Groundwater Hydrochemical Characteristics Analysis and Water Quality Evaluation in the Jiaozuo Area

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Abstract. In 2017, 42 groundwater samples in the Jiaozuo area were collected and tested. The groundwater hydrochemical characteristics and reasoning of the area were analyzed by using mathematical statistics, Piper three-line diagram and correlation of components methods. The groundwater quality in the study area were evaluated by using the method of fuzzy comprehensive evaluation method based on principal component analysis. The results show that the domination of groundwater is Ca2+, Mg2+, SO42- and HCO3-. And the shallow groundwater hydrochemical type evolves from HCO3-Ca to HCO3·SO4·Ca·Mg, HCO3·SO4·Cl·Ca·Mg, according to the direction of groundwater runoff. The chemical type of the deep groundwater is mainly HCO3·SO4·Ca·Mg type, local type is HCO3·SO4·Ca·Mg. The change of hydrochemical composition is mainly affected by weathering and leaching of carbonate, sulfate and rock salt. The fuzzy comprehensive evaluation results show that 61% and 75% of the shallow and deep groundwater quality in the study area meet the III water standards and above.

1. Introduction

Groundwater is an important water supply resource in China and an important strategic resource to support China's economic and social development [1]. In recent years, due to economic and social development and changes in the geochemical environment, the groundwater environment has been polluted to varying degrees, especially urban domestic sewage and industrial and mining. The wastewater discharged by enterprises penetrates into the groundwater system and poses a serious quality threat to groundwater [2,3]. Through the research on groundwater chemical characteristics and water quality evaluation, it is possible to grasp the groundwater environment problem, which is of great significance for promoting regional economic development, water resources management and ecological environment protection [4].

Due to the development and utilization of groundwater and the drainage of coal mine pits in the Jiaozuo area, geological environmental problems such as groundwater falling funnels and partial aquifer dewatering, water quality deterioration and ground collapse have formed. At present, the research on the water environment in the focus area is mainly focused on the pollution mechanism, migration prediction and pollution characteristics of shallow groundwater pollution sources, and there are few studies on its water chemistry characteristics, genesis and water quality evaluation. LuoYunyun et al.[5,6]used multivariate statistical analysis methods to conduct qualitative and
quantitative analysis of shallow groundwater pollution sources in the area, and evaluated the pollution indicators through fuzzy comprehensive evaluation method, and obtained the level of shallow groundwater quality in the study area. HouYusong, Jiao Fangfan et al\cite{7,8} studied the correlation between shallow groundwater hardness, chromium pollutants and other chemical properties of groundwater in the area of focus, and predicted the migration of pollutants. Huang Pinghua et al\cite{9,10} obtained the groundwater recharge characteristics and evolutionary causes of groundwater in the mining area by focusing on the groundwater hydrochemical characteristics of the mining area, but did not evaluate the groundwater quality.

The fuzzy comprehensive evaluation method is a commonly used water quality evaluation method. It considers the fuzzy problem existing in the classification of groundwater quality, and uses membership degree to characterize the degree of subordination of groundwater to various types of water, which is consistent with the ambiguity in the classification of water pollution levels. Objectively reflect the true state of groundwater quality\cite{11,12}, however, there are still some shortcomings in the selection of evaluation indicators and the determination of indicator weights. Principal component analysis method is to reduce the dimensionality of most of the original information, and transform the data into several comprehensive evaluation indicators to reflect the water quality. Comprehensive judgment\cite{13}. In view of the large number of groundwater quality evaluation indicators, the influencing factors are complex, and the comprehensive evaluation is difficult, this paper uses the principal component analysis method to carry out principal component analysis, simplifies the number of evaluation factors, and uses the compound operation of membership degree and weight set to obtain water quality and water quality standards. The degree of subordination at each level determines the water quality level of groundwater samples at the maximum degree of membership.

In this study, 42 groundwater samples from the focus area of 2017 were collected and tested. The mathematical statistics of the groundwater were analyzed by using mathematical statistics, Piper three-line diagram and correlation analysis of each component, revealing the groundwater chemistry of the study area. The distribution characteristics and causes, and the fuzzy comprehensive evaluation method based on principal component analysis were used to systematically analyze the groundwater quality in the study area. The research results can provide a basis for water quality assessment and rational development and utilization of water resources in the region.

2. Overview of the study area
The study area ranges from 113°05′ to 113°19′ east longitude and 35°02′~35°19′ north latitude. It is mainly located in the urban area and surrounding area of Jiaozuo, with an area of about 150km2. It belongs to the warm temperate continental climate. Due to the topography and climate, the atmospheric precipitation in the northern mountainous area to the southern plain gradually decreases. The average annual rainfall in the northern mountainous area is 695.7mm; the annual average rainfall in the southern plain area is 594.4mm; the annual average temperature is 14.1. Between -14.4 °C, the annual evaporation is in the range of 1721-2048 mm. In the north is the Taihang Mountains, the terrain is controlled by the fault structure, and it descends roughly in the south to the north of Jiaozuo City. The central part is the slope plain of the front slope of the mountain, inclined to the south and south to the east, with a slope of 10-17‰, and the south is the alluvial plain of the Huanghua River. The terrain is flat and the slope is less than 3‰. The terrain is generally high in the north, followed by the south and low in the middle. According to the genetic type, material composition and distribution pattern of the geomorphology, the geomorphology of the study area is divided into the slope alluvial slope, the alluvial fan-shaped land, the alluvial fan-slanted land, the alluvial fan front sag and the Huangpi River floodplain. unit.

3. Water sample collection and analysis methods

3.1 Water sample collection
According to the groundwater outcrop distribution, hydrogeological conditions, land use characteristics and potential pollution source distribution in the study area, 42 representative sampling points were arranged, including 26 shallow water samples and 16 deep water samples. The sample test is completed by the Penny Test Group Co., Ltd., which mainly tests the total hardness TH, the total dissolved solids value TDS, K⁺, Na⁺, Ca²⁺, Mg²⁺, NH₄⁺, HCO₃⁻, CO₃²⁻, Cl⁻, SO₄²⁻ and other indicators. Temperature, EC, pH, TDS, dissolved oxygen, turbidity, oxidation-reduction potential and other indicators are detected on site. The collection and analysis of all chemical components are carried out in accordance with the Technical Specifications for Groundwater Environmental Monitoring (HJ/T164-2004), in which pH and dissolved oxygen are measured on-site using a portable water quality analyzer; the main cations such as Na⁺, Ca²⁺ and Mg²⁺ are plasma. The mass spectrometry (ICP-MS) was used for the determination; the anions such as SO₄²⁻, Cl⁻, NO₃⁻, and F⁻ were determined by ion chromatography (DX-120); HCO₃⁻ was determined by acid-base neutralization titration.

### 3.2 Analysis method

After the test is completed, all test results are analyzed by SPSS20 software for statistical calculation and correlation analysis. The Piper three-line diagram is drawn by Aquachem 4.0 software, and the groundwater chemistry type of the area is analyzed, and the fuzzy comprehensive evaluation method based on principal component analysis is applied. Groundwater quality in the study area was evaluated.

### 4. Results analysis

#### 4.1 Groundwater chemical characteristics

The results of water chemical parameters such as pH value, dissolved total solids (TDS), F⁻ and conventional ions in groundwater samples in the study area are shown in Table 1. The analysis found that the main ions in shallow groundwater are SO₄²⁻, HCO₃⁻ and Ca²⁺, with an average content of 477.2 mg/L, 428.15 mg/L and 160.58 mg/L, followed by Cl⁻, Na⁺ and Mg²⁺ with an average content of 186.1 mg/L, 155.01 mg/L and 102.69 mg/L; the pH value varies from 6.92 to 7.73; the TDS varies from 385 to 7100 mg/L. Shallow groundwater is generally neutral to weakly alkaline, with high TDS and brackish water. Compared with shallow groundwater, deep groundwater is deeply buried, and is less affected by surface environmental factors. The chemical composition of each water decreases with the increase of burial depth of groundwater, and TDS shows a decreasing trend. SO₄²⁻ is still the most important. The anion has an average content of 531.43 mg/L, and its content has a significant increase, while the contents of HCO₃⁻ and Cl⁻ have decreased to some extent, indicating that there is a certain hydraulic relationship between deep groundwater and shallow groundwater. The cation is mainly Na⁺, followed by Ca²⁺ and Mg²⁺. From the coefficient of variation, the coefficient of variation of SO₄²⁻, Na⁺ and Cl⁻ exceeds 1, reflecting that it varies greatly in water, and it is easy to change with environmental factors.

| project               | PH  | TDS (mg/L) | Cation (mg/L) | Anion (mg/L) |
|-----------------------|-----|------------|---------------|--------------|
|                       |     |            | Na⁺ | Ca²⁺ | Mg²⁺ | Cl⁻ | SO₄²⁻ | HCO₃⁻ | NO₃⁻ | F⁻  |
| Shallow groundwater   |     |            | 6.92 | 385  | 13.4 | 44.3 | 25.1  | 15.5  | 57.7 | 268 | 0.19|
| Max value             | 7.75 | 7100      | 877  | 477  | 555  | 1080 | 3610  | 604   | 24.8 | 1.98|
| Average value         | 7.34 | 1431.46   | 155.01 | 160.58 | 102.69 | 186.10 | 477.20 | 428.15 | 9.56 | 0.86|
| Standard deviation    | 0.21 | 1313.44   | 186.34 | 96.80 | 101.55 | 214.10 | 731.00 | 87.56 | 8.01 | 0.58|
| Coefficient of variation | 0.03 | 0.92     | 1.20  | 0.60 | 0.99  | 1.15  | 1.53  | 0.20  | 0.84 | 0.67|
| Deep groundwater      |     |            | 7.11  | 372  | 9.62  | 53.7  | 20.7  | 12.9  | 51.2 | 224 | 0.09| 0.19|
| Max value             | 7.76 | 7020      | 1060  | 432  | 580  | 600  | 4030  | 455   | 15.6 | 1.71|
### 4.2 Water Chemistry Type

Using the Piper three-line diagram, and according to the Shukalev classification, the groundwater hydrochemical classification of the study area is shown in Figure 1. There are 6 types of shallow groundwater chemical types in the study area and 4 types of deep groundwater chemical types. The shallow groundwater chemistry types are mainly HCO₃⁻·SO₄²⁻·Ca·Mg, HCO₃⁻·SO₄²⁻·Cl·Ca·Mg·Na and HCO₃⁻·Mg·Ca, accounting for 73% of the total samples. In the alluvial fan geomorphology, HCO₃⁻·SO₄²⁻·Ca·Mg type water with a salinity of less than 0.5g/L, and HCO₃⁻·SO₄²⁻·Cl·Ca·Mg with a salinity of not more than 1g/L to the front margin Mg type water, HCO₃⁻·SO₄²⁻·Cl·Ca·Mg and HCO₃⁻·SO₄²⁻·Mg·Ca type water with salinity greater than 1.5g/L. The deep groundwater water chemistry types are mainly HCO₃⁻·SO₄²⁻·Ca·Mg and HCO₃⁻·Ca·Mg type, accounting for 81% of the total samples. The main cations in shallow groundwater are Ca²⁺ and Mg²⁺, with milliequivalent percentages of 36% and 35%. SO₄²⁻ and HCO₃⁻ are the main anions with 45% and 31% equivalents. The main cations in deep groundwater are Ca²⁺ and Mg²⁺, with a milliequivalent percentage of 37% and 32%, and SO₄²⁻ is still the main anion with a milliequivalent percentage of 56%. It can be seen that the content of Ca²⁺, Mg²⁺ and SO₄²⁻ in the groundwater of the study area is high.

![Piper diagram of shallow and deep groundwater](image)

**Fig.1** The Piper-tri-linear diagram of Hydrochemical type of groundwater

### 4.3 Correlation Analysis

Substances from different sources and hydrochemical processes show different interrelationships between groundwater components, so correlation analysis can reveal similarities and differences in groundwater hydrochemical parameters and consistency and variability in groundwater sources [14,15].

It can be seen from Calculation results that except for HCO₃⁻ in shallow groundwater, other components are positively correlated with TDS. SO₄²⁻, Cl⁻, Mg²⁺, Ca²⁺ and Na⁺ are highly correlated with TDS, and the correlation coefficient is 0.833-0.986, indicating that the salinity of both shallow and deep groundwater is equal to the concentration of SO₄²⁻, Cl⁻, Mg²⁺, Ca²⁺ and Na⁺. Closely related. SO₄²⁻ has a high correlation with Mg²⁺, Na⁺ and Ca²⁺. The study area may produce the dissolution of sulfate such as gypsum; HCO₃⁻ has a weak correlation with Ca²⁺, Na⁺ and Mg²⁺, which may cause carbonates such as calcite and dolomite. Weathering. Cl⁻ is highly correlated with Na⁺, and the correlation coefficient reaches 0.966, which may cause the dissolution of rock salt. At the same time, Cl⁻ is also highly correlated with Mg²⁺, indicating that rainwater and river water in the study area carry a large amount of soil salt into the groundwater, and Cl⁻ is the acidification and water quality change of
the water body. It has an impact \[16\]. It can be seen that the main minerals of the water-bearing strata in the study area are calcite, dolomite, gypsum and rock salt. It is speculated that the hydrochemical process of groundwater in this area is mainly based on the weathering and leaching of carbonate, sulfate and rock salt.

4.4 Saturation index analysis
Through the calculation of the saturation index of mineral phase such as rock salt, gypsum, fluorite, dolomite, calcite and CO\(_2\), it can be further determined whether the leaching effect occurs in the groundwater, thus truly reflecting the actual form of the groundwater component. The tendency of mineral dissolution or precipitation during groundwater runoff can be calculated using the saturation index SI:

\[ SI = \lg \frac{IAP}{K_{sp}} \]

In the formula, IAP is the activity product, \(K_{sp}\) is the concentration product.

When SI>0, the mineral will precipitate in the groundwater; when SI<0, the mineral will dissolve in the groundwater;

When SI=0, the mineral is in a dynamic equilibrium state when its dissolved amount and sediment amount are the same in groundwater.

Using the hydrogeochemical simulation software PHREEQC, the saturation index SI of each mineral phase at the starting point and the end point of the groundwater in the SY18-SY42 path was simulated. It can be seen from Table 2 that the rock salt, gypsum and fluorite were not in the course of runoff. When it reaches saturation, there is a tendency to continue to dissolve, while both calcite and dolomite are saturated, accompanied by dissolution of CO\(_2\).

| water sample | rock salt | gypsum | fluorite | calcite | dolomite | P(CO\(_2\)) |
|--------------|-----------|--------|----------|---------|----------|------------|
| SY18         | -6.33     | -0.8   | -2.15    | 0.43    | 0.69     | -1.22      |
| SY42         | -6.27     | -1.22  | -0.65    | 0.54    | 1.31     | -1.59      |

5. Water quality evaluation

5.1 Fuzzy comprehensive evaluation

5.1.1 Calculate the variance contribution rate and determine the principal component
Calculating the variance contribution rate of principal component \(F_i\) according to the correlation coefficient matrix eigenvalue \(\lambda_i\).

\[ E_i = \lambda_i / \sum_{i=1}^{n} \lambda_i \]  

Select the first n principal components of \(\sum_{i=1}^{n} E_i \geq 85\%\) for comprehensive analysis.

5.1.2 Principal component load calculation
The relationship between the principal component load \(l_{ij}\) and the correlation coefficient matrix eigenvector \(u_{ij}\) is:

\[ l_{ij} = u_{ij} / \sqrt{\lambda_i} \]  

5.1.3 Principal component factor analysis
According to the principal component load size, that is, the degree of correlation with the principal component, the main control factor of each principal component is selected as the evaluation factor of fuzzy comprehensive evaluation.
5.1.4 Establishment of fuzzy relation matrix

According to the membership degree of the evaluation factor to the evaluation level, a fuzzy relation matrix is obtained. Let $S_{ij}$ be the membership degree of the $i$-th evaluation factor to $j$-th evaluation level indicators, then the membership function is:

$$
S_{ij} = \begin{cases} 
1 & x_{ij} \leq C_{ij-1}, x_{ij} \geq C_{ij+1} \\
\frac{x_{ij} - C_{ij-1}}{C_{ij} - C_{ij-1}} & C_{ij-1} \leq x_{ij} < C_{ij} \\
\frac{C_{ij+1} - x_{ij}}{C_{ij+1} - C_{ij}} & C_{ij} \leq x_{ij} \leq C_{ij+1} \\
0 & x_{ij} = C_{ij}
\end{cases} \quad (3)
$$

In the formula, $x_{ij}$ is the measured value of the $i$-th evaluation factor of the $j$-th sample, and $C_{ij}$ is the evaluation standard value corresponding to the $i$-th evaluation factor.

The fuzzy relation matrix $R$ is calculated by the membership function, namely:

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

(4)

5.1.5 Establishment of fuzzy weight matrix

The weight $W_{ki}$ of the evaluation factor in the groundwater pollution weight is determined by the normalized weight calculation formula, namely:

$$
W_{ki} = (x_{ki}/S_k)/\sum_{i=1}^{n}(x_{ki}/S_k) \quad (5)
$$

In the formula, $S_k = (C_{k1} + C_{k2} + \cdots + C_{kj})$.

Combining the weight matrix $W$ with the fuzzy relation matrix $R$ to obtain a comprehensive evaluation model:

$$
B_j = A \cdot R = (W_1, W_2, \cdots, W_j) \begin{bmatrix}
{r_{11}} & {r_{12}} & \cdots & {r_{1n}} \\
{r_{21}} & {r_{22}} & \cdots & {r_{2n}} \\
\vdots & \vdots & \ddots & \vdots \\
{r_{m1}} & {r_{m2}} & \cdots & {r_{mn}}
\end{bmatrix} = (b_1, b_2, \cdots, b_j)
$$

(6)

In the formula, $b_i$ is the membership value of each indicator.

5.1.6 Fuzzy synthesis operation and results

According to the above method, the fuzzy comprehensive evaluation of the water quality of 26 groups of shallow groundwater samples and 16 groups of deep groundwater samples was carried out. The subordination degree and evaluation results of water quality of each water sample to each level of water are shown in Table 3. It can be seen that in the water samples of the shallow water 26 groups, the water quality class I water samples 5 groups, accounting for 19% of the total water samples, the class III water samples 11 groups, accounting for 42% of the total water samples; the V water samples 10 Group, accounting for 39% of the total number of water samples, no II, IV water, 61% of the drinking water standards. Among the 16 groups of deep water samples, the number of groundwater samples in the water quality class IV were 9, 0, 3, 0, and 4, respectively, accounting for 56%, 0, 19%, 0, 25% of the total deep water samples. 75% of the drinking water standard.

| Sample serial number | I  | II | III | IV | V  | Comprehensive evaluation |
|----------------------|----|----|-----|----|----|--------------------------|
| SY05                 | 0.22| 0.12| 0.26| 0.20| 0.21| III                      |
| SY06                 | 0.31| 0.10| 0.37| 0.03| 0.20| III                      |
| SY08                 | 0.35| 0.17| 0.18| 0.02| 0.28| I                        |
| SY09                 | 0.23| 0.10| 0.29| 0.07| 0.32| V                        |
| SY14                 | 0.07| 0.04| 0.10| 0.02| 0.56| V                        |
According to the sampling point location and evaluation results, the shallow groundwater V-type water samples are mainly distributed in the top area of the Dasha River alluvial fan, the middle-eastern junction of the study area and the southern Huangpi River alluvial plain. The over-standard points are mostly in the piedmont slope plain and The intersection of the Huangpi River and the alluvial plains is relatively flat and has frequent industrial and agricultural activities. In particular, there are a large number of toxic and harmful chemical wastes discharged from the upstream of the Dasha River, and the unreasonable use of large-scale pesticides and fertilizers. At the same time, the groundwater level in these areas is relatively shallow, and the degree of impact on human activities is relatively high, and the quality of groundwater is relatively poor. The I and III water samples of deep groundwater are distributed in the study area, indicating that the overall quality of deep groundwater is better in the study area, and the V type water samples are mainly distributed in the southeast of the front of the alluvial fan. According to the site investigation. According to the information, the poor groundwater quality in this area may be caused by the over-flowing of mixed wells.

| Sample | I | II | III | IV | V |
|--------|---|---|----|---|---|
| SY16   | 0.17 | 0.21 | 0.29 | 0.16 | 0.20 | III |
| SY18   | 0.15 | 0.13 | 0.28 | 0.08 | 0.45 | V |
| SY20   | 0.23 | 0.17 | 0.31 | 0.12 | 0.19 | III |
| SY21   | 0.24 | 0.18 | 0.37 | 0.04 | 0.20 | III |
| SY23   | 0.28 | 0.22 | 0.32 | 0.18 | 0.00 | III |
| SY24   | 0.64 | 0.20 | 0.27 | 0.00 | 0.00 | I |
| SY28   | 0.47 | 0.20 | 0.36 | 0.02 | 0.00 | I |
| SY29   | 0.27 | 0.06 | 0.33 | 0.21 | 0.19 | III |
| SY33   | 0.32 | 0.19 | 0.40 | 0.14 | 0.00 | III |
| SY34   | 0.17 | 0.10 | 0.45 | 0.18 | 0.16 | III |
| SY35   | 0.14 | 0.01 | 0.13 | 0.18 | 0.59 | V |
| SY36   | 0.14 | 0.14 | 0.35 | 0.23 | 0.13 | III |
| SY37   | 0.08 | 0.08 | 0.31 | 0.20 | 0.39 | V |
| SY40   | 0.06 | 0.06 | 0.04 | 0.04 | 0.82 | V |
| SY42   | 0.17 | 0.17 | 0.27 | 0.07 | 0.33 | V |
| SY43   | 0.13 | 0.08 | 0.47 | 0.17 | 0.14 | III |
| SY44   | 0.14 | 0.10 | 0.22 | 0.20 | 0.44 | V |
| SY45   | 0.59 | 0.38 | 0.03 | 0.00 | 0.00 | I |
| SY46   | 0.46 | 0.26 | 0.30 | 0.04 | 0.00 | I |
| SY47   | 0.04 | 0.01 | 0.04 | 0.01 | 0.92 | V |
| SY50   | 0.14 | 0.10 | 0.33 | 0.08 | 0.39 | V |

According to the sampling point location and evaluation results, the shallow groundwater V-type water samples are mainly distributed in the top area of the Dasha River alluvial fan, the middle-eastern junction of the study area and the southern Huangpi River alluvial plain. The over-standard points are mostly in the piedmont slope plain and The intersection of the Huangpi River and the alluvial plains is relatively flat and has frequent industrial and agricultural activities. In particular, there are a large number of toxic and harmful chemical wastes discharged from the upstream of the Dasha River, and the unreasonable use of large-scale pesticides and fertilizers. At the same time, the groundwater level in these areas is relatively shallow, and the degree of impact on human activities is relatively high, and the quality of groundwater is relatively poor. The I and III water samples of deep groundwater are distributed in the study area, indicating that the overall quality of deep groundwater is better in the study area, and the V type water samples are mainly distributed in the southeast of the front of the alluvial fan. According to the site investigation. According to the information, the poor groundwater quality in this area may be caused by the over-flowing of mixed wells.
6. Conclusions and discussion

(1) The groundwater bodies in the study area are dominated by Ca\(^{2+}\), Mg\(^{2+}\), SO\(_4^{2-}\) and HCO\(_3^-\). The water chemistry type in the shallow water area is mainly from the HCO\(_3^-\)·Ca type water in the northern recharge area, along the direction of groundwater runoff, from north to south. From northwest to southeast, it gradually evolved into HCO\(_3^-\)·SO\(_4^{2-}\)·Ca·Mg type water; while the water chemistry type of deep groundwater is mainly HCO\(_3^-\)·SO\(_4^{2-}\)·Cl·Ca·Mg type water, and HCO\(_3^-\)·Ca·Mg type water appear locally.

(2) Correlation analysis shows that the change of ion composition in water is mainly affected by the weathering and leaching of carbonate, sulfate and rock salt. In the process of groundwater runoff, dissolution of rock salt, gypsum and fluorite occurs and calcite occurs. A small amount of precipitation with dolomite is accompanied by the dissolution of carbon dioxide.

(3) Using the principal component analysis method to screen the evaluation indicators, not only reduces the problem of participating in the fuzzy comprehensive evaluation factor, but also ensures the reliability of the evaluation results. At the same time, the fuzzy comprehensive evaluation considers the influence of different evaluation indicators on water quality. The weight makes the evaluation result more reasonable and credible. The results show that the shallow groundwater reaches the sampling point that meets the water quality standards of Class III and above, accounting for 61% of the total sampling points, and the IV and V waters account for 39% of the total sampling points. The deep groundwater meets the sampling points of Class III and above water quality standards, accounting for 75% of the sampling points, and the IV and V waters account for 25% of the total sampling points. The poor water quality of shallow groundwater is mainly distributed in the intersection of the piedmont slope plain and the Huanghua River alluvial plain. The deep groundwater quality is mainly distributed in the southeast of the foreland.

References

[1] Y.H.Hu, F.H.Zhang, Z.Y.Niu, etc. (2014) Hydro-chemical characteristics of groundwater in centralized drinking water sources and its quality assessment in northern Anhui Province. Journal of University of Science and Technology of China, 44(11):913-920,925.

[2] Y.S.Lin, J.G.Pei, Y.C.Du, etc. (2016)Temporal and spatial distribution of the Hydro-chemical characteristics of Yaocun underground river in Guangxi province. Journal of Yangtze River Scientific Research Institute, 33(12):6-9,16.

[3] S.B.Yu, Z.M.Ma, H.S.Zhang. (2011) Pollutant characteristics of shallow groundwater in Jiaozuo site of the middle South-to-North water diversion project. Journal of University of Jinan(Sci. and Tech.), 26(1):91-95.

[4] L.Lu, J.Y.Yang. (2017) Effect of over exploitation of groundwater on the hydro-chemical characteristics of groundwater. Journal of Yangtze River Scientific Research Institute, 34(9):14-18,23.

[5] Y.Y.Luo, Z.M.Ma, Y.S.Hou, etc. (2013)Apportionment of pollution source of shallow groundwater system in Jiaozuo. Nonferrous Metals(Extractive Metallurgy), 2013(4):58-61.

[6] Y.Y.Luo, Z.M.Ma, Y.S.Hou. (2013)An evaluation of the quality of shallow groundwater in Jiaozuo area. China Rural Water and Hydropower, 2013(8):17-20.

[7] Y.S.Hou, Z.M.Ma, Y.Y.Luo, etc. (2014)Pollution mechanism and migration prediction of hardness of shallow groundwater in Jiaozuo area. Journal of University of Jinan(Sci. and Tech.), 28(2):151-156.

[8] F.F.Jiao, Z.M Ma, Y.S.Hou. (2014) pollution mechanism and migration prediction of Cr(VI) in shallow groundwater in Jiaozuo area. Coal Geology & Exploration, 42(6):82-86,96.

[9] P.H.Huang, J.S.Chen. (2011) The chemical features of ground water and FDA model used to distinguish source of water burst in Jiaozuo mine area. Coal Geology & Exploration, 39(2):42-46,51.

[10] P.H.Huang, J.S.Chen, C.Ning,etc. (2010)Hydro-chemical characteristics and hydro-geochemical modeling of groundwater in the Jiaozuo mining district. Geoscience, 24(2):369-376.
[11] S.X. Zhang, Z.M. Wang, T.H. Dai. (2019) Chemical characteristics and water quality assessment of karst groundwater in Bijie. Journal of Yangtze River Scientific Research Institute, 36(5):28-33,41.

[12] C. Qian, W.P. Mu, K. Wang, etc. (2016) Fuzzy comprehensive evaluation of groundwater quality based on principal component analysis. Water Resources and Power, 34(11):31-35.

[13] J.K. Du, Y. Fu, X.X. Li. (2015) Application of fuzzy comprehensive evaluation method-principal component analysis to groundwater quality evaluation. Environmental Monitoring in China, 31(4):75-81.

[14] M. Zhang, Q.M. Liu, K.X. Liu. (2018) Hydrochemical Characteristics and cause analysis of groundwater in Gubei mining district. Safety in Coal Mines, 49(5):187-190.

[15] Z.X. Zhang, M. Xu, Q. Zhang, etc. (2018) Hydrogeochemistry, genesis and water quality analysis of shallow groundwater in red-bed area of the Mianyang city. Science Technology and Engineering, 18(3):168-173.

[16] F. Zhang, F.D. Li, J. Li, etc. (2013) Hydrochemical characteristics of surface water in main rivers of the irrigation districts in the downstream of Yellow river. Chinese Journal of Eco-Agriculture, 21(4):487-493.