options, although the criteria weight vector is based on expert opinion (Hwang and Yoon 1981). In comparison with other methods of multi- attribute decision-making, an important strong point of linear assignment method is that this method is considered a hybrid technique (hard and soft) (Hwang and Yoon 1981). Hard decision-making methods are those in which the model is defined based on mathematical equation systems. In soft decision-making techniques, the model is based on a contingency table. Therefore, hybrid decision-making techniques are a combination of hard and soft decision-making techniques. This means that they seemingly follow the logic of soft techniques and are defined by contingency table but mathematical equation system is used in practice and in solution process, so they have the strong points of hard and soft techniques. This method is implemented in the following steps (Hwang and Yoon 1981):

Step one: Determining the rank of any option for each of the available criteria in the form of matrix (m × m) in which row indicates rank and column indicates the criterion.

Step two: Formation of assignment matrix or gamma (γ) matrix, a square matrix (m × m) with row as rank and column as criterion. Gamma matrix elements (γ_{ik}) include the total weight of criteria in which option *i* holds *k* rank. Gamma matrix is an assignment matrix in which optimal solution can be achieved using any of the assignment methods, including transport, Hungarian method, network method and 0 & 1 linear programming approach. Linear programming is the most common solution method in linear assignment.

Step three: Calculation of the optimal solution (final rank) using linear programming by the following model:

$$Max\, Z = \sum_{i=1}^{m}\sum_{k=1}^{m} \lambda_{ik} . h_{ik} \quad (1)$$

$$\sum_{k=1}^{m} h_{ik} = 1 \qquad i = 1,2,\cdots,m \quad (2)$$

$$\sum_{i=1}^{m} h_{ik} = 1 \qquad k = 1,2,\cdots,m \quad (3)$$

$$h_{ik} = 0\, or\, 1 \quad (4)$$

4. Results and discussion

4.1. Risk Assessment Criteria

As noted, the goal of risk assessment phase is risk measurement based on different criteria. Therefore, conventional assessment methods based on a few criteria have been used in the majority of studies, although several researchers have indicated the unreliability and lack of validity of the results of these methods. However, in some other studies, criteria such as the ability of organization to respond to risk (McDermott et al. 1996), the degree of estimation uncertainty (Klein and Cork 1998), risk control rate (Waterland et al. 2003), probability and effect of time, cost and quality of project in ranking of risks (Baccarini and Archer 2001) have also been proposed. Supplementary measures of risk management and risk proximity as well as socio-economic and environmental impacts have also been taken (Pertmaster Software 2002; Xu and Liu 2009). Overall, a comprehensive set of risk assessment criteria have not been simultaneously introduced and used. The risk assessment criteria in this study have been listed in Table 1. In criteria with positive impact, the higher the value of criteria for each risk, the higher the critical nature of that risk. In criteria with negative impact, increasing value of criteria for a risk reduces the criticality of that risk. It should be noted that these criteria are independent and there is no significant logical connection between any of them.

Table 1. Set of risk assessment criteria

Criterion	Risk probability	Risk impact	Risk detection rate	Risk exposition	Risk manageability	Risk recognition	Estimation reliability	Risk reduction
Definition	Reflects the analysts' (expert) expectation of risk event	The negative impact exerted by a risk on each component	The ability to understand the risk event and its revelation	Expresses the degree of repetition and risk exposition in the project	Organization's ability to predict risks and the ability to manage and respond to it	Notification of risk by expert in the event of risk	Assurance of risk assessment values by analyst	Reduction of risk impact on the project after preventive measures
Symbol	C1	C2	C3	C4	C5	C6	C7	C8
Impact aspect	positive	positive	negative	positive	negative	negative	negative	negative

4.2. Environmental Risk Assessment Model

In this study, a hybrid model is provided for evaluation of environmental risks in four phases:

First phase: In this stage, while identifying environmental risks in the studied area and considering the measures introduced for risk assessment, a questionnaire is designed and expert opinions are collected qualitatively (very low, low, medium and so on). Ranking and scoring in relation to any of the assessment criteria (C1 to C8) for each of the environmental risks identified in the study area is done based on a sevenfold range according to Table 2.

Second phase: At this stage, collected qualitative expert opinions are replaced with quantitative values according to Table 3 and the decision matrix is thus formed.

Third phase: Determining the relative importance of assessment criteria is an effective step in the process of problem solving in most multi- attributes decision-making techniques such as linear assessment. For this purpose, we can use methods such as expert opinions, Shannon entropy and eigenvector (Aczel and Saaty 1983). So, relative importance (weight vector) of risk assessment criteria is determined according to expert opinions using eigenvector method. Therefore, paired comparison matrix is formed while collecting expert opinions on relative importance of criteria according to clock range in Table 3. Then, by calculating the geometric mean of data per row, in order to normalize the data (normalization means equalizing the weight sum to 1), the geometric mean obtained in each row is divided by sum of geometric mean elements, and the final normalized weight of each criterion (eigenvector) is obtained (Aczel and Saaty 1983).

Fourth phase: To assess the risks in this stage, on the basis of quantitative decision matrix and weight vector of criteria determined in the previous steps, the risks are ranked using linear assignment method. The resulting ranking is a function of assessment of different risks with simultaneous consideration of a comprehensive set of criteria having different weights, enabling decision-making and programming to control and manage the risks in realistic conditions.

4.3. Case study

In order to implement the model presented in this study, eastern Alborz coal washing plant is considered as a case study. The following is a brief introduction of this project as well as environmental risk identification and assessment according to the mentioned model. Eastern Alborz coal washing plant is located in about 55 km of Shahrood in Semnan province, northeastern Iran. Geographical location and geological map of the study area is displayed in Figure 1.

This plant was opened 30 years ago. The climate in this region is temperate with cold winters. Nearly 600000 metric tons of coal is entered into the plant with a recovery rate of 50%. Therefore, nearly half of the coal input to the plant is collected as tailings near the plant. The coal is stored near the plant before entry into the coal washing plant. Stockpiling coal and its tailings in place causes several environmental problems in addition to problems arising from the plant itself. Approximately 80% of tailings related to processing is caused by jig and the rest is associated with the flotation step.

Table 2. Scoring range of different risks for assessment criteria (Aczel and Saaty 1983)

Expression variable	Very low	Low	Intermediate Low	Intermediate	High intermediate	High	Very high	Intermediate states
Numerical value	0	1	3	5	7	9	10	2, 4, 6 and 8

Table 3. Nine-quantity clock range for paired comparison of criteria (Aczel and Saaty 1983)

Expression variable	Very low importance	Low importance	Intermediate importance	High importance	Very high importance	Importance intermediate between the states
Numerical value	1	3	5	7	9	2, 4, 6 and 8

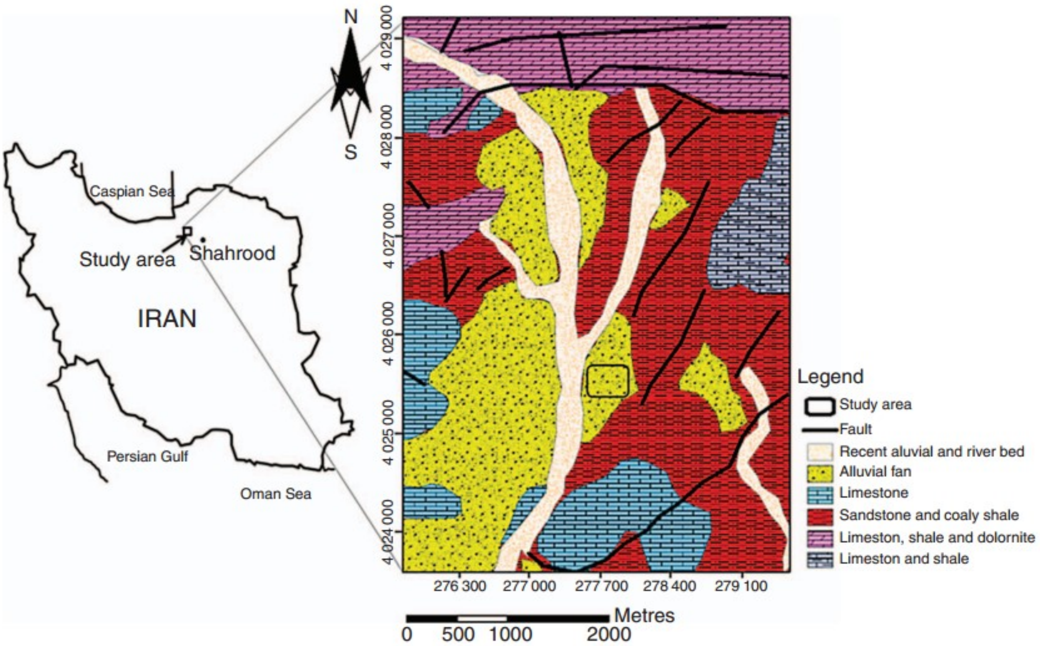

Fig 1. Geographical location and geological map of the study area (after Amirkhani Shiraz et al. 2013)

The amount of sulfide in plant input load including free sulfide, sulfate and pyrite is nearly 3% and is mainly pyrite. Tailings are divided to five parts around the plant according to type based on the record. The tailings related to flotation are first collected in two tailings dams to dry. In the present study, environmental data are first collected and environmental estimates are then performed based on the applied method.

4.4. Environmental risk assessment of eastern Alborz coal washing plant

Environmental risks of coal washing plant have been identified in the form of 17 effective factors (Table 4). Environmental components are parts of the environment affected by factors. In this study, 12 affected environmental factors have been considered according to Table 5.

To assess environmental risks of eastern Alborz coal washing plant in accordance with the model presented in this study, firstly expert opinions on 17 risks (Table 4) according to 8 criteria (Table 1) for each of the 12 affected components (Table 5) were collected. In this way, twelve 8 × 17 matrices were created. 17 represent the number of rows (identified risks) and 8 represent the number of columns (presented criteria). Qualitative values of expert opinions are elements of these matrices. For example, for assessment criteria of the first component (i.e. health and human safety), qualitative opinions of experts on various risks are shown in Table (6). In the second step, according to Table (2), qualitative values were converted to quantitative ones;

Table 4. Coal washing plant factors affecting the environment and definition of them (Ghaedrahmati and Doulati Ardejani 2012) (17 risks identified)

Number	Factors	Definition
1	Changing the usage of the area	Land use before industrial activity
2	Exposition of the plant and the tailing area	Visibility of industrial plant zone
3	Interference of input feed with surface water	Mining and industrial activities and their relationship with surface water
4	Waste water from plant	1. Discharge location of plant units' wastewater 2 Concentration in milligrams per liter in effluent
5	Increase in the traffic of the area	The impact of industrial activity on area traffic
6	Dust emissions	Dust emissions in different plant units 1. Loading 2. Traffic of trucks in the road 3. Production of dust from tailings depot and ore due to wind
7	Toxic pollutants and substances emission to air	Concentration of materials in plant in ppm
8	Noise pollution	1. Qualitative and quantitative noise level in working environment due to machinery
9	Land vibration	1. Earth tremor at the facility or place of assembly of workers in (mm/s) 2. The tremor at ground level according to the distance of installations and other sensitive areas
10	Material existed in the tailing	Contamination level of materials in tailings
11	Tailing discharge considerations	Waste disposal method Geological survey of construction site of waste depot Monitoring and control during plant operation Fencing and marking of waste dump
12	Population control	Population before and after the establishment of industrial plant and immigration control
13	Light	Light intensity in lux at work
14	Climate of the area	Weather conditions in the region, such as wet, rainy, dry, etc.
15	Topography of the area	Smooth or rugged topography of the area
16	Type of geological formations of the area	The organization and geological formations in the area
17	Method of coal washing	Coal washing method in terms of processing, e.g. jig, floatation or both

Table 5: Environmental Component influenced by factors affecting the coal washing plant (Mirmohamadi et al. 2009; Ghaedrahmati and Doulati Ardejani 2012)

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

for example, results for the first component are shown in Table (7). This Table was used as the decision matrix to apply linear assignment method.

In the third step, relative importance of risk assessment criteria has been determined using eigenvector method. For this purpose, paired comparison matrix of criteria was formed by survey of expert opinions (Table 8). In the end, geometric mean of the data for each row was calculated and the final normalized score of each criterion was obtained. Results are shown in Table (9).

In the fourth step, implementation stages of linear assignment method for data related to the first component are described. In this regard, according to the decision matrix (Table 3), the rank of any option is determined for each of the criteria. Based on table (10), a (8 × 17) matrix is formed in which the row and column indicate rank and criteria, respectively. The next step in linear assignment method is development of assignment matrix (Table 11), a 17 × 17 square matrix with row as i option (17 risks) and column as k rank. The components of this matrix are the sum of weighted criteria in which option i holds the k rank. In the next step, linear programming model was written based on equations 1 to 4. A part of this model is shown in Table 12.

Finally, solving this model in LINGO software can calculate the final rank of each of the risks. In this regard, risk ranking is as follows:

R7 > R15 > R16 > R1 > R10 > R2 > R9 > R6 > R14 > R8 > R4 > R5 > R3 > R13 > R17 > R11 > R12

Table 6. Qualitative values of expert opinions per different risks for the first component

Environmental risk	Symbol	C1	C2	C3	C4	C5	C6	C7	C8
Changing the usage of the area	R1	H	M	H	M	ML	L	MH	M
Exposition of the plant and the tailing area	R2	H	L	H	MH	L	M	M	H
Interference of input feed with surface water	R3	H	VH	VH	M	MH	H	M	H
Waste water from plant	R4	VH	VH	H	H	MH	H	MH	MH
Increase in the traffic of the area	R5	H	VH	H	MH	M	VH	H	ML
Dust emissions	R6	VH	VH	VH	VH	M	VH	M	L
Toxic pollutants and substances emission to air	R7	H	M	ML	M	L	M	L	L
Noise pollution	R8	VH	H	VH	VH	M	VH	M	ML
Land vibration	R9	H	VL	H	H	ML	H	M	ML
Material existed in the tailing	R10	MH	VH	MH	H	H	MH	M	M
Tailing discharge considerations	R11	H	VH	H	VH	VH	VH	H	H
Population control	R12	VL	VL	L	L	M	H	MH	M
Light	R13	H	VH	H	H	H	H	H	H
Climate of the area	R14	M	ML	M	ML	ML	H	M	L
Topography of the area	R15	VH	VL	H	H	M	M	M	VL
Type of geological formations of the area	R16	VH	VL	VH	H	L	M	M	VL
Method of coal washing	R17	H	MH	VH	H	H	H	H	MH

Table 7. Quantitative values of expert opinions per different risks for the first component

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
R1	9	9	5	3	1	7	5	5
R2	9	9	7	1	5	5	1	9
R3	9	10	5	7	9	5	10	9
R4	10	9	9	7	9	7	10	7
R5	9	9	7	5	10	9	10	3
R6	10	10	10	5	10	5	10	1
R7	9	3	5	1	5	1	5	1
R8	10	10	10	5	10	5	9	3
R9	9	9	9	3	9	5	0	3
R10	7	7	9	9	7	5	10	5
R11	9	9	10	10	10	9	10	9
R12	0	1	1	5	9	7	0	5
R13	9	9	9	9	9	9	10	9
R14	5	5	3	3	9	5	3	1
R15	10	9	9	5	5	5	0	0
R16	10	10	9	1	5	5	0	0
R17	9	10	9	9	9	9	7	7

Table 8. Paired comparison matrix of criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	1.00	0.89	0.44	0.56	0.44	0.67	0.78	0.56
C_2	1.13	1.00	0.50	0.63	0.50	0.75	0.88	0.63
C_3	2.25	2.00	1.00	1.25	1.00	1.50	1.75	1.25
C_4	1.80	1.60	0.80	1.00	0.80	1.20	1.40	1.00
C_5	2.25	2.00	1.00	1.25	1.00	1.50	1.75	1.25
C_6	1.50	1.33	0.67	0.83	0.67	1.00	1.17	0.83
C_7	1.29	1.14	0.57	0.71	0.57	0.86	1.00	0.71
C_8	1.80	1.60	0.80	1.00	0.80	1.20	1.40	1.00

Table 9. Final weight of criteria

Criteria	Final weight	Criteria	Final weight
C_1	0.2258	C_5	0.0451
C_2	0.1098	C_6	0.0620
C_3	0.0727	C_7	0.0492
C_4	0.0920	C_8	0.0351

Table 10: Determining the rank of options for each criterion

	C_1	C_2	C_3	C_4	C_5	C_6	C7	C8
1	R4	R3	R12	R11	R1	R7	R9	R15
2	R6	R6	R14	R10	R2	R2	R12	R16
3	R8	R8	R1	R13	R7	R3	R15	R6
4	R15	R16	R3	R17	R15	R6	R16	R7
5	R16	R17	R7	R3	R16	R8	R2	R14
6	R1	R1	R2	R4	R10	R9	R14	R5
7	R2	R2	R5	R5	R3	R10	R1	R8
8	R3	R4	R4	R6	R4	R14	R7	R9
9	R5	R5	R9	R8	R9	R15	R17	R1
10	R7	R9	R10	R12	R12	R16	R8	R10
11	R9	R11	R13	R15	R13	R1	R3	R12
12	R11	R13	R15	R1	R14	R4	R4	R4
13	R13	R15	R16	R9	R17	R12	R5	R17
14	R17	R10	R17	R14	R5	R5	R6	R2
15	R10	R14	R6	R2	R6	R11	R10	R3
16	R14	R7	R8	R7	R8	R13	R11	R11
17	R12	R12	R11	R16	R11	R17	R13	R13

Table 11: Assignment matrix

	rank 1	rank 2	rank 3	rank 4	rank 5	rank 6	rank 7	rank 8	rank 9	rank 10	rank 11	rank 12	rank 13	rank 14	rank 15	rank 16	rank 17
R1	0.173	0	0.173	0	0	0.163	0.099	0	0.138	0	0.115	0.138	0	0	0	0	0
R2	0	0.288	0	0	0.099	0.173	0.163	0	0	0	0	0	0	0.138	0.138	0	0
R3	0.086	0	0.115	0.173	0.138	0	0.173	0.077	0	0	0.099	0	0	0	0.138	0	0
R4	0.077	0	0	0	0	0.138	0	0.432	0	0	0	0.352	0	0	0	0	0
R5	0	0	0	0	0	0.138	0.311	0	0.163	0	0	0	0.099	0.288	0	0	0
R6	0	0.163	0.138	0.115	0	0	0	0.138	0	0	0	0	0	0.099	0.346	0	0
R7	0.115	0	0.173	0.138	0.173	0	0	0.099	0	0.077	0	0	0	0	0	0.225	0
R8	0	0	0.163	0	0.115	0	0.138	0	0.138	0.099	0	0	0	0	0	0.346	0
R9	0.099	0	0	0	0	0.115	0	0.138	0.346	0.086	0.077	0	0.138	0	0	0	0
R10	0	0.138	0	0	0	0.173	0.115	0	0	0.311	0	0	0	0.086	0.176	0	0
R11	0.138	0	0	0	0	0	0	0	0	0	0.086	0.077	0	0	0.115	0.237	0.346
R12	0.173	0.099	0	0	0	0	0	0	0	0.311	0.138	0	0.115	0	0	0	0.163
R13	0	0	0.138	0	0	0	0	0	0	0	0.346	0.086	0.077	0	0	0.115	0.237
R14	0	0.173	0	0	0.138	0.099	0	0.115	0	0	0	0.173	0	0.138	0.086	0.077	0
R15	0.138	0	0.099	0.250	0	0	0	0	0.115	0	0.138	0.173	0.086	0	0	0	0
R16	0	0.138	0	0.185	0.250	0	0	0	0	0.115	0	0	0.173	0	0	0	0.138
R17	0	0	0	0.138	0.086	0	0	0	0.099	0	0	0	0.311	0.250	0	0	0.115

As can be seen from the results, the risk "toxic pollutants and substances emission to air" (R7) ranks first in the components related to human health and Immunity. Afterwards, the model presented in this study for data related to other components has been implemented. Due to the high number of tables, we ignore their results and therefore the results of assessment and ranking of any of 8 risks (most important risks) has been shown in Table 13 using the model presented in this study.

According to table (13), in components of "area usage", "social issues", "surface water" and "underground water", R1, R12, R3 and R4 risks had the first rank, respectively and were introduced as the most critical risks. As can be seen, the risks in each affected component had different ranks. Therefore, in each component, there should be planning to control the risks and take appropriate timely measures in accordance with the rankings. The results of this study as a risk assessment method show that it is well-suited to prioritize the various risks for each environmental component. The method used to assess the various environmental risks caused by the Eastern Alborz coal washing plant, as an applicable example shows satisfactory results for the various environmental components. Table 13 shows the most important risks based on the priority for various environmental components. In fact, in this table, only 8 first risks for each environmental component are shown and other risks due to low importance have been ignored. For example, the various environmental risks of the plant for the environmental component of surface water, in order to preference, are Interference of input feed with surface water, Waste water from plant, Material existed in the tailing, Climate of the area, Method of coal washing, Tailing discharge considerations, Changing the usage of the area and Dust emissions that these risks and the priority of them is acceptable in environmental studies. Therefore, the modeling method used in this study can be a suitable method for quantitative evaluation of qualitative results and prioritizing the environmental hazards.

Table 12. Part of linear programming model of risk assessment and ranking problem

Max:

$$0.172\, h_{1,1} + 0.172\, h_{1,3} + 0.163\, h_{1,6} + 0.098\, h_{1,7} + 0.138\, h_{1,9} + 0.115\, h_{1,11} + 0.138\, h_{1,12} + 0.288\, h_{2,2} + 0.098\, h_{2,5} + 0.172\, h_{2,6} + 0.163\, h_{2,7} + 0.138\, h_{2,14} + 0.138\, h_{2,15} + 0.086\, h_{3,1} + 0.115\, h_{3,3} + 0.172\, h_{3,4} + 0.138\, h_{3,5} + 0.172\, h_{3,7} + 0.076\, h_{3,8} + 0.098\, h_{3,11} + 0.138\, h_{3,15} + 0.076\, h_{4,1} + \ldots\ldots + 0.138\, h_{17,4} + 0.086\, h_{17,5} + 0.0988\, h_{17,9} + 0.311\, h_{17,13} + 0.249\, h_{17,14} + 0.115\, h_{17,17}.$$

Subject to:

$$h_{1,1} + h_{1,2} + h_{1,3} + h_{1,4} + h_{1,5} + h_{1,6} + h_{1,7} + h_{1,8} + h_{1,9} + h_{1,10} + h_{1,11} + h_{1,12} + h_{1,13} + h_{1,14} + h_{1,15} + h_{1,16} + h_{1,17} = 1$$

$$h_{2,1} + h_{2,2} + h_{2,3} + h_{2,4} + h_{2,5} + h_{2,6} + h_{2,7} + h_{2,8} + h_{2,9} + h_{2,10} + h_{2,11} + h_{2,12} + h_{2,13} + h_{2,14} + h_{2,15} + h_{2,16} + h_{2,17} = 1$$

$$h_{3,1} + h_{3,2} + h_{3,3} + h_{3,4} + h_{3,5} + h_{3,6} + h_{3,7} + h_{3,8} + h_{3,9} + h_{3,10} + h_{3,11} + h_{3,12} + h_{3,13} + h_{3,14} + h_{3,15} + h_{3,16} + h_{3,17} = 1$$

…

$$h_{17,1} + h_{17,2} + h_{17,3} + h_{17,4} + h_{17,5} + h_{17,6} + h_{17,7} + h_{17,8} + h_{17,9} + h_{17,10} + h_{17,11} + h_{17,12} + h_{17,13} + h_{17,14} + h_{17,15} + h_{17,16} + h_{17,17} = 1$$

$$h_{i,j} = 0\, ,\, 1$$

End

Table 13: The results of risk ranking in each environmental component

Human health and Immunity	R7 > R15 > R16 > R1 > R10 > R2 > R9 > R6
Social issues	R12 > R14 > R3 > R4 > R5 > R16 > R7 > R17
Surface water	R3 > R4 > R10 > R14> R17 > R11> R1 > R6 >
Underground waters	R4 > R10 > R11 > R3 > R16 > R17 > R15 > R8
Air quality	R7 > R6 > R11 > R17 > R10 > R15 > R3 > R1
Area usage	R1 > R5 > R4 > R6 > R7 > R8> R11 > R3
Agriculture	R3 > R4 > R6 > R7 > R10 > R11 > R14 > R15
Ecology	R1 > R3 > R4 > R6 > R7 > R14 > R10 > R11
Area landscape	R2 > R1 > R11 > R4 > R5> R6 > R7 > R17
Quietness	R8 > R5> R12> R1 > R17 > R11 > R12 > R13
Economic issues	R1 > R7 > R12 > R4 > R3 > R9 > R6 > R9
Soil of the area	R1 > R3 > R4 > R11 > R7 > R17 > R10 > R6

5. Conclusions

Mining operations, mineral activities and related industries are closely and directly associated with the environment. Environmental impact of such industries must be controlled in such a way to minimize the risk for the environment. Substandard management of environmental risks can impose irreversible negative consequences on the environment. Ranking of risks is the main foundation of risk management and enables adequate timely response to risks. In this study, we identified 17 environmentally hazardous factors (risks) associated with eastern Alborz coal washing plant and introduced 8 criteria to assess the risks by presenting a hybrid hierarchical model and dealt with risk assessment in 12 affected environmental factors using linear assignment as one of the most important multi- attribute decision-making methods. Therefore, according to the rank obtained in each component, there should be planning to control risks and take appropriate measures. The model presented in this study provides reliable results, and risk ranking assessment using this approach is based on criticality and proximity of risk interactions. This validity is a function of consideration likelihood of several criteria at the same time, different weights for criteria and exchange between them, flexibility of the method and analysis of results. In comparison with other methods of multi-criteria decision-making, an important strong point of linear assignment method is that MADM method is considered a hybrid technique (hard and soft). Hard decision-making methods are those in which the model is defined based on mathematical equation systems. In soft decision-making techniques, the model is based on a contingency table. Therefore, hybrid decision-making techniques are a combination of hard and soft decision-making techniques. This means that they seemingly follow the logic of soft techniques and are defined by contingency table but mathematical equation system is used in practice and in solution process, so they have the strong points of hard and soft techniques.

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