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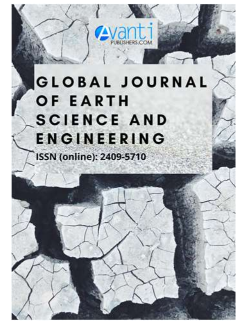

Evaluation of Mine Geological Environment Quality Based on Fuzzy Analytic Hierarchy Process

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ABSTRACT

The study of mine geological environmental quality evaluation methods has always been an important topic. Taking the mining geological environment of Muping District, Shandong Province as the research background, and based on the fuzzy analytic hierarchy process, a hierarchical structure model of the quality evaluation index of the mine geological environment in the study area was established, the relative importance of the 14 rating levels was estimated, and the weights were calculated. And sorting, establish a mine geological environment quality evaluation index system; then, according to the calculated comprehensive threshold value, establish a comprehensive evaluation grade of the mine geological environment. The results of the study show that the degree of environmental pollution (air, soil, water), vegetation coverage, topography and landform are the main factors for the evaluation of the geological environmental quality of the mines in the study area, and their weights are 0.3114, 0.1743, and 0.1184 in order. According to the principle of the maximum degree of membership, the mine geological environment quality is determined to be a good grade. Through the verification of the survey results of the mine geological environment on-site, the results show that the weights calculated by this method are reasonable, and the theoretical analysis and evaluation results obtained are in good agreement with reality. This method is worthy of popularization in the mine environment assessment work. Decision-making and governance provide decision-making support services.

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1. Introduction

The mining industry is an important foundational industry in China. Mining development promotes the development of the national economy, but also produces serious ecological environment problems, such as mining area land occupation and damage, geological disasters, environmental pollution and so on. These problems restrict the sustainable development of mining areas, so it is urgent to study the geological environment of mines [1]. Based on the related issues raised above, this article takes the mine geological environment grade evaluation in Muping District as an example to carry out research on it. There are many methods to evaluate the quality of the geological environment in mining areas. In 2011, Zhu Guowei *et al*. used a comprehensive index method to evaluate regional ecological environment [2]; In 2014, Zhao Xiaoliang *et al*. used set pair analysis and evaluation method to evaluate mine environmental quality. These methods not only reflect the relativity in the information processing of quantitative evaluation of mine environmental quality but also contain the fuzziness of the fuzzy synthesis method [3]. In 2015, Luo Dejiang *et al*. used the grey correlation analysis method to evaluate the development and utilization of mineral resources [4]. Wang Hongmei applied the analytic hierarchy process to evaluate the environmental quality of mines [5]. Inspired by Weng Yuejiao *et al*.'s evaluation of the effect of water conservancy reinforcement and renovation project based on F-AHP [6], this paper applies the F-AHP evaluation method to the mine environmental quality grade evaluation. Because it is difficult to test whether the judgment matrix is consistent in the analytic hierarchy process, and the standard for testing whether the judgment matrix is consistent lacks a scientific basis, the consistency of the judgment matrix is significantly different from that of human thinking [7]. The F-AHP evaluation method improves the existing problems of the traditional analytic hierarchy process and improves the reliability of decision-making. F-AHP evaluation method provides a basis for quantifying evaluation indicators and selecting the best plan and has been widely used. The biggest problem with the analytic hierarchy process is that when there are many evaluation indicators at a certain level (such as more than four), it is difficult to guarantee the consistency of its thinking. In this case, this article combines the analytic hierarchy process and the fuzzy evaluation method [9], uses the analytic hierarchy process to assign weights to the geological environmental quality factors of each mine, and then conducts a fuzzy comprehensive evaluation to make the environmental quality evaluation of the mines more scientific and reasonable.

2. Geological environment of the study area

Muping District is located in the east of Yantai City, Shandong Province, covering an area of 1515.20 km^2. By the end of 2015, Muping District had jurisdiction over 6 streets, 7 towns and 591 administrative villages (communities), with a total population of 456,000.

Muping district belongs to the middle latitude warm temperate monsoon continental semi-humid climate, which is regulated by the ocean, showing the characteristics of Marine climate, such as cold spring, cool summer, warm autumn and warm winter, the small temperature difference between day and night, long frost-free period and high wind. According to the survey, from 1979 to 2017, the average precipitation was 676.41 mm, the annual maximum precipitation was 1047.1 mm (2007), and the annual minimum precipitation was 334.50 mm (1999). The annual precipitation was mostly concentrated in July to September. The maximum monthly mean precipitation occurred in July and August, which were 238.20 mm and 204.20 mm, respectively.

Muping district belongs to North China stratigraphic large region, Shandong stratigraphic division, Jiao-north stratigraphic small area. The Paleoproterozoic Jingshan Group is distributed in the area, and a small range of Cretaceous strata are outcropped in some Mesozoic depression basins. Magmatic rocks are well developed in the area, especially granitic rocks, which are widely distributed, and the exposed area accounts for 59.49% of the total area of the working area. Muping area is located in the eastern part of the Sino-Korean quasi-platform (Ⅰ level), Jiao-Liaotailong (Ⅱ level), Jiaodong uplift area (Ⅲ level), and the northern part of Muping-Jimo fault zone. Since the Luliang Movement, the area has been uplifted for a long time, subjected to denudation, and widely exposed basement metamorphic rock series. Muping district belongs to the large area of the low mountain and hilly hydrogeology in eastern Shandong and the sub-area of Muping-Weihai hilly and valley hydrogeology.

The mineral resources in Muping District of Yantai City are mainly gold, granite, marble, feldspar and other non-metallic minerals. There are 35 licensed mines in the area, including 21 gold mines, 6 granite mines, 2 granite mines for construction, 1 pyrite mine, 2 gneiss mine, 2 mineral water mine and 1 feldspar mine. A total of 127 historic mines (closed and abandoned) are mainly distributed in Yulindian Town, Shuishui Town, Wanggezhuang Town, Guanshui Town and other places. According to the investigation, there are 43 damaged mountains and 71 open pits, accounting for about 95.22 ha of the damaged area. There are 11 industrial squares formed, accounting for about 20.65 ha of loss area; One goaf was formed by mining iron ore and 385 abandoned mines. The loss area of the goaf and abandoned mines formed by the closed mines was about 10.11 ha. Solid waste produced includes 1 tailings pond and 11 waste rock (soil) piles, accounting for about 24.34 ha of loss area.

According to the statistics of the annual report of mine development and utilization in 2009, the annual output of ore in the region is 1,707,800 tons, with 4,681 employees and a total industrial output value of 220.78 million yuan, among which there are 4 mines with an output value of more than 5 million yuan and a total industrial output value of 216.23 million yuan. In the output value of the mining industry, gold accounts for 55.69%, facing granite accounts for 24.80%, feldspar accounts for 14.40%, building granite accounts for 3.75% and other minerals account for 1.36%.

3 Modeling of mine geological environment quality grade evaluation

3.1. Fuzzy Hierarchical Analysis Model for Evaluation of Mine Geological Environment Quality Grade

In order to analyze the influencing factors of mine geological environment quality grade evaluation in Muping District, Shandong Province, on the basis of a large number of field investigation and literature review, it is found that the formation of mine environment is not only affected by the natural environment, but also by human factors. It is the massive exploitation of mine resources that leads to the rapid deterioration of the environment [14]. Therefore, the analysis and evaluation of mine environmental quality should take both natural factors and human factors into consideration. At the same time, the selection of mine environmental quality grade evaluation indexes should follow the principles of scientific rationality, regional particularity, system coordination, comprehensive universality, hierarchy, purpose, operability and index quantification. Based on these principles, the evaluation index of mine geological environment quality grade is selected, and the evaluation system of mine geological environment quality grade is further established to carry out the fuzzy level evaluation of mine environment[18].

According to the above analysis of the factors affecting the quality grade of mine geological environment in Muping District, Yantai City, Shandong Province, and combined with the physical geography, geological environment, social and economic conditions, the development and utilization of mineral resources, and the geological environment problems of mines left over from history, etc. Determine muping mine geological environment quality grade evaluation factors of the natural environment, social economy and ecological environment in three aspects, and establish the shandong province muping pass class hierarchy model of mine environmental quality assessment, including the target layer and index layer and the base index such as multilayer structure[21], for a total of 14 evaluation index, as shown in Figure **1**.

3.2. Quantitative standards of evaluation indicators

According to the "Soil Environmental Quality Standard" (GB15618-2018), "Groundwater Quality Standard" (DZT0290-2015), "Environmental Air Quality Standard" (GB3095-2018), "Solid Mineral Resources Reserves Classification" (GBT17766-2020), "General industrial solid waste storage and disposal site pollution Control Standard" (GB18599-2020), as well as Muping District mining field investigation and indoor collection of relevant data, the impact factors of Muping District mine geological environment quality evaluation system were evaluated. The evaluation criteria of mine geological environment in Muping District are shown in Table **1**.

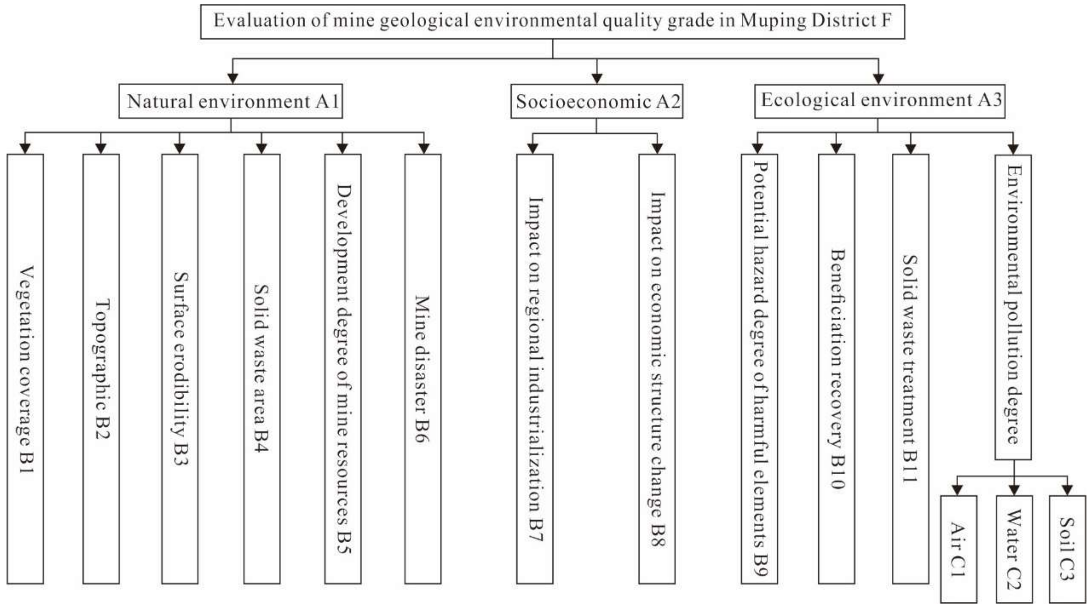

Figure 1: Hierarchical structure model of mine environmental quality grade evaluation in Muping District, Shandong Province

4. Evaluation of geological environment quality grade of Muping mine

4.1. Construction of judgment matrix and consistency test

4.1.1. Establishing a comparison judgment matrix among hierarchical elements to calculate weights

Firstly, establish a comparison judgment matrix among hierarchical elements: In the constructed mine environmental quality grade evaluation model, compare the importance of risk factors at the same index level, and sort the degree of importance, and then establish a judgment matrix according to the importance of each factor.

$$(S_{ij})_{n\times m} = \begin{bmatrix} S_{11} & \cdots & S_{1m} \\ \vdots & \ddots & \vdots \\ S_{n1} & \cdots & S_{nm} \end{bmatrix} \tag{1}$$

The S_{ij} belongs to the target layer S_i. It represents the risk factors at the criterion level. Where the S_{ij} represents the relative importance of S_i to S_j. The importance of the elements of the evaluation matrix needs to be quantified to form a quantified matrix in the form of numbers[24]. This paper adopts the commonly used 1-9 scale method [28] (Table **2**). In order to make the judgment matrix more reasonable, Delphi method can be used to consult experts' opinions.

Secondly, the weight calculation method is used to evaluate the uncertainty problem with the F-AHP evaluation method:

Step 1: Calculate the product of each row of the judgment matrix M_i

$$M_i = \prod_{j=1}^{n} S_{ij} \quad (I = 1,2,\dots,n) \tag{2}$$

Step 2: Calculate the N square root of M_i

$$\overline{W_i} = \sqrt[n]{M_i} \tag{3}$$

Table 1: Impact factor standard of mine geological environment evaluation system in Muping District

Influencing Factor Index	**Quantitative Method**	**Evaluation Rating Threshold**		
Vegetation Coverage B1	**Vegetation Coverage Area/ Mining Area**	**Mild More than 8%**	**Moderate 3%~8%**	**Severe Less than 3%**
Topographic B2	Terrain complexity, slope and type of landscape	The terrain is simple, the relative height difference is less than 50m, the ground slope is less than 8°, and the geomorphic type is single	The terrain is relatively simple, with a relative height difference of 50m~200m and a ground slope of 8°~25°. The geomorphic type is relatively simple	The terrain is complex, the relative height difference is more than 200m, the ground slope is more than 25°, and the geomorphic types are diverse
Surface e rodibility B3	Bad land and modern gully area/ mining area	Less than 10%	10%~30%	More than 30%
Solid waste area B4	Solid waste area/mining area	Less than 5%	5%~10%	More than 10%
Development degree of mine resources B5	Mining density and intensity	No mining mine; Less than 100000 t/A	The number of mining mines is 1~3; 100000 ~ 500000 t/A	The number of mining mines is more than 3; More than 500000 t/A
Mine disaster B6	The size of geological disaster events	No geological disaster event	1~2 small geological disaster events	3 or more minor or 1 major geological hazard events
Impact on regional industrialization B7	Expert scoring or experience value	0~0.3	0.3~0.7	0.7~1
Impact on economic structure change B8	Expert scoring or experience value	0~0.3	0.3~0.7	0.7~1
Potential hazard degree of harmful elements B9	Expert scoring or experience value	0~0.3	0.3~0.7	0.7~1
Beneficiation recovery B10	Quality of a useful component recovered from concentrate/ quality of the same component selected from raw ore	Take graphite ore as an example, more than 90%	Take graphite ore as an example, 85%~90%	Take graphite ore as an example, 80%~85%
Solid waste treatment B11	Expert scoring or experience value	0~0.3	0.3~0.7	0.7~1
Air pollution level C1	Environmental pollution index $PI=\sqrt{\frac{1}{2}\left[\left(\frac{C_r}{C_s}\right)^2_{max}+\left(\frac{C_r}{C_s}\right)^2_{ave}\right]}$	0~0.5	0.5~3.0	More than 3.0
Water pollution level C2		0~0.5	0.5~3.0	More than 3.0
Soil pollution C3		0~0.5	0.5~3.0	More than 3.0

Note: In the formula of environmental pollution index, $\left(\frac{C_r}{C_s}\right)^2_{max}$ and $\left(\frac{C_r}{C_s}\right)^2_{ave}$ are respectively the maximum and average values of a certain unitary pollution degree.

Table 2: Scale value and comparison rule of the relative importance of judgment matrix

Scale Value	**Comparison Rules**
1	The two factors are equally important
3	Factor 1 is slightly more important than factor 2
5	Factor 1 is more important than factor 2
7	Factor 1 is important relative to factor 2
9	Factor 1 is extremely important relative to factor 2
2,4,6,8	An intermediate value between adjacent judgments

Step 3: Normalize the vector

$$w_i = \overline{W_i} / \sum_{i=1}^{n} \overline{W_i} \quad \text{Then } W = (w_1, w_2, \dots, w_i)^T \text{ is an eigenvector.} \tag{4}$$

Then, the consistency test of the judgment matrix is carried out:

Step 1: Judgment of the maximum eigenvalue of the matrix

$$\lambda_{max} = \frac{1}{n} \sum \frac{(AW)_i}{w_i} \quad \text{Where, } (AW)_i \text{ represents the } i \text{ element of the } AW \text{ vector.} \tag{5}$$

Step 2: Consistency test of judgment matrix

$$C.I. = (\lambda_{max} - n)/(n-1) \text{ Among them, n represents the order of the judgment matrix.} \tag{6}$$

The average random consistency index $(R.I.)$ is obtained by repeatedly calculating the characteristics of the random judgment matrix and then taking the arithmetic mean [30]. When $n > 2, C.R. = (C.I./R.I.) < 0.1$, the judgment matrix is considered to have satisfactory consistency, and the weight coefficient can be obtained at this time; otherwise, the judgment matrix needs to be readjusted [31].

4.1.2. Calculation of Weights for Evaluation Indexes of Geological Environment Quality in Mine

(1) Construct the judgment matrix between F and A

Table 3: Judgment matrix F

F	A1	A3	A2	WEIGHT W
A1	1	1	4	0.4445
A3	1	1	4	0.4445
A2	0.25	0.25	1	0.1110

As can be seen from Table **3**, the eigenvalue of the matrix is $W = (w_1, w_2, w_3) = (0.4445, 0.4445, 0.1110)$, and the maximum eigenroot of the judgment matrix is calculated by the consistency test formula $\lambda_{max} = 3$, $C.I. = (\lambda_{max} - n)/(n-1) = 0$, and check it out $R.I. = 0.5149$, $C.R. = C.I./R.I. = 0 < 0.1$. Therefore, the judgment matrix meets the consistency requirements.

(2) Construct the judgment matrix between A and B

Table 4: Judgment matrix A1

A1	B1	B2	B3	B4	B5	B6	WEIGHT W
B1	1	2	3	5	7	7	0.3922
B2	1/2	1	2	4	6	6	0.2663
B3	1/3	1/2	1	3	5	5	0.1772
B4	1/5	1/4	1/3	1	3	3	0.0848
B5	1/7	1/6	1/5	1/3	1	1	0.0398
B6	1/7	1/6	1/5	1/3	1	1	0.0398

As can be seen from Table **4**, the characteristic value is $W = (w_1, w_2, w_3, w_4, w_5, w_6) = (0.3922, 0.2663, 0.1772, 0.0848, 0.0398, 0.0398)$, and the maximum eigenvalue of the judgment matrix is calculated by the consistency test formula $\lambda_{max} = 6.165$, $C.I. = (\lambda_{max} - n)/(n-1) = 0.033$, check it out $R.I. = 1.2494$, $C.R. = C.I./R.I. = 0.0264 < 0.1$. Therefore, the judgment matrix meets the requirement of consistency.

Table 5: Judgment matrix A2

A2	B7	B8	WEIGHT W
B7	1	1	0.5
B8	1	1	0.5

As can be seen from Table **5**, the eigenvalue of the matrix is $W = (w_1, w_2) = (0.5, 0.5,)$, and the maximum eigenvalue of the judgment matrix is calculated by the consistency test formula $\lambda_{max} = 2$, $C.I. = (\lambda_{max} - n)/(n-1) = 0$, $C.R. = C.I./R.I. = 0 < 0.1$. Therefore, the judgment matrix meets the requirement of consistency.

Table 6: Judgment matrix A3

A3	B9	B10	B11	B12	WEIGHT W
B9	1	2	1/3	1/8	0.0794
B10	1/2	1	1/4	1/9	0.0508
B11	3	4	1	1/7	0.1692
B12	8	9	7	1	0.7006

As can be seen from Table **6**, the characteristic value is $W = (w_1, w_2, w_3, w_4) = (0.0794, 0.0508, 0.1692, 0.7006)$, and the maximum eigenvalue of the judgment matrix is calculated by the consistency test formula $\lambda_{max} = 4.1725$, $C.I. = (\lambda_{max} - n)/(n-1) = 0.0575$, check it out $R.I. = 0.8931$, $C.R. = C.I./R.I. = 0.0644 < 0.1$. Therefore, the judgment matrix meets the requirement of consistency.

(3) Establish the judgment matrix between B and C

Table 7: Judgment matrix B12

B12	C1	C2	C3	WEIGHT W
C1	1	1	1	0.3333
C2	1	1	1	0.3333
C3	1	1	1	0.3333

As can be seen from Table **7**, the characteristic value is $W = (w_1, w_2, w_3) = (0.3333, 0.3333, 0.3333)$, and the maximum eigenvalue of the judgment matrix is calculated by the consistency test formula $\lambda_{max} = 3$, $C.I. = (\lambda_{max} - n)/(n-1) = 0$, check it out $R.I. = 0.5149$, $C.R. = C.I./R.I. = 0 < 0.1$. Therefore, the judgment matrix meets the requirement of consistency.

4.1.3. Overall ranking of the weights of Muping mine geological environment evaluation indices

After calculating the weights of the Muping Mine's geological environment evaluation indicators, the evaluation indicators are summarized and sequenced as shown in Table **8**.

Table 8: Total ranking of mine geological environment evaluation index weights in Muping District

Sort	Influencing Factors of Grade Evaluation	Serial Number	Total Weight W
1	Vegetation coverage	B1	0.1743
2	Topographic	B2	0.1184
3	Air pollution level	C1	0.1038
4	Water pollution level	C2	0.1038
5	Soil pollution	C3	0.1038
6	Surface (soil, rock) erodibility	B3	0.0788
7	Solid waste treatment	B11	0.0752
8	Impact on regional industrialization	B7	0.0555
9	Impact on economic structure change	B8	0.0555
10	Solid waste area	B4	0.0377
11	Potential hazard degree of harmful elements	B9	0.0353
12	Beneficiation recovery	B10	0.0226
13	Development degree of mine resources	B5	0.0177
14	Mine disaster	B6	0.0177

4.2. Fuzzy evaluation of geological environment quality grade in Muping mine

Establish evaluation factors and evaluation grade set: after the weight of evaluation factors is determined, an evaluation grade set is established. $U = \{U_1, U_2, U_3, \dots, U_n\}$, and $U_i(i = 1,2,3, \dots, n)$ is possible to judge the result [33]. Based on the evaluation score of mine geological environment quality grade in Muping District, the evaluation table of mine environmental quality grade in Muping District is sorted out (Table **9**).

Table 9: Evaluation and valuation table of mine geological environment quality grade in Muping District

Evaluation Factor Index	Extremely Poor	Poor	Fair	Good	Excellent
Vegetation coverage B1	0.00	0.00	0.24	0.61	0.15
Topographic B2	0.00	0.11	0.19	0.50	0.20
Surface erodibility B3	0.00	0.14	0.43	0.32	0.11
Solid waste area B4	0.00	0.00	0.13	0.72	0.15
Development degree of mine resources B5	0.00	0.26	0.31	0.43	0.00
Mine disaster B6	0.00	0.00	0.00	0.30	0.70
Impact on regional industrialization B7	0.00	0.08	0.33	0.55	0.04
Impact on economic structure change B8	0.00	0.00	0.30	0.40	0.30
Potential hazard degree of harmful elements B9	0.00	0.05	0.15	0.57	0.23
Beneficiation recovery B10	0.00	0.10	0.15	0.42	0.33
Solid waste treatment B11	0.00	0.00	0.10	0.50	0.40
Air pollution level C1	0.00	0.10	0.10	0.50	0.30
Water pollution level C2	0.00	0.10	0.10	0.50	0.30
Soil pollution C3	0.00	0.10	0.10	0.50	0.30

The grade of mine geological environment quality in Muping District is divided into five grades, which constitute the evaluation grade set $V = \{1,2,3,4,5\}$[34]. They represent extremely poor, poor, fair, good and excellent respectively. Finally, the membership matrix R value of mine geological environment quality grade evaluation in Mouping District of Shandong Province is determined, and the weight vector of Yunshan tunnel water inrush risk grade evaluation index is W.

$$R = \begin{bmatrix} 0.00 & 0.00 & 0.24 & 0.61 & 0.15 \\ 0.00 & 0.11 & 0.19 & 0.50 & 0.20 \\ 0.00 & 0.14 & 0.43 & 0.32 & 0.11 \\ 0.00 & 0.00 & 0.13 & 0.72 & 0.15 \\ 0.00 & 0.26 & 0.31 & 0.43 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.30 & 0.70 \\ 0.00 & 0.08 & 0.33 & 0.55 & 0.04 \\ 0.00 & 0.00 & 0.30 & 0.40 & 0.30 \\ 0.00 & 0.10 & 0.15 & 0.57 & 0.23 \\ 0.00 & 0.10 & 0.15 & 0.42 & 0.33 \\ 0.00 & 0.00 & 0.10 & 0.50 & 0.40 \\ 0.00 & 0.10 & 0.10 & 0.50 & 0.30 \\ 0.00 & 0.10 & 0.10 & 0.50 & 0.30 \\ 0.00 & 0.10 & 0.10 & 0.50 & 0.30 \end{bmatrix} \qquad W^T = \begin{bmatrix} 0.1743 \\ 0.1184 \\ 0.0788 \\ 0.0377 \\ 0.0177 \\ 0.0177 \\ 0.0555 \\ 0.0555 \\ 0.0353 \\ 0.0226 \\ 0.0752 \\ 0.1038 \\ 0.1038 \\ 0.1038 \end{bmatrix}$$

According to the formula $g = W \times R$ [35], we can get the fuzzy set g of mine geologi-cal environment quality evaluation grade in Muping District, $g = [0.0000，0.0682，0.1909，0.5064，0.2345]$.

5. Analysis of evaluation results

From Table 8 the total ranking of the weights of the mine geological environmental quality evaluation indicators in Muping District, we can see that the environmental (air, soil, water) pollution degree (weight of 0.3114), vegetation coverage (weight of 0.1743), topography (weight of 0.1184) are The main factors for evaluating the quality of the geological environment of the mines in Muping District, Shandong Province, followed by the degree of surface erosion (with a weight of 0.0788) and the area of solid waste (with a weight of 0.0752), of course, other evaluation factors cannot be ignored.

Fuzzy set of evaluation grade of mine geological environment quality in Muping District g, according to the principle of maximum subordinate degree, the mine geological environment quality grade of Mouping District in Shandong Province is good.

6. Conclusion

(1) The main controlling factors affecting the quality grade of mine geological environment are put forward, and the hierarchical structure model of evaluation index for the quality grade of mine geological environment is established. It is determined that the quality of mine geological environment in the study area is a good grade.

(2)The qualitative evaluation results are transformed into quantitative evaluation results by the mine geological environment evaluation model based on F-AHP evaluation method, thereby enhancing the reliability of the evaluation results.

(3) By combining the analytic hierarchy process and fuzzy comprehensive evaluation, the weight of each main control factor can be more objectively determined, so the subjective interference of man-made ratings will be greatly reduced.

(4) The evaluation results show that the comprehensive evaluation of the mine geological environment belongs to a good level, indicating that the mine geological environment in the study area is generally good. However, mine geological environmental problems have a relatively large impact on the geological environment and should be paid attention to. The evaluation results are in line with the actual conditions of the study area and can provide basic data for local mining geological environmental protection and restoration management.

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