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Original Research

Evaluation of Drinking Water Quality Using the Water Quality Index (WQI), the Synthetic Pollution Index (SPI) and Geospatial Tools in Lianhuashan District, China

Tian Hui[1,2,3]*, Liang Xiujuan[2,3], Sun Qifa[1], Liu Qiang[1], Kang Zhuang[1], Gong Yan[1]

[1]Shenyang Geological Survey Center, China Geological Survey, Shenyang 110034, China
[2]Key Laboratory of Groundwater Resources and Environment, Ministry of Education, Jilin University, Changchun 130021, China
[3]College of New Energy and Environment, Jilin University, Changchun 130021, China

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Abstract

Due to the impact of human agricultural production and climate and environmental changes, the applicability of groundwater for drinking purposes has attracted widespread attention. In order to quantify the hydrochemical characteristics of groundwater in Lianhuashan and evaluate its suitability for assessing water for drinking purposes, 71 groundwater samples were collected and analyzed. The results show that groundwater in aquifers in the study area is weakly alkaline. The abundance is in the order $HCO_3^->Cl^->SO_4^{2-}$ for anions, and $Ca^{2+}>Na^+>Mg^{2+}$ for cations. Groundwater chemical types were dominated by HCO_3-Ca, HCO_3-Ca• Mg, and HCO_3-Ca • Na. The Factor analysis, and PCA analysis show that ion exchange, and rock weathering are the main reasons affecting the water chemical composition in Lianhuashan. The analysis of water samples based on the WQI model revealed that about 69.09%, 25.45%, 1.81%, and 3.63% of the water samples were excellent, good, very poor, and unsuitable for drinking purposes, respectively. The analysis of water samples based on the SPI model showed that 18.30%, 66.19%, 7.04%, and 8.45% of the water samples were suitable, slightly polluted, moderately polluted, and highly polluted, respectively. The spatial distribution maps of the water quality index and the synthetic pollution index show that most of the groundwater resources in the study area are clean and suitable for drinking, despite the risks in the north and southwest of the study area.

Keywords: WQI, groundwater quality assessment, hydrochemistry, SPI, China

*e-mail: 359585977@qq.com

Introduction

Water is one of the natural resources necessary for human survival and economic development. [1]. However, in arid and semi-arid regions, uneven distribution of groundwater and surface water resources has become a contradiction that restricts living standards and economic development [2]. Understanding the relationship between groundwater and water demand for agricultural production is important for sustainable agricultural development [3]. Groundwater has become the main source of fresh water for household, agricultural and industrial uses due to its simple extraction and low cost [4]. In agricultural production areas, irrigation water recharges groundwater through leakage or flows directly into rivers, which has changed the hydrodynamic conditions and led to changes in groundwater hydrochemical conditions [5]. Therefore, understanding the chemical characteristics of groundwater and its influencing factors is critical to the protection and management of groundwater resources and the sustainable use of groundwater [6].

The Songnen Plain is one of the most important grain and grass production bases in China [7]. Hailen is an important part of the northeast of the Songnen Plain and plays an important role in agricultural production. After 1995, grain production increased significantly, especially rice production. At the same time, with the increase of rice yield, groundwater irrigated area increased rapidly [8]. The contradiction between the uneven distribution of water resources and the demand for irrigation water has become increasingly prominent, and farmers have to extract groundwater from aquifers for dryland irrigation. In the end, it will lead to a series of environmental and geologic problems, such as soil secondary salinization [9], the core of depression [10-11], wetland degradation [12-13], and water quality deterioration [14-15]. Therefore, the hydrogeochemical characteristics of groundwater and drinking water quality in the Lianhua district urgently need to be identified. This may restrict the protection and proper use of groundwater resources, especially the drinking water safety issues of local residents.

In order to study the hydrochemical status and the quality of groundwater in Lianhuashan, and quantitatively analyze the applicability of groundwater for drinking, 71 groundwater samples were collected from Lianhuashan between June and October in 2018. Using GIS and SPSS software, the hydrochemical properties and evolution of groundwater in the study area were characterized. The special purpose of this study is to (1) explore the hydrochemical characteristics of groundwater; (2) understand the evolution of groundwater through Factor Analysis, and PCA analysis; (3) evaluate the applicability of groundwater as drinking water using WQI and SPI models and the parameters recommended in the WHO guidelines. The results of the study help local governments strengthen management and governance in places where the groundwater environment is fragile, thereby effectively using groundwater resources in the river basin.

Study Area

Study Area Description

The Lianhuashan unique area is located in the central part of Jilin Province in northeast China, adjacent to the southeast edge of the Songnen Plain. The study area is between the latitudes of 43°45‘-43°57’N and the longitudes of 125°28‘-125°50’E, covering an area of 417 km^2. In 2014, the permanent population was about 59,000, and the regional GDP was 150 billion yuan. The entire area includes three towns, including Quanyan Town in the west, Quannongshan Town in the middle, and Sijiazi Town in the east (Fig. 1). Located in the temperate continental semi-humid monsoon climate of the northern hemisphere, Lianhua Mountain has four distinct seasons [16].

The average precipitation over the years is between 500 and 600 mm, mainly concentrated in June to August. The multi-year average temperature is 4.9-5.5ºC, and the average evapotranspiration is 1741 mm. The altitude is between 190-280 meters. The terrain slopes from southeast to northwest. The landform is divided into wavy terraces in the west, low hills in the middle, and Shitokoumen reservoir in the east. Shitoukoumen Reservoir is the largest source of water for Changchun City, with a water area of 98 km^2. The Wukai River, Quannong River, and Liusha River flow through the area, indicating that surface water resources are abundant [17]. The study area mainly produces rice and corn, and is the core area of agricultural production. Groundwater and surface water are mainly used for agricultural irrigation and domestic drinking. Over the past few decades, the excessive use of pesticides and fertilizers in agricultural production, as well as the overexploitation of groundwater and the discharge of domestic sewage, have led to prominent environmental and geologic problems in the region.

Geology and Hydro-Geology

Under the control of geomorphology and geological conditions, there are obvious differences between the quaternary strata and the Cretaceous strata in the study area between the eastern hilly area and the western undulating platform (Fig. 1b).

Below the wavy platform area in the west, Quaternary alluvium and Cretaceous strata are widely distributed. The Cretaceous Quantou Formation has the lithology of mudstone and siltstone interaction formations, with small thickness and poor water content. The daily output of a single well is 300-500 tons/day, which is the target layer for groundwater extraction in this area. Quaternary strata,

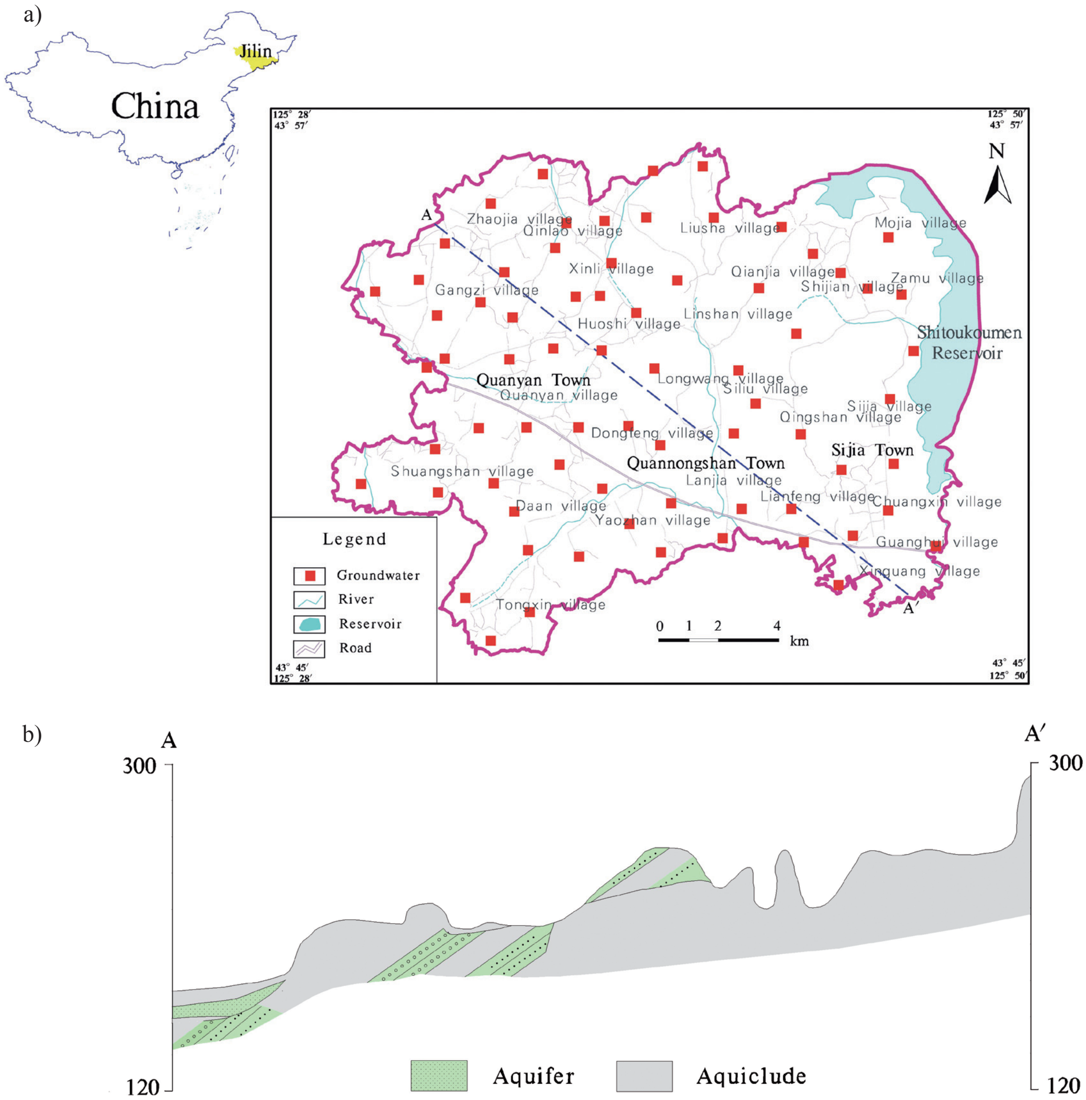

Fig. 1. a) Location of the study area with sampling points; b) Hydrogeological profile A-A`.

the upper part of which is silty clay and the lower part is a thin layer of gravel. The formation has poor water content and poor permeability of groundwater, and the daily output of a single well is less than 300 tons/day [18-19].

Below the hilly areas in the east, the aquifers are andesite, galena and granite. The thickness of the weathering shell is usually 30-40 m. Groundwater exists in the weathering zone, but the amount of groundwater is small. The daily output of a single well is less than 300 tons/day, and the groundwater level is less than 10 m. The spring water in the area is exposed, and most of the spring water flow is less than 0.1L/S [20].

In summary, the hydrogeological conditions in the Lianhuashan area are relatively complex, lacking thick aquifers and water storage structures, and lacking groundwater resources. Loose rock diving has the characteristics of large distribution area and easy exploitation. Although the water content of the gravel aquifer in the wave platform area is small, it can meet the needs of emergency situations.

Materials and Methods

Sampling and Measurements

According to the research plan, a total of 71 groundwater samples were collected in two batches from June to October 2018, which lasted 4 months.

Groundwater samples were taken from wells mainly used for water supply and irrigation in rural areas, and their distribution is shown in Fig. 1a). The spatial distribution of sampling points is consistent with the distribution of water intake wells in each village, which can objectively reflect the characteristics of groundwater in the study area. During the sampling process, in accordance with the Chinese hydrogeological survey standard, each pumping well was pumped for 10 minutes before sampling. The sampling process is divided into three steps. In the first step, the vial was rinsed 3 times with well water, then bottled and sealed. In the second step, the groundwater sample was stored in a 4ºC incubator. The third step is to return the sample to a qualified laboratory for testing. Groundwater samples were tested in a laboratory of the Shenyang Institute of Geology and Mineral Resources within three days.

The laboratory test index includes TDS, TH, K, Na, Ca, Mg, Cl, SO_4, HCO_3, Fe, Mn, NO_3, NO_2, Cr, and Pb. The concentration of NO_2 and NH_4 was obtained using gas phase molecular absorption spectrometry (GMA-3376). The concentrations of major anions (Cl, SO_4, and NO_3) were determined in the laboratory using ion chromatography (ICS-3000) and the concentration of major cations (Ca, Na, K, and Mg) was determined in the laboratory using plasma spectroscopy (ICP-6300). TDS and pH were measured in the field using a calibrated multi-parameter water quality analyzer (HACH-HQ40D).

Drinking Water Quality Index (WQI)

Water quality index (WQI) was a simple and useful approach for determining the overall quality of groundwater and its suitability for drinking purposes, and it has been widely used over the world [21]. The WQI was originally invented by Brown in 1970, and then improved by Backman in 1998. The World Health Organization (WHO) report (2008) emphasized that the WQI model helps to identify the impact of individual parameters of water quality and their combination on drinking water quality. Therefore, the WQI model can be used as a reliable tool for groundwater quality assessment [22]. Specifically, the WQI model can be divided into four steps, including relative weight (W_i) calculation, the quality rating (q_i) calculation, the subindex of parameter (SI_i), and the result of WQI.

Step1: The relative weight (W_i)

$$W_i = \sum \frac{W_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

...where W_i is the relative weight of each parameter, n refers to the number of parameters. The weight (Wi) and relative weight (Wi) of each chemical parameter are shown in Table 1. As shown in Table 1, the weight (Wi) and relative weight (Wi) of each parameter are according to WHO standards [23].

Step2: The quality rating scale is the concentration of ions in the groundwater sample divided by the respective standard (WHO 2008 version) and multiplied by 100.

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100 \quad (2)$$

...where C_i is the concentration (mg/L) of ion chemical parameters in the sample, and S_i is the limit value (mg/L) of the corresponding chemical parameter in the guidelines issued by the World Health Organization [24].

Table 1. The weight (w_i) and relative weight (W_i) of each chemical parameter.

Parameters	Units	Weight (Wi)	Relative weight (Wi)	Limit values	References
TDS	mg/L	4	0.063	500	[43]
TH	mg/L	4	0.063	500	[43]
PH	-	2	0.032	6.5–8.5	[43]
COD	mg/L	5	0.079	10	[43]
Na	mg/L	4	0.063	200	[43]
Ca	mg/L	3	0.048	300	[43]
Mg	mg/L	3	0.048	30	[43]
HCO_3	mg/L	1	0.016	120	[43]
Cl	mg/L	4	0.063	250	[43]
SO_4	mg/L	3	0.048	250	[43]
NO_3	mg/L	5	0.079	50	[43]
NO_2	mg/L	5	0.079	3	[43]
Fe	mg/L	5	0.079	1	[44]
Mn	mg/L	5	0.079	0.3	[22]
Pb	mg/L	5	0.079	0.01	[43]
Cr	mg/L	5	0.079	0.05	[43]
SUM	-	$\sum wi = 63$	$\sum wi = 1$	-	

Table 2. Water quality classification based on WQI classification standards [26].

Range (WQI)	Type of groundwater
<50	Excellent water
50≤WQI<100	Good water
100≤WQI<200	Poor Water
200≤WQI<300	Very poor water
≥300	Unsuitable for drinking/Irrigation purpose

Step3: The subindex of parameter (SI_i)

$$SI_i = W_i \times q_i \quad (3)$$

...where qi represents the rating based on concentration of its parameter, Wi is the relative weight, SI_i is the subindex of parameter [25].

Step4: The result of WQI for a single water sample

$$WQI = \sum_{i=1}^{n} SI_i \quad (4)$$

...where n is the number of parameters. According to WQI classification standards, water quality can be divided into five categories, as shown in Table 2.

The Synthetic Pollution Index (SPI)

The SPI model can be divided into three steps, including the constant of proportionality (K_i), the weight coefficient (W_i), and the synthetic pollution index (SPI). The derivation and calculation of SPI involves the following three steps [27]:

Step1: The proportionality (K_i)

$$K_i = \frac{1}{\sum_{i=1}^{n} \frac{1}{S_i}} \quad (5)$$

Step2: The weight coefficient (W_i)

$$W_i = \frac{K_i}{S_i} \quad (6)$$

Table 3. Water quality classification based on SPI classification standards [28].

Range (SPI)	Type of groundwater
SPI<0.2	Suitable
0.2≤SPI<0.5	Slightly polluted
0.5≤SPI<1.0	Moderately polluted
1.0≤SPI<3.0	Highly polluted
SPI≥3.0	Unsuitable for drinking purposes

Step3: The synthetic pollution index (SPI)

$$SPI = \sum_{i=1}^{n} \frac{Ci}{Si} \times Wi \quad (7)$$

In equations (5), (6), and (7), n is the number of water quality parameters for analysis, and Si is the threshold value of each parameter according to the WHO guidelines. According to SPI classification standards, water quality can be divided into five categories, as shown in Table 3.

Software

This article uses SPSS statistical analysis software and GIS software. SPSS19.0 is used for analysis and statistics of the component of anions and cations in water, and for principal component analysis. MapGIS6.7 software is the basic software platform for geographic information systems independently developed by China. MAPGIS6.7 is used to draw the location map of the study area, the distribution map of sampling points, the water chemistry type map, WQI and SPI evaluation map.

Results and Discussion

Groundwater hydrochemistry may be affected by one or more factors. For example, regional geological conditions, the chemical composition of precipitation, hydrogeological conditions and water-rock interaction (oxidation, reduction) will change the chemical properties of groundwater. Similarly, pesticide use, fertilizer use, groundwater extraction, groundwater recharge, biological and microbial effects will also affect the composition of groundwater.

Physicochemical Characteristics

The results of statistical analysis of physical and chemical indicators of all groundwater samples are shown in Table 4.

The pH value of the groundwater in the study area is between 7.21 and 8.23, with an average value of 7.66. According to WHO guidelines, the safe range of pH value for drinking water is 6.5-8.5. The pH value indicates that the entire water environment in the area is weakly alkaline, and the pH value is within the allowable range in the entire area.

Total hardness (TH) is the result of dissolution of calcium and magnesium ions in water. The total hardness of groundwater is mainly caused by the excessive concentrations of Ca and Mg. The value of the TH for the groundwater in the study area is 39.80-421.00 mg/L. According to WHO guidelines, the allowed hardness in water is less than 500 mg / L.

The concentration of TDS in water is one of the main parameters for assessing groundwater quality.

Table 4. Statistics of the measured parameters for water samples.

Parameters	Unit	Minimum	Maximum	Mean	SD	CV (%)
TDS	mg/L	40.82	1169.62	276.49	218.03	78.86
TH	mg/L	60.76	748.16	229.06	128.48	56.09
pH	-	6.25	7.19	6.71	0.25	3.73
COD	mg/L	0.30	9.60	1.49	1.47	98.81
Ca	mg/L	15.68	202.41	62.57	36.39	58.16
Mg	mg/L	4.28	58.69	16.68	36.39	218.23
Na	mg/L	7.87	63.69	20.92	11.33	54.16
Cl	mg/L	3.45	202.50	44.18	39.67	89.80
SO_4	mg/L	2.39	155.84	36.61	29.08	79.43
HCO_3	mg/L	45.76	319.62	136.07	66.43	48.82
NO_3	mg/L	0.02000	340.49	70.38	82.40	117.09
NO_2	mg/L	0.00472	0.35	0.03	0.0520	183.46
Fe	mg/L	0.02050	21.98	1.43	3.58	251.21
Mn	mg/L	0.00110	3.08100	0.25158	0.60000	238.49
Cr	mg/L	0.00100	0.03000	0.00714	0.00660	92.50
Pb	mg/L	0.00100	0.21040	0.00816	0.02500	306.30

CV = Coefficient of variation, SD = Standard deviation

According to WHO guidelines, the TDS allowable value for drinking water is 500 mg/L. In the study area, the TDS value of groundwater was 82.10-681.00 mg/L with an average value of 193.87 mg/L. The concentration of TDS in groundwater is relatively low and suitable for consumption.

The COD in the water represents the degree of pollution of the water environment. The value of the COD for the groundwater in the study area is 0.43-13.10 mg/L.

Cations and anions show significant difference in groundwater. As shown in Table 1, the concentrations of Ca^{2+}, Mg^{2+}, and Na^{+} in groundwater are observed in the ranges of 15.68-202.41 mg/L, 4.28-58.69 mg/L, 7.78-63.69 mg/L, respectively. The average concentrations of the analyzed cations are in the order of Ca^{2+}>Na^{+}>Mg^{2+}. The concentrations of SO_4^{2-}, HCO_3^{-}, and Cl^{-} in groundwater are observed in the ranges of 3.39-155.84 mg/L, 45.76-319.62 mg/L, 3.45-202.50 mg/L, respectively. The average concentrations of the analyzed anions are in the order of HCO_3^{-}>Cl^{-}>SO_4^{2-}.

In recent years, the concentrations of Fe and Mn in groundwater have received much attention and have been included in the evaluation standards for drinking water. In this study, the concentration of Fe in groundwater ranges from 0.0205 mg/L to 21.98 mg/L with the mean value of 1.43 mg/L (Fig. 2c). The concentration of Mn in groundwater ranges from 0.0010 mg/L to 3.0810 mg/L with the mean value of 0.2515 mg/L (Fig. 2d). According to WHO guidelines, the allowable concentration for Fe in water is 1 mg/L, and the allowable concentration for Mn is 0.3 mg/L. The concentrations of Fe and Mn in groundwater are generally high, indicating a high concentrations of Fe and Mn in depositional environment in the aquifer throughout the study area [29].

According to studies, nitrate nitrogen in water has a greater harmful effect on humans and aquatic organisms. For example, when water with a nitrate content of greater than 10 mg/L is consumed over time, methemoglobinemia occurs. A blood methemoglobin content of 70 mg/L results in suffocation. In this study, the concentration of NO_3 in groundwater ranges from 0.02 mg/L to 340.49 mg/L with the mean value of 70.38 mg/L (Figure 2a). The concentration of NO_2 in groundwater ranges from 0.0047 mg/L to 0.35 mg/L with the mean value of 0.03 mg/L (Fig. 2b). According to WHO guidelines, the allowable concentration for NO_3 in water is 50 mg/L, and the limited concentration for NO_2 is 3 mg/L. The increase of nitrate concentration is closely related to the use of chemical fertilizers and the infiltration of surface nitrogen [30].

High levels of heavy metals in drinking water can cause poisoning, carcinogenesis and various diseases [31]. In this study, the concentration of Cr in groundwater ranges from 0.001 mg/L to 0.03 mg/L with the mean value of 0.007 mg/L (Fig. 2e). The concentration of Pb in groundwater ranges from 0.001 mg/L to 0.210 mg/L with the mean value of

0.008 mg/L (Fig. 2f). According to WHO guidelines, the allowable concentration for Cr in water is 0.01 mg/L, and the limited concentration for Pb is 0.05 mg/L. In summary, the concentration of Cr and Pb is within the limited range, which indicates that the content of heavy metals in groundwater is low.

The Durov Diagram and Groundwater Hydrochemical Types

In order to accurately reflect and describe the groundwater chemistry in the study area, a Durov diagram was drawn using MapGIS 6.7 software [32].

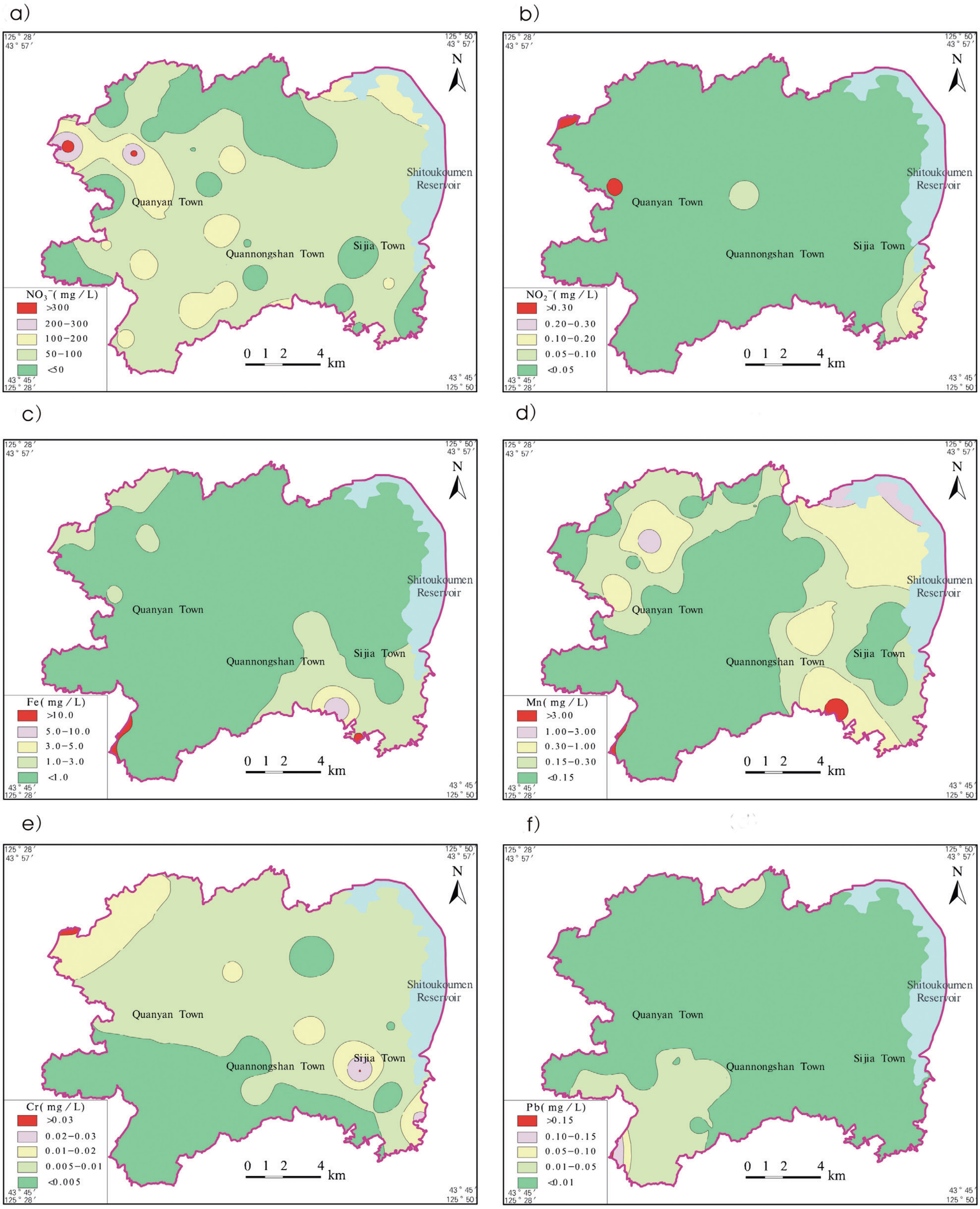

Fig. 2. Spatial distributions of groundwater chemical indexes (NO_3^-, NO_2^-, Fe, Mn, Cr, and Pb).

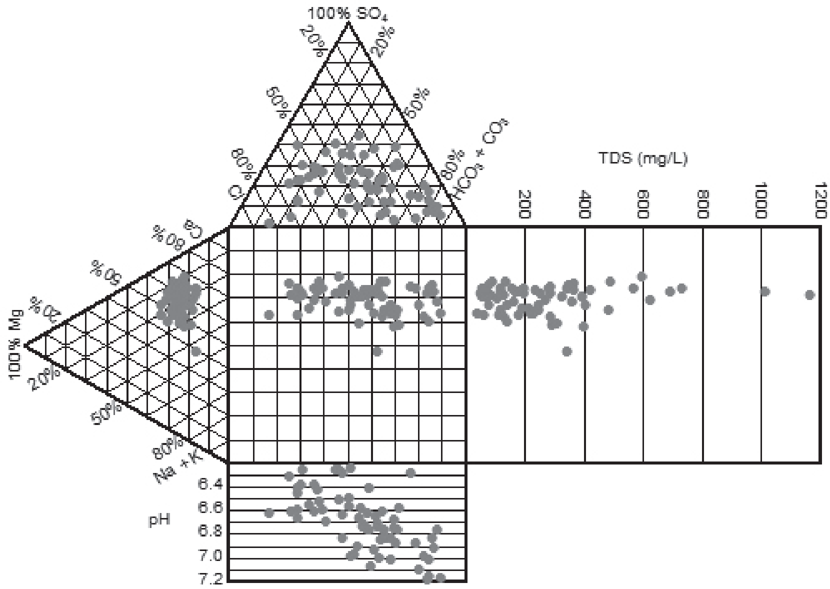

Fig. 3. Durov diagram of groundwater samples.

As shown in Fig. 3, chemical differences between groundwater anions and cations are also reflected. The diagram shows that HCO_3 and Cl are the main anions in groundwater, while Ca and Na are the main cations. The groundwater samples had a larger variated range of TDS content varying from 40 mg/L to 1169 mg/L, dominated by HCO_3. These 71 samples are mainly controlled by HCO_3-Ca, HCO_3-Ca• Mg, HCO_3-Ca • Na and other water chemistry types.

Factor and Principal Component Analyses

Statistical analysis and factor analysis can help identify relationships and sources of ions in groundwater. Three principal components with characteristic root values greater than 1 were extracted and analyzed (Fig. 4, Table 5).

Factor 1, with a variance of about 43.42%, includes TDS, Ca^{2+}, Mg^{2+}, TH, Na^+, and Cl^-, suggesting that TDS

Table 5. Groundwater physical and chemical parameter correlation matrix.

Parameter	TDS	TH	PH	COD	Ca	Mg	Na	Cl	SO_4	HCO_3	NO_3	NO_2	Fe	Mn	Cr	Pb
TDS	1.00															
TH	0.83	1.00														
PH	-0.59	-0.47	1.00													
COD	0.33	0.17	-0.05	1.00												
Ca	0.84	0.99	-0.49	0.16	1.00											
Mg	0.77	0.96	-0.40	0.18	0.93	1.00										
Na	0.75	0.75	-0.44	0.40	0.72	0.73	1.00									
Cl	0.79	0.93	-0.55	0.15	0.93	0.87	0.74	1.00								
SO_4	0.71	0.70	-0.41	0.17	0.69	0.71	0.73	0.69	1.00							
HCO_3	0.28	0.34	0.06	0.54	0.32	0.38	0.39	0.14	0.26	1.00						
NO_3	0.66	0.80	-0.46	-0.11	0.80	0.75	0.53	0.76	0.40	-0.19	1.00					
NO_2	0.10	-0.05	0.06	0.50	-0.06	-0.09	0.33	0.01	0.04	0.19	-0.14	1.00				
Fe	-0.08	-0.14	0.04	0.04	-0.19	-0.23	0.03	-0.12	-0.14	-0.02	-0.14	0.30	1.00			
Mn	0.21	0.14	-0.11	0.01	0.12	0.08	0.08	0.11	0.03	-0.09	0.22	0.01	0.31	1.00		
Cr	0.37	0.06	-0.29	0.37	0.08	-0.01	0.25	0.10	0.03	0.09	0.05	0.50	0.08	0.09	1.00	
Pb	-0.12	-0.03	0.08	-0.07	-0.04	-0.06	-0.14	-0.10	-0.07	0.12	-0.10	-0.06	0.21	0.13	-0.18	1.00

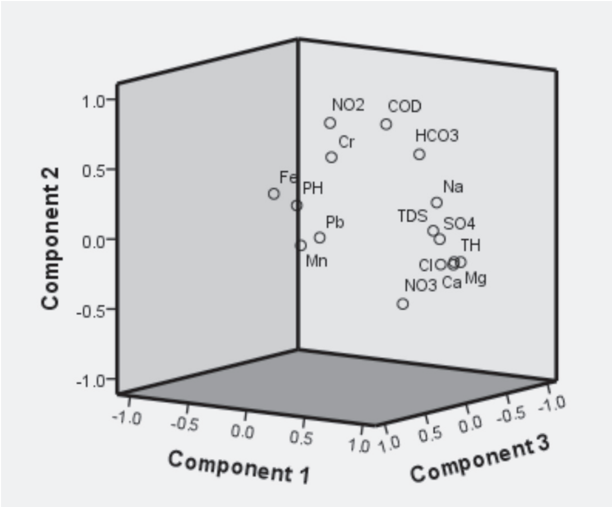

Fig. 4. PCA plot of the water (3D diagrams of factors).

and TH content of groundwater are mainly affected by Ca^{2+} and Mg^{2+} in the study area [33-34]. The high correlation between Ca^{2+}, Mg^{2+} and Na^{+} indicates that a strong exchange adsorption occurs between Ca^{2+}, Mg^{2+} and Na^{+} in groundwater. Factor 2 controls 19.62% of the water chemistry parameters, including COD, and NO_2^-. The high correlation between COD, and NO_2^- indicates that their sources are consistent and are closely related to the use of fertilizers. Factors 2 suggest that groundwater in some areas has been contaminated with agricultural chemical fertilizers, indicating that groundwater recharged by agricultural irrigation water is the main cause of groundwater pollution [35-36]. Factor 3 contains 14.66% of all variables, including Fe and Mn, suggesting the amount of Fe in groundwater is highly correlated with the content of Mn [37-38]. The high levels of Fe and Mn are related to the areas of groundwater and surface water flow pathways. However, the high Fe contents are related to the interaction of groundwater with silty mudstone and shale in the watershed. The high Mn concentration may be related to the high Mn content in the surrounding carbonates and silicates, as the water flowing through the area may be absorbing the element.

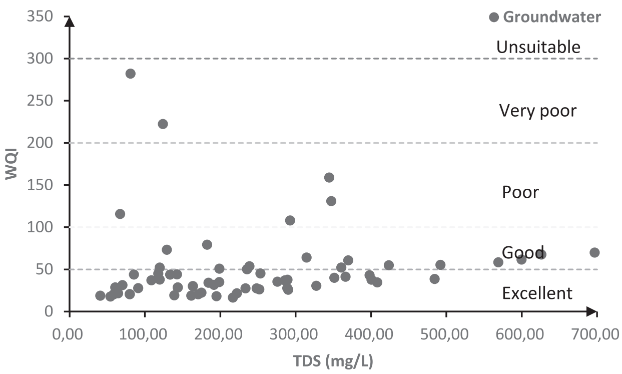

Fig. 5. The diagram of Groundwater TDS versus WQI.

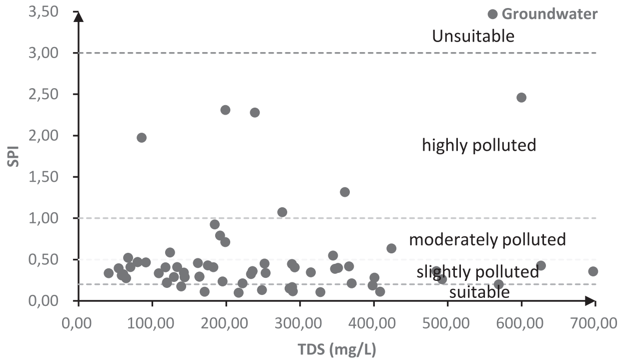

Fig. 6. The diagram of Groundwater TDS versus SPI.

Water Quality for Drinking Purpose

The results of groundwater WQI in Lianhuashan area are shown in Fig. 5 (Table 6). As shown in Fig. 5,

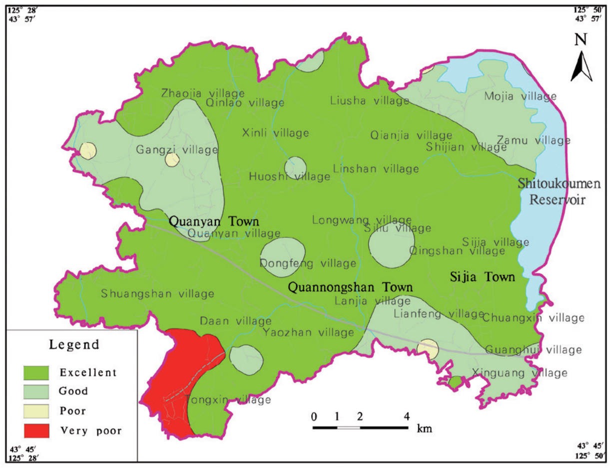

Fig. 7. Spatial distribution groundwater quality maps based on the outcomes of the WQI model.

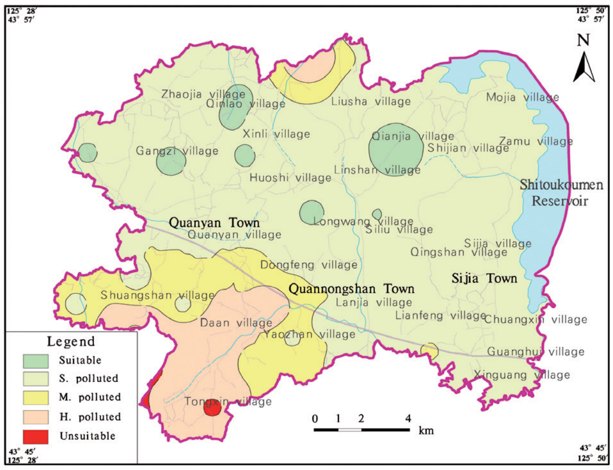

Fig. 8. Spatial distribution groundwater quality maps based on the outcomes of the SPI model.

among the 71 groundwater samples, 45 were "excellent" (grade 1), 20 were "good" (grade 2), 4 was "poor" (grade 3), and 2 were "very poor" (grade 4), accounting for 63.38%, 28.16%, 5.63%, and 3.63%, respectively. The calculation results of WQI show that the groundwater in the study area is excellent for drinking purpose, while the groundwater in some places is not suitable for drinking [39-41].

The results of groundwater SPI in Lianhuashan area are shown in Fig. 6 (Table 7). As shown in Fig. 6 (Table 7), among the 71 groundwater samples, 13 were "suitable" (grade 1), 47 were "slightly polluted" (grade 2), 5 was "moderately polluted" (grade 3), and 6 were "highly polluted" (grade 4), accounting for 18.30%, 66.19%, 7.04%, and 8.45%, respectively. The calculation results of SPI show that the groundwater in the study area is suitable, while the groundwater in some places is slightly polluted.

Based on the evaluation results of the water quality index model, the drinking water quality evaluation map of the study area was drawn (Fig. 7). The spatial distribution of the water quality index shows that most of the groundwater index concentration ranges in the study area are below the WHO guidelines and are therefore suitable for drinking. It is worth noting that in the southwest of the study area, the WQI index of groundwater in small areas was found to be higher than 200. The WQI index exceeded the standard, mainly due to the extremely high concentration of Fe and Mn in groundwater. The high concentrations of Fe and Mn are not only affected by high concentrations in the Cretaceous aquifer, but also affected by human agricultural production [42]. Therefore, the centralized water supply wells in this area should be added with Fe and Mn purification devices before drinking. Overall, it was learned from this study that the quality of groundwater complies with drinking water specifications according to WHO guidelines.

Based on the evaluation results of the synthetic pollution index model, the drinking water quality

Table 6. Categories of groundwater based on the WQI model results.

G.W. NO.	WQI	Rank	G.W. NO.	WQI	Rank	G.W. NO.	WQI	Rank
1	27.50	Excellent	25	55.34	Good	49	37.91	Excellent
2	60.67	Good	26	27.47	Excellent	50	28.55	Excellent
3	61.61	Good	27	37.70	Excellent	51	28.55	Excellent
4	21.65	Excellent	28	107.98	Poor	52	20.58	Excellent
5	25.84	Excellent	29	45.15	Excellent	53	20.58	Excellent
6	36.95	Excellent	30	41.26	Excellent	54	21.61	Excellent
7	165.23	Poor	31	16.57	Excellent	55	282.07	Very poor
8	165.23	Poor	32	158.87	Poor	56	50.82	Good
9	18.16	Excellent	33	112.18	Poor	57	52.20	Good
10	37.76	Excellent	34	73.25	Good	58	31.66	Excellent
11	30.10	Excellent	35	18.85	Excellent	59	54.87	Good
12	30.10	Excellent	36	109.96	Poor	60	34.13	Excellent
13	64.02	Good	37	20.42	Excellent	61	34.93	Excellent
14	43.07	Excellent	38	22.34	Excellent	62	19.21	Excellent
15	30.52	Excellent	39	50.20	Good	63	222.36	Very poor
16	69.89	Good	40	50.20	Good	64	53.69	Good
17	58.37	Good	41	28.62	Excellent	65	35.38	Excellent
18	39.98	Excellent	42	37.04	Excellent	66	43.86	Excellent
19	34.55	Excellent	43	52.14	Good	67	27.73	Excellent
20	26.25	Excellent	44	31.31	Excellent	68	43.78	Excellent
21	67.59	Good	45	79.24	Good	69	17.78	Excellent
22	27.74	Excellent	46	44.98	Excellent	70	115.66	Poor
23	130.92	Poor	47	20.34	Excellent	71	18.77	Excellent
24	38.60	Excellent	48	44.05	Excellent			

Table 7 Categories of groundwater based on the SPI model results.

GW. NO.	SPI	Rank	GW. NO.	SPI	Rank	GW. NO.	SPI	Rank
1	0.32	SP*	25	0.26	SP*	49	0.22	SP*
2	0.21	SP*	26	0.13	S*	50	0.29	SP*
3	2.46	HP*	27	0.17	S*	51	0.29	SP*
4	0.21	SP*	28	0.41	SP*	52	0.47	SP*
5	0.12	S*	29	0.34	SP*	53	0.47	SP*
6	0.15	S*	30	0.42	SP*	54	0.27	SP*
7	0.40	SP*	31	0.10	S*	55	7.91	U*
8	0.40	SP*	32	0.55	MP*	56	2.31	HP*
9	0.24	SP*	33	0.12	S*	57	1.32	HP*
10	0.28	SP*	34	0.29	SP*	58	0.79	MP*
11	0.29	SP*	35	0.46	SP*	59	0.63	MP*
12	0.29	SP*	36	0.18	S*	60	0.92	MP*
13	0.35	SP*	37	0.11	S*	61	0.71	MP*
14	0.19	S*	38	0.43	SP*	62	0.17	S*
15	0.11	S*	39	0.36	SP*	63	0.59	MP*
16	0.36	SP*	40	0.36	SP*	64	2.28	HP*
17	0.20	SP*	41	0.32	SP*	65	1.07	HP*
18	0.40	SP*	42	0.33	SP*	66	1.97	HP*
19	0.11	S*	43	0.22	SP*	67	0.47	SP*
20	0.45	SP*	44	0.41	SP*	68	0.41	SP*
21	0.43	SP*	45	0.41	SP*	69	0.39	SP*
22	0.45	SP*	46	0.41	SP*	70	0.52	MP*
23	0.39	SP*	47	0.31	SP*	71	0.33	SP*
24	0.36	SP*	48	0.34	SP*			

S* = suitable, SP* = slightly polluted, MP* = moderately polluted, HP* = highly polluted, US* = unsuitable

evaluation map of the study area was drawn (Fig. 8). The spatial distribution of the synthetic pollution index shows that the groundwater indicators in most areas of the study area do not exceed the WHO guidelines, but there are signs of groundwater pollution in some places. Similar to the WQI spatial distribution results, in the north and southwest of the study area, the SPI index of groundwater in small areas was found to be higher than 1.00. The SPI index exceeds 1.0, indicating that there is a high risk of contamination of groundwater in these areas, mainly due to the extremely high content of Pb in groundwater. The high concentration of Pb is mainly due to the impact of human activities [43]. In this area, there are large-scale landfills, and the leakage of landfill leachate contaminates groundwater, leading to an increase in Pb concentration. Therefore, in order to prevent serious pollution of groundwater, the leakproof layer of the landfill should be reinforced.

The Relationship between WQI and SPI Models

The relationship between the WQI and SPI models is established, and the water categories indicated by the two models are correlated through regression analysis, Eq. (8). The relationship indicates a good correlation between WQI and SPI models ($R^2 = 0.71$).

$$SPI = 0.0233 \times WQI - 0.5647 \quad (8)$$

Conclusions

In this study, the factors affecting Lianhuashan's groundwater chemistry and its quality are discussed in detail, and the groundwater hydrogeological process is analyzed. Groundwater quality assessments were also introduced to assess suitability for drinking. The following three conclusions are concluded:

1. Groundwater in aquifers in the study area is weakly alkaline. The abundance is in the order $HCO_3^->Cl^->SO_4^{2-}$ for anions, and $Ca^{2+}>Na^+>Mg^{2+}$ for cations, resulting in that the water types were dominated by HCO_3-Ca, HCO_3-Ca• Mg, and HCO_3-Ca • Na.

2. The Factor analysis, and PCA analysis show that ion exchange, rock weathering are the main reasons affecting the water chemical composition in Lianhuashan. At the same time, the high scores of NO_3^-, NO_2^-, Fe, and Mn must be widely concerned and may become the main environmental geological problems in the area.

3. The analysis of water samples based on the WQI model revealed that about 69.09%, 25.45%, 1.81%, and 3.63% of the water samples were excellent, good, very poor, and unsuitable for drinking purposes, respectively. The analysis of water samples based on the SPI model showed that 18.30%, 66.19%, 7.04%, and 8.45% of the water samples were suitable, slightly polluted, moderately polluted, and highly polluted, respectively. The spatial distribution maps of the water quality index and the synthetic pollution index show that most of the groundwater resources in the study area are clean and suitable for drinking, despite the risks in the north and southwest of the study area.

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Conflict of Interest

The authors declare no conflict of interest.

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