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Research on Evaluation of Water Inrush Risk of Coal Seam Roof Based on Weighting of FAHP-CRITIC Combination

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Abstract: *Mine water damage, as one of the major types of mine disasters, occurs frequently, causes severe damage and incurs serious economic losses. In recent years, efforts to prevent and control water hazards have been continuously strengthened, but the situation of mine water hazard prevention and control remains severe. Water inrush hazard assessment is a fundamental prerequisite and important foundation for water hazard prevention and control in mines and for achieving safe mining. As a fundamental task in the prevention and control of roof water hazards in mines, the evaluation results directly determine the scientificity, rationality and effectiveness of the water prevention and control measures taken. In this study, 10 key control indicators were selected to construct an evaluation index system for the water inrush hazard of the coal seam roof aquifer, based on the fuzzy analytic hierarchy process -CRITIC method combined weighting to propose an evaluation model for the water inrush hazard of the coal seam roof, and the zoning results of the water inrush hazard of the coal seam roof were obtained through spatial superimposed coupling calculation. The results show that most of the study area belongs to the relatively safe zone; The dangerous areas are mainly distributed in the northwest region and are affected by various factors such as the thickness of the aquifer and the permeability coefficient; The more dangerous areas are located in the southeast and are more affected by faults; Most of the central area is a transitional zone with a lower risk of water inrush. Verification of the influencing factors, evaluation methods, and evaluation results indicates that the evaluation results are consistent with the actual situation of the mine and are reliable, which can provide guidance for the prevention and control of mine water hazards.*

Keywords: *Roof inrush, FAHP-CRITIC, combined subjective and objective, weighting assessment of inrush hazard*

1. Introduction

Coal resources, as an important basic energy source, have greatly guaranteed China's energy security and socio-economic stability[1]. However, as China's coal mining continues to extend to the kilometer level underground, the triple superimposed effect of high water pressure, high ground stress and complex hydrogeological structure in deep strata has become increasingly prominent[2], and the risk of water inrush disasters and the difficulty of prevention and control have significantly increased, which has become a prominent challenge threatening the safe production of coal mines. Over nearly 30 years from the 1980s to 2010, about 250 pairs of mines were flooded, killing nearly 9,000 people and causing direct economic losses of more than 35 billion yuan[3]. From 2012 to 2023, there were 118 fatal flood accidents in coal mines across the country, killing more than 450 people[4]; The number of accidents accounted for 3.99% of all types of accidents in coal mines during the same period, and the number of deaths accounted for 14.02%, which was more than 3.5 times more dangerous than other types of accidents. All along, mine water accidents have been characterized by frequent occurrences and high mortality rates; Although significant progress has been made in hydrogeological disaster prevention and control technologies in recent years, major water inrush accidents have not been fundamentally curbed[5]. Due to the suddenness of roof water damage, once inrush occurs, it poses a great threat to the mine and sometimes even submerges[6] the working face and the entire mining area. Therefore, it is of great engineering value and practical significance to predict and evaluate the risk of water inrush in mines by using scientific and effective methods and to formulate targeted prevention and control measures in advance.

At present, domestic and foreign scholars' research on the risk of mine water inrush mainly focuses on key index method, comprehensive index method and numerical analysis method, etc. Among them, the single indicator method, based on the unit water inflow data of the mine borehole, judges the water inrush hazard according to the "water abundance grade standard of aquifer" in the "Regulations on Water Prevention and Control in Coal Mines"; The inrush coefficient method, etc., only takes into account two factors: water pressure and the thickness of the aquifer, while ignoring the influence of other inrush factors on the inrush of the coal seam floor[7]. Although these methods are simple and intuitive, they are difficult to fully reflect the complex mechanism of the coupling of multiple factors such as geological structure, water-richness of the aquifer, and water-blocking capacity of the aquifer[8].

The analytical method is based on the theory of groundwater dynamics and uses mathematical models and analytical formulas to predict the likelihood of water inrush and the volume of water inflow. The method generalizes complex well and tunnel systems into mathematical models and uses analytical solutions for calculation[9]. Zhou Quanchao used the large well method to predict the water inflow of the mine, and the results showed that the predicted water inflow differed by 607.5% from the actual water inflow[10]. Hou Enke et al.[11], taking Wenjiapo Coal Mine in Binchang mining area as the engineering background, used the "large well method" as well as different analytical methods such as "vertical infiltration - lateral runoff method" and "water collection corridor method" to predict the water inflow of Wenjiapo Coal Mine. After comparative analysis, it was concluded that the calculation results of the "vertical infiltration - lateral runoff" model were more consistent with the measured values. Numerical simulation techniques[12], by constructing a geomechanic-seepage coupling model, simulate the stress distribution of rock strata, deformation and failure, and changes in the groundwater seepage field during the mining process, thereby identifying potential inwater hazard areas and channels[13]. Hou Fujin[14], Qiu Wenge[15], Lu Xingzhou[16], Cao[17], Li et al[18]. respectively used numerical simulation to study the process of fracture propagation and penetration, the causes of disasters, the formation process and function of inwater channels, etc. This method can dynamically reflect the impact of the mining process, but the model construction is complex, the parameter acquisition is difficult, and the computational cost is high.

The exponential method determines the direction, extent and absolute amount of the impact of changes in each influencing factor on the total index by statistical index . In recent years, scholars have conducted extensive research on the optimization of the main control factors and the determination of their weights. In terms of the optimization of the main control factors, Guo Xinshan[19], Chen Xi[20], Xue Jiankun[21] used the structural fractal dimension as the main control factor, which comprehensively reflects the number, distribution density, scale and dynamic mechanism of the structures, thereby improving the accuracy of the calculation of the weights of each factor. Yan Xin[22] conducted an in-depth analysis of the hydrogeological conditions in the study area and, in combination with the research results on the hazard of aquifer from the North China coalfield, determined the main control factors such as the thickness of the aquifer, the rate of aquifer core recovery, the unit water inflow of the aquifer from the aquifer, and the water pressure on the aquifer from the aquifer for the assessment of the hazard of aquifer. To quantify the differences in the impact of different indicators on the risk of water inrush, precise weighting is the first step in building a reliable evaluation model[23]. The commonly used weighting methods are deterministic weighting and fuzzy weighting. Deterministic weighting is divided into subjective weighting and objective weighting. Subjective weighting methods rely too much on prior experience and assume that the indicators are independent of each other, making it difficult to quantify the coupling relationship among the factors[24]; Objective weighting methods, though objective, rely solely on the degree of data dispersion for weighting, which often leads to weight polarization due to excessive data variance, resulting in evaluation results deviating from hydrogeological reality[25]. Shi Longqing et al[26]. proposed the entropy weight method - analytic hierarchy process coupled weighting method, which effectively addresses the strong subjectivity problem of the traditional AHP method that overly relies on expert experience and provides a new idea for the assessment of water inrush hazard based on multi-source information fusion; Qiu Mei et al[7]. proposed a vulnerability index model based on the combined weighting of fuzzy analytic hierarchy process, entropy weight method and deviation sum of squares method, which has a good prediction effect and provides a new idea for the evaluation of water ingusation hazard of coal seam floor. Tian Yi et al[27]. constructed mine fire hazard assessment model, working face risk

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assessment model and ventilation stability assessment model through the coupling model of analytic hierarchy process (AHP - TOPSIS), which improved the prediction accuracy by more than 20% compared with the single index analysis method. In recent years, fuzzy weighting methods such as machine learning, fuzzy mathematics, and membership theory have been applied. Although these methods have improved prediction accuracy by their nonlinear mapping capabilities, their "black box" attributes mask the intrinsic physical and mechanical mechanisms of water inundation, making it difficult to directly reveal the disaster-causing mechanism of water inundation[28].

Therefore, the index evaluation method has outstanding advantages such as simple calculation, easy data access, strong operability, flexible construction of the evaluation system, reasonable determination of index weights in combination with the actual situation on site, intuitive and clear quantification results, and precise classification of danger levels. The method is widely applicable, and the evaluation results are both scientific and practical.

The study area of this paper, Jinjie mining Area, is located in the Ordos Basin division of the North China Strata Area. Above the main mining coal seam, there are weathered bedrock fissure aquifers and loose pore aquifers, which are extremely water-rich. The clay aquiclude between the two aquifers is deposited thinly, and in some local areas it is even completely extinguished and absent; In other sections, the bedrock is thin, and the coal seam mining is prone to cracking and damaging the roof aquifer, making the water-filled hydrogeological conditions of the mine even more complex. Based on the targeted construction of the mine water inrush hazard assessment index system, this paper proposes a mine water inrush hazard assessment method based on the combined subjective and objective weighting of the fuzzy analytic hierarchy process (FAHP) and the CRITIC method and applies it to the study area. This method couples subjective and objective weights based on the principle of minimum discriminant information to construct a mine water indraft hazard assessment model, which takes into account both the inherent characteristics of expert opinions and data, as well as the uncertainty and fuzziness of the evaluation process.

2. Research Methods

2.1. Overview of the study area

Jinjie well Field is located in Yaozhen Township and Majia Ta Township, Shenmu County, Yulin City, Shaanxi Province. This area is located in the northwest inland and has a typical temperate semi-arid continental climate. The topography of the study area is generally higher in the north and lower in the south, higher in the east and lower in the west, and is dominated by wind-sand landforms. Perennial gullies such as the Qingcaojie gully and Heze Gully are developed within the well field.The overview map of the study area is shown in Figure 1

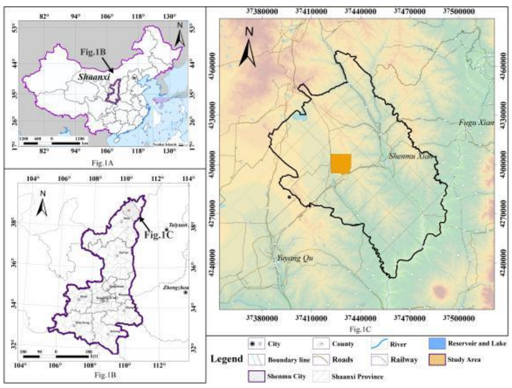

Figure 1: Overview map of the study area.

The area of the mining field is 141.82 square kilometers. The stratum is flat, and the overall trend is a monocline structure with an inclination of less than 1°, gradually sloping towards the northwest. There is no folding or magmatic activity in the field. Only small, wide, wavy undulations and three high-angle normal faults are developed. The coal-bearing strata in the area are the Yan 'an Formation, which contains 13 coal layers, including 7 exploitable coal seams. The coal seams are buried relatively shallowly, and the main mining coal seams are stable. The design adopts inclined shaft development and sets mining levels for different coal groups. The coal seam in study area 3-1 is mainly medium-thick, with little variation in thickness and a simple structure; The burial depth is generally 70

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to 120m, the recoverable area of the entire region is 129.19km^2, and the coal thickness is 2.58 to 3.61m. The Jura weathered bedrock aquifer is a direct water source for the 3-1 coal seam, with a unit water inflow of 0.0402-0.666L/S/m.

2.2. Construct the evaluation index system

This study comprehensively considers the geological and hydrological factors influencing the risk of water inrush. The necessary and sufficient condition for water filling in coal seam roof is that the water-conducting fracture zone of the roof formed by coal seam mining communicates with the overlying directly filled aquifer, and the water-richness of the aquifer reflects the water source situation of the coal seam filling, and the safety of the fracture reflects the situation of the water channel of the coal seam filling. Ultimately, 10 indicators were selected from both the water-richness of the aquifer and the safety of the fracture to evaluate the risk of water inrush from the roof as shown in Figure 2.

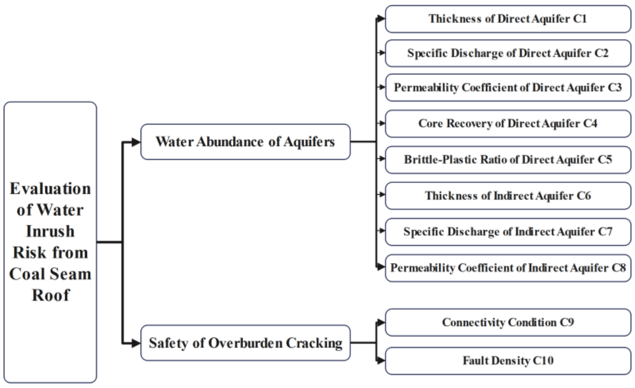

Figure 2: Evaluation Index system.

2.2.1. Aquifer abundance

(1) Aquifer thickness

Aquifer thickness is an important factor affecting the abundance of aquifers and is closely related to the migration and occurrence of groundwater. The thickness of the aquifer directly determines the amount of water stored in the water-bearing strata and is a fundamental indicator for evaluating the potential water supply pressure of the aquifer. When other hydrogeological conditions are relatively similar, the thicker the strata aquifer, the stronger the water-richness of the aquifer, the greater the amount of emergent water that can be released, and the higher the risk of emergent water[29]. When the aquifer is located within the range of the roof fall zone or the floor failure zone, a larger aquifer thickness means a greater potential amount of groundwater flowing into the mine after exploitation, and the consequences of the water inrush are more serious[30].

(2) Unit water inflow

Unit water inflow reflects the permeability of the water-bearing medium in the aquifer and whether the replenishment conditions are good. It is a key indicator factor[31] for water inrush. The size of the unit water inflow directly determines the water output capacity per unit area of the aquifer and is an important parameter for predicting the water inflow and the scale of water inrush in the mine.

(3) Permeability coefficient, core-taking rate, brittle-plastic ratio

The permeability coefficient is a quantitative indicator of the water permeability of rocks, directly reflecting the water permeability of rocks or strata. The greater the permeability coefficient, the stronger the water permeability of rocks, the stronger the water penetration capacity of rock fractures, and the better[29] the connectivity of water channels. The core-taking rate indirectly indicates the integrity of the rock mass and the degree of fracture development. The lower the core-taking rate, the higher the degree of rock mass fragmentation, the more fully the fractures develop, and the greater the possibility of water channel formation. The brittle-plastic ratio is associated with the potential for formation of structural fractures and the quality of water-conducting channels. The higher the specific gravity of the brittle rock strata, the greater the potential for formation of structural fractures in the rock strata, and the easier it is to develop[32] water-conducting channels. These three indicators together form the basic evaluation system characterizing the water-richness characteristics of aquifers and the degree of development of water-conducting channels, and are comprehensive parameters[33] that cannot be ignored in the

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assessment of the risk of water inundation.

2.2.2. Bursting safety

(1) Conduction of the water-conducting fracture zone

The subsidence zone and the water-conducting fracture zone caused by coal seam mining are the main water-conducting channels for the old air water in the mine. The difference between the height of the water-conducting fracture zone and the thickness of the overlying rock in the upper old void area reflects to some extent the hydraulic connection between the upper old void water and the current coal mining face. The smaller the difference, the greater the possibility that the mining fissures will conduct the upper old void water. In this study, based on the mechanical properties of the rocks in this area, the calculation formula for the height of the water-conducting fracture zone of medium-hard rock types in layered mining of thick coal seams as stipulated in the Code for the setting of coal pillars in buildings, Water bodies, Railways and Major Roadways and the mining of compressed coal was adopted.Figure 3 and Figure 4 present the contour lines of coal-seam thickness and overlying bedrock thickness, respectively.

(2) Fault density

Fault structures are the main water channels in mines. In fault-affected zones, fractures are often well developed and have strong water conductivity, making them the main water channels for old air in the mine.Figure 5 shows the fault distribution map of the study area.

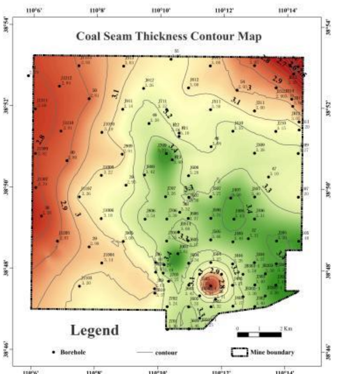


Figure 3: Contour map of coal layer thickness.

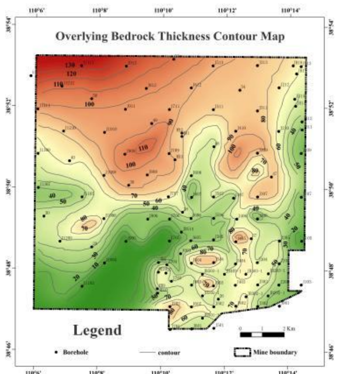


Figure 4: Contour map of equal thickness of overlying bedrock in coal seams.

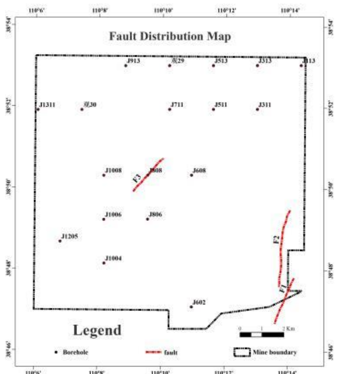


Figure 5: Schematic diagram of fault distribution.

2.3. FAHP-CRITIC combined weighting method

This study combines the Fuzzy Analytic Hierarchy Process (FAHP) with the CRITIC method to achieve complementary adjustment of subjective and objective weighting, effectively reduce the bias caused by human subjective judgment, and enhance the accuracy and stability of index weight calculation. FAHP can solve the problem through a hierarchical structure, which is logically clear but has a certain degree of uncertainty and subjectivity. CRITIC is an objective weighting method that can take into account both the contrast intensity of indicators and the conflict between indicators, and can fully reflect the relationship between indicators.Combining the advantages of both methods, the subjective weights of each indicator are first calculated based on the FAHP. Subsequently, the CRITIC method is adopted to compute the objective weights of each indicator. Finally, the minimum discrimination information principle is utilized to integrate the subjective and objective weights.

2.3.1. Subjectively weighting based on FAHP

(1) Construct a fuzzy complementary judgment matrix. Construct a fuzzy complementary judgment matrix, where $A=(a_{ij})_{n\times n}\ a_{ij}+a_{ji}=1(i\neq j),a_{ii}=0.5$.Compare and assign values to each pair of indicators based on the 0.1-0.9 scale method.

(2) Construct the fuzzy consistency matrix. S_i is the sum of the elements in the row of matrix A[34].

(3) Calculate subjective weights. Based on the fuzzy consistent judgment matrix weight ranking formula[35], the weight of the first indicator is W_i^F .

At that time, with the increase of ∂, the maximum weight value in the element was decreasing, and so was the difference in weights.

2.3.2. Objective weighting based on the CRITIC method

The CRITIC method can take into account the influence[36] of the degree of variation within the indicators and the degree of association between the indicators on the weights of the indicators. It comprehensively measures the objective weights of indicators based on the contrast strength of the evaluation indicators and the conflict between indicators. Contrast intensity is measured by the size of variation within each indicator, expressed in the form of standard deviation. The larger the standard deviation, the greater the amount of information corresponding to the indicator and the higher the weight; Conflict reflects the characteristics of the correlation between the influencing factors, expressed in terms of correlation coefficients, with larger correlation coefficients having lower weights.

(1) Calculation of the variability of evaluation indicators.

$$\sigma_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(nx_{ij} - n\bar{x}_j)^2} \tag{1}$$

In the formula, the mean of $j = 1,2,\cdots,n; n\bar{x}_j - nx_{ij}\ (i = 1,2,\cdots,n)$.

(2) Evaluation index conflict calculation.

$$R_j = \sum_{k=1}^{m}(1 - \rho_{jk}) \tag{2}$$

$$\rho_{jk} = \frac{\sum_{i=1}^{n}(nx_{ij} - nx_j)(x_{ik} - nx_k)}{\sqrt{\sum_{i=1}^{n}(nx_{ij} - nx_j)^2 \sum_{i=1}^{n}(nx_{ik} - nx_k)^2}} \tag{3}$$

In the formula, $j, k = 1,2,\cdots,n.$

(3) Calculation of objective weights for evaluation indicators.

$$w_j = \frac{\sigma_j R_j}{\sum_{k=1}^{m}\sigma_k R_k} \tag{4}$$

2.3.3. Combinatorial weighting is based on the principle of minimum discriminant information

To fully integrate the influence of subjective and objective weights on the evaluation results, this study uses the principle of minimum discriminant information to reduce the subjective and objective weight factors in the combined weights[37], and the expression is

$$\begin{cases} \min \omega = \sum_{i=1}^{n}\left(\omega_j \ln \frac{\omega_j}{W_z^j} + \omega_i \ln \frac{\omega_j}{\omega_k^j}\right) \\ s.t. \sum_{i=1}^{n}\omega_j = 1 \quad \omega_j \ge 0 \end{cases} \tag{5}$$

To find the combination weights corresponding to this minimum combination factor, the expression is

$$\omega_j = \frac{\sqrt{\omega_z^j \omega_k^j}}{\sum_{i=1}^{n}\sqrt{\omega_z^j \omega_k^j}} \tag{6}$$

In the formula: ω_j is the combined weight of the index j; ω_z^j represents the FAHP weight of the indicator j; ω_k^j represents the CRITIC weight of the metric j.

2.4. Overlay analysis

In this study, based on the subject maps of each index generated by GIS, the combined weighting weights were superimposed with each index to obtain the risk model of water inrush from the coal seam roof:

$$VI = \sum_{k}^{n} W_k f_k(x, y) \tag{7}$$

Here, VI is the risk index; W_k is the weight of the main control factor; $f_k(x, y)$ for the quantified value of the first master factor k; (x, y) for geographic coordinates; n is the number of master factors.

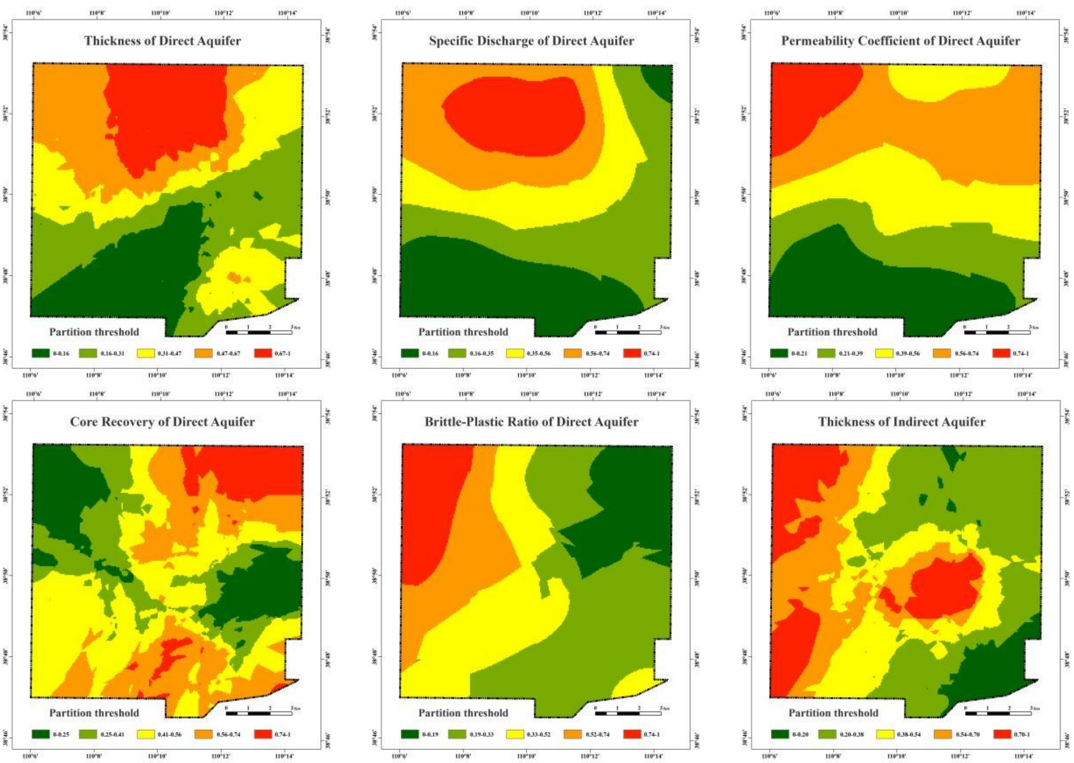
3. A model for assessing the risk of water inrush from coal seam roof based on combined weighting of FAHP-CRITIC

3.1. Evaluation results of a single index

Based on the constructed evaluation index system, ARCGIS software was used to interpolate and normalize the evaluation indicators, and the results are shown in the following figure.

3.1.1. Results of aquifer enrichment

The thickness of the direct aquifer in the study area was thinner in the south and east, and thicker in the rest of the sections. The entire group of rock strata is strongly weathered, with loose, soft and fragmented cores. A few calcareous cemented sandstones have high hardness and well-developed fractures, providing good permeability and water storage conditions. The unit water inflow of the direct aquifer is between 0.0402 and 0.666L/S.m. The permeability coefficient of the direct aquifer is between 0.142 and 0.882m/d, and the water richness is moderate; The core-taking rate of the coal seam shows the characteristics of being large in the northwest and Middle East, and smaller in the southwest to northeast band-like distribution area; The brittle-plasticity ratio of the direct aquifer is distributed in a north-south strip, decreasing from west to east. Indirect aquifers are thicker in the western and central regions and thinner in other regions; Indirect aquifers have the smallest unit water inflow in the central region and increase in sequence from the center to the periphery; The northwest region has a maximum; The permeability coefficient of the indirect aquifer is at its maximum in the northwest and southeast regions and decreases in a southwest-northeast band towards the middle.The evaluation results of water-richness for aquifer are as shown in Figure 6.



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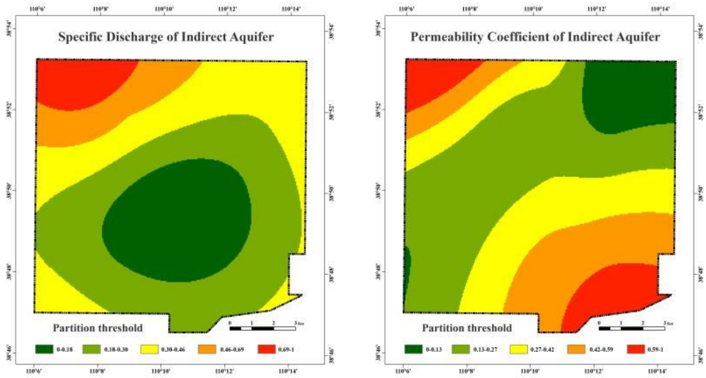

Figure 6: Thematic map of water abundance evaluation indicators of aquifers.

3.1.2. Bursting safety results

The maximum height of the water-conducting fracture zone in the 3-1 coal seam in this area was calculated to be 51.36 to 68.48m. This formula was used in the study as the basis for determining whether the water-filled aquifer was conductive in the water-conducting fissure zone.Table 1 lists the zoning criteria for caving-fracture safety.

$$W_{\text{fracture safety}} = H_{\text{overlying}\,thickness} - H_{\text{height of the water-conducting fracture zone}} \tag{8}$$

Table 1: Breakout Safety zoning.

Serial Numbers	W Crack safety	Crack security partitioning
1	W>5	Safe zone
2	0<W<5	Danger Zone
3	W<0	Fall zone

The fault density index shows larger and maximum values in the central and southeastern regions, with only three high-angle normal faults F1, F2, and F3 developing.The evaluation results of caving-fracture safety are as shown in Figure 7.

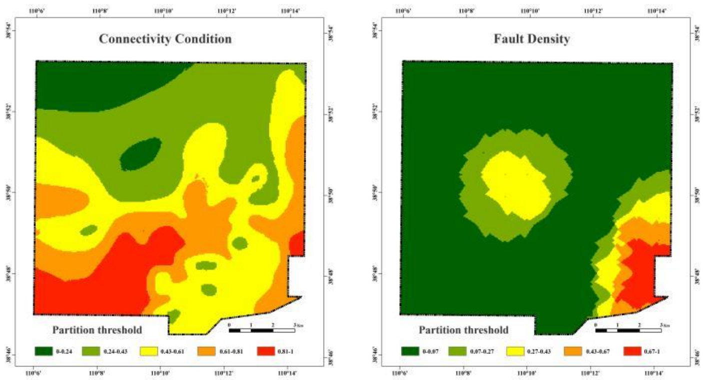

Figure 7: Thematic map of rupture safety evaluation indicators.

3.2. Combined weighting results

3.2.1. Subjective Empowerment

Based on consulting experts and using the fuzzy analytic hierarchy process, construct fuzzy complementary judgment matrices A, B1, B2.

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$$A=\begin{bmatrix}0.5 & 0.58\\0.42 & 0.5\end{bmatrix}\quad B_1=\begin{bmatrix}0.5 & 0.56 & 0.44 & 0.46 & 0.5 & 0.62 & 0.42 & 0.74\\0.44 & 0.5 & 0.28 & 0.36 & 0.5 & 0.52 & 0.4 & 0.44\\0.56 & 0.72 & 0.5 & 0.52 & 0.4 & 0.52 & 0.38 & 0.48\\0.54 & 0.64 & 0.48 & 0.5 & 0.52 & 0.42 & 0.5 & 0.46\\0.5 & 0.5 & 0.6 & 0.48 & 0.5 & 0.58 & 0.54 & 0.56\\0.38 & 0.48 & 0.48 & 0.58 & 0.42 & 0.5 & 0.38 & 0.56\\0.58 & 0.6 & 0.62 & 0.5 & 0.46 & 0.62 & 0.5 & 0.66\\0.26 & 0.56 & 0.52 & 0.54 & 0.44 & 0.44 & 0.34 & 0.5\end{bmatrix}\quad B_2=\begin{bmatrix}0.5 & 0.44\\0.56 & 0.5\end{bmatrix}$$

After calculation, the subjective weighting index weights are derived.

3.2.2. Objective weighting results

The index variability and conflict were calculated based on Formula (1-3), and the results are as shown in the table 2 below:

Table 2: Indicator Variability and Conflict.

Index	Variability	Conflict
Thickness of Direct Aquifer C1	0.23683038	7.869373344
Specific Discharge of Direct Aquifer C2	0.269802935	7.662824997
Permeability Coefficient of Direct Aquifer C3	0.227018006	7.908113647
Core Recovery of Direct Aquifer C4	0.196634551	10.9161359
Brittle-Plastic Ratio of Direct Aquifer C5	0.216036455	7.822414061
Thickness of Indirect Aquifer C6	0.210884523	9.159236424
Specific Discharge of Indirect Aquifer C7	0.175779164	7.609089613
Permeability Coefficient of Indirect Aquifer C8	0.176606334	9.37278585
Connectivity Condition C9	0.223838025	11.92083015
Fault Density C10	0.191252949	9.564803174

Using Formula (4), the final weighting results of the CRITIC method are obtained.

3.2.3. Combined weighting results

The subjective and objective weights were combined and weighted using the idea of minimum discriminant information, and the results are shown in the table 3 below.Figure 8 presents the weight comparison of evaluation indicators.

Table 3: Results of Combined Weight Assignment.

Index	FAHP	CRITIC	Combined
Thickness of Direct Aquifer C1	0.0698	0.0982	0.0856
Specific Discharge of Direct Aquifer C2	0.0621	0.1089	0.0850
Permeability Coefficient of Direct Aquifer C3	0.0683	0.0946	0.0831
Core Recovery of Direct Aquifer C4	0.0681	0.1131	0.0907
Brittle-Plastic Ratio of Direct Aquifer C5	0.0700	0.0890	0.0816
Thickness of Indirect Aquifer C6	0.0654	0.1017	0.0843
Specific Discharge of Indirect Aquifer C7	0.0727	0.0705	0.0740
Permeability Coefficient of Indirect Aquifer C8	0.0636	0.0872	0.0770
Connectivity Condition C9	0.2162	0.1406	0.1802
Fault Density C10	0.2438	0.0964	0.1585

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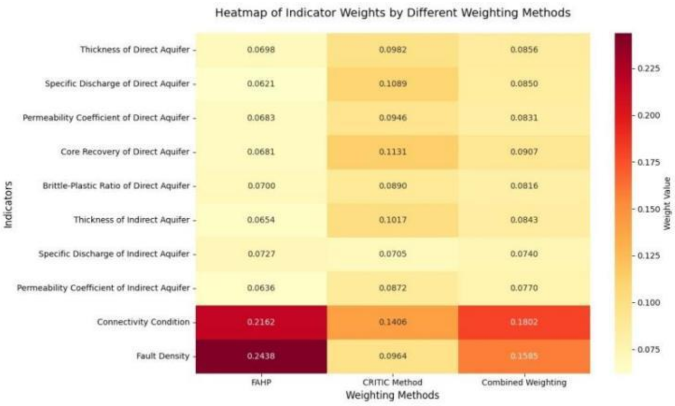

Figure 8: Comparison chart of Weights of evaluation indicators.

3.3. Water Inrush Hazard zoning

Based on the above superimposed analysis formula, construct the inrush hazard index as follows:

$$VI = \sum_{k}^{n} W_k f_k(x,y) = 0.0856 f_1(x,y) + 0.0850 f_2(x,y) + 0.0831 f_3(x,y) + 0.0907 f_4(x,y) + 0.0816 f_5(x,y) + 0.0843 f_6(x,y) + 0.0740 f_7(x,y) + 0.0770 f_8(x,y) + 0.1802 f_9(x,y) + 0.1585 f_{10}(x,y)$$

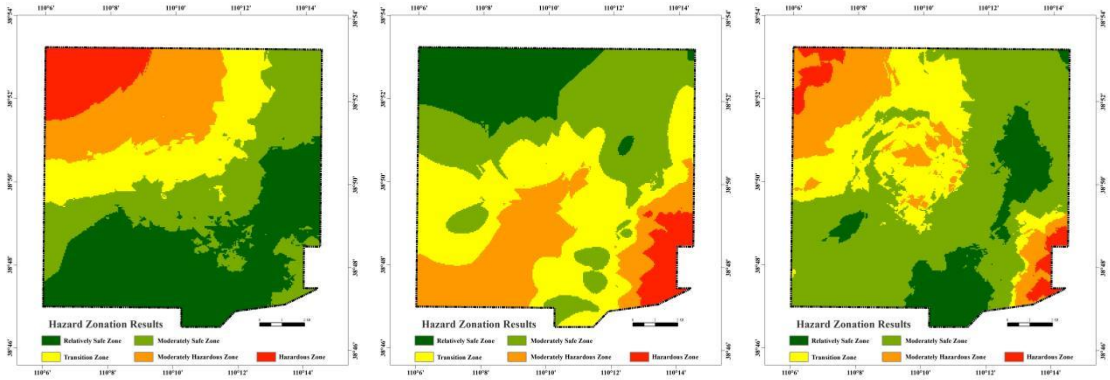

Figure 9: Water inrush hazard zoning diagram.

Calculate the risk index of coal seam water inrush and draw the risk zoning map of coal seam roof water inrush using ARCGIS as shown in Figure 9.

The risk of water inrush in the study area was divided into five levels: relatively safe zone, relatively safe zone, transition zone, relatively dangerous zone, and dangerous zone. The study area as a whole was dominated by the relatively safe zone, and the high-risk areas were distributed in a locally concentrated manner.

Among them, the relatively safe zones are distributed in large areas continuously in the middle, northeast and southwest of the study area, and are partially interrupted by the distribution of the transition zones and the relatively dangerous zones. The relative safety zones are distributed in a blocky and discrete manner, mainly concentrated in the eastern, southern and central parts of the study area. The relative safety zones in the southeast and northeast are larger in scale, and there are small relative safety zones in the west of the middle. The transition zone, as a buffer zone between the high-risk and low-risk areas, is distributed in a strip-like pattern along the edges of the dangerous and relatively dangerous areas, and is particularly concentrated in the transition zone between the northwest dangerous area and the central safe area. The overall proportion of the more dangerous and dangerous areas is relatively low, and they are concentrated in the northwest and southeast edges. Among them, the northwest side of the danger zone and the more dangerous zone are contiguous; The danger zone on the southeast side is partially distributed and connects with the more dangerous zone and the transition zone.

Overall, the water inrush hazard zoning in the study area shows a spatial pattern of "the relatively safe zone as the main body, the relatively safe zone and the transitional zone as supplements, and the

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dangerous zone and the relatively dangerous zone concentrated in the marginal zone", reflecting the spatial heterogeneity of the hydrogeological conditions in the study area, and the water inrush risk in the marginal zone is significantly higher than that in the central zone.

4. Verification

4.1. Reliability of Results

To verify the accuracy of the evaluation results, this study selected the Specific Discharge of Direct Aquifer index of the original borehole data as shown in Table 4 and compared it with the evaluation zone where the borehole was located. Based on the measured data of the mine water inflow, the distribution trend of the mine water inflow was studied.

The water abundance of the boreholes was classified in accordance with "Appendix II: Grade Standards for Water Abundance of Aquifers" in the Regulations on Water Prevention and Control in Coal mines. There are a total of 10 boreholes located in the relatively safe and safe areas, all with unit water inflow values ranging from 0 to 1L/(s • m). According to the above classification standards, they are classified as weakly and moderately water-rich, which can prove that the evaluation results are relatively accurate.

Table 4: Original borehole data.

No.	Borehole	Specific Discharge
1	J602	0.040233333
2	J1004	0.0456
3	J1006	0.1284
4	J1205	0.068266667
5	J311	0.172633333
6	J511	0.374466667
7	J113	0.06665
8	J313	0.072133333
9	J513	0.3785
10	Guan29	0.210866667

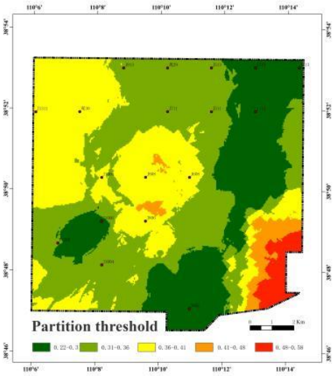
Through the study and analysis of the water inflow records of each working as shown in Table 5 , it was found that there was more water inflow in the northwest and southeast of the mine, and less in the middle. The trend of increasing from west to east and from north to south is consistent with the evaluation results.

Table 5: Records of Water Inflow at the Working Face.

Date / Working Face	106	107	201	202	401	402	403
1/7	480	611	1580		880	356	
1/14	460	561	1526		1080	447	
1/27	470	509	1357		1221	472	
2/9	465	403	1262		1301	566	
2/25	454	381	1175		1320	537	
3/4	387	381	1135		1286	537	
3/14	390	377	1127		1238	510	
3/24		348	1152		1259	510	
4/7		418	475		1160	564	
4/14		411	1118		1135	547	
4/21		425	1141		1096	522	
5/6		442	1254		1412	553	
5/19		465	1238		1391	553	
5/27		476	1349		1462	553	
6/10		473	1340		1671	524	320
6/17		467	1329		1647	524	341
6/24		425	1342	59	1541	486	355
7/1		388	1315	157	1555	522	344
7/8		425	1362	239		541	355

4.2. Method Rationality

To verify the reliability of the combined weighting method used in this paper, the results obtained by the combined weighting method are compared respectively with those obtained by using the FAHP method as shown in Figure 10 and the CRITIC method as shown in Figure 11.



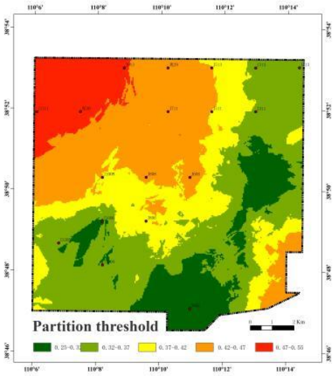


Figure 10: FAHP assessment Results. Figure 11: Assessment Results of CRITIC Method.

As shown in the figure, using the FAHP method for evaluation, there are a total of 5 boreholes in the relatively safe area, among which 3 are weakly water-rich boreholes; The FAHP-CRITIC method was used for evaluation. There were 3 boreholes in the relatively safe area, of which 2 were weakly water-rich boreholes; The combined weighting evaluation accuracy was increased by 10%.

4.3. Correlation of influencing factors

The evaluation indicators are closely related to the risk of water inrush in the mine. This study takes the northwest region of the study area as an example to verify the accuracy of the evaluation results by analyzing the relationship between the evaluation indicators and the evaluation results in this region.

It can be seen from the thematic map of the indicators that all nine evaluation indicators in the northwest area of the study are at high values, indicating that the area has the characteristics of good water storage conditions and permeability and well-developed fractures; At the same time, there are seasonal rivers on the surface, and precipitation seeps down to replenish the aquifer. The area was rated as a hazard zone in the evaluation results, which is consistent with the characteristics reflected by the evaluation indicators, thereby verifying that the evaluation method has certain feasibility and reference value.

5. Conclusions

1) This study examines the two aspects of water abundance and cracking safety of aquifers, Ten indicators were selected to construct an evaluation index system, including the thickness of the Thickness of Direct Aquifer, the unit water inflow of the direct aquifer, the permeability coefficient of the direct aquifer, the core sampling rate of the direct aquifer, the lithologic brittle-plastic ratio of the direct aquifer, the thickness of the indirect aquifer, the unit water inflow of the indirect aquifer, the permeability coefficient of the indirect aquifer, the conduction condition of the water-conducting fracture zone, and the Thickness of Direct Aquifer.

2) Based on the calculation of the subjective and objective weights of the evaluation index using the fuzzy analytic hierarchy process and the CRITIC method, combined weighting was carried out using the principle of minimum discriminant information, taking into account the advantages of the subjective and objective weights, reducing the subjectivity of the weights, and improving the accuracy of combined weighting evaluation by 10%.

3) The index was superimposed through GIS to draw the hazard zoning map of water inundation in the coal seam roof, providing a reference for water prevention and control work.

4) The majority of the area is in the relatively safe zone and the relatively safe zone, with a relatively low risk of water inrush; There are danger zones, more dangerous zones and transitional zones in the northwest, southeast and central regions. The aquifer in the northwest is thick and fissures

are well developed; Faults are distributed in the southeast and central regions, and the geological structure is complex; Precautions should be taken during the construction process.

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