The Human Health Risk Assessment and Countermeasures Study of Groundwater Quality

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The human health risk assessment and countermeasures study of groundwater quality

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Abstract

Background： Groundwater serves as the drinking water source, which chemical components directly affect human health. Different regions own their groundwater hydro-chemical characteristics based on various geological, hydro-geological conditions, human activities. From the perspective of human health, it is necessary to select groundwater quality health risk assessment （*GQHR*） factors combined with hydro-chemical characteristics of different regions.

Methods： In this paper, taking Tongzhou of Beijing,China as the study area, according to the groundwater hydro-chemical characteristics, NO_3^-, NO_2^-, NH_4^+ and F^- were extracted as assessment factors to evaluate the *GQHR*. Based on *GQHR* results, the formation and concentration characteristics of health risk factors and the prominent controlling role of influencing risk distribution were explored from natural and human factors. Furthermore, the targeted measures to prevent the increase of groundwater health risk were put forward.

Results： Assessment factors: NO_3^-, NO_2^- and NH_4^+ are derived by human factors, such as sewage irrigation, fertilization, and F^- stems from irrigation of geogenic high fluoride groundwater and fertilizer use. Still, their distribution is affected by natural factors (geology, geomorphology, and climate). The *GQHR* follows the order: children > adult females > adult males. The low and medium risk regions are located in upper groundwater, which are mainly controlled by natural factors (groundwater depth, aquifer medium, hydraulic conductivity coefficient, etc.) The measures to prevent the increase of groundwater health risk are to control the pollution sources and reduce the change of groundwater hydrodynamic conditions. The high-risk regions are located in eastern part of the study area, which are affected by both natural and human factors. The preventative measures are to reduce pollution caused by human factors and scientific groundwater resource exploitation and management.

Conclusions： In this study, corresponding preventative and control measures were

proposed for health risks caused by different dominant control effects. Meanwhile, the research results provide a scientific basis for the safety of groundwater supply and environmental exposure in this area. The research ideas and methods can be used as a reference for similar studies.

Key words: groundwater pollution; human health risk; nature factors; human factors

Background

All over the world, more than 1.5 billion people depend on groundwater for drinking water supply [1]. In China, over 400 among 655 cities (about 61%) rely on groundwater as a drinking water source [2]. According to World Health Organization (WHO), 80% of human diseases are caused by poor water quality [3,4]. With the rapid development of human society, the degree of changes in groundwater quality caused by human activities is gradually increasing [5-7], which significantly affects the hydro-chemical characteristics of groundwater.

In the natural environment, groundwater maintains stable material and energy exchange with the surrounding environment, and hydro-chemical components in groundwater maintain balance. However, hydro-chemical components in the natural groundwater are higher in some areas due to their geological conditions [8]. For example, the geogenic high-arsenic groundwater has been found in the United States, Canada, Bangladesh, Vietnam and China [9-12]. With the increasing intervention of human activities on the natural environment, such as the rapid growth of population, frequent agricultural activities, and rapid development of industry, the exchange balance between groundwater and stratigraphic media under natural conditions has been destroyed, leading to changes in the hydro-chemical characteristics of groundwater in some areas [13-15]. In most cases, the evolution of hydro-chemical composition in groundwater will have a deterioration effect on the groundwater environment and lead to groundwater pollution [16-18]. For instance, in the process of agricultural development, excessive use of nitrogen fertilizer caused groundwater pollution. Groundwater in the United States, some parts of Europe, Belgium, France, Spain, Portugal, Greece, and other countries are polluted by nitrate in different degrees [19-22].

The hydro-chemical characteristics of groundwater are influenced by both natural and human activities [23]. Different dominant factors lead to different groundwater hydro-chemical characteristics. In order to ensure the safety of groundwater supply, it is essential to clarify the hydro-chemical characteristics of groundwater caused by different dominant factors. Water-rock interaction is an important process of groundwater hydro-chemical origin, and defining its type is very important. In recent years, with the development of numerical simulation techniques, a large number of studies focus on quantitatively analyze the water-rock interaction and sources of pollutants that affect the origin of groundwater by inverse hydrogeochemical simulation [24,25]. For example, PHREEQC was used to quantitatively analyze the hydro-chemical distribution and zonation characteristics of Yinchuan Plain in China [26], and identified the source of fluorine in the groundwater of the North China Plain that mainly came from the dissolution of fluorite in aquifer medium [27].

Pollutants entering groundwater can—affect groundwater quality and cause varying degrees of hazard to human health [28,29]. Long-term drinking and contact with contaminated groundwater will cause an irreversible impact on human health [30-33]. For example, fluoride is one of the essential trace elements for human health, too high or too low of fluoride intakes will pose a significant health risk to human body, and a high level will lead to fluorosis, a low level will lead to dental caries [34-36]. To clarify the health hazards caused by contaminants in the environment and quantitatively calculate the potential health risk of pollutants to human health. The United States Environmental Protection Agency (USEPA) proposed a health risk assessment model—commonly used for carcinogenic and non-carcinogenic risk assessment of groundwater contamination in 1991[37-39]. Then in 2014, the Ministry of Environmental Protection of China, combined with China's unique humanity, geological and natural conditions, proposed a groundwater quality human health risk assessment (*GQHR*) model [40,41]. The *GQHR* model can be used in any conditions. Still, due to the difference of natural environment and human activities in different regions, the crucial controlling factors of the origin and evolution of groundwater hydro-chemical characteristics are various. Hence, the assessment index should be selected by the characteristic components combined with the actual situation in the health risk assessment.

The main objective of this study is to select the *GQHR* assessment factors, combined with hydro-chemical characteristics of groundwater in Tongzhou, a typical area of North China Plain. Based on the assessment results, the natural and human factors affecting the spatial distribution of *GQHR* are analyzed. Then, the targeted countermeasures to prevent the increase of *GQHR* in different level risk areas are put forward. The research results are of great significance to the safety of groundwater supply and the development of economic and social in this area.

Methods

Location

Tongzhou District is located in the southeast of Beijing, China, covering an area of 907 km^2 (Fig. 1). It is situated on the axis of the Beijing-Tianjin Economic Belt. Due to its geographical advantages, Tongzhou has become the base of grain production, vegetable production, non-staple food supply, receiving the evacuated population, and industrial enterprises in Beijing. As one of the critical developing satellite cities of Beijing, groundwater in Tongzhou undertakes the task of water supply for residents. In recent years, groundwater in the study area has been strongly affected by human activities, because of the change of land use type, the accelerated construction of public facilities, and the rapid growth of population.

The study area is a continental monsoon climate with an average temperature of 11.3 °C. Average annual precipitation of 620 mm, 85% of which is concentrated from June to September. Groundwater flows from northwest to southeast.

The terrain in the study area is gentle and slopes from northwest to southeast. In terms of hydrogeological units, it is located at the fan margin of Chaobai River alluvial-pluvial fan and Yongding River alluvial-pluvial fan. The surface is covered by the Quaternary strata, and groundwater mainly exists in it. The aquifer of the Quaternary aquifer system in the study area is interbedded with sand layers and clay layers, and the multi-layer arrangement involves thin sand layers divided by discontinuous heavy silt-and-clay layers. The aquifer is mainly recharged by precipitation, river infiltration, groundwater lateral runoff, and irrigation return. The main discharge involves exploitation (for agricultural irrigation) and southeast lateral runoff. The object of this study is the shallow groundwater with a buried depth of 40~60m.

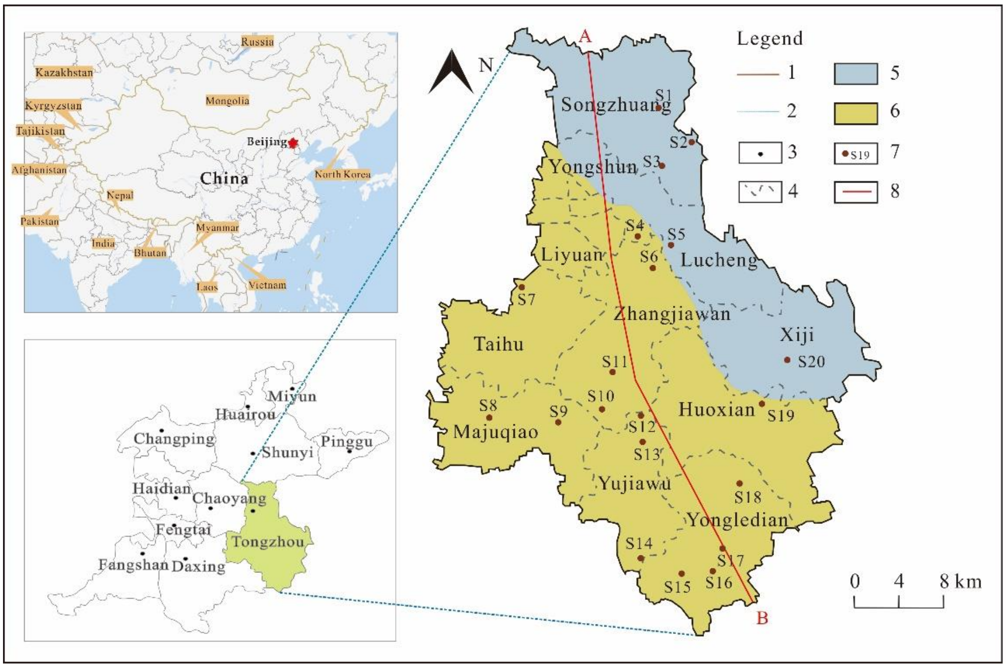

Fig. 1 Location of Tongzhou and sampling sites. (1) Boundary of Beijing, (2) district boundary, (3) administrative district, (4) town boundary, (5) Chaobai river alluvial-pluvial fan, (6) Yongding river

alluvial-pluvial fan, (7) groundwater samples, (8) section line.

Hydrogeochemical characteristics and selection of risk factors

In June 2017, 20 groundwater samples were collected from wells at a depth of 80 meters and used portable GPS to record the location (Fig 1). Samples were collected and analyzed in accordance with the “Technical Specifications for Groundwater Environmental Monitoring” (HJ/T164-2004). pH was measured in the field by a portable water quality analyzer. K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, F^-, NO_3^-, NO_2^-, NH_4^+ and TDS were analyzed in the laboratory.

The groundwater hydro-chemical types are classified according to the Shukarev classification method and showed in the zoning map (Fig. 2) and Piper diagrams (Fig. 3). Two pictures show that the hydro-chemical type of groundwater at the edge of Chaobai River alluvial-pluvial fan is mainly HCO_3-Ca·Mg (HCO_3-Ca·Na) type, and HCO_3-Na type water is distributed locally in upper. The groundwater hydro-chemical type at the edge of Yongding River alluvial-pluvial fan is mainly HCO_3-Ca·Mg·Na type in upper and changes into HCO_3·Cl-Mg·Na (HCO_3·Cl-Na·Ca) type in lower, meanwhile the cations change from Ca·Mg·Na (Mg·Ca, Ca·Mg) to Mg·Na (Ca·Na, Na·Ca). The groundwater quality is getting worse with the direction of groundwater flow.

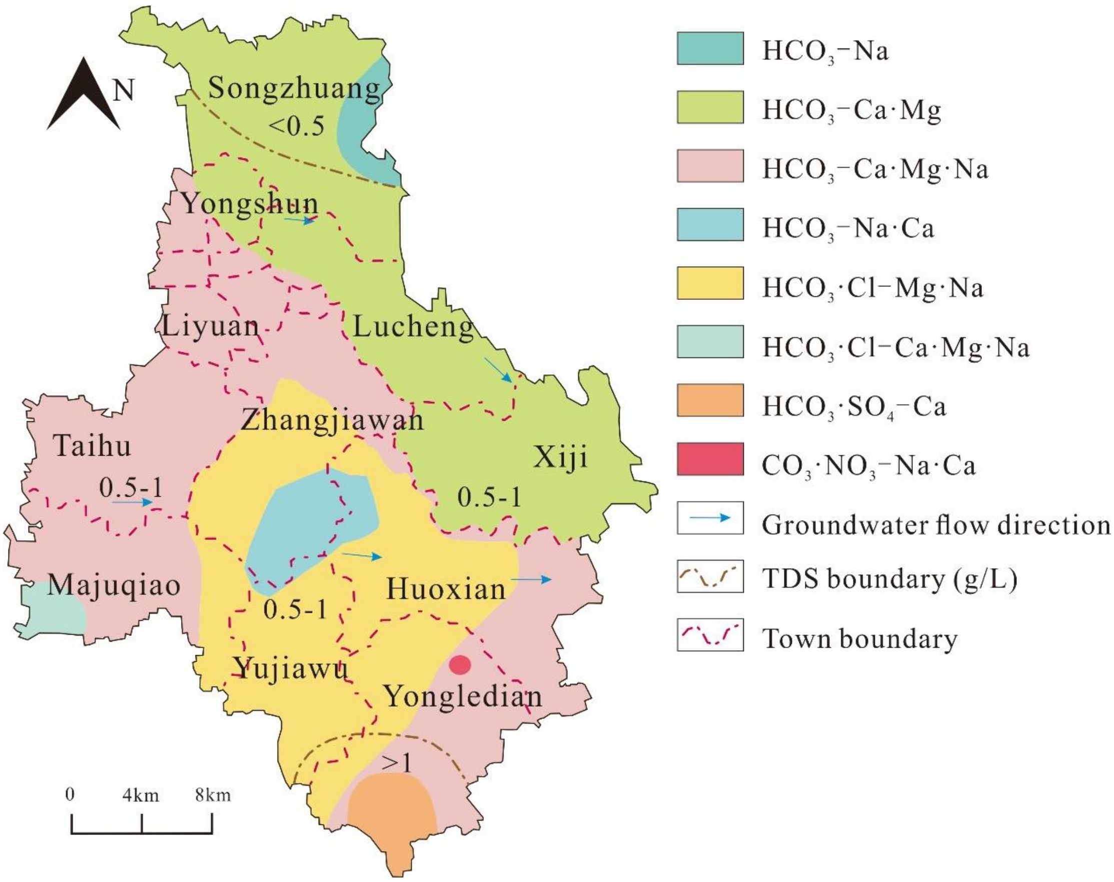

Fig. 2 Hydro-chemical types zoning map

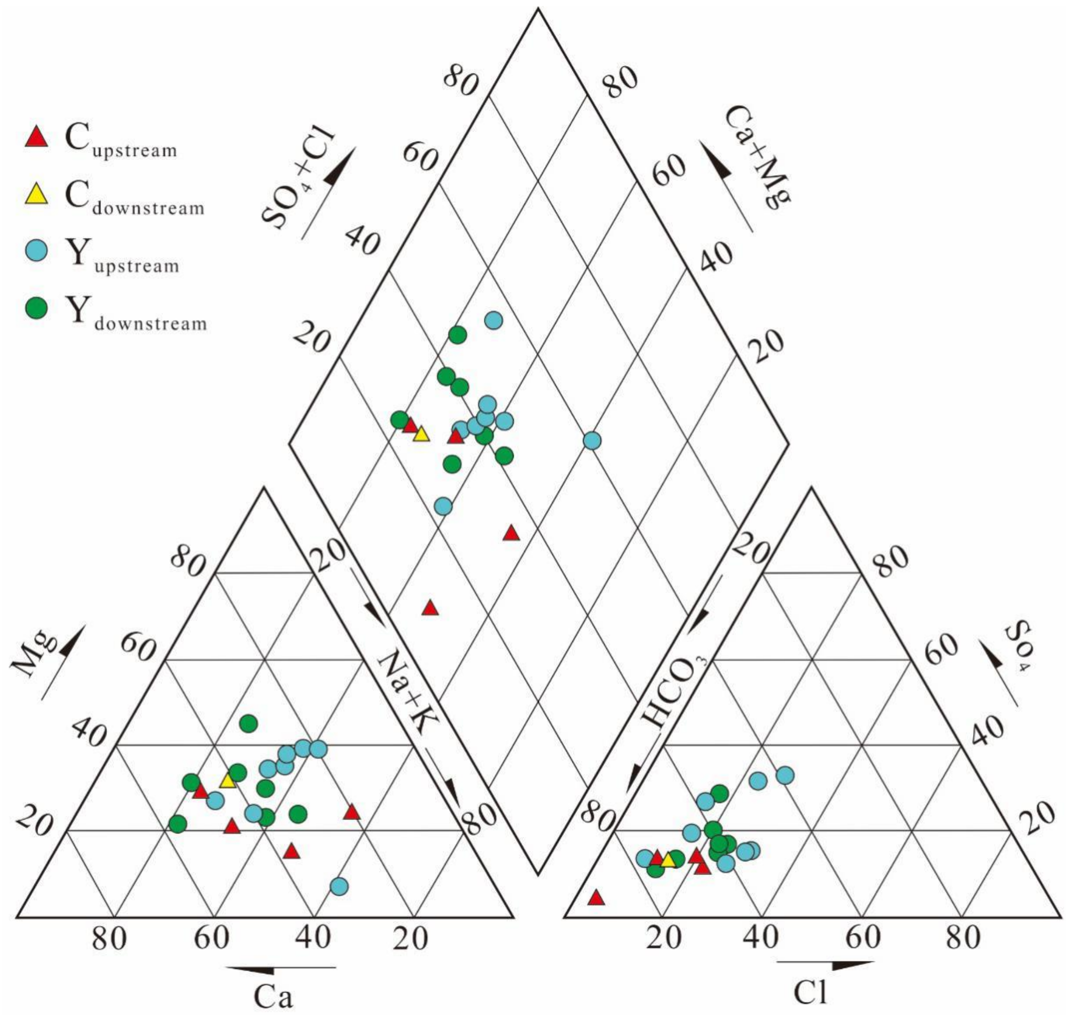

Fig. 3 Piper diagram of groundwater samples. C_{upper}- samples in the upper of Chaobai river alluvial-pluvial fan; C_{lower}- samples in the lower of Chaobai river alluvial-pluvial fan; Y_{upper}- samples in the upper of Yongding river alluvial-pluvial fan; Y_{lower}- samples in the lower of Yongding river alluvial-pluvial fan.

The ranges of groundwater pH are from 6.97 to 7.84, presenting medium-weak alkaline. The total dissolved solids (TDS) increases with the direction of groundwater flow, which changes from <0.5g/L in upper to 0.5~1g/L in lower at the edge of Chaobai River alluvial-pluvial fan and changing from 0.5~1.0g/L in upper to >1.0 g/L in lower at the edge of Yongding River alluvial-pluvial fan.

The results of counting the average content of ions in groundwater according to geomorphic units are shown in Table 1. (1) The content of each component at the edge of Chaobai River alluvial-pluvial fan is generally lower than that at the edge of Yongding River alluvial-pluvial fan. (2) In each geomorphic unit, the ion content generally increases from upper to lower. (3) The dominance of anions in groundwater is HCO_3^- ＞ SO_4^{2-} ＞ Cl^-, and for cations is Ca^{2+} ＞ K^++Na^+ ＞ Mg^{2+}(K^++Na^+ ＞ Ca^{2+} ＞ Mg^{2+}) according to their mean values. In general, HCO_3^- and Ca^{2+} are the dominant components, and K^++Na^+ is higher than Ca^{2+} both in the upper of Chaobai River alluvial-pluvial fan and lower of Yongding River alluvial-pluvial fan.

Table 1 Mean concentrations of ions.

Geomorphic unit	Mean concentration of ions (mg/L)									
	K^++Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	NO_3-N	NO_2-N	NH_4-N	F^-
CRAPFU	70.62	66.08	25.24	32.89	47.32	399.73	2.08	0.12	1.29	2.27
CRAPFD	90.33	112.57	42.09	86.45	83.00	556.23	10.72	0.06	0.18	0.52
YRAPFU	109.02	115.79	58.06	103.65	138.54	614.52	13.40	0.05	0.35	0.15
YRAPFD	160.43	112.86	71.18	142.08	188.76	604.08	25.04	0.03	0.98	0.35

**CRAPFU* : upper of Chaobai River alluvial-pluvial fan; *CRAPFD* : lower of Chaobai River alluvial-pluvial fan; *YRAPFU* : upper of Yongding River alluvial-pluvial fan; *YRAPFD* :lower of Yongding River alluvial-pluvial fan.

According to the China Drinking Water Standards (GB5749-2006) and concentration isogram distribution maps of nitrate nitrogen (NO_3-N), nitrite nitrogen

(NO_2-N), ammonia nitrogen (NH_4-N) and fluorine (F^-) (Fig. 4). The concentration of NO_3-N in groundwater ≤20mg/L in most areas and exceeds the standard only in Majuqiao and Yongledian (92.27mg/L and 175.12mg/L, respectively). The concentration of NO_2-N in Tongzhou is all ⩽1.00mg/L. The concentration of NH_4-N ≤0.5mg/L in most areas, and exceeded standard areas in Lucheng, Huoxian, and Yongledian southern region, among them, the highest concentration of NH_4-N was 3.60mg/L, which was 7.2 times of the standard concentration. F^- ups to standard in most areas, excessive points (>1.0mg/L) are mainly distributed at the edge of Chaobai River alluvial-pluvial fan, and the maximum value was 4.91mg/L, which was 5 times of the standard concentration.

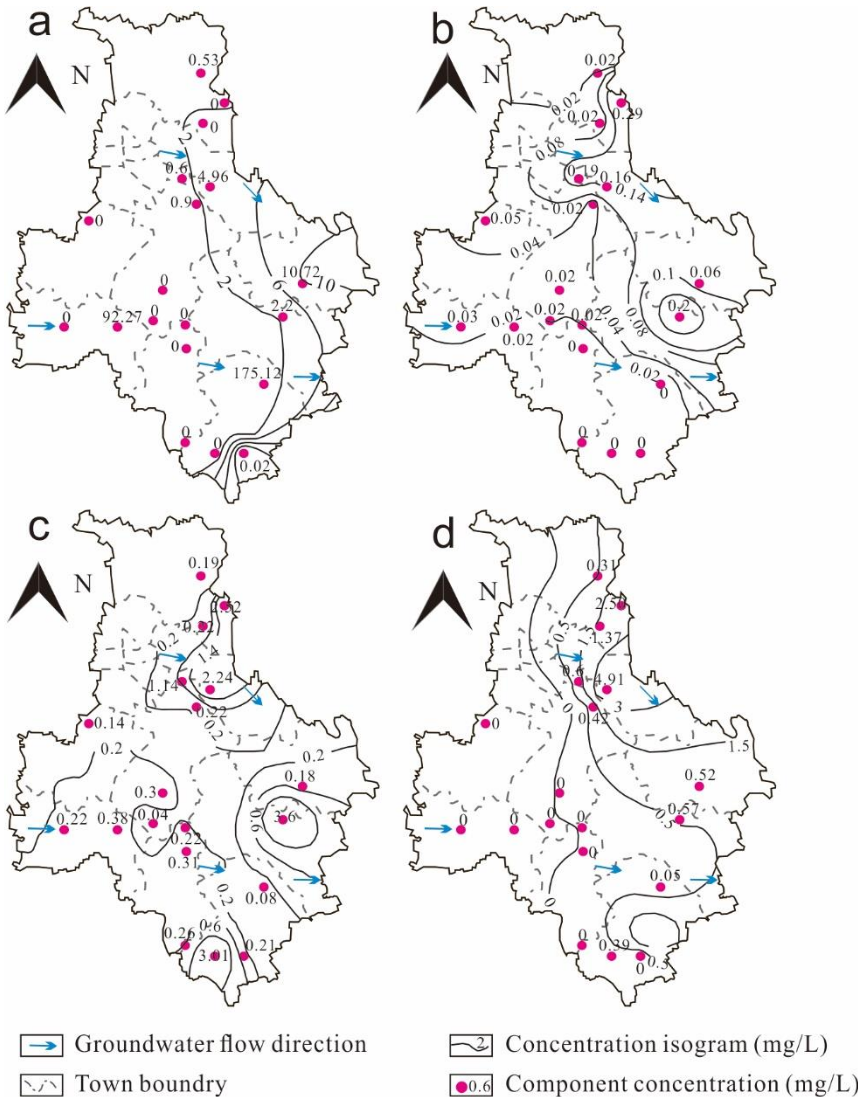

Fig. 4 Concentration isogram distribution map. (a) Nitrate nitrogen, (b) nitrite nitrogen, (c) ammonia nitrogen, (d) fluorine.

Due to the hydro-chemical characteristics of groundwater and considering that Tongzhou is a significant agricultural area accompanied by a large amount of use of nitrogen fertilizer, the *GQHR* factors in this study are selected as NO_3-N, NO_2-N, NH_4-N, and F.

Groundwater Quality Human Health Risk Assessment

The drinking water source in the study area mainly depends on groundwater, and the most common exposure pathways are oral intake and dermal contact. In this study, quantified groundwater quality human health risk using (*GQHR*) assessment models proposed by the Ministry of Environmental Protection of the People's Republic of China from the above two pathways [41]. The models of oral intake and dermal contact are as follows.

1. oral intake model

$$\mathrm{Intake}_{\mathrm{oral}} = \frac{\mathrm{C} \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \quad (1)$$

$$\mathrm{HQ}_{\mathrm{oral}} = \frac{\mathrm{Intake}_{\mathrm{oral}}}{\mathrm{RfD}_{\mathrm{oral}}} \quad (2)$$

Where $Intake_{oral}$ denotes the daily average exposure dosage through the oral pathway (drinking water intake) per unit weight (mg/(kg·d)). *C* indicates the concentration of the factors tested in the library in groundwater (mg/L). *IR* implies the ingestion rate of groundwater (L/d). *EF* and *ED* represent the exposure frequency (d/a) and exposure duration (a), respectively. *BW* and *AT* signify the average body weight (kg) and the mean exposure time (d), respectively. RfD_{oral} denotes the reference dosage of factors (mg/(kg·d)). HQ_{oral} characterizes the hazard quotient for pollutants through the oral exposure pathway.

2. dermal contact model

$$\mathrm{Intake}_{\mathrm{dermall}} = \frac{\mathrm{DA} \times \mathrm{EV} \times \mathrm{SA} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \quad (3)$$

$$\mathrm{DA} = \mathrm{K} \times \mathrm{C} \times \mathrm{t} \times \mathrm{CF} \quad (4)$$

$$\mathrm{SA} = 239 \times \mathrm{H}^{0.417} \times \mathrm{BW}^{0.517} \quad (5)$$

$$\mathrm{HQ}_{\mathrm{dermal}} = \frac{\mathrm{Intake}_{\mathrm{dermal}}}{\mathrm{RfD}_{\mathrm{dermal}}} \quad (6)$$

$$\mathrm{RfD_{dermal}} = \mathrm{RfD_{oral}} \times \mathrm{ABS_{gi}} \quad (7)$$

In these equations, $Intake_{dermal}$ represents the daily average exposure dosage through dermal intake per unit weight (mg/(kg · d)), EV is the daily exposure frequency of dermal contact, DA signifies the exposure dosage of every single event (mg/cm^2), SA indicates the skin surface area (cm^2), K denotes the coefficient of skin permeability, T implies the contact duration (h/d), CF is a conversion factor, H represents average resident height (cm), HQ_{dernal} and RfD_{dermal} represent the hazard quotient and the reference dosage (mg/(kg·d)), respectively.

3. total risk model

$$\mathrm{HI_i} = \mathrm{HQ_{oral}} + \mathrm{HQ_{dermal}} \quad (8)$$

$$\mathrm{HI_{total}} = \sum_{i=1}^{n} \mathrm{HI_i} \quad (9)$$

Where HI_i is the sum of the hazard index of contaminant i from oral intake and dermal contact, indicating the level of harm to the human body for contaminant i. And HI_{total} is the total hazard index of all contaminants concerned.

RfD_{dermal} is derived from the RfD_{oral} using Eq. (7), where ABS_{gi} is the gastrointestinal absorption factor which equals 1. Thus, the values of RfD_{dermal} and RfD_{oral} are equal. As shown in Table 2, common parameters are selected according to reference manuals of the USEPA and the Ministry of Health of the P.R. China [41,42].

Table 2 Health risk assessment model parameters

	Oral intake				Dermal contact		
	males	females	children		males	females	children

IR (L/d)	2.7	2.7	1.1	EV	1	1	1
EF (d/a)	365	365	365	K (cm/h)	0.001	0.001	0.001
ED (a)	30	30	6	t (h/d)	0.4	0.4	0.4
BW (kg)	65	55	22	CF	0.001	0.001	0.001
AT (d)	10950	10950	2190	H (cm)	165.3	153.4	99.4

Results

The values of RfD_{dermal} and RfD_{oral} both are F^- 0.04 mg/(kg·d), NO_3^- 1.6 mg/(kg·d), NO_2^- 0.1 mg/(kg·d) and NH_4^+ 0.97 mg/(kg·d). Figure 5 shows the health risks to adult males, adult females, and children when they are exposed through oral intake and dermal contact

For adult males, HQ_{oral} ranges from 0.01 to 5.39, with a mean value of 0.93, and 75% of the samples have an HQ_{oral} less than 1. Similarly, for adult females and children, the HQ_{oral} values are 0.01-6.37 and 0.01-15.93, with mean values of 1.37 and 3.44, respectively. Besides, 40% of the samples have an HQ_{oral} over than 1 for adult females, and 35% less than 1 for children. And HQ_{oral} <1 indicates that 35% of the groundwater is in a relatively safe condition by the exposure pathway of drinking groundwater in the study area.

The hazard quotient through dermal contact (HQ_{dernal}) ranging 2.77×10^{-6}~1.34×10^{-3} (adult males), 3.01×10^{-6}~1.46×10^{-3} (adult females), and 4.71×10^{-6}~2.28×10^{-3} (children), respectively. All values less than 1 signifies that the health risks through dermal contact to the four contaminants are negligible.

HI_{total} is basically the same as HQ_{oral} (mean values are 1.16, 1.37, and 3.44, respectively), indicating that the risk of dermal contact to human health is negligible compared with the risk of oral intake. Still, the values of HQ_{oral}, HQ_{dernal}, and HI_{total} show the same trend in the same species, all follow the order: males < females < children. That is, the influence order is males < females < children through contaminated groundwater on both exposure pathways and human health risks in the study area, denoting that children face higher risks than females, which are higher than males. Because children have the lowest average weight and males have the highest average weight.

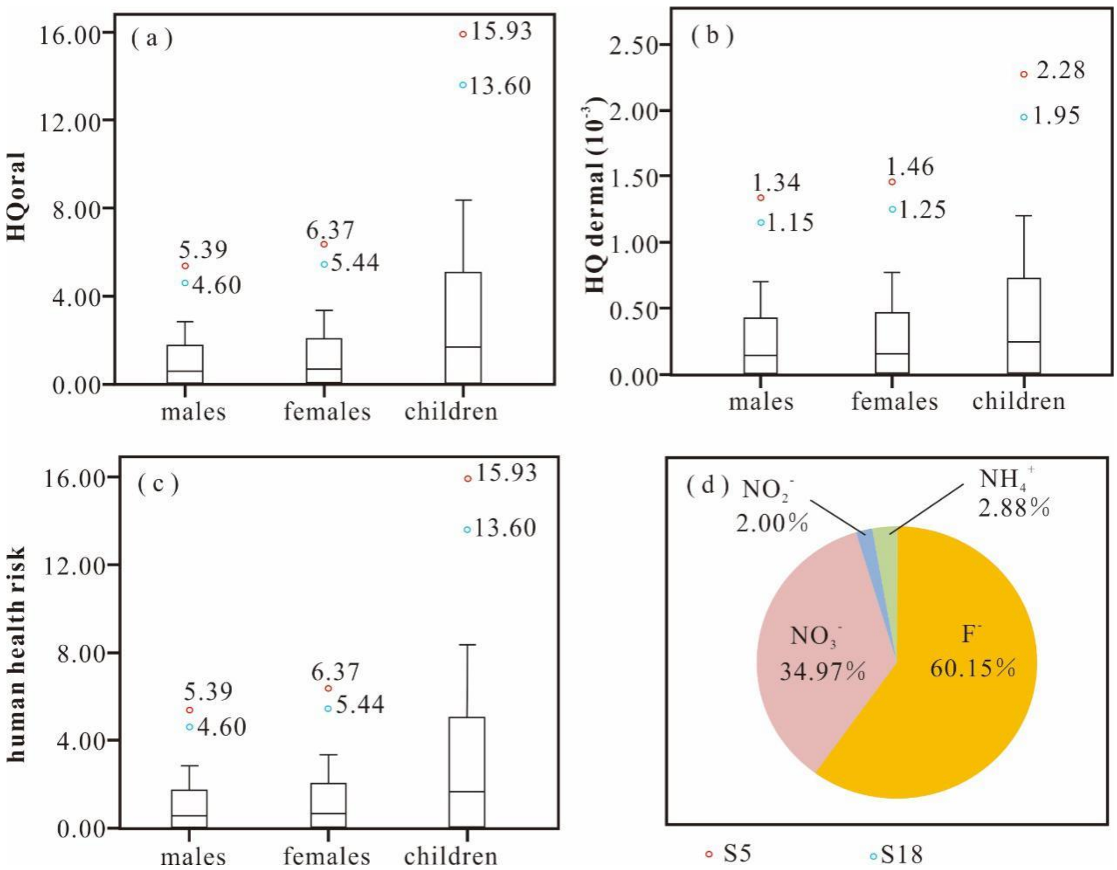

Fig. 5 Boxplots showing the results of groundwater quality human health risks assessment.

(a) Oral intake, (b) dermal contact, (c) total risk, (d) contributive ratios of factors to health risks.

S5 and S18 are the groundwater samples.

Groundwater quality human health assessment factors contribute differently to *GQHR*. As shown in Fig. 4d, F^- contributes the most to the health risk (60.15%), followed by NO_3^- (34.97%). NO_2^- and NH_4^+ are all less than 3% (2.00% and 2.88%, respectively), which means F^- and NO_3^- are the main factors affecting human health. The abnormal values in Fig. 4a, Fig. 4b, and Fig. 4c are caused by the fact that F^- and NO_3^- in groundwater samples S5 and S18 are significantly higher than other ions, which is consistent with the conclusion obtained in Fig. 4d.

Based on HI_{total}, the groundwater quality human health risk distribution map is shown (Fig. 6). It can be seen that the groundwater quality health risk increases from northwest to southeast. Low and medium risk regions are located in the west and middle of the study area, while high-risk regions are mainly located in the east. The highest risk regions are Lucheng (S5) and Yongledian (S18), which are consistent with the polluted distribution of F^-、NO_3^-、NO_2^- and NH_4^+.

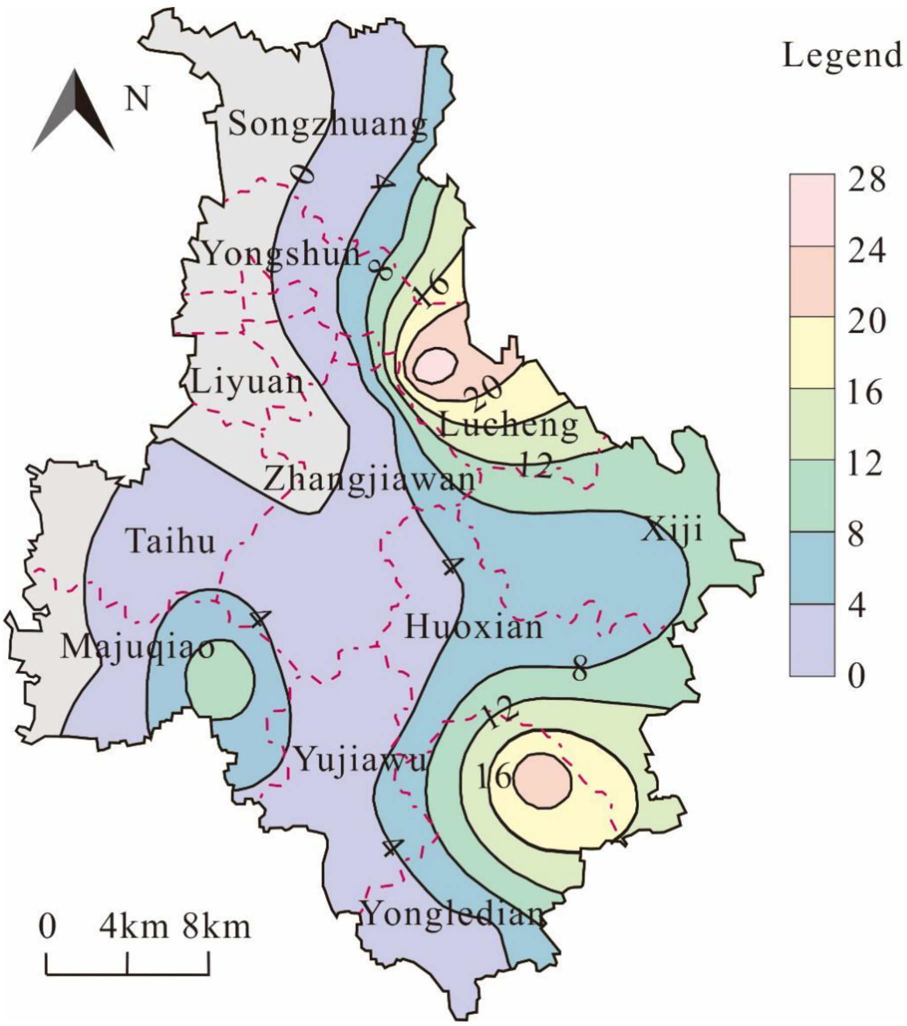

Fig. 6 Groundwater quality human health risks distribution map.

Discussion

Previous studies [23,43] showed that the sources of groundwater pollutants (including health risk assessment factors) were mainly affected by human factors, but their distributions were controlled by natural factors (water-rock interaction, precipitation infiltration and dilution, evaporation and concentration, etc.).

The low and medium risk regions are located in upper groundwater, and the pollutant load is the lowest in the study area, indicating that human factors play a small role and natural factors play a leading role.

According to the hydrogeological and hydro-chemical profile (Fig. 7), the groundwater depth in the north is deep (5-10m), the hydraulic slope is about 2‰, and the aquifer is dominated by medium-coarse sand and fine sand, which is mainly recharged by meteoric precipitation in flood season. When the recharged groundwater passes through the aquifer, the water-rock interaction mainly occurs by leaching. From the north to the south, the particle size becomes finer, the evaporation and concentration effect is enhanced. The main performance is that the hydraulic slope becomes slower (average value is 1.2‰), the groundwater depth is less than 6m, the material accumulation in groundwater, and the TDS increases (0.5-1g /L). In the south, the groundwater depth becomes shallow (0~5m), the hydraulic slope becomes slow (1‰), and with the combination of evaporation-concentration and human activities, the ionic components continue to accumulate. In the subsequent groundwater management for these regions, the monitoring of pollution sources should be strengthened, such as surface pollution monitoring and river drain contamination management, to prevent river pollution then pollute groundwater. Legitimately regulate the use of groundwater resources, improve people's awareness of resource protection and pollution prevention and control. And controlling individuals to exploit and use groundwater resources in large quantities without permission, so that avoid the increase of runoff and discharge intensity caused by changes in hydrological cycle conditions.

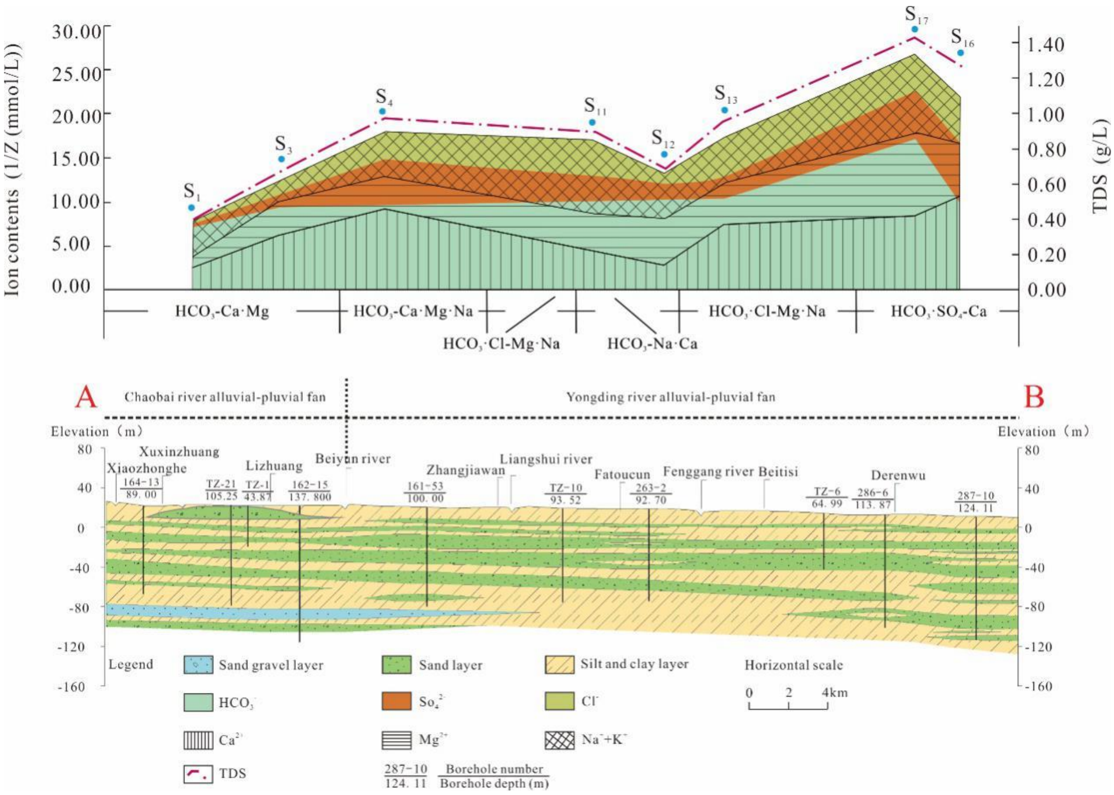

Fig. 7 Groundwater hydrogeological and hydro-chemical profile map

The high-risk regions are mainly located in the eastern part of the groundwater discharge area, which is affected by both natural and human factors. Tongzhou, as an agricultural irrigated area, is principally affected by the use of chemical fertilizers (mainly nitrogen fertilizer), and chemical fertilizers are an important source of health risk assessment factors F^-, NO_3^-, NO_2^- and NH_4^+. About 48.05% of the land is used for agriculture, and the average fertilizer application rate is 1172.8 kg/hm^2. In addition, there is primary high fluoride water in the North China Plain, and the use of high fluoride water irrigation is another important source of fluoride in groundwater. The annual average evaporation is about 3 times the precipitation in the study area, and the groundwater flow rate is slow, reflecting that the hydro-chemical changes of groundwater caused by evaporation exceed the dilution effect of rainfall. So, the groundwater depth plays a decisive role in evaporation. The high-risk regions are located in the discharge area, the groundwater depth changes from 5~10m to 0~5m, evaporation and concentration enhance, so the concentration of F^-, NO_3^-, NO_2^- and NH_4^+ increases.

As major agricultural irrigation regions, long-term use of sewage irrigation and chemical fertilizers. Lucheng (S5) and Yongledian (S18) are the areas with the highest risk and located in the discharge area of groundwater. Both human and natural factors lead to high concentrations of F^- and NO_3^- in the chemical indicators of S5 and S18.

In the regions where natural and human factors work together, the use of chemical fertilizers should be controlled, organic agriculture should be promoted and farmers' awareness of environmental protection should be raised. It is forbidden to irrigate with sewage and prevent surface soil pollution.

We should arrange agricultural irrigation scientifically and reasonably, reduce flood irrigation and promote agricultural pure water sprinkler irrigation. The groundwater pollution caused by human activities should be reduced, and the monitoring of groundwater exploitation should be strengthened to prevent pollutants from infiltrating into groundwater through the surface.

Conclusions

Ensured the hydro-chemical characteristics of the study area by analyzing components in groundwater, and the distribution of groundwater chemical composition is mainly controlled by natural conditions like geology, topography, and hydrogeological conditions, at the same time influenced by human activities.

Unlike other *GQHR* assessment studies only consider contamination status or the pollutants in study areas. Our study provides a useful method to select the indexes of *GQHR* assessment model with the characteristics and evolution of groundwater hydrochemistry, and Tongzhou is an agricultural area that means a large use of fertilizer.

In terms of the calculated results of *GQHR*, distributed degrees of *GQHR* and identified the dominant control factors. According to various degrees of risk cased by different natural factors and human factors, the targeted countermeasures of reducing the *GQHR* increase were proposed.

The research results provide a scientific basis for the safety of groundwater supply and environmental protection in Tongzhou and provide a reference for the same kind of research.

Abbreviations

GQHR: groundwater quality human health risk; NO_3^-: nitrate; NO_2^-: nitrite; NH_4^+: ammonia; NO_3-N: nitrate nitrogen; NO_2-N: nitrite nitrogen; NH_4-N: ammonia nitrogen; F^-: fluorine; K^+: calcium; Na^+: sodium; Ca^{2+}: calcium; Mg^{2+}: magnesium; Cl^-: chlorine; SO_4^{2-}: sulfate; HCO_3^-: bicarbonate; CO_3^{2-}: carbonate; TDS: total dissolved solids; WHO: The World Health Organization; USEPA: the United States Environmental Protection Agency; *CRAPFU*: upper of Chaobai River alluvial-pluvial fan; *CRAPFD*: lower of Chaobai River alluvial-pluvial fan; *YRAPFU*: upper of

Yongding River alluvial-pluvial fan; *YRAPFD*: lower of Yongding River alluvial-pluvial fan.

Author's contributions

The content of the manuscript was drafted by Tianshan Lan and revised by Yuqing Cao, Shanshan Bao and Fugang Wang. Jinjie Miao, Yaonan Bai and Sida Jia provided the basic data of this paper. All authors provided written feedback and edits on the manuscript and agreed with its content.

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Availability of data and materials

Not applicable.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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