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Evaluation of Groundwater of Al-Hassa Oasis, Eastern Region Saudi Arabia

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ABSTRACT

The study was carried to determine the groundwater chemistry of Al-Hassa Oasis and to evaluate it for irrigation purposes. One hundred thirty six (136) water samples were collected from three aquifers at depths varying from <150, 150-260 and >260 m at different locations in Al-Hassa Oasis. In 1954 according to Regional Salinity Laboratory, U.S., water classification scheme, the groundwater is classified as very high (C3) to severely high salinity (C4) and low (S1) to medium (S2) sodicity hazard. The results showed that the groundwater at some locations, if used for irrigation, may cause either soil salinity or sodicity problems due to high salt concentration and high sodium contents relative to other elements. According to irrigation water quality evaluation criteria applied, the most significant problems resulting from irrigation seem to be the salinity, potential salinity and magnesium hazard. It is expected also that continuous and prolonged irrigation without good water management (leaching requirements) can lead to severe soil salinity problems. The nitrate concentration of groundwater ranged between 8.8-78, 2.4-40.4 and 1.46-3.45 mg L^{-1} at <150 m, 150-260 m and >260 m, respectively in Al-Hassa Oasis. However, the NO_3 concentration exceeded the maximum permissible limit of 45 mg L^{-1} only in six wells. The highest concentration of NO_3^- was observed in Neogene aquifer with depth <150 m and the lowest was recorded in groundwater from deeper aquifer >260 m. In conclusion, to protect the groundwater contamination with NO_3^-, the farmers should apply nitrogen based inorganic fertilizers in proper amounts and avoid excessive use to minimize leaching losses.

Key words: Water quality, groundwater, irrigation, total water salinity, contamination, nitrate, aquifer depth, Al Hassa Oasis

INTRODUCTION

Saudi Arabia lies in the tropical and subtropical desert region. Due to aridity, there are great extremes of temperature, but also with wide variations between the seasons and regions. In the central region, the summer (May to October) is overwhelmingly hot and dry, with maximum temperatures of over 50°C, while the winter is dry and cool with night temperatures close to freezing. The western and eastern regions are hot and humid in the summer months, with maximum temperatures around 42°C, while the winters are warm. Long-term average annual precipitation has been estimated at 245.5 km^3/year, which is equal to 114 mm/year over the whole country (FAO, 2007). The total irrigation water use has increased from about 6,108 MCM in 1970 to about 19,074 MCM in 2000 (Aldakheel, 2005; Alamoud and Aldakheel, 2003). It is estimated that in 2006 total water withdrawal was at 23.7 km^3, an increase of 40% compared to 1992, shared between the various sectors as follows: agriculture 88%, municipal 9% and industry 3%. The boom in desert agriculture tripled the volume of water used for irrigation from about 6.8 km^3 in 1980 to about 21 km^3 in 2006. The total surface water and groundwater withdrawal represented 943% of the total renewable water resources (MOWE, 2008).

Al-Hassa, 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. Al-Hassa Oasis is one of the important agricultural regions in the Kingdom of Saudi Arabia. It covers an area of approximately 20000 ha and total population is around 650000. It contains three cities and 48 villages. The climate is severely arid with an average annual rainfall of 72.1 mm (Leichtweiss Institute, 1979). Presently, out of the total area (20000 ha) approximately 8000 ha is irrigated with groundwater which is considered as the main source of irrigation water in Al-Hassa Oasis. Generally, water quality for various uses depends on its physical, chemical composition and biological characteristics along with the conditions of use (FAO, 2007).

Presently, the entire irrigation, domestic and industrial water needs are fulfilled from groundwater of the Neogene aquifer in the whole Oasis. The irrigation water consumption comprises about 83% of the total water use. Three aquifers namely Neogene, Dammam and Umm er Radhuma are the main source of ground water in Al-Hassa Oasis. The water quality varies within each aquifer as well as between different aquifers. Neogene aquifer (Miocene-Paleocene) with an extent varying between 100 and 200 m depth (BRGM, 1977). This aquifer consists mainly of conglomeratic sand, sandstone and heavily fissured limestone. Dammam aquifer underlies the Neogene aquifer is mainly dolomite and dolomitic limestone. Umm-er-Raduma aquifer (Paleocene-Eocene) underlies the Khobar aquifer and consists mainly of massive dolomite and dolomitic limestone.

According to the previous investigation, the groundwater from Neogene aquifer contained high concentration of nitrate (Water Atlas of Saudi Arabia, 1984). Extensive use of inorganic and organic nitrogen fertilizers in agriculture was identified as an important source of NO_3^- pollution that contaminates both ground and surface water (O'Neill and Gordon, 1994; Kolenbrander, 1972). It was observed that a part of the applied nitrate fertilizers might have leached down into the deeper aquifers supplying drinking water. It was reported that 20-60% of the applied nitrogen (N) is taken up by arable crops and 40-80% by grass (Parker, 1972). Application of excess N fertilizer could result in high leaching losses of NO_3^- into soil profiles. Also, amending phosphate fertilizer or organic manure with nitrogen fertilizer could significantly increase NO_3^- concentration in the soil-water system and the increased the NO_3^- concentration above the plants requirements which will move downward by leaching (Guo *et al*., 2001). The hazardous effect of nitrate and nitrite on human health is known, although, nitrate itself is not toxic, nitrite originating from the reduction of nitrate induces methahemoglobinemia in infants. Nitrous acid may dissociate into OH and NO and the latter radical oxidizes Ferrous (Fe) of the hemoglobin to Ferric (Fe), altering the adsorption of O_2 (Mengel and Kirkby, 1972). According to the EPA (1976), the critical level of NO_3^- concentration in drinking water is 45 mg L^{-1} for human. The health advisory levels for most livestock are much higher (180 mg NO_3 L^{-1}). It has been reported that the level of nitrate ranged between 0-66 mg L^{-1} in Dammamm aquifer, 1-660 mg L^{-1} in Neogene aquifer and 0-195 mg L^{-1} in Wasia aquifer in Eastern region of in Saudi Arabia (Water Atlas of Saudi Arabia, 1984). Therefore, the main objective of this study was to investigate the groundwater chemistry of Al-Hassa Oasis and to evaluate it for irrigation purposes.

MATERIALS AND METHODS

Water sampling and analysis: A total of 136 water samples were collected from different wells located in the Oasis during November and December, 2008. The water samples were collected from three aquifers with depth ranging from <150, 150-260 and >260 m fro Neogene, Dammam and Wasia aquifer, respectively. The sampling location was recorded using Global Position System (GPS). The number of water samples collected from <150, 150-260 and >260 m were 73, 36 and 13, respectively. There were 14 water samples from wells with unknown depth. The water samples were collected in sterile plastic bottles stored in an ice box and transported immediately to the laboratory for analysis. Water classification for irrigation, based on the chemical characteristics, was done according to the method described in Handbook 60 (U.S. Regional Salinity Laboratory, 1954). The concentration of NO_3^- in water samples was determined by Norman *et al.* (1985) method. The location of groundwater sampling in Al-Hassa Oasis is presented in Fig. 1.

Irrigation water quality was determined according to the following parameters (Wilcox, 1958; FAO, 1973; Ayers and Westcot, 1976).

- Total water salinity was expressed as electrical conductivity (EC_{iw}, dS m^{-1})
- Chemical composition of water involved the determination of concentration of Ca, Mg, Na, K, CO_3, HCO_3, Cl and SO_4 ions

The other water quality parameters were calculated as below:

- **Sodium hazard:** It is expressed as Sodium Adsorption Ratio (SAR) or Soluble Sodium Percentage (SSP, %).

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

$$\text{SSP} = \frac{\text{Na}^+}{\sum \text{Cations}} \times 100$$

The concentration of all the cations is expressed in me L^{-1}.

- **Soluble Magnesium Hazard (SMgH):** It is expressed by the value of Soluble Magnesium Percentage (SMgP, %),

$$\text{SMgP} = \frac{[\text{Mg}^{2+}]}{[\text{Ca}^{2+} + \text{Mg}^{+2}]} \times 100$$

- **Bicarbonate hazard:** It is expressed by the value of Residual Sodium Carbonate (RSC, me L^{-1}):

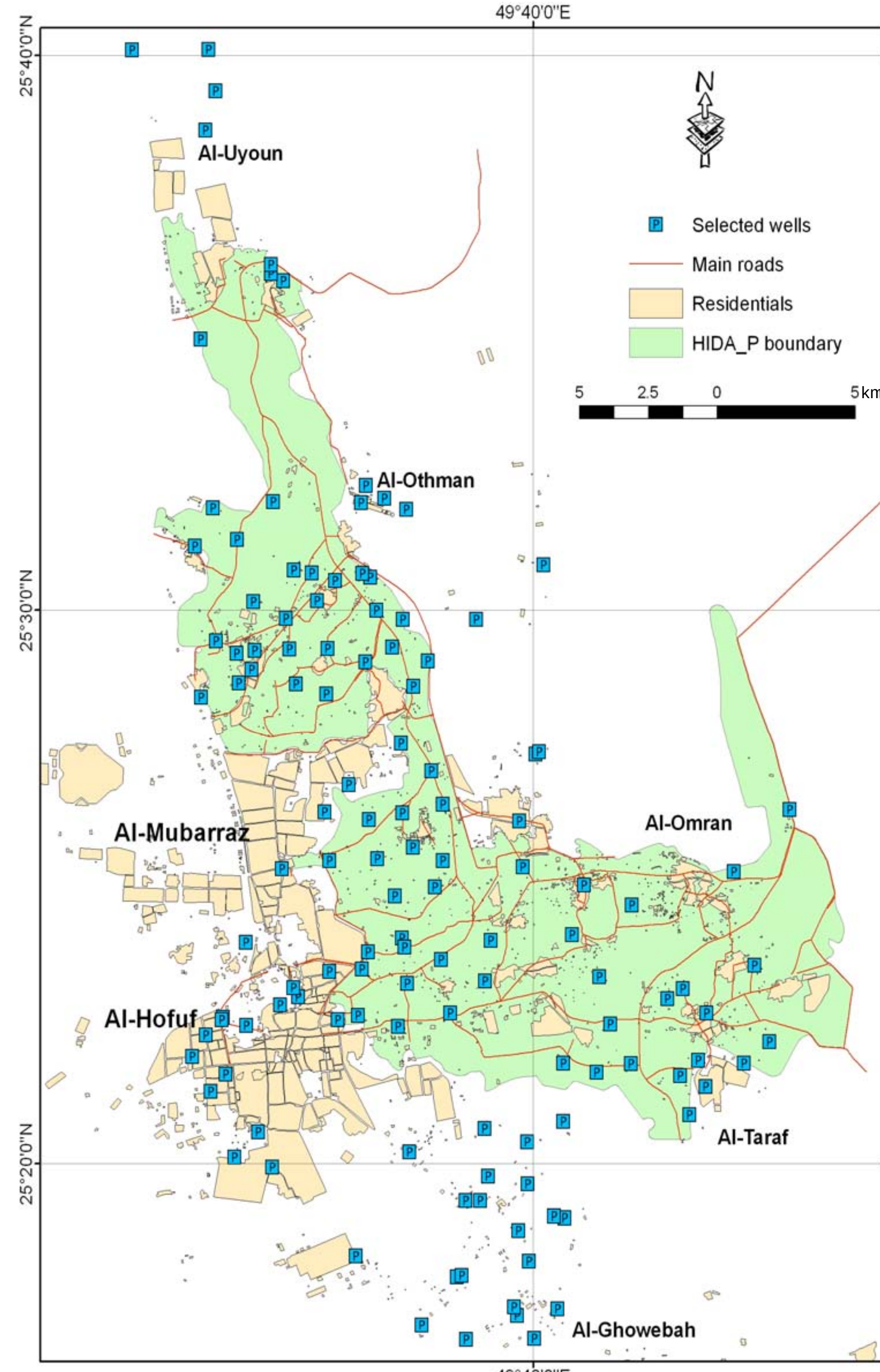

Fig. 1: Location map of water sampling in Al-Hassa Oasis

$$(RSC) = [CO_3 + HCO_3] - [Ca + Mg]$$

The concentration of all the ions is expressed in me L^{-1}.
The concentration of toxic compounds was expressed by the values of:

- Potential Salinity (PS) as me $L^{-1} = Cl + 0.5 \times SO_4$
- Nitrate concentration (NO_3, mg L^{-1})
- Boron concentration (B, mg L^{-1})

RESULTS AND DISCUSSION

Groundwater chemistry: The ranges of different water quality parameters were 1.46-16.17 dS m^{-1} (EC), 4.15-46.50 meq L^{-1} (Ca), 2.41-32.11 meq L^{-1} (Mg), 7.64-79.77 meq L^{-1} (Na), 0.31-15.47 meq L^{-1} (K), 2.06-16.12 meq L^{-1} (HCO_3), 1.20-117.80 meq L^{-1} (Cl), 0.45-43.22 meq L^{-1} (SO_4) and 1.46-78 mg L^{-1} (NO_3) in the whole Oasis (Table 1). The order of abundance for cations was Na>Ca>Mg>K while that of anions was $Cl>SO_4>HCO_3$. The regression analysis showed significant relationship between Na and Cl ions ($R^2 = 0.97$) as the Na and Cl are the dominant cation and anion, respectively in the groundwater of Al-Hassa Oasis as compared to other cations/anions.

Quality of groundwater: The total salinity of water samples (EC) ranged from 1.46-16.17 dS m^{-1} (Table 2). But the total water salinity decreased with depth and ranged between 2.13-16.17 dS m^{-1}, 2.0-6.92 dS m^{-1} and 1.46-3.45 dS m^{-1} for the aquifer depth of <150, 150-260 and >260 m, respectively. The critical level of irrigation water (EC_{iw}) salinity that can cause severe salinity problems is 3 dS m^{-1} according to Ayers and Westcot (1976). However, there are some locations (Table 3) in the Oasis where the EC of groundwater is less than the critical limit and is not likely to develop any soil permeability problems upon irrigation with these waters. On the other hand, there are exceptionally some locations where the groundwater (Table 3). EC is more than the critical level that might affect soil salinity after irrigation by salt accumulation when the water is taken up by the plants under arid climatic conditions. It is an admitted fact that continuous irrigation even with good quality water on long term basis can cause severe soil salinity and sodicity problems if proper soil, water and crop management practices such as leaching etc are not followed under arid environment.

The data revealed that the SAR of all the water samples is relatively low than the critical level of sodium hazard (less than 15) as reported by U.S. Regional Salinity Laboratory (1954). accept at location nos. 83 and 126 where the SAR of water is higher than the critical level of sodium hazard (Table 2).

With respect to Soluble Sodium Percentage (SSP), as indicator of sodium hazard, the values of SSP for water samples ranged from 32.02-59.55% and were whithin the safe limit (<60%) as reported by Wilcox (1958) (Table 2).

Besides, Soluble Magnesium Percentage (SMgP) hazard is also one of the criteria of suitability of water for irrigation. The values of SMgP in water samples ranged from 29.56-52.96% and are less than the harmful level (50%) except at certain locations (6, 29, 51, 74 and 90), the values of SMgP exceeded the harmful level (>50%) (Table 2). The magnesium salts have toxic effects on the plant and the toxicity of Mg ions is higher than the toxicity of Na ions having the same concentrations (FAO, 1973).

Table 1: Chemical composition of groundwater of Al-Hassa Oasis

				Soluble cations				Soluble anions			
				Na	K	Ca	Mg	Cl	HCO_3	SO_4	NO_3
Sample ID	Well depth	pH	EC (dS m^{-1})	(meq L^{-1})				(meq L^{-1})			(mg L^{-1})
1	420	7.06	1.46	7.64	0.31	4.15	2.41	5.80	3.83	4.88	8.00
2	110	7.12	11.68	51.82	2.09	37.56	23.55	75.58	6.38	33.07	60.50
3	120	7.10	7.35	37.29	1.58	23.19	10.15	44.20	6.38	21.64	20.80
4	215	7.13	2.19	8.81	0.43	6.10	4.88	9.80	5.10	5.32	24.80
5	235	7.05	2.68	12.87	0.56	7.12	5.20	13.30	3.83	8.62	27.20
6	250	7.16	2.67	8.39	0.66	7.77	8.75	12.90	3.83	8.84	8.20
7	250	7.14	2.07	9.81	0.72	6.70	2.97	9.10	3.83	7.28	7.00
8	250	6.95	2.35	13.56	0.50	6.02	2.69	9.00	3.83	9.95	7.40
9	260	7.11	2.16	9.16	0.45	7.18	4.08	9.20	5.10	6.56	8.60
10	200	7.19	2.38	11.26	0.59	6.15	4.69	10.80	5.10	6.79	17.00
11	---	7.62	2.14	9.42	0.43	6.85	3.81	10.00	3.83	6.69	3.60
12	260	7.66	2.31	10.06	0.42	7.06	4.53	10.60	5.10	6.37	24.60
13	67	7.01	2.38	10.33	0.48	7.12	5.22	9.80	3.83	9.53	27.20
14	90	7.31	2.27	10.64	0.52	6.62	4.26	9.20	3.63	9.20	43.20
15	135	7.04	8.37	40.26	1.90	24.07	14.93	45.50	6.38	29.29	24.50
16	110	6.89	4.24	19.18	0.99	12.05	9.50	22.00	5.10	14.63	30.40
17	115	7.02	5.43	20.38	1.21	18.81	12.22	15.60	7.65	29.37	31.40
18	120	7.19	2.56	11.91	0.33	7.43	5.69	12.00	5.10	8.27	31.60
19	250	7.06	2.33	11.88	0.44	7.07	3.29	10.30	5.10	7.27	26.40
20	112	7.27	3.59	17.53	0.86	9.75	6.53	18.70	5.10	10.87	35.40
21	148	6.99	3.05	14.93	0.73	8.96	5.33	14.90	5.10	9.95	31.20
22	160	6.94	2.99	16.84	0.61	7.62	3.85	14.10	6.38	8.44	31.80
23	250	7.26	2.00	11.21	0.39	4.34	3.21	8.80	5.10	5.26	20.20
24	450	7.23	1.58	8.27	0.33	4.49	2.61	6.00	3.83	5.87	4.20
25	130	7.42	10.34	45.87	1.85	34.14	20.85	66.40	7.65	28.66	78.00
26	380	7.33	2.80	14.21	0.60	9.22	3.87	13.40	5.10	9.39	21.60
27	130	7.28	9.07	37.49	1.78	29.39	20.21	55.00	5.10	28.76	66.50
28	250	7.32	2.09	10.04	0.44	5.55	4.06	9.00	5.10	5.98	7.20
29	80	6.75	9.80	30.79	2.40	30.83	32.11	57.00	7.65	31.49	73.50
30	120	6.78	9.57	45.36	3.33	30.96	13.74	54.90	5.10	33.40	61.00
31	250	7.16	2.13	12.29	0.46	5.46	2.44	9.30	5.10	6.24	7.60
32	350	7.14	2.58	10.94	0.54	8.57	4.88	12.30	6.38	6.25	7.80
33	130	6.78	9.50	44.95	2.36	26.13	19.71	55.40	5.10	32.64	57.50
34	450	7.20	1.85	8.06	0.33	5.66	3.63	7.40	7.65	2.63	3.20
35	35	7.55	6.44	28.97	1.29	19.26	14.13	36.10	3.83	23.72	40.20
36	210	7.26	4.75	22.27	1.08	13.85	8.91	27.30	6.38	12.42	27.60
37	250	7.21	2.45	11.78	0.56	7.05	4.37	11.10	5.10	7.56	23.20
38	250	7.06	2.40	10.86	0.56	6.82	5.38	10.50	5.10	8.02	16.20
39	80	7.26	4.39	16.48	0.98	15.21	9.88	21.20	6.38	14.97	43.50
40	500	7.15	2.56	11.91	0.33	7.43	5.69	10.90	5.10	9.37	7.40
41	90	7.16	3.17	16.16	0.60	9.61	4.48	14.90	5.10	10.85	29.80
42	90	7.00	2.88	14.06	0.69	7.82	5.24	13.60	5.10	9.11	28.60
43	120	7.28	2.71	13.27	0.65	7.96	4.74	12.60	7.65	6.36	34.40
44	100	6.99	4.51	25.40	0.91	11.49	5.81	23.20	5.10	15.32	21.60
45	105	7.11	2.99	16.76	0.59	6.49	4.80	14.20	6.38	8.07	38.00

Table 1: Continued

				Soluble cations				Soluble anions			
				Na	K	Ca	Mg	Cl	HCO_3	SO_4	NO_3
Sample ID	Well depth	pH	EC (dS m^{-1})	(meq L^{-1})				(meq L^{-1})			(mg L^{-1})
46	72	7.15	2.90	15.18	0.61	8.24	4.79	13.60	5.10	10.11	32.00
47	85	6.90	3.47	15.39	0.62	11.46	7.00	16.80	3.83	13.84	34.60
48	120	6.91	3.53	17.61	0.76	11.62	4.88	17.90	5.10	11.86	29.20
49	110	6.91	3.51	14.12	0.69	11.37	7.82	18.20	6.38	9.43	24.00
50	120	6.70	5.39	25.88	1.13	14.31	10.46	16.20	7.65	27.93	23.60
51	96	7.20	2.76	8.67	0.68	8.68	9.04	12.80	5.10	9.18	28.20
52	35	7.23	2.88	13.65	1.00	9.32	4.14	13.60	5.10	9.41	30.60
53	70	6.98	2.90	16.73	0.62	7.43	3.32	13.90	5.10	9.10	23.00
54	130	7.34	2.83	12.00	0.59	9.40	5.35	13.80	5.10	8.44	22.80
55	120	7.11	3.02	14.29	0.75	8.31	5.95	14.90	5.10	9.29	24.20
56	120	7.01	2.89	12.73	0.58	9.26	5.14	14.20	6.38	7.13	23.40
57	100	6.99	3.00	13.07	0.54	9.17	5.88	14.90	6.38	7.39	26.60
58	106	7.62	2.88	12.51	0.58	8.61	6.32	14.30	5.10	8.62	25.40
59	115	7.40	4.22	19.78	0.96	12.30	7.91	22.70	6.38	11.88	18.60
60	110	7.56	2.88	13.85	0.66	8.28	5.14	14.10	5.10	8.73	20.80
61	120	7.10	2.80	12.67	0.65	7.96	6.27	13.70	5.10	8.76	29.60
62	116	7.22	2.79	10.47	0.62	9.67	6.28	13.50	5.10	8.44	34.80
63	100	7.58	4.43	20.61	0.57	12.86	9.85	24.00	5.10	14.80	19.40
64	116	7.00	2.79	14.22	0.53	8.46	3.94	13.60	5.10	8.45	29.40
65	80	7.09	2.87	14.01	0.69	7.79	5.22	13.80	5.10	8.82	23.20
66	120	7.36	3.23	15.81	0.77	9.48	5.65	16.30	5.10	10.31	31.00
67	70	6.98	3.24	18.25	0.66	8.26	4.17	16.30	6.38	8.66	22.60
68	112	7.24	3.04	17.04	0.60	6.60	4.88	15.40	5.10	8.62	22.20
69	110	6.98	3.92	20.52	0.83	11.13	6.47	21.70	5.10	12.15	23.20
70	430	6.96	2.87	12.73	0.51	9.48	5.79	14.00	5.10	9.41	21.20
71	120	7.53	2.96	15.02	0.64	9.54	4.09	14.30	5.10	9.89	21.40
72	100	7.10	2.89	11.63	0.57	9.36	6.44	13.80	5.10	9.10	21.20
73	85	7.49	3.40	16.33	0.71	9.03	6.60	16.80	5.10	10.76	24.00
74	115	6.94	2.95	9.27	0.72	9.28	9.67	14.40	5.10	9.44	24.60
75	250	7.12	2.83	13.41	0.98	9.16	4.06	12.80	5.10	9.72	13.80
76	250	6.91	3.12	18.00	0.67	7.99	3.57	14.80	6.38	9.06	28.00
77	98	6.76	3.69	15.64	0.77	12.26	6.98	18.90	5.10	11.64	21.00
78	92	6.82	3.50	16.56	0.87	9.63	6.89	17.90	5.10	10.95	21.00
79	230	6.80	3.42	15.06	0.68	10.95	6.09	14.20	5.10	13.48	14.40
80	230	7.00	3.18	13.85	0.57	9.72	6.23	15.10	5.10	10.18	14.20
81	150	6.96	3.77	16.37	0.76	11.28	8.27	20.20	5.10	11.38	13.00
82	238	6.78	4.59	21.52	1.04	13.38	8.61	26.90	6.38	11.27	22.40
83	90	6.87	16.17	79.77	3.68	46.50	28.85	117.80	6.38	34.63	18.00
84	---	7.28	3.44	15.56	0.80	9.78	7.71	17.50	6.38	9.98	25.60
85	87	6.52	2.72	14.24	0.58	7.72	4.49	13.10	7.65	6.28	9.40
86	150	7.24	2.42	10.74	0.43	7.99	4.88	11.30	8.20	4.54	24.20
87	120	6.90	2.13	10.81	0.39	7.01	2.94	8.90	8.93	3.33	21.40
88	---	7.28	3.20	12.87	0.63	10.37	7.13	14.80	8.93	7.27	22.20
89	---	7.14	2.55	12.24	0.53	6.77	4.95	12.10	11.48	0.92	20.80
90	129	7.06	2.78	8.73	0.68	8.75	9.11	10.10	11.48	5.70	19.40

Table 1: Continued

				Soluble cations				Soluble anions			
				Na	K	Ca	Mg	Cl	HCO_3	SO_4	NO_3
Sample ID	Well depth	pH	EC (dS m^{-1})	(meq L^{-1})				(meq L^{-1})			(mg L^{-1})
91	---	7.29	2.65	12.56	0.92	8.57	3.81	16.70	8.21	0.95	25.40
92	200	7.26	3.22	18.58	0.69	8.25	3.68	16.90	8.93	5.38	20.80
93	---	7.02	2.14	9.07	0.44	7.11	4.05	9.20	6.38	5.10	21.00
94	110	7.03	3.17	15.00	0.79	8.72	6.24	15.20	7.65	7.90	25.80
95	75	7.16	2.17	9.56	0.43	6.95	3.86	9.00	7.65	4.15	23.20
96	---	7.22	2.24	9.76	0.40	6.85	4.39	9.20	8.93	3.28	22.40
97	130	7.29	3.68	15.98	0.74	11.01	8.07	1.20	8.93	25.67	21.00
98	---	7.24	3.20	15.00	0.73	9.33	6.00	16.30	7.65	7.11	17.00
99	120	7.00	3.30	15.87	0.75	9.49	5.89	16.80	10.20	5.00	18.20
100	110	7.22	4.86	21.99	1.13	13.82	10.89	9.50	11.91	26.42	20.00
101	250	7.10	2.26	8.48	0.50	7.83	5.09	15.70	5.75	0.45	19.60
102	80	6.99	5.50	25.59	0.71	15.96	12.24	31.10	8.93	14.47	37.80
103	160	7.17	2.16	11.01	0.41	6.55	3.05	10.10	8.48	2.44	7.60
104	---	7.55	2.64	12.89	0.63	7.17	4.80	11.40	11.48	2.62	22.60
105	260	7.08	2.98	14.59	0.50	8.75	5.21	15.30	12.75	1.00	21.20
106	---	7.39	2.88	16.22	0.58	7.34	3.71	13.20	10.03	2.63	23.80
107	---	7.14	2.33	13.06	0.46	5.06	3.74	10.20	7.48	0.64	22.80
108	450	7.61	2.23	10.57	0.51	6.41	3.98	8.86	5.84	6.77	2.40
109	70	7.62	3.78	16.02	0.88	10.75	8.47	24.46	2.06	9.60	27.60
110	150	7.48	3.96	17.25	0.88	13.72	8.91	23.81	3.43	13.51	40.40
111	150	7.51	6.92	32.44	0.90	20.08	15.39	30.97	16.12	21.73	36.80
112	450	7.55	2.00	9.62	0.38	6.06	2.82	9.93	2.85	6.11	1.46
113	250	7.57	2.34	9.78	0.61	7.36	4.26	11.31	3.35	7.35	2.40
114	240	7.63	2.12	9.86	0.50	6.22	3.71	9.32	3.92	7.06	2.60
115	450	7.51	2.29	12.18	0.46	5.84	2.95	8.77	3.73	8.93	2.40
116	220	8.00	2.23	11.92	0.44	5.84	3.58	9.50	5.27	7.02	0.73
117	250	7.41	3.84	21.63	0.81	10.91	6.34	17.43	8.23	14.03	6.40
118	130	7.21	7.45	34.99	1.33	24.60	15.02	34.81	13.32	27.81	32.00
119	135	7.40	2.95	13.09	0.63	9.71	5.08	13.54	6.51	8.46	19.60
120	---	7.23	9.42	38.93	1.85	30.52	20.99	38.79	15.14	38.37	42.60
121	390	7.47	2.06	9.76	0.43	5.47	4.00	8.35	3.29	8.02	2.40
122	120	7.34	3.30	16.04	0.81	10.38	6.81	17.94	2.51	13.59	17.60
123	100	7.71	5.17	24.46	1.80	16.73	7.43	26.83	6.22	17.37	10.20
124	----	7.65	5.25	28.11	1.34	16.01	7.15	15.08	7.40	30.13	12.60
125	40	7.44	3.01	14.11	0.62	10.00	5.69	14.11	6.00	10.32	14.80
126	120	7.35	13.95	73.01	15.47	31.62	23.03	89.58	10.32	43.22	8.80
127	90	7.46	4.65	22.36	1.15	12.79	9.65	20.56	10.18	15.22	13.20
128	250	7.31	2.69	12.84	3.15	7.31	4.74	14.01	3.82	10.21	6.80
129	250	7.31	2.51	12.29	2.93	7.37	4.39	12.26	4.20	10.51	10.60
130	420	7.67	3.45	18.06	0.80	10.13	6.28	13.10	8.35	13.81	1.47
131	---	7.36	2.98	13.22	2.36	9.84	6.01	14.26	5.43	11.74	6.00
132	80	7.22	5.25	25.87	0.55	14.30	10.43	31.84	2.95	16.37	11.00
133	95	7.26	4.61	21.61	0.96	15.39	7.16	19.85	11.25	14.02	9.80
134	90	7.41	4.24	19.98	1.08	12.24	8.20	18.89	6.75	15.86	10.20
135	450	7.53	2.02	11.38	2.31	5.15	2.60	9.53	4.31	7.60	4.91
136	250	7.35	2.73	15.30	3.02	5.93	4.38	12.01	6.96	9.65	7.60

Table 2: Water quality parameters of Al-Hassa well waters to be used as irrigation water

Serial No.	Well depth	EC (dS m^{-1})	SAR	SSP (%)	RSC (meq L^{-1})	SMgP (%)	PS (meq L^{-1})	NO_3 (mg L^{-1})	B (mg L^{-1})
1	420	1.46	4.22	52.67	-2.73	36.76	8.24	8.00	1.07
2	110	11.68	9.37	45.05	-54.74	38.54	92.11	60.50	1.25
3	120	7.35	9.13	51.64	-26.97	30.45	55.02	20.80	1.17
4	215	2.19	3.76	43.58	-5.88	44.46	12.46	24.80	1.39
5	235	2.68	5.19	49.99	-8.49	42.23	17.61	27.20	1.33
6	250	2.67	2.92	32.81	-12.69	52.96	17.32	8.20	1.23
7	250	2.07	4.46	48.56	-5.85	30.74	12.74	7.00	1.10
8	250	2.35	6.50	59.55	-4.88	30.87	13.97	7.40	1.31
9	260	2.16	3.86	43.88	-6.16	36.27	12.48	8.60	1.37
10	200	2.38	4.84	49.64	-5.74	43.25	14.19	17.00	0.83
11	---	2.14	4.08	45.94	-6.84	35.72	13.34	3.60	1.23
12	260	2.31	4.18	45.59	-6.49	39.07	13.79	24.60	1.15
13	67	2.38	4.16	44.64	-8.52	42.32	14.56	27.20	1.06
14	90	2.27	4.56	48.30	-7.24	39.15	13.80	43.20	1.26
15	135	8.37	9.12	49.60	-32.63	38.29	60.14	24.50	1.04
16	110	4.24	5.84	45.98	-16.45	44.08	29.31	30.40	1.34
17	115	5.43	5.18	38.74	-23.38	39.38	30.29	31.40	0.91
18	120	2.56	4.65	46.96	-8.02	43.39	16.13	31.60	1.21
19	250	2.33	5.22	52.38	-5.26	31.77	13.94	26.40	1.22
20	112	3.59	6.14	50.56	-11.18	40.11	24.14	35.40	1.32
21	148	3.05	5.59	49.86	-9.19	37.32	19.87	31.20	1.32
22	160	2.99	7.03	58.23	-5.10	33.57	18.32	31.80	1.23
23	250	2.00	5.77	58.51	-2.45	42.50	11.43	20.20	0.99
24	450	1.58	4.39	52.67	-3.27	36.76	8.94	4.20	0.63
25	130	10.34	8.75	44.66	-47.34	37.92	80.73	78.00	1.23
26	380	2.80	5.55	50.94	-7.98	29.56	18.10	21.60	0.71
27	130	9.07	7.53	42.18	-44.50	40.75	69.38	66.50	0.72
28	250	2.09	4.58	49.99	-4.50	42.23	11.99	7.20	0.93
29	80	9.80	5.49	32.02	-55.30	51.02	72.74	73.50	1.10
30	120	9.57	9.59	48.56	-39.61	30.74	71.60	61.00	1.18
31	250	2.13	6.19	59.55	-2.79	30.87	12.42	7.60	0.98
32	350	2.58	4.22	43.88	-7.07	36.27	15.42	7.80	1.28
33	130	9.50	9.39	48.26	-40.73	43.00	71.72	57.50	1.30
34	450	1.85	3.74	45.59	-1.63	39.07	8.71	3.20	0.91
35	35	6.44	7.09	45.51	-29.57	42.32	47.96	40.20	0.97
36	210	4.75	6.60	48.30	-16.38	39.15	33.51	27.60	1.17
37	250	2.45	4.93	49.60	-6.32	38.29	14.88	23.20	0.87
38	250	2.40	4.40	45.98	-7.10	44.08	14.51	16.20	1.14
39	80	4.39	4.65	38.74	-18.71	39.38	28.69	43.50	1.09
40	500	2.56	4.65	46.96	-8.02	43.39	15.58	7.40	1.26
41	90	3.17	6.09	52.38	-8.99	31.77	20.32	29.80	1.27
42	90	2.88	5.50	50.56	-7.96	40.11	18.16	28.60	1.07
43	120	2.71	5.27	49.86	-5.05	37.32	15.78	34.40	1.09
44	100	4.51	8.64	58.23	-12.20	33.57	30.86	21.60	1.27
45	105	2.99	7.05	58.51	-4.92	42.50	18.23	38.00	0.95
46	72	2.90	5.95	52.67	-7.92	36.76	18.66	32.00	0.94
47	85	3.47	5.07	44.66	-14.63	37.92	23.72	34.60	0.86
48	120	3.53	6.13	50.51	-11.39	29.56	23.83	29.20	0.90

Table 2: Continued

Serial No.	Well depth	EC (dS m^{-1})	SAR	SSP (%)	RSC (meq L^{-1})	SMgP (%)	PS (meq L^{-1})	NO_3 (mg L^{-1})	B (mg L^{-1})
49	110	3.51	4.56	41.52	-12.82	40.75	22.91	24.00	1.01
50	120	5.39	7.35	49.99	-17.12	42.23	30.16	23.60	0.20
51	96	2.76	2.91	32.02	-12.63	51.02	17.39	28.20	0.63
52	35	2.88	5.26	48.56	-8.35	30.74	18.30	30.60	0.46
53	70	2.90	7.22	59.55	-5.65	30.87	18.45	23.00	0.77
54	130	2.83	4.42	43.88	-9.65	36.27	18.02	22.80	0.68
55	120	3.02	5.35	48.79	-9.15	41.73	19.55	24.20	0.73
56	120	2.89	4.74	45.94	-8.02	35.72	17.76	23.40	0.54
57	100	3.00	4.76	45.59	-8.68	39.07	18.59	26.60	0.40
58	106	2.88	4.58	44.64	-9.83	42.32	18.61	25.40	0.51
59	115	4.22	6.22	48.30	-13.84	39.15	28.64	18.60	0.52
60	110	2.88	5.35	49.60	-8.32	38.29	18.46	20.80	0.55
61	120	2.80	4.75	45.98	-9.13	44.08	18.08	29.60	0.53
62	116	2.79	3.71	38.74	-10.84	39.38	17.72	34.80	0.71
63	100	4.43	6.12	46.96	-17.61	43.39	31.40	19.40	0.64
64	116	2.79	5.71	52.38	-7.30	31.77	17.83	29.40	0.75
65	80	2.87	5.49	50.56	-7.91	40.11	18.21	23.20	0.70
66	120	3.23	5.75	49.86	-10.03	37.32	21.46	31.00	0.68
67	70	3.24	7.32	58.23	-6.06	33.57	20.63	22.60	0.47
68	112	3.04	7.11	58.51	-6.38	42.50	19.71	22.20	0.70
69	110	3.92	6.92	52.67	-12.50	36.76	27.77	23.20	0.45
70	430	2.87	4.61	44.66	-10.16	37.92	18.70	21.20	0.76
71	120	2.96	5.75	51.28	-8.53	30.00	19.24	21.40	0.70
72	100	2.89	4.14	41.52	-10.70	40.75	18.35	21.20	0.70
73	85	3.40	5.84	49.99	-10.52	42.23	22.18	24.00	0.54
74	115	2.95	3.01	32.02	-13.85	51.02	19.12	24.60	0.71
75	250	2.83	5.22	48.56	-8.12	30.74	17.66	13.80	0.69
76	250	3.12	7.49	59.55	-5.19	30.87	19.33	28.00	0.60
77	98	3.69	5.04	43.88	-14.14	36.27	24.72	21.00	0.68
78	92	3.50	5.76	48.79	-11.42	41.73	23.37	21.00	0.65
79	230	3.42	5.16	45.94	-11.94	35.72	20.94	14.40	0.55
80	230	3.18	4.90	45.59	-10.86	39.07	20.19	14.20	0.65
81	150	3.77	5.24	44.64	-14.45	42.32	25.89	13.00	0.61
82	238	4.59	6.49	48.30	-15.61	39.15	32.54	22.40	0.66
83	90	16.17	13.00	50.23	-68.98	38.29	135.11	18.00	0.84
84	---	3.44	5.26	45.98	-11.11	44.08	22.49	25.60	0.69
85	87	2.72	5.76	52.67	-4.56	36.76	16.24	9.40	0.63
86	150	2.42	4.23	44.66	-4.67	37.92	13.57	24.20	0.65
87	120	2.13	4.84	51.10	-1.03	29.56	10.56	21.40	0.70
88	---	3.20	4.35	41.52	-8.57	40.75	18.44	22.20	0.50
89	---	2.55	5.06	49.99	-0.24	42.23	12.56	20.80	0.64
90	129	2.78	2.92	32.02	-6.38	51.02	12.95	19.40	0.66
91	---	2.65	5.05	48.56	-4.17	30.74	17.18	25.40	0.65
92	200	3.22	7.61	59.55	-3.01	30.87	19.59	20.80	0.69
93	---	2.14	3.84	43.88	-4.78	36.27	11.75	21.00	0.63
94	110	3.17	5.48	48.79	-7.31	41.73	19.15	25.80	0.74
95	75	2.17	4.11	45.94	-3.16	35.72	11.08	23.20	0.78
96	---	2.24	4.12	45.59	-2.32	39.07	10.84	22.40	0.66

Table 2: Continued

Serial No.	Well depth	EC (dS m^{-1})	SAR	SSP (%)	RSC (meq L^{-1})	SMgP (%)	PS (meq L^{-1})	NO_3 (mg L^{-1})	B (mg L^{-1})
97	130	3.68	5.17	44.64	-10.16	42.32	14.04	21.00	0.48
98	---	3.20	5.42	48.30	-7.68	39.15	19.85	17.00	0.68
99	120	3.30	5.72	49.60	-5.18	38.29	19.30	18.20	0.57
100	110	4.86	6.26	45.98	-12.80	44.08	22.71	20.00	0.74
101	250	2.26	3.34	38.74	-7.17	39.38	15.93	19.60	0.71
102	80	5.5	6.82	46.96	-19.27	43.39	38.34	37.80	0.76
103	160	2.16	5.03	52.38	-1.12	31.77	11.32	7.60	0.54
104	---	2.64	5.27	50.56	-0.50	40.11	12.71	22.60	0.51
105	260	2.98	5.52	50.22	-1.21	37.32	15.80	21.20	0.60
106	----	2.88	6.90	58.23	-1.02	33.57	14.51	23.80	0.44
107	----	2.33	6.23	58.51	-1.32	42.50	10.52	22.80	0.77
108	450	2.23	4.64	49.23	-4.55	38.29	12.24	2.40	0.70
109	70	3.78	5.17	44.36	-17.15	44.08	29.26	27.60	0.66
110	150	3.96	5.13	42.32	-19.20	39.38	30.57	40.40	1.04
111	150	6.92	7.70	47.14	-19.36	43.39	41.83	36.80	0.59
112	450	2.00	4.56	50.93	-6.03	31.77	12.98	1.46	0.91
113	250	2.34	4.06	44.46	-8.26	36.65	14.98	2.40	0.93
114	240	2.12	4.43	48.59	-6.01	37.32	12.85	2.60	0.71
115	450	2.29	5.81	56.84	-5.06	33.57	13.24	2.40	0.74
116	220	2.23	5.49	54.72	-4.16	37.99	13.01	0.73	0.72
117	250	3.84	7.37	54.50	-9.02	36.76	24.44	6.40	0.76
118	130	7.45	7.86	46.07	-26.30	37.92	48.72	32.00	0.69
119	135	2.95	4.81	45.91	-8.27	34.33	17.76	19.60	0.48
120	---	9.42	7.67	42.18	-36.37	40.75	57.97	42.60	0.44
121	390	2.06	4.49	49.66	-6.17	42.23	12.36	2.40	0.47
122	120	3.30	5.47	47.12	-14.68	39.63	24.74	17.60	0.41
123	100	5.17	7.04	48.52	-17.93	30.74	35.51	10.20	0.45
124	----	5.25	8.26	53.43	-15.76	30.87	30.15	12.60	0.47
125	40	3.01	5.04	46.37	-9.70	36.27	19.27	14.80	1.23
126	120	13.95	13.97	51.01	-44.32	42.14	111.19	8.80	1.11
127	90	4.65	6.68	48.67	-12.26	43.00	28.17	13.20	1.11
128	250	2.69	5.23	45.79	-8.23	39.36	19.12	6.80	0.92
129	250	2.51	5.07	45.56	-7.56	37.32	17.52	10.60	1.08
130	420	3.45	6.30	51.20	-8.06	38.29	20.01	1.47	0.87
131	---	2.98	4.70	42.06	-10.42	37.92	20.13	6.00	1.01
132	80	5.25	7.36	50.57	-21.78	42.17	40.02	11.00	0.52
133	95	4.61	6.44	47.89	-11.30	31.77	26.86	9.80	0.48
134	90	4.24	6.25	48.16	-13.68	40.11	26.82	10.20	0.41
135	450	2.02	5.78	53.08	-3.44	33.57	13.33	4.91	0.67
136	250	2.73	6.74	53.45	-3.35	42.50	16.84	7.60	1.27

The Residual Sodium Carbonate (RSC) evaluates the tendency of irrigation water to form carbonates and to dissolve or to precipitate the calcium and to a less degree the magnesium carbonates. The precipitation of poorly soluble carbonates increases the sodium hazard of irrigation water and as a result increases the sodicity of irrigated soils. The RSC values of all the water samples is negative, because the Ca^{2+} + Mg^{2+} ions concentration is higher than the CO_3^{2-} + HCO_3^- ions which indicated that irrigation with these waters will not develop any soil sodicity problems.

The Potential Salinity (PS) for all water samples ranged from 8.24-135.11 meq L^{-1}. The high values of PS above the critical level of 5 meq L^{-1} as reported by U.S. Regional Salinity Laboratory (1954) might be due to higher concentration of Cl and SO_4 ions in groundwater (Table 2).

Nitrate (NO_3) concentration: Mean nitrate concentration (mg L^{-1}) of groundwater in Al-Hassa Oasis ranged between 8.8-78, 2.4-40.4 and 1.46-3.45 mg L^{-1} at depth <50, 150-260 and >260 m, respectively (Table 2). The special distribution of NO_3 in al-Ahsa Oasis is presented in Fig. 2. Out of the total water samples, only 6-well waters contained higher concentration of NO_3^- which ranged between 57.5 and 78 mg L^{-1}. These wells are located in the vicinity of highly intensive agricultural area called as Ghiwibah village. The higher concentration might be due to use of high doses of nitrogen fertilizers by the local farmers to obtain high crop production which might have resulted high nitrogen losses thus contaminating the shallow groundwater aquifer. The highest concentration of NO_3^- was detected in Neogene aquifer with a total depth <150 m. The lowest NO_3^- concentrations were recorded at deep groundwater aquifer with total depth >260 m. 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 revealed that the groundwater contains low level of nitrate which is within the maximum permissible limits for drinking purposes according to WHO (1984) drinking water quality standards without serious health hazards. The results of shallow groundwater agreed with those of O'Neill and Gordon (1994) and Pekarova and Pekar (1996). They reported that the decrease in nitrate concentration in surface water is mainly due to the decrease in mineral nitrogen fertilizer. Also, Chinkuyu *et al.* (2000) found that the poultry manure at a rate of 168 kg N ha^{-1} resulted in the lower NO_3 concentration in sub-surface drain water when compared with the application of commercial N fertilizer. In the same manner, Kryza and Stasko (2000) concluded that increasing nitrate concentration up to 12 mg L^{-1} of NO_3 was due to the extensive use of mineral fertilizer. The increasing NO_3^- content of shallow groundwater due to the use of mineral nitrate fertilizer increases the NO_3^- hazard as water pollutant, where NO_3^- concentration exceeded the level recommended by WHO (1984).

The boron concentration in water samples ranged from 0.2-1.39 mg L^{-1} at various locations (Table 2). The B concentration of about 29% water samples is above the permissible limit of 1 mg L^{-1} for drinking and agricultural use, while the B concentration of the remaining 71% water samples is within the permissible safe limits for drinking and agriculture use according to Ayers and Westcot (1976) and WHO (1993) standards.

Overall, it appears from the study results that majority of the groundwater samples may cause one or another problem in developing saline or sodic soils after irrigation. According to the criteria used for interpreting irrigation water quality for irrigation, the major problems might be ascertained as total salinity, potential salinity and magnesium hazards both for the soils and crops.

Evaluation of groundwater according to US Salinity laboratory method: Based on the U.S. Regional Salinity Laboratory (1954) water classification scheme for irrigation, the water samples fall in the category of C3-S1 (high salinity hazard and low sodium hazard) and C4-S1 (very high salinity hazard and low sodium hazard) except samples Nos. 83 and 126 which are in the category of C4-S2 (very high salinity hazard and medium sodium hazard) (Table 4).

Table 3: Water sampling locations have EC less (left side) or more (right side) than the critical limit (3 dS m^{-1})

Serial No.	EC (dS m^{-1})	Well depth	Serial No.	Well depth	EC (dS m^{-1})	Serial No.	EC (dS m^{-1})	Well depth	Serial No.	Well depth	EC (dS m^{-1})
1	1.46	420	62	116	2.79	2	11.68	110	84	---	3.44
4	2.19	215	64	116	2.79	3	7.35	120	88	----	3.20
5	2.68	235	65	80	2.87	15	8.37	135	92	200	3.22
6	2.67	250	70	430	2.87	16	4.24	110	94	110	3.17
7	2.07	250	71	120	2.96	17	5.43	115	97	130	3.68
8	2.35	250	72	100	2.89	20	3.59	112	98	---	3.20
9	2.16	260	74	115	2.95	21	3.05	148	99	120	3.30
10	2.38	200	75	250	2.83	25	10.34	130	100	110	4.86
11	2.14	---	85	87	2.72	27	9.07	130	102	80	5.50
12	2.31	260	86	150	2.42	29	9.80	80	109	70	3.78
13	2.38	67	87	120	2.13	30	9.57	120	110	150	3.96
14	2.27	90	88	---	3.20	33	9.50	130	111	150	6.92
18	2.56	120	89	---	2.55	35	6.44	35	117	250	3.84
19	2.33	250	90	129	2.78	36	4.75	210	118	130	7.45
22	2.99	160	91	---	2.65	39	4.39	80	120	---	9.42
23	2.00	250	93	---	2.14	41	3.17	90	122	120	3.30
24	1.58	450	95	75	2.17	44	4.51	100	123	100	5.17
26	2.80	380	96	---	2.24	47	3.47	85	124	---	5.25
28	2.09	250	101	250	2.26	48	3.53	120	125	40	3.01
31	2.13	250	103	160	2.16	49	3.51	110	126	120	13.95
32	2.58	350	104	---	2.64	50	5.39	120	127	90	4.65
34	1.85	450	105	260	2.98	55	3.02	120	130	420	3.45
37	2.45	250	106	---	2.88	57	3.00	100	132	80	5.25
38	2.40	250	107	---	2.33	59	4.22	115	133	95	4.61
40	2.56	500	108	450	2.23	63	4.43	100	134	90	4.24
42	2.88	90	112	450	2.00	66	3.23	120			
43	2.71	120	113	250	2.34	67	3.24	70			
45	2.99	105	114	240	2.12	68	3.04	112			
46	2.90	72	115	450	2.29	69	3.92	110			
51	2.76	96	116	220	2.00	73	3.40	85			
52	2.88	35	119	135	2.95	76	3.12	250			
53	2.90	70	121	390	2.06	77	3.69	98			
54	2.83	130	128	250	2.69	78	3.50	92			
56	2.89	120	129	250	2.51	79	3.42	230			
57	3.00	100	131	---	2.98	80	3.18	230			
58	2.88	106	135	450	2.02	81	3.77	150			
60	2.88	110	136	250	2.73	82	4.59	238			
61	2.80	120				83	16.17	90			

Special distribution of EC of groundwater: Data in Fig. 3 showed that the water salinity in the whole study area is uniform except only at few place where the water salinity is in the range of 0.75-2.25 dS m^{-1} (high water salinity class).

Special distribution of SAR of groundwater: Data is Fig. 4 depicted the special distribution of Sodium-Adsorption-Ratio (SAR) of water samples. The results indicated that majority of water samples in the study area fall in the category of SAR ranging from 3-10 value except around Al-Othman area where the SAR of water is high and ranges between 11-18 value (a category of medium to high sodicity problem waters).

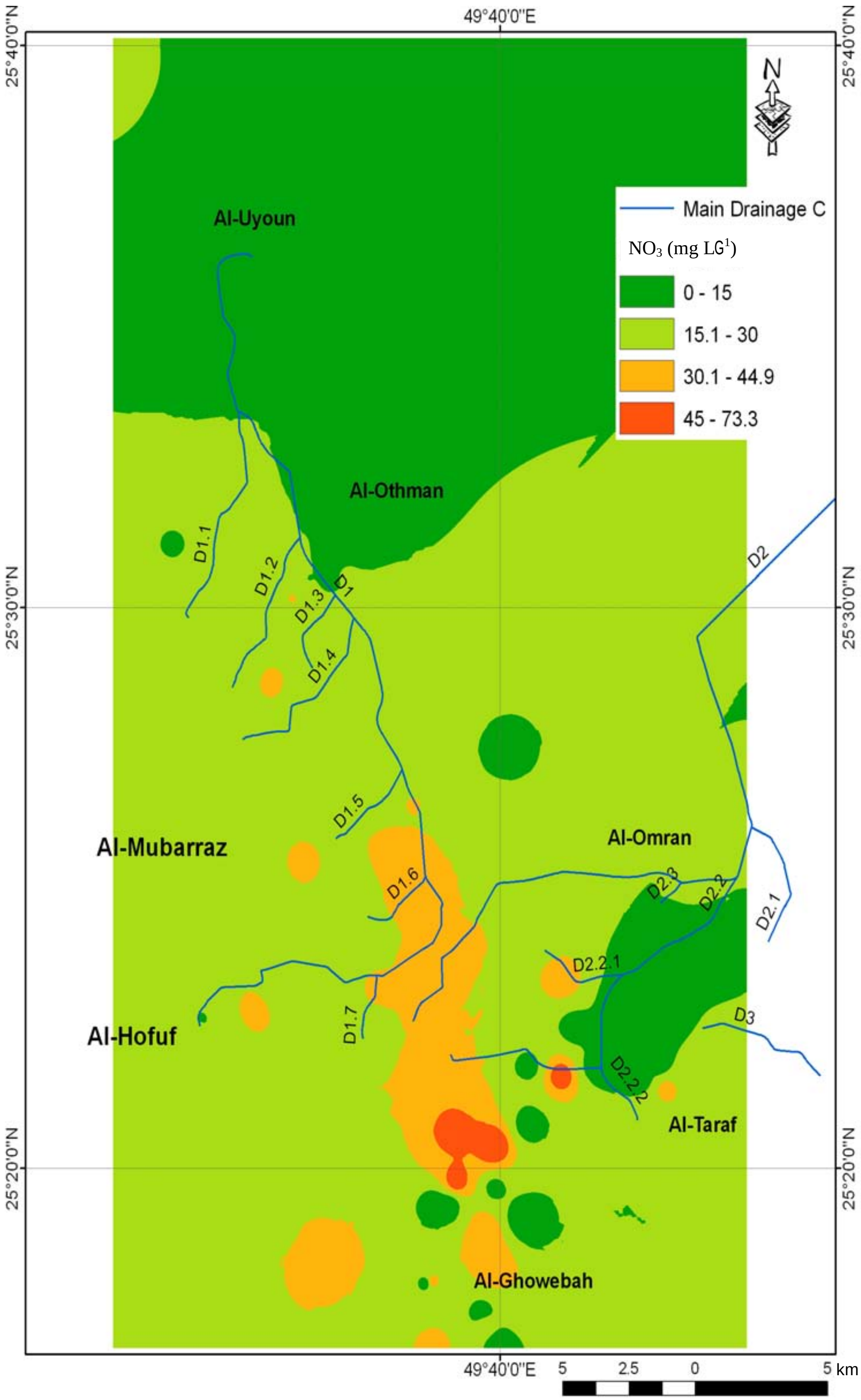

Fig. 2: Spatial distribution of NO_3 in Al-Hassa Oasis

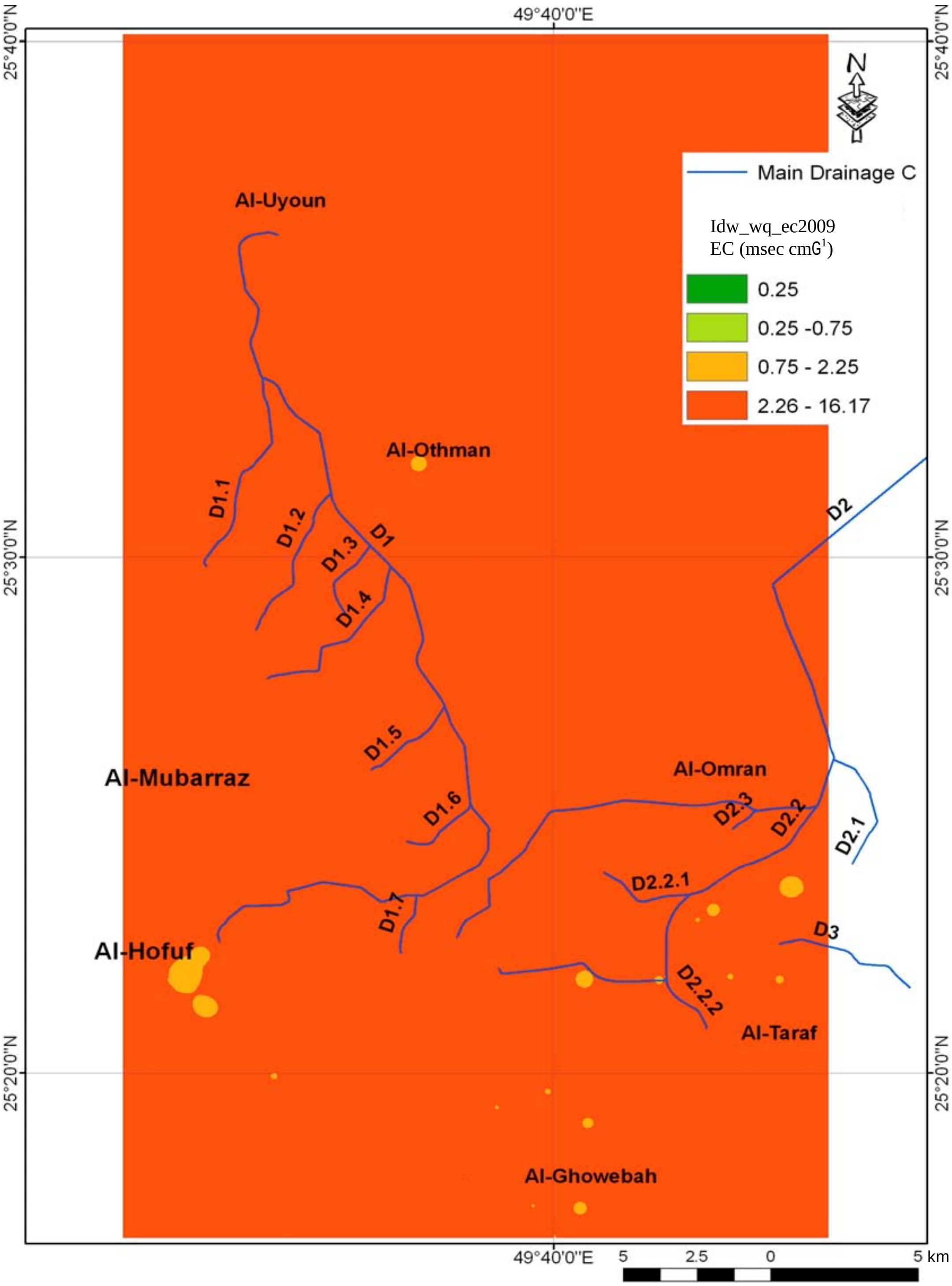

Fig. 3: Spatial distribution of EC in Al-Hassa Oasis

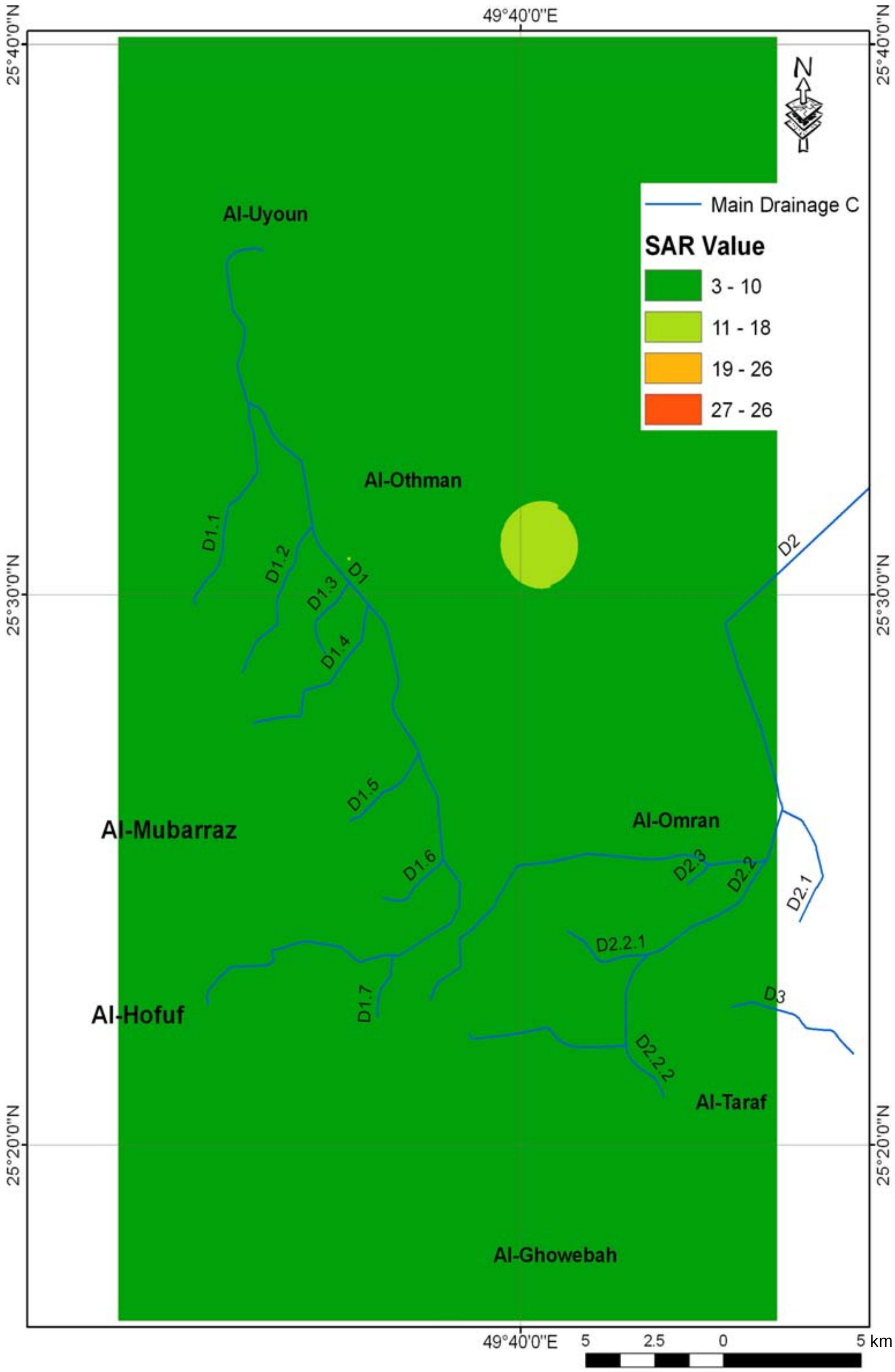

Fig. 4: Spatial distribution SAR of groundwater in Al-Hassa Oasis

Table 4: Water quality evaluation according to U.S. Regional Salinity Laboratory (1954) water classification scheme

Serial No.	EC (dS m^{-1})	SAR	Category	Serial No.	EC (dS m^{-1})	SAR	Category
1	1.46	4.22	C3-S1	48	3.53	6.13	C4-S1
2	11.68	9.37	C4-S1	49	3.51	4.56	C4-S1
3	7.35	9.13	C4-S1	50	5.39	7.35	C4-S1
4	2.19	3.76	C3-S1	51	2.76	2.91	C4-S1
5	2.68	5.19	C4-S1	52	2.88	5.26	C4-S1
6	2.67	2.92	C4-S1	53	2.90	7.22	C4-S1
7	2.07	4.46	C3-S1	54	2.83	4.42	C4-S1
8	2.35	6.50	C4-S1	55	3.02	5.35	C4-S1
9	2.16	3.86	C3-S1	56	2.89	4.74	C4-S1
10	2.38	4.84	C4-S1	57	3.00	4.76	C4-S1
11	2.14	4.08	C3-S1	58	2.88	4.58	C4-S1
12	2.31	4.18	C4-S1	59	4.22	6.22	C4-S1
13	2.38	4.16	C4-S1	60	2.88	5.35	C4-S1
14	2.27	4.56	C4-S1	61	2.80	4.75	C4-S1
15	8.37	9.12	C4-S1	62	2.79	3.71	C4-S1
16	4.24	5.84	C4-S1	63	4.43	6.12	C4-S1
17	5.43	5.18	C4-S1	64	2.79	5.71	C4-S1
18	2.56	4.65	C4-S1	65	2.87	5.49	C4-S1
19	2.33	5.22	C4-S1	66	3.23	5.75	C4-S1
20	3.59	6.14	C4-S1	67	3.24	7.32	C4-S1
21	3.05	5.59	C4-S1	68	3.04	7.11	C4-S1
22	2.99	7.03	C4-S1	69	3.92	6.92	C4-S1
23	2.00	5.77	C3-S1	70	2.87	4.61	C4-S1
24	1.58	4.39	C3-S1	71	2.96	5.75	C4-S1
25	10.34	8.75	C4-S1	72	2.89	4.14	C4-S1
26	2.80	5.55	C4-S1	73	3.40	5.84	C4-S1
27	9.07	7.53	C4-S1	74	2.95	3.01	C4-S1
28	2.09	4.58	C3-S1	75	2.83	5.22	C4-S1
29	9.80	5.49	C4-S1	76	3.12	7.49	C4-S1
30	9.57	9.59	C4-S1	77	3.69	5.04	C4-S1
31	2.13	6.19	C3-S1	78	3.50	5.76	C4-S1
32	2.58	4.22	C4-S1	79	3.42	5.16	C4-S1
33	9.50	9.39	C4-S1	80	3.18	4.90	C4-S1
34	1.85	3.74	C3-S1	81	3.77	5.24	C4-S1
35	6.44	7.09	C4-S1	82	4.59	6.49	C4-S1
36	4.75	6.60	C4-S1	83	16.17	13.00	C4-S2
37	2.45	4.93	C4-S1	84	3.44	5.26	C4-S1
38	2.40	4.40	C4-S1	85	2.72	5.76	C4-S1
39	4.39	4.65	C4-S1	86	2.42	4.23	C4-S1
40	2.56	4.65	C4-S1	87	2.13	4.84	C3-S1
41	3.17	6.09	C4-S1	88	3.20	4.35	C4-S1
42	2.88	5.50	C4-S1	89	2.55	5.06	C4-S1
43	2.71	5.27	C4-S1	90	2.78	2.92	C4-S1
44	4.51	8.64	C4-S1	91	2.65	5.05	C4-S1
45	2.99	7.05	C4-S1	92	3.22	7.61	C4-S1
46	2.90	5.95	C4-S1	93	2.14	3.84	C3-S1
47	3.47	5.07	C4-S1	94	3.17	5.48	C4-S1
95	2.17	4.11	C3-S1	116	2.23	5.49	C3-S1

Table 4: Continued

Serial No.	EC (dS m^{-1})	SAR	Category	Serial No.	EC (dS m^{-1})	SAR	Category
96	2.24	4.12	C3-S1	117	3.84	7.37	C4-S1
97	3.68	5.17	C4-S1	118	7.45	7.86	C4-S1
98	3.20	5.42	C4-S1	119	2.95	4.81	C4-S1
99	3.30	5.72	C4-S1	120	9.42	7.67	C4-S1
100	4.86	6.26	C4-S1	121	2.06	4.49	C3-S1
101	2.26	3.34	C3-S1	122	3.30	5.47	C4-S1
102	5.50	6.82	C4-S1	123	5.17	7.04	C4-S1
103	2.16	5.03	C3-S1	124	5.25	8.26	C4-S1
104	2.64	5.27	C4-S1	125	3.01	5.04	C4-S1
105	2.98	5.52	C4-S1	126	13.95	13.97	C4-S2
106	2.88	6.90	C4-S1	127	4.65	6.68	C4-S1
107	2.33	6.23	C4-S1	128	2.69	5.23	C4-S1
108	2.23	4.64	C3-S1	129	2.51	5.07	C4-S1
109	3.78	5.17	C4-S1	130	3.45	6.30	C4-S1
110	3.96	5.13	C4-S1	131	2.98	4.70	C4-S1
111	6.92	7.70	C4-S1	132	5.25	7.36	C4-S1
112	2.00	4.56	C3-S1	133	4.61	6.44	C4-S1
113	2.34	4.06	C4-S1	134	4.24	6.25	C4-S1
114	2.12	4.43	C3-S1	135	2.02	5.78	C3-S1
115	2.29	5.81	C4-S1	136	2.73	6.74	C4-S1

C3-S1: High salinity hazard and low sodium hazard. C4-S1: Very high salinity hazard and low sodium hazard. C4-S2: Very high salinity hazard and medium sodium hazard

CONCLUSIONS

Based on the groundwater quality in Al-Hassa, the use of these waters for irrigation may develop either soil salinity or sodicity problems. According to the irrigation water classification criteria, the major problems seem to be the total water salinity, potential water salinity and the magnesium hazards. The groundwater is classified as high (C3) to very high salinity (C4) and low (S1) to medium (S2) sodicity hazard waters. Continuous and prolonged use of these waters fro crop irrigation without adopting good water management practices (leaching requirements, proper crop selection and improved irrigation methods etc) can led to severe soil salinity and sodicity problems. The NO_3^- concentration of groundwater is within safe limits for drinking and irrigation purposes according to WHO (1998). Standards except 6-wells where the NO_3^- concentration is very high. The highest concentration of NO_3^- was detected in Neogene aquifer <150 m with a range between 35-150 m. The lowest NO_3^- concentrations were recorded at deep groundwater >260 m with well depth between 260-500 m.

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