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Evaluation of Water Isolation Capability of Coal Floor Rocks Based on ArcGIS Vulnerability Index Method

Bo Chen[1], Junchao Cui[2], Qi Wang[3], Bo Zhang[4], Xinyi Wang[1, 5, 6, *]

[1]Institute of Resources & Environment, Henan Polytechnic University, Jiaozuo, China

[2]Pingdingshan Tian'an Coal Industry Co. Ltd, Pingdingshan, China

[3]College of Geosciences and Engineering, North China University of Water Resources and Electric Power, Zhengzhou, China

[4]Institute of Energy and Chemical Industry, China Pingmei Shenma Group, Pingdingshan, China

[5]The Central Plains Economic Zone (Shale) of Coal Seam Gas Collaborative Innovation Center in Henan Province, Jiaozuo, China

[6]State Collaborative Innovation Center of Coal Work Safety and Clean-efficiency Utilization, Jiaozuo, China

Email address:

wangxy@hpu.edu.cn (Xinyi Wang)

[*]Corresponding author

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Abstract: The composite strata of coal floor is an important barrier to block the lifting and bursting of thick limestone groundwater into the mining space. Taking J3 and J4 mining areas of Handicapping Coalfield as the object, this paper selected the thickness ratio of plastic brittle rock core recovery rate, composite comprehensive strength, Equivalent water barrier coefficient, Effective water-resistant layer thickness and fault complexity as the main control factors, and determined the comprehensive weight of index factors based on the entropy weight theory. Using the Archaist vulnerability index grading evaluation model, the water-isolation ability of the composite strata in the floor of $J_{16\text{-}17}$ coal seam is quantitatively evaluated and divided into five grades: extremely weak, weak, medium, strong and extremely strong. The results show that the areas with strong and extremely strong water-isolation ability of the composite strata of coal floor account for 38.67% of the total area, the areas with moderate and extremely weak water-isolation ability account for 51.45%, and the areas with weak and extremely weak water-isolation ability account for 9.88%. In this paper, the coupling effect of multiple factors on composite strata is considered, and the quantitative classification and zoning discrimination of water-isolation ability of composite strata is realized, which provides technical support for accurate evaluation of water-inrush risk of coal floor.

Keywords: Composite Rock Formations, Entropy Theory, Geographic Information System (GIS), Vulnerability Index, Classification of Natural Discontinuities

1. Introduction

Permian Carboniferous coal seams are mainly mined in North China type coalfields, which are threatened by water inrush from Ordovician or Cambrian thick limestone aquifer in the floor during mining [1-2]. The coal seam is separated from the underlying Ordovician or Cambrian thick limestone aquifer by a composite rock stratum composed of sandstone, mud stone, thin limestone and thin coal seam. According to the statistics of coal mine water inrush disasters in recent 10 years, there are 106 accidents caused by the poor water separation capacity of rock stratum, resulting in 413 deaths. The water separation performance of coal seam floor has an important impact on mine safety production. Therefore, the quantitative and graded evaluation of the water impermeability of coal seam floor strata will provide a scientific basis for accurately identifying the risk of floor water inrush, predicting and warning floor water damage in real time, and formulating practical water control countermeasures.

At present, many scholars at home and abroad have carried out systematic research on the water separation performance of rock stratum. The water inrush coefficient method commonly used in the risk assessment of water inrush from coal seam floor in China is to characterize the water resisting capacity of rock stratum by the thickness of water resisting layer [3]. Zhou ET AL. [4] combined rock, water and stress to produce water conducting cracks in the water resisting rock layer, reducing its strength and water resistance.

Yang ET AL. [5] analyzed that the interaction between various media of surrounding rock and groundwater makes the rock stratum have the ability of decompression and water separation, so he puts forward the concept of water separation coefficient. Xu ET AL. [6] put forward the "key layer" theory to judge the water inrush from the coal seam floor, and considered that whether the key layer of the coal seam floor is damaged is the core to control whether the water inrush from the coal seam floor occurs. Bai ET AL. [7] believed that carbonate rock with undeveloped karat fissures at the top of Ordovician and Cambrian in North China can be used as a key layer for water separation. Li ET AL. [8] analyzed the performance of composite water resisting key layer of coal floor from two aspects of rock mechanics and mechanics, and concluded that the conduction degree between coal floor and Ordovician aquifer determines its water resisting capacity. Feng ET AL. [9] studied the influence of different ethological characteristics of floor water-barrier layer on its water-barrier performance through experiments and numerical simulation. Chen ET AL. [10-11] studied the characteristics of aquifer and geological structure in view of the stability of water resisting rock mass of coal floor, and concluded that geological structure is an important factor controlling the stability of water resisting rock mass. Zhang ET AL. [12] proposed that the alternation of soft and hard rock layers is a better combination of water separation capacity based on the test of rock layer composite structure and water separation performance. Zhang ET AL. [13] used servo permeability test to compare the permeability of full stress-strain process of soft and hard rocks under different pressure conditions, and obtained that the water resisting rock stratum capacity is related to the interaction between mine and hydraulic pressure. Xu ET AL. [14] proposed and used the structural division method of "three-layer section" of rock stratum to qualitatively evaluate the water barrier capacity of rock stratum from the damage type resisted by each layer in the "three-layer section" and the nature of its own rock stratum. Pang ET AL. [15] evaluated the comprehensive water separation performance on the ethological combination, karat development, spatial distribution and other characteristics of the Ordovician Water Separation rock section. Li ET AL. [16] evaluated the water separation performance of the composite rock stratum based on the ethology at the top of Ordovician limestone, fissure karat filling, drilling water leakage, rock mechanical indexes and permeability test results.

Obviously, the research on the water barrier ability of rock stratum has developed from only considering the thickness of rock stratum at the beginning to comprehensively considering the combined action of multiple factors such as thickness, structure, strength and permeability of rock stratum, which makes the index system for judging the water resistance of floor rock stratum richer and richer. However, due to the lack of field data and the difficulty of accurate quantification of index factors, the research on the coupling effect of mining failure, geological structure, equivalent water barrier and other factors is relatively insufficient. In this study, on the basis of various factors affecting the waterproof performance of coal seam floor, the plastic brittle rock thickness ratio of rock mass, core recovery rate, composite compressive strength, equivalent waterproof coefficient, effective waterproof layer thickness and fault complexity are selected as the index factors. Entropy weight theory is coupled with comprehensive weight, which overcomes the subjective and objective singleness of calculating weight by analytic hierarchy process or grey correlation method. ArcGIS vulnerability index model can realize data management, simulation calculation and rapid mapping of things under the influence of mufti index factors, which lays a foundation for automatic and quantitative evaluation of water resisting capacity of coal seam floor. The expected results can provide technical support for the accurate evaluation of water inrush risk of coal seam floor, and also provide reference for the identification of floor water disasters in other mining areas in North China coalfield.

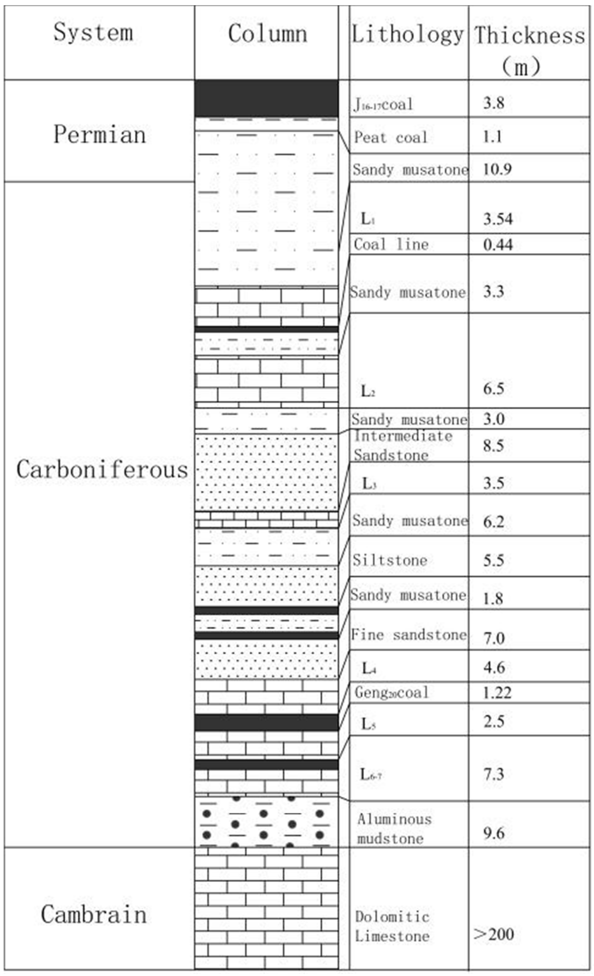

Figure 1. *Column chart of composite floor of J_{16-17} group coal seam.*

2. Geological and Archaeological Survey

2.1. Mine Geology

2.1.1. Stratum Ethology

Pingmei No. 13 coal mine belongs to North China type coal bearing formation. The Carboniferous Taiyuan Formation and Permian Shanxi formation are the main coal bearing strata, and the Cambrian limestone aquifer is the main potential safety hazard of coal seam mining. (Figure 1 ~ Figure 3). At present, the mine mainly exploits the J_{16-17} coal of the Permian Shanghai formation, which is divided into four mining areas, i.e. J1, J2, J3 and J4, of which the J1 mining area and J2 mining area have been excavated. The thickness of J_{16-17} coal seam is 2.12-7.76m, with an average of 3.88M. There are sandy mud stone, medium fine sandstone, thin coal layer, thin limestone and aluminum between J_{16-17} coal seam and Cambrian limestone It is composed of soil mud stone, with a thickness of 81-103m and an average of 90.6m.

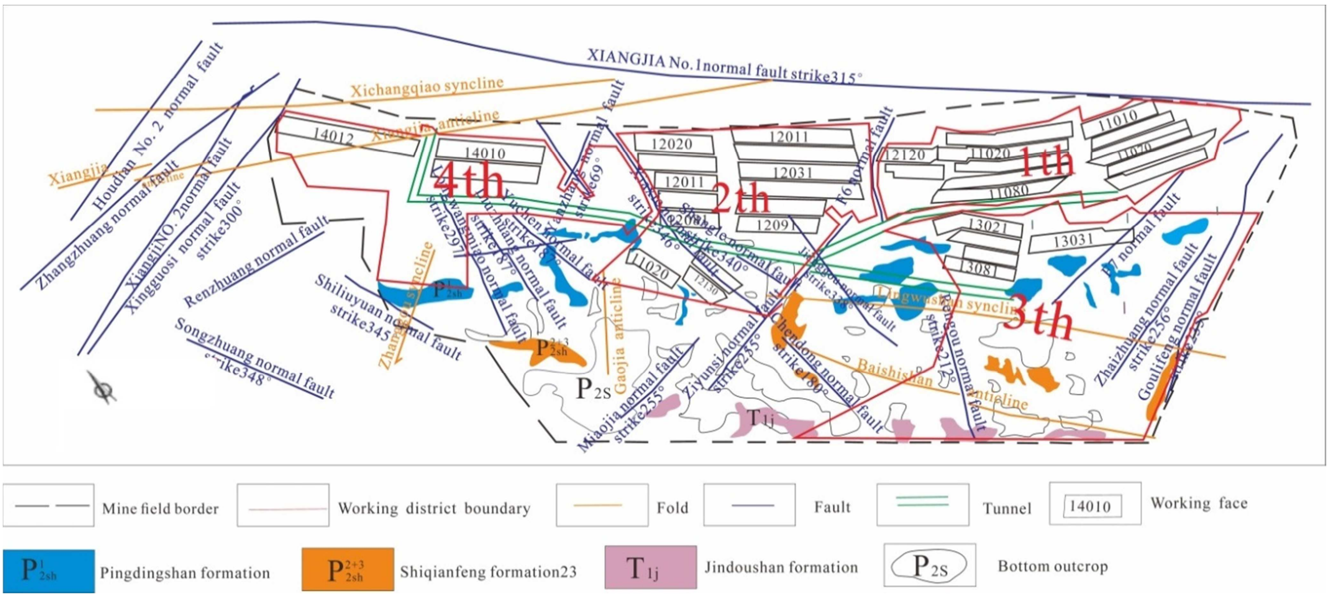

Figure 2. *Sketch map of bedrock and geological structure distribution of No. 13 mine.*

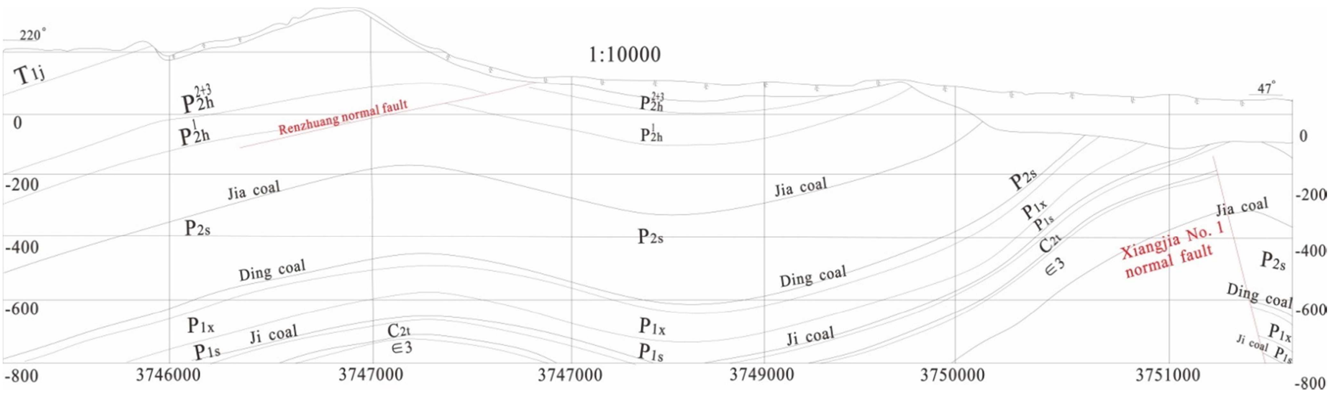

Figure 3. *Geological Section of No. 13 mine.*

2.1.2. Geological Characteristics

The main structure of the mine field is the southwest wing of Xiaoping anticline, the northwest is mono clinic structure, and the South East fluctuates in waves due to the "wedge" of loansharking geosyncline and Banish anticline. At present, 28 faults have been found in the mine field (Figure 2 and Figure 3), among which Xiaoping No. 1 normal fault, lifelong normal fault, Xingu normal fault, Xiaoping No. 2 normal fault and Guangzhou normal fault block the hydrodynamic connection between mine 13 and the external groundwater and surface water. Renounce normal fault, Shijiazhuang normal fault, Chen dong normal fault in Jinan mining area and Longstanding normal fault, pomegranate garden normal fault and Hangzhou normal fault in Isis mining area Normal faults have affected the integrity of limestone aquifer in varying degrees, and also affected the safe mining of Ji_{16-17} coal seam.

2.2. Mine Hydro Geology

2.2.1. Aquifer

The floor water-filled aquifers affecting the mining of J_{16-17} coal are the L_2, L_{6-7} limestone aquifers of the Carboniferous

Taiyuan Formation and the Cambrian limestone aquifers (Figure 2). The average thickness of the L_2 aquifer is 6.5m, the unit water inflow is0.0001-0.0043L/s·m, the permeability coefficient is 0.0189-0.0003m/d, and the water richness is poor; the average thickness of the L_{6-7} limestone aquifer is 7.3m, and the unit water inflow is 0.075-0.019L/s·m, permeability coefficient 0.335~0.528m/d, weak water richness; the distance between Cambrian aquifer and J_{16-17} coal is between 80-90m, the average thickness is greater than 200m, and the unit water inflow is 2.27-26.62L/s·m, permeability coefficient 1.092-7.47m/d, strong water richness but uneven distribution.

The above-mentioned aquifers are mainly separated by poorly permeable mud stone, sandy mud stone, sandstone, and thin coal seams (line), as shown in Figure 2. Under normal circumstances, the hydraulic connection between each other is weak, but there may be a relatively close hydraulic connection between adjacent aquifers in the geological structure development zone.

2.2.2. Water Filling Characteristics

L_2 aquifer is the direct water filling source for the mining of J_{16-17} coal. It is easy to be drained due to its thin thickness and poor water yield, which has little impact on the mining of J_{16-17} coal. L_{6-7} aquifer is the indirect water filling source for the mining of J_{16-17} coal. Although it is thin and has poor water yield, its water level is basically the same as that of the Cambrian aquifer due to its proximity to the Cambrian aquifer and the influence of faults, which has a great impact on the mining of J_{16-17} coal. The Cambrian aquifer is relatively far away from the J_{16-17} coal, which poses little threat to the J_{16-17} coal mining under normal conditions; However, due to its strong water yield, large water pressure and high water temperature, controlled by the dual factors of fault and floor disturbance and damage, it can exert influence on the mining of J_{16-17} coal through L_{6-7} aquifer, which is the main hazard water source during the mining of J_{16-17} coal in No. 13 coal mine.

3. Determination of Index Factors

3.1. Index Factor Selection

The factors affecting the water separation capacity of the J_{16-17} coal bottom slate layer in No. 13 coal mine include geological characteristics, archaeological and engineering geological conditions and mining layout. The main control factors can be selected by analyzing the existing exploration data and underground mining exposure information and referring to the achievements of others [17].

Geological elements mainly include the lithology composition, integrity and fault complexity of coal seam floor. The lithology composition can be characterized by the thickness ratio of brittle plastic rock exposed by 24 boreholes; The integrity can be based on the core recovery rate of 24 boreholes; The fault complexity can be quantitatively identified by using the fractal dimension of fractal theory according to the fault shape and trajectory revealed by comprehensive exploration and underground.

Archaeological factors mainly refer to the permeability of rock strata. In view of the differences in permeability of rock strata of different ethology, the equivalent water barrier coefficient of composite rock strata can be determined according to the thickness of single rock stratum exposed by drilling and the equivalent water barrier coefficient. Engineering geological elements mainly refer to the ability of rock stratum to resist water pressure. 24 boreholes can be used to extract the core, and the measured comprehensive strength and rock stratum thickness can be used to give the composite comprehensive strength.

The thickness of the effective water resisting layer is a favorable barrier for the water resisting effect of coal mining, that is, the thickness of the composite rock layer minus the disturbance and failure depth of the floor can be determined according to the drilling data and the layout of the working face.

3.2. Index Factor Set

According to the data of 24 geological boreholes in I 3 and I 4 mining areas of No. 13 coal mine, Thickness ratio of plastic brittle rock and core recovery rate can be statistically obtained. Based on 24 borehole data and indoor measured mechanical parameters, three factor values of composite comprehensive strength [18], Equivalent water barrier coefficient [19] and Effective water-resistant layer thickness [20] can be obtained through standardized calculation of MATLAB software. The fault shape and trajectory can be determined by using drilling and geophysical data and underground exposure information. In order to correspond to the evaluation of rock stratum water barrier ability, the fault complexity factor value takes the reciprocal of fractal dimension [21-22]. The quantitative values of the six main control factors are listed in Table 1.

Table 1. *Main control factor quantitative value.*

Drilling hole	Thickness ratio of plastic brittle rock	Core recovery rate	Composite comprehensive strength/Amp	Equivalent water barrier coefficient	Effective water-resistant layer thickness (m)	Fault factor values
1	0.7263	0.5200	4.93	0.9127	60.50	1.0477
2	0.7941	0.5000	4.84	0.9254	62.05	1.0192
3	0.7869	0.4150	4.85	0.9234	65.02	1.0095
4	0.7259	0.5320	4.93	0.9131	60.19	1.0198
5	0.7676	0.5950	4.84	0.9130	66.40	1.1728
6	0.7245	0.5250	4.91	0.9080	63.87	0.9912
7	1.2733	0.8640	4.00	0.9018	73.83	0.8814
8	1.1905	0.8430	4.15	0.9113	75.05	0.8524
9	1.0572	0.8430	4.30	0.9033	70.54	0.8813

Drilling hole	Thickness ratio of plastic brittle rock	Core recovery rate	Composite comprehensive strength/Amp	Equivalent water barrier coefficient	Effective water-resistant layer thickness (m)	Fault factor values
10	0.9407	0.8100	4.48	0.9028	67.69	0.9060
11	0.3707	0.7510	5.78	0.8926	56.29	0.8772
12	0.8549	0.6570	4.66	0.9100	65.90	0.9411
13	0.6035	0.9750	5.13	0.8945	58.73	0.9528
14	0.4865	0.7960	5.37	0.8799	54.56	0.9538
15	0.4977	0.8057	5.22	0.8522	50.50	0.9005
16	0.7866	0.5710	4.82	0.9168	66.80	1.0558
17	0.8177	0.5154	4.79	0.9224	59.20	1.0281
18	0.8075	0.5100	4.82	0.9252	60.40	1.0215
19	0.7556	0.5300	4.90	0.9195	61.70	1.0284
20	0.7626	0.5170	4.88	0.9185	63.90	1.1695
21	0.5690	0.7000	5.20	0.8917	49.60	1.0476
22	0.7928	0.6650	4.79	0.9120	65.90	0.9923
23	0.7802	0.6500	4.83	0.9158	81.10	0.9087
24	1.2500	0.8470	4.02	0.8997	72.90	0.8861

4. Comprehensive Weight Calculation

4.1. Subjective Weight

Using the analytic hierarchy process (AHP) and referring to the existing research results [23], the weight of six index factors of water resisting capacity of composite rock floor can be determined. The judgment matrix of the evaluation system composed of six index factors is shown in Tables 2 to 5.

Table 2. *A-B_i judgment matrix and its calculation results (i=1,2,3).*

A	B_1	B_2	B_3	w (A/B_i)	Consistency test	
					M_{ax}	CR
B_1	1	5/2	2	0.5242	3.0037	0.0036
B_2	2/5	1	2/3	0.1973		
B_3	1/2	3/2	1	0.2785		

Note: maximum characteristic valuel_{ess}=3.0037, CI=0.0018<0.1, CR=0.0036<0.1.

When using AHP model to determine the weight of subjective factors, only when the consistency index CI < 0.1 and consistency ratio CR < 0.1 of the discrimination matrix are established, can it be explained that the judgment matrix and the single ranking of factors in the layer have logical consistency, and the calculation result is credible. Obviously, the results of all levels in Table 2 to table 5 have passed the consistency test, and the determined index factor weight is credible. The results are shown in Table 6.

Table 3. *B_1-C_i judgment matrix and its calculation results (i=1,2).*

B_1	C_1	C_2	w (B_1/C_i)	Consistency test	
				M_{ax}	CR
C_1	1	2/9	0.1818	2	0
C_2	9/2	1	0.8182		

Note: maximum characteristic valuel_{ess}=2, CI=0<0.1, CR=0<0.1.

Table 4. *B_2-C_i judgment matrix and its calculation results (i=1,2).*

B_2	C_3	C_4	w (B_2/C_i)	Consistency test	
				M_{ax}	CR
C_3	1	3/5	0.375	2	0
C_4	5/3	1	0.625		

Note: maximum characteristic valuel_{ess}=2, CI=0<0.1, CR=0<0.1.

Table 5. *B_3-C_i judgment matrix and its calculation results (i=1,2).*

B_3	C_5	C_6	w (B_2/C_i)	Consistency test	
				M_{ax}	CR
C_5	1	3/4	0.4286	2	0
C_6	4/3	1	0.5714		

Note: maximum characteristic valuel_{ess}=2, CI=0<0.1, CR=0<0.1.

Table 6. *Subjective weight of evaluation index factors.*

Indicators	Thickness ratio of plastic brittle rock	Core recovery rate	Composite comprehensive strength	Equivalent water barrier coefficient	Effective water-resistant layer thickness	Fault factor values
weight W_j'	0.1591	0.1233	0.0740	0.1194	0.0953	0.4289

4.2. Objective Weight

The objective weight can be calculated by using the grey correlation analysis method [24]. According to the main control factor values of 24 boreholes in Table 1, the overall reference series of main control factors can be obtained:

$$X_0 = \{1.2733, 0.9750, 5.7800, 0.9254, 81.10, 0.8524\}$$

For the reference series X_0 and N comparison series X_1, X_2,..., A_n, the formula for calculating the correlation coefficient is:

$$\xi_i(k) = \frac{m_i in\, m_k in \left|x_o(k) - x_i(k)\right| + \rho \bullet m_i axm_k ax \left|x_o(k) - x_i(k)\right|}{x_o(k) - x_i(k) + \rho \bullet m_i axm_k ax \left|x_o(k) - x_i(k)\right|} \quad (1)$$

$$r_i = \frac{1}{N}\sum_{k=1}^{N} \xi_i(k) ... i = 1, 2, \cdots, m \quad (2)$$

After the correlation coefficient R_I is normalized, its value is the objective weight [25]:

$$\omega_i = \frac{r_i}{\sum_{i=1}^{m} r_i} \cdot\cdot i = 1, 2, \cdots m \tag{3}$$

In the formula, ρ=0.5.

According to formula (3), the weights of six index factors can be obtained, and their values are shown in Table 7.

Table 7. *Objective weight of evaluation index factors.*

Indicators	**Thickness ratio of plastic brittle rock**	**Core recovery rate**	**Composite comprehensive strength**	**Equivalent water barrier coefficient**	**Effective water-resistant layer thickness**	**Fault factor values**
weight W_j''	0.1331	0.1483	0.1600	0.2051	0.1559	0.1976

4.3. Comprehensive Weights

According to the subjective and objective weights obtained, the comprehensive weight can be calculated by using the following formula [26-27]:

$$\omega_i = \frac{\left(\omega_{1i} * \omega_{2i}\right)^{0.5}}{\sum_{i=1}^{n} (\omega_{1i} * \omega_{2i})^{0.5}} \tag{4}$$

Where ω_{1i} and ω_{2i} are the subjective and objective weights, respectively. Further application of entropy weight theory [28] can calculate the relative entropy value:

$$H(U,V) = \sum_{i=1}^{n} U_i \ln \frac{U_i}{V_i} \tag{5}$$

Where *H(U, V)* is the relative entropy of *U* and *V*, and *n* is the number of indicators.

Based on equation (4), the comprehensive weight values of 6 main control factors can be determined, as shown in Table 8; The relative entropy of comprehensive weight and subjective and objective weight can be obtained by using equation (5), as shown in Table 9.

Table 8. *Comprehensive weight of evaluation index factors.*

Indicators	**Thickness ratio of plastic brittle rock**	**Core recovery rate**	**Composite comprehensive strength**	**Equivalent water barrier coefficient**	**Effective water-resistant layer thickness**	**Fault factor values**
Comprehensive weight	0.1517	0.1410	0.1134	0.1632	0.1271	0.3036

Table 9. *Relative entropy of each weight.*

Weight	**Comprehensive weight and subjective weight**	**Comprehensive weight and objective weight**
Relative entropy	0.043	0.040

Obviously, the relative entropy of comprehensive weight and subjective and objective weight is less than 0.1 and tends to 0, indicating that the distribution of comprehensive weight and subjective and objective weight is more scientific and reasonable [29-30].

5. Grading Evaluation of Water Separation Capacity

5.1. Construction of Evaluation Model

Archaist spatial analysis [31-32] refers to the process of data analysis and data mining of spatial information and obtaining information from one or more spatial data thematic layers. Its essence includes detecting the analysis of spatial data, studying the relationship between data and establishing spatial data model, so that spatial data can more intuitively express its potential meaning, so as to realize the prediction and control of something. Archaist can realize the basic functions of spatial analysis, including spatial query and measurement, overlay analysis, buffer analysis, network analysis, etc.

Import the collected spatial point index data into Archaist database, Spatial interpolation method and its mask analysis (taking the boundary of the study area as the mask boundary) establish thematic layers in the form of grid of each main control factor. Based on its grid layer overlay analysis function, overlay each thematic layer according to its comprehensive weight. Based on the contribution mechanism of the main control factor to the water impermeability, establish a vulnerability index model to identify the water impermeability of the composite strata of the coal seam floor [33-34] According to the natural discontinuity classification method, the water separation capacity is divided.

For the six main control factors affecting the water impermeability of composite strata, the vulnerability index calculation model is constructed as follows:

$$VI = \sum_{k=1}^{n} W_k f_k\left(\mathrm{x},\mathrm{y}\right) = 0.1271 f_1(\mathrm{x},\mathrm{y}) + 0.3032 f_2(\mathrm{x},\mathrm{y}) + 0.1134 f_3(\mathrm{x},\mathrm{y}) + 0.1632 f_4(\mathrm{x},\mathrm{y}) + 0.1591 f_5(\mathrm{x},\mathrm{y}) + 0.1233 f_6(\mathrm{x},\mathrm{y}) \tag{6}$$

Where, *VI* is the vulnerability index; W_k is the main controlling factor weight; b_k (x, y) is the function of single factor influence value; n is the number of main controlling factors; (x, y) are geographical coordinates.

Substituting the value of the main control factor into the formula (6) can obtain the vulnerability index of the $J_{16\text{-}17}$ coal seam floor composite rock.

5.2. Waterproof Capacity Zoning

Based on Archaist information processing technology, six quantitative thematic maps of main control factors can be drawn (Figure 4), and then using its spatial composite superposition function, the quantitative superposition map of the main control factors can be obtained. For the quantitative superposition layer, the natural break point classification method is applied to study the spatial attributes of the vulnerability index frequency histogram of each regional unit, and four classification thresholds of 0.2009, 0.2542, 0.3525 and 0.4562 can be obtained (Figure 5). According to the classification threshold, the water isolation capacity can be divided into five grades (table 10).

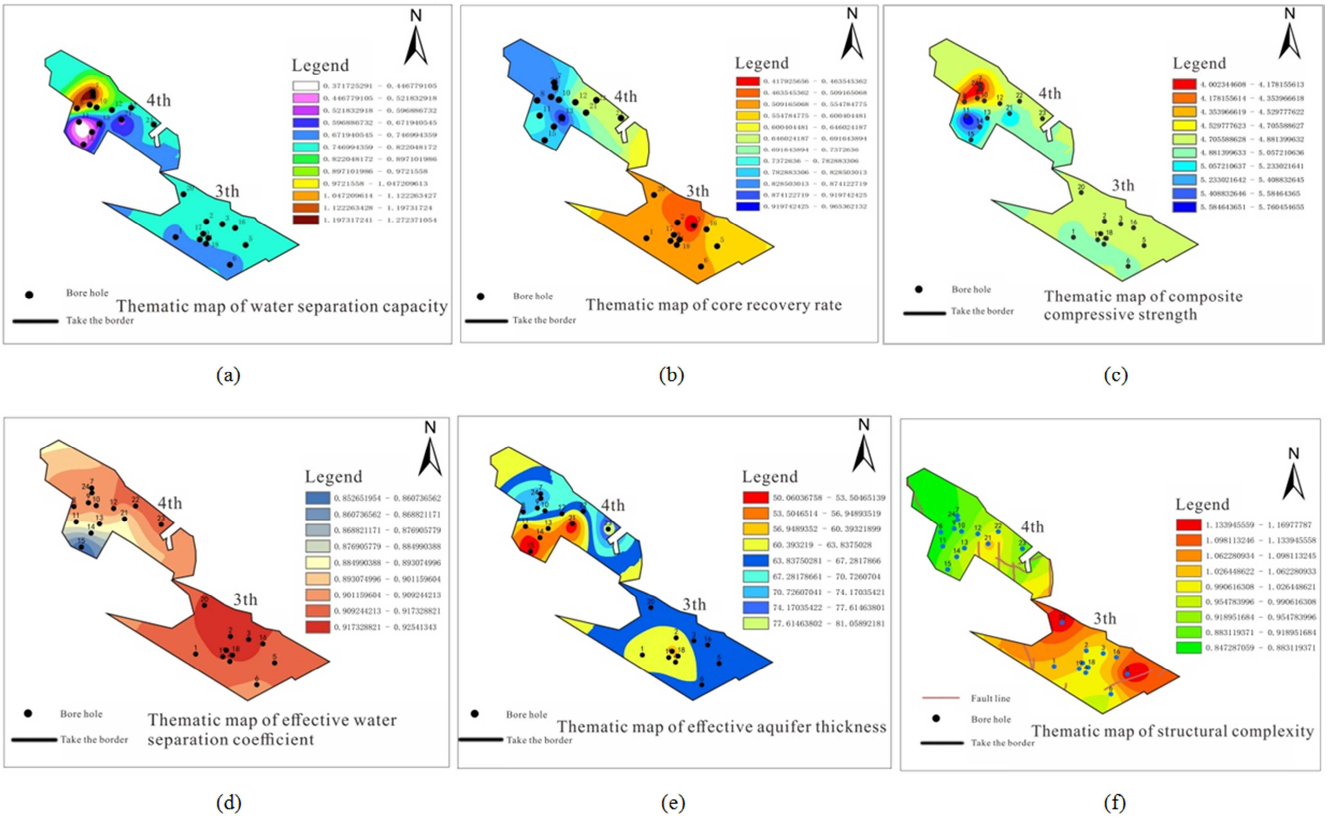

Figure 4. *Quantitative thematic map of main controlling factors of floor water inrush.*

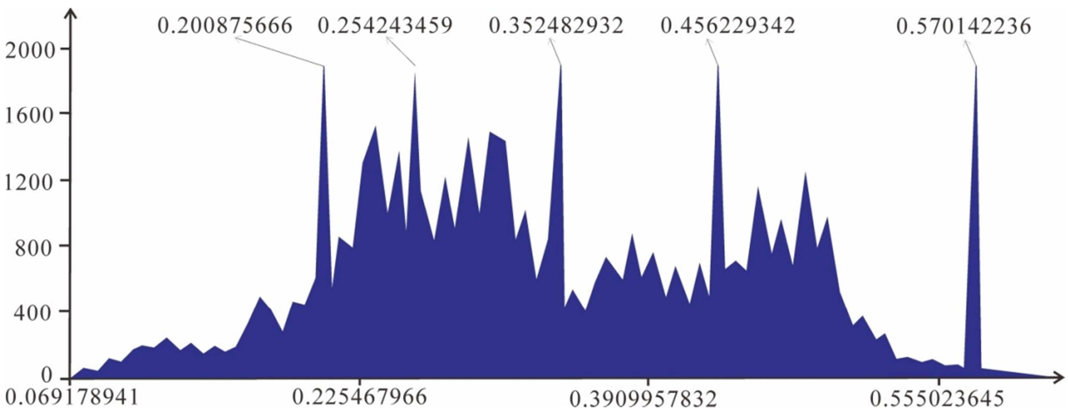

Figure 5. *Classification of natural discontinuities and classification of vulnerability.*

Table 10. *Vulnerability assessment partition table.*

Waterproof ability grade	Extremely weak (I)	Weak (II)	Medium (III)	Strong (IV)	Very strong (V)
Level eigenvalue	W<0.2009	0.2009≤W<0.2542	0.2542≤W<0.3525	0.3525≤W<0.45	W≥0.45

By comparing and analyzing the vulnerability index and classification threshold, the water resistance of the floor composite rock stratum can be divided into five grades: very weak, weak, medium, strong and very strong. The higher the grade, the stronger the water resistance of the coal seam floor composite rock stratum. The classification and zoning of water separation capacity of composite rock stratum of coal floor in Jinan and Isis mining areas of Peiping No. 13 coal mine is shown in Figure 6.

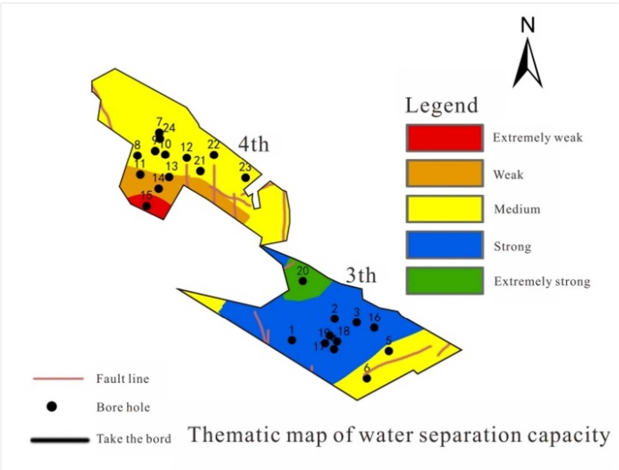

Figure 6. *Zoning of water-impermeability of composite rock formations of $J_{16\text{-}17}$ coal floor.*

Statistics show that in the study area, 38.67% of the total area is composed of strong and extremely strong areas, 51.45% is composed of medium areas, 9.88% is composed of weak and extremely weak areas, and relatively high, weak and extremely weak areas are composed of medium areas.

5.3. Comparative Analysis with Water Inrush Coefficient Results

The water inrush coefficient is commonly used to judge the water inrush risk of coal seam floor [35], and the calculation formula is:

$$T = p / M \tag{7}$$

Where: T is water inrush coefficient, Amp/m; P is the water pressure borne by the bottom water resisting layer, Amp; M is the thickness of bottom water resisting layer, m.

According to the Regulations [3], the water inrush coefficient is not greater than 0.06mpa/m in the section with geological structure of coal seam floor water resisting layer; In the section without geological structure, the water inrush coefficient shall not be greater than 0.01mpa/m. As the geological structure of No. 13 mine is relatively developed, the section with water inrush coefficient less than 0.06mpa/m is defined as the area with strong water impermeability, and the section with water inrush coefficient greater than or equal to 0.06mpa/m is defined as the area with weak water impermeability.

The water inrush coefficient of 24 boreholes can be calculated by using equation (7), and the thematic map of water separation capacity zoning of coal seam 16-17 of No. 13 coal mine can be drawn based on Archaist interpolation, as shown in Figure 7.

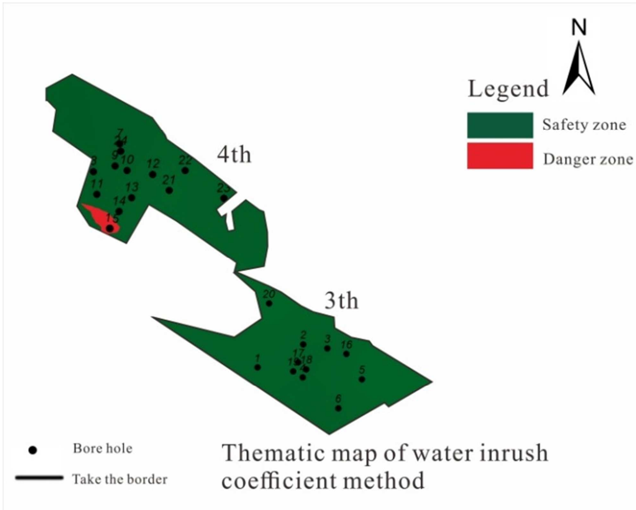

Figure 7. *Division of water inrush coefficient method for composite strata of $J_{16\text{-}17}$ coal floor.*

It can be seen from figure 7 that the water inrush coefficient of borehole 15 is 0.069 MPA / m, which belongs to the area with weak water separation capacity; The No. 15 borehole identified by Archaist vulnerability index method is a zone with extremely weak water impermeability (Figure 6). The consistency of the evaluation results of the two methods at No. 15 borehole shows the reliability of Archaist vulnerability index method in identifying the water impermeability of coal seam floor.

The water inrush coefficient method only considers the two factors of the thickness of the water resisting layer of the coal seam floor and the bearing water pressure, which has the advantages of simple calculation and less data. However, due to the rough identification results, it is difficult to accurately describe the spatial difference of the water resisting capacity of the coal seam floor. The Archaist vulnerability index method considers many influencing factors, and can realize the automatic quantitative evaluation of the water resisting capacity of the coal seam floor. The grading and zoning evaluation results are of great significance for the mine to take targeted water control countermeasures.

6. Conclusions

(1) Based on the study of multiple influencing factors on the water resistance of the composite rock layer of the floor of coal seam $J_{16\text{-}17}$ in the mining areas of J_3 and J_4 of Pingmei No. 13 coal mine, six main control factors such as Thickness ratio of plastic brittle rock core recovery rate, composite comprehensive strength, Equivalent water barrier coefficient, Effective water-resistant layer

thickness and fault complexity are selected, which provides a guarantee for the accurate identification of the water resistance capacity of the composite rock layer of the floor of the coal seam.

(2) Based on the subjective and objective weight, coupling the comprehensive weight and ArcGIS vulnerability index method, a mathematical model for evaluating the threat degree of water barrier ability of composite rock stratum is constructed. Based on the quantitative value and weight value of six index factors, the water resisting capacity of the composite rock layer of the floor of coal seam J_{16-17} is quantitatively identified and divided into five grades: extremely weak, weak, medium, strong and extremely strong, which lays a foundation for the prevention and accurate evaluation of water inrush disaster in the floor of coal seam.

(3) Based on ArcGIS information processing technology, the thematic layers in the form of grid of six main control factors are drawn, the thematic layers are superimposed according to their comprehensive weight by using the grid layer superposition function, the vulnerability evaluation model of water resisting capacity of coal seam floor is established, the classification threshold is determined according to the natural discontinuity classification method, and the water resisting capacity of floor composite strata is divided.

(4) The classification evaluation of Archaist vulnerability index method shows that the strong and very strong areas, 51.45% and 9.88% of the total area, the medium and very weak areas, and the medium, weak and very weak areas account for 38.67%, 51.45% and 9.88% of the total area. The zoning result is to take targeted measures to formulate the prevention and control of floor water damage Measures provide guarantee.

7. Deficiencies and Suggestions

Taking the J3 and J4 mining areas of Pingmei No. 13 coal mine as the research object, this paper evaluates the water inrush from the composite strata of the coal seam floor. Although some progress has been made, there are still many problems, which should be further studied on this basis, mainly including the following four aspects:

(1). In order to better carry out the floor water prevention and control work in the whole area of Pingdingshan coalfield, more mining areas need to be selected for research in the follow-up work.

(2). There are many influencing factors for water inrush from coal seam floor composite strata, but this paper only selects six main controlling factors. The influence of other factors and how to quantify their data need to be further explored.

(3). If the three-dimensional risk area map can be derived with ArcGIS according to geological and hydrogeological information, engineers and technicians can better predict the water inrush risk of coal seam floor in the mining process.

(4). With the continuous change of mine mining area, the factors and quantitative values affecting water inrush from coal seam floor composite strata are also changing. At present, artificial intelligence has been widely valued and applied in the computer field. How to use artificial intelligence technology to transform evaluation and prediction from relatively "static" to relatively "dynamic" is a new idea for future research.

References

[1] CHEN J P, ZHU J C, YIN X C, et al. Discrimination of mine water inrush source based on PHREEQC reverse simulation-cluster analysis method [J]. Coal Technology, 2020, 39 (11): 75-78.

[2] ZHU Z K, XU Z M, SUN Y J, et al. Water barrier of the upper Cambrian and its application in pressure mining in Malingshan Mine [J]. Safety Engineering, 2014, 31 (02): 226-231.

[3] The fine rule of prevention and control of water in coal mine [M]. Coal Industry Press, State Bureau of Coal Mine Safety Supervision, 2018.

[4] ZHOU H T. Study on the evolution characteristics of confined seepage flow in fractured rock mass and its hydraulic mechanism [D]. China University of Mining and Technology, 2017.

[5] YANG S N. "Water resistance coefficient" and its application [J]. Coal Geology, 1986 (03): 41-46.

[6] XU J L, QIAN M G. Application research and practice of rock formation control key layer theory [J]. CHINA MINING MAGAZINE, 2001 (06): 56-58.

[7] BAI H B. Study on the seepage mechanics characteristics of the top rock strata of Ordovician and its application as a key water-proof layer [J]. Chinese Journal of Rock Mechanics and Engineering, 2011 (06): 224.

[8] LI J L, ZHAO S P, CUI Y H. Evaluation of Water Inrush Hazard in No. 15 Coal Seam Floor of Chengzhuang Coal Mine after CBM Mining [J]. Journal of Henan Polytechnic University (Natural Science Edition), 2021, 40 (05): 1-7.

[9] FENG M M, MAO X B, ZHU Q H. The influence of lithology combination characteristics of floor water-resistant layer on water-resistant performance [J]. Safety Engineering,, 2010, 27 (03): 404-409.

[10] CHEN J P, LI J Z, WANG X D, et al. Application of Improved Vulnerability Index Method in Evaluation of Water Inrush from Coal Floor [J]. The Chinese Journal of Geological Hazard and Control, 2019, 30 (03): 67-74.

[11] HU Y, LI W, LIU S, et al. Risk assessment of water inrush from aquifers underlying the Qiuji coal mine in China [J]. Arabian Journal of Geosciences, 2019, 12 (3): 1-17.

[12] ZHANG W Q, LI B Y, LI J X. The relationship between the water resistance of the rock formation and its structural composition and combination form [J]. Coal Geology, 1992 (04): 41-44.

[13] Y Zhang. Mechanism of Water Inrush of a Deep Mining Floor Based on Coupled Mining Pressure and Confined Pressure [J]. 2021.

[14] XU Z M, LIU S S, CHEN T C, et al. Research on the evaluation method of coal seam floor hydrogeological structure and water blocking ability [J/OL]. Coal Science And Technology: 1-9 [2021-09-24]. http://kns.cnki.net/kcms/detail/11.2402.TD.20210706.1130.002.html.

[15] PANG G G. Key technology of Ordovician ash water damage prevention and control in Baode coal mine floor [J] Safety in Coal Mines, 2020, 51 (01): 75-79.

[16] LI X M, LIU D M, LIAN H Q, et al. Research and application of water-proof performance of carbonate rock formation in Fengfeng Formation of Zhaozhuang Mine [J]. Coal Engineering, 2019, 51 (10): 102-107.

[17] Chen Y, Wang X, Zhao Y, et al. Quantitative Evaluation for the Threat Degree of a Thermal Reservoir to Deep Coal Mining [J]. Geofluids, 2020, 2020 (12): 1-15.

[18] LEI S, KANG H P, GAO F Q, et al. Research and application of rapid determination method for uniaxial compressive strength of broken coal in Xinyuan Coal Mine [J]. Journal of China Coal Society, 2019, 44 (11): 3412-3422.

[19] HE X L, XIA Y C, DING X, et al. Calculation of wide area adaptive safe water conservation thickness and evaluation of mining impact zoning in Maowusu Desert Area [J]. Journal of China Coal Society, 2019, 44 (003): 796-803.

[20] LI J Y, LIU Q M, LIU Y, et al. Risk assessment of coal seam roof water inrush based on GIS and entropy method [J]. Coal Engineering, 2019, 51 (08): 115-119.

[21] CHEN P, PENG S Y, WANG P F, et al. Fractal and multifractal characteristics of faults and their controlling effects on outburst distribution [J]. Coal Science and Technology, 2019, 47 (07): 47-52.

[22] XU W J, ZHANG S S, WU C, et al. Quantitative Evaluation of Structural Complexity of Coal Reservoir Based on Analytic Hierarchy Process [J]. Journal of Henan Polytechnic University (Natural Science Edition), 2019, 38 (02): 20-26.

[23] Wang X, Wang T, Qi W, et al. Evaluation of Floor Water Inrush based on Fractal Theory and an Improved Analytic Hierarchy Process [J]. Mine Water and the Environment, 2016, 36 (1): 1-9.

[24] HE R, WANG B, YANG W L. Grey Relational Model for Evaluation of Mining Damage Grade of Buildings in Mining Areas [J]. Journal of Henan Polytechnic University (Natural Science Edition), 2016, 35 (04): 482-486.

[25] WANG X S, CHEN Z M. Optimization of mining and drainage scheme in open-pit mine based on AHP-GRAP method [J]. Coal Engineering, 2019, 51 (06): 62-67.

[26] SHI L Q, ZHANG R A, HAN J, et al. Risk Assessment of Water Inrush Based on Entropy Weight Method and Analytic Hierarchy Process [J]. Journal of Henan Polytechnic University (Natural Science Edition), 2020, 39 (03): 17-25.

[27] LI B, GUO X M, XU S, et al. Evaluation of water inrush hazard from coal seam floor based on fuzzy judgment and comprehensive weighting [J]. Journal of Henan Polytechnic University (Natural Science), 2014, 33 (01): 6-11.

[28] SHI L Q, ZHANG R A, HAN J, et al. Multi-source information fusion water inrush risk assessment based on the coupling weighting of entropy weight method and analytic hierarchy process [J]. Journal of Henan Polytechnic University (Natural Science), 2020, 39 (03): 17-25.

[29] HOU E K, JI Z C, CHE X Y, et al. Prediction method of weathered bedrock water richness based on the coupling of improved AHP and entropy weight method [J]. Journal of China Coal Society, 2019, 44 (10): 3164-3173.

[30] WANG C Y, PAN X H, SA Z Y, et al. Application of combined weight variable set model in coal and gas outburst evaluation [J]. Journal of Henan Polytechnic University (Natural Science), 2017, 36 (02): 35-40.

[31] ZHOU W B, FENG N. Application of Geographic Information System in Coal Mine [J]. Coal Technology, 2020, 39 (05): 174-176.

[32] WEN G C, DENG Y S, YU Y Q. Design and implementation of mine flood forecasting platform based on GIS and modeling theory [J]. Journal of Henan Polytechnic University (Natural Science), 2010, 29 (06): 709-714.

[33] LIU X Y, ZHANG J J, LIU S Q, et al. Application of AHP vulnerability assessment of coal seam floor water inrush based on GIS [J]. Coal Technology, 2018, 37 (10): 209-212.

[34] HOU E K, LONG T W, LIU Q L, et al. Evaluation of water abundance of aquifer in Luohe Formation based on ArcGIS [J]. Coal Geology & Exploration, 2019, 47 (02): 151-156.

[35] LI J L, CHEN G S, ZHANG B, et al. Evaluation of water inrush hazard from coal seam floor based on five-figure double-coefficient method [J]. Journal of Henan Polytechnic University (Natural Science), 2017, 36 (02): 30-34+40.