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Original Research

Evaluation of Groundwater Quality, Health Risk Assessment and Prediction of Water Quality Evolution in Water Source Area of Zhangji

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Abstract

Zhangji water source is related to the safe water and health of nearly 9 million people in Xuzhou. The groundwater quality standards were evaluated. In this study, the Entropy fuzzy comprehension evaluation method (EFCE) was used to analyze the groundwater quality of Zhangji water source. According to (GB/T 14848-2017), the water quality assessment results can be divided into five levels (from most suitable to least suitable). The results show that there are three areas where the groundwater quality is Class III and the rest are Class I. Moreover, according to the analysis of the health risk assessment results of drinking water sources, the increasing trend of the hazard index of fluoride and nitrite to human health in Zhangji water sources is obvious. For this reason, this paper used the Shuffle Complex Evolution Algorithm (SCE-UA) to establish a water quality evolution model for the Zhangji water source. Simulation results show that nitrate concentrations, mineralization and fluoride have not exceeded the limit in most areas of the Zhangji water source in the past five years. However, concentrations of pollutants such as nitrate are gradually approaching the Class III water limit in the Groundwater Quality Standard (GB/T 14848-2017), indicating a gradual deterioration in water quality at source, albeit a slower trend, which is influenced by human activities.

Keywords: groundwater quality, entropy fuzzy comprehension evaluation method, health risk assessment, water quality evolution

Introduction

Water is the source of life and an inseparable and essential component of living organisms. The quality and safety of drinking water is also an important aspect of human survival and sustainable development [1]. With the development of society, people are more and more concerned about the safety of drinking water. In particular, it is about the changing water quality of drinking water sources. The human health problems caused by contamination of the water quality of drinking water sources are becoming increasingly serious [2-4]. Examples include the seasonality of drinking water sources and the effect of drinking water sources

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on intestinal infections in children in Limpopo Province, South Africa [5], the health effects of pesticides present in drinking water sources in Japan and the Netherlands [6, 7], the problem of excess lithium in drinking water sources in the United States [8] and organochlorine pesticides in drinking water sources of the Yangtze River, among others [9]. These things indicate that the water quality of drinking water sources is suffering from great challenges.

China is a country with a large population and the available water resources cannot fully meet the demand for freshwater resources for people's living and production [10-12]. The water resources in China are extremely unevenly distributed, resulting in the scarcity of freshwater resources in the western and northern parts of the country [13-16]. Therefore, drinking water sources are also a scarce and valuable resource in China. Xuzhou is also one of the water-scarce cities in China, and since the completion of Zhangji water source, it has greatly improved the water supply in Xuzhou. The water source of Zhangji is mainly composed of fissure karst water. Under natural conditions, it is easy to form a self-flowing karst water area of about 100 km^2, and the volume of water flowing from a single well in the self-flowing area is usually about 2,000-3,000 m^3/d. The water needs of more than 900,000 people in the vicinity of the water source are basically met. Therefore, the Zhangji water source is particularly significant for Xuzhou and the surrounding region.

In recent years, the problem of drinking water pollution in China has become more and more obvious [17, 18]. If the water quality of water sources can be objectively and accurately evaluated, it can provide an important decision-making basis for the environmental management of water sources. To understand the water quality situation of water sources and ensure the safety of regional drinking water, the water environment of water sources must be scientifically evaluated [19]. Health risk assessment of drinking water sources can link the contamination of drinking water sources to human health [20]. The quantitative description of health hazards can provide an important basis for decision making in water source protection and management [21]. In some cases, chemical elements in water are also influenced by anthropogenic factors [22]. Fluoride is one of the two most common elements that affect drinking water [23]. Ingestion of highly fluoridated water may cause adverse health effects and even disability [24-26].

As an important drinking water source in Xuzhou, the study of water quality characteristics and health risk assessment of Zhangji water source is necessary to ensure the water quality safety of the water source. In addition, the prediction study of the evolution trend of water quality in Zhangji water source can provide guidance for the sustainable development, utilization and protection of local water resources. In this paper, the SCE-UA algorithm was used to predict the water quality evolution trend of Zhangji water source. The objectives of this study are: (1) Evaluate the groundwater quality of Zhangji water source and check its suitability for drinking; (2) Assess the health risk situation of the water source contaminants to the residents; (3) Predict the water quality evolution trend of the water source in the next ten years by using SCE-UA algorithm considering different hydrogeological parameters zoning. The results of the study will provide the necessary knowledge and information for water quality protection and management of the Zhangji water source.

Study Area

Zhangji water source is located in the southeastern part of Xuzhou City, with longitude 117°15′58″ to 117°35′54″ east and latitude 34°01′21″ to 34°13′19″ north, with a total area of 356.41 km^2 (Fig. 1). The overall topography is mostly plain areas, with ground elevations ranging from 28 to 38 m. The elevation of the hilly areas in the north and south is between 60 and 237 m. Zhangji water source is a warm-temperate semi-humid monsoon climate zone with four distinct seasons. The average annual precipitation in the water source is 846.63 mm, and the average annual evaporation rate is 1807.47 mm.

Zhangji water source is designed to take 100,000 m^3/d, 36.5×10^{7}m^3/y. The water source effectively improves the water quality type water shortage in Xuzhou city and relieves the water supply tension in Xuzhou city at special times.

Materials and Methods

Sample Collection and Analysis

The water quality of the water source is regularly monitored by local government departments. A total of 15 areas in the Zhangji water source were monitored (Fig. 1). The water samples were collected in 500 mL narrow-mouth polyethylene bottles, which were washed 2-3 times with the water to be tested before sampling, sealed to prevent leakage and sent to the laboratory for testing as soon as possible. The samples were sent to the laboratory of Xuzhou City Water Supply Water Quality Testing Center and placed in a refrigerator at temperatures below low temperature (2-4ºC) until analysis was completed. In the laboratory, all water samples are filtered through 0.45μm membrane filters prior to testing to separate suspended particles. The water sampling method was based on Kent and Payne 1988 [27]. The samples were analyzed for 29 physicochemical parameters, including pH, chemical oxygen demand (COD), ammonia N, Cu, Zn, F^-, Cr^{6+}, and cyanide.

In this study, the suitability of groundwater for drinking and living was evaluated by meeting the values

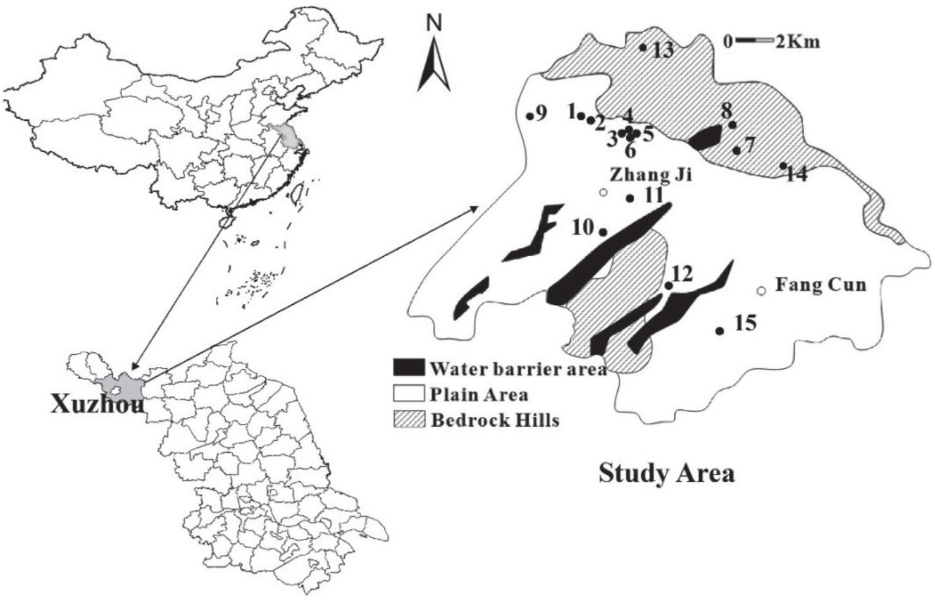

Fig. 1. Location of the study area.

of various groundwater quality parameters according to the Groundwater Quality Standard (GB/T14848-2017) in China. This standard specifies the classification of groundwater quality, groundwater quality monitoring, evaluation methods and groundwater quality protection, and is the only way to evaluate groundwater quality in China at present [28]. It also corresponds to the groundwater quality evaluation method used in this paper, which classifies groundwater quality into five grades: excellent (I), good (II), medium (III), poor (IV) and very poor (V). Among them, I, II, III water can be used directly as a source of drinking water, IV must be properly treated as drinking water, V water should not be used as a source of drinking water.

Principle for Entropy Fuzzy Comprehension Evaluation (EFCE) Method

Fuzzy evaluation is a method to evaluate things by fuzzy transformation according to the given evaluation criteria and the actual measured values, yet the general fuzzy evaluation method has a certain subjectivity in the analysis of evaluation factors. The entropy method is a method to determine the weight of each index under objective conditions by the judgment matrix composed of the detection values of each evaluation index. The entropy fuzzy comprehension evaluation (EFCE) method can effectively avoid the subjectivity of general fuzzy evaluation weights and make the evaluation results reflect the actual situation better. Thus, the entropy fuzzy comprehensive evaluation method is selected in this paper to determine the weight of each evaluation parameter. The calculation mainly includes the following three steps: Calculate the affiliation index, Calculation of weights, Calculate the evaluation matrix.

Calculate the Affiliation Index

This evaluation uses “descending half trapezoid” to calculate the affiliation degree r_{ij} ($0<r_{ij}<1$), according to each indicator affiliated with each water quality level, to determine the different affiliation functions (Equation 1).

$$\mu_{ij} = \begin{cases} \left(x - a_{i,j-1}\right)/\left(a_{i,j} - a_{i,j-1}\right) & x \in \left[a_{i,j-1}, a_{i,j}\right] \\ \left(a_{i,j+1} - x\right)/\left(a_{i,j+1} - a_{i,k}\right) & x \in a_{i,j}, a_{i,j+1} \\ 0 & x \notin \left[a_{i,j-1}, a_{i,j+1}\right] \end{cases} \tag{1}$$

Where a_{ij} represents the standard value of i indicator j water quality, x represents the actual measured value of each evaluation indicator in the water sample.

Calculation of Weights

First, establish the judgment matrix of the original data $X = (x_{ij})$ n×m. Second step, normalize the judgment matrix of the original data (Equation 1). Third step, calculate the entropy weight matrix (Equation 2, Equation 3, Equation 4).

$$b_{ij} = \frac{x_{ij}-x_{min}}{x_{max}-x_{min}} \tag{2}$$

$$H_j = -\frac{1}{\ln z}\left(\sum_{i=1}^{z} f_{i_j} \ln f_{i_j}\right) \tag{3}$$

$$w_i = \frac{1-H_i}{n-\sum_{i=1}^{n} H_i} \tag{4}$$

Where $f_{ij} = \frac{1+b_{ij}}{\sum_{i=1}^{z}(1+b_{ij})}$, (i = 1, 2...., z; j = 1, 2..., n), x_{max}, x_{min} are the maximum and minimum values in the measured values, respectively, n-evaluation index, z-evaluation object.

Calculate the Evaluation Matrix

According to the affiliation function of each factor, the fuzzy relationship matrix R (Equation 5) is calculated in turn. In selecting the fuzzy operator, the multiplicative summation fuzzy operator is used (Equation 6).

$$R = \left[r_{ij}\right] = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1,m-1} & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2,m-1} & r_{2m} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{n,m-1} & r_{nm} \end{bmatrix} \tag{5}$$

Where: i = 1, 2, ..., n for the number of indicators, j = 1, 2, ..., m for the number of water quality levels. The rows of the matrix indicate the degree of affiliation of the participation factor to the j (j = 1, 2, ..., m) level of water quality.

$$b_j = \sum_{i=1}^{n}\left(w_i \times r_{ij}\right) \quad j=1，2\ldots n \tag{6}$$

where b_j is the affiliation of index the sample to the j level of criteria, w_i is the weight of the I participation factor, r_{ij} is the fuzzy relationship matrix R.

Method of Heath Risk Assessment

The widely used health risk evaluation model was developed by the National Research Council of the National Academy of Sciences to identify contaminants contained in source water and their health effects on the drinking population [29-32]. The non-carcinogenic risk of drinking water intake can be estimated based on Equations (7) and (8).

$$E = \frac{C \cdot IR \cdot EF \cdot ED}{BW \cdot AT} \tag{7}$$

$$HI = \frac{E}{RfD} \tag{8}$$

where *C* is the concentration of contaminants in the water source (mg/L); *IR* is the drinking rate (L/d, U-S-EPA recommended value: 2 L/d), indicating the average daily water intake of human body; *EF* is the exposure frequency (d/a, drinking water is necessary daily, so it is "the number of days/a in the evaluation period "), indicating the average annual human intake of the evaluation pollutant days during the evaluation period; *ED* is the exposure time, indicating the lifetime human intake of the evaluation pollutant years; *BW* is the average human body weight (kg, it is appropriate to use 60 kg in China); *AT* is the average time (d, 70a × 365d/a for carcinogenic, *ED* × 365d/a for non-carcinogenic), *HI* is the hazard index, and *RfD* is the reference dose (mg/kg•d).

Shuffle Complex Evolution Algorithm (SCE-UA)

The SCE-UA algorithm is a global optimization algorithm, and the basic idea is to combine the deterministic-based composite search technique with the principle of competitive biological evolution in nature. The default values of the parameters of the SCE-UA algorithm are m = 2n + 1, q = n + 1, x = 1, y = 2n + 1, where m is the number of points in the complexes, q is the number of points in each subcomplexes, x is the number of successive offspring produced by the evolution of each subcomplexes, y is the number of steps in the evolutionary operation of each subcomplexes, and n is the number of parameters to be optimized. p is the number of complexes, and if the number of complexes is chosen more, it will increase the computation, and if it is chosen less, it will not achieve the optimization effect. Therefore, this paper takes p = 2.

Based on the hydrogeological conditions of the study area, it can be vertically divided into three layers. The first layer is the Quaternary loose layer, which is closely associated with atmospheric precipitation recharge. The second layer is a karst submerged aquifer characterized by well-developed karst fractures and excellent permeability. The third layer is a karst-bearing aquifer that features mudstone at the bottom, effectively preventing the further downward infiltration of water. The second and third layers represent the primary water reservoirs in the area. The simulation area (Fig. 2) is divided into three layers, namely: no pressure water surface to 0m reference surface, 0m reference surface to -75 m level, -75 m level to -150 m level. The simulation area is dissected with the uppermost layer as the control layer, and the grid form and number of each layer are the same, with 8636 cells in a single layer, creating 25908 cells in total.

According to the established conceptual model of hydrogeology it is known that groundwater flow can be generalized to three-dimensional unsteady flow, the mathematical model of which is Eq. (9) and the mathematical model of solute transport is Eq. (10).

$$\begin{cases} \frac{\partial}{\partial x}\left(K_{xx}\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial x}\left(K_{yy}\frac{\partial H}{\partial y}\right)+\frac{\partial}{\partial x}\left(K_{zz}\frac{\partial H}{\partial z}\right)+W=\mu_s\frac{\partial H}{\partial t},(\mathrm{x},\mathrm{y},\mathrm{z})\in\Omega \\ H(\mathrm{x},\mathrm{y},\mathrm{z},\mathrm{t})\big|_{t=0}=H_0(\mathrm{x},\mathrm{y},\mathrm{z},\mathrm{t}),(\mathrm{x},\mathrm{y},\mathrm{z})\in\Omega \\ K\frac{\partial H}{\partial n}=q,(\mathrm{x},\mathrm{y},\mathrm{z})\in S_2 \end{cases} \tag{9}$$

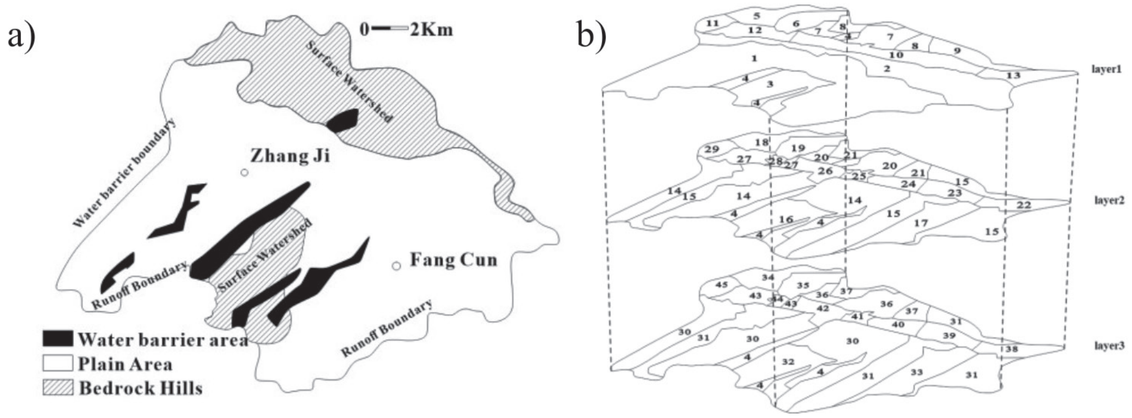

Fig. 2. a) Diagram of the study area; b) Schematic diagram of model.

$$\begin{cases} \dfrac{\partial c}{\partial t} = \dfrac{\partial}{\partial x_i}\left(D_{ij}\dfrac{\partial c}{\partial x_j}\right) - \dfrac{\partial}{\partial x_i}(cv_i) + I, (x,y,z) \in \Omega \\ c(x,y,z,t)\big|_{t=0} = c_0(x,y,z,t), (x,y,z) \in \Omega \\ c(x,y,z,t) = c(x,y,z), (x,y,z) \in B_2 \\ \end{cases} \tag{10}$$

Where: H- groundwater head (m), K_{xx}, K_{yy}, K_{zz}, - permeability coefficient in the direction of the main axis (m/d), μ_s- water storage rate of karst water-bearing system (m^{-1}), for pore water-bearing system becomes water-supply degree, W-source and sink terms, i.e. the volume of water discharged and recharged per unit volume of water-bearing system, which can be expressed as $W = W_p + W_s + W_r + W_e - Q$, W_p is the intensity of precipitation infiltration recharge (m/d), W_s is the intensity of irrigation infiltration recharge (m^3/d), W_r is the intensity of reservoir leakage recharge (m^3/d), W_e is the intensity of evaporation (m/d); Q is the intensity of extraction (m^3/d). Ω – the extent of the study area, S_2 – is the second type of boundary, q – Runoff volume per unit area per unit time (m^3/d) on the second type of boundary, c – solute concentration (mg/m^3), D_{ij} – hydrodynamic dispersion coefficient (m^2/d), V_i – Groundwater flow rate (m/d), I – source and sink terms (mg/ m^3/d).

Results and Discussion

Water Quality Assessment

According to the available water quality information and the conditions of application of the entropy weighting method, the values for Cu, Zn and COD in the study area are very small and even lower than the standards for Class I water. Thus, we use a total of eight indicators of manganese, sulphate, chloride, total dissolved solids, fluoride, nitrate nitrogen, ammonia nitrogen and nitrite. The calculated weights W_i = (0.3535, 0.0817, 0.0846, 0.0977, 0.0873, 0.1056, 0.0618, 0.0679). The highest affiliation calculated based on the entropy weighting method reached 0.879 and the average affiliation reached 0.579, indicating that the results of the EFCE method are more accurate.

The water quality of the water sources was comprehensively evaluated according to the applicable domestic groundwater quality classes (Chinese 2017) (Table 1). Whereas the water quality in sample 3, sample 13 and sample 14 is Class III compared to the other areas which are Class I, suggests that the water quality in these three areas has been affected by contaminants.

A survey of the corresponding areas based on the evaluation results showed that agriculture and farming were more prosperous in the eastern and northern plains (sampling areas of samples 3, 13 and 14), and the use of organic matter such as pesticides, fertilizers and feed was significantly higher than in other areas. The more frequent application of pesticides and fertilizers has led to a significant increase in ammonia nitrogen and nitrate concentrations in groundwater in these areas, which has affected groundwater quality.

Heath Risk Assessment

Four consecutive years of water quality monitoring information from the water source were used for this health risk assessment (due to the confidential nature of the information, four years of water quality monitoring information is not presented). The results show that the top 5 contaminants in the hazard index at the water source are all fluoride, arsenic, nitrate nitrogen, hexavalent chromium and lead (Table 2). None of the pollutants had a combined hazard index above 1 indicating no non-carcinogenic chronic toxic effects on the drinking population, but there is a clear trend of increasing year on year. In addition, the hazard indices for fluoride and arsenic both exceeded 0.1, with arsenic in particular showing serious exceedances of 21 to 32 times. The hazard index for nitrate nitrogen was close to 0.1, showing a clear trend of increase (Fig. 3).

Table 1. Result of entropy fuzzy comprehension evaluation method.

The number of the sample	Classify					Result
	I	II	III	IV	V	
1	0.488	0.141	0.371	0.000	0.000	Excellent
2	0.864	0.086	0.050	0.000	0.000	Excellent
3	0.345	0.267	0.387	0.000	0.000	Moderate
4	0.769	0.190	0.040	0.000	0.000	Excellent
5	0.730	0.204	0.066	0.000	0.000	Excellent
6	0.425	0.194	0.380	0.000	0.000	Excellent
7	0.879	0.079	0.043	0.000	0.000	Excellent
8	0.847	0.101	0.053	0.000	0.000	Excellent
9	0.508	0.089	0.402	0.000	0.000	Excellent
10	0.507	0.087	0.406	0.000	0.000	Excellent
11	0.441	0.191	0.368	0.000	0.000	Excellent
12	0.542	0.036	0.376	0.045	0.000	Excellent
13	0.379	0.190	0.431	0.000	0.000	Moderate
14	0.380	0.170	0.421	0.029	0.000	Moderate
15	0.453	0.147	0.400	0.000	0.000	Excellent

Fluoride, arsenic, nitrate-nitrogen, hexavalent chromium and lead are common contaminants in water that can adversely affect human health. Excessive fluoride intake can cause bone lesions, dental disease and, in severe cases, bone softening and deformation. Arsenic intake above acceptable limits can cause lung cancer, skin cancer and other diseases. Excessive nitrates can lead to nitrite poisoning, which in severe cases can cause oxygen deprivation, poisoning and even death. High levels of hexavalent chromium can cause diseases such as lung cancer and nasopharyngeal cancer. Excess lead can have adverse effects on the nervous, haematopoietic and renal systems. It is therefore important to monitor changes in these indicators closely as they have a significant impact on health. The above findings indicate that the water source is potentially contaminated and that efforts to monitor water quality need to be intensified. Appropriate measures should be taken at an early stage to prevent further deterioration of the situation.

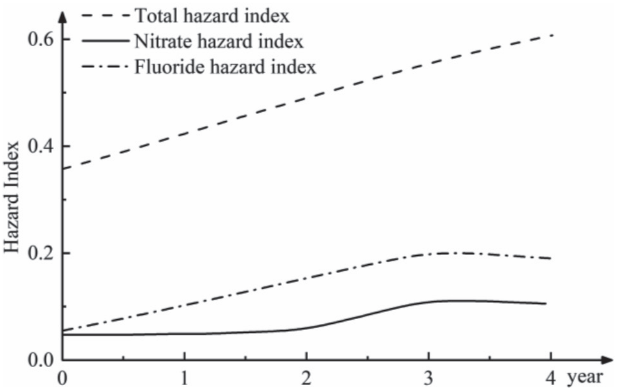

Fig. 3. Trend graph of the hazard index.

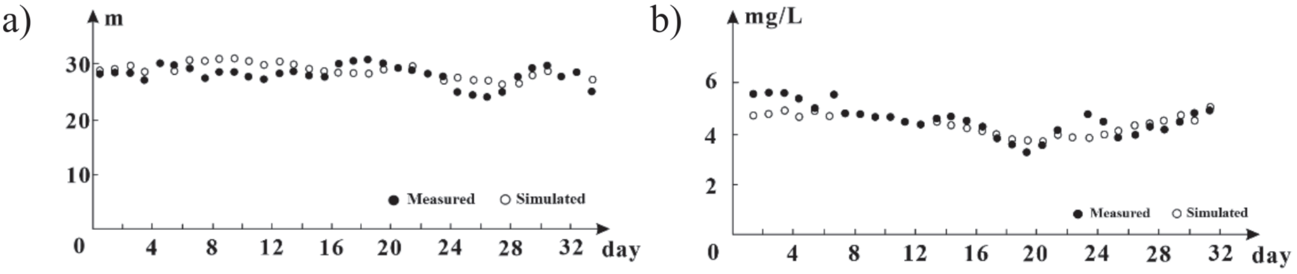

Fig. 4. Results of model tuning a) Comparison of measured and simulated water level values; b) Comparison of measured and simulated nitrate values.

Table 2. Results of health risk assessments.

Evaluation factors	Carcinogenic risk (Annual average)				Health Hazard Index (Annual average)			
	First Year	Second year	Third year	Fourth year	First Year	Second year	Third year	Fourth year
Cr^{6+}	-	4.17E-07	4.17E-07	4.17E-07	-	4.44E-02	4.44E-02	4.44E-02
As	3.00E-05	2.14E-05	2.14E-05	3.21E-05	1.56E-01	1.11E-01	1.11E-01	1.67E-01
Pb	3.14E-06	3.14E-06	3.14E-06	3.14E-06	3.81E-02	3.81E-02	3.81E-02	3.81E-02
Cd	-	-	-	-	2.00E-02	2.00E-02	2.00E-02	2.00E-02
Volatile phenols	-	-	-	-	2.22E-04	2.22E-04	2.22E-04	2.22E-04
CN	-	-	-	-	3.33E-03	3.33E-03	3.33E-03	3.33E-03
Hg	-	-	-	-	1.11E-02	1.11E-02	1.11E-02	1.11E-02
F^{-}	-	-	-	-	1.46E-01	1.69E-01	1.89E-01	1.85E-01
NO_3^-	-	-	-	-	5.44E-02	6.26E-02	9.68E-02	9.44E-02
Fe	-	-	-	-	1.59E-02	1.11E-02	1.11E-02	1.11E-03
Mn	-	-	-	-	1.41E-03	7.14E-04	4.76E-04	2.38E-03
Cu	-	-	-	-	3.08E-03	1.73E-03	1.67E-03	1.67E-03
Zn	-	-	-	-	5.56E-03	5.56E-03	5.56E-03	5.56E-03
Se	-	-	-	-	-	3.33E-02	3.33E-02	3.33E-02
Total	3.31E-05	2.50E-05	2.50E-05	3.57E-05	4.55E-01	5.13E-01	5.66E-01	6.08E-01

Note: — Indicates that the detected value is too low or not measured to be calculated

Prediction of Water Quality Evolution Trends

The water quality transport in the study area is influenced by the movement of water, and the water quality transport model is generalised to a non-stationary three-dimensional hydrodynamic dispersion model. Concentration values are based on observations from the water quality observation sites and the

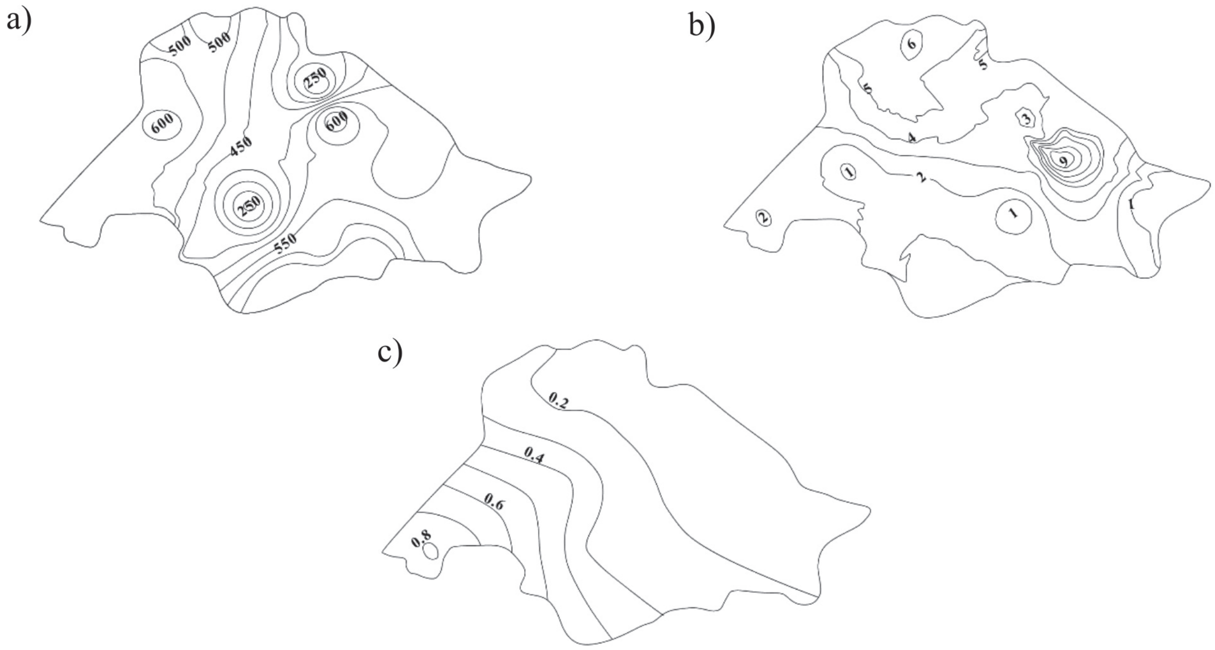

Fig. 5. Predicted water quality trends a) Nitrate concentration contour map (mg/L); b) Mineralisation contour map (mg/L); c) Fluoride concentration contour (mg/L).

simulation duration is 5 years. Firstly, the model needed to be re-referenced to make the simulation results more accurate (Fig. 4). Based on water levels and nitrate, the numerical simulations were in good agreement with the actual conditions.

As volatile phenols, mercury, arsenic, hexavalent chromium, lead, selenium, chromium and cadmium are then extremely low in water quality tests, they disappear quickly in the model with power dispersion. Therefore, changes in nitrate nitrogen, mineralisation and fluoride concentrations were selected to illustrate the simulation results in this case (Fig. 5).

Predicted nitrate nitrogen concentrations are higher in some areas in the east and north, with a maximum value of 9 mg/L (limit value set by Groundwater Quality Standards: <10 mg/L). Predicted mineralisation values are low in the mountainous areas and relatively high in the plain areas, with a maximum value of 600 (the limit set in Groundwater Quality Standards: <1000 mg/L); predicted fluoride is significantly higher in the south-western areas than in other areas, with a maximum value of 0.8 (the limit set in Groundwater Quality Standards: <1 mg/L). The predicted results for nitrate nitrogen concentration, mineralisation and fluoride show that the concentrations of the three water quality indicators are close to the limit values, but none will be exceeded within five years.

Conclusion

This study analysed the water quality characteristics of 15 areas in the Zhangji water source in Xuzhou City. EFCE was used to conduct a comprehensive evaluation of water quality in the water sources. Health risk assessment and water quality evolution trend analysis were carried out considering the influence of pollutants. The main conclusions are as follows.

(1) The affiliation of the evaluation using the EFCE method reached 0.879, indicating that the comprehensive evaluation model based on the entropy weight method has a good application effect on the evaluation of groundwater quality. The water quality of 13 well samples at the water source was class I. Nevertheless, the wells of sample 3, sample 13 and sample 14 are class III. The result shows that the water quality in these three areas has been affected by contaminants.

(2) According to the health risk evaluation results, it can be seen that the combined hazard index of the pollutants does not exceed 1, indicating that it will not produce non-carcinogenic chronic toxic effects on the drinking population. But, there is a trend of increasing year by year. Although the carcinogenic substance arsenic is far below the limit value of the Groundwater Quality Standards, its carcinogenic index exceeds the limit by as much as 21 to 32 times, which is mainly related to the environmental background value and the use of pesticides, and should be the main object of future research and prevention.

(3) Based on the hydrogeological conditions and hydrodynamic field observation data, a numerical model of water quality and water quantity coupling in the study area was established, and the SCE-UA algorithm was used to optimise the calculation, and it was concluded that nitrate nitrogen concentration, mineralisation and total hardness would not be exceeded in the next five years. However, the concentrations of pollutants are largely close to the limit values. This also indicates that pollution in the water source area is gradually increasing. Although this trend is slow, it is a cause for alarm.

This study could provide an important reference framework for government decisions to improve groundwater quality in the study area. In addition, this study could serve as a guide for future researchers to accurately and precisely assess groundwater conditions.

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Conflict of Interest

The authors declare no competing interests.

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