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Chemistry of Groundwater of Al-Ahsa Oasis Eastern Region Saudi Arabia and Its Predictive Effects on Soil Properties

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Abstract: Saudi Arabia is an arid and the largest country in the middle east with a total land area of 2.253×10^6 km^2. Recent urban and rural expansion has shown manifold increases in water use in various sectors. Water resources are limited and non-renewable coupled with unpredicted scanty rainfall. In order to meet the rising water needs, evaluation of water quality is important for allocation to various uses. A total of 101 well water samples were collected from Al-Ahsa Oasis. Water samples were analyzed for total salt concentration, pH, Ca, Mg, Na, K, HCO_3, Cl, SO_4, NO_3, F and B contents. Soil Salinity Development (SSD), adjusted sodium adsorption ratio (adj.SAR), adjusted sodium adsorption ratio (adj. R_{Na}) and Exchangeable Sodium Percentage (ESP) were calculated. The EC of groundwater ranged between 1.23 and 5.05 dS m^{-1}. Sodium was the most abundant cation followed by Ca, Mg and K in descending order. Chloride was the most abundant anion followed by SO_4 and HCO_3 in groundwater of Al-Ahsa Oasis. A significant correlation was found between Na and Cl (R^2 = 0.936). Thermodynamics calculation revealed that an appreciable amount of Ca and Mg is associated with Cl and SO_4 ions. The SAR and ESP values are within the permissible limits according to Ayers and Westcot, 1985. The NO_3 concentration is within safe limits for drinking purpose according to WHO (1998) standards. The Saturation Indices (SI) indicated that groundwater is under-saturated (negative SI) with respect to certain minerals (for example: calcite, dolomite, gypsum, anhydrite, halite, pyrite, fluorite and aragonite) and oversaturated (positive SI) with respect to some other minerals (For example: Goethite, Siderite and hematite). The negative saturation index (SI) reveals that most of minerals are in un-saturated state and will dissolve more Ca and Mg into the soil solution after irrigation. A good relationship exists between Cl and other ions (Na, Ca and Mg) as well as between SO_4 and Ca and Mg ion of groundwater. The salinity and sodicity hazards of groundwater of Al-Ahsa Oasis were classified as C3S1 and C4S2 i.e., high salinity with medium sodicity problems. The predicted soil salinity suggested application of 15-20% leaching requirements to keep soil salinity within permissible limits. Cultivation of slight to moderate salt and sodium tolerant crops is recommended for optimal agricultural production and efficient water use.

Key words: Water salinity, sodium adsorption ratio, saturation indices, nitrate, soil salinity, leaching requirements

INTRODUCTION

Al-Ahsa, often referred to as the largest and the oldest Oasis in the Arabian Peninsula, is located in the Eastern Region of Saudi Arabia about 150 km south of the port of Dammam and 320 km south-east of the capital, Riyadh. It extends from approximately 25° 21' to 25° 37' latitude north and from 49° 33' to 49° 46' longitude east. It embraces an L-shaped area of 320 km^2 with vertical stroke lying in a due north-south direction and the province capital, Hofuf lying in the corner of the L. The entire cultivated area, which used to be over 20,000 ha, is not continuous at present, being interrupted around the towns of Hofuf and Al-Mubaraz in the south-western corner of the Oasis. The overall area is considered as twin Oasis with an Oasis in the north and the other in the south.

Saudi Arabia is an arid and the largest country in the middle east with a total land area of 2.253×10^6 km^2. Recent urban and rural expansion has shown manifold increases in water use in various sectors. For example in the agricultural sector, the total cropped area in the Kingdom increased from 1.25 (1988) to 1.51 (1992) million hectares (Anonymous, 1992). Consequently, the demand for irrigation supplies showed manifold increases from 1.75 billion m^3 in 1975 (Anonymous, 1985) to 22.93 billion m^3 in 1992 (Dabbagh and Abderrahman, 1997). According to an estimate, more than 80% of water demand in agriculture sector is currently being met from non-renewable groundwater sources (Anonymous, 1992).

The quality of water for various uses is determined by its physical characteristics, chemical composition, biological parameters and the conditions of use. Because all the waters, surface or sub-surface, contain salts in different amounts and proportions and will increase the salt concentration of soil solution upon irrigation, because water will evaporate under highly evaporative environmental conditions thus leaving the salt into the soil. Besides Al-Ahsa Oasis (Hussain and Sadiq, 1991; Al-Hawas, 2002), many researchers have evaluated water quality in other regions of Saudi Arabia such as Wadi Al-Yamamiyah (Bazuhair and Alkaff, 1989); Al-Qassim Region (Faruq *et al*., 1996); Saudi Ground water chemistry (Mee, 1983) and chemical composition of ground waters of Saudi Arabia (Anonymous, 1985; Allael-Din *et al*., 1993).

Information on the chemistry of groundwater in Al-Ahsa Oasis is limited for determining its use for various purposes. The main objective of this paper is to study the chemistry of groundwater of Al-Ahsa Oasis and predict its effects on soil properties.

Climate of Saudi Arabia: The Arabian Peninsula is located in an arid belt extending from Northern Africa through Arabian Peninsula, Iran and Mongolia. According to Lin (1984), the yearly potential evaporation (Hofuf-3359 mm) is much greater than the yearly mean rainfall (Hofuf-69.6 mm). High evaporative conditions and inadequate irrigation supplies determine the hydrology, land development and vegetation of the area.

High temperature during summer is the most significant climatic factor of Saudi Arabia. An extreme maximum air-temperature of 51.3°C was recorded at Hofuf in June 1983. However, in general, the maximum daily air-temperature often exceeds 45°C and the relative humidity is also very low in summer. The diurnal variation of the air-temperature is strikingly high and causes the apparent diurnal variations of relative humidity. Though the overall air-temperature variation have been observed from -2.6 to 51.3°C but night frosts are rare.

The arable land in Al-Ahsa Oasis was estimated to be about 16,000 ha (Vidal, 1951). During the following 15 years, this area decreased to about 8,000 ha due to resalination of the soil because of over irrigation and or inadequate drainage. Alfalfa, dates, vegetables, melons etc were the main agricultural products. According to a report from the statistical section of Hassa Irrigation and Drainage Authority (HIDA) in 1978-80, the agricultural productive land was as below:

Total area of Oasis	= 15,920 ha
Land able to be irrigated	= 13,434 ha

Accordingly, only 40% of the total area is being cultivated to grow different types of crops.

The extension service of HIDA advises farmers about the modern techniques of cultivation and use of fertilizers. As a result, the agricultural acreage increased and statistics for 1983 were as follows:

Land actually cultivated (well farmed)	= 7,906 ha
Land actually cultivated (not well farmed)	= 4,438 ha
Total land actually cultivated	= 11,534 ha
Fallow land	= 1,900 ha

Water resources: A number of sources contribute to the overall water supplies in Al-Ahsa Oasis as follows.

The annual rainfall is around 73 mm and is considered practically negligible from agricultural point of view (Anonymous, 1979).

Important aquifers in the eastern regions of Saudi Arabia are Wasia, Umm-Er-Radhuma, Al-Khobar, Alat and Neogene. The water quality varies within each aquifer as well as between aquifers. It generally increases in the direction of the hydraulic gradient ranging between 2000-6000 mg L^{-1} (Wasia) and 1000-3500 mg L^{-1} (Neogene).

Free flowing springs are the basis for existence of Al-Ahsa Oasis. Early records on number, location, water quality, water temperature, purity and discharge date back to 1941 and 1951 (Vidal, 1951). From the research done on springs for the design of HIDA, it was found that only 32 springs have enough production to be connected to the new irrigation project (Anonymous, 1978). The 32 main springs are:

- Group of Springs (Al-Mutarifi) = 7
- Group of Springs (East of Hofuf) = 22
- Ain-Harah (Mubarraz) = 1
- Ain-Jauihariyah (Al-Buttaliya) = 1
- Ain-Nasser (Al-Qrain Village) = 1

Total Springs = 32

Wakuti (1964) conducted first detailed study on spring discharge while doing feasibility study for the entire Oasis. The detail is given as:

Description	Discharge (L^{-1})
Three hundred and thirty six wells, free flowing or pumped/well (estimated)	0.5-10
Eighty Five small springs, free flowing or pumped/spring (estimated)	2.5-20
Thirty two main springs (maximum discharge)	25.0-1700

MATERIALS AND METHODS

The study was conducted in Al-Ahsa Oasis in the Eastern Province of Saudi Arabia about 80 km to the northwest of capital Dammam during 2004. The irrigation network in the Oasis is covered by a well defined network of drainage canals to carry excess water (irrigated fields) to two common lakes (D-1 and D-2).

A total of 101 water samples were collected from different wells located in the Oasis during the winter months of November and December 2004 in the year (Fig. 1) and about 1 L water was collected. The water samples were collected in plastic bottles, pH and EC were measured instantly and the samples were stored in an ice box during transportation. Each sample was divided into two portions; one for cation analysis and the other for anion determinations. Concentration of total dissolved ions, Ca, Mg, Na, K, CO_3, HCO_3, Cl, SO_4, F and NO_3 were determined. The analytical procedures used for these determinations were those described in UDSA Handbook No. 60 (1954) and are shown in Table 1.

Soil Salinity Development (SSD), adjusted sodium adsorption ratio (adj. SAR), Adjusted sodium adsorption ratio (adj. R_{Na}) and Exchangeable Sodium Percentage (ESP) were calculated from the analytical data (Oster and Rhoades, 1977). The SSD was calculated according to Ayers and Westcot (1985). The equations used to calculate different water quality evaluation parameters were:

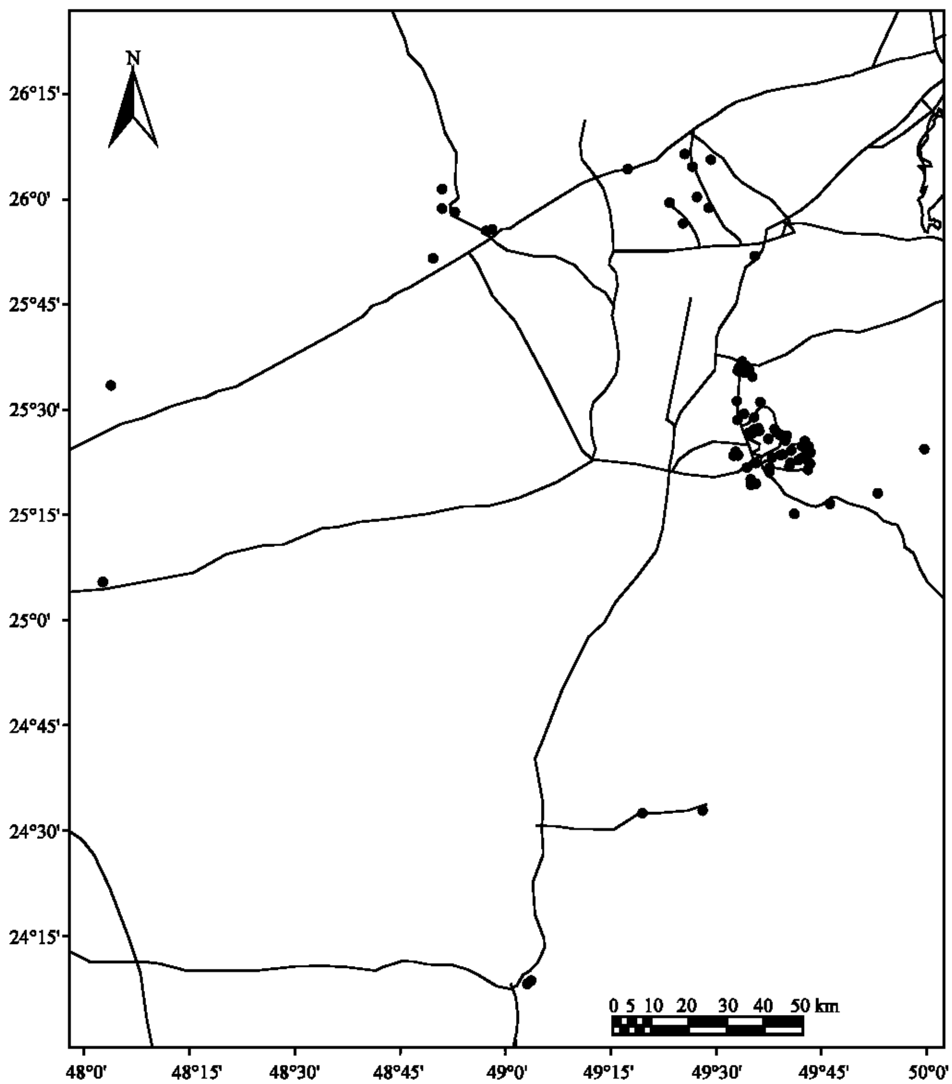

Fig. 1: Location map of groundwater sampling in Al-Ahsa Oasis

Table 1: Analytical methods used in the study

Parameters	Method
Electrical conductivity	Conductivity bridge
pH	Glass electrode
Sulfate	Turbidiometrically
Chloride	Titration method
Alkalinity	Titration method
Total dissolved salts	Gravimetrically
Cations	Flame photometer

$$SSD = EC_{dw} = EC_{iw}/LF \quad (1)$$

Where:

Ec_{dw} = Salinity of the drainage water percolating below the plant root zone

Ec_{iw} = Salinity of irrigation water

LF = Leaching fraction is the amount of irrigation water that leaves the root zone as drainage water

The Sodium Adsorption Ratio (SAR) was calculated as below (USDA, 1954):

$$SAR = Na/[(Ca + Mg)/2)]^{1/2} \quad (2)$$

The adjusted Sodium Adsorption Ratio (adj.SAR) was calculated as (Ayers and Westcot, 1976):

$$adj.SAR = SAR_{iw} [1 + (8.4\text{-}pH_c] \quad (3)$$

Where:

SAR_{iw} = Sodium adsorption ratio of the groundwater as calculated by the normal SAR equation

pH_c = a theoretical calculated pH of irrigation water when in contact with lime and in equilibrium with soil CO_2

$$pH_c = (pK'_2\text{-}pK'_c) + P(Ca + Mg) + P(Alk)$$

Where, P(Ca+Mg) and P(Alk) are negative logrithms of the molar concentration of Ca+Mg and titrable CO_3 + HCO_3, respectively. The pK_2' and pK'_c are the negative logrithms of the second dissociation constant of H_2CO_3 and solubility product of $CaCO_3$, respectively. Positive values indicate that $CaCO_3$ should precipitate and negative values indicate that water will dissolve $CaCO_3$. The data for calculating pH_c is given by Ayers and Westcot (1976).

The $(pK'_2\text{-}pK'_c)$ is obtained by using the sum of Ca + Mg + Na of irrigation water in meq L^{-1} and P(Alk) is obtained by using the sum of CO_3 + HCO_3 of irrigation water in meq L^{-1}.

The adjusted sodium adsorption ratio (adj. R_{Na}) was calculated according to Suarez (1981) using the following equation:

$$adj.\ R_{Na} = Na/[Ca_x + Mg/2]^{1/2} \quad (4)$$

Where, all concentrations in (meq L^{-1}), Ca_x represents concentration after counting for HCO_3 of the irrigation waters.

The Exchangeable Sodium Percentage (ESP) was determined as:

$$ESP = \frac{100\,(-0.0126 + 0.01475 \times SAR}{1 + (-0.0126 + 0.01475 \times SAR)} \quad (5)$$

Where:

SAR = The SAR of the soil solution resulting from irrigation with groundwater

The irrigation waters were classified according to the water classification scheme of US Salinity Laboratory Staff USDA (1954) and Ayers and Westcot (1985).

The calculated adj.SAR takes into account the effect of Na and CO_3 + HCO_3 of irrigation water on soil properties. This concept was developed by Bower *et al.* (1968) and has been found very useful for predicting the effect of sodium hazard of irrigation water on soil properties. Moreover, the new term adj. R_{Na} is used in place of the normal SAR to evaluate better the potential of the water to cause an infiltration problem due to relatively high sodium in irrigation water supplies. It was assumed in this equation that only Ca in the irrigation water precipitates as $CaCO_3$ and the Mg remains in solution and the partial pressure of CO_2 near the soil surface (P_{CO_2}) is 0.0007 atmosphere.

The chemistry data were evaluated by applying various statistical techniques according to Snedecor and Cochran (1973).

RESULTS AND DISCUSSION

Chemistry of groundwater: The ranges of different water quality parameters were 1.23-5.05 dS m^{-1} (EC), 1.80-31.94 meq L^{-1} (Ca), 3.77-12.88 meq L^{-1} (Mg), 6.09-31.33 meq L^{-1} (Na), 0.24-0.89 meq L^{-1} (K), 1.88-4.20 meq L^{-1} (HCO_3), 5.77-32.59 meq L^{-1} (Cl), 4.25-9.17 meq L^{-1} (SO_4), 5.30-37.50 meq L^{-1} (NO_3), 1.51-8.30 (SAR) and 1.97-10.31 (adj. RNa) and 4.15-21.78 (adj.SAR) in the whole Oasis (Table 2). The order of abundance for cations was Na>Ca>Mg, while that of anions was Cl >SO_4>HCO_3. A significant correlation was found between Na and Cl ions (R^2 = 0.936) because Na and Cl were the dominant cation and anion, respectively in the groundwater of Al-Ahsa Oasis when compared with other cations/anions. This means that the groundwater of Al-Ahsa is mainly Na and Cl water with other parameters being within the safe limits for irrigation. Thermodynamic calculations revealed that a significant fraction of Ca and Mg in the groundwater was associated with SO_4 and HCO_3. However, most of the Na and Cl were found in free

Table 2: Chemical composition of groundwater of Al-Ahsa Oasis (Sample No. 0 is the used standard according to WHO, 1998)

Sample No.	pH	EC ($dS\ m^{-1}$)	TDS ($mg\ L^{-1}$)	Ca	Mg	Na	K ($Meq\ L^{-1}$)	HCO_3 ($Meq\ L^{-1}$)	Cl	SO_4	NO_3 ($mg\ L^{-1}$)	F ($mg\ L^{-1}$)	SAR	Water class
0											45.00	1.50		
1	6.70	2.98	1928	8.98	6.00	16.44	0.73	2.64	22.45	7.51	26.20	1.10	6.01	C4S2
2	7.00	2.85	1910	8.98	6.00	16.27	0.73	2.64	22.12	7.42	12.30	1.30	5.95	C4S2
3	7.10	2.25	1660	8.38	6.00	12.61	0.45	3.08	15.55	8.71	26.80	1.30	4.70	C3S2
4	7.00	2.43	1732	9.18	6.00	12.98	0.42	3.20	15.74	9.58	24.00	1.20	4.71	C4S2
5	6.90	2.16	1660	8.78	6.00	12.61	0.47	3.28	15.53	8.70	17.10	1.20	4.64	C3S1
6	7.00	2.64	1824	7.78	6.00	15.85	0.63	2.84	18.68	8.83	16.80	1.30	6.04	C4S2
7	6.90	2.45	1692	8.78	4.93	13.53	0.72	2.84	16.93	8.25	16.50	1.50	5.17	C4S2
8	7.10	2.80	1836	8.78	5.64	15.66	0.68	3.04	20.54	7.13	25.70	1.00	5.83	C4S2
9	7.00	2.10	1624	8.58	6.00	13.13	0.45	3.87	14.60	7.97	24.90	1.20	4.86	C3S2
10	7.00	2.07	1480	7.98	5.60	10.53	0.52	3.08	14.23	7.29	25.70	1.20	4.04	C3S1
11	7.70	2.00	1328	7.98	4.40	9.94	0.45	3.16	13.12	6.46	27.30	1.10	3.99	C3S1
12	7.20	2.10	1398	8.78	4.40	9.81	0.45	3.12	13.32	6.59	27.30	1.10	3.82	C3S1
13	6.90	2.64	2084	10.78	7.42	15.94	0.67	2.84	22.79	9.17	28.50	1.10	5.29	C4S2
14	7.10	2.09	1382	7.19	5.60	9.85	0.50	3.36	13.29	6.34	26.60	1.10	3.90	C3S1
15	6.80	5.05	3566	15.37	12.88	31.33	0.89	3.04	43.66	13.88	21.30	1.20	8.34	C4S3
16	7.10	2.28	1578	8.38	6.00	11.53	0.53	2.96	16.80	6.84	20.70	1.10	4.30	C4S2
17	7.50	1.84	1372	6.39	6.00	10.24	0.45	3.08	13.84	6.51	6.80	1.50	4.12	C3S1
18	7.30	1.84	1302	5.99	5.60	9.89	0.44	3.20	12.92	6.09	6.40	1.50	4.11	C3S1
19	7.50	2.40	1504	7.29	5.20	12.11	0.52	2.96	15.94	6.56	8.40	1.20	4.85	C4S2
20	7.10	4.09	2948	16.47	10.79	21.33	0.73	2.84	31.26	15.08	28.60	1.20	5.78	C4S2
21	7.60	1.23	952	4.39	4.80	6.09	0.45	3.24	7.27	5.57	5.80	2.50	2.84	C3S1
22	7.30	1.95	1352	6.99	4.80	10.27	0.50	3.04	13.99	5.96	6.30	1.70	4.23	C3S1
23	7.20	3.30	2386	10.68	10.39	18.47	0.61	3.08	25.56	11.42	31.30	1.10	5.69	C4S2
24	7.20	3.73	2416	11.88	6.49	21.31	0.69	2.96	26.17	10.96	37.50	1.20	7.03	C4S2
25	7.60	3.40	3262	29.54	13.19	6.98	0.53	2.64	5.77	42.03	6.20	2.70	1.51	C4S1
26	6.90	1.60	1104	6.39	6.00	6.09	0.26	3.20	9.43	6.14	9.20	1.30	2.45	C3S1
27	7.60	1.81	1294	6.19	5.44	9.58	0.48	3.08	12.76	6.17	6.50	1.60	3.97	C3S1
28	7.20	1.99	1336	6.89	4.96	9.95	0.46	3.16	12.75	6.65	7.40	1.70	4.09	C3S1
29	6.70	3.40	3452	31.94	12.79	9.65	0.45	3.70	10.70	39.48	6.00	3.00	2.04	C4S1
30	7.40	1.99	1360	6.79	6.00	9.68	0.50	3.20	12.30	6.90	26.00	1.30	3.83	C3S1
31	7.10	2.80	2396	17.17	11.19	9.83	0.48	3.04	12.85	22.82	13.60	1.80	2.61	C4S1
32	7.30	3.50	2394	8.88	6.32	23.67	0.78	2.84	26.57	10.11	29.10	1.40	8.59	C4S3
33	7.30	2.70	1902	8.38	6.13	16.46	0.73	2.84	21.16	7.75	23.70	1.50	6.11	C4S2
34	7.30	2.56	1854	8.33	6.13	15.93	0.70	3.28	20.03	7.76	21.40	1.50	5.93	C4S2
35	6.80	2.62	1764	8.23	6.13	14.61	0.70	3.04	19.13	7.38	18.90	1.00	5.45	C4S2
36	7.70	2.61	1786	8.58	6.16	14.53	0.73	3.00	19.64	7.42	17.20	1.10	5.35	C4S2
37	6.60	2.61	1720	7.98	6.00	14.80	0.76	2.84	18.68	7.05	19.60	1.10	5.60	C4S2
38	6.80	2.52	1720	7.98	6.00	14.72	0.73	2.88	18.79	7.09	19.80	1.10	5.57	C4S2
39	6.80	3.71	2726	11.58	11.59	22.63	0.70	3.08	30.24	12.91	5.80	1.80	6.65	C4S2
40	7.50	3.61	2724	11.28	10.82	23.24	0.76	2.84	29.62	12.60	47.20	1.50	6.99	C4S2
41	7.80	3.72	2670	11.18	9.99	23.40	0.71	2.84	29.12	11.99	49.60	1.50	7.19	C4S2
42	2.10	2.43	1494	7.30	4.43	12.81	0.53	2.92	15.38	6.26	27.10	0.95	5.29	C4S2
43	6.90	2.30	1502	7.04	5.00	12.62	0.54	2.88	15.58	6.30	27.10	0.95	5.14	C4S2
44	7.00	2.80	1878	8.60	5.66	16.54	0.53	2.76	21.83	6.88	28.50	0.80	6.20	C4S2
45	7.20	2.10	1442	6.91	4.75	11.76	0.48	2.80	14.67	6.35	28.90	1.00	4.87	C3S2
46	7.00	2.20	1362	6.79	3.77	10.80	0.47	3.08	13.27	6.15	28.20	1.10	4.70	C3S2
47	7.10	2.30	1366	6.79	4.59	10.93	0.47	3.04	13.52	6.08	28.30	1.20	4.58	C3S2
48	7.00	2.10	1392	6.71	5.00	10.97	0.48	3.04	14.03	6.04	27.50	1.00	4.53	C3S2
49	6.90	2.10	1396	7.12	4.90	10.85	0.47	3.04	14.11	6.02	25.80	1.00	4.42	C3S2
50	7.10	2.20	1428	7.30	4.18	11.69	0.48	2.76	14.67	6.17	24.70	1.00	4.88	C3S2
51	7.20	3.10	1890	8.53	5.49	17.15	0.55	2.80	22.63	6.36	27.60	1.10	6.48	C4S2
52	7.20	3.00	1924	7.98	5.99	18.10	0.59	2.84	22.69	6.54	29.00	1.10	6.85	C4S2
53	7.10	3.00	1938	8.38	5.73	17.93	0.57	2.88	22.72	6.75	29.70	1.10	6.75	C4S2
54	7.20	2.80	1756	8.34	5.17	15.46	0.58	2.92	19.35	6.71	27.80	1.10	5.95	C4S2
55	7.00	2.80	1720	7.86	5.24	15.24	0.58	2.80	19.47	6.26	25.80	1.10	5.95	C4S2
56	7.20	2.70	1720	7.86	5.24	15.30	0.59	2.80	19.24	6.37	27.10	1.10	5.98	C4S2
57	7.20	2.60	1742	9.00	5.16	14.70	0.59	2.80	17.06	8.39	19.40	1.40	5.52	C4S2
58	6.90	2.80	1702	8.35	4.83	14.88	0.55	3.00	18.62	6.46	26.80	1.10	5.80	C4S2
59	6.80	2.85	1754	8.59	5.16	15.03	0.58	3.00	18.62	7.30	28.00	1.10	5.73	C4S2
60	6.90	2.93	1746	8.67	5.16	14.88	0.59	3.00	18.76	7.05	27.50	1.10	5.66	C4S2
61	7.00	2.50	1710	8.76	5.41	13.92	0.56	3.00	16.82	8.29	20.60	1.20	5.23	C4S2
62	7.10	2.72	1808	8.84	5.82	14.77	0.58	3.00	17.94	8.81	16.80	1.30	5.45	C4S2
63	7.30	2.82	1922	8.18	5.49	18.12	0.65	2.96	21.45	7.62	16.00	1.40	6.93	C4S2
64	7.00	3.20	1980	8.35	5.57	18.68	0.63	3.00	21.38	8.52	15.80	1.30	7.08	C4S2
65	7.00	2.98	1848	8.02	5.49	17.08	0.60	2.88	20.23	7.63	16.30	1.30	6.57	C4S2

Table 2: Continued

Sample No.	pH	EC (dS m^{-1})	TDS (mg L^{-1})	Ca	Mg	Na	K (Meq L^{-1})	HCO_3 (Meq L^{-1})	Cl	SO_4	NO_3 (mg L^{-1})	F (mg L^{-1})	SAR	Water class
66	6.60	2.47	1648	8.82	4.44	13.85	0.61	2.96	18.05	6.36	19.90	1.3	5.38	C4S2
67	6.70	2.54	1640	8.76	4.34	14.01	0.57	2.84	17.92	6.31	18.70	1.3	5.48	C4S2
68	7.10	2.40	1676	8.84	4.59	14.20	0.58	3.00	18.17	6.69	18.90	1.1	5.48	C4S2
69	7.30	1.49	990	6.29	3.93	6.33	0.24	2.88	9.00	4.25	30.90	1.0	2.80	C3S1
70	7.40	1.38	990	6.29	3.93	6.30	0.24	2.92	8.72	4.42	28.80	1.1	2.78	C3S1
71	7.20	1.72	1258	6.71	4.51	9.36	0.51	3.00	11.70	5.94	19.40	1.0	3.95	C3S1
72	7.00	1.98	1308	7.11	4.27	9.98	0.48	3.00	11.00	7.51	5.30	1.0	4.18	C3S1
73	6.70	4.10	2446	16.77	4.00	18.80	0.72	1.88	24.03	13.79	5.50	1.1	5.84	C4S2
74	7.00	3.99	2654	16.77	7.99	18.98	0.75	3.04	26.93	13.85	20.50	1.2	5.39	C4S2
75	7.10	2.43	1476	1.80	9.59	8.29	0.47	3.08	12.67	9.17	6.60	2.7	3.47	C4S1
76	7.20	2.50	2446	13.17	8.79	18.63	0.49	3.04	24.82	11.87	63.40	1.5	5.62	C4S2
77	7.30	3.42	2588	18.76	9.03	14.30	0.39	3.04	19.46	19.36	20.90	1.8	3.84	C4S2
78	7.30	4.20	2856	12.38	8.39	26.98	0.43	3.24	32.59	10.73	78.60	1.1	8.37	C4S2
79	7.20	3.98	2480	11.98	7.59	21.85	0.40	3.16	26.80	10.21	73.80	1.1	6.98	C4S2
80	6.80	3.40	2944	15.57	3.77	19.59	0.53	3.24	18.06	26.04	6.50	2.2	6.30	C4S2
81	7.20	2.68	2214	14.37	10.79	10.37	0.36	3.20	10.21	22.03	6.90	1.8	2.92	C4S1
82	7.10	2.40	1740	8.78	5.20	15.04	0.55	3.16	19.13	6.71	15.20	1.1	5.69	C4S2
83	7.20	3.40	2128	10.38	7.19	18.62	0.50	3.20	26.09	6.64	27.50	1.1	6.28	C4S2
84	7.40	2.10	1422	8.38	4.40	10.55	0.58	3.24	13.12	6.79	31.10	1.0	4.17	C3S1
85	7.50	1.62	976	4.99	5.00	6.66	0.27	3.48	7.40	5.52	6.30	2.1	2.98	C3S1
86	7.20	1.80	1156	6.39	6.00	7.26	0.27	3.24	10.72	5.69	7.20	1.1	2.92	C3S1
87	7.20	2.80	1662	7.98	6.00	14.16	0.47	3.20	17.49	7.18	8.80	1.5	5.35	C4S2
88	6.90	2.35	1446	7.98	5.20	10.98	0.49	3.16	14.95	6.15	13.30	1.5	4.28	C4S2
89	7.18	2.16	1266	7.98	4.00	9.24	0.35	3.24	12.33	5.27	27.00	1.0	3.78	C3S1
90	7.30	2.60	1456	7.98	5.25	11.11	0.39	3.20	14.25	6.81	15.10	1.2	4.32	C4S2
91	7.10	2.40	1514	7.98	5.20	12.11	0.41	3.20	14.43	7.52	12.10	1.3	4.72	C4S2
92	7.10	2.50	1454	8.22	5.20	10.90	0.40	3.20	14.14	6.74	20.00	1.6	4.21	C4S2
93	6.80	2.30	1420	7.98	5.20	10.72	0.38	3.36	14.40	5.75	25.30	1.2	4.18	C4S2
94	6.80	2.32	1388	8.78	4.00	10.46	0.41	3.20	14.39	5.53	18.50	1.2	4.14	C4S1
95	7.10	2.20	1684	9.06	4.00	15.23	0.32	3.72	16.02	7.66	24.10	1.2	5.96	C3S2
96	7.00	2.80	1670	9.26	4.00	16.02	0.50	3.16	18.62	7.30	27.00	1.2	6.22	C4S2
97	7.00	2.83	1824	9.98	4.00	16.10	0.52	3.24	18.76	7.91	27.10	1.2	6.09	C4S2
98	7.00	1.95	1578	6.39	7.99	12.62	0.50	4.20	15.47	6.75	26.40	1.8	4.71	C3S2
99	7.30	1.90	1368	5.99	6.00	10.97	0.38	3.24	13.68	5.88	23.70	1.1	4.48	C3S2
100	7.20	2.15	1470	7.98	7.99	9.13	0.32	3.44	14.40	6.85	27.90	1.1	3.23	C3S1
101	7.30	2.20	1276	6.39	6.00	9.36	0.32	3.36	11.99	6.14	26.10	1.0	3.76	C3S1

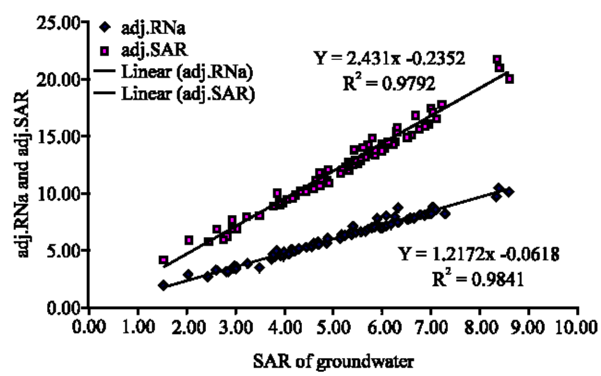

Fig. 2: Relationship between SAR vs predicted adj-RNa and adj.SAR of groundwater of Al-Ahsa oasis

form. A strong relationship was found between SAR and the corresponding calculated adj.SAR and adj. RNa of groundwater to determine the sodicity hazards in soils when irrigated with this groundwater (Fig. 2). The adj.SAR showed that only 15% of total well water samples in the study area could create soil sodicity hazard and the others are safe for crop irrigation.

The salinity and sodicity hazards of groundwater were classified as C3S1 to C4S3 i.e., that is high to very high salinity and slight to very high sodicity problems (USDA, 1954). Mostly the groundwater is high to very high saline with medium to high sodium problems and could be used for irrigation provided management practices such as application of excess water to meet leaching requirement, selection of medium to high salt tolerant crops and improved irrigation system (drip or subsurface) are adopted. These management practices would help to maintain soil salinity within acceptable limits for the cultivation of most crop without appreciable yield reduction.

Ion inter-relationships: There was a strong relation between Na and Cl ions (R^2 = 0.936) followed by poor relation between Ca vs Cl (R^2 = 0.262) and Mg vs Cl (R^2 = 0.153) ions in descending order (Fig. 3). There is a tendency of higher Na values with increased Cl in the groundwater. A good relationship also existed between Ca and SO_4 (R^2 = 0.498) as well as between Mg and SO_4 ions (R^2 = 0.477) in groundwater of Al-Ahsa Oasis (Fig. 4).

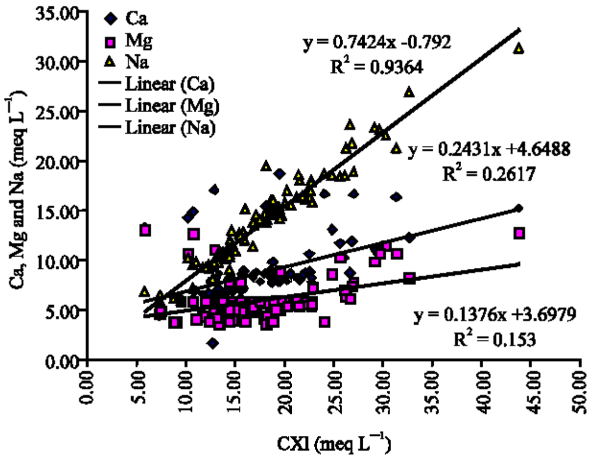

Fig. 3: Relationship between Cl vs Ca, Mg and Na of groundwater of Al-Ahsa Oasis

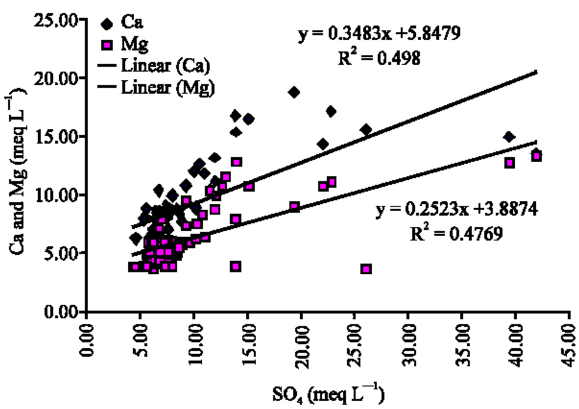

Fig. 4: Relationship between SO_4 vs Ca, Mg of groundwater of Al-Ahsa Oasis

With increased SO_4, the Ca and Mg values tend t increase as well, suggesting interactions between aqueous and solid phases.

The Ca/Mg ratio indicate that Ca concentration is 1.0-2.5 times higher than that of Mg in the groundwater except few wells where the ratio is 1:1 (Fig. 5). This suggests that Ca dominant soils will develop if irrigated with these waters thus improving the soil structure. Overall, the groundwater is mainly Na and Ca dominant water rather than Ca and Mg dominant water and will not create any serious soil salinity problem.

The Cl/SO_4 ratio showed Cl ion as the dominant anion than SO_4 ion in the groundwater. Its range varies between 0.025 to over 3.5 times higher (Fig. 4). The research findings agree with those of Al-Hawas (2002) who concluded that Al-Ahsa groundwater is mainly Na and Ca dominant water with little possibility of developing soil salinity problems after irrigation.

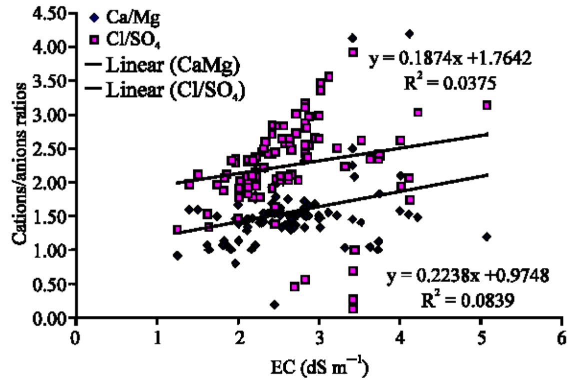

Fig. 5: Relationship between EC vs cations and anions ratios of groundwater of Al-Ahsa Oasis

Nitrate (NO_3) concentration of groundwater: Most of the nitrogen in the groundwater is probably derived from the biosphere. The nitrogen originally fixed from the atmosphere, is mineralized by soil bacteria into ammonium, which is converted into nitrate by nitrifying bacteria under aerobic conditions (Tindall *et al*., 1995). Mean nitrate concentration (mg L^{-1}) of groundwater of Al-Ahsa Oasis is between 5.30 and 37.50 (Table 3) except four wells where the concentration is between 47.20 and 82.90 mg L^{-1}. These wells are located in the vicinity of highly intensive agricultural productive area. The farmers seemed to be using high doses of nitrogen fertilizers to obtain increased crop production which might have caused high nitrogen losses thus contaminating the shallow groundwater aquifer. The maximum permissible limit of nitrate concentration in water for various purposes especially for drinking is 45 mg L^{-1} according to WHO (1998). The data reveal that the groundwater contains low level of nitrate which is within permissible limits for drinking purposes according to WHO (1984) drinking water quality standards without serious health hazards.

Fluoride (F) concentration of groundwater: Fluoride exists fairly abundantly in earths crust and can enter groundwater by natural processes. Mean fluoride concentration (mg L^{-1}) ranged from 0.80-2.7 in the groundwater of Al-Ahsa Oasis (Table 2). According to WHO (1984), fluoride is an effective agent for preventing dental caries if taken in optimal amounts. Water is a major source of fluoride intake. The WHO (1984) guidelines suggested that in areas with a warm climate, the optimal fluoride concentration in drinking water should remain below 1 mg L^{-1}, while in cooler climate it could go up to 1.2 mg L^{-1}. The guidelines value (permissible upper limit) for fluoride was set at 1.5 mg L^{-1}. However, the F concentration of groundwater in about

Table 3: Mean Saturation Indices (SI) of different minerals of groundwater of al-Ahsa oasis, eastern region Saudi Arabia

			SI-Range		Percentile	
Mineral	Formula	Total samples	Minimum	Maximum	Unsaturated	Saturated
Halite	NaCl	101	-6.562	-3.725	100	0
Calcite	$CaCO_3$	101	-8.104	0.281	65	35
Anhydrite	$CaSO_4$	101	-3.390	-0.147	100	0
Gypsum	$CaSO_4.2H_2O$	101	-3.376	0.030	99	1
Dolomite	CaMg (CO_3)	101	-16.190	0.744	79	21
Flourite	CaF_2	101	-3.846	0.042	99	1
Hamitite	Fe_2O_3	101	-8.980	25.425	1	99
Goethite	FeO(OH)	101	-6.019	11.688	1	99
Aragonite	$CaCO_3$	101	-8.241	0.142	76	24
Pyrite	FeS_2	101	-106.196	-8.573	100	0
Siderite	$FeCO_3$	101	-5.857	4.944	3	97

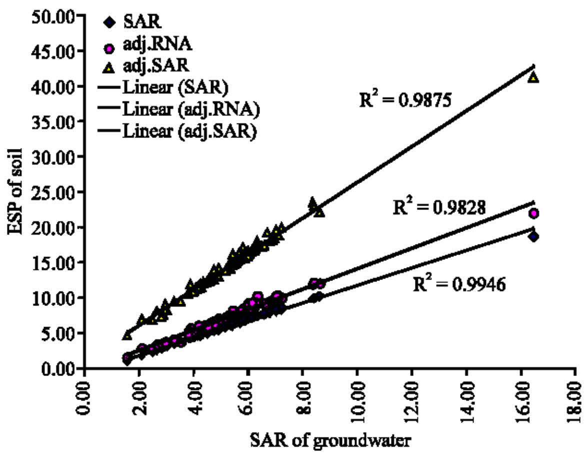

Fig. 6: Relationship between SAR and predicted ESP of soil

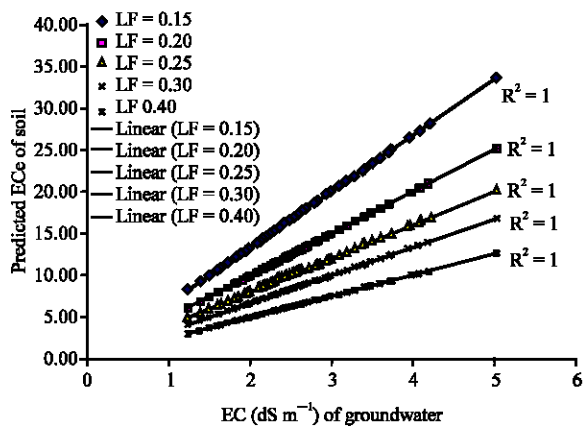

Fig. 7: Predicted Ece of soil against different hypothetical leaching fractions

85% of water samples was found within permissible limit of WHO (1984). The SI value of fluorite mineral is negative in 99% of water samples of study area. This indicates more dissolution of F in water due to water-rock interaction especially during water flow through the fluoride bearing mineral rocks.

Effect of water quality on soil properties: Groundwater is the only source of irrigated agriculture in the Oasis. Therefore, the effect of the prolonged use of groundwater was predicted on the soil salinity and sodium hazards using saline groundwater for crop production. The SAR of groundwater was calculated. This information was used to calculate adj.SAR and adj.R_{Na} which accounts for alkalinity hazards and the Exchangeable-Sodium-Percentage (ESP) of soil. The SAR of groundwater ranged from 1.41-8.30 with corresponding adj.R_{Na} and adj.SAR ranging from 1.97-10.30 and 4.15-21.78, respectively (Table 2 and Fig. 2). The predicted Exchangeable-Sodium-percentage (ESP) resulting from groundwater irrigation is shown in Fig. 6. The ESP values predicted from adj.SAR are much higher than those predicted from adj. R_{na} and SAR of groundwater. Since, the adj.SAR over predicts the sodium hazards of groundwater and is no longer a valid criteria for predicting the sodicity hazards of soil. The ESP predicted from two other SARs (SAR and adj.R_{Na}) does not show any sodicity hazards from irrigation of groundwater. The upper safe limit of ESP value for soil is 15 according to USDA (1954) and Ayers and Westcot (1985), hence there is no immediate soil sodicity problem from groundwater irrigation except in few cases where the SAR is more than the recommended limits. In the case of long term irrigation practice, there might be some soil sodicity problems which could be avoided if management practice such as leaching requirement (application of 15-20% excess water above crop ET requirements) is followed to keep soil salinity and sodicity within safe limits.

Development of soil salinity from groundwater irrigation was also considered and predicted using five hypothetical leaching fractions ranging from 0.15-0.40 (Fig. 7). It was found that around 40% of the groundwater will develop soil salinity more than 8 dS m^{-1} which is considered as moderate to highly saline soil where cultivation of moderate to high salt tolerant crops could be possible without significant yield reduction provided

15% excess water above crop water requirements (ET) is applied as leaching requirement to maintain soil salinity within acceptable limits.

Saturation indices: The chemical composition of natural waters is derived from many different sources of solutes including both gases and aerosols from the atmosphere and the weathering and erosion of rocks and soils. Dissolution and precipitation reactions of minerals occur below the soil surface where their concentration is influenced by many environmental factors, especially the position and the solubility of rock strata (water-rock interaction) (Lin and Clemency, 1980; Ronge and Claesson, 1982).

Saturation Indices (SI) were calculated for 100 groundwater samples only from Al-Ahsa Oasis using the speciation code WATEQ4 (Ball and Nordstrom, 1992) and the PHREEQC model developed by Parkhurst (1995). One water sample was missing and ignored in the calculations. Mean saturation indices of different minerals are given in Table 3. The groundwater is under-saturated (negative SI) with respect to certain minerals (for example: Calcite, dolomite, gypsum, anhydrite, halite, pyrite, fluorite and aragonite) and oversaturated (positive SI) with respect to some other minerals (For example: goethite, Siderite and hematite). Actually, the SI is a measure of the thermodynamics state of a solution relative to the equilibrium with a specified solid-phase mineral. In the study area, most of the groundwater is under-saturated with respect to calcite, dolomite, gypsum, anhydrite, halite, pyrite, fluorite and aragonite, the groundwater flow is capable of dissolving the aquifer rock thus increasing both its porosity and permeability. The groundwater is oversaturated with respect to goethite, Siderite and hematite (SI is positive), these minerals will precipitate and adversely affect the aquifer properties.

CONCLUSIONS

The EC of groundwater ranged between 1.23 and 5.05 dS m^{-1} with Na and Cl as the most abundant cation and anion, respectively. The SAR and ESP values are within the permissible limits according to USDA, 1954. The NO_3 concentration is within safe limits for drinking purpose according to WHO (1998) standards except few samples where the NO_3 concentration is very high. The groundwater is under-saturated (negative SI) with respect to certain minerals (for example: calcite, dolomite, gypsum, anhydrite, halite, pyrite, fluorite and aragonite) and oversaturated (positive SI) with respect to some other minerals (For example: goethite, Siderite and hematite). The negative saturation index (SI) reveals that most of minerals are in un-saturated state and will dissolve more Ca and Mg into the soil solution after irrigation. A good relationship exists between Cl and Na, Ca and Mg ions as well as between SO_4 and Ca and Mg ion of groundwater. Medium to high salinity and slight to moderate sodicity problems could be expected from the prolonged use of groundwater. The groundwater of Al-Ahsa oasis is mainly Na and ca water rather than Ca and Mg dominant water and will not create any serious soil salinity problem. The predicted soil salinity suggests application of 15-20% excess water above crop ET to fulfill leaching requirements to keep soil salinity within permissible limits in the crop root zone. Cultivation of slight to moderate salt and sodium tolerant crops is recommended for optimal agricultural production and efficient water use.

REFERENCES

Al-Hawas, I.A., 2002. Irrigation water quality evaluation of Al-Hassa springs and its predictive effects on soil properties. Pak. J. Biol. Sci., 5: 651-655.

Allael-Din, M.N., I.M. Madany, A. Al-Tayaran, A.H. Al-Jubair and A. Gomaa, 1993. Quality of water from some well in Saudi Arabia. Water Air Soil Pollut., 66: 135-143.

Anonymous, 1978. Water Resources of Al-Hassa Oasis. Leichtweiss Institute. Ibid Publication No. 22.

Anonymous, 1979. The Water Potential of the Al-Hassa Oasis. Leichtweiss Institute. Ibid Publication No. 38.

Anonymous, 1985. Fourth Development Plan. Ministry of Planning, Riyadh, Saudi Arabia.

Anonymous, 1985. Water Atlas of Saudi Arabia. Water Resource Department. Ministry of Agriculture and Water, Riyadh, Saudi Arabia.

Anonymous, 1992. Agriculture Statistical Year Book. Department of Economic Studies and Statistics, Ministry of Agriculture and Water, Riyadh, Saudi Arabia, Vol. 7.

Ayers, R.S. and D.W. Westcot, 1976. Water quality for agriculture. FAO Irrigation and Drainage Paper 29, FAO, Rome, pp: 97.

Ayers, R.S. and D.W. Westcot, 1985. Water quality for agriculture. FAO Irrigation and Washington, DC.

Ball, J.W. and D.K. Nordstrom, 1992. Geochemical model to calculate speciation of major, trace and redox elements in natural waters. US. Geological Survey. International Groundwater Modeling Center, pp: 189.

Bazuhair, A.S. and A. Alkaff, 1989. Evaluation of ground water quality in Wadi Al-Yamaniyah Saudi Arabia. Arab Gulf J. Sci. Res., 7: 21-38.

Bower, C.A., G. Ogata and J.M. Tucker, 1968. Sodium hazard of irrigation waters as influenced by leaching fraction and by precipitation or solution of calcium carbonate. Soil Sci., 106: 29-34.

Dabbagh, A.E. and W.A. Abderrahman, 1997. Management of groundwater resources under various irrigation water use scenarios in Saudi Arabia.

Faruq, I.M., M. Jahangir and A.S. Al-Shareef, 1996. Chemical characteristics of Saudi ground water, Al-Qassim. Biol. Sci. Saudi Biol. Soc. J., 4: 123-140.

Hussain, G. and M. Sadiq, 1991. Metal chemistry of irrigation and drainage waters of Al-Ahsa Oasis of Saudi Arabia and its effects on soil properties. Water. Air Soil Pollut., 57-58: 773-783.

Lin, F. and C. Clemency, 1980. The kinetics of dissolution of muscovites at 25°C and 1 atm CO_2 partial pressure. Proceedings of 3rd International Symposium on Water-Rock Interaction, Edmonton.

Lin, M.T., 1984. Agrometerology Study of Al-Hassa Oasis. Hofuf, Saudi Arabia.

Mee, J.M., 1983. Saudi ground water chemistry and significance. Arab Gulf J. Sci. Res., 1: 113-120.

Oster, J.D. and J.D. Rhoades, 1977. Various Indices for Evaluating the Effective Salinity and Sodicity of Irrigation Waters. In: Proceeding Inst. Salinity Conf. Texas Tech. Univ., Dregne, H.E. (Ed.). Lubbock, 16-20 August. 1976, pp: 1-14.

Parkhurst, D.L., 1995. Users guide to PHREEQC: A computer program for speciation, reaction path, active transport and inverse geochemical calculations. USGS Water Resources Investigations Report, Vol. 33.

Ronge, B. and T. Cleasson, 1982. *Bergarters och minerals* L. slight I hetvatten (Water-Rock interactions at elevated temperatures). Stiftelsen Bergteknish Forskining- BeFo No. 72: 1/82. Swedish Rock Eng. Res. Found. (BeFo in Swedish with English summary).

Snedecor, G.W. and W.G. Cochran, 1973. Statistical Methods. 6th Edn. Iowa University Press, Ames.

Suarez, D.L., 1981. Relation between pH_c and sodium adsorption ratio (SAR) and an alternate method of estimating SAR of soil or drainage waters. Soil Sci. Soc. Am. J., 45: 469-475.

Tindall, J.A., R.L. Petrusak and P.B. McMohan, 1995. Nitrate transport and transformation processes in unsaturated porous media. J. Hydrol., 169: 51-94.

USDA, 1954. Diagnosis and Improvement of Saline and Alakli Soils, United State Department of Agriculture. USDA Handbook No. 60. US Government Printing Office, Washington, DC.

Vidal, F.S., 1951. The Oasis of Al-Hassa. ARAMCO, Dhahran, Saudi Arabia. Water Atlas of Kingdom of Saudi Arabia, 1985. Ministry of Agriculture and Water, Riyadh, Saudi Arabia.

Wakuti, 1964. Studies of the project of improving irrigation and drainage in the region of Al-Hassa, Saudi Arabia. Vol. 4, Siegen, West Germany.

WHO, 1984. Guideline for Drinking Water Quality Vol. 2. Health Criteria and Other Supporting Information. World Health Organization, Geneva.

WHO, 1998. Guidelines for Drinking Water Quality. Vol. 16. Health Criteria and Other Supporting Information. World Health Organization, Geneva.