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Research Article

Research on Water-Filled Source Identification Technology of Coal Seam Floor Based on Multiple Index Factors

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According to the No. 13 Mine of Pingdingshan Coal Co. Ltd., the fault dimension of the study area is calculated based on fractal theory. The four impact factors such as water inflow, water pressure, water inrush coefficient, and fault fractal dimension of 21 water boreholes are used as evaluation indices, and a mathematical model for identifying the water-filled source of the coal seam floor is established by coupling an entropy weight method and fuzzy variable set theory. The model is used to identify the water-filled source of 7 boreholes, which provide a reliable reference for the identification of the water-filled source. According to the calculation result of the entropy weight method, the water volume per unit of the borehole and the groundwater pressure have a significant impact on the water source identification, which accounts for 89.93% of the weight value. In the fuzzy variable set model, when the distance parameter p is 1 and the optimization criterion parameter α is 2, the accuracy of the water sample identification of the water source category to be identified is 85.71%, which is at a high recognition level. The more typical the impact factors selected and the more samples, the accuracy of water-filled source identification is much higher.

1. Introduction

The Pingdingshan coalfield is located in a North China typical coalfield area. At present, the No. 2-1 coal seams of the Permian Shanxi formation are studied. The coal distribution has 5–7 layers of Carboniferous thin limestone aquifer and a thick layer of Cambrian limestone aquifer. Due to the influence of geological structures and coal mining disturbance, faults and fissures are developed in thin layer of limestone aquifers and aquicludes, which lead to a close hydraulic connection between the thin layer of limestones and the thick layer of limestone aquifers, so the coal seam mining process is threatened by the high-pressure aquifer of the bottom limestone. In order to reduce the influence of water inrush on safe underground production, the key to controlling mine water disasters is to identify the water source quickly and accurately. At present, the main methods for identifying water-filled sources include geological analysis, hydrodynamic analysis, hydrochemical analysis, water temperature analysis, and geophysical prospecting [1].

Liu et al. considered the influence of water temperature and water level combined with a QLT mathematical model to identify the water-filled source in the Panxie mining area [2]. Gui and Lu analyzed the main water inrush and the hydraulic connection between aquifers in the Wanbei mining area by using the radioactive isotope tritium as the discriminant index [3]. Yuan and Gui established the ground temperature equation according to the geothermal characteristics

when judging the water source of the Renlou coal mine and achieved good results based on the temperature analysis method [4]. Chen established a three-dimensional (3D) geological model based on the geological structure of the Sunan mining area and identified the water-filled source by simulating the groundwater flow [5]. Wang et al. used six conventional ions as the discriminating factor for the Jiaozuo mining area. Based on the distance discriminant analysis and grey system correlation degree method, the discriminant model of water-filled source identification was established, and the application test was carried out in the Xin'an mining area under similar hydrogeological conditions [6]. Wang et al. analyzed the 6 conventional ions in the groundwater of Pingdingshan coalfield and refined the hydrogeological unit. Based on this, the water source discrimination model was established [7]. Gao carried out hydrogeological pumping and water injection tests in Qiganlou Iron Mine, analyzed its hydrogeological parameters, and predicted the water-filled source of the mine [8]. Wang et al. quantitatively analyzed the structural faults in the Luan mining area and, combined with the improved analytic hierarchy process (AHP), evaluated the dangerous degree of water inrush in the Luan mining area [9]. With the continuous development and improvement of science and technology, a large amount of high-precision equipment has been applied to water source identification. Based on geographic information system technology and drilling depth water temperature fitting results, Ma et al. constructed a model to identify water-filled sources [10]. Zhang used laser-induced fluorescence technology as a means for identifying the water-filled source based on changes in water fluorescence caused by different parameters, such as water temperature and the flow rate of the water source [11]. These achievements provide a reference for future generations to study the water-filled source of mines.

Previous studies have used modern mathematical methods to establish identification models and identify water-filled sources using typical water chemical components, temperature, water level, etc. These methods are simple and fast. However, due to the difficulty of water sample collecting and the external interference of water sample test results, the established identification model is inconsistent with the reality. When geological structure and hydrogeological parameters are used as indicators, they are not quantitatively analyzed. They have space limitations in applicability and cannot be used as a general method to solve problems in other places, which in turn makes it difficult to accurately judge individual water-filled sources.

In this paper, the Carboniferous thin layer and the Cambrian thick limestone aquifer in the coal seam floor of Pingmei No. 13 Mine are used as the object, and the fractal theory is used to quantitatively evaluate the fault complexity of the mining area. Taking groundwater pressure, water inrush coefficient, water inflow per borehole, and fractal dimension of faults as index factors, the weight of each index is calculated based on the entropy weight method, and then the fuzzy variable set theory is used to obtain the comprehensive relative membership degree of the water sample to be discriminated. Finally, the water samples are classified according to the principle of maximum membership degree to identify the water-filled source. The key factors of water inrush are fully considered when the model is built, and the external disturbance is removed to the greatest extent, so as to accurately identify the water-filled source of the coal seam floor.

2. Mathematical Method

2.1. Entropy Weight Method. Determining the weight of each index is the key to calculating the relative membership degree of each water sample. The accuracy of the identification results is directly related to the selection of appropriate methods. The methods for determining weights include AHP, fuzzy inverse equation method, and entropy weight method [12]. Among them, the weight value of the entropy weight method is objective and reliable and can quantify the effective information of each index and provide a new idea for the comprehensive evaluation of each discriminant index. Therefore, this paper uses the entropy weight method to calculate the weight of each index. The calculation steps are as follows [13].

There are m kinds of water sources to judge, and the identification indices are n. Based on the average value of each identification index r_{ij}, the evaluation matrix R is set up.

$$R = \begin{matrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{matrix}, \tag{1}$$

where the entropy value is as follows:

$$H_j = -\frac{\sum_{i=1}^{m} v_{ij} * \ln v_{ij}}{\ln m} (i = 1, 2, \cdots, m;\ j = 1, 2, \cdots, n). \tag{2}$$

When $v_{ij} = 0$, then $H_j = 0$.

In the formula, $v_{ij} = (r_{ij} / \sum_{i=1}^{m} r_{ij})(i = 1, 2, \cdots, m;\ j = 1, 2, \cdots, n)$.

The weight value is as follows:

$$w_j = \frac{1 - H_j}{n - \sum_{i=1}^{m} H_j} (j = 1, 2, \cdots, n). \tag{3}$$

2.2. Fuzzy Variable Set Theory. Fuzzy variable set theory is established based on fuzzy set theory. Using the relative membership function, the theory constructs a relative difference function with relativity and dynamic variability, and the concept and model of fuzzy variable set are depicted. This theory expands the static concept and definition of the fuzzy set membership function, overcomes the defect of the static and unique membership function of the fuzzy set, and is widely used in the field of hydrological resources and other engineering examples [14–17].

2.2.1. Determination of Relative Membership Degree. Starting with a fuzzy concept A (phenomenon or thing) on the domain, let u be any element on U and satisfy $u \in U$. Let u denote the relative membership degree of the attraction

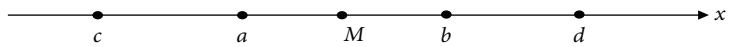

Figure 1: Position graph of x.

property of the fuzzy concept A as $\mu_A(u)$, and the relative membership degree of the repellent property is $\mu_{A^c}(u)$. If $\mu_A(u) = \mu_{A^c}(u)$, it means that the two properties reach dynamic equilibrium; if $\mu_A(u) > \mu_{A^c}(u)$, it means that u equals A and attracts the dominant property; if $\mu_A(u) < \mu_{A^c}(u)$, the opposite is true.

$$D_A(u) = \mu_A(u) - \mu_{A^c}(u). \tag{4}$$

$D_A(u)$ is the relative difference degree of u to A on the continuous number axis, in the formula $\mu_A(u) \in [0, 1]$, $\mu_{A^c}(u) \in [0, 1]$.

$$\text{mapped as} \begin{cases} D_A : D \longrightarrow [-1, 1], \\ u| \longrightarrow D_A(u) \in [-1, 1]. \end{cases} \tag{5}$$

This is the relative difference function of u to A.

In addition, the definition of the redundant set of fuzzy variable sets is as follows:

$$\mu_A(u) + \mu_{A^c}(u) = 1. \tag{6}$$

Therefore, the relative membership degree is as follows:

$$\mu_A(u) = \frac{1 + D_A(u)}{2}. \tag{7}$$

2.2.2. Construction of Relative Differential Function Model. Let $X_0 = [a, b]$ be the interval range of $0 < D_A(u) < 1$ on the number axis x (Figure 1), i.e., the attraction domain of the fuzzy set V; $X_0 = [c, d]$ is an interval within a finite range of $X_0 (X_0 \subset X)$; $[c, a]$ and $[b, d]$ are the interval ranges of $D_A(u) < 0$ on the axis x, the repulsive domain of the fuzzy set V.

M is located in the middle of the $[a, b]$ interval, when the position of $D_A(u) = 1$. When any point x is on the left of M, the relative difference function model is as follows:

$$\begin{aligned} D_A(u) &= \left(\frac{x-a}{M-a}\right)^U, \quad x \in [a, M], \\ D_A(u) &= \left(\frac{x-a}{c-a}\right)^U, \quad x \in [c, a]. \end{aligned} \tag{8}$$

When any point x is on the right of M, the relative difference function model is as follows:

$$\begin{aligned} D_A(u) &= \left(\frac{x-b}{M-b}\right)^U, \quad x \in [M, b], \\ D_A(u) &= -\left(\frac{x-b}{d-b}\right)^U, \quad x \in [b, d]. \end{aligned} \tag{9}$$

In formulas (8) and (9), $U = 1$ is generally used to denote when the model function is a linear function. Formulas (8) and (9) should satisfy (1) when $x = a$ or $x = b$, then $D_A(u) = 0$; (2) when $x = M$, then $D_A(u) = 1$; (3) when $x = c$ or $x = d$, then $D_A(u) = 0$; or (4) when $x \notin [c, d]$, $D_A(u) = -1$, $\mu_A(u) = 0$.

2.2.3. Comprehensive Relative Membership Calculation. Compared to the standard samples of the h level, the comprehensive relative membership degree of the t identified sample is u_{th}. The weight value of each evaluation factor determined by the entropy weight method is w_j. According to equations (4)–(7), the relative membership degree $u_A(jh)$ of each standard sample to the evaluation factor can be calculated, and then the comprehensive relative membership degree of each sample to the different standard samples can be obtained according to model (10) [18, 19].

$$u_{th} = \frac{1}{1 + \left(d_{hg}/d_{hb}\right)a}. \tag{10}$$

In the above formula, $d_{hg} = \{\sum_{j=1}^{n} [w_j(1 - u(jh))]^p\}^{1/p}$ and $d_{hb} = [\sum_{j=1}^{n} (w_j u(jh))^p]^{1/p}$, where n is the number of evaluation factors, w_j is the evaluation factor weight, p is the distance parameter, and α is the optimization criterion parameter.

2.3. Fractal Theory. Research results at home and abroad show that the distribution of geological faults in the deep part of the strata is a complex and self-similar fractal system [20]. Therefore, the fractal dimension that can quantitatively describe the irregularity of the fractal structure is used as an index for evaluating fault complexity [21, 22].

Fractal theory includes a variety of research methods, in which fault analysis mainly uses the network coverage method to study the fractal structure of geometric objects in a region. Based on this theory, the study is divided into several square lattices with side length r. Since there are different levels of cracks and faults inside the fractal, some lattices are empty, and some lattices cover part of the fractal, counting the number $N(r)$ of points or lines entering the grid. According to the ratio of 1/2, r is reduced, the number of corresponding lattice numbers $N(r)$ is counted, and so on. The obtained data are plotted in a double logarithmic coordinate graph $\ln N(r) - \ln r$, and then the line $\ln N(r) = e + f * \ln r$ is fit based on the least squares method. The slope $|f|$ of the fitted line is the fractal dimension Ds. The fractal dimension can be directly related to the complexity of the fault, i.e., the larger the Ds, the more complex the fault.

3. Construction of Index Factors

3.1. Mining Situation. Pingdingshan Coal Co. Ltd. 13 Mine (hereinafter referred to as No. 13 Mine) is located to the northeast of Pingdingshan City, Henan Province. The mine is about 15 km long from East to West and about 4 km wide

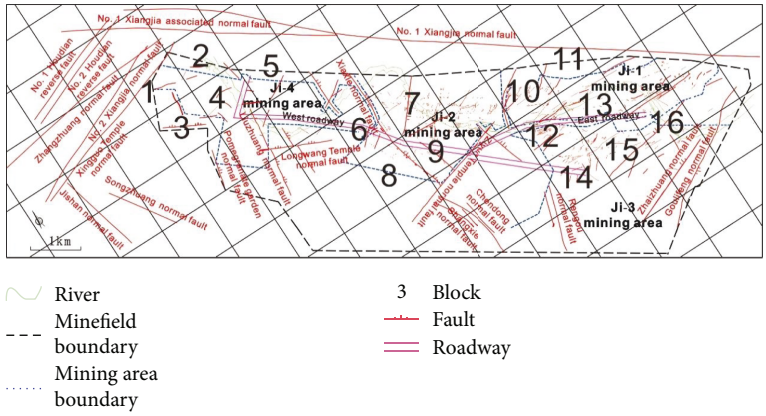

Figure 2: Grid partition diagram for fractal evaluation of the faults in the No. 13 Mine.

Table 1: Fractal dimension and the correlation coefficient of each block.

Block number	Fractal dimension (Ds)	Correlation coefficient (R)	Block number	Fractal dimension (Ds)	Correlation coefficient (R)
1	1.055	0.978	9	1.684	0.995
2	1.129	0.998	10	1.618	0.997
3	1.294	0.996	11	1.051	0.999
4	1.385	0.993	12	1.765	0.996
5	1.160	0.984	13	1.667	0.993
6	1.539	0.993	14	1.632	0.997
7	1.766	0.998	15	1.681	0.994
8	1.274	0.996	16	1.601	0.994

from North to South, with an area of 54 km^2. At present, the No. 2-1 coal seam of the Shanxi formation from the Permian is mainly mined, with an annual output of 2.1 million tons. The northwest boundary of the mine starts from the normal fault of Xingguo Temple, the southeast stops at the Goulifeng normal fault, the northeast is bounded by the normal fault of No. 1 Xiangjia, and the southwest is bounded by the contour line of the -800 m floor of the No. 2-1 coal seam. The minefield is divided into four mining areas, Ji-1, Ji-2, Ji-3, and Ji-4. At present, the Ji-1 and Ji-2 mining areas have been excavated, and the Ji-3 and Ji-4 mining areas are in the process of mining production. The main water hazards in mine excavation come from the Carboniferous limestone aquifer and the Cambrian limestone aquifer under the No. 2-1 coal seam. The thickness of the aquifers is 50-75 m and 90-130 m, respectively, and the groundwater temperature is between 28 and 50°C.

3.2. Complexity of Fault. The study area is divided into several rectangular grids with side length $r = 1000$ m according to the longitude and latitude, and they are, respectively, labeled (Figure 2). The similarity ratios $\omega = 1$, 1/2, 1/4, and 1/8 are, respectively, taken (the square grid is further refined into 1, 4, 16, and 64 square grids), and the number of square grids $N(r)$, including the fault traces under different scales, is counted. The fractal dimension Ds of each block is obtained according to the method described above (Table 1).

3.3. Water Inflow and Water Pressure. The water-filled source is identified based on the geological analysis method and the hydrodynamic analysis method. The data from the 21 boreholes of the No. 13 Mine Cambrian limestone aquifer and Carboniferous limestone aquifer are taken as standard water sample data, and the discriminant indices are water inflow, water pressure, water inrush coefficient, and fault fractal dimension (Table 2). The water-filled Carboniferous aquifer and the Cambrian limestone aquifer are represented by I and II, respectively. The distribution characteristics of the water pressure and water inflow are shown in Figure 3.

3.4. Water Inrush Coefficient. According to the water inrush coefficient of each borehole, the contour map of the water inrush coefficient for the No. 13 Mine water inrush point can be drawn using Surfer software (Figure 4). The water inrush coefficients of the Ji-1 and Ji-3 mining areas in the study area are higher, the water inrush coefficients of the Ji-4 and Ji-2 mining areas are lower, and the overall trend from the northwest to the southeast is gradually increasing.

4. Establishment of Evaluation Model

4.1. Entropy and Weight Calculation. For the 21 water boreholes of the coal seams in the No. 13 Mine, the entropy and weight values of each discriminant are calculated according to equations (2) and (3) (Table 3). According to the

Table 2: Discriminant index of water inrush water source.

Water sample label	Water inflow (m^3/h)	Water pressure (MPa)	Water inrush coefficient (MPa/m)	Fault fractal dimension	Water-filled source
W1	1.4	2.5	0.063	1.632	I
W2	1.0	0.8	0.071	1.681	I
W3	43.0	3.5	0.318	1.539	I
W4	0.5	0.7	0.058	1.160	I
W5	2.0	0.6	0.050	1.385	I
W6	0.1	0.6	0.055	1.765	I
W7	3.0	0.2	0.017	1.539	I
W8	3.0	0.4	0.033	1.274	I
W9	20.0	0.6	0.050	1.274	I
W10	7.0	0.6	0.055	1.601	I
W11	30.0	3.2	0.146	1.539	II
W12	40.0	4.3	0.051	1.632	II
W13	30.0	2.0	0.091	1.385	II
W14	35.0	2.0	0.024	1.632	II
W15	15.0	1.2	0.055	1.601	II
W16	20.0	2.6	0.031	1.632	II
W17	45.0	1.0	0.046	1.385	II
W18	25.0	2.6	0.031	1.632	II
W19	25.0	1.8	0.021	1.632	II
W20	40.0	1.9	0.022	1.632	II
W21	3.0	1.9	0.022	1.632	II

calculation results in Table 3, the weights of water inflow and water pressure are 0.6367 and 0.2626, respectively, and the weight ratio of the two indexes is 89.93%, which is much larger than the other two indices, indicating that the water inflow and water pressure have a greater impact on the water-filled source identification in the study area.

4.2. Calculation of Comprehensive Relative Membership Degree. A relative difference function model was established based on the 21 water samples of the two types of water sources, and the data points with large deviations in each index data were removed before analysis. The midpoint M of the model is the average value of each discriminant index of the water source, i.e., $\bar{x}$, and the matrix M can be obtained. The values of a and b are calculated based on the mean-standard deviation method. If the standard deviation is s, then $[a, b] = [\bar{x} - 0.5s, \bar{x} + 0.5s]$ and $[c, d] = [\bar{x} - 1.1s, \bar{x} + 1.1s]$. When $c < 0$, then make $c = 0$, and matrices AB and CD of $[a, b]$ and $[c, d]$ can be calculated accordingly.

$$AB = \begin{bmatrix} [4.75, 11.45] & [0.543, 1.553] & [0.036, 0.118] & [1.39, 1.58] \\ [25.97, 35.04] & [1.8, 2.72] & [0.033, 0.07] & [1.52, ,1.62] \end{bmatrix},$$
$$CD = \begin{bmatrix} [0.73, 15.47] & [0, 2.159] & [0, 0.167] & [1.276, 1.694] \\ [20.523, 40.477] & [1.248, 3.272] & [0.011, 0.092] & [1.46, 1.68] \end{bmatrix}, \quad (11)$$
$$M = \begin{bmatrix} 8.1 & 1.048 & 0.077 & 1.485 \\ 30.5 & 2.26 & 0.052 & 1.570 \end{bmatrix}.$$

According to the calculated matrices AB, CD, and M, the relative position of the index value of the sample in Figure 1 and M can be discriminated, and the relative difference degree can be calculated according to a suitable algorithm in formulas (8) and (9) of the index value. Then the relative membership degree can be obtained by substituting the

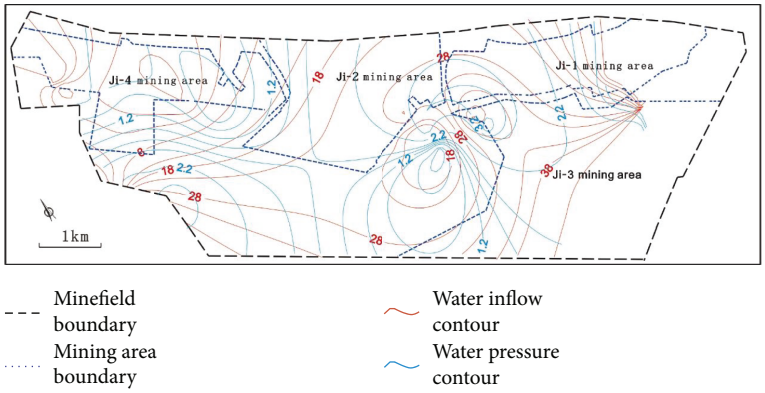

Figure 3: The contour map of water inflow and water pressure.

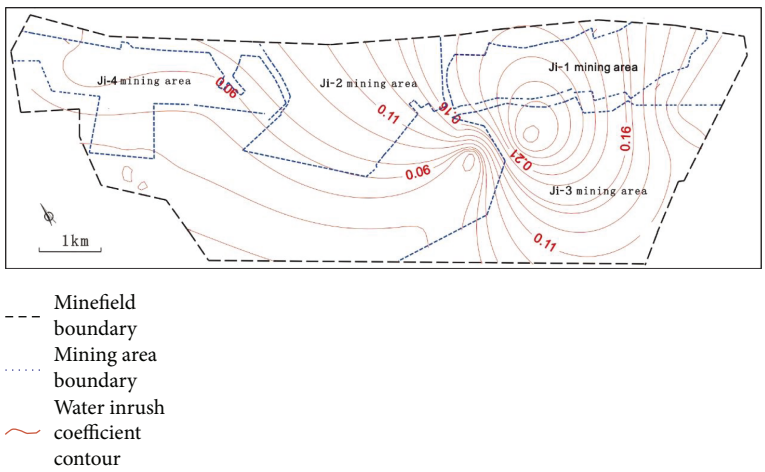

Figure 4: The contour map of water inrush coefficient.

Table 3: Calculation results of entropy and weight values.

Category	Discriminant index			
	Water inflow	Water pressure	Water inrush coefficient	Fault fractal dimension
Entropy	0.7681	0.9044	0.9639	0.9994
Weight	0.6367	0.2626	0.0990	0.0017

transformed formula (7). Finally, according to formula (10), the comprehensive relative membership degree of each sample for different levels of the standard samples can be obtained, and the water-filled source can be identified according to the principle of maximum membership degree.

5. Discrimination of Water-Filled Source

5.1. Water Source to Be Identified. The identification data of the water burst holes for the 7 water sources to be identified in the No. 13 Mine are shown in Table 4.

According to the calculation steps listed in Section 4.2, water sample Z1 is taken as an example to explain the process of solving the comprehensive relative membership degree.

As shown in Table 4, the discrimination parameter of water sample Z1 is $t_{1j} = [25,1.3,0.055,1.294]$, and t_{11} is compared with AB_{1h}, CD_{1h}, and M of the standard water sample matrix in formula (10).

$$AB_{1h} = [[4.75, 11.45][25.97, 35.04]],$$
$$CD_{1h} = [[0.73, 15.47][20.523, 40.477]], \quad (12)$$
$$M = [8.1, 30.5].$$

According to the position of each parameter value of t_{1j} in the established relative difference function model, the relative difference degree is calculated by using formulas (8) and (9). Since $t_{11} = 25$, $c_{11} = 0.73$, and $d_{11} = 15.47$, i.e., $t_{11} \notin [c_{11}, d_{11}]$. According to this, $D_A(u) = -1$, and then according to formula (7), the relative membership degree $\mu_A(u) = 0$ can be calculated, so that we can get the relative

Table 4: Parameters of water sample to be identified.

Water sample label	Water inflow (m^3/h)	Water pressure (MPa)	Water inrush coefficient (MPa/m)	Fault fractal dimension
Z1	25.0	1.3	0.055	1.294
Z2	22.0	0.6	0.027	1.385
Z3	35.0	1.0	0.046	1.385
Z4	60.0	2.0	0.091	1.385
Z5	30.0	1.9	0.022	1.632
Z6	15.0	1.4	0.017	1.632
Z7	30.0	2.2	0.026	1.632

Table 5: Identification results of water inrush.

Water sample label	Comprehensive relative membership degree		Discriminant result	Actual type
	Class I water	Class II water		
Z1	0.149	0.249	II	II
Z2	0.150	0.190	II	II
Z3	0.170	0.310	II	II
Z4	0.101	0.106	II	II
Z5	0.010	0.930	II	II
Z6	0.080	0.003	I	II
Z7	0.001	0.980	II	II

membership degree of t_{1h} at all levels. The following matrix is the relative membership degree matrix of water sample Z1.

$$U(Z1) = \begin{bmatrix} 0 & 0.41 \\ 0.8495 & 0.047 \\ 0.7256 & 0.93 \\ 0.08 & 0 \end{bmatrix}. \quad (13)$$

For formula (10), generally p is 1 (Haiming distance) and α is 2, and the comprehensive membership degree of water sample Z1 for different aquifers can be calculated [18].

$$u_{1h} = (0.149, 0.249). \quad (14)$$

From the above discussion, we find that the comprehensive relative membership degree of water sample Z1 to class I water and class II water is 0.149 and 0.249, respectively. According to the principle of maximum membership degree, water sample Z1 belongs to class II water, which is consistent with the actual situation.

5.2. Discriminant Result Analysis. Referring to the steps in Section 5.1, the water-filled sources of remaining water samples to be identified are analyzed. The comprehensive relative membership degree matrix is as follows. The recognition results are shown in Table 5. According to the results of the table, except for water sample Z6, the water-filled source of other water samples was accurately identified, and the accuracy rate was 85.71%, which belongs to a higher level.

The weight values of each index calculated by the entropy weight method remain unchanged. Formula (10) uses four different parameter transformation combinations, $\alpha = 1$, $p = 1$; $\alpha = 2$, $p = 1$; $\alpha = 1$, $p = 2$; and $\alpha = 2$, $p = 2$, to calculate the comprehensive relative membership degree of the water sources to be identified in the No. 13 Mine. The results are shown in Table 6.

According to Table 6, after changing the parameters of the fuzzy variable set model, the comprehensive relative membership of each water sample for aquifers of different levels changes, but it is basically stable in a small range, indicating that the calculation method used in this paper is more reliable. When $p = 1$ and $\alpha = 2$, the recognition accuracy of model parameters is higher than that of other parameters, indicating that the entropy weight-fuzzy variable set method is suitable for water-filled source identification under this parameter combination.

5.3. Discussion. The authors believe that the accuracy of the water-filled source is determined by the representativeness and reliability of the model.

The representativeness of the established water-filled source identification model is related to the typical degree of the selected impact factor. If the impact factors are more typical, the recognition results are more consistent with the actual situation. Therefore, it is necessary to systematically analyze the hydrogeological conditions and mining conditions in the study area and select key identification factors to ensure the representativeness of the model.

The reliability of the model is closely related to the number of samples of the impact factors. The more the number of samples, the more obvious the marker characteristics indicating the change of the impact factor, the easier it

Table 6: Recognition results under different parameters.

Water sample label	$a = 1, p = 1$		$a = 2, p = 1$		$a = 1, p = 2$		$a = 2, p = 2$	
	I	II	I	II	I	II	I	II
Z1	0.295	0.365	0.149	0.249	0.268	0.38	0.119	0.274
Z2	0.187*	0.123*	0.150	0.190	0.191*	0.132*	0.053*	0.023*
Z3	0.312	0.401	0.170	0.310	0.287	0.443	0.140	0.388
Z4	0.251	0.256	0.101	0.106	0.225	0.238	0.078	0.090
Z5	0.086	0.790	0.010	0.930	0.086	0.825	0.009	0.957
Z6	0.232*	0.050*	0.08*	0.003*	0.224*	0.054*	0.077*	0.003*
Z7	0.036	0.877	0.001	0.980	0.049	0.893	0.003	0.986

Note: $*$ is the result of the error recognition.

is to quantify, and the more reliable it is to identify. Therefore, it is necessary to fully collect and comprehensively monitor the information of various water-filled sources, establish a sound data management system, and lay a foundation for establishing a reliable identification model.

6. Conclusion

(1) Four factors, such as water inflow, water pressure, water inrush coefficient, and the fractal dimension of faults, are taken as the evaluation indices to judge the water-filled source, and the weights of each index are calculated by the entropy weight method. The weights of water inflow and water pressure are 63.67% and 26.26%, respectively, which are much higher than the other two indicators, indicating that they have a greater impact on the identification of the water-filled sources

(2) Based on the drilling data of the 21 target strata for the No. 13 Mine reaching the thin layer of the coal seam and the thick layer of limestone, respectively, the fuzzy variable set theory was used to construct a model to identify the water-filled source and applied to the 7 water sources to be identified. The accuracy rate is 85.71%, which provides a strong support for the reliable identification of water-filled sources

(3) For the No. 13 Mine, the accuracy of the entropy weight-fuzzy variable set is higher when the distance parameter p is 1 and the optimization criterion parameter α is 2 in the water-filled source model of the coal seam floor

Data Availability

Data for underlying the findings of the study may therefore be accessed directly from the author or Professor Wang or from the No. 13 Mine of Pingdingshan Coal Co. Ltd.

Disclosure

This study was undertaken as part of a master's study by the first author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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