http://www.pjbs.org

PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet

Asian Network for Scientific Information

308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 5(6): 651-655, 2002

Irrigation Water Quality Evaluation of Al-Hassa Springs and its Predictive Effects on Soil Properties

Ibrahim A. Al-Hawas
Department of Soil and Water, College of Agriculture and Food Sciences,
King Faisal University, P. O. Box 400 Al-Hassa 31982, Kingdom of Saudi Arabia

Abstract: The chemical composition of spring waters of Al-Hassa oasis, their water quality classification, its predictive effects on soil properties were determined and some potential management practices were suggested for maximizing its use without serious soil degradation and loss of soil productivity. The ranges for different water quality parameters were: EC (2.90-4.24 dS m^{-1}), SAR (4.44-6.90), adj.SAR (9.76-16.56), ajd.R_{Na} (5.00-8.07). The ratios calculated among different cations and anions ranged between 1.35-5.54 (Ca/Mg) and 1.88-4.33 (Cl/SO_4). The spring waters were higher in Ca^{+2} and Cl^- contents than the corresponding Mg^{+2} and SO_4^- ions. A positive correlation was found among different water quality parameters such as EC, SAR, ajd.SAR and adj.R_{Na}. The salinity and sodicity hazards of spring waters are classified as C_4S_2 i.e. very high salinity with medium sodicity problems. A leaching fraction of 15-20 % is recommended providing certain management practices such as provision of adequate drainage, proper crop selection, suitable seeding practices and improved irrigation systems are adopted to minimize the harmful effects expected from the use of these waters under the prevailing agro-climatic and plant growth conditions.

Key words: Al-Hassa, spring water, salinity, SAR, ajd.SAR, adj.R_{Na}, correlation, management

Introduction

Saudi Arabia is an arid and the largest country in the middle east with a total land area of 2.253 x 10^6 km^2. The total cropped area in the Kingdom has increased from 1.25 (1988) to 1.51 (1992) million hectares (Ministry of Agriculture and Water, 1992). Consequently, the demand for irrigation supplies has shown manifold increases from 1.75 billion m^3 in 1975 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.

The quality of water for irrigation is determined by its chemical composition and the conditions of use. Because all the waters, surface or sub-surface, contain salts in different amounts and proportions and, will increase the concentration of the soil solution upon irrigation. Besides Al-Hassa Oasis, many researchers have evaluated water quality in other regions of Saudi Arabia such as Wadi Al-Yamaniyah (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 (Allael-Din, *et al.*, 1993).

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 has been observed from -2.6 to 51.3°C but night frosts are rare (Lin, 1984).

The arable land in Al-Hass Oasis was estimated to be about 16,000 hectares (Vidal, 1951). Water resources comprise mainly 1). Rainfall which is about 73 mm annually 2). Important water aquifers are Wasia, Umm-er-Radhuma, Al-Khober, Alat and Neogene and 3). There are 32 free flowing water springs according to Vidal (1951) (Fig. 1).

Information on the quality of spring waters in Al-Hassa Oasis is inadequate for guidance to the farming community for optimal crop production. The main objective of this paper is to review irrigation water quality of Al-Hassa springs, its predictive effects on soil properties and to determine its possible use in the field of agriculture in Al-Hassa Oasis.

Materials and Methods

The study was conducted in Al-Hassa Oasis which is, often referred to as the largest and the oldest Oasis in the Arabian Peninsula, located in the Eastern Region of Saudi Arabia about 150km south of the part of Dammam and 320km south-east of the capital, Riyadh. It extends from approximately 25° 21' to 25° 37' (Table 1), latitude north and from 49° 33' to 49° 46' longitude

Table 1: Analytical methods used in the study

Parameters	Methods	References
Electrical conductivity	Conductivity Bridge	USDA (1954)
pH	Glass electrode	"""""
Sulfate	Turbidimetrically	"""""
Chloride	Titration method	"""""
Alkalinity	Titration method	"""""
Total dissolved salts	Gravimetrically	"""""
Cations	Flame photometer	"""""

Table 2: Data for Calculating pH_c

Sum of concentrations (me L^{-1})	pK'_2-pK'_c	p(Ca+ Mg)	P(Alk)
0.05	2.0	4.6	4.3
0.10	2.0	4.3	4.0
0.15	2.0	4.1	4.0
0.20	2.0	4.0	3.8
0.25	2.0	3.9	3.7
0.30	2.0	3.8	3.6
0.40	2.0	3.7	3.5
0.50	2.1	3.6	3.4
0.75	2.1	3.4	3.1
1.00	2.1	3.3	3.0
1.25	2.1	3.2	2.9
1.50	2.1	3.1	2.8
2.00	2.2	3.0	2.7
2.50	2.2	2.9	2.6
3.00	2.2	2.8	2.5
4.00	2.2	2.7	2.4
5.00	2.2	2.6	2.3
6.00	2.2	2.5	2.2
8.00	2.3	2.4	2.1
10.0	2.3	2.3	2.0
12.5	2.3	2.2	1.9
15.0	2.3	2.1	1.8
20.0	2.4	2.0	1.7
30.0	2.4	1.8	1.5
50.0	2.5	1.6	1.3
80.0	2.5	1.4	1.1

(Source: Ayers and Westcot, 1976).

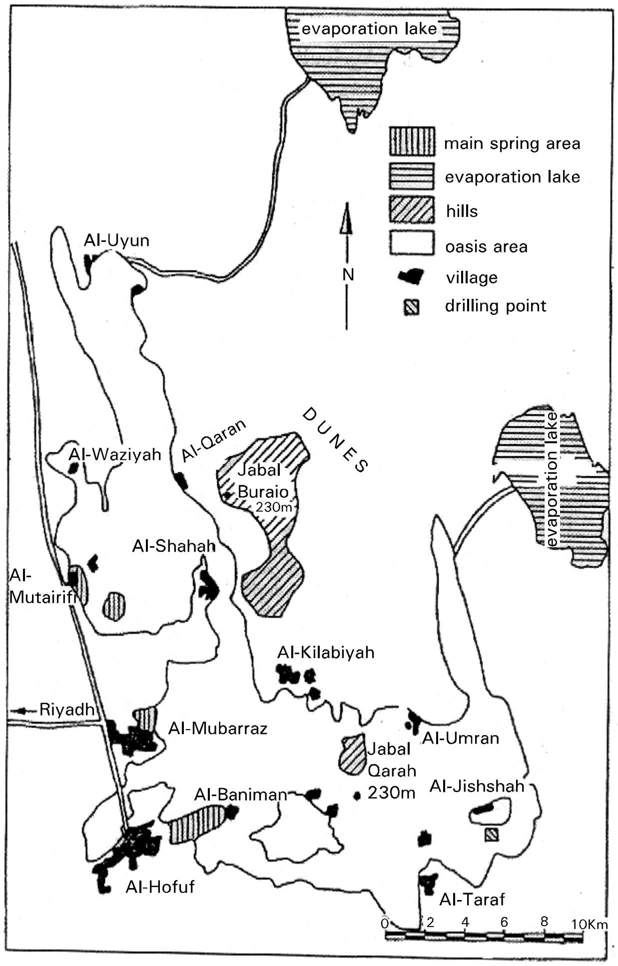

Fig. 1: General map of the Oasis of Al-Hassan

east. It embraces an L-shaped area of 320 km^2 (Fig. 1) 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, 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-westren corner of the Oasis. The overall area can be considered as twin Oasis with an Oasis in the north and the other in the south.

Previously, there were 32 major and minor free flowing springs. The Water from these springs is utilized to meet irrigation demands of the Oasis. However, excess water, over the crop water requirements, is applied to leach salts out of plant root zone. The irrigation network is covered by a well defined network of drainage canals to carry excess water (leachate from fields) to two common lakes.

Presently, the most active springs were selected for sampling where water was available either as free flow or being pumped through a well installed at the site of a particular spring. About one liter water was collected in November, 2000. The water samples were collected in plastic bottles, pH and EC were measured, and the samples were stored in an ice box during transportation. Each sample was filtered through 0.45mm pore size filter paper and divided into two portions; one for cation analysis and the other for anion determinations. Concentration of total dissolved salts, Ca, Mg, Na, K, CO_3, HCO_3, Cl and SO_4 were determined. The analytical procedures used for these determinations were those described in USDA Handbook No. 60, (1954) and are summarized in Table 2.

Soil salinity development (SSD), adjusted sodium adsorption ratio (adj.SAR), Adjusted Na Ratio (adj. R_{Na}), and Exchangeable Sodium Percentage (ESP) were calculated from the analytical data. The SSD was calculated according to Ayers and Westcot, (1985). The equation used was:

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

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.

a. The Sodium Adsorption Ratio (SAR) was calculated as below:

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

b. The Adjusted Sodium Adsorption Ratio (adj.SAR) was calculated as Ayers and Westcot (1976).

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

Where SAR_{iw} is sodium adsorption ratio of the irrigation water as calculated by the normal SAR equation and pH_c is a theoretical calculated pH of irrigation water when in contact with lime and in equilibrium with soil CO_2.

$$pH_c = (pK'_2 - pK'_c) + P(Ca + Mg) + P(Alk)$$

Where P(Ca + Mg) and P(Alk) are negative logarithms of the molar concentration of Ca+ Mg and titrable CO_3 + HCO_3, respectively. The pK_2' and pK'_c are the negative logarithms 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 in Table 2.

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

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

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:

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

Where SAR is the SAR of the soil solution resulting from irrigation with spring waters. The irrigation waters were classified according to the water classification scheme of U.S. Salinity Laboratory, Staff, USDA (1954).

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

The calculated adj.SAR takes into account the effect of Na and CO_3 + HCO_3 of irrigation water on soil properties (Bower *et al.*, 1968).

Results and Discussion

Chemical composition of irrigation waters: Different water quality parameters ranged between 2.90-4.24dS m^{-1} (EC), 7.10-7.46 (pH), 1856-2714mg L^{-1} (TDS), 253-395mg L^{-1} (Na), 147-179mg L^{-1} (Ca), 28-75mg L^{-1} (Mg), 21-31mg L^{-1} (K), 170-194mg L^{-1} (HCO_3), 540-738 mg L^{-1} (Cl), 241-465 mg L^{-1} (SO_4), 4.3-6.9 (SAR), 9.76-16.56 (adj.SAR) and 5.00-8.07 (adj.R_{Na}) in spring waters (Appendix I & II). The dominant cation is sodium (Na) followed by calcium (Ca) and magnesium (Mg) whereas the dominant anion is chloride (Cl) followed by sulfate (SO_4) and bicarbonate (HCO_3) in that order. The waters are classified as C_4S_2 according to USDA Handbook No. 60 (1954). Therefore, the present spring waters fall in the category of very high salinity with medium sodicity problems. These spring waters can be used safely for irrigation provided certain land and water management practices are adopted for controlling the salt build up in soils. A strong correlation was found between EC, SAR, adj.SAR and adj.R_{Na} (Fig. 2), with correlation coefficient (r) values of 0.678 (EC vs SAR), 0.774 (EC vs adj.SAR) and 0.731 (EC vs adj.R_{Na}). The relationship indicate that the SAR values increase with the square root concentration of any increase in water salinity.

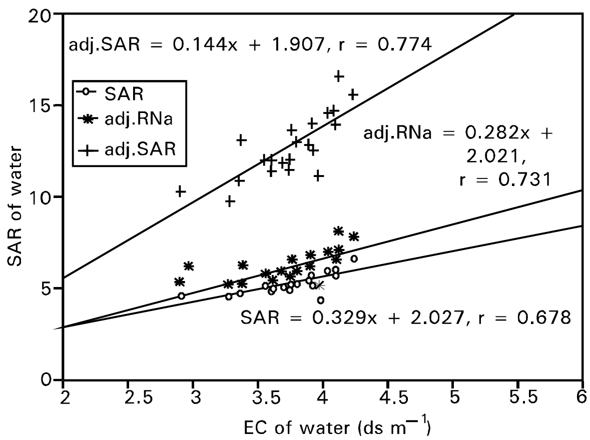

Fig. 2: Relationship between EC vs SAR, adj.SAR and adj.RNa

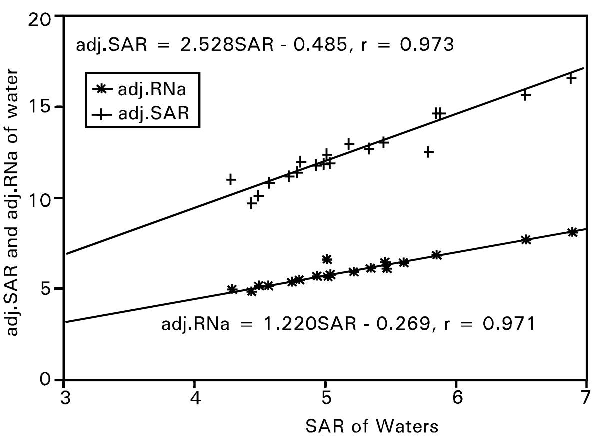

Fig. 3: Relationship between SAR vs adj.SAR and adj.RNa

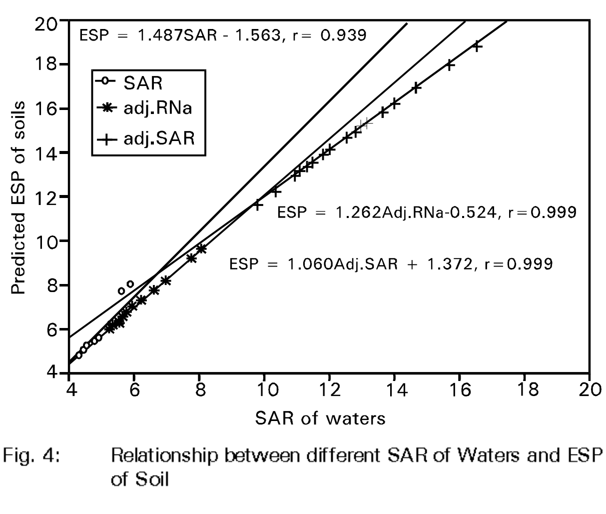

Fig. 4: Relationship between different SAR of Waters and ESP of Soil

Table 3: Prediction of soil salinity (EC of saturation paste extract, dS m^{-1}) from irrigation with spring waters

Spring	Water-EC ($dS\ m^{-1}$)	Leaching fraction 0.15	0.20	0.30	0.40	0.50
Al-Harrah	3.89	25.93	19.45	12.97	9.73	7.78
Al-Huweirrat	4.24	28.27	21.20	14.13	10.60	8.48
Um Sabah	4.03	26.87	20.15	13.43	10.08	8.06
Mansur	3.91	26.07	19.55	10.03	9.78	7.82
Abu Nasser	4.09	27.27	20.45	13.63	10.23	8.18
Al-Jawahriya	4.10	27.73	20.50	13.67	10.25	8.20
Al-Khadood	3.28	21.87	16.40	10.93	8.20	6.56
Al-Lawami	3.74	24.93	18.70	12.47	9.35	7.48
Al-Manna	3.69	24.60	18.45	12.30	9.23	7.38
Um Alif	3.61	24.07	18.05	12.03	9.03	7.22
Ain Bahjah	3.60	24.00	18.00	12.00	9.00	7.20
Ain Brabar	3.55	23.67	17.75	11.83	8.88	7.10
Ain Um Dali	3.80	25.33	19.00	12.67	9.50	7.80
Ain Ammara	3.76	25.07	18.80	12.53	9.40	7.52
Ain Raseeb	3.97	26.47	19.85	13.23	9.93	7.94
Um Qurash	3.37	22.47	16.85	13.48	8.43	6.74
Um Saif	3.36	22.90	16.80	11.20	8.40	7.72
Ain Bari Mann	3.75	25.00	18.75	12.50	9.38	7.50
Ain Sahla	3.92	26.13	19.60	13.07	9.80	7.84
Ain Al-Bahriya	2.90	19.33	14.50	9.67	7.23	5.80
Ain Al-Hawarat	4.12	27.47	20.60	13.73	10.30	8.24

Table 4: Changes in spring water salinity

Spring	EC dS m^{-1} 1975[a]	1990[b]	2000
Khudud	2.1	2.34	3.25
Haql	2.1	2.02	---
Umm Saif	2.2	--	3.36
Amarah	2.4	--	3.76
Rasibe	2.2	--	3.97
Barabir	2.4	2.91	3.55
Umm Allif	2.6	2.84	3.61
Buhadji	2.4	2.76	3.60
Manah	2.4	2.81	3.69
Luwaimi	2.4	3.02	3.74
Umm Dalli	2.5	3.35	3.80
Bsetinat	2.4	3.02	--
Jaburiyah	2.6	2.83	2.90
Bahlah	2.4	2.49	3.92
Huweirrat	2.5	2.69	4.24
Abu Nasser	2.5	--	4.09
Umm Sabah	2.4	2.64	4.03
Jauhariyah	2.3	2.69	4.10
Mansur	2.4	2.55	3.91
Harrah	2.4	2.70	3.89
Ain Sumbor	2.5	2.69	--

[a](Source: Anonymous, 1984)
[b](Source: Hussain and Sadiq, 1991)

Appendix I: Chemical composition of spring waters

Lab. Ref.	Sender Id	EC $dS\ m^{-1}$	pH	TDS (mg/l)	Total Hardness (mg/l)	Cations (mg/l) Na	K	Ca	Mg	Anions (mg/l) SO_4	HCO_3	Cl	SAR
01	Ain Al-Hara	3.89	7.12	2490	712	328	28	168	71	367	178.1	660	5.3
02	An Al-Hawarat	4.24	7.44	2714	691	395	31	179	59	410	185.4	717	6.5
03	Ain Um-Saba	4.03	7.09	2579	666	348	29	163	63	416	187.9	618	5.9
04	Ain Mansoor	3.91	7.40	2502	706	343	31	169	69	235	194.0	767	5.6
05	Ain Nasser	4.09	7.23	2618	662	348	29	167	59	286	189.7	710	5.9
06	Ain Al-Jawahriya	4.10	7.43	2624	718	345	27	176	68	404	184.2	660	5.6
07	Ain Al-Khadood	3.28	7.45	2099	626	255	21	148	62	299	163.5	540	4.4
08	Ain Al-Lowaimi	3.74	7.10	2394	720	295	22	171	71	408	175.1	582	4.8
09	Ain Al-Manna	3.69	7.16	2362	689	298	22	159	71	352	178.7	604	4.9
10	Ain Um-Allif	3.61	7.15	2310	676	288	22	157	69	362	184.2	568	4.8
11	Ain Bahjah	3.60	7.20	2304	699	288	22	167	69	365	172.0	589	4.7
12	Ain Brabir	3.55	7.09	2272	680	300	22	163	67	241	182.4	682	5.0
13	Ain Um-Dalli	3.80	7.10	2432	708	318	22	168	70	262	186.7	710	5.2
14	Ain Amarah	3.76	7.06	2406	704	333	23	177	64	435	186.1	604	5.5
15	Ain Rasseb	3.97	7.10	2541	769	273	23	184	75	345	183.6	625	4.3
16	Ain Um-Quraish	3.37	7.13	2157	668	325	21	154	69	347	170.2	639	5.5
17	Ain Um-Saif	3.36	7.09	2150	689	275	21	158	71	355	175.1	568	4.6
18	Ain Bani Mann	3.75	7.13	2400	743	315	22	171	77	336	177.5	682	5.0
19	Ain Bahla	3.92	7.13	2509	748	315	24	253	28	331	190.3	682	5.0
20	Ain Al- Bahriyia	2.90	7.46	1856	601	253	21	147	57	246	181.2	547	4.5
21	Ain Al-Hawarat	4.12	7.28	2637	718	425	31	168	73	465	190.9	738	6.9

Appendix-II: Chemical composition of spring waters

Spring	SAR	adj. SAR	adj. R_{Na}	ESP-1	ESP-2	ESP-3	Class
Ain Al-Hara	5.34	12.82	6.14	6.21	15.01	7.23	C_4S_2
Ain AL-Hawarat	6.54	15.69	7.76	6.21	15.01	7.23	C_4S_2
Ain Um-Saba	5.86	14.65	6.88	7.96	16.92	8.16	C_4S_2
Ain Mansoor	5.61	14.03	6.61	7.64	16.28	7.83	C_4S_2
Ain Nasser	5.88	14.70	6.98	7.98	16.96	8.29	C_4S_2
Ain Al-Jawahriya	5.60	14.00	6.55	6.54	16.25	7.75	C_4S_2
Ain Al-Khadood	4.44	9.76	5.00	5.02	11.61	5.76	C_4S_2
Ain Al-Lowaimi	4.78	11.48	5.53	5.47	13.56	6.45	C_4S_2
Ain Al-Manna	4.93	11.84	5.70	5.67	13.94	6.67	C_4S_2
Ain Um Allif	4.81	12.03	5.55	5.56	14.15	6.48	C_4S_2
Ain Bahjah	4.73	11.35	5.44	5.41	13.41	6.34	C_4S_2
Ain Brabir	5.00	12.01	5.72	5.76	14.13	6.34	C_4S_2
Ain Um Dalli	5.19	12.98	5.98	6.61	15.17	7.03	C_4S_2
Ain Amarah	5.45	13.64	6.42	6.35	15.87	7.59	C_4S_2
Ain Rasseb	4.28	1.12	5.03	4.81	13.15	5.80	C_4S_2
Ain Um Quraish	5.47	13.13	6.21	6.37	15.33	7.32	C_4S_2
Ain Um Saif	4.56	10.94	5.20	5.18	12.95	6.02	C_4S_2
Ain Bani Mann	5.03	121.06	5.83	5.80	14.18	6.84	C_4S_2
Ain Bahla	5.01	12.54	6.67	5.78	14.70	7.90	C_4S_2
Ain Al-Bahriyia	4.48	10.31	5.17	5.08	12.24	5.99	C_4S_2
Ain Al-Hawarat	6.90	16.56	8.07	8.19	18.81	9.62	C_4S_2

ESP-1 calculated from simple SAR, ESP-2 calculated from adj.SAR and ESP-3 calculated from adj.RNa

Table 5: Cations/Anions ratios of different spring waters

Spring	Water-EC ($dS\ m^{-1}$)	Ratios Ca/Mg	Cl/SO_4
Al-Hara	3.89	1.43	2.43
Al-Hawarat	4.24	1.82	2.37
Um Saba	4.03	1.58	2.01
Mansoor	3.91	1.49	4.33
Nasser	4.09	1.70	3.36
Al-Jawahriya	4.10	1.56	2.21
Al-Khadood	3.28	1.45	2.44
Al-Lawami	3.74	1.46	1.93
Al-Manna	3.69	1.36	2.32
Um Alif	3.61	1.39	2.12
Ain Bahjah	3.60	1.47	2.18
Ain Brabar	3.55	1.48	3.83
Ain Um Dali	3.80	1.47	3.67
Ain Ammara	3.76	1.69	1.88
Ain Raseeb	3.97	1.48	2.45
Um Qurash	3.37	1.36	2.49
Um Saif	3.36	1.36	2.17
Ain Bani Mann	3.75	1.35	2.75
Ain Bahla	3.92	5.54	2.78
Ain Al-Bahriya	2.90	1.56	3.00
Ain Al-Hawarat	4.12	1.40	2.15

Relationship between SAR and adj.SAR & adj.R_{Na}: The SAR of spring waters ranged between 4.44-6.90 with corresponding adj.SAR and adj.R_{Na} between 9.76-15.65 and 5.03-8.07, respectively. A strong relationship between SAR and adj.SAR (r = 0.973) and between SAR and adj.R_{Na} (r = 0.971) was noted (Fig. 3). The increase in adj.SAR with a unit increase in SAR of spring waters were almost half of that of the adj.R_{Na}. This implies that adj.SAR, as determined here, would over predict the Na hazards to soils. Similar conclusions were drawn by Oster and Rhoades (1977), Oster and Schroer (1979) and Suarez (1981).

Predicted effects on ESP of soils: The ESP of soils, which would be irrigated with spring waters, were predicted and plotted (Appendix II & Fig. 4). The SAR, adj. R_{Na} and adj. SAR were all significantly correlated to ESP (r= 0.939, 0.999 and 0.999, respectively). The ESP values predicted from adj. SAR were higher than those calculated from adj. R_{Na} and SAR. The ESP values greater than 15 indicate Na hazards (USDA Handbook No. 60, 1954). The predicted ESP from different SAR values of soil is marginally higher than the thrash hold value of 15 only for waters of six springs. As such, there is no immediate concern regarding the development of any serious Na problem from the use of these waters for crop irrigation if certain water management practices are followed.

Similarly, ESP of soils could be predicted for various quality irrigation waters intended for use in agriculture. This would also provide an opportunity for proper management of marginal quality waters containing high level of sodium without considerable yield reduction of crops. Because irrigation with high Na waters will deteriorate the soil physical conditions by developing Na-soils by replacing Ca and partly Mg from soil exchange complex (Oster and Schroer, 1979; Bingham, *et al.*, 1979).

Development of soil salinity: Irrigation water is the main source of addition of salts to soils and its magnitude depends on the total water salinity, chemical composition, leaching requirements considered, soil type, drainage conditions, climate, management practices, and the consumptive use of crops to be cultivated. Salt build up showed decreases with increase in leaching fractions, because more water will be available for salt removal from the soil profile beyond root zone (Table 3). It is also evident from the data that salinity development will be faster in soils irrigated with high total salinity waters as compared with less saline waters. It also implies that only medium to high salt tolerant crops would be possible with proper agricultural practices. In addition to the above, highly saline waters could successfully be used for the reclamation of highly salt affected soils at its initial stage of development. Because the final soil salinity at equilibrium will not exceed that of irrigation water.

Changes in total water salinity: A comparison was made between water salinity after a period of 25 years (Table 4). The results indicated a significant degradation in water quality ranging from 1.40-1.80 times in the Year 2000 as compared with the Year 1975. The possible reason could be the increase in pumping of water from the shallow aquifer due to increased demand for water consumption for increasing agricultural production to meet the growing demand for food and shelter. This increase in total water salinity could cause serious soil salinity and water management problems if an appropriate management practices are not adopted. The management alternatives could be specified as application of leaching requirements and cultivation of moderate to high salt tolerant crops.

Cation and anion ratios: Cations and anions ratios were calculated to determine the effect of excess cations or anions on soil properties and plant nutrition. The Ca/Mg ratio ranged between 1.36-5.54 in different spring waters (Table 5). It was observed that Ca is the dominant cation over Mg in the spring waters of Al-Hassa. Irrigation with these waters will have no adverse effect on soil physical and chemical properties. Because high Ca waters will develop calcium dominant soils with much improved soil structure. The Cl/SO_4 ratio ranged between 1.88-4.33 in different spring waters (Table 5). This shows that Cl^- is dominant than SO_4^{-2} anions in these waters. There is a possibility that irrigation with these waters could increase Cl^- contents in the soil solution after irrigation which can create nutrient imbalance and cause Cl^- toxicity in plants.

In conclusion, the spring waters are higher in Ca^{+2} and Cl^- contents than corresponding Mg^{+2} and SO_4^{-2} ions. These waters are classified as C_4S_2 i.e. very high salinity with medium sodicity problems. The water quality in terms of total salinity degraded significantly in 2000 as compared to the year 1975. There is no immediate concern regarding the development of any serious Na problem from the use of these waters for crop irrigation provided certain management practices such as provision of adequate drainage, proper crop selection, suitable seeding practices and improved irrigation systems are adopted.

References

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 and Soil Pollution, 66:135-143.

Anonymous, 1984. Water Research Department, Annual Report, Hassa Irrigation and Drainage Authority (HIDA), Hofuf, Saudi Arabia.

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

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 Drainage Paper 29 (Rev.), FAO, Rome, pp: 174.

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.

Bingham, F.T., R.J. Mahler and G. Sposito, 1979. Effects of irrigation water composition on exchangeable sodium status of a field soil. Soil Sci., 127: 248-252.

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 and Soil Pollution, 57-58: 773-783.

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. pp.1-14. In H. E. Dregne (ed.) Proc. Int. Salinity Conf. Texas Tech. Univ., Lubbock, 16-20 August, 1976.

Oster, J.D. and F. W. Schroer, 1979. Infiltration as influenced by irrigation water quality. Soil Sci. Soc. Am. J., 43: 444-447.

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. Amer. J., 45: 469-475.

USDA., 1954. Diagnosis and Improvement of Saline and Alakli Soils. USDA Handbook No. 60, United States Department of Agriculture, Washington, DC., USA., Pages: 160.

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

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