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Quality Evaluation of Shallow Groundwater in Luoyang City Based on Fuzzy Mathematics

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Abstract. Based on the investigation of shallow groundwater environment in Luoyang City, thirty two groups of groundwater samples were collected and conducted relevant water quality analysis, sixteen of which were selected as the evaluation indexes. A comprehensive evaluation of Luoyang groundwater was conducted by resorting to fuzzy mathematics. It is concluded that water sample I, sample II, sample III, sample IV, sample V accounted for 6.25%, 37.5%, 37.5%, 6.25, 12.5% of the total. The groundwater quality was largely at a moderate state. In conclusion, comparative analysis by resorting to comprehensive index method, fuzzy comprehensive method using membership degree to evaluate groundwater quality, and it proved fuzzy mathematics more comprehensive and reasonable. Groundwater pollution is mainly concentrated in industrial parks and densely populated urban areas. Such parameters as total hardness and nitrogen were the main causes of groundwater contamination in the study area.

Keywords: Luoyang city; groundwater quality; fuzzy mathematics; comprehensive index method

1 Introduction

Luoyang City is located in the west of Henan Province, the western end of the Luoyan basin, the eastern part of the Eurasian Continental Bridge, across the middle reaches of the Yellow River, geographical coordinates: latitude 33 ° 35'~ 35 ° 05', longitude 111 ° 08'~ 112 ° 59'[1]. Luoyang City, as the focus of the construction of the central and western cities, the scale of the city has been expanding in recent years, and the population continues to increase, industrial and agricultural pollution is also more and more serious. Groundwater is the main drinking water source of the city in Luoyang, which accounts for 90 percent of the city's total water supply. The excessive exploitation of groundwater in Luoyang and the irrational discharge of waste water caused by industrial and agricultural production have been increasing. The content of certain chemical components in groundwater has been increasing continuously, which has a significant impact on the regional groundwater environment[2-4]. Therefore, it is necessary to carry out the analysis of groundwater quality and water quality evaluation in Luoyang city area, and to further explore its causes and highlight the corresponding prevention and control measures according to the geological and hydrological conditions and the characteristics of pollution sources in the study area.

At present, there are many researches about groundwater quality evaluation at home and abroad, including single factor pollution index[5], comprehensive pollution index method[6], fuzzy comprehensive evaluation method[7-9], artificial neural network method[10], etc.. Fuzzy comprehensive evaluation overcomes the shortcomings of other methods considering the ambiguity of nature, with membership to represent the influence degree of each index measured concentration on water quality, has certain scientific and rational, also accord with the actual status of pollution[11]. A comprehensive evaluation of Luoyang groundwater was conducted by resorting to fuzzy mathematics. It has high theoretical value and practical guiding significance for scientific and rational utilization of Luoyang groundwater resources.

2 The Brief Introduction of Research Area

Luoyang city for many years, the average total water resources 2 billion 809 million m^3, the per capita share of less than 450m^3, with the province's per capita share of basic flat, about 1/5 of the country's per capita share, is a serious shortage of water in the North City[12]. The annual average precipitation 625mm, day maximum precipitation is 134.9mm (p=50year), maximum annual precipitation is 1063.2mm, the minimum annual rainfall 337.9mm. Precipitation is concentrated in June, July, August and September. The average annual evaporation is 1829.1mm. The main water system in the study area is the porous water system of loose rock, which is mainly distributed in the plain area of Luoyang City, mainly in the Quaternary Cenozoic sediments, and the landform type is Yiluo River alluvial plain. Shallow groundwater system receives atmospheric precipitation, surface water, irrigation back to the water. Groundwater excretion through artificial mining, diving, lateral runoff, etc, horizontal runoff is weak [13]. In the multi-year average groundwater level with the following, the total storage of water amounted to 1.171 billion m^3, the annual comprehensive supply volume reached 252.4 million m^3, of which from the Luo River, Jian River, Yi River and other surface water supply of 156.1 million m^3, accounting for 62% of total groundwater recharge. Especially the Luo River supply of 114 million m^3, accounting for 45% of total groundwater recharge [14].

3 The Sources of Data

The groundwater monitoring data of 32 wells were selected in Luoyang city in 2012. Distribution of groundwater monitoring well in the study area is shown as figure 1.The main quality components including pH, Al, Fe, Mn, Cu, Zn, Chloride, Sulfate, Total dissolved solids, Total hardness, Oxygen consumption, Volatile phenols (Phenol), Ar, Cd, Cr^{6+}, Hg, Se, Fluoride, Cyanide and Nitrate (N), a total of 21 water quality data statistics is shown as table 1.

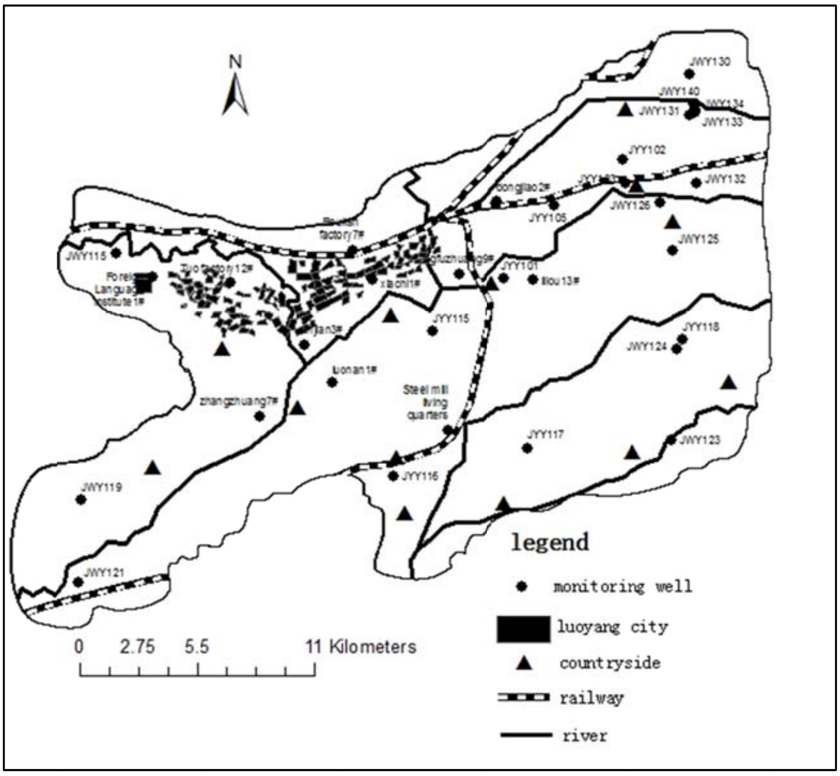

Figure 1. Distribution of groundwater monitoring well in the study area

Table 1. Statistics of main indicators' content features of groundwater quality in the study area

name	average value	max	min	variance	Skewness
pH	7.68125	6.97	8.63	0.416224	-0.07243
Al	0	0	0	0	0

Fe	0.0590625	0	0.35	0.075181	1.954998
Mn	0.0009375	0	0.01	0.002915	2.926498
Cu	0	0	0	0	0
Zn	0.0075	0	0.08	0.016583	3.269787
Chloride	65.1453125	9.08	323.16	57.4284	2.971266
Sulfate	100.5184375	17.05	276.41	47.11266	1.53416
Total dissolved solids	640.684375	239	1779.9	263.6166	2.525931
Total hardness ($CaCO_3$)	431.2134375	179.94	1011.51	154.9845	1.461533
Oxygen consumption	0.8440625	0.27	3.36	0.689592	3.146694
Volatile phenols	0	0	0	0	0
Ar	0.00003125	0	0.001	0.000174	5.656854
Cd	0	0	0	0	0
Cr^{6+}	0.0054375	0	0.031	0.009107	1.810233
Pb	0.000115625	0	0.0037	0.000644	5.656854
Hg	0.0000875	0	0.0015	0.00034	3.830122
Se	0.000690625	0	0.0055	0.001147	2.669964
Cyanide	0.00075	0	0.002	0.000968	0.542149
Fluoride	0.3921875	0.18	0.83	0.134088	0.993362
Nitrate（N）	19.211875	1.03	164.91	27.31999	4.928819

unit: mg/L

4 Fuzzy Comprehensive Evaluation of Plain Groundwater in Luoyang Based on Fuzzy Mathematics

4.1 Brief Introduction of Fuzzy Comprehensive Evaluation Method

Due to complex hydro-geological systems and inherent uncertainties in measurement and analysis, water pollution is a fuzzy concept. Fuzzy comprehensive evaluation is a very effective multi-factor decision-making method for making a comprehensive evaluation of things affected by various factors. It is characterized by a fuzzy set to represent the evaluation results rather than absolutely positive or negative. The introduction of fuzzy mathematics into groundwater quality assessment can better reflect the uncertainty and fuzziness[15]. The fuzzy mathematics comprehensive evaluation method mainly includes several parts:

1. Determination of Membership Function Y

The membership degree can be expressed by the membership function. The linear membership function is used to determine the degree of membership of each rating factor:

j=1,

$$y = \begin{cases} 1 & X_i \le S_{i,j} \\ \dfrac{S_{i,j+1} - X_i}{S_{i,j+1} - S_i} & S_{i,j} < X_i < S_{i,j+1} \\ 0 & X_i > S_{i,j+1} \end{cases} \tag{1}$$

j=2, 3, 4,

$$y = \begin{cases} 0 & X_i < S_{i,j-1} \\ \dfrac{S_{i,j+1} - X_i}{S_{i,j+1} - S_{i,j}} & S_{i,j} \le X_i < S_{i,j+1} \\ \dfrac{X_i - S_{i,j-1}}{S_{i,j} - S_{i,j-1}} & S_{i,j-1} \le X_i < S_{i,j} \\ 0 & X_i < S_{i,j+1} \end{cases} \tag{2}$$

j=5,

$$y = \begin{cases} 0 & X_i < S_{i,\, j-1} \\ \dfrac{X_i - S_{i,\, j-1}}{S_{i,\, j} - S_{i,\, j-1}} & S_{i,\, j-1} < X_i < S_{i,\, j} \\ 1 & X_i \geq S_{i,\, j} \end{cases} \tag{3}$$

where, Y is the factor belonging to each level of water membership;

X is measured concentration of each factor;

$S_{i.\ j}$, $S_{i.\ j+1}$, $S_{i.\ j-1}$ are the various levels of water quality standards.

2. Establishment of Fuzzy Relation Matrix R

The fuzzy relation matrix R reflects the membership of the j-th water quality category corresponding to the i-th water quality index, the formula is:

$$R = r_{ij} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{4}$$

3. Weight and Normalization

According to the parameters exceeding the standard weight, the more the standard, the greater the weight.

$$\textit{Weight value is};\ \mathrm{W}_i = \frac{C_i}{S_i} \tag{5}$$

where, Wi is the index of excess of the average pollutant content of i pollutants;

Ci is measured concentrations of i pollutants;

Si is the arithmetic mean of all kinds of standard values of i pollutants.

In order to perform the fuzzy operation, each individual weight is normalized:

$$\mathrm{V}_i = \frac{W_i}{\sum_{i=1}^{n} W_i} = \frac{C_i / S_i}{\sum_{i=1}^{n} C_i / S_i} \tag{6}$$

where, Vi is normalized weight of i pollutant;

Ci is ditto;

Si is ditto.

Thus the weight set is $A = \begin{pmatrix} V_1 & V_2 & \cdots & V_i \end{pmatrix}$

4. Fuzzy Matrix Compound Operation

The weight A and the fuzzy evaluation matrix R are combined to obtain the parameter evaluation matrix B of the evaluated water quality, such as the formula:

$$B = A \bullet R = \begin{pmatrix} V_1 & V_2 & \cdots & V_i \end{pmatrix} \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} = \begin{pmatrix} b_1 & b_2 & \cdots & b_i \end{pmatrix} \tag{7}$$

5. According to the Principle of Maximum Membership to Determine the Water Quality Grade.

4.2 Fuzzy Comprehensive Evaluation Results of Study Area

According to the above related principles to evaluate the water quality of the study area. Steps are as follows:

1. Select Evaluation Indicators

The selection of Fe, Mn, Cu, Zn, Chloride, Sulfate, Total dissolved solids, Total hardness ($CaCO_3$), Volatile phenols (phenol), Ar, Cd, Cr^{6+}, Pb, Hg, Cyanide and nitrate (N), a total of 16 index.

2. Determine the Water Quality Criteria

According to the groundwater quality standard, the quality of groundwater is classified into five categories, as shown in table 2.

Table 2. Sixteen groundwater quality classification indicators

name	average value	max	min	variance	Skewness
pH	7.68125	6.97	8.63	0.416224	-0.07243
Al	0	0	0	0	0
Fe	0.0590625	0	0.35	0.075181	1.954998
Mn	0.0009375	0	0.01	0.002915	2.926498
Cu	0	0	0	0	0
Zn	0.0075	0	0.08	0.016583	3.269787
Chloride	65.1453125	9.08	323.16	57.4284	2.971266
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Oxygen consumption	0.8440625	0.27	3.36	0.689592	3.146694
Volatile phenols	0	0	0	0	0
Ar	0.00003125	0	0.001	0.000174	5.656854
Cd	0	0	0	0	0
Cr^{6+}	0.0054375	0	0.031	0.009107	1.810233
Pb	0.000115625	0	0.0037	0.000644	5.656854
Hg	0.0000875	0	0.0015	0.00034	3.830122
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Nitrate（N）	19.211875	1.03	164.91	27.31999	4.928819

unit:mg/L

3. Compute Fuzzy Matrix R

According to formula (1), (2) and (3) calculate the degree of membership of each indicator to the water quality grade, each indicator is calculated to have five levels of membership, and the 16 selected indicators can get 16 sets of numerical value. Taking JYY101 water sample as an example, the fuzzy matrix R is:

$$R^T = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 0.34 & 0.577 & 1 & 1 & 1 & 1 & 1 & 1 & 0.889 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.66 & 0.423 & 0 & 0 & 0 & 0 & 0 & 0 & 0.111 & 0.746 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.254 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}^T$$

4. Establish the Weight Fuzzy Matrix A

According to formula (8), the weight W of the 16 indexes is calculated to form a 1 × 16 matrix, and the matrix is normalized to obtain a modified weight fuzzy matrix A. Taking JYY101 as an example, the result of weight calculation is:

$$A = \begin{bmatrix} 0 & 0.0127 & 0 & 0.005 & 0.057 & 0.098 & 0.208 & 0.298 & 0 & 0.017 & 0 & 0 & 0 & 0 & 0.021 & 0.283 \end{bmatrix} \quad (8)$$

5. Calculation of Membership Degree and Classification of Water Quality

According to formula (7), the above two fuzzy matrix is combined to obtain the membership degree matrix B. For example, JYY101 membership matrix B= {0.451258 0.47689 0.071851 0 0}, according to the principle of maximum membership to determine the water quality level, of which 0.47689 is the maximum value of five values, in the class II water quality. Therefore, the comprehensive water quality of the monitoring well is determined as category II. According to the above methods, the water quality grades of the other 31 wells in the study area are obtained. The results are shown in table 3.

Table 3. Water quality calculation result of fuzzy comprehensive evaluation method

name	I	II	III	IV	V	result
JYY101	0.451258	0.47689	0.071851	0	0	II
JYY102	0.688795	0.311205	0	0	0	I
JYY103	0.194543	0.580095	0.225363	0	0	II
JYY105	0.167778	0.40579	0.426433	0	0	III
JWY115	0.120315	0.097462	0.444693	0.135222	0.285599	III
JWY119	0.164033	0.584151	0.251816	0	0	II
JWY121	0.062242	0.266819	0.407208	0.263731	0	III
JWY123	0.272389	0.585482	0.142129	0	0	II
JWY124	0.125919	0.200056	0.274292	0.399733	0	IV
JWY125	0.144404	0.292399	0.335654	0.227544	0	III
JWY126	0.113148	0.255959	0.417122	0.213987	0	III
JYY115	0.353654	0.56858	0.077766	0	0	II
JYY116	0.193292	0.386475	0.420233	0	0	III
JYY117	0.102765	0.336839	0.194492	0	0.365905	V
JYY118	0.286278	0.029097	0	0	0.684625	V
JWY130	0.62808	0.37192	0	0	0	I
JWY131	0.062255	0.405553	0.284734	0.247458	0	II
JWY132	0.086	0.42904	0.231869	0.253092	0	II
JWY133	0.017488	0.032661	0.060033	0.139098	0.750721	V
JWY134	0.136372	0.398837	0.464792	0	0	III
JWY140	0.093397	0.33349	0.263152	0	0.309961	II
Luonan1#	0.232207	0.662872	0.104921	0	0	II
Zhangzhuang7#	0.194192	0.650897	0.154911	0	0	II
Linjian4#	0.120881	0.178564	0.406049	0.294506	0	III
Wangfuzhuang9#	0.067561	0.214472	0.407844	0.010104	0.300019	III
Xiachi1#	0.185629	0.607841	0.20653	0	0	II
Lilou13#	0.130415	0.164518	0.590886	0.11418	0	III
Dongjiao1#	0.120006	0.166261	0.285631	0.428102	0	IV
Roulian factory 4#	0.123157	0.144897	0.280692	0.132684	0.31857	V
Tuo factory 6#	0.186057	0.305634	0.47421	0.034099	0	III
Foreign Language Institute1#	0.163156	0.215524	0.566154	0.055165	0	III
Steel mill living quarters	0.147715	0.498155	0.35413	0	0	II

4.3 Groundwater quality Evaluation Based on Comprehensive Index Method

According to the "Groundwater environmental quality standard" (GB/T14848-93 [S]), the comprehensive evaluation of groundwater quality by annotated scoring methods should be performed as follows. Firstly, evaluate the individual component to determine the quality category. Secondly, according to the table 4 determine the individual component evaluation score F_i, and then according to equation (9) calculate the comprehensive evaluation score F. Finally, according to the F value classify groundwater quality level.

Table 4. Evaluation score table for single fator

sort	I	II	III	IV	V
F_i	0	1	3	6	10

$$\overline{F} = \frac{1}{n}\sum_{i=1}^{n} F_i \tag{9}$$

$$F = \sqrt{\frac{F_{max}^2 + \overline{F}^2}{2}} \tag{10}$$

where, $\overline{F}$ is the average value of each individual component score F_i;

F_{max} is the maximum value of the individual component evaluation score F_i;

n is the index number.

Table 5. Comprehensive classification scoring table for groundwater quality

sort	excellent	good	preferably	poor	range
F	F<0.8	0.8≤F<2.5	2.5≤F<4.25	4.25≤F<7.20	F≥7.20

According to the above methods the F value can be calculated, and according to Table 5, the groundwater quality level in the study area is shown in Table 6.

Table 6. Calculation results table of comprehensive index method

name	F	sort	name	F	sort
JYY101	2.132	II	JWY131	4.290	IV
JYY102	0.711	I	JWY132	4.276	IV
JYY103	2.157	II	JWY133	7.191	IV
JYY105	2.163	II	JWY134	2.187	II
JWY115	7.131	IV	JWY140	7.110	IV
JWY119	2.157	II	Zhangzhuang7#	2.145	II
JWY121	4.271	IV	Linjian4#	2.145	II
JWY123	2.145	II	Wangfuzhuang9#	4.290	IV
JWY124	4.295	IV	Xiachi1#	4.301	IV
JWY125	4.271	IV	Lilou13#	2.157	II
JWY126	4.301	IV	Dongjiao1#	4.285	IV
JYY115	2.129	II	Roulian factory 4#	4.290	IV
JYY116	2.151	II	Tuo factory 6#	4.290	IV
JYY117	7.114	IV	Foreign Language Institute1#	4.290	IV
JYY118	7.082	IV	Steel mill living quarters	4.290	IV
JWY130	4.260	IV	Zhangzhuang7#	2.157	II

4.4 Evaluation Result Analysis

A comprehensive evaluation of Luoyang groundwater was conducted by resorting to fuzzy mathematics. Water sample I, sample II, sample III, sample IV, sample V accounted for 6.25%, 37.5%, 37.5%, 6.25, 12.5% of the total. The traditional GB method evaluated the quality of groundwater in the study area, water sample I, sample II, sample IV account for 3.12%, 37.5%, 59.38% respectively.

It can be seen that the water quality comprehensive index evaluation method highlights the largest pollution factor, and the index classification is based on the binary logic, thus cannot describe the continuity of environmental quality, and cannot objectively reflect the influence of the index value near the water quality grade limit on the water quality evaluation and classification. So the result of evaluation is extreme, and it is not suitable for the evaluation of groundwater quality in the study area. Fuzzy comprehensive evaluation using membership degree to evaluate groundwater quality, considering the weight of each factor, can reflect how close the actual concentration of boundary water quality index of water quality; make the evaluation more comprehensive and reasonable.

5 Mechanism Analysis of Groundwater Pollution in Study Area

The main groundwater pollutants in the study area are total hardness and nitrate. The total hardness of more than 450 mg / L is classified as extremely hard water, fail to reach the water quality standard is exceeded. The total hardness of the study area is mainly concentrated in the third class. Total hardness excessive monitoring wells for 16, the over-standard rate of the total number was 50%. Nitrate excessive monitoring wells for 10, the over-standard rate of the total number was 31.25%. According to the distribution of groundwater quality in the study area (Fig. 2), industrial waste water discharge is due to Pangcun Town Industrial Zone, Baima Temple Huoquan Industrial Zone, Hongshan Township Industrial Zone, Li Village, Nanzhai Industrial Zone and other local factories gathered. Excessive discharge of industrial waste water and domestic sewage is the main cause of groundwater pollution.

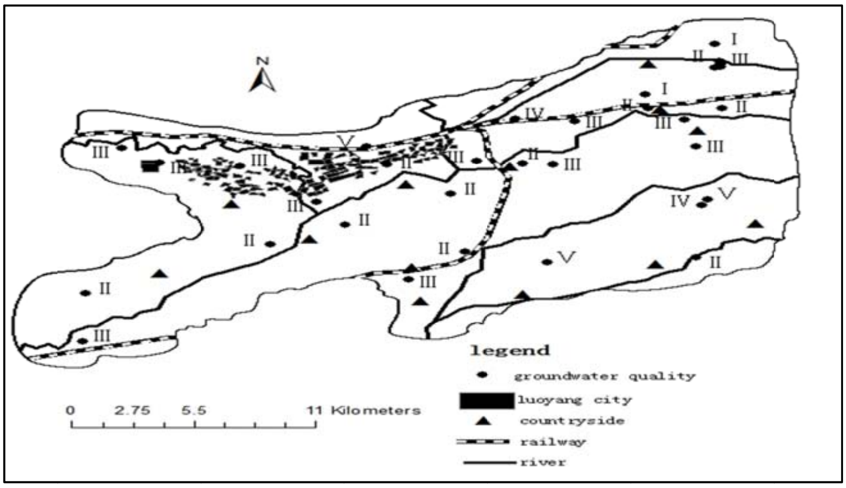

Figure 2. Distribution of groundwater quality in the study area

6 Conclusion

The following conclusions can be obtained through the evaluation of the groundwater quality of 32 water samples in Luoyang city in 2012:

1. A comprehensive evaluation of Luoyang groundwater was conducted by resorting to fuzzy mathematics. Water sample I, sample II, sample III, sample IV, sample V accounted for 6.25%, 37.5%, 37.5%, 6.25, 12.5% of the total. The groundwater quality was largely at a moderate state;
2. The pollution degree of water quality belongs to the fuzzy concept. Compared with the traditional groundwater comprehensive index method, the fuzzy mathematics method is more in line with the water quality of the study area, and it is a better method for groundwater quality evaluation;
3. The spatial distribution of groundwater quality is obviously more serious in industrial parks and residential areas;
4. The main excessive components of groundwater in the region are the total hardness and nitrate. In order to improve the status of groundwater and reasonable scientific planning of groundwater extraction, it is necessary to strictly control the industrial wastewater and domestic sewage discharge.

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