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Research on Discriminant Model of Water Inrush Source By Principal Component-cluster Analysis in Jiaozuo Mining Area

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ABSTRACT

This paper takes Jiaozuo Mining Area as the research object, based on the analysis of the hydrogeological conditions of the mining area, expounds the characteristics of coal strata, aquifers and groundwater recharge, runoff and discharge in the mining area; analyses the water inrush sources and water diversion channels in the mining area, analyses the routine water chemical data of each aquifer in the mining area, draws the piper three-line diagram and confirms it. To determine the hydrochemical type of groundwater in aquifer, six common water chemical ions are used as discriminant factors, a discriminant model of water inrush source is established by combining principal component analysis and cluster analysis, and the principal component of conventional water chemical ions is extracted as cluster variable to discriminate Water Inrush Source in Jiaozuo Mining Area. In order to prove the rationality and validity of the model, another group of inrush sources in Jiaozuo Mining Area is discussed. The water sample data are discriminated and the results obtained by cluster analysis are compared to verify the accuracy of the model. The results show that the model is feasible. To sum up, the identification model of inrush water source by principal component-cluster analysis can accurately and effectively identify the source of inrush water in Jiaozuo Mining Area.

KEYWORDS

Inrush Water; Discrimination of Mine Source; Piper; Principal Component Analysis; Cluster Analysis.

1. INTRODUCTION

Foreign coal mining has a long history, mine water inrush also caused a great problem to mine mining, a large number of scholars have studied the mechanism of mine water inrush and water damage prevention. Around the 1940s, the concept of "floor relative water barrier layer" was first proposed by Hungarian scholar Vigo Frans, who pointed out that floor water inrush was affected by the thickness and water pressure of the water barrier layer, and the conditions of water inrush were restricted by the thickness of the relative water barrier layer. In the 1960s and 1970s, their research direction still centered on mechanics and statics and other related disciplines, but the influence of geological factors such as water flow and rock structure on mine water inrush came to the attention of scholars. In the late 1970s and 1980s, some rock mechanics researchers began to study the failure mechanism of the floor and analyzed the bearing capacity of the floor[1]. At the end of the 20th century, hydrogeochemical research on mine water inrush began to develop, and great progress was made in identifying water inrush sources through the analysis of groundwater ions and hydrochemical characteristics[2]. Foreign scholars have accumulated valuable experience in the identification of mine water inrush sources, but the European and American countries are economically developed and pay more attention to safety issues, so the coal mining is not deep, and there are not many related literatures on the identification of mine water inrush sources.

Domestic research on the mechanism of water inrush began around 1960, noting the application of foreign floor relative water barrier theory in practice, the relevant problems of mine water inrush were raised, and the corresponding theories began to develop. After the 1960s, scholars focused on the water inrush problem of coal mine floor and put forward many theories such as the “Three Underlying Belts” Theory [3], the zero failure theory [4], and the "strong seepage channel" theory [5]. With the continuous efforts of domestic scholars, the relevant theories are becoming more and more perfect, and the research on the mechanism of water inrush is also more in-depth. The identification method of water inburst source has also developed from simple analogical analysis of water quality and identification of chemical composition characteristics to nonlinear analysis methods and multivariate statistical analysis [6-9]. The establishment of mathematical models to analyze the chemical characteristics of water inburst source has become one of the conventional identification methods of water inburst source.

Li Dongchen [10] analyzed the water chemical characteristics of the main aquifer in Baimiao Coal Mine and predicted the source of water inburst by using the comprehensive element method and the grey correlation degree method. Yue Mei and Zhang Huigong [11] introduced the grey system theory to conduct multivariate correlation analysis of water quality, and analyzed the source and correlation degree of water.

In terms of multivariate statistical analysis, Chen Hongjiang [12] comprehensively analyzed the chemical composition of aquifer standard components and water samples at water inwelling points, and established Fisher discrimination model. Li Zhifeng [13] established a decision tree for water inrush source identification by using hierarchical clustering and Fisher discrimination. The combination of stepwise discrimination and Bayes criterion has been widely used in the identification of water inrush sources [14-15].

In terms of neural networks, Wu Qiang [16] used the coupling technology of GIS and ANN to analyze the control factors of the vulnerability of coal seam floor in the study area, and established a model for assessing the vulnerability of coal seam floor to water inrush. Zhu Cui, Qian Jiazhong et al [17] established a BP neural network discrimination model and compared it with the fuzzy comprehensive evaluation method. Xu Zhongjie and Yang Yongguo [18] et al used BP neural network to learn the training samples and distinguished the water inrush samples according to the trained model. This paper takes Jiaozuo mining area as the research area, through the analysis of the hydrogeological conditions of Jiaozuo mining area and the hydrogeochemical characteristics of the main aquifer in the mining area, the mathematical model is built, and the application of the principal component cluster analysis model in the identification of water inburst sources in Jiaozuo mining area is studied.

2. GEOLOGICAL CONDITION OVERVIEW

2.1. Overview of stratum conditions

The exposed strata in Jiaozuo mine area include Archean, Proterozoic Sinian, Lower Paleozoic Cambrian, Ordovician, Upper Paleozoic Carboniferous, Permian, Mesozoic Triassic and Quaternary.The main coal-bearing strata in the mining area are Carboniferous and Permian.

At the bottom of Permian is Shanxi Formation 21 coal seam, the general thickness of about 6 m, is the main mining coal seam in the mining area. There are two layers of coal in the Carboniferous system that can reach mining thickness locally, namely, the No.15 coal in the middle of the carboniferous system (commonly known as "No.2 coal") and the No. 21 coal in the bottom of the carboniferous system (commonly known as "No.3 coal").

In the mining area, various structures have developed extensively since the Yanshan Movement, especially the faulted structures. Under the control of fault structure, the inner layer of the mining area descends in a stepped pattern from north to south. In the mining area, the east-west structure mainly includes Fenghuangling fault, Pangusi - Xinxiang fault, Dagao village east fault, etc. These structures have played a certain control role in terrain and stratigraphic distribution. The NE-trending structure is the most developed structure in the mining area. The larger faults include Jiulishan fault, Majangquan fault and thin-wall fault, and the smaller faults include Wangfeng fault and No.3 Jing fault. There are Pingling fault and Wuzhi fault in the NW trending structure, which are inferior in scale and activity to those in other directions.

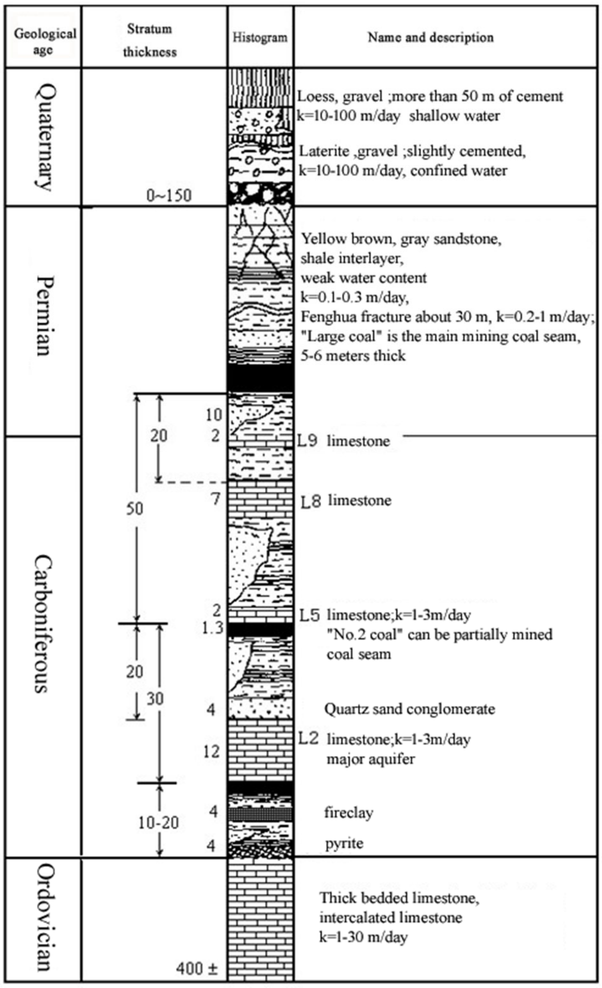


Figure 1. Stratigraphic column

The east-west tectonic belt in the mine area is a large scale base fault. Based on the east-west tectonic belt, a second-order northeast-southwest trending fault structure is formed in the mining area, which can be used as the natural boundary for dividing coal seam and well field. The western part of the mine is characterized by horst and graben appearing alternately, while the eastern part is characterized by stepped fault blocks ascending from south to north. In the mining area, large and medium fissures control groundwater migration, while small fissures provide conditions for mine water inrush .

2.2. Overview of aquifer conditions

There are four main aquifers in the mining area, from top to bottom are the quaternary sandstone pore aquifer, the Permian sandstone fissure aquifer, the carboniferous limestone karst aquifer, and the Middle Ordovician limestone karst aquifer. The characteristics of each aquifer are as follows:

(1) Quaternary sandstone pore aquifer

The fourth system is mainly composed of loose deposits such as sand, coarse sand, gravel and clay. The lower part is red clay and gravel, and the upper part is secondary loess, gravel and flowing sand, etc. Generally, the thickness is 30-200 m. It is directly fed by atmospheric precipitation and surface water and has strong water richness.

(2) Permian sandstone fissure aquifer

The Permian system in the area is composed of sandstone, sandy mudstone, mudstone and coal interlayer, which is the main coal-bearing stratum in the area. The aquifer is located at the top of the Permian system, and the sandstone fractures are not developed, and the development is interspersed with mudstone or argillaceous sandstone, and the water permeability is weak and the recharge condition is poor.

(3) Carboniferous limestone karst aquifer

The carboniferous system in the area is interlayered with limestone, sandstone, siltstone, shale and coal seams, among which there are 9 thin layers of limestone. The second limestone (second limestone, L2) and the eighth limestone (eight limestone, L8) are thick and stable. The thickness of L2 is 4-21 m, the karst fissure is developed, the water rich is strong, and there is a certain hydraulic connection with the Ordovician limestone aquifer. The karst fissure of L8 is relatively developed, and the water-rich strength is uneven. Due to the unstable location and thin thickness of L9 limestone beds, the confined water of L8 can inrush water to No.21 coal seam through water channels such as faults, which is the direct water filling source of No.21 coal seam.

(4) Middle Ordovician limestone karst aquifer

The Ordovician system in this area is composed of brecciate limestone, thick bedded limestone and dolomitic limestone. The deep fissure is poorly developed, and the middle cave is relatively developed, which is the main water source of the river. It can accept the recharge of atmospheric precipitation and surface water, turn into underground runoff, recharge other aquifers in the mining area, and is also an important water source for eighth limestone and second limestone.

3. ESTABLISHMENT OF PRINCIPAL COMPONENTS-CLUSTER ANALYSIS MODEL

3.1. Principal component analysis

The principal component analysis method uses the idea of dimensionality reduction to transform the original multiple related indicators into a series of linearly independent indicators, which are called principal components. The principal component retains most of the information of the original data, and the newly generated principal component indicators are linearly independent of each other, which eliminates the correlation between the original indicators and reduces the workload of index selection. The proportion of principal components in the original data can be expressed by the contribution rate.

Principal component analysis is to take the original p variables as the elements of the linear combination $Y = AX$, that is

$$Y_i = a_{i1}X_1 + a_{i2}X_2 + ... + a_{in}X_P \tag{3-1}$$

In formula (3-1), $a_{i1} + a_{i2} + ... + a_{in} = 1$,Y_i and Y_j ($i \neq j$, i,j=1,2,3...p) Linearly independent. The calculation steps of principal component analysis are as follows:

(1) Standardize the original data and calculate the covariance matrix of each variable;

(2) Calculate the eigenvalue λi of the covariance matrix and find the corresponding unit eigenvector a_i, and sort the eigenvalues in order from large to small ($\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_m \geq 0$) to obtain the variance of

the corresponding m principal components, and the corresponding eigenvector a_i is the coefficient of the principal components;

(3) The principal component is selected according to the cumulative contribution rate of the principal component, which should contain most of the information of the original variable. If the cumulative contribution rate of m principal components exceeds 85%, m principal components can be selected.

(4) Calculate the principal component score, substitute the standardized sample data for the principal component expression, and obtain the principal component score of each sample.

3.2. Cluster analysis

Cluster analysis is a multivariate analysis technique. The object of study is regarded as a point in the same space, and according to the density relationship between points, the closely related points are classified into one category, otherwise they are classified into different categories. Cluster analysis divides similar objects into different groups or more subsets by static classification, so that the member objects in the same subset have similar attributes. Systematic clustering is a kind of cluster analysis commonly used. The steps of systematic clustering analysis are as follows:

(1) Determine the index of cluster analysis and corresponding measurement values;

(2) Transform the original data to make it become relatively consistent data;

(3) Measure the density relationship between samples according to the transformed data, determine the clustering method, so that the samples are closely related into a category;

(4) Draw pedigree diagram and analyze the clustering results.

4. VERIFICATION OF WATER INRUSH SOURCE DISCRIMINATION MODEL

4.1. Analysis of water inrush condition in mining area

4.1.1. Water inrush source

The coal mine is mainly mined for No.21 coal, and its water source includes: roof water source and bottom water source. The water source of the roof is the pore water of the quaternary loose rock in the No.21 coal seam, and the burial is shallow. Due to the weathered fissure zone, the local weathered fissure at the top of the sandstone layer communicates with the quaternary sand and gravel aquifer, and the pore water flows directly into the well through leakage, becoming the water source. The main water source of floor filling is L_8 karst fissure water. Because the water barrier between coal seam and Baash aquifer is thin and unstable, when mining meets the fault fracture zone, L_8 water will enter the coal seam, resulting in water gushing or water inrush accident. L_8 water is the main water source of No.21coal, with a large outburst of water and a strong incoming force. L_2 limestone water is the indirect water source of coal. The aquifer of L_2 is close to the aquifer of Ordovician limestone. When there are water-conducting faults, the two ash and Ordovician limestone karst fissure water can supplement the L_8 water and become the indirect water source of the two coal.

4.1.2. Water inrush passage

There are many kinds of water-filled channels in the mining area, such as fracture zone, L_2 and L_8 combined channels, fissure channels caused by mining and "skylight" channels. In the mining process, the Austrian ash water supplies the L_2 water and L_8 water through the fault zone or "skylight", and then enters the mine along the structural crack or directly breaks through the water barrier floor, resulting in the mine water filling.

4.2. Hydrochemical analysis

The water sample data of four aquifers in Jiaozuo mining area (table below) are analyzed. The data in the table is the content of ion components, the unit is mg/L.

Table 1. Hydrochemical data of water samples from Jiaozuo mining area

Serial	Category	Na^+	Mg^{2+}	Ca^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
1	1	274.7	110.9	113.7	510.8	246.5	351
2	1	54.4	26.7	114	430.1	34	63.5
3	1	2.5	31.6	53.2	194.7	14	60
4	1	2.6	77.3	56.1	420.7	21	56.5
5	1	189.8	69.1	92	473.1	68	354
6	1	89.9	30.2	120.9	401.9	34	133.5
7	1	39.8	13.8	42.9	215.1	10	29.5
8	1	43.5	35	39.7	291	13	47
9	1	74.1	28	59.9	214.3	29	131.5
10	1	60.3	21.4	54.5	193.8	33	85
11	1	266.6	6.1	24.9	503.9	26.5	69.5
12	1	70.9	38.5	136	322.5	89.5	214.5
13	2	30.3	16.2	72.5	248.7	16	52.5
14	2	34.3	23.4	64.9	301.8	9.5	36.5
15	2	17.1	24.9	64.5	290.2	7	25
16	2	97.6	9.2	6.5	42.4	7	145
17	2	13.3	15.3	59.1	212.2	5	33
18	3	17.6	23.9	66.7	285.8	6.5	27.5
19	3	15.4	26.3	61.7	260.9	7.5	35.5
20	3	7.4	24.8	55.2	256.6	5	19.5
21	3	13.3	14.6	67	185.5	7.5	74.5
22	3	119.6	6.8	16.2	307.3	11.5	23
23	3	4.2	27.8	62	295.4	9	2.5
24	3	4.7	27.1	68.6	255.2	6.5	43.5
25	3	58	30.5	145.4	319.7	69.5	217
26	3	172.3	2.2	2.9	367.7	11	19
27	3	9.7	43.8	108.9	307.5	53.5	103
28	4	263.3	2.2	4.7	630.3	8	2.5
29	4	303.6	0.5	4.3	685.2	15	1.5
30	4	120.8	4.1	16.9	288.9	9.5	38
31	4	157.5	13.8	54.1	535.7	27.5	2
32	4	225.2	17	41.1	659.4	61	133
33	4	2.8	46.7	98.2	495.3	12.5	3
34	4	202.1	6.88	17.23	239.1	14.11	6.49

Conventional hydrochemical analysis was performed on the data and piper was drawn as shown in Figure.2.

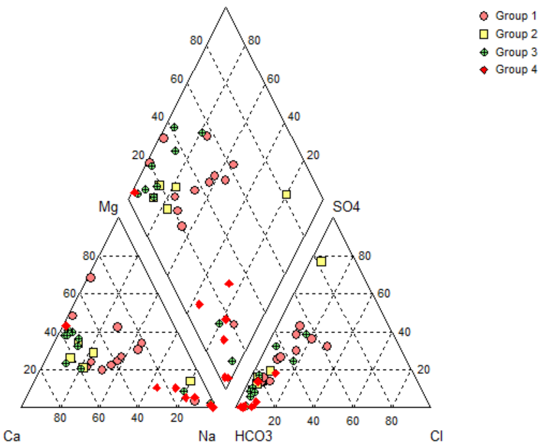
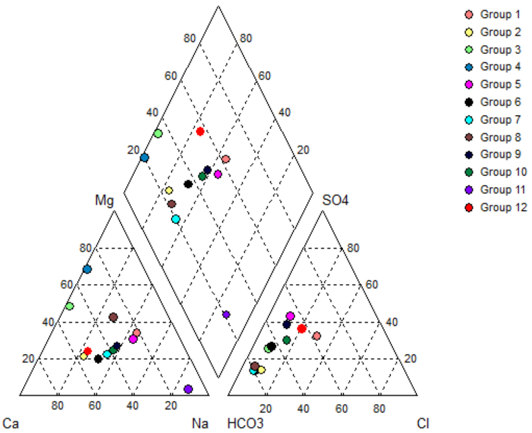
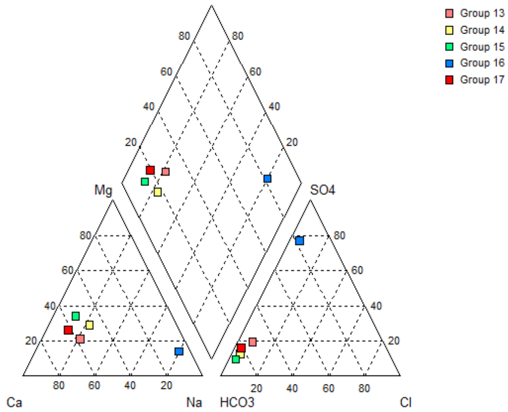


Figure 2. Piper of water sample in Jiaozuo mining area

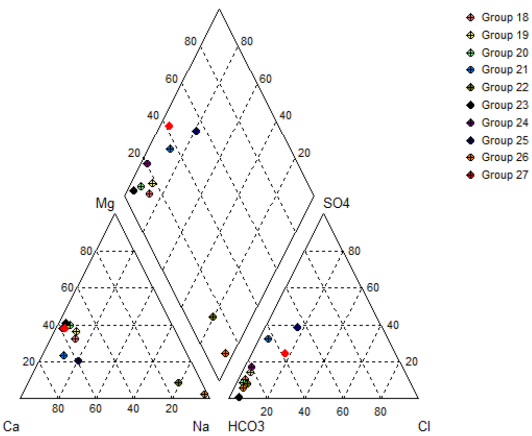
Group1-4 in the figure represents Quaternary water, Ordovician limestone water, carboniferous limestone water and Permian sandstone water respectively. It can be seen from piper figure that quaternary water is mainly Ca-Na-Mg-HCO_3 type. The main types of Austrian lime water and lime water are Ca-Mg-HCO_3 type. The main type of Permian sandstone water is Na-HCO_3. Hydrochemical analysis was carried out separately for each type of water sample, and the piper three-line diagram of the water sample obtained was shown as follows.



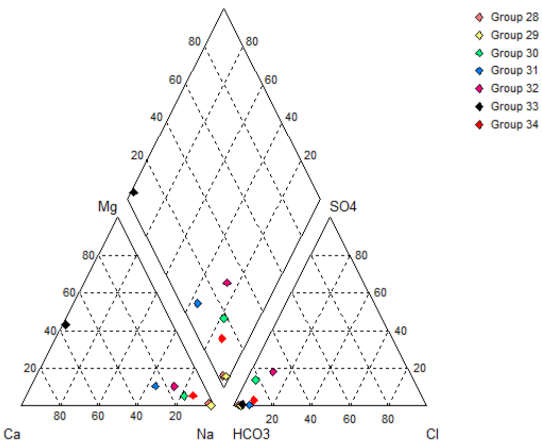
(a) piper diagram of quaternary water sample



(b) piper map of Ordovician limestone water sample



(c) Piper of carboniferous limestone water sample



(d) Piper of Permian sandstone water sample

Figure 3. Piper of water samples from different aquifers

According to the piper diagram of each type of water sample, the distribution of water samples No. 3, 4, 11 and 12 in the quaternary water is inconsistent with other water samples in the piper diagram. The abnormal data of Austrian gray water sample is No. 16; The abnormal data of lime water samples are No. 22 and No. 26; The abnormal data of Permian sandstone water sample is No. 33. The piper diagram of water sample in Jiaozuo mining area after removing the above abnormal data is shown in Figure 3.

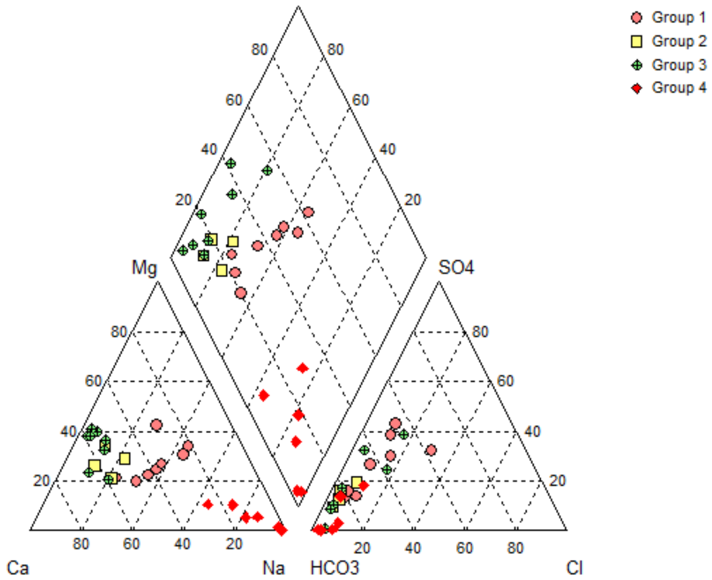


Figure 3. Piper of water sample in Jiaozuo Mining Area (excluding abnormal data)

4.3. Select the principal component variable

Principal component analysis was performed on the water sample data, and the results were as follows.

Table 2. Correlation table of each ion

		Na^+	Mg^{2+}	Ca^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
correlation	Na^+	1.000	0.128	-0.321	0.817	0.464	0.312
	Mg^{2+}	0.128	1.000	0.616	0.093	0.852	0.830
	Ca^{2+}	-0.321	0.616	1.000	-0.133	0.483	0.614
	HCO_3^-	0.817	0.093	-0.133	1.000	0.348	0.212
	Cl^-	0.464	0.852	0.483	0.348	1.000	0.809
	SO_4^{2-}	0.312	0.830	0.614	0.212	0.809	1.000

It can be seen that there is a certain correlation between ion concentrations in the table, for example, the correlation between Cl^- and Mg^{2+} is 0.852, so it is necessary to use principal component analysis to process the original data. The resulting total variance is explained and the extracted gravel map is shown below

Table 3. Total explanatory variance

Ingredient	Initial eigenvalue			Extract the sum of squared loads		
	Total	Percent variance	Cumulative percentage	Total	Percent variance	Cumulative percentage
1	3.268	54.471	54.471	3.268	54.471	54.471
2	1.944	32.395	86.866	1.944	32.395	86.866
3	0.425	7.090	93.956	0.425	7.090	93.956
4	0.200	3.325	97.281			
5	0.129	2.150	99.431			
6	0.034	0.569	100.000			

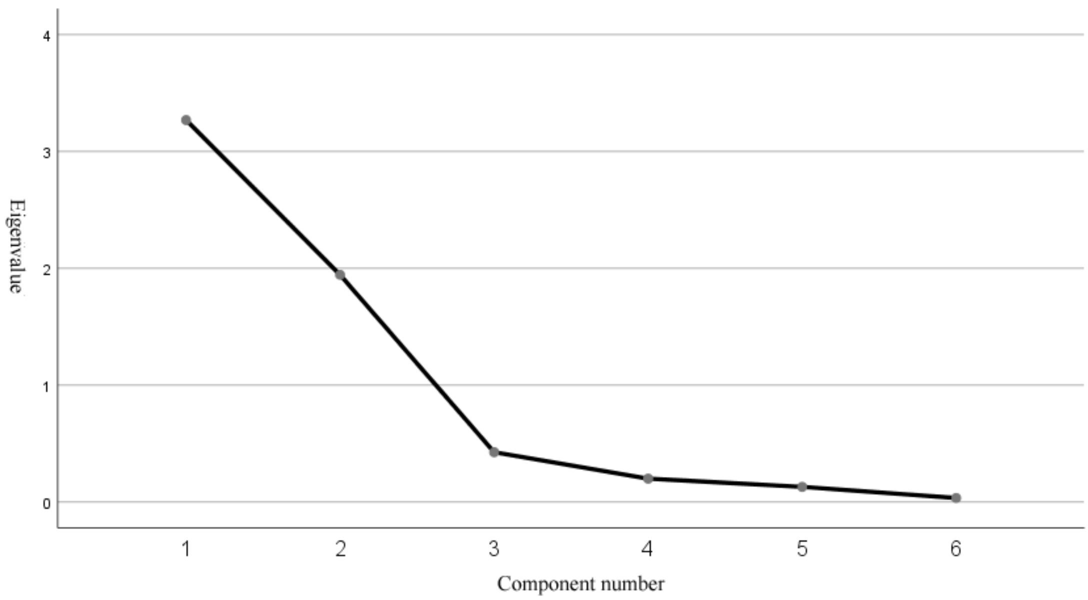


Figure 4. Principal component lithotripsy diagram

According to the lithograph, the curve becomes smooth after the third principal component, indicating that the principal component after the third principal component contains less information of the original data. Therefore, three principal components are selected to extract, and the first three principal components contain 93.956% information of the original data, which meets the requirements. The obtained component score coefficient matrix is shown in Table 4.

Table 4. Component score coefficient

成分	Na^+	Mg^{2+}	Ca^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
1	0.129	0.276	0.188	0.118	0.289	0.284
2	0.453	-0.138	-0.328	0.422	0.032	-0.063
3	-0.216	-0.461	1.052	0.906	-0.382	-0.138

The principal component coefficients are calculated according to the component score coefficient matrix, as shown in Table 5.

Table 5. Principal component coefficient

F1	0.071	0.153	0.104	0.065	0.160	0.157
F2	0.325	-0.099	-0.235	0.303	0.023	-0.045
F3	-0.331	-0.707	1.614	1.390	-0.586	-0.212

The principal component expression is:

$$F_1= 0.071Na^{+}+0.153Mg^{2+}+0.104Ca^{2+}+0.065HCO_3^{-}+0.160Cl^{-}+0.157SO_4^{2-} \quad (4\text{-}1)$$

$$F_2= 0.325Na^{+}-0.099Mg^{2+}-0.235Ca^{2+}-0.303HCO_3^{-}+0.023Cl^{-}-0.045SO_4^{2-} \quad (4\text{-}2)$$

$$F_3=-0.331Na^{+}-0.707Mg^{2+}+1.614Ca^{2+}+1.390HCO_3^{-}-0.586Cl^{-}-0.212SO_4^{2-} \quad (4\text{-}3)$$

4.4. Cluster analysis of principal component variables

No. 8, No. 14, No. 21 and No. 29 were selected as the water samples to be measured, and the calculated principal component data were analyzed by clustering, and the pedigree diagram was obtained as shown in Figure.5

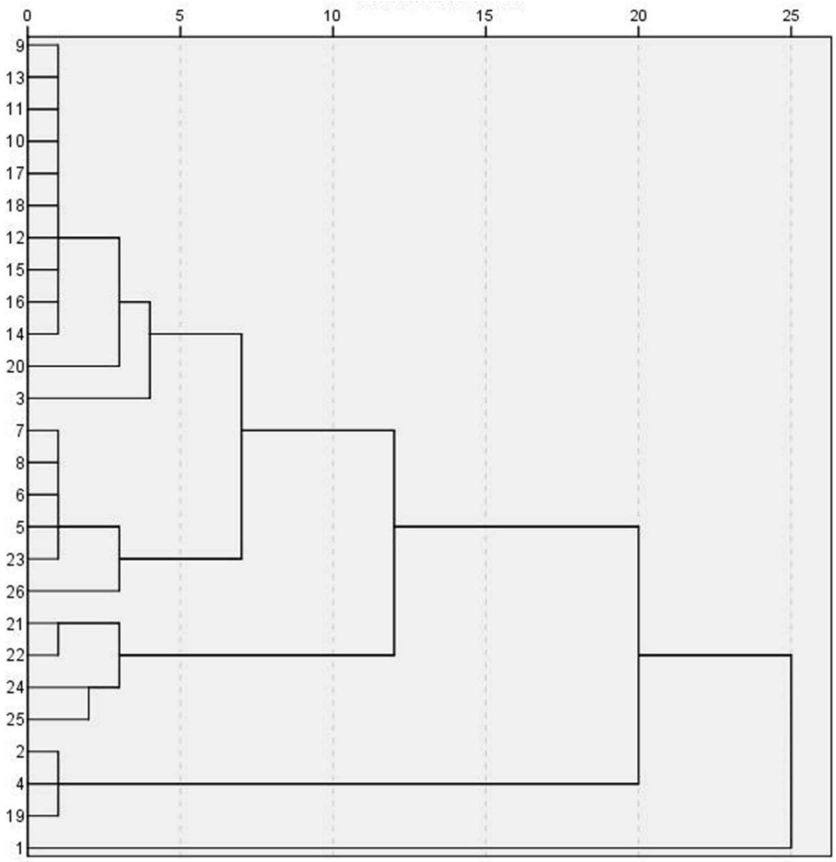


Figure 5. Principal components-cluster analysis pedigree

According to the pedigree chart. The result of the discrimination of the water sample to be tested is compared with the actual type, as shown in Table.6.

Table 6. Model discrimination result

Serial number of water sample	Discriminant type	Actual type
8	Quaternary water	Quaternary water
14	Ordovician limestone water	Ordovician limestone water
21	Carboniferous limestone water	Carboniferous limestone water
29	Permian sandstone water	Permian sandstone water

5. CONCLUSION

This paper takes Jiaozuo mining area as the research area, selects water samples from aquifer of Jiaozuo mining area as the research object, collects the data of hydrogeological conditions of Jiaozuo mining area, selects 6 kinds of conventional ions Na^+, Mg^{2+}, Ca^{2+}, HCO_3^-, Cl^- and SO_4^{2-} as variables to distinguish water inrushing source, and establishes water inrushing source identification model. And the model is analyzed. The main conclusions are as follows:

(1) The relevant data of hydrogeological conditions in Jiaozuo mining area were sorted out and analyzed, the conditions of groundwater recharge, runoff and discharge in the mining area were identified, the types and characteristics of each aquifer formation in the mining area were summarized, and the hydraulic relations between each aquifer were discussed.

(2) Based on the analysis of hydrogeological conditions in Jiaozuo mining area, the water samples of aquifer inburst in mining area were analyzed by hydrochemistry, piper three-line map was drawn, and the main types of groundwater in each aquifer were identified.

(3) Based on the analysis results of hydrochemical data in mining area, the method of dimensionality reduction is adopted to process the original water sample data based on principal component analysis and cluster analysis. The principal component, which retains most of the original data information, is used as a variable for clustering. The identification model of water inburst source in mining area is established by principal component-cluster analysis, and the feasibility and accuracy of the model are tested.

(4) Compared with using cluster analysis method alone to distinguish water inburst source, the model and the discrimination results were analyzed, and the superiority of the model compared with using cluster analysis method alone was verified.

REFERENCES

[1] Q Wu,M Wang,X Wu. Investigations of groundwater bursting into coal mine seam floors from fault zones[J]. International Journal of Rock Mechanics and Mining Sciences,2003,41(4).

[2] M. Carroll,C. Romanek,L. Paddock. The relationship between the hydrogen and oxygen isotopes of freshwater bivalve shells and their home streams[J]. Chemical Geology,2006,234(3).

[3] Jiang Yaodong,Lv Yukai,Zhao Yixin,et.al.Similar Simulation Test For Breakage Law Of Working Face Floor In Coal Mining Above Aquifer[J].Chinese Journal of Rock Mechanics and Engineering,2011,30(08):1571-1578.

[4] Zhang Fengda. Study on lithologic effect of mining-induced failure mechanism of coal seam floor[J]. Coal Science and Technology,2023,51(11):166−178.

[5] Wang Q ,Zheng S ,Shi Z , et al. Mechanism of and Prevention Technology for Water Inrush from Coal Seam Floor under Complex Structural Conditions—A Case Study of the Chensilou Mine[J].Processes,2023,11(12).

[6] Nonlinear Research; New Data from Jadavpur University Illuminate Findings in Nonlinear Research (Two-frequency parametric excitation and internal resonance of a moving viscoelastic beam) [J].Journal of Technology Science,2015.

[7] Monitoring water quality of the Sergipe River basin: an evaluation using multivariate data analysis [J]. RBRH, 2018, 23 (23).

[8] Caballero-Villalobos J ,Figueroa A ,Xibrraku K , et al. Multivariate analysis of the milk coagulation process in ovine breeds from Spain [J]. Journal of Dairy Science, 2018, 101 (12): 10733-10742.

[9] Razzak A M ,Molla U H M .A new analytical technique for strongly nonlinear damped forced systems[J].Ain Shams Engineering Journal,2015,6(4):1225-1232.

[10] Li Dongchen. Recognizing Hydrochemical Featuresof Basal Water And Water Gushsource In Baimiao Coal Mine[J]. Carsologica Sinica,1995(04):295-304.

[11] Yue Mei,Zhang Huaigong.Application of the multiple-variables correlationanalysis with gray system theory in judging thesource of mine gushed water[J]. Journal of Huainan Mining Institute,1998(02):7-10.

[12] Chen Hongjiang, Li Xibing, Liu Aihua, et al. Identifying Of Mine Water Inrush Sources By Fisher Discriminant Analysis Method[J]. Journal Of Central South University (Science And Technology),2009,40(04):1114-1120.

[13] Li Zhifeng,Zhai Zhen. Fisher discriminant model of water inrush source in coal mine [J]. Expressinformation Of Miningindustry,2008,(09):57-58.

[14] Chen Hongjiang,Li Xibin,Li Aihua. Studies Of Water Source Determination Method Of Mine Water Inrush Based On Bayes' Multi-Group Stepwise Discriminant Analysis Theory [J]. Rock And Soil Mechanics,2009,30(12):3655-3659.

[15] Wan Wen. BDA models and application for recognizing the headstreams of mine waterbur st [J]. Mineral Engineering Research,2009,24(03):27-30.

[16] Wu Qiang,Pang Wei,Dai Yingchun,et al. Vulnerability Forecasting Model Based On Coupling Technique Of Gis And Ann In Floor Groundwater Bursting [J]. Journal Of China Coal Society,2006,(03):314-319.

[17] Zhu Cui,Qiang Jiazhong,Zhou Xiaoping,Et Al. Water-Inrush Source Discrimination With Bp Neural Network In Pansan Mine [J]. Journal Of Anhui Institute Of Architecture & Industry,2010,18(05):35-38.

[18] Xu Zhongjie,Yang Yongguo,Tan Lin.Application of bp neural network in evaluation of water source in mine[J]. Safety In Coal Mines,2007,(02):4-6+17.