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Applicability evaluation of groundwater in the People's Victory Canal Irrigation Area, China

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ABSTRACT

With the influence of natural factors and human activities on the evolution of groundwater quality, the analysis on applicability of groundwater plays an important role in guiding its development and utilization. Based on 44 groups of groundwater samples in dry and wet seasons of People's Victory Canal Irrigation Area in 2016, this paper uses single-factor evaluation and exceeding standard rate to analyze the applicability of groundwater as drinking water and reveal the main exceeding standard factor. US Salinity Laboratory diagram is used to evaluate the applicability of groundwater as irrigation water. Based on the three aspects of scaling, bubbling and corrosion, the applicability of groundwater for industrial use is evaluated. The results show that groundwater in the study area is not suitable for drinking, while the hardness and total dissolved solids contribute most to the groundwater quality exceeding standard. The over-standard contribution rates of total hardness, total dissolved solids, Cl^- and SO_4^{2-} in wet season are lower than those in dry season, while the over-standard contribution rates of NH_4^+, NO_3^- and NO_2^- increase. Except the four areas of G01, G08, G11 and G20, the groundwater in other areas can be used as irrigation water for agriculture, but the possibility of salt damage caused by long-term irrigation is greater. When groundwater in the study area is used as industrial water, more than 80% of the areas will not produce corrosiveness but will produce a large amount of bubbles and boiler scale. Therefore, it is not suitable for industrial water use.

Keywords: Groundwater quality; Groundwater hydrochemistry; Applicability of groundwater; People's Victory Canal Irrigation Area

1. Introduction

Located in the north of Henan Province, China, the People's Victory Canal Irrigation Area as an important base for grain, cotton and oil production is the first large-scale gravity irrigation area to be irrigated by the Yellow River water, which is built in the lower reaches of the Yellow River after the founding of New China. The People's Victory Canal Irrigation Area is located in upper section of the lower reaches of the Yellow River, with good water diversion conditions, and the irrigation area has gradually developed from the initial agricultural gravity irrigation into a multi-functional water use area of urban and rural industry and domestic water [1]. With the increasing sharp contradiction between supply and demand of water resources in the Yellow River Basin and the impact of water and sediment regulation, the amount of water diverted from the Yellow River in the People's Victory Canal Irrigation Area has been limited; thus groundwater has become an important irrigation source. Under the strong interference of human

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activities, the chemical composition of groundwater has changed, which directly determines the direction of groundwater utilization [2,3]. Therefore, in order to ensure the safety of drinking water and the full and rational utilization of groundwater resources in irrigation area, it is necessary to study the applicability of groundwater in irrigation area.

At present, some scholars in China have studied groundwater in the People's Victory Canal Irrigation Area, for example, Zhou [4] analyzed the characteristics and influencing factors of groundwater dynamic change, and conducted a simulation study. Liu et al. [5] analyzed the evolution characteristics of groundwater level, revealed the influence mechanism of various influencing factors on groundwater level, and determined the dominant driving factors. Zhao [1] established a numerical simulation model of groundwater and predicted groundwater flow field in the irrigation area in 2020 and 2030. Liu et al. [6] and Yuan [7] analyzed spatial evolution characteristics of groundwater hydrochemistry, and revealed the types and evolution mechanism of groundwater hydrochemistry. The existing achievements have laid a good foundation for this study, but they mainly focus on the quantity and hydrochemical evolution law of groundwater in the People's Victory Canal Irrigation Area, while the research on groundwater supply quality in the irrigation area is relatively less. Therefore, this paper focuses on the applicability of groundwater quality in domestic, agricultural and industry use, and provides scientific basis for rational utilization of groundwater resources in irrigation area.

2. Study area and data sources

2.1. Study area

The People's Victory Canal Irrigation Area is located in Xinxiang City, Henan Province, at 113°31′–114°25′E and 35°0′–35°30′N. Covering an area of 1,183 km^2, the irrigation area is shown with sloping zonal distribution from west to east, with a length of more than 100 km and a width of 5–25 km. The topography of irrigation area is decreasing from west to east, with an average ground slope of 1/4,000. The weather in irrigation area belongs to continental monsoon climate in warm temperate zone, with the annual average temperature of 14.5°C. The multi-year average rainfall is 581.2 mm, with uneven annual rainfall distribution. The rainfall from June to September accounts for 70%–80% of annual rainfall, with the multi-year average annual evaporation of 1,864.0 mm.

Groundwater in irrigation area mainly exists in pore of loose rock mass and the pore-fissure of semi-cemented clastic rock mass, flowing from southwest to northeast [1]. The bottom of shallow aquifer as the main exploiting layer of groundwater in irrigation area is 80–130 m deep, and the aquifer medium is coarse sand, medium sand and fine sand of Upper Pleistocene and Holocene series. Due to the insufficient water supply from the Yellow River in the downstream of irrigation area and at the end of the main and branch canals of the Yellow River diversion, groundwater becomes the main source of irrigation water. City life and urban industry in the irrigation area are relatively concentrated, and water use mainly depends on the extraction of groundwater, while by 2002, groundwater supply accounted for half of the total supply [5].

2.2. Data sources

The data used in this paper are mainly the 44 groups of data taken from the 22 groundwater sampling points in dry and wet seasons in 2016, and the distribution of sampling points in the study area is shown in Fig. 1. By using the 425 type discrete interval sampler of Solinst Company in Canada for groundwater sampling, the samples are stored

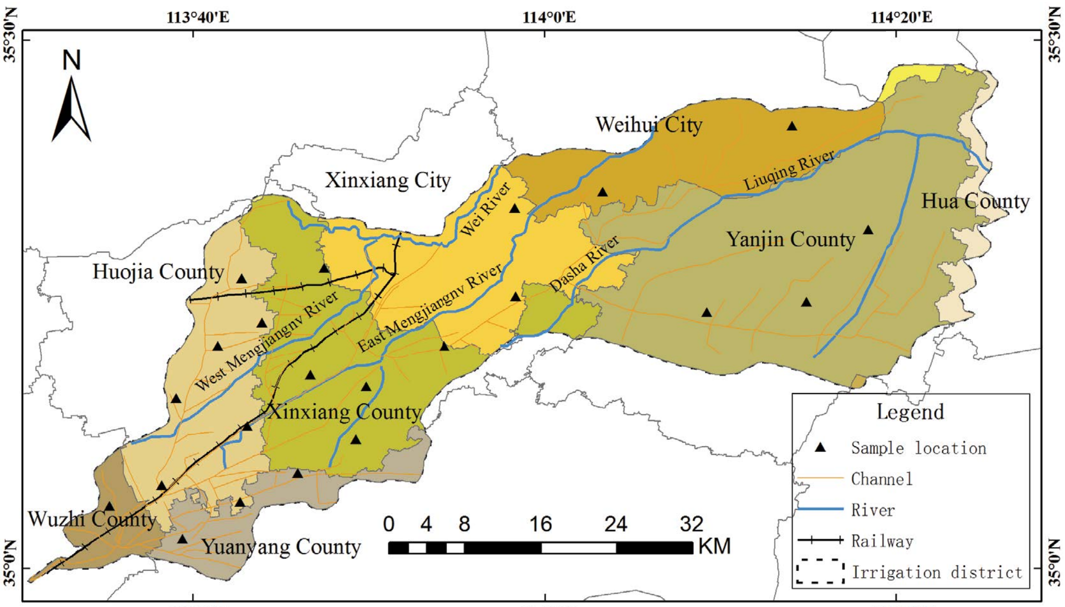

Fig. 1. Overview of the study area and sample location.

at low temperature after collection and sent to the First Institute of Geological Environment Investigation in Henan Province for testing within 4 d.

In this study, 28 indexes including K^+, Na^+, Ca^{2+}, Mg^{2+}, NH^{4+}, Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, OH^-, NO_3^-, NO_2^-, F^-, Al^{3+}, Fe^{2+}, HPO_4^{2-}, H_2SiO_3, COD_{Mn}, pH, free CO_2, total dissolved solids (TDS), total hardness (TH), electrical conductivity (EC), permanent hardness, temporary hardness, negative hardness, total alkalinity and total acidity are detected, in which, the pH value is measured by the glass electrode method in situ with the help of PHS-3C digital acidity meter, EC is measured on the spot by conductivity meter, and other indicators were tested by the laboratory in the First Institute of Geological Environment Investigation in Henan Province.

3. Methods

3.1. Applicability analysis methods of drinking water

The applicability of groundwater as drinking water is evaluated by single-factor evaluation method in this paper, which is to compare the measured value of index with the limit value of corresponding index in "Sanitary Standard of Drinking Water" (GB 5749-2006) [8], thus the index that does not exceed the limit value is suitable for drinking water, and the index that exceeds the limit value is the index of exceeding standard. The evaluation indexes here mainly include 13 items, respectively as sodium, aluminum, iron, nitrogen, nitrate, nitrite, chloride, sulfate, fluoride, total dissolved solids, total hardness ($CaCO_3$), oxygen consumption (COD_{Mn} method, O_2) and pH value, which are included in the "Sanitary Standard of Drinking Water" (GB 5749-2006).

For those indexes which exceed the limit values stipulated in "Sanitary Standard of Drinking Water" (GB 5749-2006), the main factors of influencing the quality of groundwater drinking water are identified by using the method of contribution rate of single index. The contribution rate of single index generally refers to the over-standard contribution rate of single index, whose formula is as follows [9,10]:

$$\text{Contribution rate of single index exceeding standard} = \frac{\text{Number of single index exceeding standard}}{\text{Total number of exceeding standard}} \times 100\% \quad (1)$$

3.2. Applicability analysis methods of irrigation water for agriculture

Salt content and sodium ion concentration are the important factors for irrigation water [11,12]. Excessive salt content will lead to the formation of saline soil, reduce the osmotic activity of plants, interfere with the absorption of water and nutrients in soil; excessive sodium ions can combine with carbonate to form alkaline soil or chloride ions to form saline–alkaline soil, affecting the normal growth of plants [12–14]. In this paper, US Salinity Laboratory (USSL) diagram is used to evaluate the applicability of groundwater as irrigation water.

The USSL diagram was proposed by the Saline Soil Chamber of the United States in 1954 to classify the levels of irrigation water according to sodium adsorption ratio (SAR) and EC [15]. SAR refers to the estimation on absorption degree of sodium ions in water by soil [16], which reflects the relative activity of sodium ions in soil exchange reaction [11]. The calculation formula is as follows [17]:

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\left(\text{Ca}^{2+} + \text{Mg}^{2+}\right)/2}} \quad (2)$$

The concentration unit of all ions in above formula is meq/L. According to the division rules of Saline Soil Chamber of the United States, SAR can be divided into four grades: S1 low-sodium water (SAR < 10 meq/L), S2 medium-sodium water (10 meq/L < SAR < 18 meq/L), S3 high-sodium water (18 meq/L < SAR < 26 meq/L) and S4 extremely high-sodium water (SAR > 26 meq/L). EC can also be divided into four grades: C1 low-salinity water (EC < 250 us/cm), C2 medium-salinity water (250 us/cm < EC < 750 us/cm), C3 high-salinity water (750 us/cm < EC < 2250 us/cm) and C4 extremely high-sodium water (EC > 2250 us/cm). Therefore, the USSL diagrammatic representation can divide irrigation water into 16 types.

3.3. Applicability analysis methods of industrial water use

Based on the three aspects of scaling, bubbling and corrosion which are the important chemical factors affecting industrial water consumption [18,19], the applicability of groundwater for industrial use is evaluated. Scaling is judged by the total amount of boiler scale and the coefficient of hard scale, while bubbling and corrosion are judged by the bubbling coefficient and corrosion coefficient, respectively.

3.3.1. Total amount of boiler scale H_0 and coefficient of hard scale K_n

The calculation formula of total amount of boiler scale H_0 is as follows [17,20]:

$$H_0 = S + C + 72\left[\text{Fe}^{2+}\right] + 51\left[\text{Al}^{3+}\right] + 400\left[\text{Mg}^{2+}\right] + 118\left[\text{Ca}^{2+}\right] \quad (3)$$

where H_0 is the total concentration of boiler scale, mg/L; S is the concentration of suspended solids, mg/L; C is the concentration of colloid, mg/L; [Fe^{2+}], [Al^{3+}], [Mg^{2+}] and [Ca^{2+}] are the ion concentrations, mmol/L, while the coefficients in the formula are calculated according to the molar mass of the produced precipitates.

Based on H_0, the water can be divided into four levels: very little boiler scale when $H_0 < 125$; less boiler scale when $H_0 = 125$–250; more boiler scale when $H_0 = 250$–500; very much boiler scale when $H_0 > 500$.

The calculation formula of coefficient of hard scale K_n is as follows [21]:

$$K_n = \frac{H_n}{H_0} \quad (4)$$

$$H_n = \left[\text{SiO}_2\right] + 40\left[\text{Mg}^{2+}\right] + 68\left(\left[\text{Cl}^-\right] + 2\left[\text{SO}_4^{2-}\right] - \left[\text{Na}^+\right] - \left[\text{K}^+\right]\right) \quad (5)$$

where K_n is the coefficient of hard scale; H_n is the total concentration of hard scale, mg/L; [SiO_2] is the concentration of silicon dioxide, mg/L; meanings of other symbols are the same as before.

Based on K_n, the water can be divided into three types: water with soft sediment when $K_n < 0.25$; water with medium sediment when $K_n = 0.25–0.5$; water with hard sediment when $K_n > 0.5$.

3.3.2. Bubbling coefficient F

Bubbling coefficient F is calculated as follows [21,22]:

$$F = 62\left[\mathrm{Na}^+\right] + 78\left[K^+\right] \tag{6}$$

where F is bubbling coefficient; [Na^+] and [K^+], respectively, denote the ion concentrations of Na^+ and K^+, mmol/L.

When $F < 60$, it is the no-bubbling water; when F is between 60 and 200, it is the semi-bubbling water; when $F > 200$, it is the bubbling water.

3.3.3. Corrosion coefficient K_k

The calculation formula of corrosion coefficient K_k is as follows [21,22].

3.3.3.1. Acidic water

$$K_k = 1.008\left(\left[\mathrm{H}^+\right] + 3\left[\mathrm{Al}^{3+}\right] + 2\left[\mathrm{Fe}^{2+}\right] + 2\left[\mathrm{Mg}^{2+}\right] - 2\left[\mathrm{CO}_3^{2-}\right] - \left[\mathrm{HCO}_3^-\right]\right) \tag{7}$$

3.3.3.2. Alkaline water

$$K_k = 1.008\left(2\left[\mathrm{Mg}^{2+}\right] - \left[\mathrm{HCO}_3^-\right]\right) \tag{8}$$

where K_k is corrosion coefficient, [H^+] denotes the ion concentration of H^+, mmol/L, and the others are the same as above.

When $K_k > 0$, it is corrosive water; when $K_k < 0$, and $K_k + 0.0503Ca^{2+} > 0$, it is semi-corrosive water; when $K_k + 0.0503Ca^{2+} < 0$, it is non-corrosive water.

4. Results and discussion

4.1. Applicability analysis of drinking water

4.1.1. Evaluation result of groundwater quality

The quality evaluation results of groundwater as drinking water at each sampling point in dry and wet seasons in 2016 are shown in Table 1.

According to the results of single-factor evaluation, it is found that in dry season, except the three sampling points of G03, G04 and G15, all the other areas have the indexes exceeding the limit values stipulated in "Sanitary Standard of Drinking Water" (GB 5749-2006); in wet season, every sampling point in the study area has the indexes exceeding the limit values. Therefore, groundwater in the area where G03, G04 and G15 are located can be used as drinking water only in dry season, while the other areas in dry season and all areas in wet season are not suitable for drinking water.

4.1.2. Analysis of over-standard contribution rate

Among the 13 indexes, the spatial distributions of the number of indexes exceeding the "Sanitary Standard of Drinking Water" (GB 5749-2006) of groundwater at each sampling point in dry and wet seasons are shown in Fig. 2. The number of over-standard groundwater in the south of the study area is slightly less than that in the north. From dry to wet season, where the number of over-standard groundwater is in 1–2 and 5–6 intervals, has decreased, while the region area, where the number of over-standard groundwater is between 3 and 4, has increased significantly.

Contribution rates of single index exceeding standard in dry and wet seasons are shown in Fig. 3.

In dry season, the over-standard contribution rate of total hardness is 27.94%, ranking the first, followed by the total dissolved solids and sulfate, whose contribution rates are both between 10% and 20%, while the contribution rates of the other indexes are all less than 10%. In wet season, the over-standard contribution rate of total hardness is 24.32%, still ranking the first, followed by the total dissolved solids, chemical oxygen demand and nitrogen, whose contribution rates are 14.86%, 13.51% and 12.16%, respectively, while the contribution rates of other indexes are all less than 10%. Taken together, the total hardness exceeds the standard most seriously, whose over-standard contribution rates in dry and wet seasons are both more than 20%, followed by the total dissolved solids, whose contribution rates in dry and wet seasons are 17.65% and 14.86%, respectively, while aluminum and pH values do not exceed the standard in dry and wet seasons.

The value of total hardness in study area is between 130.6 and 2,286.53 mg/L, and the mean values of total hardness in dry and wet seasons are 775.07 and 656.95 mg/L, respectively, which are higher than the limit value of 450 mg/L in the "Sanitary Standard of Drinking Water" (GB 5749-2006). In dry season, 86.36% and 13.6% of water samples are hard water and very hard water, while in wet season, 81.82% are very hard water and 9.1% are hard water, which do not meet the "Sanitary Standard of Drinking Water" (GB 5749-2006), and are not suitable for drinking water.

The mean values of total dissolved solids in dry and wet seasons are 1,367.9 and 1,129.9 mg/L, respectively, which are higher than the limit value of 1,000 mg/L in the "Sanitary Standard of Drinking Water" (GB 5749-2006). The total dissolved solids at 55% and 50% sampling points of the study area in the dry and wet seasons exceed the standard.

The contribution rates of each index in dry season and wet season are shown in Fig. 4. From dry to wet seasons, the over-standard contribution rates of sulfate, sodium, chloride, total hardness, total dissolved solids, fluoride and iron ion decrease, and their decrease degrees decrease in turn; aluminum and pH do not exceed the standard in both dry and wet seasons, so the variation of their over-standard contribution rates from dry to wet seasons is 0. The over-standard contribution rates of nitrate, nitrite, chemical oxygen demand and nitrogen increase from dry to wet seasons, and their increase degrees increase in turn, while the over-standard contribution rate of nitrogen increases most obviously. From dry to wet seasons, precipitation increases obviously and groundwater recharge increases. Because of

Table 1
Results of groundwater quality evaluation as drinking water in dry and wet seasons

Index well	Na^+	NH_4^+	Al^{3+}	Fe^{3+}	Cl^-	SO_4^{2-}	NO_3^-	NO_2^-	F^-	COD_{Mn}	TH	TDS	pH
G01	N/N	—/N	—/—	—/N	N/N	N/N	—/—	—/—	—/—	N/N	N/N	N/N	—/—
G02	—/—	—/—	—/—	—/—	—/—	N/—	N/—	—/—	—/—	—/—	N/N	N/N	—/—
G03	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/N	—/—	—/—
G04	—/—	—/N	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/N	—/—	—/—
G05	—/—	—/—	—/—	N/—	—/—	—/—	—/N	—/N	—/—	—/N	N/—	N/—	—/—
G06	—/—	—/N	—/—	—/—	N/—	N/N	—/—	—/—	—/—	—/N	N/N	N/N	—/—
G07	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/N	N/N	—/—	—/—
G08	N/N	—/—	—/—	—/—	N/N	N/N	—/N	—/—	N/—	—/—	N/N	N/N	—/—
G09	N/—	—/—	—/—	—/—	—/—	N/—	—/—	—/—	N/—	—/N	N/—	N/—	—/—
G10	N/—	—/—	—/—	N/—	—/—	N/—	—/—	—/—	—/—	—/N	N/N	N/N	—/—
G11	N/—	—/—	—/—	—/—	N/N	N/N	N/N	N/—	—/—	N/—	N/N	N/N	—/—
G12	—/—	—/—	—/—	—/—	—/—	—/—	—/N	—/—	—/—	—/—	N/N	—/—	—/—
G13	—/—	—/N	—/—	—/—	—/—	—/—	—/—	—/N	—/—	—/N	N/—	—/—	—/—
G14	—/—	—/N	—/—	—/N	—/—	—/—	—/—	—/—	—/—	—/N	N/—	—/—	—/—
G15	—/N	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/N	—/N	—/—
G16	N/—	N/N	—/—	—/—	N/—	—/—	—/—	—/—	—/—	N/N	N/N	N/N	—/—
G17	—/N	—/N	—/—	—/—	—/—	N/—	N/—	—/—	N/N	—/N	N/N	N/N	—/—
G18	—/—	—/—	—/—	—/—	—/—	—/—	—/N	—/N	—/—	N/—	N/N	N/N	—/—
G19	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	N/N	—/—	—/—
G20	N/—	—/N	—/—	—/—	N/—	N/N	N/—	—/—	—/N	—/—	N/N	N/N	—/—
G21	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	N/N	—/—	—/—
G22	—/—	—/N	—/—	—/—	—/—	—/—	—/—	—/—	—/—	—/—	N/N	—/—	—/—

"—" represents suitable and "N" represents not suitable.

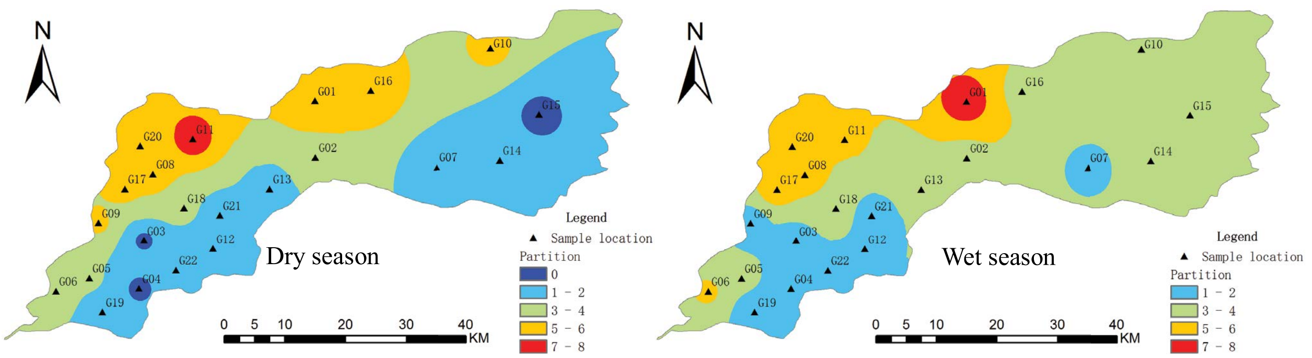

Fig. 2. Spatial distribution of groundwater exceeding standard in each sampling point during dry and wet season.

the low ion content in precipitation, the concentrations of sodium ion, chloride ion and sulfate ion in groundwater decrease, the total dissolved solids in groundwater decrease, and the total hardness of groundwater decreases, while the increases of nitrate, nitrite, chemical oxygen demand and ammonia nitrogen may be related to agricultural fertilization.

In conclusion, except the three sampling points of G03, G04 and G05 in study area can be used as drinking water only in dry season, the others are not suitable for drinking water. The total hardness and total dissolved solids are the most important factors affecting groundwater quality in the study area. Groundwater in over 80% of the study area is the very hard water, and the total dissolved solids in groundwater in over 50% areas of the study area exceed the standard. The over-standard contribution rates of total hardness, total dissolved solids, Cl^- ion and SO_4^{2-} ion in wet season are lower than those in dry season, while the over-standard contribution rates of NH_4^+, NO_3^- and NO_2^- increase.

4.2. Applicability analysis of irrigation water for agriculture

USSL diagram of the study area based on SAR and EC in dry and wet seasons in 2016 is shown in Fig. 5.

In the study area, the EC values of shallow groundwater in dry and wet seasons are between 300 and 7,000 μs/cm, and the SAR values are between 0 and 8. In dry and wet seasons,

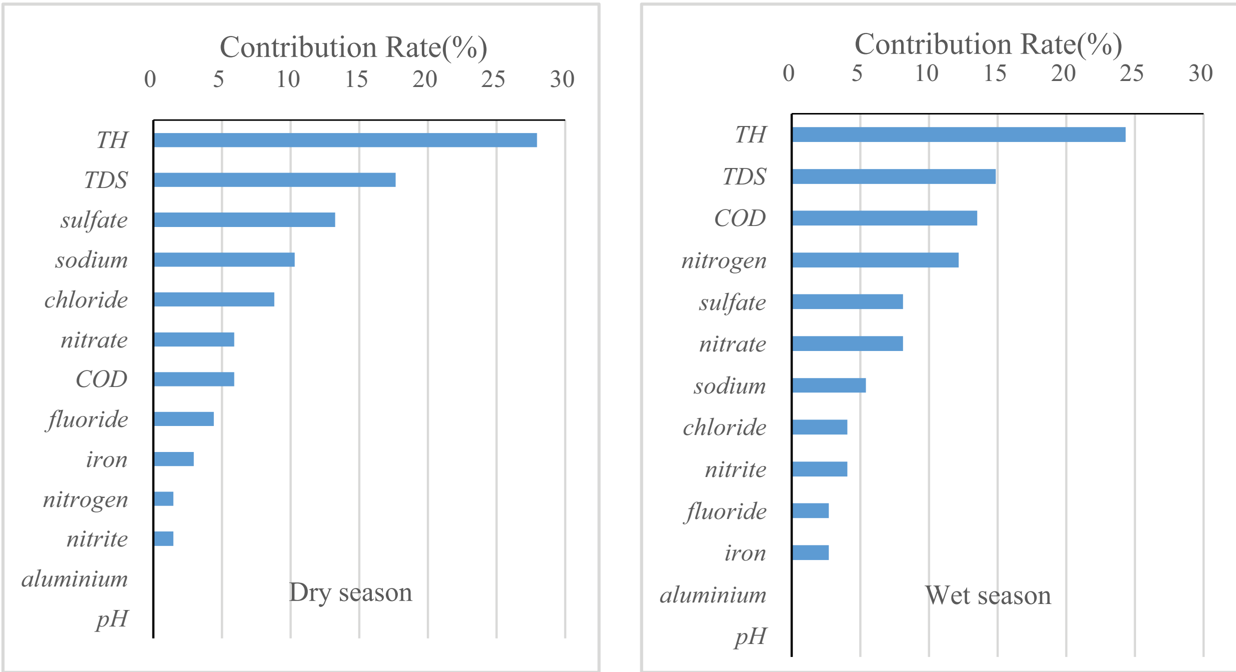

Fig. 3. Contribution rate of single index exceeding standard in dry and wet season.

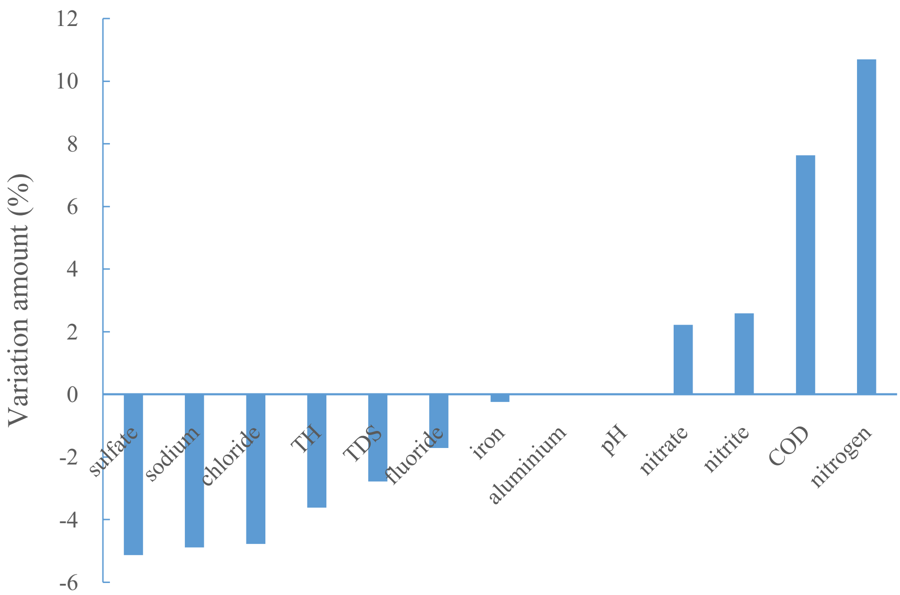

Fig. 4. Variation of contribution rate of each index in dry season to wet season.

there are 82% of the sampling points located in C3S1 area, indicating that most of the groundwater in the study area is low-sodium and high-salt water. Irrigation with this water would not cause sodium and salt hazard, but it is necessary to select the plants with good salt tolerance and do well drainage measures [18,23]. In dry season, there are four sampling points located in C4 area, in which, G01, G11 and G16 are located in area C4S2, belonging to extremely-high-salt and medium-sodium water, and sampling point G08 is located in C4S3 area, belonging to extremely-high-salt and high-sodium water, thus both being not suitable for irrigation water. In wet season, sampling points G01 and G08 are located in C4S2 area, belonging to extremely-high-salt and medium-sodium water, and sampling point G11 is located in C4S1 area, belonging to extremely-high-salt and low-sodium water, thus both being not suitable for agricultural irrigation water. Sampling point G09 is located in C2S1 area in wet season, belonging to medium-salt and low-sodium water, which has good water quality and can be used for irrigation.

In a word, the salt content of G01, G08 and G11 is higher in both dry and wet seasons, while that of G16 is higher only in dry season. Therefore, except the groundwater in these four sampling points is not suitable for irrigation water, groundwater in other areas can be used for agricultural irrigation,

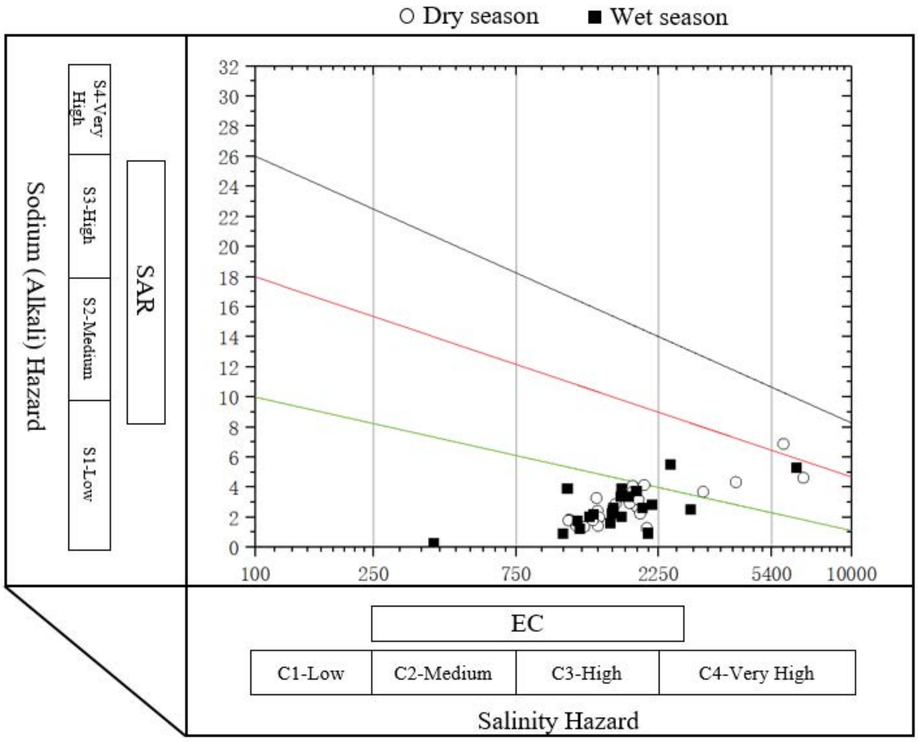

Fig. 5. Classification of groundwater for irrigation based on sodium and salinity hazard.

but after long-term irrigation by groundwater, the possibility of producing sodium hazard is smaller, and the possibility of producing salt hazard is greater.

4.3. Applicability analysis of industrial water

4.3.1. Scaling

The statistics of boiler scale in dry and wet seasons is shown in Fig. 6.

In the study area, the total amount of boiler scale at two sampling points is less than 500 mg/L only in wet season, while that at the other sampling points in wet season and all sampling points in dry season is more than 500 mg/L, indicating that a large amount of boiler scale will be produced when the groundwater in more than 90% area is used as boiler water.

The statistics of hard scale coefficient in dry and wet seasons is shown in Fig. 7.

In the study area, more than 77% of the sampling points in dry season belong to water with soft sediment, while the other sampling points belong to water with medium sediment. In wet season, the hard scale coefficient of 86% sampling points is less than 0.25, which belongs to the water with soft sediment. The hard scale coefficient of two sampling points is between 0.25 and 0.5, which belongs to the water with medium sediment. The hard scale coefficient of one sampling point is more than 0.5, which belongs to the water with hard sediment. Therefore, soft sediment will be produced when groundwater in over 77% area is used as boiler water, which is easy to wash and remove, while medium or hard sediment will be produced in other areas, which is not easy to remove, thus it is necessary to replace the water regularly.

In conclusion, as far as scaling is concerned, a large amount of boiler scale will be produced when the groundwater in over 90% area is used as boiler water, and the soft sediments will be produced when over 77% of groundwater is used as boiler water. Therefore, groundwater in the study area should not be used as general industrial water.

4.3.2. Bubbling

The calculation result of bubbling coefficient of groundwater in the study area is shown in Table 2. All the bubbling coefficients of groundwater at all sampling points in dry season are greater than 200, belonging to bubbling water, which is not suitable for industrial water. While in wet season, the bubbling coefficient of more than 80% sampling points is greater than 200, that of 13.6% sampling points is between 60 and 200, and only that of the sampling point G09 is less than 60, which indicates that when groundwater in more than 80% area of the study area is used as general industrial water during wet season, a large number of bubbles will occur, which will affect the normal operation of boilers.

4.3.3. Corrosion

The calculation result of corrosion coefficient in the study area is shown in Tables 3 and 4. The corrosion coefficients of G01, G08, G11 and G20 are all greater than 0 in dry and wet seasons, indicating the existence of corrosiveness, which is not suitable for general industrial water use, while groundwater in other areas will not produce corrosion.

In conclusion, if groundwater in the study area is used as general industrial water, more than 80% of the area

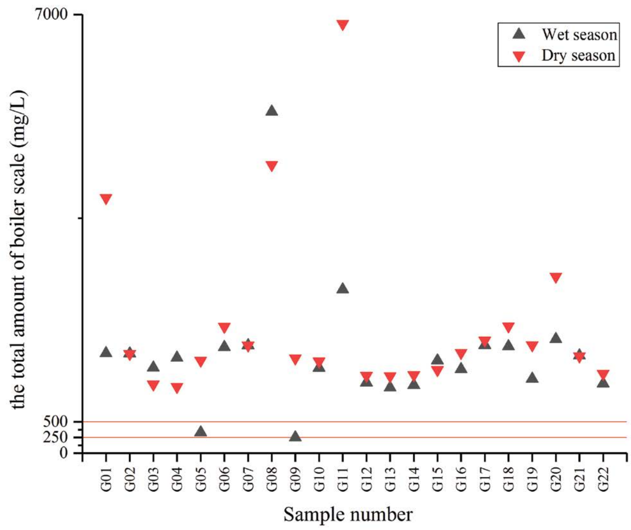

Fig. 6. Total amount of boiler scale in dry season and wet season.

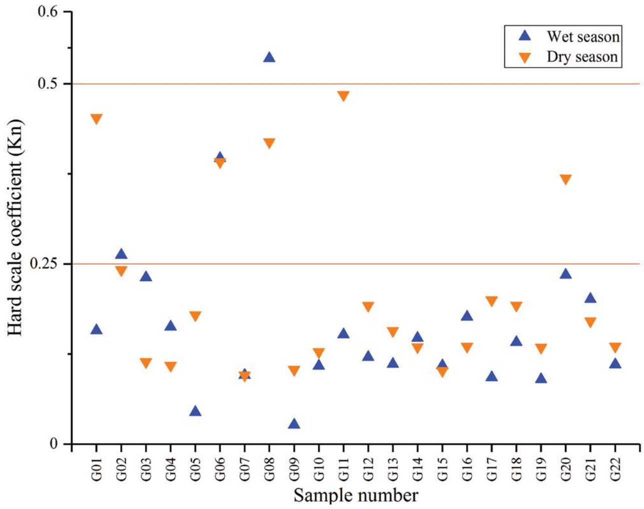

Fig. 7. Hard scale coefficient in dry season and wet season.

Table 2
Bubbling coefficient in dry and wet season

Sample number	G01	G02	G03	G04	G05	G06	G07	G08	G09	G10	G11
Dry season	1,012.48	431.82	239.47	231.37	457.58	248.06	439.87	1,768.09	581.26	546.44	1,457.83
Wet season	833.52	437.59	343.45	377.27	412.14	187.36	404.51	1,626.59	25.82	485.29	571.23
Sample number	G12	G13	G14	G15	G16	G17	G18	G19	G20	G21	G22
Dry season	201.15	340.09	200.26	429.19	638.19	506.27	395.48	295.84	749.09	221.23	260.32
Wet season	181.82	244.21	153.83	545.17	504.07	573.70	337.20	313.54	481.72	259.02	284.76

Table 3
Corrosion coefficient in dry season

Sample number	G01	G02	G03	G04	G05	G06	G07	G08	G09	G10	G11
K_k	11.89	–3.48	–3.67	–4.19	–4.61	–2.69	–5.21	10.71	–4.21	–4.67	19.82
$K_k + 0.0503Ca^{2+}$		–3.09	–3.46	–3.97	–4.26	–2.08	–5.00		–4.01	–4.40	
Sample number	G12	G13	G14	G15	G16	G17	G18	G19	G20	G21	G22
K_k	–4.24	–3.47	–4.48	–5.72	–4.73	–2.21	–4.41	–2.88	3.29	–4.30	–5.16
$K_k + 0.0503Ca^{2+}$	–3.93	–3.21	–4.22	–5.58	–4.44	–1.92	–4.02	–2.68	–	–4.00	–4.86

Table 4
Corrosion coefficient in wet season

Sample number	G01	G02	G03	G04	G05	G06	G07	G08	G09	G10	G11
K_k	1.18	–3.34	–4.53	–5.24	–1.06	–4.41	–5.58	11.92	–1.70	–4.47	0.84
$K_k + 0.0503Ca^{2+}$		–2.91	–4.19	–4.96	–0.93	–3.69	–5.36		–1.60	–4.22	
Sample number	G12	G13	G14	G15	G16	G17	G18	G19	G20	G21	G22
K_k	–5.22	–4.48	–3.86	–6.79	–3.52	–4.90	–4.16	–4.82	0.16	–4.48	–5.05
$K_k + 0.0503Ca^{2+}$	–4.92	–4.22	–3.63	–6.61	–3.22	–4.69	–3.83	–4.55	–	–4.12	–4.76

will not produce corrosiveness, but over 90% of the area will produce a large amount of boiler scale, and over 80% of the area will produce a lot of bubbles. Therefore, groundwater in irrigation area is not suitable for general industrial water.

5. Conclusion

Except G03, G04 and G15 in dry season meet the requirements of drinking water, other sampling points in the study area are not suitable for drinking water. The total hardness and total dissolved solids contribute most to groundwater quality exceeding the standard. The over-standard contribution rates of total hardness, total dissolved solids, Cl^- and SO_4^{2-} ions in wet season are lower than those in dry season, while the over-standard contribution rates of NH_4^+, NO_3^-, NO_2^- ions increase. Except G01, G08, G11 and G20, groundwater in other areas can be used as agricultural irrigation water. After long-term irrigation with groundwater, the possibility of sodium hazard is less, but the possibility of salt hazard is greater. When groundwater in the study area is used as industrial water, more than 80% of the area will not produce corrosion, but will produce a large number of boiler scales, with a lot of bubbles. Therefore, most of the groundwater in the study area is not suitable for general industrial water.

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