

## Research Article

# Environmental Evaluation of Coal Mines Based on Generalized Linear Model and Nonlinear Fuzzy Analytic Hierarchy

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To create a good working environment for workers in coal mines and ensure that they can work safely and comfortably, environmental assessments of coal mines represent an important method used to achieve this goal. In this paper, a comprehensive environmental evaluation model of coal mines was established based on generalized linear theory and fuzzy analytic hierarchy processes. First, the importance degree of each index factor was obtained by analyzing the statistical source data of air, water, soil, ecological compensation, and other indexes that affect the ecological environmental safety of coal mines using generalized linear theory. Based on the importance degree of each index factor, a pairwise comparison matrix was constructed by the logarithmic fuzzy preference programming method, and the influence weight value of each index factor was accurately obtained through MATLAB software. The results indicated that the model can effectively reduce the impact of expert subjectivity on the evaluation results, which is consistent with the reality of coal mines. In addition, in the process of environmental assessment of coal mines, the model is proven to be convenient, precise, and easy to operate.

## 1. Introduction

Resource safety is an important part of national strategic safety, and the development of mineral resources is always an important mission [1–3]. In particular, in the past 30–40 years, the development of mineral resources has provided strong support and protection for the rapid development of the economy and society. Due to technological reasons and the pursuit of high profits, the strength of mine ecological protection and restoration management has not been as strong as people would prefer, leading to the intensification of the contradiction between the coal mine development and ecological safety, e.g., the high production rate of three wastes of coal mines, the long potential harm of radiation, and the serious pollution to the air, water and soil [2]. In particular, the disordered development in some areas has led to geological disasters, such as surface collapse and debris flow, which have intensified land desertification and led to the degradation of ecological environmental quality [3]. Therefore, it

is urgent to explore a new technology of mine geological environmental governance and ecological restoration to prevent the further degradation of ecological health. The current ecological environmental safety assessment of coal mines can not only measure the overall status of the ecological quality of coal mines but also reflect the governance of the ecological environmental pollution. Additionally, it can quickly identify the important factors that cause the deterioration of the mine environment, allowing for the quick adoption of the most effective measures to control the “culprits” that make the mine environment worse.

Currently, many scholars have constructed a series of safety evaluation models, e.g., analytic hierarchy process, fuzzy comprehensive evaluation, grey theory, and neural network method, and applied them to mine ecological environmental safety evaluations. For instance, Zhao et al. [4] established an evaluation index system of the mine geological environment using the analytic hierarchy process (AHP) and applied this method to the mining field of Hainan Island; the

TABLE 1: Scale of triangular numbers with different importance.

Logical variable	Scale of TFN	Reciprocal scale of TFN
Equally important	(1, 1, 1)	(1, 1, 1)
Weakly important	(1/2, 1, 3/2)	(2/3, 1, 2)
Fairly important	(1, 3/2, 2)	(1/2, 2/3, 1)
Strongly important	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strongly important	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Extremely important	(5/2, 3, 7/2)	(7/2, 1/3, 2/5)

authors found that the evaluation value basically conformed to the situation of the mine site. Bascetin et al. [5] constructed a decision support system based on an analytical hierarchy process to evaluate the production of coal mines in Turkey. Samantra et al. [6] created an improved decision method based on fuzzy set theory and distinguished the ranges of evaluated risk ratings, ultimately suggesting an action requirement plan to guide the management of the mine environment. Yang et al. [7] selected four factors that affect the mine environment, including the water environment, atmospheric environment, geological disaster, and ecological environmental characteristics, as the evaluation factors to build a fuzzy comprehensive evaluation model of the mine environment for the quantitative study of the mine environment. Su et al. [8] established an engineering geological evaluation model based on grey mathematics theory and evaluated the engineering geological situation of typical mines by determining the evaluation weight index. Zhao et al. [9] used the principle of BP neural networks and the random interpolation method to build an evaluation model of the BP artificial neural network on mine ecological safety.

Each evaluation model has its own shortcomings. To fully consider the influence of all factors and present the comprehensive evaluation results scientifically and accurately, many scholars have combined various models to carry out comprehensive evaluations according to the characteristics of the different models, namely, the combined comprehensive evaluation model. For instance, based on fuzzy theory, Chen et al. [10] collected the key factors influencing the mine environment by remote sensing technology, determined the influence weight of the environmental evaluation factors by using AHP, and finally built the AHP-fuzzy mine environment evaluation model. Besides, Wei et al. [11] established the comprehensive evaluation of the underground heat source based on the AHP and fuzzy comprehensive evaluation (FCE) to construct the evaluation model, and some suggestions on thermal stress control are put forward. Based on the theories of uncertainty measurement evaluation (WME) and AHP, Dong et al. [12] established the comprehensive risk evaluation of underground goafs using multiple indexes. Dong et al. [13] also established and calibrate the comprehensive models using the random forest, support vector machine, Bayes' classifier, Fisher's classifier, logistic regression, and neural networks. Based on grey system theory, Wei et al. [14] used the analytic hierarchy process to determine the weight of each influencing factor and constructed a grey comprehensive evaluation model of the mine geological environment. To scientifically and accurately obtain the

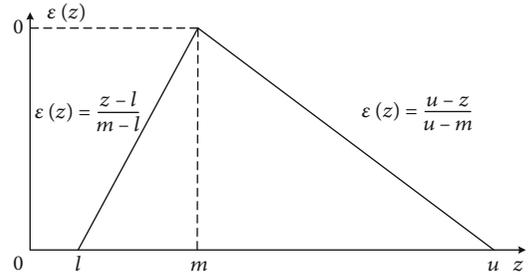


FIGURE 1: Triangular fuzzy number.

membership degree of each influencing factor, Liu et al. [15] built a fuzzy-grey combination evaluation model based on grey correlation analysis and fuzzy evaluation theory.

However, there are many factors that affect ecological environmental safety, and the relationship between the evaluation factors and the safety level is fuzzy, which makes the shortcomings of the current evaluation model more obvious. For instance, although the neural network model can overcome the subjectivity of expert experience and ensure a higher accuracy of evaluation results, it is easy to fall into the dilemma of a local minimum and slow convergence speed in the calculation process of weight, and this method cannot address the relationships between various index factors clearly. Although the AHP and grey theory evaluation methods can deal with the relationship of each index well, they rely on the experience of experts for evaluation when determining the weight of influencing factors; therefore, they cannot avoid subjectivity. The fuzzy analytic hierarchy process is the best method to address the fuzzy relationship of all factors; however, it also cannot avoid the evaluation of experts when building the comparison matrix.

To overcome the subjectivity of evaluation experts in the evaluation of the influence degree of each index factor and to further improve the uncertainty of data processing, in this paper, a comprehensive evaluation model of the coal mine environment is established based on generalized linear theory and fuzzy level theory. First, the importance of each index in relation to the target index is obtained by the initial statistics of the source data of each lowest level index based on generalized linear theory. Then, according to the statistical value obtained by generalized linear theory, the pairwise comparison matrix is constructed by the logarithmic fuzzy preference programming method (LFPP). Finally, the influence weight value of each index factor is accurately obtained through MATLAB software. The model is applied to a coal mine for an environmental assessment.

## 2. Methodology

**2.1. Triangular Fuzzy Number Theory.** There are many kinds of distribution functions used to imitate probability theory, such as the normal distribution function, trapezoid distribution function, triangular fuzzy number, k-th parabola distribution, Cauchy distribution, and S-type distribution. The triangular fuzzy numbers (TFN) is widely adopted to express the decision perception of alternatives' performances with respect to each criterion [16]. In order to easy the judgment

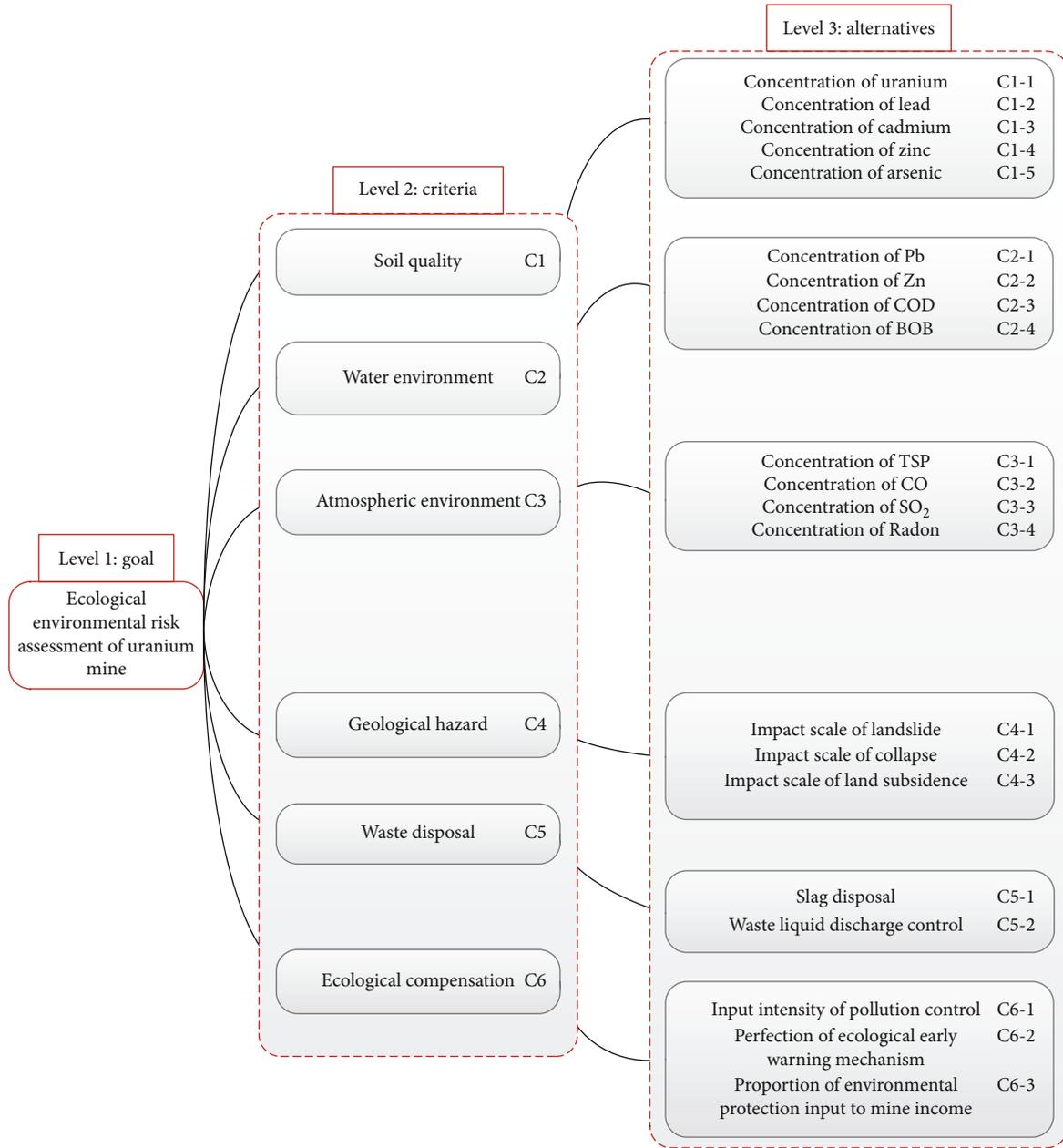


FIGURE 2: The diagram of environmental safety level analysis in coal mines.

TABLE 2: Statistical compensation indexes for mine ecological safety.

Year	Input intensity of pollution control	Improvement of ecological early warning system	Proportion of environmental protection investment to total income	Synthetic index of compensation
2005	40.7	1.72	3.88	0.27
2006	39.5	1.76	4.2	0.21
2007	38.6	1.76	4.48	0.20
2008	37.7	1.8	4.76	0.21
2009	36.8	1.8	5.08	0.23

process, linguistic variables are introduced (section 2.3), and it is a kind of variable whose values are not numbers but words and sentences [17]. Therefore, the triangular fuzzy theory is mainly used to build a model to evaluate the ecological environment of coal mines in this paper.

In a given region  $Z$ , for any  $z \in Z$ , the fuzzy set  $A$  can be defined as

$$A = \{(z, \varepsilon_A(z)) | z \in Z\}, \tag{1}$$

where  $\varepsilon_A$  is the membership degree of  $z$  to  $A$  and  $\varepsilon_A(x) \in (0, 1)$ .

Let  $l$ ,  $m$ , and  $u$  be the minimum possible value, the intermediate value, and the maximum possible value of a certain

TABLE 3: Statistics of influencing factors of atmosphere, soil, and water in coal mines.

Point	Atmosphere				Synthetic index of atmosphere	Soil					Surface water				Synthetic index of water
	TSP	CO	SO <sub>2</sub>	Rn		Pb	Zn	Cd	As	U	Pb <sup>2+</sup>	Zn <sup>2+</sup>	COD	BOD	
1	0.41	5.1	0.05	26.2	0.775	167.5	368	0.1	13.54	64.4	0.48	3.68	3.92	5.5	0.51
2	0.23	3.12	0.09	34.4	0.625	234.9	888	0.3	10.96	62.9	0.66	5.32	14.3	12.7	0.45
3	0.2	5.5	0.12	35	0.6	220	2339	0.6	9.63	56.8	0.57	4.43	15.6	17.1	0.26
4	0.3	4.4	0.11	133	0.45	224.8	1521	0.7	14.47	54.7	0.60	4.31	22	16.8	0.2
5	0.2	3.6	0.13	37.3	0.65	263.2	1267	0.4	12.1	60.3	0.52	5.07	24	19.1	0.2
6	0.2	4.4	0.04	35.2	0.64	223.2	401.9	0.4	14.34	63.5	0.57	4.37	4.03	14.3	0.43
7	0.15	3.2	0.13	38.1	0.51	244.8	986	0.3	12.76	61.7	0.56	5.22	14.3	10.7	0.49
8	0.25	5.3	0.10	25.4	0.61	236.7	2021	0.8	14.63	53.9	0.61	3.83	16.7	19	0.27
9	0.13	5.0	0.20	135	0.43	171.3	1320	0.7	12.87	56.3	0.47	4.03	23	21.1	0.21
10	0.3	3.1	0.15	124	0.41	200.7	1268	0.5	12.1	62.3	0.58	5.11	21	20.2	0.2

Synthetic index of soil.

TABLE 4: Importance of indicators at all levels to objectives.

First level index	Weight		Second level index	Weight
Soil quality indicators	C1	0.393	Pb C1-1	0.319
			Zn C1-2	0.103
			Cd C1-3	0.117
			As C1-4	0.104
			U C1-5	0.357
Water environmental quality	C2	0.385	Pb <sup>2+</sup> C2-1	0.397
			Zn <sup>2+</sup> C2-2	0.183
			COD C2-3	0.207
			BOD C2-4	0.213
Atmospheric environmental	C3	0.091	SO <sub>2</sub> C3-1	0.238
			Rn C3-2	0.344
			CO C3-3	0.217
			TSP C3-4	0.201
Ecological compensation indicators	C6	0.131	Input intensity of pollution control C6-1	0.416
			Improvement of ecological early warning system C6-2	0.302
			Environmental protection investment/total income C6-3	0.282

TABLE 5: The grading standard of the relative importance of the corresponding index to the goal.

Logical variable	Grade corresponding to factor weight ratio
Equally important	0.96
Weakly important	0.8
Fairly important	0.64
Strongly important	0.48
Very strongly important	0.32
Extremely important	0.16

fuzzy variable  $z$ , respectively, all of which are real numbers. Then, the three numbers  $(l, m, u)$  constitute a triangular fuzzy number,  $\tilde{A}$ . Let  $\tilde{A} = (l, m, u)$  and  $l \leq m \leq u$ , and the function diagram of the triangular fuzzy number is shown in Figure 1. The membership function [18] is

$$\varepsilon(z) = \begin{cases} 0 & z < l \\ \frac{z-l}{m-l} & l \leq z \leq m \\ \frac{u-z}{u-m} & m \leq z \leq u \\ 0 & z \geq u \end{cases}, \quad (2)$$

where the parameter  $m$  denotes the maximum possible value describing a fuzzy event, and  $l$  and  $u$  represent the upper and lower bounds of the boundary, respectively.

TABLE 6: The comparison matrix with respect to the goal.

	Present method			
	C1	C2	C3	C6
C1	(1, 1, 1)	(2/3, 1, 2)	(2, 5/2, 3)	(3/2, 2, 5/2)
C2	(1/2, 1, 3/2)	(1, 1, 1)	(2, 5/2, 3)	(3/2, 2, 5/2)
C3	(1/3, 2/5, 1/2)	(1/3, 2/5, 1/2)	(1, 1, 1)	(2/3, 1, 2)
C6	(2/5, 1/2, 2/3)	(2/5, 1/2, 2/3)	(1/2, 1, 3/2)	(1, 1, 1)

$\lambda = 0.4798, M = 1015.$

2.2. *Generalized Linear Model Theory.* The generalized linear model is a direct extension of the normal linear model, which is suitable for continuous data and discrete data; that is, the independent variable can be a continuous variable, classified variable, or ordered variable. Its basic form can be expressed as

$$\mu_i = E[Y_i] = g^{-1} \left( \sum_j X_{ij} \beta_j + \xi_i \right), \quad (3)$$

where  $\mu_i$  is the mathematical expectation;  $Y_i$  is the dependent variable vector;  $g(x)$  is the connection function;  $X_{ij}$  is the independent variable matrix;  $\beta_j$  is the model parameter vector to be estimated; and  $\xi_i$  is the interference term.

Combined with equation (3), the observed value of the dependent variable can be connected with the expected value of the explanatory variable by linear addition; therefore, the relationship between the mathematical expectation  $\mu_i$  and the linear factors can be expressed as

$$g(\mu_i) = X_i \beta', \quad (4)$$

where  $g(\mu_i)$  is a strictly monotonic function and is differentiable, which is called a continuous function.

The expected value of the observed value of the dependent variable is related to the explanatory variable by equation (4-1). It is assumed that there are N sets of observation data, i.e.,  $(y|X_i) = (y|x_1, x_2, \dots, x_k)$  and  $(i = 1, 2, \dots, n)$ .  $y_i \in (0, 1, \dots, j)$  is a multcategory dependent variable with  $j$  categories, indicating that the conclusion of the safety evaluation model has  $j$  grades.  $X = (x_1, x_2, \dots, x_k)$  is the explanatory variable, i.e., the influencing factor affecting the conclusion grade of the model.

It is assumed that  $\omega_i$  is the cumulative influence weight of a certain level  $y_i$  under the condition of the index factor variable

$$\omega_i = \omega(y_i \leq j|X_i), \omega_i = \omega_{i+1} - \omega_i, \quad (5)$$

where  $\bar{\omega}_i$  is the influence weight of an evaluation level.

To better describe the relationship between the cumulative influence weight of the level and the index factor variables, in this paper, the relationship is transformed by logistic transformation, that is

$$\log it(\omega_i) = \ln \left[ \frac{\omega_i(y_i \leq j|x_i)}{1 - \omega_i(y_i \leq j|x_i)} \right] = \beta_0 + \sum_{i=0}^k \beta_i x_i, \quad (6)$$

where the relationship between the logit ( $\omega$ ) transformed and the independent variable is linear, and its value range is  $(-\infty, +\infty)$ , which is conducive to its estimation.

The regression equation can be obtained by substituting the estimated value of parameter  $\beta$  into equation (6)

$$\omega'(y_i \leq j|(x_1, x_2, \dots, x_k)_i) = \frac{\exp \left( \beta'_0 + \sum_{i=0}^k \beta'_i x_i \right)}{1 + \exp \left( \beta'_0 + \sum_{i=0}^k \beta'_i x_i \right)}. \quad (7)$$

2.3. *The Fuzzy Analytic Hierarchy Process.* First, the weight value of each index influencing the target value is determined by generalized linear theory, and then the importance of each pair of factors is judged by the weight of each index factor. According to the linguistic variable in Table 1, the relative importance of each pair of factors can be obtained. Then, the comparison matrix  $\tilde{U}$  can be created.

$$\tilde{U} = (\tilde{u}_{ij})_{n \times n} = \begin{bmatrix} 1 & (l_{12}, m_{12}, u_{12}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & 1 & \cdots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \cdots & 1 \end{bmatrix}, \quad (8)$$

where if  $i \neq j$ , then  $\tilde{u}_{ij} = (l_{ij}, m_{ij}, u_{ij}) = \tilde{u}_{ij}^{-1} = (1/u_{ji}, 1/m_{ji}, 1/l_{ji})$ ,  $(i = 1, 2, \dots, n)$ , and  $(j = 1, 2, \dots, n)$ .

To facilitate the research, the comparison matrix  $\tilde{U}$  is processed by the logarithmic transformation [19, 20]

$$\ln \tilde{u}_{ij} \approx (\ln l_{ij}, \ln m_{ij}, \ln u_{ij}). \quad (9)$$

By substituting equation (9) into equation (2), the following can be obtained

$$\mu_{ij} \left( \ln \left( \frac{s_i}{s_j} \right) \right) = \begin{cases} 0 & \ln \left( \frac{s_i}{s_j} \right) < \ln l_{ij} \\ \frac{\ln (s_i/s_j) - \ln l_{ij}}{\ln m_{ij} - \ln l_{ij}} & \ln l_{ij} \leq \ln \left( \frac{s_i}{s_j} \right) \leq \ln m_{ij} \\ \frac{\ln u_{ij} - \ln (s_i/s_j)}{\ln u_{ij} - \ln m_{ij}} & \ln m_{ij} \leq \ln \left( \frac{s_i}{s_j} \right) \leq \ln u_{ij} \\ 0 & \ln \left( \frac{s_i}{s_j} \right) > \ln u_{ij} \end{cases}. \quad (10)$$

TABLE 7: The comparison matrix with respect to the soil quality.

	Present method				
	C1-1	C1-2	C1-3	C1-4	C1-5
C1-1	(1, 1, 1)	(2, 5/2, 3)	(3/2, 2, 5/2)	(2, 5/2, 3)	(2/3, 1, 2)
C1-2	(1/3, 2/5, 1/2)	(1, 1, 1)	(2/3, 1, 2)	(2/3, 1, 2)	(1/3, 2/5, 1/2)
C1-3	(2/5, 1/2, 2/3)	(1/2, 1, 3/2)	(1, 1, 1)	(1/2, 1, 3/2)	(2/5, 1/2, 2/3)
C1-4	(1/3, 2/5, 1/2)	(1/2, 1, 3/2)	(2/3, 1, 2)	(1, 1, 1)	(1/3, 2/5, 1/2)
C1-5	(1/2, 1, 3/2)	(2, 5/2, 3)	(3/2, 2, 5/2)	(2, 5/2, 3)	(1, 1, 1)

$$\lambda = 0.8200, M = 1018.$$

TABLE 8: The comparison matrix with respect to the water environmental quality.

	Present method			
	C2-1	C2-2	C2-3	C2-4
C2-1	(1, 1, 1)	(3/2, 2, 5/2)	(1, 3/2, 2)	(1, 3/2, 2)
C2-2	(2/5, 1/2, 2/3)	(1, 1, 1)	(1/2, 2/3, 1)	(1/2, 2/3, 1)
C2-3	(1/2, 2/3, 1)	(1, 3/2, 2)	(1, 1, 1)	(2/3, 1, 2)
C2-4	(1/2, 2/3, 1)	(1, 3/2, 2)	(1/2, 1, 3/2)	(1, 1, 1)

$$\lambda = 0.6230, M = 1017.$$

TABLE 9: The comparison matrix with respect to the atmospheric environment.

	Present method			
	C3-1	C3-2	C3-3	C3-4
C3-1	(1, 1, 1)	(2/3, 1, 2)	(1/2, 1, 3/2)	(1, 3/2, 2)
C3-2	(1/2, 1, 3/2)	(1, 1, 1)	(1, 3/2, 2)	(1, 3/2, 2)
C3-3	(2/3, 1, 2)	(1/2, 2/3, 1)	(1, 1, 1)	(1/2, 1, 3/2)
C3-4	(1/2, 2/3, 1)	(1/2, 2/3, 1)	(2/3, 1, 2)	(1, 1, 1)

$$\lambda = 0.4819, M = 1015.$$

In this paper, to solve the problem that a specific value  $\lambda$  results in an inconsistency between weights and fuzzy judgements in  $U$ , the nonnegative deviation parameters of  $\gamma_{ij}$  are introduced [17, 18].

$$\text{Minimize } K = (1 - \lambda)^2 + G \sum_{i=1}^{n-1} \sum_{j=i+1}^n (\gamma_{ij} + \varsigma_{ij})^2 \text{ S.t.}$$

$$\left\{ \begin{array}{l} \ln s_i - \ln s_j - \lambda \ln \left( \frac{m_{ij}}{l_{ij}} \right) + \gamma_{ij} \geq \ln l_{ij} \\ i = 1, \dots, n-1; j = i+1, \dots, n \\ -\ln s_i + \ln s_j - \lambda \ln \left( \frac{u_{ij}}{m_{ij}} \right) + \varsigma_{ij} \geq -\ln u_{ij} \\ i = 1, \dots, n-1; j = i+1, \dots, n \\ \lambda \geq 0, \gamma_i \geq 0, i = 1, \dots, n-1 \\ \gamma_{ij} \geq 0, \varsigma_{ij} \geq 0, i = 1, \dots, n-1; j = i+1, \dots, n \end{array} \right. \quad (11)$$

TABLE 10: The comparison matrix with respect to ecological compensation.

	Present method		
	C6-1	C6-2	C6-3
C6-1	(1, 1, 1)	(1/2, 1, 3/2)	(1, 3/2, 2)
C6-2	(2/3, 1, 2)	(1, 1, 1)	(1/2, 1, 3/2)
C6-3	(1/2, 2/3, 1)	(2/3, 1, 2)	(1, 1, 1)

$$\lambda = 0.6017, M = 1012.$$

where  $G$  is a specific constant, which is used to determine the weights in the fuzzy judgements.

The normalized priority calculation of the fuzzy pairwise comparison matrix  $\tilde{U}$  can be expressed by

$$\omega_i^* = \frac{\exp((\ln s_i)^*)}{\sum_{j=1}^n \exp((\ln s_j)^*)} \quad (12)$$

### 3. Application

**3.1. Determination of Index Factors.** According to the survey, the main indicators affecting the ecological safety of coal mines are atmospheric environmental indicators, water environmental quality indicators, soil quality indicators, geological hazard damage indicators, waste disposal indicators of coal mines, and ecological compensation indicators of coal mines. Among them, atmospheric environmental indicators mainly include factors affecting atmospheric environmental safety, e.g., TSP, CO, SO<sub>2</sub>, and radon. Water environmental quality indicators mainly include the concentrations of Pb, Zn, COD, and BOB. Soil quality indicators mainly refer to the concentrations of coal, lead, cadmium, zinc, and arsenic. The index of the degree of destruction of geological hazards mainly refers to the proportion of all kinds of geological hazards in the total area of mines, i.e., the impact scale of landslides, collapses, and land subsidence. The waste disposal indexes of coal mines mainly include slag disposal and waste liquid controlled discharge. The ecological compensation index of coal mines includes the input intensity of pollution control, the perfection of ecological early warning mechanisms, and the proportion of environmental protection input to mine income.

**3.2. Determine the Weights of the Responding Index Factors.** The decision problem in the hierarchical structure is decomposed, as shown in Figure 2. The hierarchy consists of three levels, including goals, criteria and alternatives. This goal

TABLE 11: The priorities of risk factors to the coal mine.

Factors	Local weight	Global weight	Ranking
Soil quality C1		0.6655	I
Concentration of coal C1-1	0.4521	0.3009	1
Concentration of lead C1-2	0.1481	0.0986	4
Concentration of cadmium C1-3	0.1827	0.1215	3
Concentration of zinc C1-4	0.1085	0.0722	6
Concentration of arsenic C1-5	0.1086	0.0723	5
Water environmental quality C2		0.2293	II
Concentration of Pb C2-1	0.7002	0.1606	2
Concentration of Zn C2-2	0.1339	0.0308	8
Concentration of COD C2-3	0.1060	0.0242	9
Concentration of BOB C2-4	0.0599	0.0137	11
Atmospheric environment C3		0.0679	III
Concentration of TSP C3-1	0.7754	0.0526	7
Concentration of CO C3-2	0.1871	0.0127	12
Concentration of SO2 C3-3	0.0322	0.0022	15
Concentration of radon C3-4	0.0053	0.0004	16
Ecological compensation indicators C6		0.0373	IV
Input intensity of pollution control C6-1	0.3790	0.0141	10
Perfection of ecological early warning mechanism C6-2	0.3313	0.0124	13
Proportion of environmental protection input to mine income C6-3	0.2896	0.0108	14

TABLE 12: The consistency of each fuzzy comparison matrix.

Hierarchy	Consistency $\lambda$
Soil quality indicators (Table 7)	0.8200
Water environmental quality (Table 8)	0.6230
Atmospheric environment (Table 9)	0.4819
Ecological compensation indicators (Table 10)	0.6017

layer is mainly used to assess the ecological environmental risk of coal mines. The criteria and alternatives are located at the second level and the third level, respectively.

The ecological environment monitoring data of several typical coal mines in China are selected to evaluate the ecological environmental safety. The ecological compensation index is generally calculated by comprehensively considering the benefits of the mine, the income expectations of leaders and miners, and the laws and regulations. The data of influencing factors of air, soil, and water indexes are mainly collected from the concentration of some harmful substances specified in relevant national standards. Based on the analysis of the evaluation indexes of the coal mine according to references [21–26], the ecological safety compensation index value and the index factor index value of air, soil, and water indexes of the coal mine are obtained, as shown in Tables 2 and 3.

The cumulative influence weight of the corresponding grade of the first level indicator and the influence weight of each grade under the second level indicator factor are obtained through the analysis of the generalized linear model (the influence weight of each grade indicator is mainly

obtained through the Statistical Analysis System (SAS), as shown in Table 4), and then the maximum value of the influence weight of each grade is taken as the influence weight of the corresponding category. The weight of each index factor is used to judge the relative importance of each index factor. The maximum likelihood ratio of each category is 42.684, 35.033, 43.556, and 41.022, respectively, all of which are within the allowable error range, indicating that the generalized linear model has a good fit.

The influence weight of the grade corresponding to the second level index and its corresponding first level index is analyzed through the generalized linear model, and the comparison matrix of the first level index and the second level index can be obtained according to Table 5, as shown in Tables 6–10.

## 4. Results and Discussion

**4.1. Results.** The results of local and global weights on the environmental impact factors of coal mines obtained by the present evaluation model based on the generalized linear and fuzzy analytic hierarchy process are shown in Table 11, which shows that the soil quality has the most important index influence on the environmental risk of coal mines among the four influencing factors, followed by water environmental quality, atmospheric environment, and ecological compensation indicators. Therefore, it is necessary to monitor the dangerous elements in soil and water on a regular basis and take timely measures to prevent exceeding the standard to control the dangerous sources during the early risk stage.

TABLE 13: The priorities of risk factors to the coal mine [27].

Factors	Local weight	Global weight	Ranking
Soil quality C1		0.478	I
Concentration of coal C1-1	0.5588	0.2671	1
Concentration of lead C1-2	0.0967	0.0462	6
Concentration of cadmium C1-3	0.2219	0.1061	3
Concentration of zinc C1-4	0.0663	0.0317	9
Concentration of arsenic C1-5	0.0563	0.0269	10
Water environment quality C2		0.363	II
Concentration of Pb C2-1	0.6903	0.2506	2
Concentration of Zn C2-2	0.1493	0.0542	5
Concentration of COD C2-3	0.1118	0.0406	7
Concentration of BOB C2-4	0.0485	0.0176	13
Atmospheric environment C3		0.0831	III
Concentration of TSP C3-1	0.7449	0.0619	4
Concentration of CO C3-2	0.2358	0.0196	12
Concentration of SO <sub>2</sub> C3-3	0.0168	0.0014	15
Concentration of radon C3-4	0.0025	0.0002	16
Ecological compensation indicators C6		0.0759	IV
Input intensity of pollution control C6-1	0.4598	0.0349	8
Perfection of ecological early warning mechanism C6-2	0.3083	0.0234	11
Proportion of environmental protection input to mine income C6-3	0.2319	0.0176	14

In addition, Table 11 shows that the concentration of coal (C1-1), concentration of Pb (C2-1), concentration of cadmium (C1-3), and concentration of lead (C1-2) have a great influence on the environmental risk of coal mines. However, the perfection of an ecological early warning mechanism (C6-2), proportion of environmental protection input to mine income (C6-3), concentration of SO<sub>2</sub> (C3-3), and concentration of radon (C3-4) have little influence on the environmental risk of coal mines. Table 11 also reveals that the environmental investment management of coal mines in the later stage has little impact on the environmental assessment. This result is mainly because in the later stage, the environment of coal mines has caused many irreversible losses and has had many human and financial costs. From a sustainable point of view, the compensation and management of the mine environment in the later period are definitely not a good long-term strategy.

**4.2. Verification of the model's Validity.** According to the literature, the validity of a model is usually verified by calculating the value of consistency and the nonnegative deviation variable of the fuzzy pairwise comparison matrices, i.e., the consistency  $\lambda$  and nonnegative deviation variable  $\gamma$  are the key parameters to determine the validity of a model. There are two cases in which  $\lambda = 0$  and  $\lambda \neq 0$ . When  $\lambda$  is not equal to zero, the greater the value of parameter  $\lambda$  is, the better the consistency of the model is. When  $\lambda$  is equal to zero, if  $\gamma = 0$ , the consistency of the model is still good. If  $\gamma \neq 0$ , it indicates that the model is inconsistent. The greater the nonnegative deviation variable  $\gamma$  is, the worse the consistency of the model is. With the help of MATLAB software, the value of  $\lambda$  in every matrix is obtained, as shown in Table 12. From

the consistency index aspect, the proposed model is confirmed to be acceptable.

In the second perspective, we compare the results of the present method we used in this paper with the results of the representative comprehensive evaluation method [27]. The results of the representative comprehensive evaluation method are shown in Table 13. We have obtained similar results on some factors. In particular, the impact of the first level index factors on the safety environment of uranium mines is basically the same. From all above, the proposed model was proven to be valid.

**4.3. Advantages and Disadvantages of the Present Model.** Based on generalized linear theory, the influence value of index factors on the environmental evaluation of coal mines was obtained using SAS software to count the original data of the index factors. Then, the fuzzy pairwise comparison matrices were established according to the influence value of index factors on the environmental evaluation, which greatly reduced the influence of human subjectivity on the construction of the comparison matrix. In addition, the linguistic variables and the TFN were introduced in the process of solving the factor weight, which enabled managers to quickly determine the relative importance of each pair of factors through the linguistic variables.

However, in the present model, although the importance degree of each factor was obtained using a linear generalized model to count the original data of each factor, the relative importance degree of each factor was judged by experts. Therefore, it is urgent to establish an evaluation formula and basis for the relative importance degree of each factor. In addition, according to the literature, although the

comparison matrices are consistent, the fuzzy number of the comparison matrix can lead to inconsistent results to some extent.

## 5. Conclusions

This paper develops a comprehensive environmental evaluation model of coal mines based on generalized linear theory and fuzzy analytic hierarchy processes.

- (1) The model is consistent with the results of literature [27] and let the evaluation process more efficient
- (2) In this paper, the linguistic variables are a kind of variable whose values are not numbers but words or sentences, and they are closer to the feelings of the decision makers. Therefore, the present model can effectively solve the problem of multiclassification in safety evaluations
- (3) In addition, in the environmental evaluation model, based on prior knowledge of the sample statistical source, the importance degree of each index factor on the environmental factor index is preliminarily obtained through generalized linear theory, and the influence weight value of each index factor was accurately obtained based on the logarithmic fuzzy preference programming method, which overcomes the defect of artificial empowerment and has more accurate evaluation results

## Data Availability

The data used to support the findings of this study are included within the article.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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