Recognition Method of Mine Water Sources Based on Factor Analysis

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Abstract: Taking Jiaozuo mining area as the research background, according to the survey of water samples among the main water-filled aquifers of the mine and water gushing sources due to the exploitation of the No.2_1 coal seams in Shanxi group, six kinds of water chemical composition were selected as the sample indexes, including Cl^-, SO_4^{2-}, HCO_3^-, Na^++K^+, Ca^{2+}, Mg^{2+}, based on the data of groundwater chemical composition, and a principal component analysis was applied to establish the mathematical model by the method of factor analysis. A piper diagram was used to intuitively conduct the synthetical analyses for the general chemical characteristics and water quality types of the water samples. At the same time, via the comparative analysis between the water properties of water exits and that of the main aquifers in the Jiaozuo mining area, discrimination of the hybridization of the multiple water gushing sources due to coal mining was done. Moreover, by dint of the SPSS factor analysis, the water chemical proxies were carried on dimensionality reduction from the six kinds of water chemical composition to the three major factors, which replaced the original variables to participate in the data modeling. The results of the study showed that the combination of the piper diagram and the factor analysis modeling could effectively identify the water gushing sources owing to exploiting the No.2_1 coal seams of the Shanxi group in the Jiaozuo mining area and rank on the basis of the contributions of each aquifer to the amounts of water bursting in the mine, solving the problems of information superposition and correlations consisted in the identification of water gushing sources, which provides a theoretical basis for the prevention and cure of the mine water disasters.

Keywords: Mine water inrushes; Recognition of mine water sources; Piper diagram; Factor analysis.

INTRODUCTION

China is a country with coal as the major energy resource, and it is also a country with frequent mines water hazards. The proportions of coal consumption in the Chinese energy consumption structure have been about 65%~70% for a long time. Although China is vigorously developing and using new energy, according to "the 13th Five-Year plan for energy development" [1] in 2016, and striving to decrease the proportions of coal consumption to about 58% by 2020 in China, it is forecasted that the consumption of coal in Chinese structure of energy consumption will still account for more than 50% even by 2050. Therefore, coal will still be the major energy resource in our country for a long time. After mining more than half a century, the shallow coal resources have been almost exhausted, and most of the mines have entered deep mining in China, which intensifies the complexity of the geological and hydrogeological conditions, resulting in the frequent occurrence of mine water disasters and the diversity of types of mine gushing sources [2-7]. The deaths caused by coal mining in China are four times the total number of deaths among the major coal mining countries in the world from 2004 to 2010 [8-13]. Thirty-eight serious casualty accidents occurred in nationwide coal mining in 2008. Out of these, one incident that caused the death of more than ten people at a time; seven hundred and seven people died in it. The number of deaths caused by water inrush accidents reached one hundred and thirty-five people, accounting for 19.1% of the total number, which is next to the personal casualties caused by gas accidents [14-19]. According to the incomplete statistics based on related data, one hundred and eighty-two people died because of mining water hazards in China from 2013 to 2016. Therefore, it can be seen that the mining water hazards are the long-standing practical problems existing in the safety production of coal mining and need to be solved continuously [20-24].

How to monitor the water exits, distinguishing whether the known water sources and the water exits are connected, and the supplies of water sources for the yield of water exits is the basis for preventing and treating mining water hazards [25-30]. Currently, in the field of identifying water sources being from mine water gushing, the scholars have adopted different methods to distinguish the characteristics of the groundwater chemical composition and then predicted the types of water gushing sources [31-35]. For instance, Zhou et al. [36] proposed water-bursting source determination of a mine based on distance discriminant analysis model. Chen et al. [37-38] identified mine water inrush sources by Fisher's discriminant analysis method and

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Bayes' multi-group stepwise discriminant analysis theory. Yu et al. [39] applied the Fuzzy comprehensive evaluation method in identifying water sources of water-rush in the underground shaft. Jiang et al. [40] presented the particle swarm optimization support vectors machine method for identifying standard components of ions of groundwater. All of the above methods have achieved a certain guiding value to the fieldwork. However, because water bursting in mine is affected by various indicators such as climate, hydrological characteristics, and faulted structure of the mining area, the extraction of effective field data is relatively less [41-49]. When the evaluation index is multidimensional, there will be a problem of information superposition and relatively lesser data volume [50]. For example, although the literature [36] has well sorting performance, it is still a preliminary attempt to apply the theory to the identification and modeling of the mine water gushing sources, and there are still some problems to be further studied. The literature [40] has gained preferable results, but the prediction accuracy of LSSVM depends mainly on the selection of the penalty parameter C and the kernel function σ. So, it is a difficult problem needed to be resolved that how to accurately identify the situation of mine water gushing sources in the process of the working face in advance, in order to provide effective ways to prevent and control the water bursting in mine. In this study, we adopted the method based on the factor analysis, combining the practical engineering application of exploiting the No.2_1 coal seams of Shanxi group in the Jiaozuo mining area, using a piper diagram to roughly distinguish the hybridization of various water gushing sources. Based on full consideration of the six kinds of water chemical composition, we analyzed the relativity between the original variables and used SPSS factor analysis modeling to solve the core functions of each factor. And then solved the comprehensive scores of the influencing factors of the water gushing sources by the method of variable calculation and rank through the contributions of each aquifer to the water yield of mine inrushes, selecting the aquifers making greater contributions from the study results as the key protection targets of the water bursting in mine, and achieving the crucial significance of identifying the mine water gushing sources under limited information. Moreover, a living example proved by the cluster analysis of the known water samples of water exits showed that integrating the original variables into a few factors, which participate in data modeling instead of the original variables, preferably resolves the problems of information superposition and relativity between the evaluation indexes of water gushing sources. It is feasible to distinguish the mine water gushing sources by applying the multivariate statistical method of the factor analysis, and the discrimination is superior.

MATERIALS AND METHODS

Assume that the simple correlation coefficient matrix of the original variables is R

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix}$$

We conducted a study of the correlation between the original variables using the KMO inspection method [51]. If $KMO \geq 0.8$, there is strong relativity between the original variables. So, the original variables are suitable for factor analysis. Assuming that the number of the original variables is p, we can define them as $x_1, x_2, x_3, \ldots, x_p$. Each of the original variables is expressed by the linear combination of the $k(k<p)$ factors [51], such as $f_1, f_2, f_3, \ldots, f_k$.

$$\begin{aligned} x_1 &= a_{11} f_1 + a_{12} f_2 + a_{13} f_3 + \cdots + a_{1k} f_k + \varepsilon_1 \\ x_2 &= a_{21} f_1 + a_{22} f_2 + a_{23} f_3 + \cdots + a_{2k} f_k + \varepsilon_2 \\ &\cdots \\ x_p &= a_{p1} f_1 + a_{p2} f_2 + a_{p3} f_3 + \cdots + a_{pk} f_k + \varepsilon_p \end{aligned} \quad (1)$$

Where x_i is the original variable. f_i is the principal component. a_{ij} is the linearity coefficient. ε_i is the constant.

Firstly, we standardized the p original correlation variables x_i and calculated the simple correlation coefficient matrix R_1 between the original variables. Besides, gain the eigenvalues $\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_p$ of the correlation coefficient matrix R_1 and the unit eigenvectors $\vec{\mu}_1, \vec{\mu}_2 \ldots \vec{\mu}_p$ corresponding to the eigenvalues. Moreover, via the coordinate conversion, the p standardized original correlation variable x_i is carried on the linear combination, transforming a group of uncorrelated variables y_i [51]. The results are as follows:

$$\begin{aligned} y_1 &= \mu_{11} x_1 + \mu_{12} x_2 + \mu_{13} x_3 + \cdots + \mu_{1p} x_p \\ y_2 &= \mu_{21} x_1 + \mu_{22} x_2 + \mu_{23} x_3 + \cdots + \mu_{2p} x_p \\ &\cdots \\ y_p &= \mu_{p1} x_1 + \mu_{p2} x_2 + \mu_{p3} x_3 + \cdots + \mu_{pp} x_p \end{aligned} \quad (2)$$

Where y_i is the uncorrelated variable. μ_{ij} is the unit eigenvector. x_i is the original variable.

Obtain the factor loading matrix as follows [51]:

$$A=\begin{bmatrix} a_{11} & a_{12} & \Lambda & a_{1k} \\ a_{21} & a_{22} & \Lambda & a_{2k} \\ \mathrm{M} & \mathrm{M} & & \mathrm{M} \\ a_{p1} & a_{p2} & \Lambda & a_{pp} \end{bmatrix}=\begin{bmatrix} \mu_{11}\sqrt{\lambda_1} & \mu_{21}\sqrt{\lambda_2} & \Lambda & \mu_{k1}\sqrt{\lambda_k} \\ \mu_{12}\sqrt{\lambda_1} & \mu_{22}\sqrt{\lambda_2} & \Lambda & \mu_{k2}\sqrt{\lambda_k} \\ \mathrm{M} & \mathrm{M} & & \mathrm{M} \\ \mu_{1p}\sqrt{\lambda_1} & \mu_{2p}\sqrt{\lambda_2} & \Lambda & \mu_{kp}\sqrt{\lambda_k} \end{bmatrix}$$

Determine the number of factors, supposing it is k, according to the accumulative variance contribution of the factors [51]. It is:

$$a_k=\frac{\sum_{i=1}^{k}\lambda_i}{\sum_{i=1}^{p}\lambda_i} \qquad (3)$$

Where a_k is the accumulative variance contribution. λ_i is the eigenvalue. k is the number of principal components. p is the number of original variables.

Selecting $a_k \geq 0.85$, which means the quantity of the eigenvalues is equal to the number of the factors, and the mathematical model is established by factor analysis.

Study Area

The Jiaozuo mining area (Fig. **1**) is located on the southern side of the uplift of the anticlinorium, situating in the composite area of the East-West structure and the Neocathaysian structural system. The major coal-bearing series being in the Jiaozuo mining area is the Permo-Carboniferous coal seams. The No.2_1 coal seams in the Shanxi group, with an average of 6.0 m thickness of coal seams, were primarily exploited [52]. The major water-filled aquifers affecting the mine production in the study area mainly consist of the hydrated layer of quaternary system featured by sand-gravel pore water, the Permian system aquifers featured by sand-shale crevice water, the carboniferous system aquifers featured by lamina carbonate crevice-karst water, and the Ordovician system aquifers featured by carbonatite karst water [53], but the aquicludes exist among the aquifers. However, there were thousands of water gushing caused by exploiting the No.2_1 coal seams of Shanxi group in the Jiaozuo mining area, where the critical discharge over 600 m^3 per hour occurred 75 times, over 6000 m^3 per hour occurred 8 times, and the maximum discharge of the mine water gushing is up to 1920 m^3 per hour [52]. In order to ascertain the mine water gushing sources caused by exploiting the No.2_1 coal seams in the Shanxi group, the water sources, stemming from 32 sampling sites and 4 water exits, including the hydrated layer of the quaternary system, the roof sandstone aquifers, and the underlying aquifers mainly containing the Ordovician limestone formation and the Carboniferous limestone formation, were sampled to carry on detection. On the basis of the observed prototype data, six kinds of ion compositions with a distinct meaning Cl^-、SO_4^{2-}、HCO_3^-、Na^++K^+、Ca^{2+}、Mg^{2+}, were selected as the chemical characteristics of the different water sources. Table **1** shows the content of ion composition detected in the 32 water samples of the aquifers [53]. Table **2** shows the content of ion composition detected in the 4 water samples of the water exits [53].

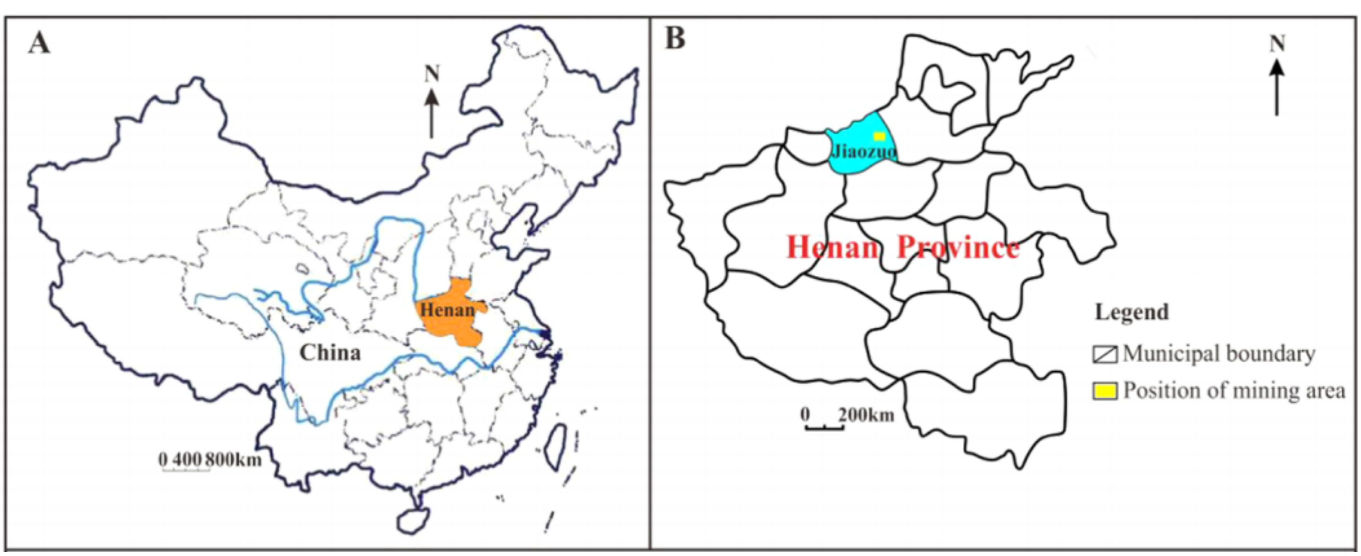

Figure 1: Location map of the Jiaozuo mining area.

Table 1: The Content of Ion Composition Detected in the 32 Water Samples of the Aquifers

The Sources of Water Samples	The Content of Ion Composition					
	Ca^{2+}	Mg^{2+}	$Na^{+}+K^{+}$	HCO_3^{-}	SO_4^{2-}	Cl^{-}
The Ordovician limestone aquifers1	76.15	15.56	11.98	292.84	26.90	8.50
The Ordovician limestone aquifers2	65.73	18.48	19.34	239.19	67.24	10.64
The Ordovician limestone aquifers3	84.57	24.81	11.50	253.83	82.61	19.86
The Ordovician limestone aquifers4	52.50	16.29	19.78	229.43	37.66	9.93
The Ordovician limestone aquifers5	46.20	17.60	35.10	212.90	43.20	35.80
The Ordovician limestone aquifers6	73.24	24.80	44.88	303.56	85.97	24.07
The Carboniferous limestone aquifers1	61.23	29.33	10.29	309.85	47.46	12.16
The Carboniferous limestone aquifers2	59.30	28.40	10.64	291.68	34.70	12.59
The Carboniferous limestone aquifers3	69.30	26.39	8.00	295.24	43.88	10.96
The Carboniferous limestone aquifers4	63.43	24.10	6.45	266.34	41.90	9.24
The Carboniferous limestone aquifers5	63.50	26.90	8.30	282.52	43.85	11.19
The Carboniferous limestone aquifers6	63.00	24.70	7.10	266.13	37.80	7.35
The Carboniferous limestone aquifers7	67.10	39.00	7.70	281.57	46.50	8.82
The Carboniferous limestone aquifers8	68.70	24.90	7.00	282.16	43.77	11.70
The Carboniferous limestone aquifers9	62.96	17.28	17.85	284.57	23.31	6.68
The Carboniferous limestone aquifers10	61.59	18.85	13.59	276.69	23.57	6.68
The Carboniferous limestone aquifers11	63.87	32.83	10.00	295.87	65.09	4.06
The Carboniferous limestone aquifers12	69.39	29.38	12.69	325.08	34.54	13.64
The roof sandstone aquifers1	3.10	1.10	98.10	638.70	43.84	23.50
The roof sandstone aquifers2	34.75	11.16	207.35	558.82	46.54	23.78
The roof sandstone aquifers3	16.25	2.04	311.75	736.76	20.56	33.58
The roof sandstone aquifers4	10.24	8.55	303.12	773.45	17.47	32.84
The roof sandstone aquifers5	5.77	3.61	304.82	628.96	53.00	40.77
The roof sandstone aquifers6	10.22	3.72	358.58	691.17	14.69	32.68
Hydrated layer of quaternary system1	86.50	31.80	9.10	348.31	57.80	22.40
Hydrated layer of quaternary system2	99.20	31.10	13.25	361.12	83.00	29.85
Hydrated layer of quaternary system3	106.7	39.10	9.20	402.10	69.80	40.10
Hydrated layer of quaternary system4	98.20	20.60	17.30	354.40	53.20	20.24
Hydrated layer of quaternary system5	69.14	22.93	4.68	251.26	13.38	26.67
Hydrated layer of quaternary system6	74.67	16.92	19.58	272.94	27.62	24.46
Hydrated layer of quaternary system7	70.47	16.78	19.90	294.47	10.79	18.40
Hydrated layer of quaternary system8	51.73	16.04	20.54	236.00	12.34	24.34

Table 2: The Content of Ion Composition Detected in the 4 Water Samples of the Water Exits

The Sources of Water Samples	The Content of Ion Composition					
	Ca^{2+}	Mg^{2+}	$Na^{+}+K^{+}$	HCO_3^{-}	SO_4^{2-}	Cl^{-}
Water exit 1	66.40	19.59	23.76	255.29	57.26	18.13
Water exit 2	64.45	26.84	9.97	288.14	40.53	9.59
Water exit 3	8.93	3.63	294.75	680.51	24.24	30.27
Water exit 4	81.96	24.41	14.19	315.08	40.99	25.81

RESULTS

Distribution Characteristics of Mine Water Quality

Piper diagram is an analytic procedure in common use to determine the hydrochemistry ion composition, which can be used to intuitively analyze the general chemical characteristics and the types of water quality among the water sources [54-59]. In this study, based on the six ion compositions with a distinct meaning, Cl^-、SO_4^{2-}、HCO_3^-、$Na^+ + K^+$、Ca^{2+}、Mg^{2+}, extracted from the 32 sampling sites and 4 water exits, adopting hydrochemistry software AqQA, we analyzed the distribution characteristics of water quality among the water samples of the main aquifers and water exits in Jiaozuo mining area. Meanwhile, through the comparison of hydrochemistry composition and hydrochemistry content among the water samples, the possible water gushing sources were distinguished, which were caused by exploiting the No.2_1 coal seams in the Shanxi group. The results are shown in Fig. **2**.

It can be seen from the figure that the water samples of the overlying aquifers and the underlying aquifers are all concentrated in the rhombic area, respectively, belonging to HCO_3^--Na^++K^+ and HCO_3^--Ca^{2+}. The water samples of the water exits are basically located in the third area of the rhombic basin, where the content of weak chloroplatinate ion is greater than that of strong acid ion, meaning that the content of HCO_3^- is greater than that of SO_4^{2-} and Cl^-, so the type of water quality belongs to HCO_3^--Ca^{2+}·Na^++K^+. And there are four water samples of the water exits, staggered among the distribution range of the roof sandstone aquifers and the floor limestone aquifers, reflecting that the water quality of the coal measures rushing is close to that of the overlying and underlying aquifers. It means that the water yield caused by exploiting the No.2_1 coal seams of the Shanxi group in the Jiaozuo mining area is jointly supplied by the overlying and underlying aquifers.

Variable Correlation Analysis

The strong correlation between the original variables is an essential prerequisite for the extraction of public factors and the factor analysis [51]. So, this paper carries out the correlation analysis among the original variables with the help of the method of *KMO* inspection. The results of the analysis are shown in Table **3**.

Table 3: The Results of the *KMO* and *Bartlett* Inspection

***Kaiser-Meyer-Olkin* Measure with Adequate Sampling**	**0.805**
The sophericity test of *Bartlett* Approximate chi square distribution	168.985
df	15
Sig.	0.000

As seen from Table **3**, the observed value of the sphericity test of *Bartlett* statistic is 168.985, and its corresponding probability value *P* is less than the given

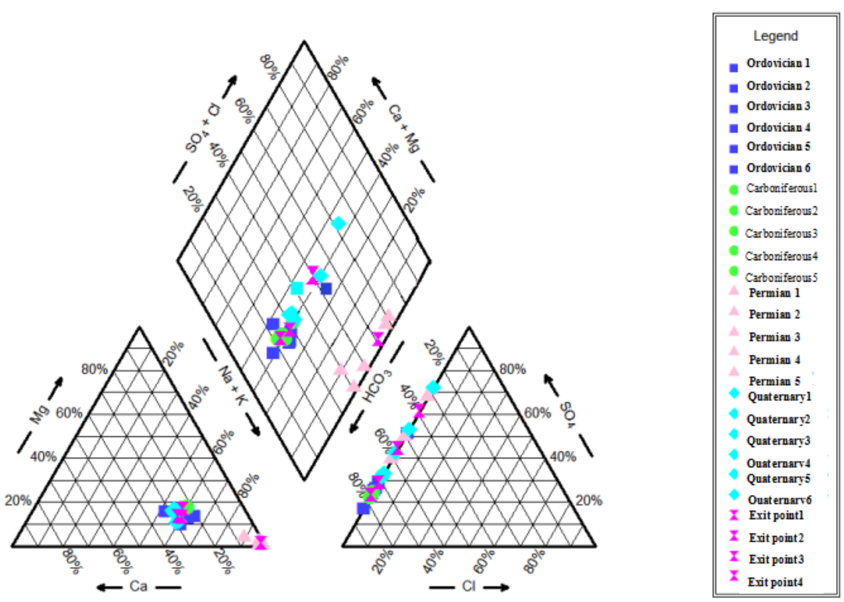

Figure 2: Piper diagram.

significance level. In addition, the result of the *Kaiser-Meyer-Olkin* measure is 0.805. According to the comparison between the above-mentioned analysis results and the modules, we can conclude that the original variables are suited for factor analysis.

Modeling for the Recognition of Mine Water Gushing Sources Based on the SPSS Factor Analysis

According to the correlation coefficient matrix of the original variables, adopting the method of the principal component analysis specifies three factors to be extracted, and the initial solution is obtained. The analysis results are shown in Table **4** to **6**.

Table 4: The Common Factor Variances

	Initial Value	Extraction
Ca^{2+}	1.000	0.918
Mg^{2+}	1.000	0.818
Na^{+}+K^{+}	1.000	0.936
HCO_3^-	1.000	0.889
SO_4^{2-}	1.000	0.981
Cl^-	1.000	0.979

As seen from the extraction results, in the case of specifying three eigenvalues to be extracted, the communalities between all the original variables have a higher level, and the cumulative contribution of variances can account for 100%. The three factors explain 92.014% of the total square deviation among the original variables. It can be seen from the scree graph (Fig. **3**) that the first factor has a higher eigenvalue, making a greater contribution to interpreting the original variables. Therefore, the total effect of the factor extraction is satisfactory in this study. The factor analytic modeling is shown as follows:

$$\begin{aligned}&Na^{+}+K^{+}=0.952f_1+0.145f_2-0.090f_3;\ \ HCO_3^{-}=0.909f_1+0.227f_2-0.109f_3\\&Ca^{2+}=-0.898f_1+0.205f_2+0.263f_3;\ \ Mg^{2+}=-0.877f_1+0.209f_2+0.071f_3\\&Cl^{-}=0.614f_1+0.609f_2+0.480f_3;\ \ SO_4^{2-}=-0.453f_1+0.777f_2-0.416f_3\end{aligned}\quad(4)$$

where f_i is the principal component.

Table 6: The Component Matrix

	Composition		
	1	2	3
Na^{+}+K^{+}	0.952	0.145	-0.090
HCO_3^-	0.909	0.227	-0.109
Ca^{2+}	-0.898	0.205	0.263
Mg^{2+}	-0.877	0.209	0.071
Cl^-	0.614	0.609	0.480
SO_4^{2-}	-0.453	0.777	-0.416

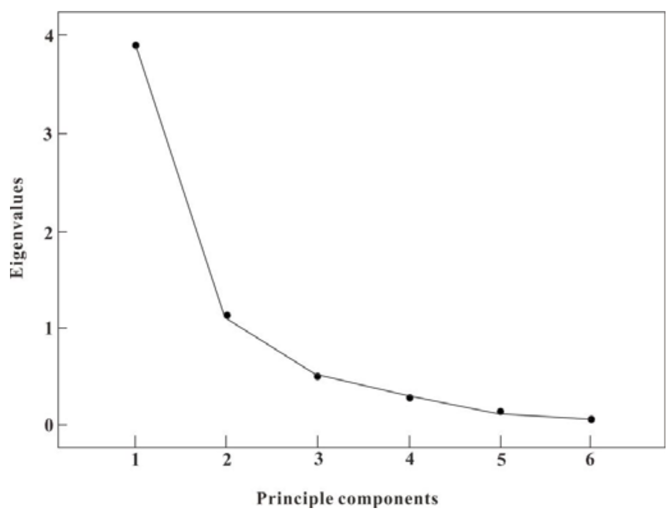

Figure 3: The Scree Graph of Factor Analysis.

The five variables present higher loading on the first factor. So adopting the method of varimax conducts the orthogonal rotation for the factor loading matrix

Table 5: Total Variances of Interpretation

Ingredients	Initial Eigenvalues		Extraction of Sum of Squares		Rotation of Sum of Squares	
	Variances%	Accumulation%	Variances%	Accumulation%	Variances%	Accumulation%
1	64.841	64.841	64.841	64.841	50.748	50.748
2	18.880	83.721	18.880	83.721	22.011	72.760
3	8.293	92.014	8.293	92.014	19.254	92.014
4	4.674	96.688				
5	2.272	98.960				
6	1.040	100.000				

according to the descending order of the first-factor loading, as shown in Table **7**, Table **8**, and Fig. **4**.

Table 7: The Rotational Component Matrix

	Composition		
	1	2	3
Ca^{2+}	-0.918	-0.066	0.266
$Na^{+}+K^{+}$	0.863	0.423	-0.109
HCO_3^-	0.832	0.444	-0.022
Mg^{2+}	-0.804	-0.181	0.372
Cl^-	0.267	0.952	0.026
SO_4^{2-}	-0.219	0.030	0.966
Factor contributions	50.748%	22.012%	19.254%

Table 8: The Component Transition Matrix

Composition	1	2	3
1	0.866	0.410	-0.285
2	-0.043	0.630	0.775
3	-0.498	0.659	-0.564

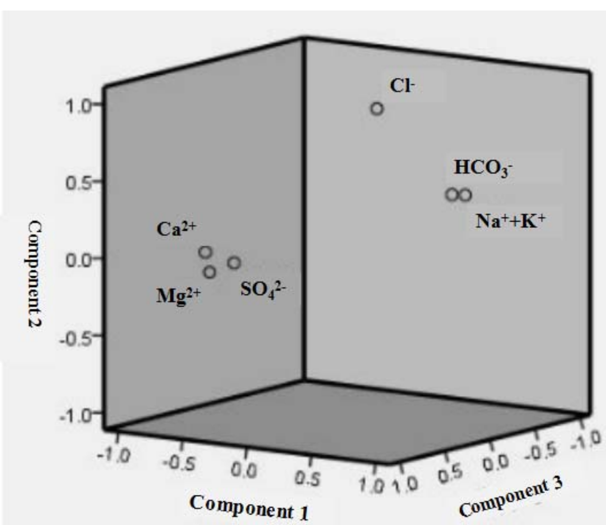

Figure 4: The Load Intensity Diagram of the Rotated Factors.

Via the orthogonal rotation, the first-factor loading accounts for 50.748%, and the water-quality indexes closely connected with the first principal factor contain $Na^{+}+K^{+}$、HCO_3^-、Mg^{2+}、Ca^{2+}. The second factor loading accounts for 22.012%, and the water-quality index closely connected with the second principal factor is Cl^-. The third factor loading accounts for 19.254%, and the water-quality index closely connected with the third principal factor is SO_4^{2-}. Owing to the contribution rate of the first principal factor is greater than that of other principal factors, as shown in Table **9**, there is no linear correlation among the three factors. So, the key impacting indicators of the mine water gushing sources caused by exploiting the No.2_1 coal seams of Shanxi group in the Jiaozuo mining area include $Na^{+}+K^{+}$、HCO_3^-、Mg^{2+}、Ca^{2+}. So using the regression method estimates the factor score coefficient as seen from Table **10**. The factor score functions are as follows:

$$
\begin{aligned}
F_1 &= -0.471Ca^{2+} - 0.274Mg^{2+} + 0.296Na^{+} + K^{+} + 0.303HCO_3^{-} + 0.286SO_4^{2-} - 0.366Cl^{-} \\
F_2 &= 0.368Ca^{2+} + 0.118Mg^{2+} + 0.062Na^{+} + K^{+} + 0.078HCO_3^{-} - 0.167SO_4^{2-} + 1.039Cl^{-} \\
F_3 &= -0.092Ca^{2+} + 0.127Mg^{2+} + 0.131Na^{+} + K^{+} + 0.212HCO_3^{-} + 1.036SO_4^{2-} - 0.172Cl^{-}
\end{aligned} \quad (5)
$$

Where F_i is the factor score.

Table 9: The Component Score Covariance Matrix

Composition	1	2	3
1	1.000	0.000	0.000
2	0.000	1.000	0.000
3	0.000	0.000	1.000

Table 10: The Component Score Coefficient Matrix

	Composition		
	1	2	3
Ca^{2+}	-0.471	0.368	-0.092
Mg^{2+}	-0.274	0.118	0.127
$Na^{+}+K^{+}$	0.296	0.062	0.131
HCO_3^-	0.303	0.078	0.212
SO_4^{2-}	0.286	-0.167	1.036
Cl^-	-0.366	1.039	-0.172

DISCUSSION

Recognition of Mine Water Gushing Sources Caused by Exploiting the No.2_1 Coal Seams of Shanxi Group in the Jiaozuo Mining Area

Using the factor score functions obtained above, we can calculate the scores that the water samples from various water-bearing strata obtain on the different factors. Select the top ten rankings as shown in Table **11**.

On the basis of comprehensive factor analysis modeling to construct the evaluating pattern solve the synthesis scores of the key influencing factors for the

Table 11: Scoring and Ranking of the Principal Factors

Aquifers	F_1		F_2		F_3	
	Scores	Rank	Scores	Rank	Scores	Rank
The roof sandstone aquifers 1	227.646	5	72.72	10	198.117	5
The roof sandstone aquifers 2	217.75	6	87.323	6	195.633	6
The roof sandstone aquifers 3	303.792	3	115.525	2	221.477	3
The roof sandstone aquifers 4	312.44	1	115.893	1	226.181	2
The roof sandstone aquifers 5	278.801	4	105.062	4	228.209	1
The roof sandstone aquifers 6	304.219	2	113.828	3	211.837	4
The Ordovician limestone aquifers 3	50.954	28	59.065	18	136.626	10
The Ordovician limestone aquifers 6	80.982	7	64.522	15	155.47	8
Hydrated layer of quaternary system 1	69.073	13	73.602	9	132.861	12
Hydrated layer of quaternary system 2	72.426	8	83.161	7	158.981	7
Hydrated layer of quaternary system 3	70.706	11	102.426	5	153.236	9
Hydrated layer of quaternary system 4	70.015	12	76.476	8	127.974	13
The Carboniferous limestone aquifers 1	70.78	10	53.153	23	116.656	15
The Carboniferous limestone aquifers11	71.88	9	42.186	32	133.603	11

Table12: The Scoring and Ranking of the Multi-Stress

F	Scores	Rank	*F*	Scores	Rank
The roof sandstone aquifers 4	236.74784	1	The Carboniferous limestone aquifers 2	67.39675	17
The roof sandstone aquifers 3	231.5787	2	The Carboniferous limestone aquifers 5	67.2188	18
The roof sandstone aquifers 6	229.08026	3	The Ordovician limestone aquifers 2	66.9025	19
The roof sandstone aquifers 5	217.80654	4	The Carboniferous limestone aquifers 8	66.20584	20
The roof sandstone aquifers 1	177.48713	5	The Carboniferous limestone aquifers 7	66.08724	21
The roof sandstone aquifers 2	175.38181	6	The Carboniferous limestone aquifers 9	63.51757	22
Hydrated layer of quaternary system 3	94.97373	7	The Ordovician limestone aquifers 1	63.37892	23
Hydrated layer of quaternary system 2	92.19889	8	The Carboniferous limestone aquifers 4	62.61554	24
The Ordovician limestone aquifers 6	91.48338	9	The Carboniferous limestone aquifers 6	61.2348	25
Hydrated layer of quaternary system 1	82.67795	10	Hydrated layer of quaternary system 7	61.20247	26
Hydrated layer of quaternary system 4	82.55326	11	Hydrated layer of quaternary system 6	61.08956	27
The Carboniferous limestone aquifers11	76.6355	12	The Carboniferous limestone aquifers 10	61.02502	28
The Carboniferous limestone aquifers 1	75.00508	13	The Ordovician limestone aquifers 5	60.50413	29
The Carboniferous limestone aquifers 12	73.44	14	The Ordovician limestone aquifers 4	58.43372	30
The Ordovician limestone aquifers 3	70.80702	15	Hydrated layer of quaternary system 8	51.73281	31
The Carboniferous limestone aquifers 3	68.90218	16	Hydrated layer of quaternary system 5	49.04206	32

mine water gushing sources. The results of the reckoning are shown in Table **12**.

As seen from Table **12**, thirty-two water samples of the aquifers were generally ranked from high to low according to the scores. It means that the principal sources of mine water inrushes caused by exploiting the No.2_1 coal seams of the Shanxi group in the Jiaozuo mining area are the roof sandstone aquifers [60-70], followed by the floor limestone aquifers and the hydrated layer of the quaternary system [71-79]. In order to further illustrate the situation of mine water inrushes with the working face advanced during the process of exploitation in the Jiaozuo mining area, we

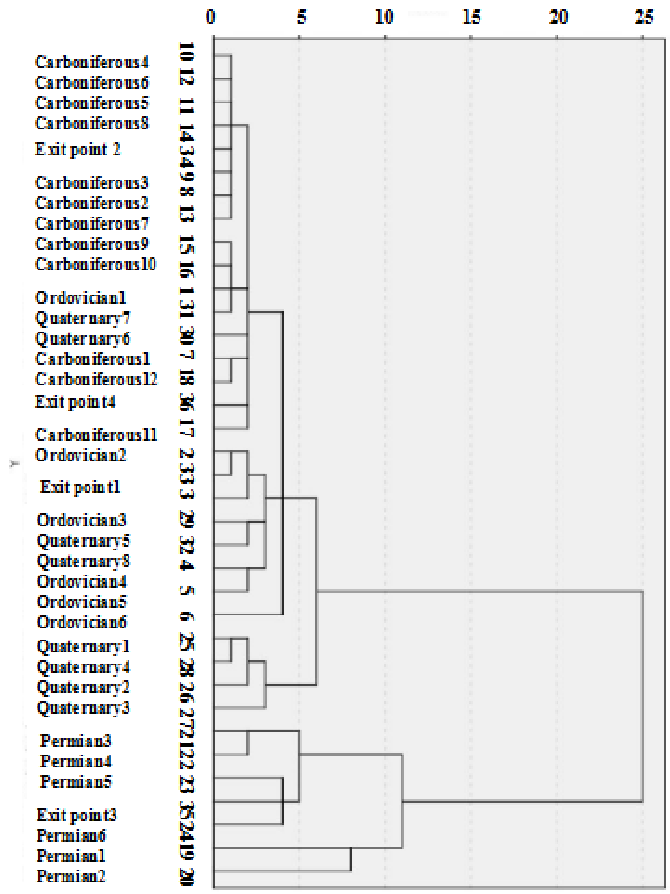

Figure 5: The dendrograms of hierarchical clustering.

adopted the analytic procedure of hierarchical clustering to carry on the discrimination and classification of the mine water gushing sources for the four detected water exits. The recognized results are shown in Fig. **5**. From the chart, we can find out that the mine water bursting sources of the four known water exits come from the Ordovician limestone aquifers 2, several Carboniferous limestone aquifers, the roof sandstone aquifers 3, and several Carboniferous limestone aquifers, respectively. Therefore, when mining coal seams in the Jiaozuo mining area, we should make the roof sandstone aquifers and the floor limestone aquifers acquiring the higher comprehensive factor scores as the key point of monitoring, preventing the occurrence of mining water hazards [80-89].

CONCLUSIONS

1) In the case of mine water inrushes from the multiple water sources, recognizing the mine water gushing sources and distinguishing the contribution proportions of water gushing sources has an important directive function for preventing and curing the mining water hazards. In this paper, factor analytic modeling is applied to discriminating the sources of water bursting in mine. Based on the data of groundwater chemical composition, a model was established to recognize the gushing water sources, combining the practical application of discriminating the water gushing sources caused by exploiting the No.2_1 coal seams of the Shanxi group in the Jiaozuo mining area to prove the applicability and scientificalness of the model.

2) Based on the analysis results of the piper diagram and the SPSS factor modeling, the main gushing water sources caused by exploiting the No.2_1 coal seams of the Shanxi group in the Jiaozuo mining area are the roof sandstone aquifers, followed by the floor limestone aquifers and the hydrated layer of the quaternary system.

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