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THEMATIC ISSUE

Human health risk assessment of groundwater nitrogen pollution in Jinghui canal irrigation area of the loess region, northwest China

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Abstract
Nitrogen pollution of groundwater is becoming more and more serious due to intense and extensive industrial and agricultural activities. This may exert great influence on human health. In this paper, human health risk due to groundwater nitrogen pollution in Jinghui canal irrigation area in Shaanxi Province of China where agricultural activities are intense was assessed. Forty-seven groundwater samples were collected from shallow wells and analyzed for physicochemical indices in the study area. Water samples were analyzed for pH, total dissolved solids (TDS), total hardness (TH), major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO^{3-}, $CO_3{}^{2-}$, Cl^- and $SO_4{}^{2-}$), nitrate (NO_3–N), nitrite (NO_2–N) and ammonia nitrogen (NH_4–N). General groundwater chemistry was described by statistical analysis and the Piper diagram. Water quality was quantified via comprehensive water quality index (CWQI), and human health risk was assessed considering the age and exposure pathways of the consumers. The results show that the shallow groundwater is slightly alkaline and groundwater types are $HCO_3{\cdot}SO_4{\cdot}Cl$–Mg and $HCO_3{\cdot}SO_4{\cdot}Cl$–Na. Rock weathering and evaporation are main natural processes regulating the groundwater chemistry. The CWQI indicates that groundwater in the study area is seriously polluted by TH, TDS, $SO_4{}^{2-}$, Cl^- and $NO_3{}^-$. Human health risk is high because of high concentrations of nitrate in drinking water. The results also show that children are at higher risk than adults. The health risk through dermal contact is much lower than that through drinking water intake and can be ignored.

Keywords Health risk assessment · Nitrogen pollution · Water quality · Human activity · Loess area

Introduction

Water resources are indispensable resources for human survival (Li et al. 2012), but there are lots of water-related problems such as water shortage and water pollution, threatening human health and affecting the sustainable development of society (Li and Qian 2018a; Qian et al. 2012). In particular, in the loess regions of China where most parts are dominated by arid and semiarid climate, water resources are relatively scarce, accounting for only 22% of the national per capita water resources of China (Su 1996; Li and Qian 2018b; Shi and Shao 2000). This is a hidden threat to the sustainability of the Belt and Road Initiative proposed by China (Li et al. 2015, 2017a). In addition to water shortage, water pollution in the loess areas is also a serious problem. For example, serious As and nitrogen pollution has been observed in Datong Basin and Guanzhong Basin (Guo and Wang 2005; Luo et al. 2014). Li et al. (2014a) reported high fluoride groundwater in and around a university campus situated near the Weihe River, China, and the high fluoride groundwater may have adverse impacts on students' health. Vegetable production is also reported to be suffering from increasing heavy metal contamination via various pollution sources, such as agricultural, industrial and other activities in the loess areas of China (Xu and Zhang 2017). All these studies signify that water pollution will essentially affect the safety of human health.

Due to the importance of groundwater in arid and semiarid regions, many interesting and comprehensive studies

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on groundwater pollution and associated health risk have been carried out worldwide (e.g. Bempah and Ewusi 2016; Golekar et al. 2013; Wu and Sun 2016; Li et al. 2017b). Rasmussen (1996) argued that agricultural activity was one of the main contributing factors to shallow groundwater contamination. This argument applies to many arid and semiarid areas of China. For instance, the pollution of nitrogen, Mn, Cr and other pollutants in groundwater of the Weining Plain, northwest China, are largely due to intensive and extensive agricultural and industrial activities (Li et al. 2014b, 2016a, b). These findings enable us to better understand the sources of pollution, thus seeking suitable measures to control the pollution.

Many scholars have also carried out human health risk assessment of groundwater pollution in different regions, which provide useful insight into safeguarding human health. Batayneh (2012) suggested that heavy metals pollution in the Yarmouk basin would affect human health, and the human health risk in wet season was higher than that in dry season. Wongsasuluk et al. (2014) believed that people living in warmer climates were more susceptible to groundwater contamination because of their increased daily drinking water intake. Han et al. (2006) found that volatile organic compounds such as tetrachlorethylene and trichlorethylene could be reduced by 85% after the water was boiled, thus reducing its health risk.

The Jinghui canal irrigation area is a part of the Loess Plateau, China. Like many other irrigation areas of the Loess Plateau, the Jinghui canal irrigation area suffers water shortage, unreasonable irrigation pattern, over exploitation of groundwater, groundwater contamination and soil salinization induced by irrational water resources management (Li et al. 2018a). Many studies have shown that such issues are likely to deteriorate water quality and threaten human health (Li et al. 2017c). Particularly, agricultural activities and industrial development will lead to groundwater nitrogen contamination and trace metal pollution, which will seriously threaten human health (Hayashi et al. 2009; Wu and Sun 2016). The Jinghui canal irrigation area has been experiencing water quality deterioration since the late twentieth century because of intensive agricultural activities (Liu and Zhu 2011). According to the investigation in 2008, groundwater in this area was contaminated seriously by nitrogen, high total hardness and high trace metal concentrations, although the situation was slightly improved in 2009 (Han 2010). However, health risks due to water pollution have never been assessed in this area.

Therefore, groundwater quality in the Jinghui canal irrigation area and associated human health risk through exposure pathways of drinking water intake and dermal contact were evaluated in this paper. The results were compared with other irrigation areas. The main objectives of this article are (1) to evaluate the groundwater quality in the area through water quality index, (2) to quantify the human health risk considering age and different exposure pathways (drinking water intake and dermal contact), and (3) to compare and analyze the human health risks in different irrigation areas. The study results can provide decision makers with meaningful support for local and regional decision making in terms of groundwater quality protection and groundwater resources management.

Study area

Location and climate

The Jinghui canal irrigation area, a typical loess area in China, is located at the center of Guanzhong Plain of Shaanxi Province. The total area is about 1180 km^2, and elevation ranges between 350 and 450 m above the mean sea level (Lei et al. 2015). The Jinghui canal irrigation area is administratively divided into four counties and two districts, i.e., Jingyang County, Sanyuan County, Gaoling County and Fuping County, Lintong District and Yanliang District (Fig. 1). The area is characterized by convenient transportation and is one of the important grain production bases in northwest China. Due to heavy groundwater abstraction for agricultural purposes, groundwater level in Jinghui canal irrigation area has been dropped significantly in recently years (Tao et al. 2015).

The study area belongs to a continental semi-humid to semiarid climate zone, characterized by hot summer with strong evaporation and heavy rainfall, cold and dry winter, and cool but short autumn and spring (Li et al. 2014a). The average annual precipitation in the area is about 512.5 mm, and its spatial and temporal distribution is uneven. Precipitation in July to September accounts for 50–60% of the total annual precipitation, and the rainfall decreases from south to north. The annual average temperature is 13.1–13.4 °C, and the highest and lowest temperatures are usually recorded in July and January, respectively.

Geology and hydrogeology

The irrigation area can be divided into two main geomorphological types: alluvial terraces and loess tablelands. The alluvial terraces with sand layers are rich in groundwater, while the loess tablelands composed of silty clay and loam are weak in water yielding capacity.

Due to strong movements of the earth crust in the Cenozoic era, thick Quaternary sediment is deposited on the ground surface. Geomorphologically, the sediment constitutes the first and second level loess tablelands and the alluvial terraces. The second level loess tableland is mainly distributed to the north of the Qingyu River, with an elevation

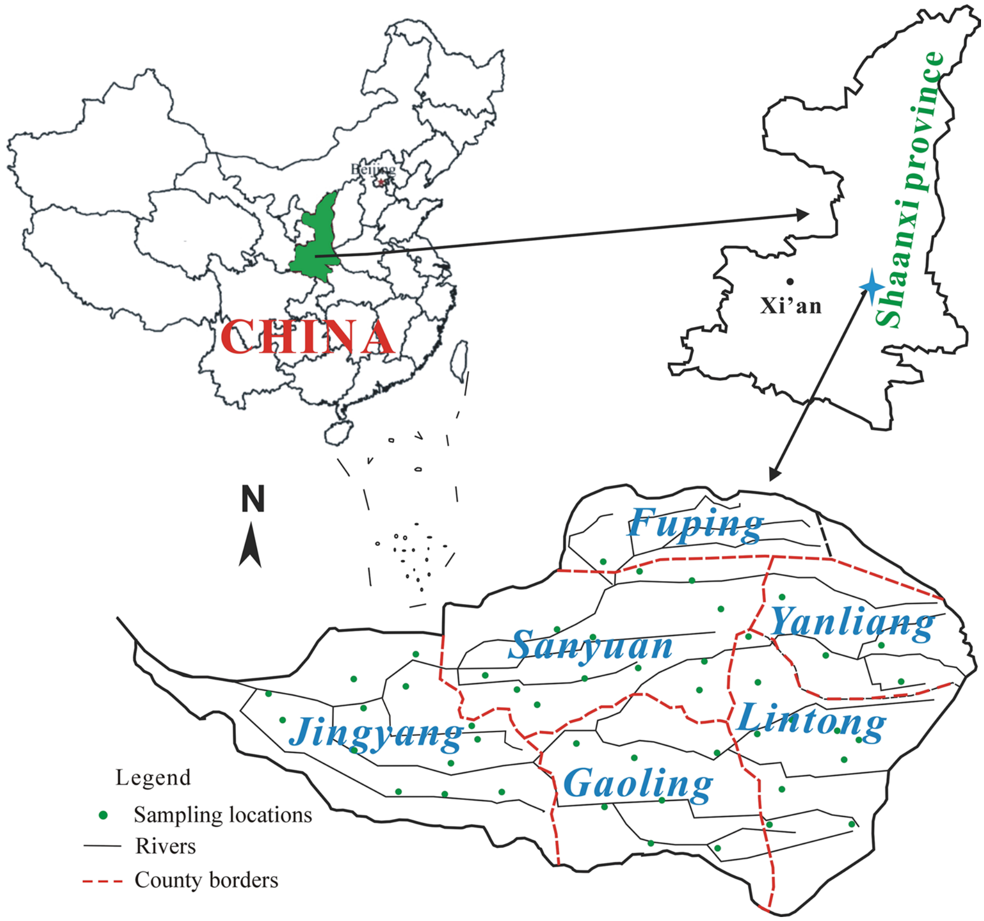


Fig. 1 Study area and sampling locations

of about 450 m. The first level loess tableland is mainly located to the south of the Qingyu River and to the north of the Jingyang and Sanyuan. The elevation of the first level loess tableland ranges between 380 and 450 m. The alluvial terraces of the Jinhe River and Weihe River have an elevation of 350–400 m (Zhou 2011).

Phreatic groundwater occurs mainly in the Quaternary alluvial layers. Groundwater level depth is shallow, and groundwater is easy to exploit. Groundwater level depth in the floodplain and the first and second level terraces is generally 2–10 m. In the transition zone between the loess tablelands and terraces, the water level depth is about 10–20 m. The aquifer here is mainly consists of clay, fine sand and gravels, and aquifer thickness ranges from 20 to 50 m (Wei 2009). The loess aquifer in the study area is thick, but the groundwater yielding capacity is low, because the loess layers are mainly composed of silty clay and loam (Li and Qian 2018b). It is hard to extract groundwater from the loess aquifer.

Precipitation is the main groundwater recharge source. Infiltration of irrigation water and percolation of irrigation channels are minor but direct recharge source for phreatic water. Controlled by topography, the groundwater generally flows from northwest to southeast. However, flow direction varies in local areas due to groundwater exploitation, microtopography and geomorphology. Discharge of groundwater in the area has two categories: vertical discharge and horizontal discharge. Vertical discharge is dominated by evapotranspiration and artificial exploitation. Horizontal discharge is mainly in the form of runoff toward to the Qingyu River, Jing River, and Wei River. Vertical discharge is the dominant form of groundwater discharge in the area. As a major grain production area, chemical fertilizer is widely used in the irrigation area (Han 2010), resulting in surface water and groundwater contamination in the study area.

Materials and methods

Sample collection and analysis

In this study, 47 groundwater samples were collected from the phreatic aquifer through pumping wells during November 2009. The sampling processes follow national technical regulations. The containers are polyethylene plastic bottles, rinsed with deionized water in the laboratory, and washed again using the groundwater to be sampled before sampling. After sampling, the samples were sealed, and timely sent to Shaanxi Testing Center of Drinking Aquatic Products to measure the following indices: pH, total dissolved solids (TDS), total hardness (TH), major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, CO_3^{2-}, Cl^- and SO_4^{2-}), nitrate (NO_3–N), nitrite (NO_2–N) and ammonia nitrogen (NH_4–N). Among these, pH was measured in situ using a portable pH meter without acidification, and Ca^{2+} Mg^{2+} and TH were determined by EDTA titrimetric method. Nitrogen (NH_4–N), SO_4^{2-}, Cl^-, HCO_3^-, and CO_3^{2-} were all measured by routine titrimetric methods. And flame atomic absorption spectrometry was used for analysis of Na^+ and K^+. In order to ensure the accuracy of these indices, the charge balance error (%CBE) was calculated to check the accuracy of the analysis (Li et al. 2016c, d):

$$\%\ \text{CBE} = \frac{\sum N_c - \sum N_a}{\sum N_c + \sum N_a} \times 100\% \tag{1}$$

When %CBE within ± 5% is perfect for analysis, and in this study, the highest %CBE is 4.02%.

Methods

Water quality assessment

There have been numbers of approaches proposed for water quality assessment (Li et al. 2012, 2017d), among which the comprehensive water quality index method (CWQI) is widely used in water quality assessment. It is a weighted multi-factor environmental quality index. The specific formulas are as follows (Li et al. 2014c):

$$\overline{F_\text{i}} = \frac{1}{n}\sum_{i=1}^{n} F_i \tag{2}$$

$$\text{CWQI} = \sqrt{\frac{\overline{F_i}^2 + F_{i\max}^2}{2}} \tag{3}$$

where F_i is the standardized index of contaminants in groundwater, $i = 1, 2, 3\ldots n$. F_i should be determined by comparing the concentration of the index with the guideline values given by the Chinese Quality Standard for Groundwater (Bureau of Quality and Technical Supervision of China 1994). $\overline{F_i}$ is the average of F_i, and $F_{i\ \max}$ denotes the maximum value of F_i. n is the number of indices considered in the assessment. C_i represents the measured concentration of indices in groundwater (mg/L), and S_i is the standard value of indices prescribed in groundwater quality guidelines (mg/L). When CWQI < 0.8, groundwater quality is classified as excellent (Grade 1); when 0.8 < CWQI < 2.5, groundwater quality is good (Grade 2); when 2.5 < CWQI < 4.25, groundwater quality is fair (Grade 3); when 4.25 < CWQI < 7.2, groundwater is contaminated and water quality is poor (Grade 4); and when CWQI > 7.2, groundwater is seriously polluted and water quality is very poor (Grade 5). Excellent and good quality waters are ideal for drinking and irrigation, fair quality water is acceptable for drinking and irrigation, but when used for drinking some treatment may be required, poor quality water and very poor quality water are not suitable for drinking but may be conditionally used for irrigation (Li et al. 2014c).

Human health risk assessment

Human health risk assessment is an important basis for the protection of water resources. Through human health risk assessment, it is easy to estimate the impacts of pollutants on human health (Li et al. 2014b). Among available exposure pathways, drinking water intake and dermal contact are the most common exposure pathways (Wu and Sun 2016; Li et al. 2016a). The model recommended by the Ministry of Environmental Protection of the P. R. China (2014) which is based on the United States Environmental Protection Agency models (Li et al. 2016a) was adopted and applied in this study. In this paper, the main pollutants are nitrate, nitrite and ammonia nitrogen. Their non-carcinogenic risks through drinking water intake and dermal contact can be calculated, respectively, as follows:

$$\text{HI}_E = \frac{E}{\text{RfD}} \text{ or } \text{HI}_D = \frac{D}{\text{RfD}} \tag{4}$$

E and D represent the daily average exposure dosage through drinking water intake and dermal contact, respectively. The reference dose RfD in this paper was referenced from the USEPA: nitrate 1.6 mg/(kg.days), nitrite 0.1 mg/(kg.days), ammonium nitrogen 0. 97 mg/(kg.days).

Through drinking water intake (Bempah and Ewusi 2016):

$$E = \frac{C \times \text{IR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \tag{5}$$

In this equation, C is the chemical pollutant concentration (mg/L), measured by the laboratory. IR is the ingestion rate of water (L/days). In this paper, the values of 1.5 and 0.7 L/days were adopted, respectively, for adults and children (Wu and Sun 2016; Li et al. 2016a). EF represents the exposure frequency (days per year), and it is 365 days per year for both adults and children. ED is the exposed duration, recommended value for adults is 30 years, and for children it is 12 years; BW represents the average body weight (kg), the proposed value of BW for adults is 60 kg and 15 kg for children. AT represents the average time, and the recommended value of AT is

ED × 365 days/year, that is 10,950 days for adults, and 4380 days for children.

Dermal contact:

$$D = \frac{DA \times EV \times ED \times EF \times SA}{BW \times AT} \quad (6)$$

$$DA = K \times C \times t \times CF \quad (7)$$

EV is the daily exposure frequency of dermal contact, set as 1 in this paper (Wu and Sun 2016; Li et al. 2016a). The value of AT is calculated by ED × 365 days/year; SA is the skin surface area (cm^2). DA indicates the absorbed dose of the skin (mg/cm^2). K is the coefficient of skin permeability. The recommended value of K is 0.001 cm/h, and t is the contact time (h). According to the local bathing habits and the physical characteristics of Chinese people, the adult skin exposure area when bathing is about 16,600 cm^2, and for children it is 12,000 cm^2. It is assumed that both adults and children take a bath three times a week on average in the study, and each time lasts 0.35 h. However, residents wash their faces and hands every day. When washing the face and hands, the sums of face and skin exposure areas are 1930 and 1800 cm^2, respectively, for adults and children. And the washing time is 0.03 h each time. CF is a conversion factor which equals to 1000.

To reflect the overall effects of multiple chemical pollutants on human health, the overall risk (HI_T) can be computed as follows:

$$HI_i = HI_E + HI_D \quad (8)$$

$$HI_T = \sum_{i=1}^{n} HI_i \quad (9)$$

Result and discussion

Groundwater chemistry

As shown in Table 1, pH ranged from 7.14 to 8.48, with an average value of 7.76. The acceptable pH value for drinking water is 6.5–8.5 according to the standard limit set by the World Health Organization (WHO 2011). The groundwater in this area is weakly alkaline water which is beneficial to human health. The TDS and TH values of the groundwater in the irrigation area were 874.1–4285.1 mg/L and 350.4–1320.1 mg/L, respectively. More than 90% of the water samples exceeded the standards of TH and TDS given by the WHO (2011). Groundwater in the study area is generally brackish and hard water. The high salinity may be due to the dissolution of soluble salts and minerals into groundwater, evaporation of groundwater and human activities (Bouzourra et al. 2015; Li et al. 2016b; Wu et al. 2014, 2015).

As shown in Table 1, for the cation, $Na^+ + K^+$ ranged within 98.96–1186.75 mg/L with an average of 398.33 mg/L. The content is high in some samples, which may be ascribed to cation exchange and dissolution of evaporites such as halite (Li et al. 2010, 2013). Ca^{2+} and Mg^{2+} are critical elements in water and will threaten human health if their contents are too high. In this paper, Ca^{2+} was 20–140.3 mg/L, with a mean of 75.69 mg/L, and Mg^{2+} ranged from 57.7 to 270.4 mg/L, with the average being 152.26 mg/L. They are largely controlled by rock wreathing and water–rock interactions (Li et al. 2018b, c; Qian and Li 2011). Their concentrations are within the recommended values for drinking purpose. For anions, HCO_3^- ranged from 299 to 1031.2 mg/L, Cl^- ranged from 122.1 to 645.5 mg/L, and SO_4^{2-} ranged from 156.1 to 1711.1 mg/L. The mean concentrations of

Table 1 Statistical analysis results of physiochemical parameters

Index	Sample number	Unit	Minimum	Maximum	Mean	National standard
pH	47	–	7.14	8.48	7.76	6.5–8.5
TH	47	mg/L	350.4	1320.1	815.98	450
TDS	47	mg/L	874.1	4285.1	1868.03	1000
Na^++K^+	47	mg/L	98.96	1186.75	398.33	200
Ca^{2+}	47	mg/L	20	140.3	75.69	–
Mg^{2+}	47	mg/L	57.7	270.4	152.26	–
CO_3^{2-}	47	mg/L	Nil	54	1.91	–
HCO_3^-	47	mg/L	299	1031.2	663.05	–
Cl^-	47	mg/L	122.1	645.5	331.83	250
SO_4^{2-}	47	mg/L	156.1	1711.1	575.59	250
NO_3–N	47	mg/L	Nil	82.8	28.51	20
NO_2–N	47	mg/L	Nil	0.15	0.01	0.02
NH_4–N	47	mg/L	Nil	3.52	0.11	0.20

Cl^- and SO_4^{2-} exceeded the acceptable limits for drinking water given by the World Health Organization (WHO 2011). This may be due to the effects of water–rock interactions and human factors such as industrial sewage.

The contamination of nitrogen is serious in the study area. High content of NO_3^- may reduce oxygen-carrying capacity of blood, resulting in health problems such as blue baby syndrome (Chen et al. 2016; Majumdar 2003). It is widely accepted that NO_3^- is an effective indicator of agricultural contamination (Wu and Sun 2016). The National standards have set the acceptable limits of nitrate, nitrite and ammonia nitrogen for drinking groundwater as 20, 0.02, and 0.2 mg/L, respectively. In this area, nitrate content ranged from Nil to 82.8 mg/L, and approximately 50% of the groundwater samples in the study area exceeded the drinking water standards. Nitrite ranged from Nil to 0.15 mg/L, and 10% of the samples were unacceptable for drinking due to excessive nitrite concentration. Ammonia nitrogen content varied within Nil-3.52 mg/L, and only one sample exceeded the prescribed limit (Table 1). As shown in Fig. 2, nitrate shows some high concentration spots in the study area and is high in particular in the mid-north and southeast parts of the area. Sanyuan, Fuping and Lintong are three counties that are mostly contaminated by nitrate (Fig. 2a). Nitrite generally shows a decreasing trend from west to east, while ammonia nitrogen is high in the mid-south of the study area. The highest nitrite concentration was observed in Jingyang (Fig. 2b), and highest ammonia nitrogen was found in Gaoling (Fig. 2c).

The nitrogen pollution in the area is mainly due to extensive agricultural activities in the region. The main crops in study area are wheat and maize, and chemical fertilizers are widely used, leading to the enrichment of NO_3^- in groundwater (Li et al. 2016c). NH_4–N and NO_2^- can be transformed into NO_3^- under different conditions, which is another reason responsible for high nitrate concentration in the area. The transformation of them can be expressed as follow:

$$NH_4^+ + 2O_2 \xrightarrow{\text{nitrobacteria}} 2H_2O + NO_2^- \quad \text{(R1)}$$

$$2NO_2^- + O_2 \xrightarrow{\text{nitrobacteria}} 2NO_3^- \quad \text{(R2)}$$

Hydrochemical types of groundwater are determined by major ions. The hydrochemical types of groundwater are shown in the Piper diagram (Piper 1944; Wu et al. 2017). As shown in Fig. 3, all water samples are plotted at the center of the lower right triangle, indicating that there is no dominance of the anions. On the contrary, water samples plotted in the lower left triangle indicate the abundance of Mg^{2+} and Na^+ over Ca^{2+}. Therefore, the hydrochemical types are mainly $HCO_3 \cdot SO_4 \cdot Cl$–Mg and $HCO_3 \cdot SO_4 \cdot Cl$–Na. These hydrochemical types imply the complex processes of groundwater hydrochemical formation impacted by rock weathering, evaporation, cation exchange and human activities.

To better understand the different hydrogeochemical processes controlling groundwater chemistry in the study area, Gibbs diagrams (Gibbs 1970) were applied to explain

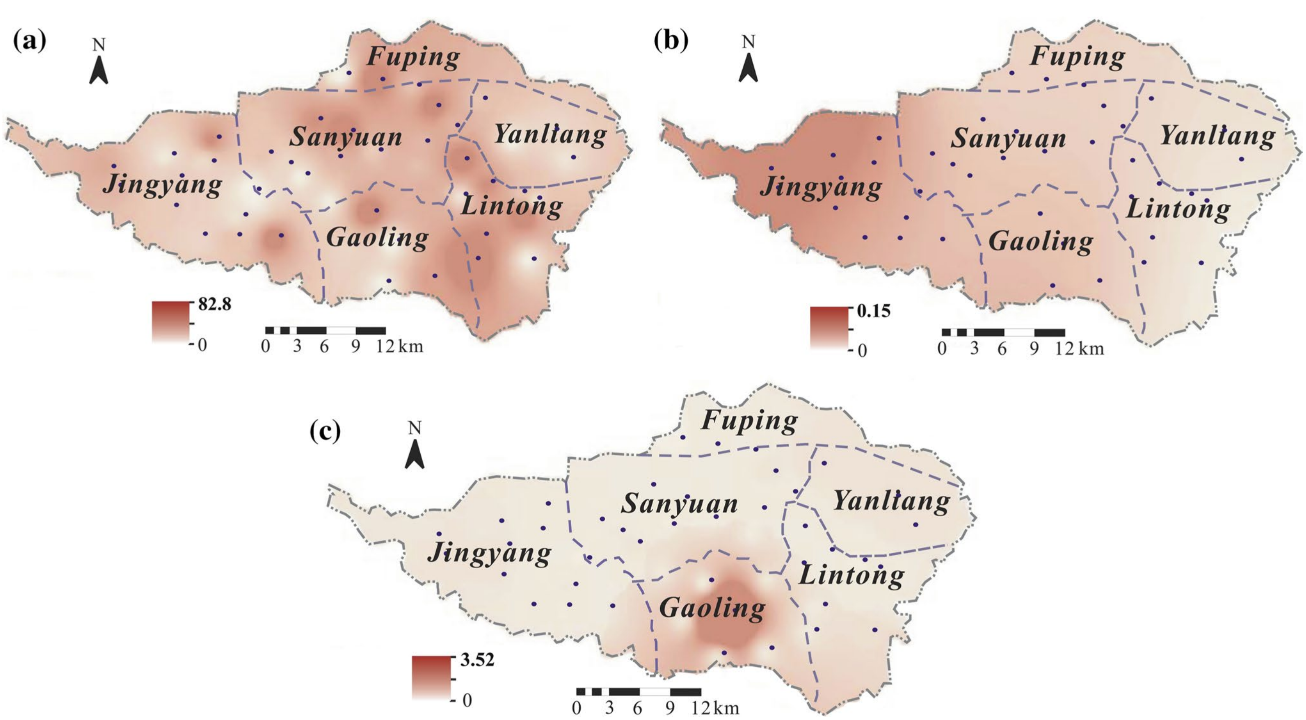
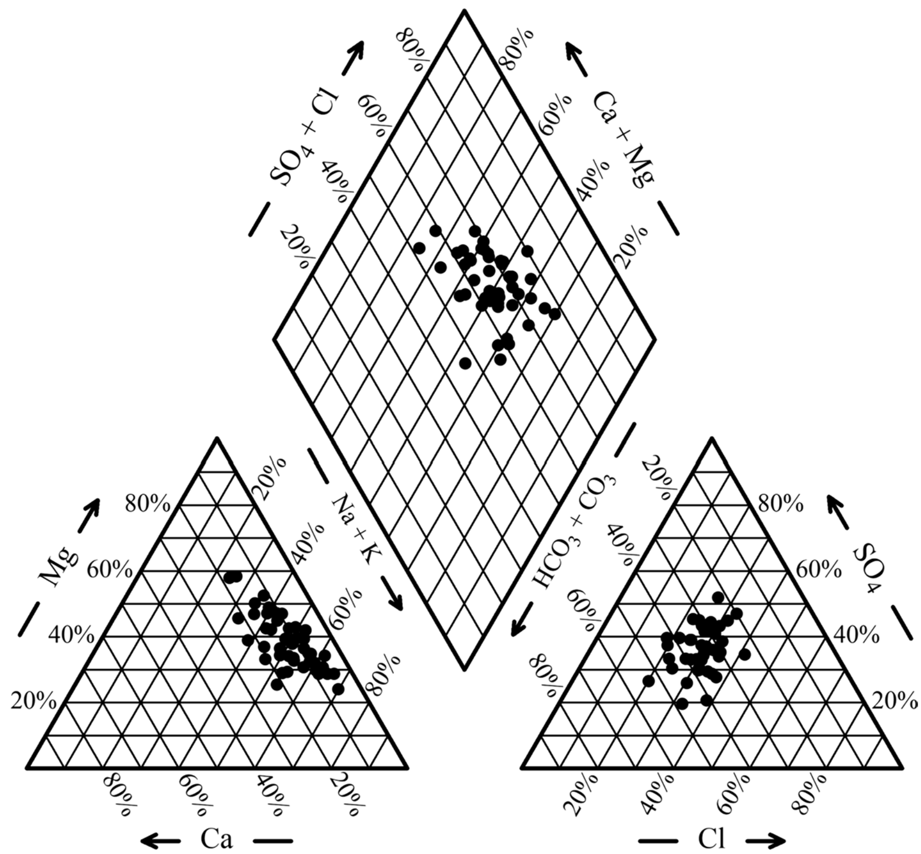


Fig. 2 Spatial distribution of nitrate, nitrite and ammonia nitrogen. **a** nitrate, **b** nitrite, and **c** ammonia nitrogen

Fig. 3 Piper diagram of groundwater samples



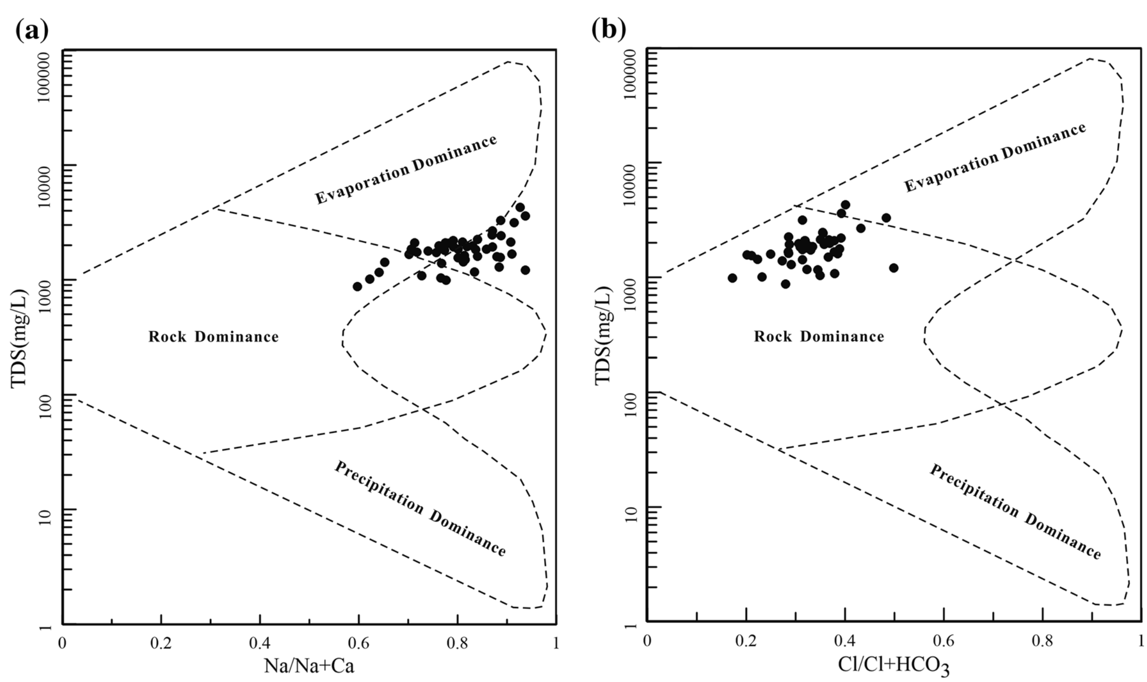


Fig. 4 Gibbs diagrams showing the major mechanisms controlling groundwater chemistry

the evolution of groundwater chemistry. Gibbs diagram (Fig. 4) classified the evolution processes into three types: rock dominance, precipitation dominance and evaporation dominance (Gibbs 1970). In this study, water–rock interaction and evaporation play a dominant role in groundwater hydrochemical evolution. Typically, groundwater quality is regulated by water–rock interactions. However, Jinghui canal irrigation area belongs to a continental semi-humid to semiarid climate zone, and the evaporation rate is relatively high, which is responsible for the derivation of plots toward the evaporation dominance zone in Fig. 4. Human activities can also influence the hydrochemical evolution processes of groundwater, which cannot be interpreted from the Gibbs diagram (Li et al. 2016b). For example, sewage infiltration may result in the increase in Cl^- and SO_4^{2-} in groundwater, making the plots derivate toward the evaporation dominance zone.

Groundwater quality assessment

Overall groundwater quality was assessed in this study using the CWQI introduced previously, and TDS, TH, SO_4^{2-}, Cl^-, NO_3–N, NO_2–N and NH_4–N were selected as the parameters in the assessment. The results are shown in Table 2.

As shown in Table 2, when TH, TDS, SO_4^{2-}, Cl^-, NO_3^-, NO_2^- and NH_4^+ are selected as the assessment parameters, groundwater quality in the study area is very poor except one sample which belongs to poor-quality water. High levels of TH, TDS, SO_4^{2-}, Cl^- and NO_3^- should be responsible for the very poor water quality in the study, which may be largely attributed to natural processes such as rock weathering, the effects of evaporation and concentration, and the process of ion exchange (Li et al. 2016a). High level of TH, TDS, SO_4^{2-} and Cl^- in groundwater are difficult to control, because they are mainly of natural origin, whereas it is easy to lower their concentrations during water supply. NO_3^- might be due to the application of chemical fertilizer in agriculture. High levels of NO_3^- in groundwater could be reduced by regulating agricultural activities and fertilizer application. Local governments should take actions to reduce nitrogen contamination in local groundwater. The water quality assessment results have shown that groundwater quality in this area is unsuitable for human consumption. However, residents in this area, especially those living in the rural areas, continue consuming groundwater for drinking and other domestic uses, because fresh and clean water in this area is scarce. Consumption of such poor-quality water will affect the health of local residents, whereas the health risk due to consumption of poor-quality water has never been assessed in this area. In addition, fresh and clean water sources are urgently required for water supply. Local governments should take measures to guarantee the safety of water supply for residents.

Health risk assessment

Water samples were collected by pumping wells, which are used by local residents for drinking and other daily uses. The serious nitrate contamination of groundwater may cause significant health risk to residents, especially to infants with disease known as the blue baby syndrome or methemoglobinemia. The blue baby syndrome is widely believed to be caused by nitrate contamination in drinking water, which results in decreased ability of blood to carry oxygen in babies and leads to death (Majumdar 2003). This study assessed the human health risk of adults and children

Table 2 Assessment results of groundwater quality in Jinghui canal irrigation area

Sample	WQI	Water quality	Sample	WQI	Water quality	Sample	WQI	Water quality
1	7.77	Very poor	17	8.93	Very poor	33	8.30	Very poor
2	8.57	Very poor	18	8.63	Very poor	34	8.81	Very poor
3	9.06	Very poor	19	8.19	Very poor	35	8.05	Very poor
4	8.30	Very poor	20	5.16	Poor	36	7.86	Very poor
5	8.93	Very poor	21	7.95	Very poor	37	8.69	Very poor
6	8.81	Very poor	22	8.46	Very poor	38	8.46	Very poor
7	7.65	Very poor	23	7.82	Very poor	39	8.30	Very poor
8	8.09	Very poor	24	8.57	Very poor	40	8.81	Very poor
9	8.69	Very poor	25	7.77	Very poor	41	8.93	Very poor
10	7.95	Very poor	26	7.77	Very poor	42	8.09	Very poor
11	8.30	Very poor	27	8.09	Very poor	43	8.09	Very poor
12	8.25	Very poor	28	8.99	Very poor	44	8.30	Very poor
13	7.86	Very poor	29	8.46	Very poor	45	8.69	Very poor
14	8.25	Very poor	30	8.69	Very poor	46	7.91	Very poor
15	8.41	Very poor	31	7.65	Very poor	47	8.19	Very poor
16	8.46	Very poor	32	9.25	Very poor			

Table 3 Health risk of different contaminants

	Nitrite		Nitrate		Ammonia nitrogen	
	Adult	Children	Adult	Children	Adult	Children
Maximum	3.8×10^{-2}	7.0×10^{-2}	1.30	2.42	9.1×10^{-2}	1.7×10^{-1}
Minimum	0	0	0	0	0	0
Mean	3.1×10^{-3}	5.8×10^{-3}	0.45	0.83	2.9×10^{-3}	5.4×10^{-3}

due to nitrogen pollution of groundwater. Table 3 shows the health risk of individual contaminant through drinking water intake and dermal contact. As shown in Table 3, the risk of nitrite to adults through drinking water intake and dermal contact ranged from Nil to 3.8×10^{-2} with an average of 3.1×10^{-3}, and the risk of nitrite to children varied from Nil to 7.0×10^{-2} with the average of 5.8×10^{-3}. The risks of nitrite on adults and children are both lower than 1, indicating minimal and acceptable health risk (Li et al. 2016a). Similarly, the risks of ammonia nitrogen to adults and children through drinking water intake and dermal contact were also lower than 1, demonstrating a minimal risk from ammonia nitrogen. The risks of nitrate to adults and children were 0–1.30 and 0–2.42 with means of 0.45 and 0.83, respectively, suggesting that groundwater nitrate would have significant health affects on residents, though the mean risk was acceptable. This is the main factor affecting the health risk in the area, which should be well addressed by local decision makers. However, the mean risk in the study area is lower than the acceptable limit (Wu and Sun 2016), which explains the rare report of blue baby syndrome in this area.

Table 4 shows the risks through different pathways. As shown in Table 4, the total risks via dermal contact for both adults and children are less than 1, and this implies that the health risks through dermal contact are low and will not likely to threaten human health. On the contrary, the risks of nitrogen contaminants through drinking water intake for adults and children in the region are generally greater than 1, suggesting potential health impacts on human health. The health risk through dermal contact in the study area is much lower than that through drinking water intake and can be ignored. Overall, the total risk in the study area due to nitrogen contamination is high for both adults and children, especially the risk posed by nitrate. Therefore, groundwater nitrate contamination should be urgently treated. The local residents in Jinghui canal irrigation area contact the polluted water only by bathing and washing, which is not frequent. Therefore, dermal contact is the secondary exposure pathways in this study area.

Tables 3 and 4 also suggest that the risks of adults through both exposure pathways are significantly higher than those for children in the study area. Children are more susceptible to groundwater nitrogen contamination. The similar conclusion has also been obtained by Wu and Sun (2016), Li et al. (2016a) and Chen et al. (2016). In general, the area is a high-risk area mainly because of groundwater nitrate pollution.

Several similar studies have been carried out in other irrigation areas. Through comparative analysis, it is found that agricultural activities are the most important reason responsible for groundwater nitrate pollution in irrigation areas. For example, in the Weining Plain and Yinchuan Plain of northwest China, serious nitrogen pollution has also been discovered (Chen et al. 2016). In Weining plain NO_3^- is the highest health risk index (Li et al. 2016a). However, the risk caused by nitrate in the present study is slightly higher than that in the Yinchuan Plain and Weining Plain. This is because the Jinghui canal irrigation area is located in the Guanzhong Basin, a semi-humid area where rotation plantation is common and the amount of fertilizer used in agriculture is large. The climatic and hydrogeological conditions in this area favor the transformation of nitrite and ammonia nitrogen to nitrate. The Yinchuan Plain and Weining Plain are situated in semiarid areas, and the climatic and hydrogeological conditions may not as favorable as those in the Guanzhong Basin to accelerate the nitrogen transformation. The geological formation is also an important factor affecting the transformation of nitrogen. In the Jinghui canal irrigation area, loess, a fine-grained windblown sediment is widely distributed (Li and Qian 2018b), while in the Yinchuan Plain and Weining Plain alluvial fine sands that contain more fertile material than loess are common.

Table 4 Health risk of different exposure pathways

	Dermal contact		Drinking water intake		Total	
	Adult	Children	Adult	Children	Adult	Children
Maximum	2.9×10^{-3}	8.6×10^{-3}	1.30	2.42	1.30	2.43
Minimum	0	0	0	0	0	0
Mean	1.0×10^{-3}	3.0×10^{-3}	0.45	0.84	0.45	0.85

Conclusions

Based on the analysis of physicochemical indices of 47 groundwater samples collected from the Jinghui canal irrigation area, the quality of groundwater was assessed by the comprehensive water quality index method (CWQI). The non-carcinogenic health risks due to groundwater nitrogen contamination were assessed for adults and children considering different exposure pathways. The following conclusions can be obtained.

1. The groundwater is slightly alkaline water. TDS and TH values are 874.1–4285.1 and 350.4–1320.1 mg/L, respectively, indicating generally brackish and hard water. The main hydrochemical types are $HCO_3 \cdot SO_4 \cdot Cl$–Mg and $HCO_3 \cdot SO_4 \cdot Cl$–Na types, which are controlled by complex natural and anthropogenic factors. Rock weathering and evaporation are main mechanisms controlling groundwater chemistry in the area. Nitrate, in particular, is high in groundwater due to extensive agricultural activities.
2. Groundwater quality in the study area is very poor and TH, TDS, SO_4^{2-}, Cl^- and NO_3^- are the major parameters affecting the suitability of groundwater for drinking. High levels of TH, TDS, SO_4^{2-} and Cl^- may be largely attributed to natural processes, but high level of NO_3^- might be due to the application of chemical fertilizer in agriculture. Therefore, local governments should take actions to reduce nitrogen contamination in local groundwater and seek new fresh and clean water sources to guarantee the safety of water supply for residents.
3. Residents who take groundwater as domestic uses are generally at high risk due to groundwater nitrogen contamination. The assessment results show that the risks through the exposure pathways of dermal contact are low and acceptable for adults and children and can be ignored. However, the risks through drinking water intake are high for both adults and children, and nitrate contributes the highest risk to human in this study. Therefore, nitrate in groundwater should be treated before consumption. The assessment also finds that children usually face higher risk than adults, which indicates that children are more susceptible to groundwater pollution.

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