



Irrigation Water Quality Evaluation of Aldelam Groundwater

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ABSTRACT

Good quality water helps to maintain agricultural productivity and sustain soil fertility. Agricultural activities in Saudi Arabia depend on surface water and groundwater as the main sources for irrigation. Groundwater is the main source used for irrigation purposes in this area. This study was done to evaluate the status of groundwater quality and its suitability for irrigated agriculture. To achieve this objective, water samples from fourteen wells were collected from different areas of Aldelam in May and July of 2011. The water quality of these wells in the study area was estimated from different water quality parameters such as chloride, bicarbonate, sodium, calcium, total dissolved solids (TDS), EC, pH, sodium adsorption ratio, and percentage of sodium. The results showed that the overall concentration of all the ions was very high, but the sodium hazard in the well water was moderate. About 78 percent of the wells had suitable water quality for boron, and they had a concentration below the permissible limit for crop irrigation. TDS in the groundwater ranged between 1114.88 to 2897.71 ppm during the investigation period. High EC and low SAR in all the wells showed that the water from these wells could be used for irrigation purposes with special management.

Keywords: Groundwater, quality, boron, irrigation, Saudi Arabia.

INTRODUCTION

The quality of groundwater is determined by the physical and chemical characterization of groundwater, which is the major source of water for domestic, agricultural, and industrial purposes in many countries. Groundwater quality has recently begun to be of concern as the population has expanded and more water demands have to be provided. Intensive agricultural activities have

increased the demand on groundwater resources in Saudi Arabia. There are no perennial streams or rivers in Saudi Arabia. Therefore, the main water sources are underground water aquifers, rainfall, and seawater desalination¹. There are increasing needs for water, as there is rapid growth of population and agricultural activities are increasing around the country². According to an estimate, more than 80% of the water demand in the agricultural sector is currently being met from non-renewable

groundwater sources, which are the main source of irrigation water. About 90 % of it is consumed in agricultural activity³. To meet the growing demand of water for the domestic, industrial, and agricultural sectors, exploration of alternative sources of water, especially for use in agriculture, is important. In Saudi Arabia, there are increasing needs of water, as there is rapid growth of the population and agricultural activities are increasing around the country². Saudi Arabia is an arid country with limited water supplies. About 80-85% of water supplies come from groundwater, which is essentially classified as a non-renewable water resource⁴. In arid regions such as Saudi Arabia, limited water resources (groundwater and surface water) and a sensitive desert environment are major features of its ecosystems. Saudi Arabia depends mainly on groundwater and sea water desalination to cover its needs for drinking water and irrigation⁵.

The suitability of irrigation water depends upon many factors including the quality of the water, soil type, salt-tolerant characteristics of the plants, climate, and drainage characteristics of the soil⁶. The determination of major ions, such as carbonate, bicarbonate, magnesium, calcium, sulphate, and hardness are important to measure irrigation water quality⁷. Among the major cations are sodium, calcium, and magnesium, which influence the suitability of groundwater for human consumption, agricultural irrigation, and other purposes. Some crops are sensitive to boron, so it is often included in the analysis. Some of these cations are beneficial for crop production at low concentrations. Otherwise, they affect properties of soil, cause toxicity to plants, and make management practices difficult⁸. To deal with such problems, information concerning the quality of irrigation water and its effect on soils and crops is necessary. The importance of water quality becomes more significant in arid climates due to the lack of natural leaching of deposited salts and a high rate of evaporation⁹. Keeping in mind the importance of water quality assessment, a study regarding the groundwater quality of the Dalamm aquifer, Saudi Arabia, was carried out to classify groundwater from wells on the basis of different criteria. The quality of some water is not suitable for irrigating crops. Irrigation water must be compatible with both the crops and soils to which it will be applied. The total dissolved solid contents in

groundwater may vary from 20 mg/l in areas of high rainfall to over 100,000 ppm in some desert brines of Karanth¹⁰.

In this study, because many of the wells are still in use the groundwater of the Aldelam area was evaluated for quality of irrigation water. The following were determined: total amount of dissolved salts (TDS) in the water, sodium adsorption ratio (SAR), sodium concentration (Na%), electrical conductivity (imhos/cm), and amounts of individual chemicals, such as, chloride (Cl), sodium (Na), nitrate (NO₃), calcium (Ca), potassium (K), magnesium (Mg), boron (B), iron (Fe), and sulfate (SO₄). They were measured to identify the characteristics that are important for plant growth, to determine acceptable levels of concentrations, and to choose irrigation techniques to avoid crop damage. In the future, water demand for agricultural developments in the Aldelam area will have to come from local groundwater resources.

MATERIALS AND METHODS

Study area

The study area was located between longitudes 47° 6' 23.00"E and 47° 10' 7.82" E and 23°49' 36.50" N and 24° 3' 17.14" N (Fig. 1). It is located in the middle part of Saudi Arabia, south of Riyadh, Saudi Arabia's capital. The map of Aldelam is shown in Figure 1. Most of the people of the area meet their demands for irrigation, drinking, and domestic water supply by tapping the deep aldelaq aquifer. Depths of the monitoring wells ranged from 100 to 700 m below the surface.

The Aldelam area is a flat plain and it has many farms. It is covered by alluvial deposits belonging to the quaternary period, and the Aldelam aquifer constitutes the principal groundwater aquifer of the area. These deposits are gravel, sand, clay, and sabkha. The climate of the region is an arid type with low winter rain and a dry, very hot summer. The most important economic activity of this area is agriculture, and the major crops are date trees and alfalfa. The irrigation system is mostly fed by the deep groundwater

Water sampling, processing, and analysis

Field research was conducted to evaluate

the suitability of groundwater for irrigated agriculture of the Aldelam area. A total of 14 groundwater samples were collected from various sites based on a field survey. Figure 1 shows the groundwater sampling locations zones. The experimental design was a randomized complete block. Groundwater samples were collected during the months of May and July in the year of 2011. The samples were taken from the wells after pumping them about 30 minutes, and then the samples were collected in clean polyethylene bottles. Prior to collection, the sample bottles were rinsed three to four times using sampling water. The water samples were taken by pumping, so the sample was representative and contamination from the surface was avoided. The samples were stored in an ice box during transportation. Collected samples were transported to the laboratory the same day and stored at 4°C. Some parameters, including electrical conductivity (EC) and pH, were measured in the field immediately after the collection of the samples using portable field meters.

The TDS values displayed by the conductivity/TDS meter were calculated from the specific conductance of the groundwater and could be approximated by the following equation (e.g., [11]):

$$\text{TDS} = k_e \text{ EC} \quad \dots(1)$$

Where TDS is expressed in milligrams per liter and EC is the electrical conductivity in microsiemens per centimeter at 25°C (specific conductance). The correlation factor k_e varies between 0.55 and 0.8. The k_e for samples measured using the conductivity/ TDS meter in this study was 0.64 regressed from the TDS vs. specific conductance data. Each sample was divided into two portions: one for cation analysis and the other for anion analysis.

The chemical analyses of the groundwater samples were carried out at the Faculty of King-Abdulaziz-City-for-Science-and-Technology, where the samples for cation analysis were filtered at 0.45 μm and preserved (pH < 2) using ultrapure HCl in the laboratory. And also samples for anions were filtered through 0.45 μm . Anion constituents were analyzed by ion chromatography (IC, DX-120, DIONEX), and other cationic constituents were

analyzed by ICP-MS (Ultramass 700, Varian), AA (5100PC, Perkin Elmer), and ICP (ICP-IIIS, Shimadzu) following USEPA standard methods.

Ground water quality

Various irrigational parameters used to evaluate quality of irrigation water for sustainability of agriculture use are: sodium adsorption ratio (SAR) and percentage of sodium (Na %). SAR is defined by Karanth [10]. It was estimated by the following formula :

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

Na% is calculated by using the following formula :

$$\text{Na\%} = \frac{\text{Na}^+ + \text{K}^+}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{K}^+} * 100 \quad \dots(3)$$

RESULTS AND DISCUSSION

The groundwater from the study area showed that it had no color, odor, or turbidity. The results of the chemical analysis of groundwater samples of the study area of Aldelam are presented in Table 1, and the statistical parameters like minimum, maximum, mean, and the standard deviation values of the water samples also are given in Table 1. The data of the chemical results showed a considerable variation, which reflected their chemical composition.

Table 1 shows that the pH of groundwater in this area ranges from 7.33 to 8.11 with an average of 7.69. Inspection of these values (Table 1) reveals that all samples lie within the permissible range of 6.0 – 8.5¹²⁻¹³.

Electrical Conductivity (EC)

Electrical conductivity is an indication of the concentration of total dissolved solids and major ions in a given irrigation and drinking water body. The well water samples showed a wide variation in the samples collected from the same area, and they ranged between 1742 and 4572 $\mu\text{S}/\text{cm}$ with an average value of 2904.64 $\mu\text{S}/\text{cm}$. It is easy to presume from the EC values (Table 1) that the

irrigation water of the study area is unsuitable for irrigation purposes as it falls under the category of high to very high salinity. Salinization in the end makes groundwater inadequate for the growth and productivity of many crops¹⁴. Based on the EC values, we found that 64.29 % of the wells are in the

range of 1500-3000 micromhos/cm and 35.71 % of the wells are above 3000 micromhos/cm (Table 2). The EC values of the majority of the samples are higher than the permissible limit¹. High EC in water leads to formation of saline soil, whereas high Na content in water causes alkaline soil¹⁵.

Table 1: Chemical composition of groundwater of the Aldelam area

well NO	pH	EC μS/cm	TDS ppm	Na ppm	K ppm	Mg ppm	Ca Ppm	F ppm	Br Ppm	NO ₃ N ppm	SO ₄ ppm	SAR
1	7.66	2203.00	1409.92	76.67	6.67	57.67	181.00	11.86	Nil	83.50	651.14	7.02
2	7.47	4527.67	2897.71	180.33	17.33	95.67	189.67	10.46	Nil	59.59	660.41	15.10
3	7.56	1775.67	1136.43	82.00	7.33	41.67	131.67	13.05	Nil	80.18	280.59	8.81
4	7.42	2184.33	1397.97	191.33	10.67	93.33	191.33	10.14	25.74	92.96	591.27	16.04
5	7.53	1742.00	1114.88	85.33	18.00	33.33	129.67	12.98	Nil	50.85	474.03	9.45
6	7.33	2496.00	1597.44	164.00	9.00	101.00	199.67	11.81	Nil	114.10	637.19	13.38
7	7.42	2302.00	1473.28	159.67	11.67	80.33	187.67	10.02	Nil	79.28	534.12	13.79
8	7.88	3800.00	2432.00	202.67	14.00	101.67	410.33	9.71	Nil	69.42	949.13	12.67
9	7.77	3764.67	2409.39	232.00	11.00	95.67	371.67	16.72	26.43	189.11	477.15	15.18
10	7.88	4043.33	2587.73	162.67	10.00	117.00	463.37	11.47	Nil	60.11	1240.56	9.55
11	7.84	2750.67	1760.43	184.33	11.33	79.00	251.00	11.17	Nil	64.08	397.86	14.35
12	7.88	4043.33	2587.73	169.00	9.33	113.33	469.33	13.83	26.05	70.05	1615.95	9.90
13	8.11	2570.67	1645.23	175.33	14.33	92.33	191.33	11.81	Nil	114.06	636.98	14.72
14	7.89	2461.67	1575.47	144.00	9.00	102.33	209.33	11.86	Nil	114.51	639.50	11.54
Mean	7.69	2904.64	1858.97	157.81	11.40	86.02	255.50	11.92	26.07	88.70	698.99	12.25
Median	7.72	2533.34	1621.33	166.50	10.84	94.50	195.50	11.81	26.05	79.73	637.09	13.02
Std. dev.	0.24	931.00	595.84	46.51	3.41	25.34	119.47	1.83	0.35	35.81	352.57	2.85
Minimum	7.33	1742.00	1114.88	76.67	6.67	33.33	129.67	9.71	25.74	50.85	280.59	7.02
Maximum	8.11	4527.67	2897.71	232.00	18.00	117.00	469.33	16.72	26.43	189.11	1615.95	16.04

Table 2: Classification of groundwater from conductivity values

Conductivity range micromhos/cm	Classification	No. of sample	Percentage of samples
< 1500	Permissible	0	0
1500-3000	Not permissible	9	64.29
> 3000	Hazardous	5	35.71

Table 3: Classification of water based on TDS. Source: (Davis and Wiest, 1996)

S. No	Water Condition	Value in ppm	Number of samples	Percentage of samples
1	Fresh Water	Less than , 1000	0	0
2	Slightly Saline	1000 to 3000	14	100
3	Moderated Saline	3000 to 10000	0	0
4	Very Saline	10000 to 35000	0	0
5	Brine	More than 35000	0	0

The total dissolved solids (TDS)

The total dissolved solids are the concentrations of all dissolved minerals in water, and they indicate the general nature of salinity of the water. In all wells, the TDS values ranged from 1114.88 to 2897.71 ppm with an average of 1858.97 ppm (Table 3). According to the salinity classification of Davis and De Wiest¹⁶, the results showed that one hundred per cent of the samples fell under the water category of slightly saline.

TDS concentrations above 1000 ppm cause yield declines for salt-sensitive crops and, around 3000 ppm, even salt-tolerant plants can exhibit significant yield declines¹². Dissolved solids

can also contribute to clogging problems in drip irrigation systems [12]. High and very high salinity water is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and plants with very good salt tolerance should be selected¹⁵. It is also important to consider the TDS in water, because many of the toxic solid materials may cause harm to plants¹⁷.

Sodium Absorption Ratio (SAR)

SAR is important to plant growth because its magnitude is an indication of the availability of

Table 4: Classification of water based on USSL sodium hazard for irrigation

Sodium hazard class	Rang	Water Class	Number of samples	Percentage of samples
S1	< 10	Excellent	5	35.71
S2	10-18	Good	9	64.29
S3	18-26	Doubtful	0	0.00
S4	>26	Unsuitable	0	0.00

Table 5: Suitability for irrigation based on Na%

Na%	Suitability for irrigation	Number of samples	Percentage
<20	Excellent	Nil	Nil
20-40	Good	11	78.6
40-60	Permissible	3	21.4
60-80	Doubtful	Nil	Nil
>80	Unsuitable	Nil	Nil

Table 6: Correlation matrix for different water quality parameters

	ph	EC	TDS	Na	K	Mg	Ca	F	Br	NO3 N	SO4
ph	1.0000										
EC	0.3231	1.0000									
TDS	0.3231	1.0000	1.0000								
Na	0.2334	0.6288	0.6288	1.0000							
K	-0.0152	0.2259	0.2259	0.2172	1.0000						
Mg	0.3451	0.7152	0.7152	0.7570	-0.0907	1.0000					
Ca	0.5213	0.7626	0.7626	0.5372	-0.1238	0.6955	1.0000				
F	0.1979	0.0733	0.0733	0.0007	-0.1972	-0.1137	0.2178	1.0000			
Br	0.6872	0.7508	0.7508	0.6806	0.2437	0.0487	0.5933	0.9917	1.0000		
NO3 N	0.1231	0.0033	0.0033	0.4208	-0.2689	0.2314	0.0559	0.6054	0.7976	1.0000	
SO4	0.3891	0.6314	0.6314	0.2164	-0.0982	0.6454	0.7989	-0.0017	-0.1491	-0.2584	1.0000

soil pore water to plant roots¹⁸. The sodium hazard of the irrigation water can be evaluated using SAR, which is calculated from Ca, Mg, and Na contents. SAR is an important parameter for determining suitability of groundwater for irrigation, because it is a measure of alkali / sodium hazards to crops [15]. The sodium adsorption ratio (SAR) content in the study area showed variation from 7.02 to 15.18 with an average value of 12.25 (Table 1). The values

of the SAR showed that 35.71% of groundwater samples of the wells were less than 10, which indicated excellent quality for irrigation and samples fell in the excellent (S1) category, while 64.29 % of groundwater samples of the wells fell within range for SAR of 10-18, which indicated good quality for irrigation and the samples fell in the good (S2) category (Table 4).

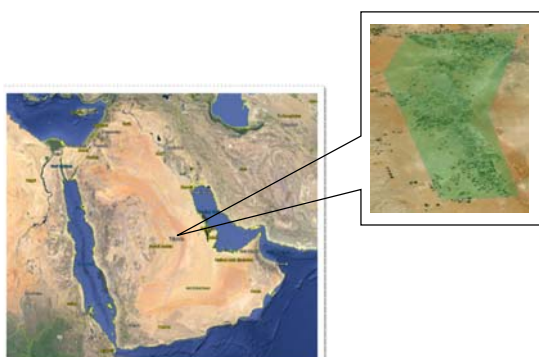


Fig. 1: Location of Aldelam area and blocks used for sampling. The blocks image was obtained from Google Earth® image

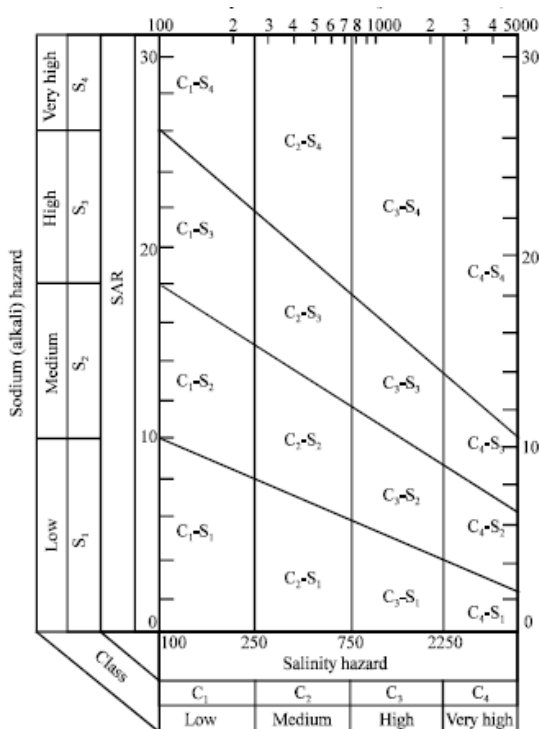


Fig 2: Classification of groundwater samples of study area from¹⁵

In Figure 2, we plot SAR and electrical conductivity (EC) using the U.S. Salinity Laboratory (USSL) salinity diagram¹⁵.

The water quality of samples from the study area showed that about 35.85% of the samples fell in the C₄-S₄ category (very high salinity with very high alkalinity hazard), 35.71% of the samples fell in the category C₄-S₃ (very high salinity with high alkalinity hazard), and 21.42% of the samples fell in the category C₃-S₂ (high salinity with medium alkalinity hazard). These classifications for groundwater samples showed that they had high to very high salinity hazards with medium alkali hazards.

The higher the SAR values in the water, the greater the risk of sodium, which leads to the development of an alkaline soil¹⁹, while a high salt concentration in water leads to formation of saline soil. These results are similar to those found by Saeed *et al.*,²⁰. They found SAR values lower than 15 and high EC values in the Jilh aquifer. Sodium concentration (Na %)

Sodium concentration is important in classifying irrigation. The suitability of water for irrigation is based on Na%. Sodium is an important cation, which in excess deteriorates the soil structure and reduces crop yield²¹⁻²². When the concentration of sodium is high in irrigation water, it will tend to be adsorbed by clay particles displacing Mg²⁺ and Ca²⁺ ions. This exchange process of sodium in water for Mg²⁺ and Ca²⁺ ions in soil reduces the permeability and finally results in soil with poor internal drainage. Na% results are given in Table 5, and they showed that 78.6 % of the wells had a good irrigation water quality, while 21.4 % of the wells had permissible irrigation water quality.

Correlation matrix for the water quality parameters

Correlation analysis is a preliminary descriptive technique to estimate the degree of association among the variables involved. Correlation matrix between the different chemical parameters of groundwater of the wells samples are shown in Table 6. A high positive correlation is observed between TDS and EC because conductivity increases as the concentration of all dissolved constituents/ions increases. pH does not show any significant correlation between the pH and all other parameters, except boron (Table 6).

CONCLUSION

A study of water samples collected from 14 wells of the Aldelam area, south of Riyadh, indicated that water from most of the wells can be used for application to the fields. The salinity of the water in the wells showed that 78.37 % of the EC values were greater than 1500 micromohs/cm. Medium salinity class is good for the plants with moderate salt tolerance and can be used, but special practices and special management are required for salinity control. Groundwater of the study area contained undesirable level of TDS. The data indicated that application of fertilizer for agriculture will contribute to higher concentration of ions in aquifer of Aldelam.

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