Groundwater quality for drinking and irrigation purpose in a loess aquifer Northwestern China: a case study in Liquan loess tableland

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Abstract. Knowledge of groundwater quality is a crucial issue for the scientific and sustainable exploitation of the groundwater resources in loess aquifer, northwest of China. In this study, analysis of water quality for drinking and irrigation were proceeded in a loess aquifer. Based on the analysis of 52 groundwater samples, the groundwater is characterized by high sodium, with 54\% samples have sodium exceed WHO limit, observed in the central of loess tableland where the water table is shallow. EC, SAR, and SSR indices are used to appraise the water quality for irrigation. The results showed groundwater can pose high risks of salinity and medium sodium hazard, without any measures and management.

1. Introduction

Groundwater is a crucial resource for the development of society and economy in arid and semiarid regions characterized by scarce precipitation and runoff [1]. The physical and chemical reactions between water and aquifer media generally dominate the groundwater chemistry compositions. Hydrogeochemical characterization of groundwater has been a hot topic in the past decades due to the increasingly awareness of groundwater protection [2-3].

The spatial distribution and relationships of chemical composition of groundwater, where the aquifer geology could play a dominant role, reveal the genesis and characteristics of groundwater [4]. Mutual interactions between water and rock prompt the variations of composition in groundwater. Hydrogeochemistry is a pervasive approach to analyze the origin and features of chemical composition of groundwater in many countries [5-11], such as China, India, USA, Italy, Iran, Canada, Ireland, Mexico. Similar researches were conducted by plenty of scholars to solve various water problems, Tossou et al have used geochemical approaches to identify the hydrogeochemical processes and the high fluoride problems in a drinking water source [12]. Martinez et al have analyzed the impact of a landfill on the groundwater quality in Quaternary loess like sediments by analyzing the mineralogical composition of the aquifer sediments and characterizing the hydrogeochemical processes [13]. Sun et al have identified potential sources of groundwater salinity which is a major concern in the arid inland basin northwest China using isotopic and geochemical analyses [14]. The description of temporal and spatial variation of ions is the first perception of groundwater chemistry.
by means of multivariate statistics, such as cluster analysis, principal component analysis, and graphic representation, such as contours of ion concentration, scatter plots. Afterwards, researchers strive to elucidate the hydrogeochemical processes of groundwater. Geographical setting, relations between groundwater with other waterbody and anthropogenic activities are the significant factors controlling the groundwater chemistry. Mineralogy, hydrogeochemical modeling, analysis of ion ratios, isotopic analysis are the efficient approaches to identify the controlling mechanisms.

In the Loess Plateau, northwest of China, there are many loess tablelands of different sizes, known as “arid tableland”. For a long time, because of the shortage of water, economic development in these arid loess tablelands is slow and most of the areas are in a poverty and backward state. The dilemma was not relieved until a series of irrigation districts were established gradually since the 1930s. Groundwater is the crucial irrigation water resource for the agriculture in the loess areas [15]. Due to climate change and the decrease of surface water runoff, groundwater is inevitably faced with substantial exploitation. Nowadays, loess areas in northwestern China are facing multiple pressures from environment, economy, and population. Rapid society development necessitates increasing groundwater exploitation, which induces water quality and quantity problems. However, because of the desire for rapid economic development, little attention has been paid to the environment. Furthermore, the water table is far below the surface in this area, groundwater quality problems are unobservable because of the lack of concerns from government and the public.

Some investigations have been performed in Guanzhong basin, which were largely relate to the hydrogeochemical features of fluorine, arsenic and iodine in local and regional scales [16]. However, no recent studies have been carried out in Liquan loess tableland. As groundwater is the main source for drinking and irrigation water, the quality of groundwater is significant for the sustainable development of local area [17]. Therefore, the present study aims (1) to delineate the water quality characteristics of groundwater for drinking purpose and (2) assess the water quality of groundwater for irrigation purpose. The study will be meaningful for local decision makers to make sound decisions for groundwater quality protection in this water-shortage stricken area and to facilitate its sustainable economic development.

2. Materials and methods

2.1. Study area
This study was conducted in Liquan loess tableland with an area of approximate 1700km², northwest of Xi’an City, China (Figure 1). This area is a significant part of the Belt and Road initiative proposed by China and is therefore attracting much attention from researchers. This region has temperate monsoon climate characterized by high-temperature rainy summer and a cold dry winter. The climate is semi-arid with average annual precipitation ranges from 517mm to 596mm, in addition the 51% of the total rainfall occurs in July to September. The average evaporation rate is 1110mm, nearly twice of precipitation that makes the deficit of water demand. Therefore, due to the scarce and unevenly distribution of water resources, it is essential to use the water resources efficiently in this area.

The study area is located in the south edge of Loess Plateau of China, north of Wei river, between Qishui river and Jing river. The terrain is gradually decrease in height southeastwards from about 700m near the upstream of Qishui River to 400m. The landform is pluvial fan with gentle slope in the piedmont of Bei hilly area, then towards south, is expansive and flat loess tableland with depressions at the central area. Sediments of Quaternary are well developed in this region with the thickness of 300m to 400m. Lithologically, the quaternary sediments are divided into two types, coarse-grain sediments consisted of gravel and loess sediments. The former is formed by alluvial, pluvial and lacustrine actions in the early and middle Pleistocene varied with landforms. The loess sediments are formed by aeolian accumulation from middle Pleistocene to Holocene.
2.2. Data collecting
The groundwater sampling was conducted by the First Hydrogeological Team of Shaanxi Institute of Geological Survey (SIGS). The collecting and analyzing procedures followed the groundwater quality test method (DZ T 0064.1~0064.80-93) promulgated by Ministry of Geology and Mineral Resources of P.R. China. The fifty-two samples were all collected from pumping wells. Before collecting, at least three times of the water holding in the tube should be pumped from the well. The polyethylene sampling bottles were pre-cleaned by the water to be sampled then filled with 1000 mL samples without any contamination. All bottles were sealed by wax and labeled with number, sampling date, and water type. PH, total dissolved solid (TDS), were measured in situ with portable meter. Na⁺, Ca²⁺, Mg²⁺, Cl⁻, HCO₃⁻, SO₄²⁻, total hardness(TH) were analyzed in laboratory of SIGS within 10 days. Ca²⁺, Mg²⁺, Cl⁻, HCO₃⁻, TH were measured by titration method, Cl⁻, SO₄²⁻ were measured by ion chromatography method.

3. Results and discussion

3.1. Groundwater quality for drinking purpose
From the summary statistics of measured parameters of groundwater samples (table 1), groundwater pH values vary from 7.1 to 8.2, indicating neutral to slightly alkaline water over the study area. The TDS values range from 340.88 to 1394.98 mg/L with an average of 752.05 mg/L, indicating this area is mainly freshwater. Nine samples have TDS >1000 mg/L which were observed in the central low-lying land, suggesting low-lying land may form saline water. Sodium and Magnesium are the dominate cation in groundwater which range from 79.72 to 412.85mg/L, 13.98 to 103.33 mg/L respectively. Twenty-eight samples have Na⁺ exceed the limit of WHO [18], maybe suggesting intense ion exchange. The concentrations of Ca²⁺ vary from 9.02 to 52.10mg/L with an average of 24.09 mg/L. Bicarbonate is the dominate anion which ranges from 265.43 to 854.24mg/L with an average of 556.53 mg/L. The concentrations of Cl⁻ vary from 10.64 to 264.83 mg/L. Except one sample, all the other samples are within the Na⁺ limit of WHO. The concentrations of SO₄²⁻ vary from 11.53 to 622.00mg/L. The SO₄²⁻ enrichment is significant with the maximum value is 2.5 times the WHO limit.

3.2. Groundwater quality for irrigation purpose
The total concentration and components of dissolved salts should be taken into consideration when appraising the groundwater quality for irrigation. In this study, the total concentration is expressed in total dissolved solid, and the exchangeable sodium is largely considered among the dissolved salts.
Table 1. Summary statistics of measured parameters of groundwater samples\(^a\) and the number of samples beyond the desirable limits.

| Parameter | Ca\(^{2+}\) | Mg\(^{2+}\) | Na\(^+\) | Cl\(^-\) | HCO\(_3\)\(^-\) | SO\(_4\)\(^{2-}\) | pH | TDS |
|-----------|------------|------------|----------|--------|-------------|--------------|----|-----|
| Sample Num | 52         | 52         | 52       | 52     | 52          | 52           |     | 52  |
| Min       | 9.02       | 13.98      | 79.12    | 10.64  | 265.43      | 11.53        | 7.10| 340.88 |
| Max       | 52.10      | 103.33     | 368.00   | 264.83 | 854.24      | 622.00       | 8.20| 1394.98 |
| Average   | 24.13      | 44.32      | 203.53   | 68.81  | 553.35      | 123.59       | 7.57| 741.05 |
| Median    | 22.55      | 39.51      | 208.04   | 51.94  | 572.34      | 82.61        | 7.55| 690.20 |
| St. Dev.  | 9.81       | 22.60      | 67.19    | 52.22  | 113.42      | 130.14       | 0.24| 250.28 |

| National standard (GB5749-2006) | - | - | 200 | 250 | - | 250 | 6.5-8.5 | 1000 |

| WHO | - | - | 200 | 250 | - | 250 | 6.5-8.5 | 1000 |

| No. of samples beyond desirable limit (of 52) | - | - | 28 | 1 | - | 7 | - | 9 |

U.S. Salinity Laboratory (1954) proposed the classification standard of groundwater quality for irrigation based on electrical conductivity [19]. Water can be classified into four grades (Table 2). In this study, only TDS values of samples were analyzed. An approximate linear relation with the slope of 0.55 was used to get the EC values. The low salinity water for irrigation with an EC of 100-250 \(\mu\)s/cm, which is equivalent to TDS of 200mg/L, is suitable for all kinds of crops, and there is no salt accumulation in soil. The medium salinity water has an EC of 250-750 \(\mu\)s/cm, which is equivalent to TDS of 200-500mg/L. This kind of water is permissible in the case of the salts can be removed via leaching. The high salinity water has an EC of 750-2250 \(\mu\)s/cm, which is equivalent to TDS of 500-1500mg/L. Well drainage system is needed if this water used to irrigate. When the EC exceed 2250 \(\mu\)s/cm, the salinity of water is too high to irrigate.

Excess sodium impedes the formation of soil granular structure, resulting in poor permeability and surface crusting in the soil. Sodium adsorption ratio (SAR) is a widely used index to measure soil sodium hazard. The calculation formula for SAR is given below, which concentrations expressed in meq/L. Water are classified into four zones with respect to SAR (Table 2).

\[
SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}
\]

The EC and SAR values of groundwater samples are plotted in Figure 2 to show the integrate effect of salinity hazard and sodium hazard. As the figure 2 shown, 92% samples have the EC less than 2250 \(\mu\)s/cm, 94% samples have the SAR less than 10. The groundwater samples almost fall under C3-S1 and C3-S2 zones, indicating that groundwater can pose high risks of salinity and medium sodium hazard, without any measures and management.

Table 2. Classification of water quality for irrigation.

| EC    | SAR  | Water quality |
|-------|------|---------------|
| 100-250 | <10  | Good          |
| 250-750 | 10-18 | Permissible   |
| 750-2250 | 18-26 | Doubtful      |
| >2250  | >26  | Unsuitable    |
Soluble sodium percentage (SSP) is also called percent sodium or sodium percentage, which is calculated by the following equation.

$$SSP = \left( \frac{Na^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \right) \times 100$$ (2)

Water is classified into five grades, using two indices, electrical conductivity and SSP. As figure 3 shown, 66% samples belong to permissible-level, suggesting the groundwater has high sodium percentage with high salinity. 11% samples are doubtful for irrigation due to the high salinity.
4. Conclusions
The analysis of major ions demonstrates the characteristics of groundwater quality and the assessment of water quality for irrigation provides a summary overview of the applicability of groundwater. Major results can be reached as follows:

1) The groundwater in this area is characterized by high sodium contents, with 54% of samples having sodium contents that exceed the limit of WHO; the high sodium samples are observed in the central of loess tableland where the water table is shallow.

2) The EC, SAR, and SSR indices are used to appraise the water quality for irrigation. Based on SAR, samples mainly belong to C3-S2 (58%) and C3-S1(33%). Based on SSR, 66% samples belong to permissible water. The above assessment indicates a high salinity and medium sodium hazard could be produced on soil without special measures and management exist. Further studies on the effect of special remedial measures and management practices would be more comprehensive.

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