Discriminatory analysis of spring water supply direction

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Abstract. In this paper, 56 groups of underground water samples were collected in Baotu Spring Catchment, and a discriminant model was established to judge the recharge direction and aquifer of the four major spring groups. The results showed that Baotu Spring Group and Black Tiger Spring Group mainly recharge from southwest direction Ordovician karst water, Central south direction of Ordovician karst water respectively, and Five Dragon Pool Spring Group and Pearl Spring Group received from southwest direction and southeast direction Cambrian karst water supplement respectively. The research results are of great significance to the implementation of Jinan spring conservation and precise source replenishment measures. At the same time, it shows that the karst water system in northern China has the characteristics of uneven karst development.

1. Introduction

Jinan as a typical northern karst area, karst springs is an important karst hydrogeological phenomenon in the northern karst area of China [1]. Jinan spring water and karst groundwater, with its excellent water quality and abundant resources, make it a good water source for urban life, industry, agriculture and ecology. Due to the increasing demand for water use in Jinan, the spring water in Jinan has been cut off many times, and the rational development and utilization of spring water and karst water is of great significance to the social and economic development of Jinan. In order to ensure the continuous gushing of spring water, Jinan City adopted a number of measures to limit the exploitation. In order to ensure the optimal implementation of the program, the study of the direction of spring water supply has become particularly important.

At present, the recharge aquifers and the supply ratio of spring water is analyzed by frequency analysis method [2], hydrochemical formula method [3] and so on. Discriminant models are mostly used to distinguish different water sources in mixed water by hydrochemical data [4]. In this paper, a discriminant model is established, and 7 groups of parameters are selected to analyze the recharge direction and aquifer of spring water in Baotu Spring catchment.
2. Study Area
Baotu Spring Catchment is located in the north wing of Mount Tai, and the large area of sedimentary cover in the southern hilly area is the rock strata of Cambrian and Ordovician dominated by carbonate rocks. The Himalayan movement causes the southern uplift of Jinan, the northern subsidence and the low north-south topography, which forms the natural conditions for the movement of groundwater from south to north. A horst is formed between the Qianfo Mountain Fault and the wenhuaqiao fault, and the limestone aquifer is uplifted as a whole. The karst water movement is blocked on three sides, and the pressure is raised. Springs are formed in the parts with favorable topography and structure and strong weathering of rock mass, forming four spring groups represented by Baotu Spring.

3. Methodology

3.1. Sampling and chemical analysis

![Figure 1. Distribution of Jinan spring catchment and groundwater sampling points](image)

In order to reveal the hydrochemical characteristics of the groundwater in the spring area, the recharge direction and the location of the recharge aquifer were analyzed by using the hydrochemical parameters. Samples were collected in mid-August 2018 (Fig. 1). 56 groups of water samples were collected near the south Xinglong recharge area, the southeastern Longdong recharge area, and the southwestern Yufu River recharge area (including 22 groups of water samples from the direct recharge area, 20 groups of water samples from the indirect supply area, 6 groups of water samples from the discharge area, and 8 groups of water samples from the surface). The collection of water samples controls the whole process of recharge, runoff and discharge from the karst water system to the spring group. Water samples are strictly in accordance with the Technical Specification for Groundwater Environmental Monitoring (HJ/T 164-2004). The test method is shown in Table 1.
### Table 1. Method for determination of various ion components in groundwater.

| Test items | Determination method |
|------------|----------------------|
| K⁺, Na⁺, Ca²⁺, Mg²⁺ | Flame atomic absorption spectrophotometry |
| Cl⁻, HCO₃⁻, SO₄²⁻, NO₃⁻, F⁻ | Titration method |
| pH | Chromatography of ions |
| COD | Acidimetric method |
| TDS, EC | Potassium dichromate oxidation method |
| TH | Portable conductivity meter (field measurement) |
|  | EDTA titration |

#### 3.2. Discriminant analysis

With m totals, \( G_1, G_2, \ldots, G_m \), their prior probabilities are \( q_1, q_2, \ldots, q_m \) respectively, and the density function is \( f_1(X), f_2(X), \ldots, f_m(X) \) (in discrete cases is a probability function). When a water sample \( x \) is observed, the Bayesian formula can be used to calculate its posterior probability from the \( g \)-th population:

\[
p(g/x) = \frac{q_g f_g(X)}{\sum_{i=1}^{m} q_i f_i(X)}, \quad g = 1, 2, \ldots, m
\]

And when

\[
p(h/x) = \max_{1 \leq g \leq m} p(g/x)
\]

determines that \( X \) comes from the \( h \)-th population. In addition, in order to reasonably consider the loss caused by the wrong judgment, the discriminant function is determined by using the concept of the minimum error of the wrong judgment. At this point, the average loss of the \( X \)-error to the \( h \)-th population is defined as:

\[
E(h/x) = \sum_{g=1}^{m} \frac{q_g f_g(x)}{\sum_{i=1}^{m} q_i f_i(x)} \cdot L(h/g)
\]

Where \( L(h/g) \) is called the loss function. It indicates that the \( g \)-th overall sample was misjudged as the \( h \)-th overall loss. Then the criterion is, if

\[
E(h/x) = \min_{1 \leq g \leq m} E(g/x)
\]

Then, determine that \( X \) comes from the \( h \)-th population. Under the condition that the covariance matrix is equal, the discriminant function can be derived, and then the supply direction of each spring group can be discriminated and classified.
4. Results and Discussion

The hydrochemical data of the study area are divided into 12 types (Fig. 2), in which the recharge water source is divided into 1-Yufu River recharge area, 2-Liyang Lake recharge area, 3-Urban Yellow River recharge water, 4-Xingji River recharge area. The underground water is divided into 5-Southeastern Ordovician karst water, 6-Southeastern Cambrian karst water, 7-Central South Ordovician karst water, 8-Central South Cambrian karst water, 9-Southwestern Ordovician karst water, 10-Southwestern Cambrian karst water, 11-Karst water in the west of Jinan. Four great springs group discharge area.

Figure 2. Computational zoning map of study area

In order to discriminate the recharge sources of the four major springs, $K^+ + Na^+$, $Cl^-$, $SO_4^{2-}$, $HCO_3^-$, $Ca/Mg$, COD and EC (specific conductivity) were selected and analyzed by stepwise discriminant analysis of Bays.

$$P_1 = 0.298(K^+ + Na^+) - 0.621Cl^- - 0.228SO_4^{2-} - 0.219HCO_3^- + 1.288(Ca/Mg) + 2.402COD + 0.191EC - 39.138$$

Where $P_1$ denotes the discriminant function; $K^+ + Na^+$, $Cl^-$, $SO_4^{2-}$, $HCO_3^-$, $Ca/Mg$, COD, EC all indicate their content; $Ca/Mg$ represents the ratio of its $Ca^{2+}$ to $Mg^{2+}$ equivalent.

Table 2. Fisher linear differentiation function established

|       | P1   | P2   | P3   | P4   | P5   | P6   | P7   | P8  | P9  | P10 | P11  |
|-------|------|------|------|------|------|------|------|-----|-----|-----|------|
| $K^+ + Na^+$ | 0.298 | 0.248 | 0.698 | 0.317 | 0.262 | 0.421 | 0.372 | 0.516 | 0.367 | 0.493 | 0.62 |
| $Cl^-$    | -0.621 | -0.4  | -1.121 | -0.353 | -0.563 | -0.539 | -0.51  | -0.719 | -0.575 | -0.669 | -0.916 |
| $SO_4^{2-}$ | -0.228 | -0.212 | -0.442 | -0.278 | -0.229 | -0.251 | -0.294 | -0.279 | -0.292 | -0.3  | -0.446 |
| $HCO_3^-$ | -0.219 | -0.057 | -0.206 | 0.02  | -0.039 | -0.002 | 0.016  | -0.042 | -0.037 | -0.04 | -0.094 |
| $Ca/Mg$  | 1.288 | 0.363 | -0.264 | -0.122 | -0.69  | 1.316 | -0.548 | 2.079 | -0.244 | 0.505 | 0.06  |
| COD     | 2.402 | -1.486 | -1.83  | -4.279 | -4.145 | -3.775 | -5.151 | -3.569 | -4.162 | -3.871 | -3.811 |
| EC      | 0.191 | 0.135 | 0.29  | 0.142 | 0.183 | 0.141 | 0.171  | 0.174 | 0.188 | 0.185 | 0.238 |
| Constant | -39.138 | -24.66 | -63.983 | -40.902 | -50.08 | -35.761 | -51.797 | -47.15 | -49.82 | -46.193 | -53.405 |
Table 3. Test of discrimination results

| Type                  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|-----------------------|---|---|---|---|---|---|---|---|---|----|----|
| Misjudgment           | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 1 | 1 | 1  | 0  |
| Misjudgment rate %    | 0 | 0 | 0 | 0 | 28.6 | 22.2 | 28.6 | 12.5 | 25 | 20 | 0  |

As shown in Fig.3, the difference between Cambrian and Ordovician karst water is obvious and easy to distinguish, while the difference between Cambrian karst water and karst water in the west of Jinan is small, which may lead to misjudgment; in addition, the boundary of Ordovician / Cambrian karst water in different directions is not obvious, which increases the difficulty of discrimination. According to the established discriminant model, the recharge direction and the recharge layer of the four springs group are discriminated, and the correct rate is 80%(Table 3), and the results are shown in Table 4.

Table 4. Discriminatory results

| Spring Groups                  | Source of Supply                     |
|--------------------------------|--------------------------------------|
| Baotu Spring Group             | Southwest Ordovician karst water     |
| Black Tiger Spring Group       | Central South Ordovician karst water |
| Five Dragon Pool Spring Group  | Southwest Cambrian karst water       |
| Pearl Spring Group             | Southeast Cambrian karst water       |

5. Conclusion

To sum up, the Baotu Spring Group and the Black Tiger Spring Group mainly accept the Ordovician karst water recharge in the southwest direction Ordovician karst water and the Central South Ordovician karst water respectively, while the Five Dragon Pool Spring Group and the Pearl Spring Group mainly accept the Cambrian karst water supply in the southwest direction and the Cambrian karst water supply in the southeast direction respectively, and their discrimination rate reaches 80%.
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