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Hydrogeochemistry characteristics of groundwater and its suitability for water supply and irrigation in Jilin City, China

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Abstract Groundwater is the most important water resources in modern water supply, and its quality is the determining factor, especially for the groundwater supply under extreme events. Groundwater quality survey has been carried out in Jilin City, which is a famous industrial city in northeast China. The results show that (1) the distribution of major ions in the groundwater is as follows: $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ and $HCO_{3-} > SO_4^{2-} > Cl^- > NO_{3-}$; the Piper's, Gibbs's, and Langelier–Ludwig's diagrams suggest that groundwater was evolved due to the water–rock interaction; (2) geochemical relations (Ca/Mg ratio, Ca + Mg versus HCO_3 + SO_4, Na versus Cl) suggest that the dissolution of carbonate minerals gypsum and halite is the significant mechanism dominating the groundwater chemistry, the relations also suggest that the ion exchange is the secondary processes for higher concentrations of Ca^{2+} and Mg^{2+} ions; (3) the influences of agricultural fertilizers and irrigation practice are the other reasons for increasing NO_3^- ions in the groundwater; according to the drinking water quality standards, the groundwater is not suitable for drinking with reference to the concentrations of total hardness, Ca^{2+}, Mg^{2+}, NO_3^-, F^-, and Fe in many locations; (4) based on the parameters mentioned (sodium adsorption ratio, Kelly's ratio, sodium percent, permeability index, and magnesium hazard), the groundwater quality is assessed and the overall irrigation qualities of wells are demarcated as suitable for irrigation.

Introduction

As the most important water resources in modern society, groundwater is playing more and more influences for the sustainable development. Groundwater quality investigation and assessment are the fundamental works in the regional groundwater management (Subramani et al. 2005; Nagarajan et al. 2010; Ako et al. 2011; Wang 2013; Agca 2014; Al-Khashman et al. 2014). As the surface water bodies are polluted seriously around the world, groundwater quality becomes controlling factors in modern water management decisions (Jang et al. 2012; Re et al. 2014; Erdlenbruch et al. 2014; El-Fadel et al. 2014). Especially for the hydrogeochemistry characteristics and its responses for the changing climate and human activities, groundwater quality assessment has more and more important influence to the changing world (Gorelick and Zheng, 2015). Groundwater has become the major source of water supply for domestic, industrial, and agricultural sectors of many countries (Du et al. 2013; Su et al. 2014a, 2014b; Fu et al. 2014).

Although main cities are located along big rivers and the water supply is always mainly based on the surface water resources, the urbanization is making an increased water demand, groundwater resources are playing important sources of water supply, especially in arid and semi-arid areas (Zhang et al. 2010; Zhai et al. 2015), groundwater even becoming sole

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source in some city or under critical events (Ghislain et al. 2012; Nazzal et al. 2014). In this study, Jilin City has been selected as the study area, although the groundwater resources only occupied about 2.72 % daily water supply; however, groundwater could be the sole water resource (Huan et al. 2012). There is a famous petrochemical plant that exploded in Jilin Province, China, on November 13, 2005, and approximately, 100 tons of toxic substances including benzene, aniline, and nitrobenzene spilled into the Songhua River (Zhang et al. 2010), groundwater becoming the emergent water supply source. The groundwater resources monitoring and assessment would be very useful for the social sustainable development and safety under extreme events. Hence, groundwater suitability for drinking and irrigation should be investigated, the assessment result could be important guidance for local groundwater management under an emergent event.

Study area

Jilin City has been selected as the study area, the location could be seen in Fig. 1; from the figures, it could be seen that the study area is along the Songhua River, which is a big river in northeastern China, and the area is about 104.5 km^2.

The precipitation in this area is about 645.5 mm/a, and evapotranspiration is about 1506 mm/a. Quaternary Holocene alluvial is distributed in the floodplain, and the First terrace and quaternary upper Pleistocene alluvial is distributed in the Second terrace. Lower Pleistocene Series is continuously overlaid by Holocene alluvial and upper Pleistocene alluvial. The types of sediments in the vadose zone mainly consist of loamy sand, sandy loam, sandy clay, loam, silt clay, and silt (Huan et al. 2012, 2015).

In the study area, the phreatic aquifer is composed of Quaternary unconsolidated deposits, including sands, gravels, and pebbles. Rainfall and irrigation infiltration recharge the groundwater from May to September. The groundwater flows mainly from southeast to northwest. The groundwater discharges typically towards rivers except during the flood season. Evaporation only occurs in the area where the groundwater depth is less than 4.95 m, between late November and the following April. Abstraction of groundwater constitutes a significant resource output, especially in the groundwater source areas such as Jiuzhan, Hadawan, and Songyuanhada (Huan et al. 2015).

According to recent research, the groundwater has been polluted by human activities in Jilin City area, especially for nitrogen contamination; the process to derive a NO_3-N concentration at the pumping well is presented, based on determining the maximum nitrate loading limit to satisfy China's drinking-water quality standards (Huan et al. 2015). Hydrogeochemistry characteristic analysis is the foundation for local groundwater resource evaluation and management.

Sampling and methodology

A regional geological survey of the study area was carried out during May 2002 and May 2004, and 262 groundwater samples were collected from private, municipal, and observation wells, which were distributed over the whole region (Fig. 1).

Samples were collected in polyethylene bottles with capacity of 1 L. Prior to their filling with sampled water, these bottles were rinsed to minimize the chance of any contamination. The sample preservation and the used analytical techniques were in accordance with the standard methods from the American Public Health Association (American Public Health Association, APHA, 1995). Unstable parameters such as hydrogen ion concentration (pH) and total dissolved solids (TDS) were determined at the sampling sites with the help of a pH meter and a TDS meter. The calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+) ions were determined by atomic absorption spectrophotometer (Shimadzu AA-6300CF). Total iron and total manganese were analyzed by spectrophotometer. Bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) were analyzed by titrimetric methods. Total alkalinity as $CaCO_3$ and total hardness as $CaCO_3$ were analyzed by titration with EDTA and titration with HCl, respectively. Chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), and fluoride (F^-) were measured by ionic chromatography. Then, ionic balance was calculated by cations minus anions over total ion concentration, and samples above 5 % error were discarded (Appelo and Postma 2005).

Carbonate hardness, non-carbonate hardness, and excess alkalinity were computed. The values, which were the lowest among total alkalinity and total hardness, were placed under carbon hardness; when the value of total alkalinity was greater than total hardness, the difference value of total alkalinity was considered as excess alkalinity, and when total hardness was more than total alkalinity, the excess value of total hardness was taken as non-carbonate hardness.

Hydrogeochemical classification and groundwater evolution have been discussed using bivariate plots, Piper's plot, Gibb's plots, chloro-alkaline indices, and meteoric genesis indices. For drinking-water quality assessment, the results were compared with the World Health Organization (WHO, 2011) standards. The suitability for agriculture use was assessed using sodium adsorption ratio, sodium percentage, Kelley's ratio, residual Mg/Ca ratio, permeability index, and magnesium hazard.

Results and discussions

General chemistry

According to the groundwater sample test results (Table 1), it could be seen that the groundwater samples are slightly acidic

Fig. 1 Distribution of
groundwater samples
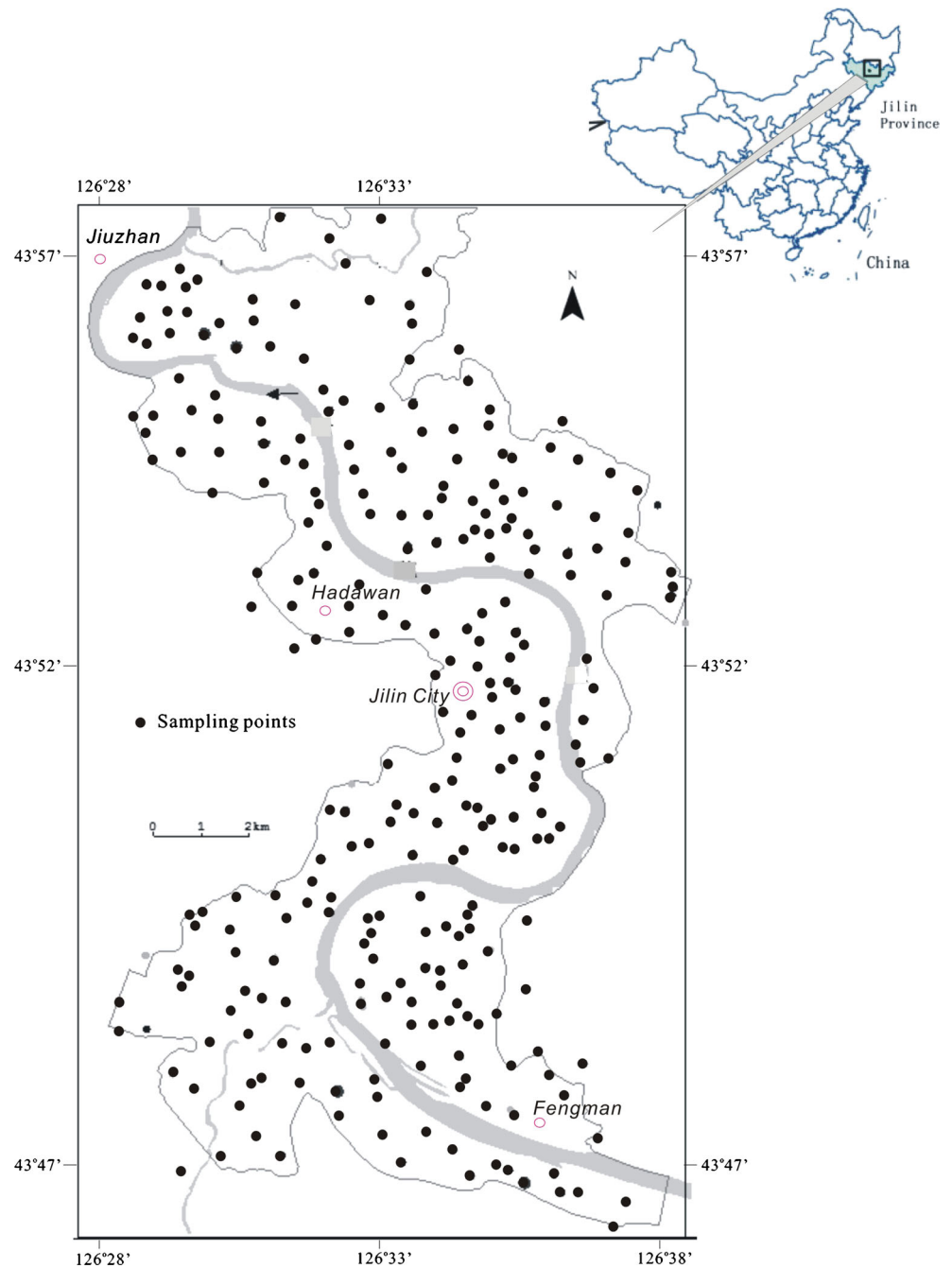
to neutral, the pH values range from 6.2 to 7.3. The total
dissolved solids (TDS) range from 91.4 to 1140 mg/L with
an average value of 410 mg/L, only two groundwater samples
are brackish water with TDS values more than 1000 mg/L,
and the other groundwater samples are fresh water with TDS
values less than 1000 mg/L (Fetter 2014).

The total alkalinity is in between 35.5 and 558 mg/L
(Table 1). This is due to the HCO_3^- ions, as the pH varies
from 6.2 to 7.3 which results in no presence of CO_3^{2-}.

The total hardness of groundwater samples in Jilin City could
be seen in Table 2; from the table, it could be seen that, the total

hardness ranges from 131 to 1169 mg/L, which mean that there is
about 57 % of the groundwater samples that fall into the classi-
fication of hard (150–300 mg/L) and 43 % of the groundwater
samples fall into the classification of very hard (>300 mg/L).

The relationship between total alkalinity and total hardness
could be used to calculate the carbonate hardness and non-
carbonate hardness, the result could be seen in Table 1. From
the results, it could be seen that while carbonate hardness
could be removed easily by water boiling due to a presence
of weak acids, the non-carbonate hardness cannot be removed
due to strong acids.

Table 1 Statistical summary of the chemical composition of groundwater

Chemical parameter	Expressed	Minimum	Maximum	Mean	Median	Standard deviation
pH	units	6.2	7.3	6.8	6.7	0.30
TDS	mg/L	91.4	1140	409.8	345	216.66
Total alkalinity	mg/L	35.5	558	138.4	130.9	77.64
Total hardness	mg/L	131	1169	324.8	271.6	188.31
Carbonate hardness	mg/L	35.5	558	138.2	130.9	77.57
Non-carbonate hardness	mg/L	0	988	186.6	149	159.66
Ca^{2+}	mg/L	13.5	295	71.7	55.6	48.79
Mg^{2+}	mg/L	11.7	134	35.7	28.6	21.22
Na^+	mg/L	3.2	79.7	27	24.3	14.42
K^+	mg/L	0.3	33	4.5	3	5.24
HCO_3^-	mg/L	43	680	168	151	94.63
Cl^-	mg/L	2	359	53.2	33.7	63.50
SO_4^{2-}	mg/L	10	922	107	94.1	101.00
NH_4^+	mg/L	0.03	15.6	1.07	0.43	2.25
NO_2^-	mg/L	0	3.3	0.13	0.03	0.43
NO_3^-	mg/L	0	193	37	21.2	44.63
F^-	mg/L	0.1	1.6	0.36	0.32	0.30
Fe	mg/L	0	30.2	2.28	0.34	5.35

The distribution orders of major ions in the groundwater samples are $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ and $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-$. The concentration of Ca^{2+} in the study area ranges from 13.5 to 295 mg/L, 37 % of the groundwater samples exceed the limit of 75 mg/L. The concentrations of Mg^{2+} range from 11.7 to 134 mg/L with an average value of 35.7 mg/L. Most of the Mg^{2+} concentrations (52 %) are within the desirable limit of 30 mg/L. The concentrations of Na^+ and K^+ ions vary from 3 to 80 and 0.3 to 33 mg/L, respectively (Table 1). The major source of Ca^{2+} in the groundwater is due to ion exchange of minerals from rocks of this area. Further, this may also be due to the presence of $CaCO_3$ and $CaSO_4$ minerals present in the soil horizon, gypsum anhydrides, dolomite, etc.

The HCO_3^- concentration ranges from 43 to 680 mg/L with an average of 168 mg/L. The SO_4^{2-} concentrations range from 10 to 922 mg/L, with an average value of 107 mg/L. Only one sample has SO_4^{2-} concentration greater than the permissible limit of 250 mg/L. The Cl^- concentration ranges from 2 to 359 mg/L, averaging 53.2 mg/L. Two samples have Cl^- concentration more than the permissible limit of 250 mg/L. The NO_3^- concentration ranges from 0 to 193 mg/L with an average of 37 mg/L. As much as 30 % sample has more than the permissible NO_3^- concentration (45 mg/L).

Hydrochemical classification

The classification of groundwater facies was done using Piper's diagram (Piper 1944). The plots of desirable data on the diamond-shaped field classify the groundwater types into two groups (Fig. 2).

The diagram of Langelier and Ludwig can also reflect these two groundwater types. Langelier–Ludwig diagram (1942) shows four parts, and each part is divided by 50 % of the total ions (Fig. 3). They are related to $Ca^{2+} + Mg^{2+} + HCO_3^-$, $Na^+ + HCO_3^-$, $Na^+ + Cl^-$, and $Ca^{2+} + SO_4^{2-}$ compositions. The computed percentages of $Ca^{2+} + Mg^{2+}$, $Na^+ + K^+$, HCO_3^-, and $Cl^- + SO_4^{2-}$ vary from 68 to 95, 5 to 32, 6 to 87, and 13 to 94, respectively. Twenty-five percent of the groundwater sampling points fall in the area of $Ca^{2+} + Mg^{2+} + HCO_3^-$ composition (Fig. 3). $Ca^{2+} + Mg^{2+} + HCO_3^-$ water types represent meteoric signatures or fresh recharged water. The residual samples (75 %) fall in $Ca^{2+} + Mg^{2+} + SO_4^{2-}$ which show evolved groundwater type where unique chemical masking is achieved through rock–water interaction, ion exchange, and reverse ion exchange; reactions within unsaturated zones; increased resident time; and anthropogenic influences.

Table 2 Distribution of groundwater samples based on the classification of total hardness

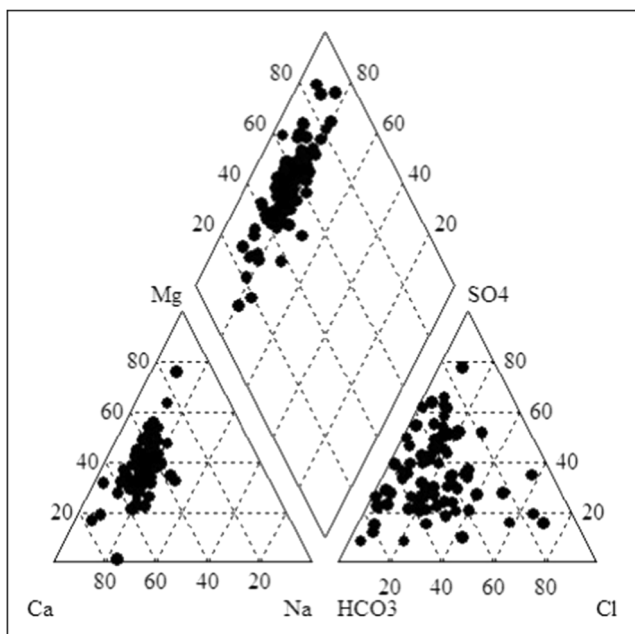| Classification of total hardness (mg/L)	Sample numbers	Percentage of samples (%)	Water type
<75	–	–	Soft
75–150	2	2	Moderately hard
150–300	46	57	Hard
>300	33	41	Very hard

Fig. 2 Piper plot for groundwater facies classifications

Hydrochemical evolution

Gibbs's diagram In order to know the hydrogeochemical processes during groundwater recharge, runoff, and discharge, two Gibbs's diagrams have been proposed as Fig. 4, they are related to the weight ratios of cations ($Na^+:Na^+ + Ca^{2+}$) and anions ($Cl^-:Cl^- + HCO_3^-$) against TDS.

From Fig. 4, it could be seen that the cation ratios ($Na^+:Na^+ + Ca^{2+}$) vary from 0.06 to 0.49 and the anion ratios ($Cl^-:Cl^- + HCO_3^-$) vary from 0.01 to 0.81, which mean that
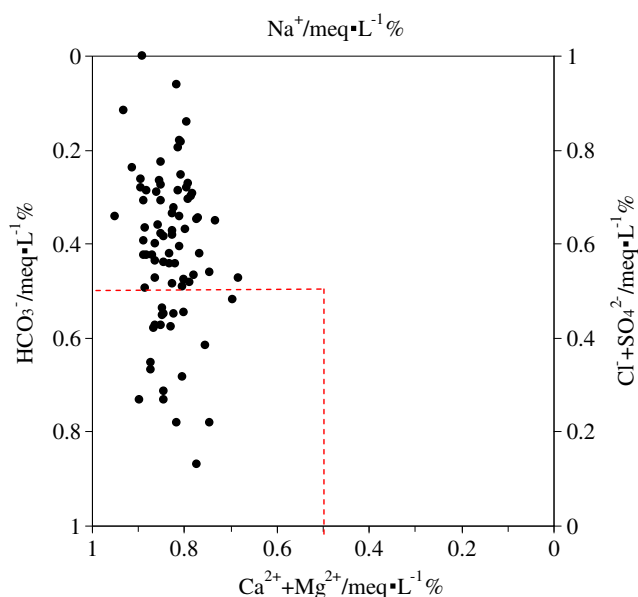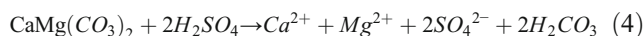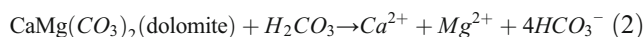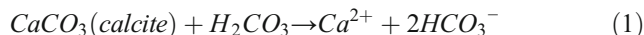

Fig. 3 Classification of groundwater chemistry

the main source of dissolved ions is rock–water. The rock–water interaction generally includes the chemical weathering of rocks, dissolution–precipitation of secondary carbonates, and ion exchange between water and clay minerals. The moving of groundwater sampling points from the rock-domain towards the evaporation-domain in Fig. 4b suggests an increase of Cl^- ions, and consequent higher TDS due to water contamination caused by the influences of irrigation practice; as water–rock interaction was the dominant process governing the groundwater chemistry, it is reasonable to identify the origin of different ions (Kumar et al. 2014).

Hydrogeochemical relations

Hydrogeochemical characteristics and their relationships could be used to find the groundwater species original and the controlling hydrogeochemical process during the groundwater recharge, runoff, and discharge.

Ca^{2+} and Mg^{2+} were the dominant cations, and HCO_3^- was the dominant anion in wide areas. The abundance of Ca^{2+} and Mg^{2+} in the groundwater could be related to the presence of carbonate rock in the basin, while weathering of carbonate and silicates may contribute Ca^{2+} and Mg^{2+} in the groundwater. The dissolution of calcite and dolomite can be shown by the groundwater's Ca^{2+}/Mg^{2+} molar ratio. A Ca^{2+}/Mg^{2+} molar ratio that is equal to one indicates dissolution of dolomite rocks (Mayo and Loucks 1995), while a greater ratio may represent a more dominant calcite contribution from the rocks. A Ca^{2+}/Mg^{2+} ratio, greater than 2, may represent the dissolution of silicate minerals into the groundwater (Katz et al. 1997). While 30 % of the groundwater samples had a lower Ca^{2+}/Mg^{2+} ratio than 1, which indicated that the dissolution of dolomite, 60 % of the samples had a Ca^{2+}/Mg^{2+} ratio between 1 and 2, which indicated the dissolution of calcite that contributes Ca^{2+} and Mg^{2+} to the groundwater. Only a few samples (around 10 %) were indicative of the effect of silicate minerals with Ca^{2+}/Mg^{2+} ratio > 2 (Fig. 5a). The dissolution of carbonate minerals could be represented in the following reactions ((1) to (4)) in natural systems (Mukherjee et al., 2009; Kura et al. 2013):

$$CaCO_3(calcite) + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3^- \qquad (1)$$

$$CaMg(CO_3)_2(dolomite) + H_2CO_3 \rightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^- \quad (2)$$

$$CaCO_3 + H_2SO_4 \rightarrow Ca^{2+} + SO_4^{2-} + H_2CO_3 \qquad (3)$$

$$CaMg(CO_3)_2 + 2H_2SO_4 \rightarrow Ca^{2+} + Mg^{2+} + 2SO_4^{2-} + 2H_2CO_3 \quad (4)$$

Dissolution is a simple and common weathering reaction in carbonate rocks (Drever 1997). It is specified by the 1:2 ratio of Ca^{2+}/HCO_3^- and 1:1 equivalent ratio of $Ca^{2+} + Mg^{2+}/HCO_3^-$, in the groundwater. The lower value of $Ca^{2+} + Mg^{2+}/HCO_3^-$ indicates other sources of HCO_3^- such as

Fig. 4 Mechanisms governing
groundwater chemistry
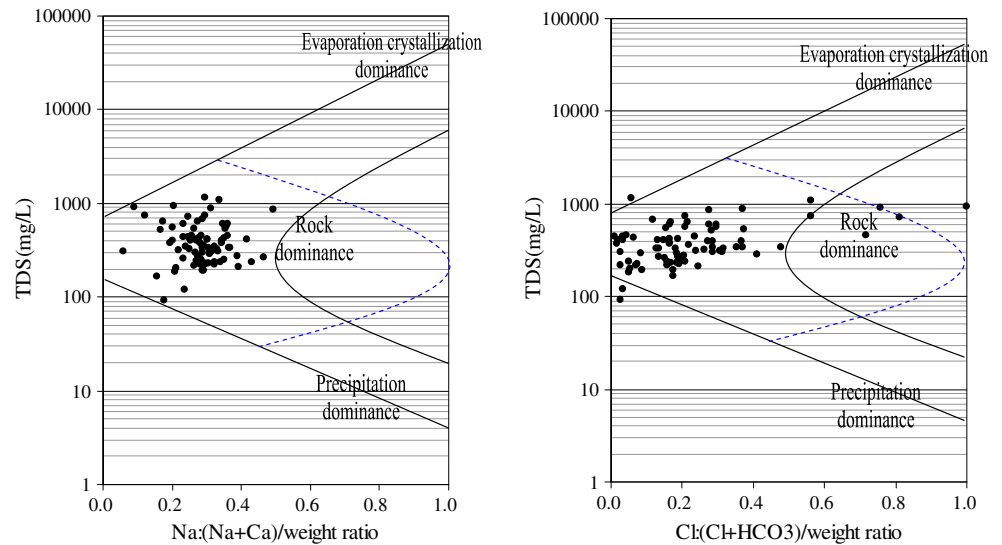
silicate weathering, and the higher ratio of $Ca^{2+} + Mg^{2+}$ to
HCO_3^- represents that the excess of $Ca^{2+} + Mg^{2+}$ has been
balanced by Cl^- and SO_4^{2-} in the study area. The plot of
$Ca^{2+} + Mg^{2+}$ versus $HCO_3^- + SO_4^{2-}$ will be near to 1:1 line
if Ca^{2+}, Mg^{2+}, SO_4^{2-}, and HCO_3^- are derived from the disso-
lution of carbonate, such as the minerals of calcite, dolomite,
and gypsum. The data points tend to shift to the right due to
excess of $HCO_3^- + SO_4^{2-}$ when ion exchange is the dominant

process, the ion exchange mechanism could be described by
following reaction:

$$\frac{1}{2}Ca - Clay_2 + Na^+ \rightarrow \frac{1}{2}Ca^{2+} + Na - \text{Clay} \qquad (5)$$
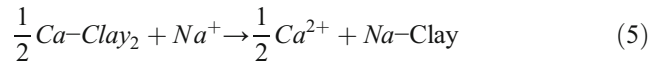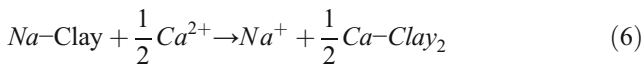
If the points were above the median line, a reverse ion
exchange was the active reaction for the excess of $Ca^{2+} +$

Fig. 5 Distribution of ionic ratios
for major groundwater ions from
the study area
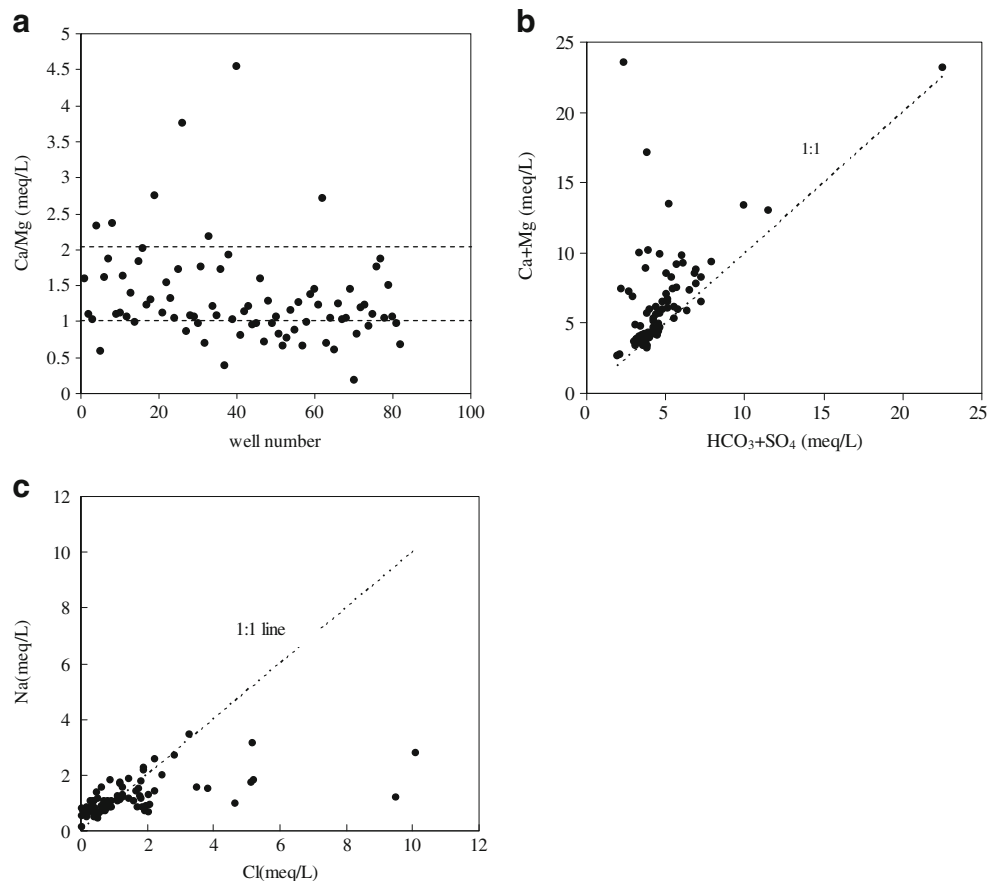
Mg^{2+} over $SO_4^{2-} + HCO_3^-$, which could be represented by the following reaction:

$$Na-\text{Clay} + \frac{1}{2}Ca^{2+} \rightarrow Na^+ + \frac{1}{2}Ca-\text{Clay}_2 \qquad (6)$$

Based on the plot, the majority of samples were scattered close to the 1:1 line, indicating that Ca^{2+}, Mg^{2+}, SO_4^{2-}, and HCO_3^- in the groundwater may be due to the dissolution of calcite, dolomite, and gypsum. Moreover, a considerable number of samples fall above the median line, indicating that reverse ion exchange tended to be the dominant reaction over ion exchange, which was responsible for the higher Ca^{2+} and Mg^{2+} concentration in the groundwater (Fig. 5b).

Halite is a dominant source of Na^+ and Cl^- in the groundwater; the molar ratio varies spatially as a result of the cation exchange (Wayland et al. 2003). The ratio of Na^+/Cl^- being equal to one indicated that halite dissolution could be responsible for the sodium and chloride concentration in the water samples. In most groundwater samples, the chemical data in a plot of Na^+ versus Cl^- fall around the uniline (Fig. 5c). This infers Na^+ and Cl^- are

mainly from the dissolution of halite. Chloride is a conservative component in the groundwater; therefore, a higher concentration of Cl^- versus Na^+ indicates the decency of Na^+ and the truth that groundwater samples with higher chloride concentration versus Na^+ also shows higher $Ca + Mg$ versus $HCO_3 + SO_4$. Thus, the reverse ion exchange was testified.

Quality criteria for drinking water supply and irrigation

Drinking water

In order to assess the suitability of groundwater for drinking water supply, the species chemistry concentration in groundwater samples could be compared with drinking-water quality standard (Ministry of Health of the People's Republic of China 2006).

The pH threshold limit ranges from 6.5 to 8.5 for drinking water (Fig. 6a), the water would affect the mucous membrane when the pH is beyond this limit (Rao

Fig. 6 Comparison of groundwater quality (pH, TDS, and total hardness) for drinking purpose with standard limit (*dash line*)
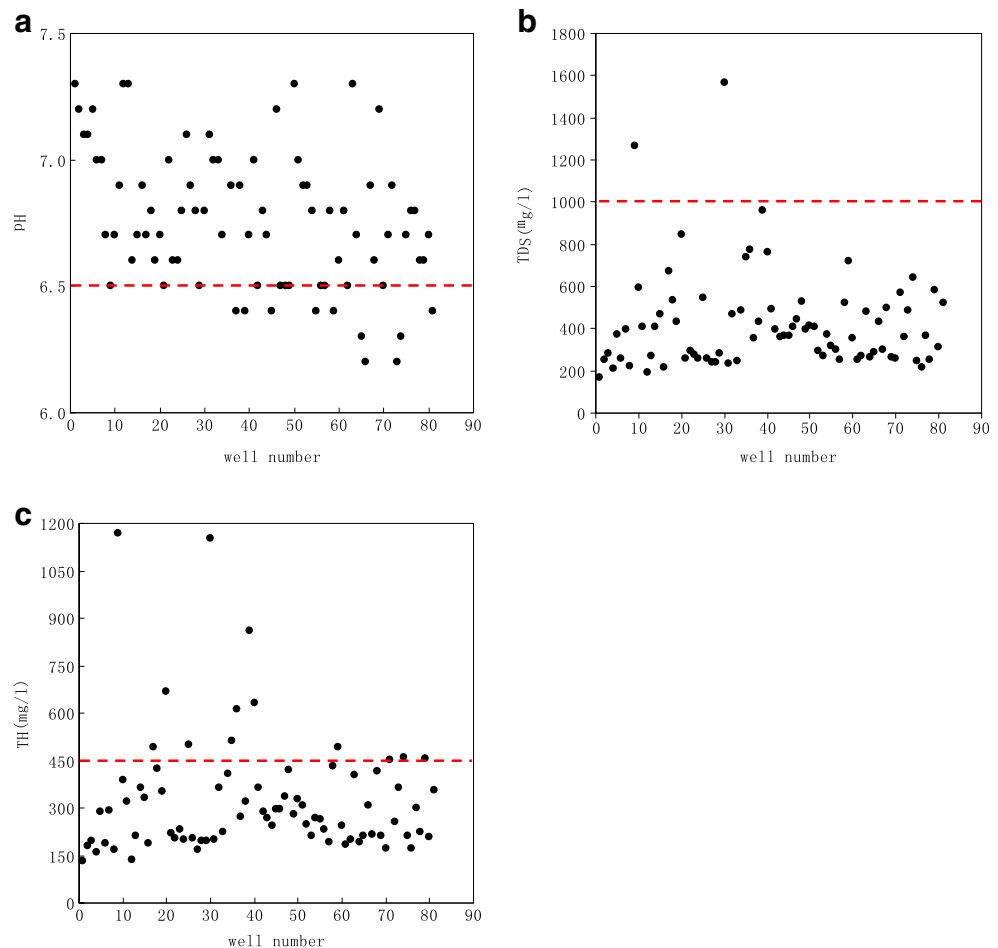
et al. 2012). The pH values of majority groundwater samples in Jilin City range from 7.6 to 8.5, which are not beyond the recommended pH limit, the groundwater samples are potable for drinking. The TDS concentration in all groundwater samples in Jilin City ranges from 91 to 1140 mg/L, which is lower than that of threshold limit in drinking water (1000 mg/L) (Fig. 6b), the groundwater samples are potable for drinking. The threshold limit of total hardness for drinking water is 450 mg/L (Ministry of Health of the People's Republic of China 2006). Accordingly, the groundwater in 16 % of the total water samples is not suitable for drinking (Fig. 6c). The higher concentration of total hardness in potable water causes to develop gall bladders, urinary stones, and arthritis (Garg et al. 2009).

The prescribed limit of Ca^{2+} for drinking water is 75 mg/L, and about 37 % groundwater samples from the study area exceed the safe limit with reference to Ca^{2+} (Fig. 7a). The Mg^{2+} (12–134 mg/L), in excess of the permissible limit of 30 mg/L allowed for drinking water, has led groundwater sample to become unsuitable in 48 % of the total groundwater samples (Fig. 7b). None of the groundwater samples exceeds this limit so that the water is potable (Fig. 7c). Potassium is essential to maintain the

fluid in balance stage in the body. Generally, it is less than 10 mg/L in water. In the study area, it is more than 10 mg/L in approximately 11 % of the groundwater samples (Fig. 7d).

The chemical data of the study area show that the concentration of HCO_3^- (43–680 mg/L) exceeds the desirable limit of 300 mg/L in 11 % of the groundwater samples (Fig. 8a). The allowed limit of Cl^- for drinking water is 250 mg/L (Fig. 8b). The groundwater samples observed from the study area show Cl^- from 2 to 359 mg/L, and only two samples encountered a higher chloride concentration than the safe limit. The groundwater samples of the study area show SO_4^{2-} from 10 to 922 mg/L, and the majority are below the recommended limit of SO_4^{2-} for drinking water except two samples (Fig. 8c).

The data show that 30 % samples have a higher concentration than the desirable limit, which means NO_3^- in the groundwater may cause a severe health threat to the local residents (Fig. 9a). The safe limit of F^- from 0.5 to 1.0 mg/L is essential for normal growth of bones, in potable water. Less than 0.6 mg/L of F^- causes dental caries, while more than 1.0 of F^- results in fluorosis. The groundwater in the

Fig. 7 Comparison of groundwater quality (Ca^{2+}, Mg^{2+}, Na^+, and K^+) for drinking purpose with standard limit (dash line)
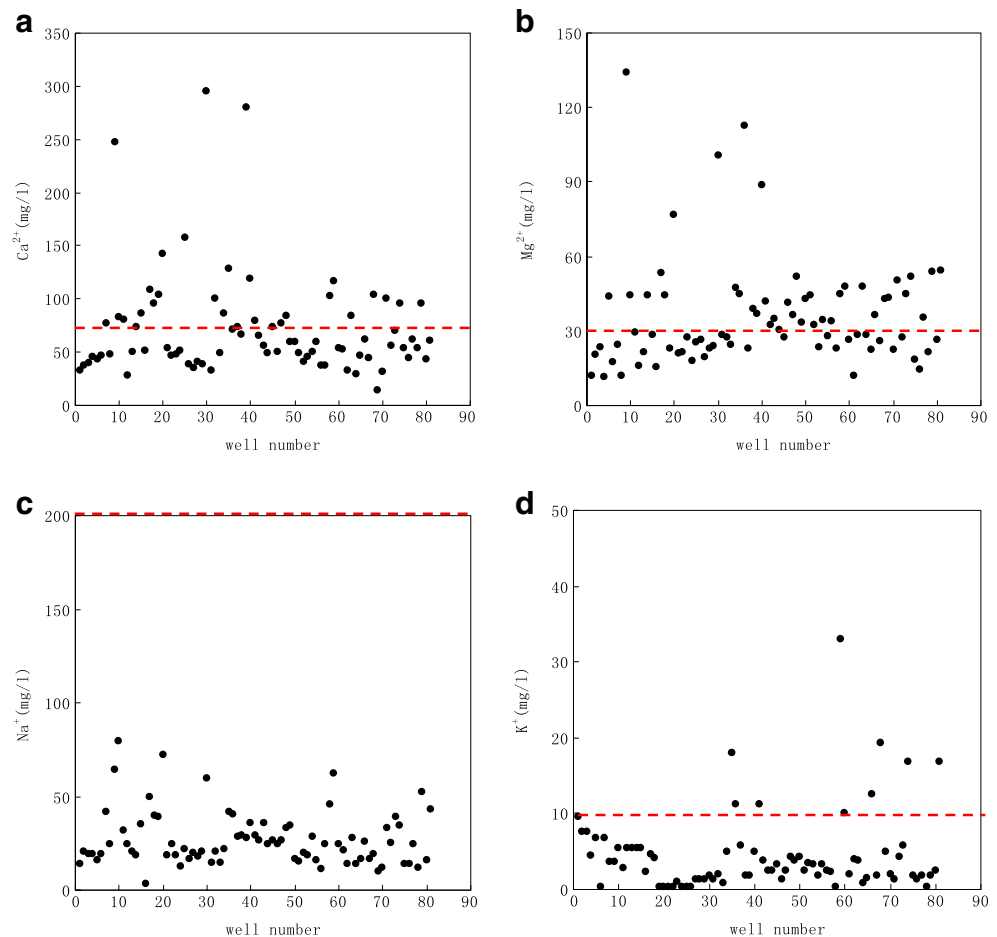
Fig. 8 Comparison of groundwater quality (HCO_3^-, Cl^-, and SO_4^{2-}) drinking purpose with standard limit (*dash line*)
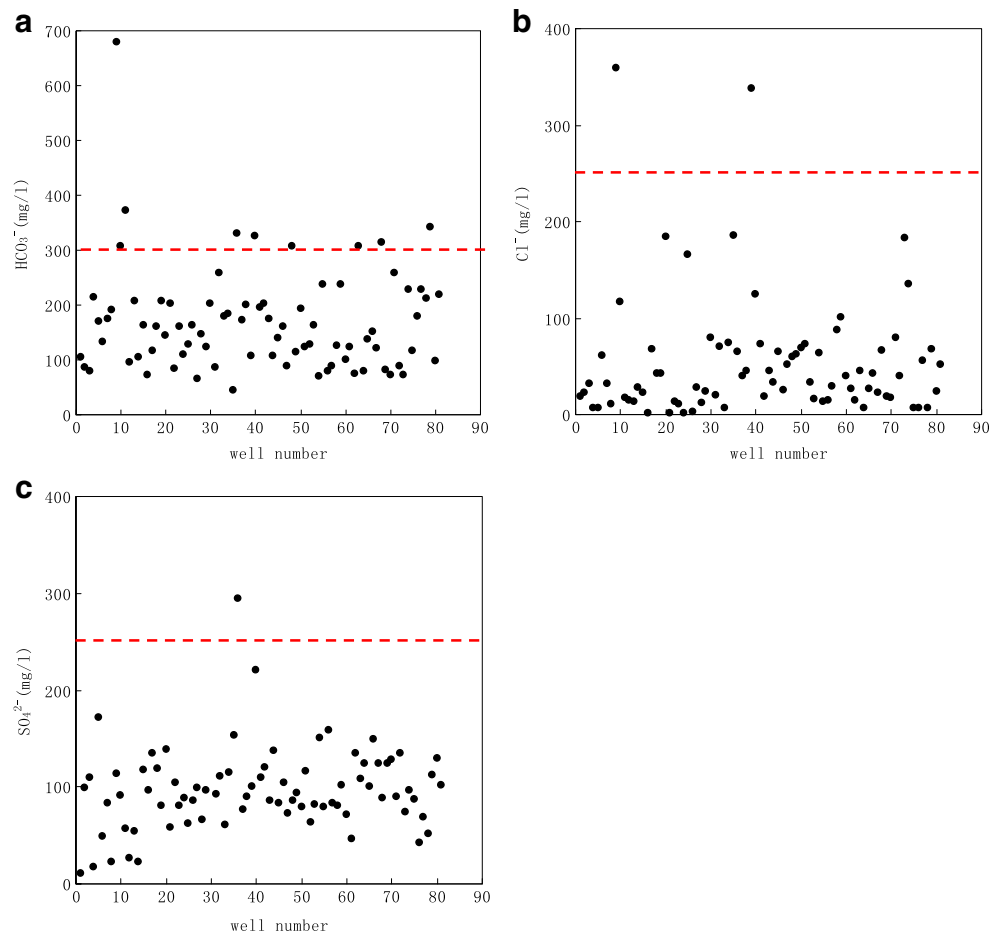
study area has the concentration of F^- ranging from 0.1 to 1.6 mg/L. About 74 % of the samples have a lower fluoride concentration than 0.5 mg/L, and the rest are within the desirable limit. The deficiency of fluoride may be the result from the formation of F^--bearing minerals due to the presence of rich Ca^{2+} in the groundwater. Fe is an important element for human's health, but if it exceeds the limit in groundwater, some fatal diseases would occur (WHO 2011). The safe limit of iron is 0.3 mg/L, 43 % samples have a higher iron concentration than the safe limit. Thus, the residents in the study area face the threat of excess iron in drinking water.

Groundwater quality for irrigation purposes

Groundwater is the main irrigation water sources in Jilin City, and the groundwater quality assessment for irrigation could be useful in the future regional water resource management. Different parameters have been used to assess the suitability of groundwater for irrigation, such as sodium adsorption ratio (SAR), Kelly's ratio (KR), sodium percent (Na%), permeability index (PI), and magnesium hazard (MH).

SAR has been used to assess the suitability of groundwater for irrigation (Rao 2006; Rao et al. 2012). The calculated SAR values have been shown in Table 3. From the table, it could be seen that the values of SAR in the study area range from about 0.1 to 1.8, and there is no well with SAR value that exceeds 26, which indicate that the irrigation with these groundwater could not induce high sodium hazard. According to the calculation results of SAR, it could be seen that the groundwater in Jilin City could be used for regional irrigation.

The KR values also could be seen in Table 3; from the table, it could be seen that the KR values of groundwater samples in Jilin City range from 0.04 to 0.44, which indicate that none of the groundwater samples is unsuitable for irrigation, the results match with that of SAR.

The Na% calculated results could be seen in Table 3; from the table, it could be seen that the Na% ranges from 5 to 32 %, all the results are less than 60 % (threshold limit), which mean that all groundwater samples are suitable for irrigation in Jilin City. According to the calculated MH values, 93 % sample classifies to be in safe category and the remaining samples show groundwater moderate suitability for irrigation.

Fig. 9 Comparison of groundwater quality (NO_3^-, F^-, Fe) for drinking purpose with standard limit (*dash line*)
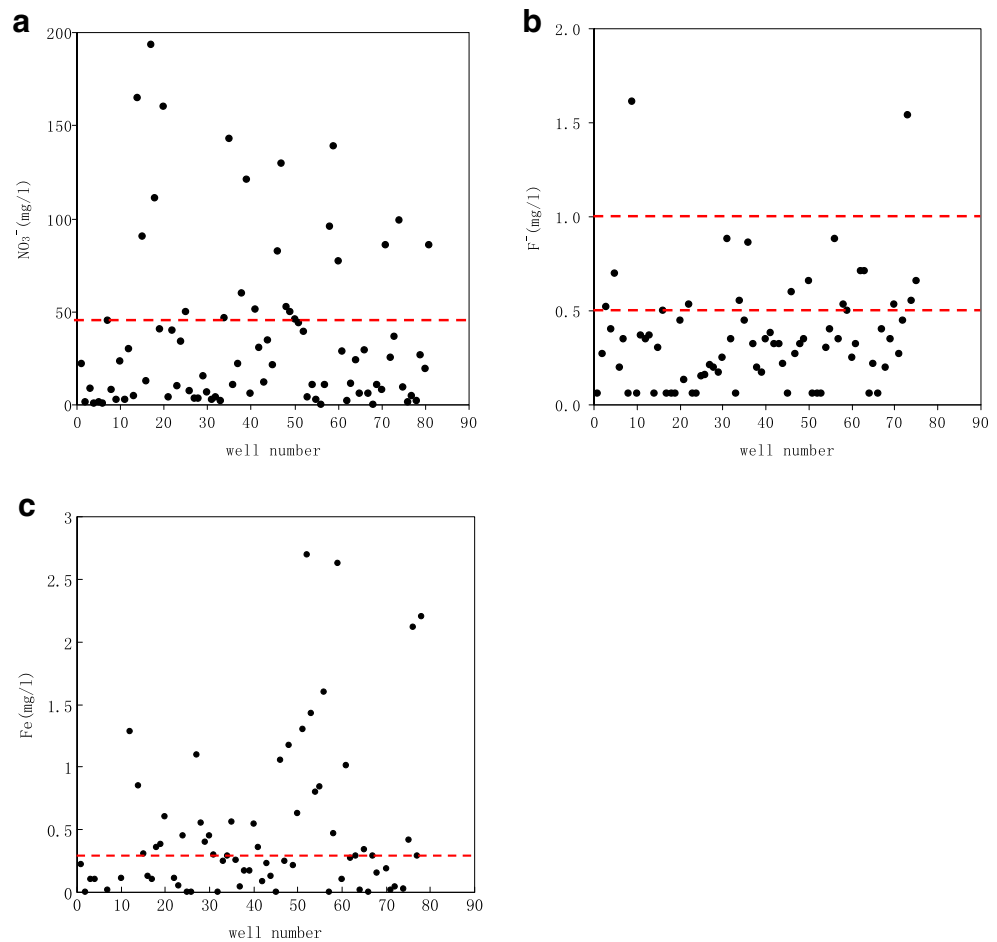
Conclusion

From the discussion, we can see that the distribution of major ions in the groundwater is as follows: $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ and $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-$; the Piper's, Gibbs's, and Langelier–Ludwig's diagrams suggest that groundwater was evolved due to the water–rock interaction; geochemical relations (Ca/Mg ratio, Ca + Mg versus HCO_3 + SO_4, Na versus Cl) suggest that the dissolution of carbonate minerals gypsum and halite is the significant mechanism dominating the groundwater chemistry, the relations also suggest that the ion exchange is the secondary processes for higher concentrations of Ca^{2+} and Mg^{2+} ions; according to the drinking-water quality standards, the groundwater is not suitable for drinking with reference to the concentrations of total hardness, Ca^{2+}, Mg^{2+}, NO_3^-, F^- and Fe in many locations; based on the parameters mentioned (sodium adsorption ratio, Kelly's ratio, sodium percent, permeability index, and magnesium hazard), all the groundwater samples fall into the classification of suitable irrigation.

Table 3 Classification of groundwater for irrigation use

Parameters	Range	Water class	Number of samples
Alkalinity hazard (SAR)	<10	Excellent	281
	10–18	Good	–
	18–26	Doubtful	–
	>26	Unsuitable	–
Kelley's ratio	<1	Safe	281
	>1	Unsafe	–
Na%	<20	Excellent	262
	20–40	Good	19
	40–60	Permissible	–
	60–80	Doubtful	–
	>80	Unsuitable	–
Permeability index	>75	Safe	–
	75–25	Marginally safe	276
	<25	Unsafe	5
RSC	<1.25	Good	281
	1.25–2.5	Doubtful	–
	>2.5	Unsuitable	–
Residual Mg/Ca ratio	<1.5	Safe	275
	1.5–3.0	Moderate	6
	>3.0	Unsafe	–

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