Spatial distribution characteristics of irrigation water quality assessment in the Central-Western Guanzhong Basin, China

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Abstract. Groundwater plays an important role for agricultural irrigation in the Guanzhong Basin. In order to investigate its spatial distribution characteristics of groundwater suitability for irrigation in the central-western Guanzhong Basin, total 97 groundwater samples were collected and analysed. Four indicators, including sodium percentage (Na%), residual sodium carbonate (RSC), magnesium hazard (MH), and potential salinity (PS), were selected to evaluate the groundwater for irrigation use. The results show that the groundwater in the southern and western areas is more suitable for irrigation than that in the northern and central areas of the basin. Besides, the consistent evaluation results are obtained based on these four indicators, which indicates that they are applicable for the assessment of groundwater irrigation use in study area. Furthermore, the findings of this study would provide guidance for spatial management decision of irrigation groundwater in the central-western Guanzhong Basin.

1. Introduction
Groundwater is important for domestic drinking, industrial production, and agricultural irrigation all over the world, especially in arid and semi-arid regions [1-4]. China is facing water crisis, especially in the rural areas [3, 5]. Improper operation of groundwater resources would not only cause the shortage of water resources, but also lead to the changes in water quality [6]. The quality of groundwater has been regarded as a decisive factor for a country’s sustainable development [7]. The security of irrigation water depends on groundwater resources to a large extent [8].

Guanzhong Basin has been supporting important agriculture since the Qin Dynasty [9-10], and has multiple irrigation areas, such as Jiaokou Irrigation Area, Baojixia Irrigation Area, and Jinghuiqu Irrigation Area [11-13]. Long-term irrigation could result in the rise of groundwater level, the salt accumulation of groundwater, and the increase in nitrogen content of groundwater, hence, groundwater quality would be deteriorated [11, 14]. Excessive dissolved ions in water will affect soil properties and prevent plants from absorbing water [6, 8]. It can be seen that groundwater quality is important for crop growth. Irrigation water quality can be evaluated by various indexes [6, 8, 12, 15-17]. However, different areas have different geological and geomorphic conditions, and water conservancy and irrigation projects, resulting in the regional distribution of groundwater quality [17]. Therefore, the aim of the study is to investigate the spatial distribution characteristics of groundwater suitability for irrigation in the central-western Guanzhong Basin. These findings can provide...
information for policy-makers to achieve the sustainable development of groundwater agricultural irrigation.

2. Study area
The Guanzhong Basin (106°30' ~ 110°30'E, 33°00' ~ 35°20'N) is located in the center of Shaanxi province, China, covering an area of 2×10^4 km^2 (Figure 1) [18-19]. The basin has an average elevation is approximately 400 m [20]. Wei River traverses the Guanzhong Basin from west to East, with the total length of 818 km (Figure 1), and is the major surface water source in the basin [18]. The hydrographic net on the south bank of Wei River is more developed than that on the north bank, due to the abundant precipitation in the Qinling Mountains piedmont [8]. The study area is characterized by warm temperate semi-humid continental monsoon climate, with the average annual temperature and precipitation of 13.7 °C and 569.6 mm, respectively [9, 18, 20].

3. Sampling and assessment methods

3.1. Sample Collection and Analysis
Totally, 97 groundwater samples were collected in the Guanzhong Basin. The sampling sites are presented in Figure 1. The pH and TDS of groundwater samples were measured using portable device in the field. The contents of anions (HCO_3^-, SO_4^{2-}, Cl^-) and cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) were determined by laboratory methods, which were described in the reference of [8]. Based on the analysis of ion concentrations, the charge balance error (CBE) was calculated for each sample using formula (1) [16]:

\[
CBE = \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \times 100\%
\]

where the unit of cations and anions was in meq/L. The values of CBE are within the range of ± 5%, which are considered acceptable [21]. In this study, the CBE values ranged between -2.43 and 4.54, indicating the reliability of the analysis results of ion contents.

Figure 1. Map of Guanzhong Basin and sampling sites: compiled from [8].
3.2. Evaluation index of irrigation water quality

In this study, four indicators, including sodium percentage (Na%), residual sodium carbonate (RSC), magnesium hazard (MH), and potential salinity (PS), were selected to evaluate the groundwater for irrigation purposes. These indicators were obtained using the following formulas [8]:

\[
\text{Na\%} = \frac{(\text{Na}^+ + \text{K}^+) \times 100}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+} \quad (2)
\]

\[
\text{RSC} = \left(\text{CO}_3^{2-} + \text{HCO}_3^-\right) - \left(\text{Ca}^{2+} + \text{Mg}^{2+}\right) \quad (3)
\]

\[
\text{MH} = \frac{\text{Mg}^{2+}}{\text{Ca}^{2+} + \text{Mg}^{2+}} \times 100 \quad (4)
\]

\[
\text{PS} = \text{Cl}^- + \frac{1}{2} \text{SO}_4^{2-} \quad (5)
\]

where all the ionic concentrations used in the above formulas were expressed in meq/L. Based on these indicators, the classifications of groundwater quality for irrigation were presented in Table 1.

| Indicator | Unit | Range | Water quality |
|-----------|------|-------|---------------|
| Na%       | %    | <20   | Excellent     |
|           |      | 20-40 | Good          |
|           |      | 40-60 | Permissible   |
|           |      | 60-80 | Doubtful      |
|           |      | >80   | Unsuitable    |
| RSC       | meq/L| <1.25 | Good          |
|           |      | 1.25-2.50 | Doubtful |
|           |      | >2.50 | Unsuitable    |
| MH        | %    | <50   | Suitable      |
|           |      | >50   | Unsuitable    |
| PS        | meq/L| <3.0  | Excellent to good |
|           |      | 3.0-5.0 | Good to injurious |
|           |      | >5.0  | Injurious to unsatisfactory |

4. Results and discussion

4.1. Chemical Parameters

The statistical characteristics of chemical parameters of groundwater samples are presented in Table 2. From Table 2, it can be seen that the pH values ranged between 7.0 and 8.3, with a mean of 7.7, indicating the groundwater were weak alkaline on the whole. TDS was in a wide range of 140-1324.2 mg/L, and has a mean of 473.5 mg/L. Combined with the statistical characteristics of anions and cations, they also had wide ranges of concentrations. The chemical characteristics of groundwater are different in spatial distribution, that is, the suitability of groundwater for irrigation also has spatial variability.

| Parameters | pH | TDS (mg/L) | K⁺+Na⁺ (mg/L) | Ca²⁺ (mg/L) | Mg²⁺ (mg/L) | Cl⁻ (mg/L) | SO₄²⁻ (mg/L) | HCO₃⁻ (mg/L) |
|------------|----|------------|---------------|-------------|-------------|------------|--------------|--------------|
| Maximum    | 8.3| 1324.2     | 412.9         | 125.5       | 86.2        | 400.6      | 416.9        | 742.0        |
| Minimum    | 7.0| 140.0      | 3.9           | 10.0        | 2.1         | 2.5        | 2.2          | 121.4        |
| Mean       | 7.7| 473.5      | 98.8          | 47.2        | 26.6        | 38.4       | 52.9         | 396.9        |
4.2. Groundwater Suitability for Irrigation

Na% is a parameter of the sodium harm and determines the aeration and infiltration of soil [8, 17]. If the value is too high, the soil structure would be destroyed, and the irrigation effect could be affected. From Table 3, Na% ranges from 3.7 to 83.8, with a mean of 41.2, indicating that the average level of irrigation water quality is permissible. Figure 2(a) shows spatial distribution of Na%. It can be found that Na% increased from south to north, which revealed the applicability of irrigation water was weakened. This may be due to that the precipitation in the northern Guanzhong Basin is relatively small, and the evaporation is strong, resulting in the enrichment of Na⁺.

RSC is an indicator for examining the suitability of irrigation water. The water with high RSC easily results in high pH, and soil irrigated with such water would become infertile because of deposition of sodium carbonate [22]. From Table 3, RSC has a range between -6.9 and 9.3, with mean of 1.9, indicating that the average level of irrigation water quality is doubtful. In figure 2(b), the spatial distribution of RSC basically presents a growth trend of RSC from south to north in the basin. Combined with figure 1, it can be inferred that the loess plateau are rich in calcite and dolomite, which are the source of carbonate and bicarbonate. In addition, clay minerals are widely distributed in loess, and the reduction of Ca²⁺ and Mg²⁺ is closely related to cation exchange [14]. Therefore, the groundwater in the northern basin has high RSC, which is mainly classified as doubtful and unsuitable water types.

MH is an important index in evaluating the water quality for irrigation [6, 22]. Generally, more Mg²⁺ in water would results in the soils become more alkaline [22]. It can reduce the permeability, and thus adversely affect crop yields [8, 22-23]. MH has a range of 15.8-80.2, with an average of 48.8 (Table 3). This indicates overall irrigation water quality level is suitable, but it is significantly affected by the regional distribution of groundwater. Figure 2(c) presents spatial distribution of MH of the study area. From figure 2(c), high MH makes groundwater unsuitable for agriculture in northern basin. And the more suitable quality of groundwater for irrigation occurs in the west, rather than in the central basin.

PS, which is established by the relationship between sulfate and chloride, also can evaluate the irrigation water quality [6, 8]. PS ranges between 0.1 and 12.2, and its mean is 1.6. This indicates that the average irrigation level of groundwater is excellent to good type. From figure 2(d), it is found that the groundwater in the whole basin is basically classified as excellent to good type, except for several small areas in the northern basin where the good to injurious and the injurious to unsatisfactory types of groundwater can be seen. This parameter also indicates the more suitable quality of groundwater for irrigation in the southern basin.

Table 3. Statistical characteristics of evaluation indices of irrigation water quality

| Indices | Na% (%) | RSC (meq/L) | MH (%) | PS (mea/L) |
|---------|---------|-------------|--------|------------|
| Maximum | 83.8    | 9.3         | 80.2   | 12.2       |
| Minimum | 3.7     | -6.9        | 15.8   | 0.1        |
| Mean    | 41.2    | 1.9         | 48.8   | 1.6        |
5. Conclusions
The aim of this study is to investigate the spatial distribution characteristics of groundwater suitability for irrigation in the central-western Guanzhong Basin. Total 97 samples were collected, and the major cations and anions were analysed. Na%, RSC, MH, and PS, were selected to evaluate the groundwater for irrigation use. The main conclusions can be drawn as follows:

The spatial variation of chemical characteristics of groundwater leads to the spatial variability of irrigation water quality. In general, the groundwater in the south of Guanzhong Basin is more suitable for irrigation, and the groundwater in the west area is more suitable than that in the central area. In addition, the evaluation results of the four indicators are consistent, suggesting that they are applicable to the evaluation of groundwater irrigation use in this area. These findings would provide guidance for spatial management decision of irrigation groundwater in the central-western Guanzhong Basin.

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