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Groundwater Suitability for Drinking and Agricultural Usage in Yinchuan Area, China

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ABSTRACT

On the purpose of assessing the degree of ionic toxicity of groundwater sources as irrigation and drinking purposes, groundwater samples were collected and analyzed for various elements of major cations and anions such as Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-} CO_3^{2-} and other minor ions Fe, NH_4-N, NO_2-N, NO_3-N, As, Gr^{6+}, Cd, Hg, $I^-$and F^- as well as such important chemical parameters as Total Dissolved Solid (TDS), Total Hardness (TH), pH, COD and odor. The TDS, Sodium Adsorption Ratio (SAR), Soluble Sodium Percent (SSP) and Residual Sodium Carbonate (RSC) were used for irrigation suitability assessment. The results show that the groundwater in the study area is not entirely fit for direct drinking with respect to TDS, TH, Fe, F^-, Cl^- and SO_4^{2-}. In some of the samples collected, the concentrations of these constituents exceed the permissible limits of the Standards for Drinking Water Quality of China. Based on TDS, 75% of water samples are suitable for drinking and 80% of samples are fit for drinking based on TH. Heavy metals such as As, Gr^{6+}, Hg and Cd are well below the permissible limits. Based on TDS, SAR and RSC, all the samples are suitable for irrigation, whereas, based on SSP, S17 and S31 are unsuitable for irrigation. However, S17 and S31 can be still used for irrigation if they are mixed with other samples, and therefore all the samples are classified into suitable group for agricultural irrigation.

Key words: groundwater quality, hydrochemical parameter, groundwater quality assessment, Yinchuan area

1. Introduction

Groundwater is an important source of freshwater for agricultural, drinking and domestic uses in many regions of the world (Balachandar et al. 2010). In China, groundwater is used to irrigate more than 40% of China's farmland and for about 70% of the drinking water in the dry northern and northwestern regions (Qiu 2010). In recent years, because of climate change and government regulation, the surface water available for drinking and irrigation is decreasing in Yinchuan area, and hence, groundwater is becoming more and more important for human and agriculture. Groundwater assessment for drinking and irrigation has become a necessary and important task for present and future groundwater quality management. Nowadays, a lot of studies have focused on groundwater quality monitoring and evaluation for domestic and agricultural activities around the world (Mitra et al. 2007; Jain et al. 2009; Hakim et al. 2009; Nagarajan et al. 2010).

Yinchuan area is a traditional agricultural area with heavy population. Located in a semi-arid area, groundwater has always been the major source for drinking and irrigation due to the lack of surface water. Therefore, carrying out groundwater suitability assessment for

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agricultural, drinking and domestic uses in Yinchuan area is practically significant. The aim of the present study is to deal with the task.

2. Materials and methods

2.1 Sample collection and analysis

The study area is located in the middle part of Yinchuan Plain, in Ningxia Hui Autonomous Region, Northwest China. It ranges from longitude 105°49′E to 106°53′E and latitude 37°29′N to 38°53′N, and covers an area of 1839 km^2 .In this study, 40 groundwater samples were collected during January 2009 to February 2009 and all these samples were collected from different pumping wells. Of all these samples, 18 were collected from confined aquifer and the other 22 were collected from phreatic aquifer. The water samples were collected after 30 minutes of pumping to avoid stagnant and contaminated water. The white plastic containers were rinsed out 3-4 times with the water to be sampled. Then the containers were filled up to the brim and were immediately sealed to avoid exposure to air. After the collection, the containers were labeled for identification and brought to the laboratory. During sample collection, handling, and preservation, standard procedures recommended by the Chinese Ministry of Water Resources were followed to ensure data quality and consistency.

The groundwater samples were analyzed in the Laboratory of Ningxia Geo-Environmental Monitoring Station. All these samples were analyzed for pH, Total Dissolved Solids (TDS), total hardness (TH), odor, chemical oxygen demand (COD), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), sulphate (SO_4^{2-}), chloride (Cl^-) and carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), soluble iron (Fe), arsenic (As), nitrate-nitrogen (NO_3^--N), ammonia-nitrogen (NH_4^+-N), nitrite- nitrogen (NO_2^--N), iodine (I), fluoride (F^-), cadmium (Cd), chromium (Gr^{6+}) and chromium (Hg). Among the analyzed parameters, Na^+ and K^+ were determined by using flame photometer (Systronics k-1/mk-III). Ca^{2+}, Mg^{2+}, HCO_3^-, and Cl^- were analyzed by titrimetric method, Fe and As were analyzed by atomic absorption spectrophotometer.

2.2 Methods

Irrigation water containing large amounts of sodium is of special concern due to sodium's effects on the soil and possibility to pose a sodium hazard. Sodium hazard is usually expressed in terms of the Sodium Adsorption Ratio (SAR) which can be calculated from the ratio of sodium to calcium and magnesium (Fipps 2003). The equation is expressed as follows (Hakim et al. 2009):

$$SAR = \frac{Na^{2+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (1)$$

Where, all the ions are expressed in meq/L.

Soluble Sodium Percent (SSP) is also used to evaluate sodium hazard. SSP is defined as the ration of sodium to the total cation. Water with a SSP greater than 60% may result in sodium accumulations that will cause a breakdown in the soil's physical properties (Khodapanah et al. 2009). SSP is expressed as follows:

$$SSP = \frac{\text{Soluble Na}^{2+}\text{ concentration}}{\text{Total cations concentration}} \times 100 \quad (2)$$

Where, all the ionic concentrations are expressed in meq/L.

The Residual Sodium Carbonate (RSC) were also calculated and used for irrigation water quality assessment. RSC is calculated as follows:

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \quad (3)$$

Where, all the ions are expressed in meq/L.

3. Results and discussion

3.1 Quality assessment for drinking

Statistical analysis results of various chemical constituents of collected samples used for drinking usage were presented in Table 1.

Table 1: Statistical analysis results of chemical constituents for drinking usage (Unite: mg/L except pH)

Parameters	Phreatic aquifer water					Confined aquifer water				
	Min	Max	Mean	SD	SNBPL	Min	Max	Mean	SD	SNBPL
Cl^-	61.36	397.79	146.29	85.17	2	20.75	1037.70	127.19	233.93	1
SO_4^{2-}	52.48	684.38	223.97	147.27	5	2.69	885.21	117.58	200.02	1
Fe	0.02	8.00	0.57	1.68	5	0.02	16.80	1.09	3.93	5
F^-	0.10	1.60	0.37	0.37	2	0.10	2.40	0.46	0.54	1
TH	260.04	635.52	401.32	111.65	6	187.11	1256.82	324.30	246.08	2
pH	7.89	8.48	8.11	0.15	0	7.68	8.47	8.17	0.19	0
TDS	306.18	1904.13	857.41	415.03	7	346.76	2936.48	641.08	612.99	3
As	0.000	0.008	0.002	0.002	0	0.000	0.008	0.002	0.003	0
Cr^{6+}	0.000	0.006	0.001	0.002	0	0.000	0.008	0.001	0.002	0
Hg	0.000	0.000	0.000	0.000	0	0.000	0.000	0.000	0.000	0
Cd	0.000	0.002	0.000	0.001	0	0.000	0.001	0.000	0.000	0

SNBPL: sample numbers beyond permissible limits

TDS is usually affected mainly by topography, lithology of aquifer, recharge, runoff and discharge conditions of groundwater. It is an important parameter for assessing groundwater quality. According to Standards for Drinking Water Quality of China (SDWQ), the permissible value of TDS for drinking water is 1000 mg/L. In this study, TDS in phreatic aquifer water ranges from 306.18-1904.13 mg/L and ranges from 346.76-2936.46 mg/L in confined water. 31.8% of the samples from phreatic aquifer exceed the permissible limit of SDWQ and 16.7% of confined water samples are beyond the permissible limit. It can be seen from the above analysis that the groundwater in the region is partially unsuitable for drinking without pretreatment. A contour map was drawn to illustrate the distribution of TDS which is shown in Figure 1. Figure 1 shows that the area is divided into two parts. In the southwest part, TDS is less than 1000 mg/L and the groundwater in this half part is suitable for drinking.

However, in the northeast part of the area, the concentration of TDS is higher than 1000 mg/L which is unsuitable for human consumption without proper pretreatment.

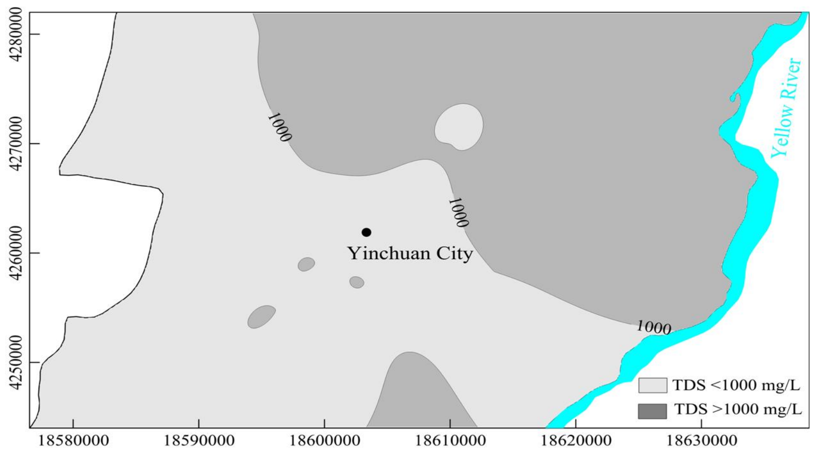

Figure 1: TDS distribution in the study area

Total hardness of water is a measure of dissolved Ca and Mg in water expressed as $CaCO_3$ (Mitra et al. 2007). According to the grading standards of TH, groundwater can be divided into soft water (TH<150mg/L), moderately hard water (150<TH<300mg/L), hard water (300<TH<450mg/L), extremely hard water (TH>450mg/L). The permissible value of TH for drinking water is 450 mg/L. It can be seen from Table 1 that both in phreatic water and confined water, TH is to some degree beyond the limits of SDWQ. 6 samples from phreatic aquifer exceed the permissible limit and 2 from confined aquifer are beyond the permissible limit, accounting for 27.3% and 11.1% respectively. A contour map of TH was presented to show the distribution of TH (Figure 2). It can be seen from Figure 2 that in most parts of the area, TH ranges from 150-450 mg/L, which is fit for drinking. Only in the southwest and mid-north part locally, TH is higher than 450 mg/L which is not fit for direct drinking.

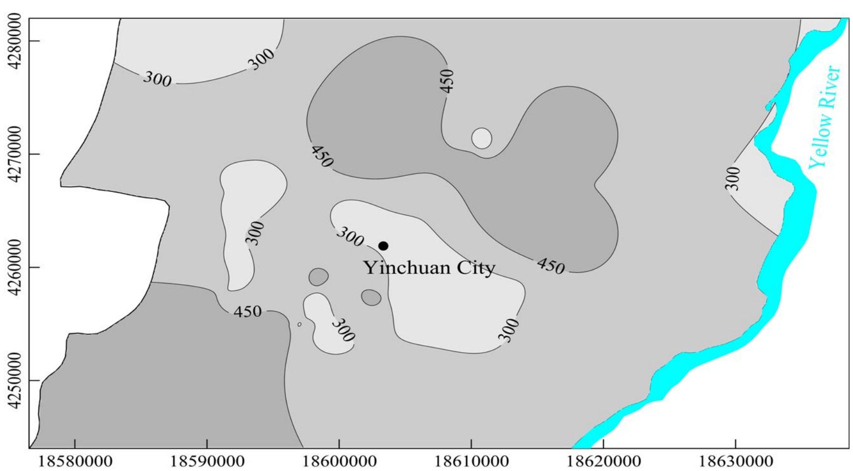

Figure 2: Distribution of TH

The permissible limit for Cl^- and SO_4^{2-} is 250 mg/L. It can also been from the Table 1 that the concentrations of Cl^- and SO_4^{2-} are to some degree beyond the permissible limits for drinking water. The Cl^- concentration varies from 61.36 to 397.79 mg/L for phreatic water and varies from 20.75 to 1037.70 mg/L for confined water. The SO_4^{2-} concentration for phreatic water varies from 52.48 to 684.38 mg/L and five samples exceed the permissible limit, accounting for 22.73%. The SO_4^{2-} concentration for confined water ranges from 2.69 to 885.21 mg/L. The SO_4^{2-} pollution in phreatic water is more serious than that in confined water. The contour maps of Cl^- and SO_4^{2-} are drawn to illustrate their spatial distribution (Figure 3 and 4). It can be seen from the Figure 3 that in most parts of the area, the Cl^- concentration is lower than 250 mg/L and the Cl^- concentration generally increases from Yellow River and west boundary to the middle part. Figure 4 indicates that the SO_4^{2-} concentration in nearly half of the area is higher than 250 mg/L and it increases from west to east and northeast.

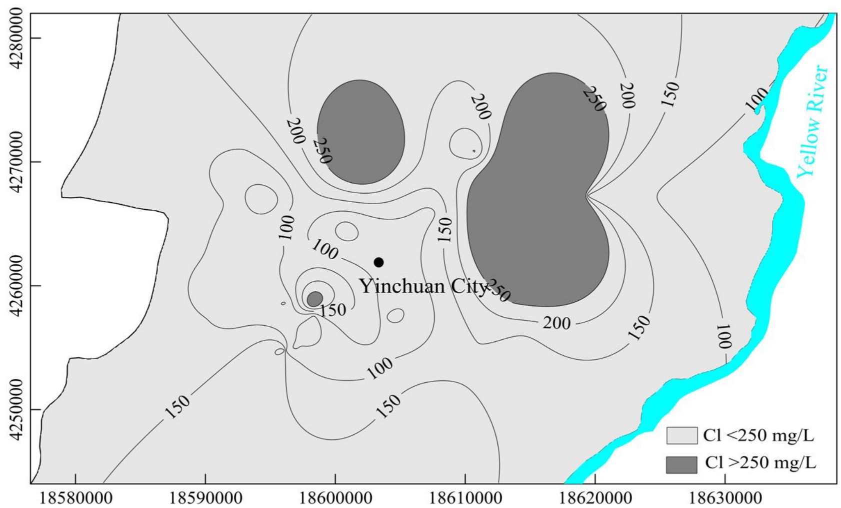

Figure 3: Contour map of Cl^- concentration

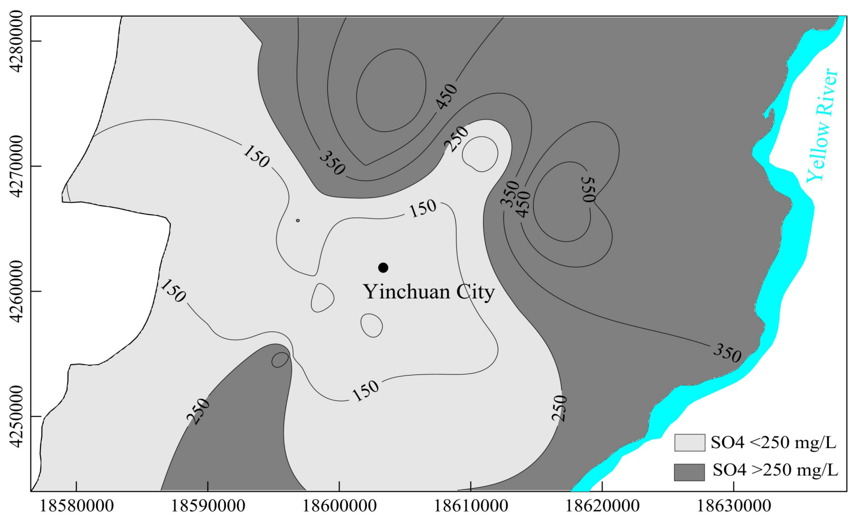

Figure 4: Contour map of SO_4^{2-} concentration

Heavy metals, such as As, Gr^{6+}, Hg and Cd, play important roles in determining the groundwater quality. Many heavy metals are poisonous to human body and can cause many serious diseases. Fortunately, all the heavy metals studied in the area are well below the permissible limits which may not likely to cause those heavy metal induced diseases.

The above analyses show that TDS, TH, Fe, F^-, Cl^- and SO_4^{2-} are the major chemical parameters influencing the groundwater quality. This may be attributed to the chemical plants and waste residue sites in the area. The wastes from these kinds of pollution sources infiltrate into groundwater with rainfall and the polluted the groundwater. Although these parameters are not decisive for drinking use and the high values of the concentrations can be reduced by some manual treatment such as manual mixing, great attention should be paid to control and prevent further pollution.

3.2 Quality assessment for irrigation

The suitability of groundwater for irrigation is contingent on the effects on the mineral constituents of the water on both the plant and the soil (Khodapanah et al. 2009). Salts can not only limit growth of plants physically, by restricting the taking up of water through modification of osmotic processes, but also may damage plant growth chemically by the effects of toxic substances upon metabolic processes. In this study, TDS, SAR, SSP and RSC were used to carry out the assessment of the suitability of water for irrigation purposes.

The permissible concentration of TDS in groundwater for irrigation is <3000 mg/L (Nagarajan et al. 2010). When the concentration is >3000 mg/L, the risk to cause salinity may be higher. SAR gives the clear idea about the adsorption of sodium by soil. It is widely used in the USA and some western countries for the assessment of sodium hazards. Sodium adsorption ratio is the proportion of sodium to calcium and magnesium, which affect the availability of the water to the crop (Singh 2008). Based on the grading criteria of water for irrigation, SAR is classified into excellent (<10), good (10-18), permissible (18-26), unsuitable (>26) (Khodapanah et al. 2009). Irrigation water is classified based on RSC as suitable (<1.25), marginal (1.25–2.5), and not suitable (>2.5) (Lloyd and Heathcote 1985). The assessment results with these methods are listed in Table 2.

The TDS varies from 306.18 to 2936.48. The large variation of TDS may be attributed to the lithological composition and anthropogenic activities prevailing in this region. Fortunately, none of the water samples fall into salinity contamination class. The calculated SAR ranges from 0.23 to 6.64 in groundwater in the study area and all the samples fall into excellent category. The values for the soluble sodium percent (SSP) in the study area range from 5.75 to 65.65%. It is observed that only 2 samples have high sodium percent (above 60%) and are not suitable for irrigation purposes. With respect to RSC, all samples fall into suitable category and can be used for agricultural irrigation purpose.

It is revealed from the study that nearly all the collected groundwater samples, including phreatic water and confined water, are suitable for irrigation except S17 and S31. In fact, S17 and S31 can still be used for irrigation if they are mixed with other water samples, because only two unsuitable samples will not significantly influence the practical use of groundwater. However, when groundwater in the region is used for domestic use, pretreatment should be made to ensure the groundwater quality is fit for consumption and will not cause serious health problems.

Table 2: Assessment results of groundwater for irrigation

Sample No.	Water type	Assessment results and grading for irrigation purpose							
		TDS	Grading	SAR	Grading	SSP	Grading	RSC	Grading
S1	confined water	356.43	suitable	0.98	excellent	23.22	suitable	-0.54	suitable
S2	confined water	465.18	suitable	1.83	excellent	35.94	suitable	0.07	suitable
S3	confined water	2936.48	suitable	5.72	excellent	43.58	suitable	-24.94	suitable
S4	confined water	346.76	suitable	0.76	excellent	19.03	suitable	-0.24	suitable
S5	confined water	373.89	suitable	1.23	excellent	28.08	suitable	-0.18	suitable
S6	confined water	450.09	suitable	0.75	excellent	16.72	suitable	-1.85	suitable
S7	confined water	383.64	suitable	0.23	excellent	5.75	suitable	-2.45	suitable
S8	confined water	410.95	suitable	0.63	excellent	14.35	suitable	-1.56	suitable
S9	confined water	381.95	suitable	0.51	excellent	12.23	suitable	-0.93	suitable
S10	confined water	493.52	suitable	3.06	excellent	50.61	suitable	1.55	suitable
S11	confined water	390.58	suitable	2.02	excellent	41.30	suitable	0.81	suitable
S12	confined water	1129.61	suitable	3.12	excellent	37.12	suitable	0.58	suitable
S13	confined water	443.88	suitable	1.00	excellent	21.89	suitable	-1.02	suitable
S14	confined water	558.63	suitable	0.78	excellent	21.25	suitable	-0.47	suitable
S15	confined water	365.91	suitable	1.26	excellent	28.97	suitable	0.08	suitable
S16	confined water	414.01	suitable	1.85	excellent	37.65	suitable	0.05	suitable
S17	confined water	1001.64	suitable	6.64	excellent	65.65	unsuitable	-0.97	suitable
S18	confined water	636.21	suitable	4.24	excellent	57.98	suitable	-0.57	suitable
S19	phreatic water	1172.04	suitable	4.10	excellent	45.67	suitable	-3.19	suitable
S20	phreatic water	532.27	suitable	0.28	excellent	6.10	suitable	-5.78	suitable
S21	phreatic water	716.56	suitable	1.16	excellent	19.88	suitable	-3.21	suitable
S22	phreatic water	521.16	suitable	1.50	excellent	27.97	suitable	-1.00	suitable
S23	phreatic water	579.72	suitable	2.26	excellent	38.70	suitable	-1.63	suitable
S24	phreatic water	818.91	suitable	2.53	excellent	37.28	suitable	-3.56	suitable
S25	phreatic water	552.44	suitable	1.63	excellent	30.62	suitable	-2.50	suitable
S26	phreatic water	306.18	suitable	3.06	excellent	45.33	suitable	-0.11	suitable
S27	phreatic water	1177.66	suitable	2.53	excellent	32.33	suitable	-8.65	suitable
S28	phreatic water	1096.69	suitable	4.95	excellent	53.21	suitable	-0.02	suitable
S29	phreatic water	750.81	suitable	2.44	excellent	37.54	suitable	-2.59	suitable
S30	phreatic water	1148.00	suitable	5.12	excellent	55.18	suitable	-1.46	suitable
S31	phreatic water	942.37	suitable	5.87	excellent	62.57	unsuitable	-0.42	suitable
S32	phreatic water	584.47	suitable	1.51	excellent	27.56	suitable	-1.18	suitable
S33	phreatic water	1878.25	suitable	6.42	excellent	54.11	suitable	-3.42	suitable
S34	phreatic water	1904.13	suitable	6.12	excellent	49.74	suitable	-3.89	suitable
S35	phreatic water	659.76	suitable	1.36	excellent	23.90	suitable	-3.90	suitable
S36	phreatic water	659.76	suitable	1.36	excellent	23.90	suitable	-3.90	suitable
S37	phreatic water	564.97	suitable	1.26	excellent	24.05	suitable	-3.23	suitable
S38	phreatic water	619.31	suitable	3.46	excellent	51.84	suitable	0.56	suitable
S39	phreatic water	606.30	suitable	1.26	excellent	23.49	suitable	-2.83	suitable
S40	phreatic water	1071.36	suitable	3.06	excellent	37.83	suitable	-1.40	suitable

4. Conclusions

The groundwater in Yinchuan area has been assessed for its chemical constituents and suitability for drinking and irrigation uses. According to the findings of this study, the groundwater in the study area is not entirely fit for direct drinking with respect to TDS, TH, Fe, F^-, Cl^- and SO_4^{2-}. In some of the samples collected, the concentrations of these constituents exceed the permissible limits of SDWQ. Based on TDS, 75% of water samples are suitable for drinking and 80% of samples are fit for drinking based on TH. Heavy metals such as As, Gr^{6+}, Hg and Cd are well below the permissible limits.

The assessment for irrigation use reveals that based on TDS, SAR and RSC, all the samples are suitable for irrigation, whereas, based on SSP, S17 and S31 are unsuitable for irrigation. S17 and S31 can be still used for irrigation if they are mixed with other samples, that is to say, only two samples will not restrict the use for irrigation and therefore all the samples can be used for agricultural irrigation.

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