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Elemental Composition of Groundwater and Spring Waters in Al-Ahsa Oasis, Eastern Region Saudi Arabia

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ABSTRACT

A study was conducted to evaluate the elemental and geochemistry of groundwater aquifer in Al-Ahsa Oasis Eastern region, Saudi Arabia. Total Dissolved Solids (TDS) varies from 2250-3500 mg L^{-1} in the study area. The concentration order of cations was Na>Mg>Ca and K in descending order and the anion concentration order was $Cl>SO_4>HCO_3$. The groundwater and the spring waters were classified as C3S1 to C4S2, i.e., high salinity and medium sodium to very high salinity to high sodium waters. The groundwater of Al-Ahsa is unsaturated with respect to calcite, dolomite, gypsum, anhydrite, halite and oversaturated with respect to goethite and hematite minerals. The hardness of groundwater is very high as compared to the established standards for domestic use. The Fluoride (F) contents are within permissible limits for drinking water. The nitrate contents are within permissible limits for domestic use. Two water types, i.e., Na-Ca-Cl-SO_4 and Na-Ca-Mg-Cl-SO_4 dominate the groundwater aquifer in Al-Ahsa Oasis. Crop irrigation with groundwater will not create any soil salinity and soil permeability problems. Overall, the review study highlighted the important elemental composition and geochemistry of groundwater of Al-Ahsa Oasis.

Key words: Groundwater, total-dissolved-solids, ion inter-relationship, trace elements, heavy metals, sodium-adsorption-ratio, saturation indices, nitrate

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. Its geographical location is between 49° 10´ and 49° 55' eastern longitude and 25° 05' and 25° 40´ Northern latitude (Al-Taher, 1999) which is around 130-160 m above sea level (Al-Barrak, 1993). 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.

Natural water springs were widespread along the Western edge of the Oasis from South of Al-Hofuf to North of Al-Mutirifi village and divided under four main groups (Fig. 1). Three of these groups are located within the jurisdiction of Al-Hassa Irrigation and Drainage Authority (HIDA) and the fourth group is situated out of this organization. These groups are over three main sectors i.e., Eastern, Middle and Northern sectors. Ain Umm Sabah was classified under third group and is located South of Al-Mutirifi village. Previously, Al-Hassa Oasis was irrigated by limited groundwater resources represented by a hundred water wells and natural springs.

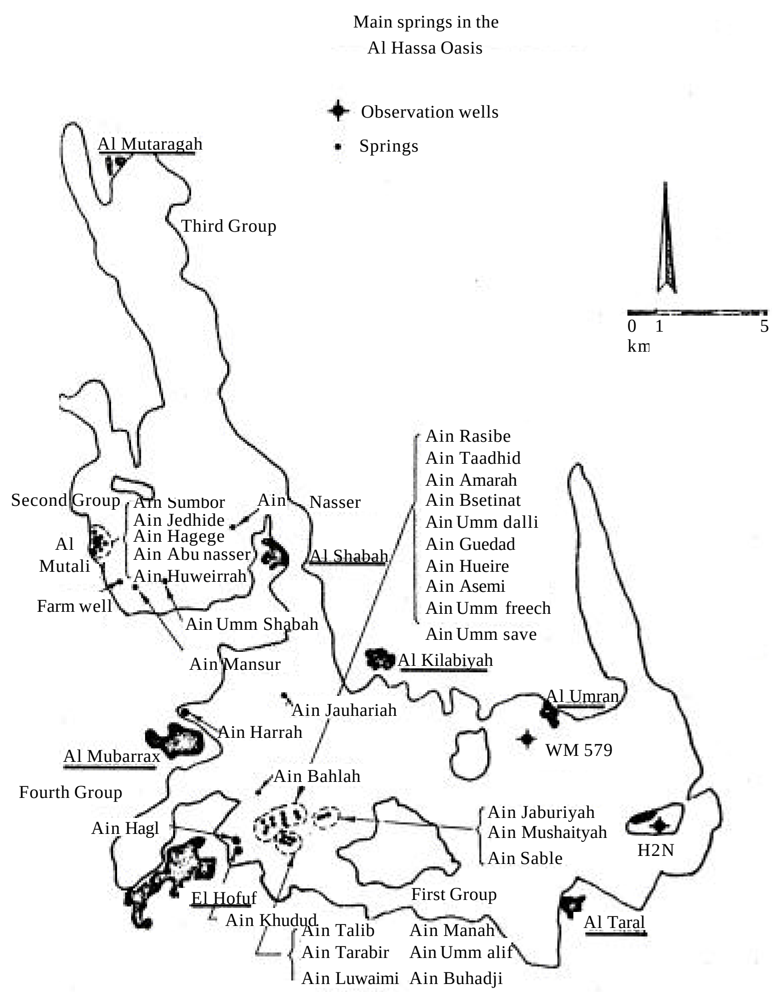

Fig. 1: Adapted from Al-Naeem (2008)

Al-Kuwaiti and Ahmed (2003) stated that the total water discharge of free flowing springs was 10 m^3 sec^{-1} according to BRGM (1977) and 15.2 m^3 sec^{-1} as recorded by HIDA in cooperation with Waste Water Authority and the Directorate of Agriculture and Water. Leichtweiss-Institute reported that the discharge of all free flowing water springs was 10.3 m^3 sec^{-1} (Anonymous, 1978).

Water salinity of Ain Umm Sabah, one of the main natural springs, was 1536 mg L^{-1} in 1979 (Anonymous, 1984), 1540 and 1560 mg L^{-1} by Leichtweiss-Institute in 1978 and 1979, respectively, 1750 mg L^{-1} (top of Ghawar Structure) to 2200 mg L^{-1} (East of Shedgam Plateau) in 1978 and 1690 mg L^{-1} by Hussain and Sadiq (1991) and 2579 mg L^{-1} by Al-Hawas (2002). The temporal changes in water quality especially the total water salinity may be the result of intensive pumping to meet water requirements for various uses (Blaszyk and Gorski, 1981; Appelo and Postma, 1994).

Metal composition of groundwater depends on the aquifer geology, rock-water interface, recharge from precipitation, deep percolation of drainage water, seepage from irrigation fields into the shallow aquifers, intrusion of seawater due to over exploitation of groundwater resources to meet growing water needs for different uses and nutrient losses from irrigated fields into the groundwater. The main objective of this study was to determine elemental chemistry of groundwater in Al-Ahsa Oasis where the main water supply sources were the free flowing springs (now replaced by wells) and the shallow groundwater aquifers such as Neogene and Al-Khobar.

Hydrogeology of the study area: The geology and hydrogeology of the aquifers in the Eastern Province of Saudi Arabia were described by Naimi (1965). The ground water potential of the area has been investigated in great details during the last two decades by Italconsult (1969), BRGM (1977) BRGD (1976, 1977), GDC (1980) and Water Atlas of Kingdom of Saudi Arabia (1985) and Ministry of Agriculture and Water (1992).

The Dammam Formation, which mainly consists of carbonate rocks with inter-bedded shales and marls, is bounded at the base by the chalky limestones of the Rus Formation and at the top by the Eocene-Neogene unconformity. The Formation is subdivided into five members: the Midra Shale, the Saila Shale, the Alveolina Limestone, the Khobar and the Alat Member (Fig. 2). The last two members consist of an upper limestone unit and a lower unit and they are the most economically exploitable aquifers in the Dammam Formation.

The Midra and Saila Shale members are considered a single lithological unit in view of the great lithological similarity between them. They constitute the basal level of the Dammam Formation and consists of blue to blue gray marl or shales and the limestones. Their combine thickness over the whole study area ranges from zero on the top of the Ghawar anticline west of Hofuf, to 20-25 m in the coastal belt area, the average thickness being 15-20 m. These two members, together with the underlying Rus |Formation, form the hydraulic separation between the Dammam and Umm Er Radhuma Formations.

The Alveolina Limestone member overlies the Midra and Saila Shales and is bounded at the top by the Khobar member. The thickness of this member ranged from Zero to about 20 m. The Khobar member overlies the Alveolina Limstone member. It is bounded at the top by the marls of the Alat Member and it consists mainly of skeletal-detrital limestone, dolomitic limestone and a basal marl unit. The limestone and dolomitic limestone of the Khobar Member form the most productive reservoir in the Dammam Formation. The thickness of the Khobar limestone member ranges from a minimum of zero meter to a maximum of about 60 m.

Previous investigations by Italconsult (1969) and BRGM (1977) have shown that the transmissivity of the Khobar aquifer is extremely variable, ranging from a minimum of 3.0×0^{-6} m^2 sec^{-1} to a maximum of 3.0×10^{-1} m^2 sec^{-1}. Storage coefficient (10^{-3} to 10^{-5}) are low, indicating a confined aquifer behavior.

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 factors 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. Mean annual rainfall is about 70.3 mm (Al-Kuwaiti and Ahmed, 2003).

Age		Formation	Member	Generalized lithologic description	Range of thickness	Hydrogeology
Quaternary		Surficial deposits		Gravel, sand and slit	Generally less than 30 m.	Variable productivity, depending on recharge.
Tertiary	Neogene	Hofuf		Sandy marl and sandy limestone	0-95 m	Generally called Neogene Aquifer Irregular occurrences of water. Prolific aquifer in Al-Ahsa.
		Dam		Marl and shale; subordinate sandstone; limestone	0-125 m	
		Hadrukh		Marly sands, siltstones and sandy limestone	0-90 m	
	Eocene	Dammam	Alat	Limestone with sandy fissures; orange marl at the base	0-85 m	Moderate aquifer
			Khobar	Skeletal-detrital limestones, dolomitic limestones, marls at the base	0-60 m.	Aquifer
			Alveolina Limestone	Limestone interbeded with marls or shales	0-20 m.	Aquitard
			Salla Shale Midra Shale	Dark-coloured fissile shales and marls with small gypsiferous lenses	0-25 m.	Aquitard
		Rus		Marl, chalky limestone, anhydrite	10-200 m	Aquitard
	Paleocene	Umm Er Radhuma		Limestone, dolomitic limestone and dolomite	200-600 m	Aquifer
Cretaceous		Aruma		Limestone; subordinate dolomite and shale	400-600 m	Poor aquifer

Fig. 2: Generalized Litho-stratigraphic Sequence of Tertiary in Eastern Saudi Arabia [After Italconsultant (1969)]

Water resources: Main water sources in Al-Ahsa Oasis were the free flowing springs (now replaced by wells) and the different groundwater aquifers namely Neogene, Al-Khobar and Umm-Radhuma. Presently, most of the free flowing springs are not operating naturally due to depletion in groundwater level as a result of intensive groundwater pumping by the shallow and deep wells in order to meet increasing water demand for agricultural expansion and urbanization. The significance of the two major water supply sources is summarized below.

Free flowing natural springs: Free flowing springs (now replaced by wells) are the basis for the existence of Al-Hassa Oasis. Early records on number, location, water quality, water temperature, purity and discharge date back to 1941 and 1951 (Vidal, 1951). Early investigations carried out on free flowing springs for the design of Hassa Irrigation and Drainage Authority (HIDA) showed that only 32 springs were productive and useable for the establishment of new irrigation project. The new irrigation project consisted of irrigation channels (major and minor) for the supply of irrigation water for agricultural activities and the drainage network for the disposal of drainage water to the two main evaporation lakes on the edges of Oasis covering the South and East part of the Oasis. The main springs are situated on a line connecting Hofuf, Mubarraz, Al-Mutarifi on the Western Border of Oasis (Fig. 1). The 32 main springs were:

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 below:

Sr.No.	Description	Discharge (L^{-1})
1	336 wells, free flowing or pumped/well (estimated)	0.5-10
2	85 small springs, free flowing or pumped/spring (estimated)	2.5-20
3	32 main springs (maximum discharge)	25-1700

After the completion of HIDA project in 1971, only 32 main springs, considered most productive and active, were used for water supply. The evident decrease in spring discharge after 1980 is not only due to the project implementation but also due to the increase in private well drilling which is now thought to be in excess of 2000 wells tapping the Neogene aquifer alone. The once free flowing springs are now dried and replaced by wells.

Groundwater aquifers: Important aquifers in the Eastern Region 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) as reported by Ministry of Agriculture and Water (1992).

Chemistry of groundwater

Water salinity (EC dS m^{-1}): Al-Zarah (2008) surveyed the groundwater of Al-Ahsa Oasis and observed that mean EC (expressed as dS m^{-1}) ranged from 1.23-5.05 (Table 1). The groundwater is classified as C2S1 to C4S3, i.e., medium salinity and high sodium to very high salinity and high sodium waters.

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

Sample		EC	TDS	Ca	Mg	Na	K				NO_3	F		Water
No.	pH	(dS m^{-1})	(dS m^{-1})	--------------(Meq L^{-1})------------------				HCO_3	Cl	SO_4	----(mg L^{-1})---		SAR	class
1	6.7	2.98	1928	8.98	6.00	16.44	0.73	2.64	22.45	7.51	26.20	1.1	6.01	C4S2
2	7.0	2.85	1910	8.98	6.00	16.27	0.73	2.64	22.12	7.42	12.30	1.3	5.95	C4S2
3	7.1	2.25	1660	8.38	6.00	12.61	0.45	3.08	15.55	8.71	26.80	1.3	4.70	C3S2
4	7.0	2.43	1732	9.18	6.00	12.98	0.42	3.20	15.74	9.58	24.00	1.2	4.71	C4S2
5	6.9	2.16	1660	8.78	6.00	12.61	0.47	3.28	15.53	8.70	17.10	1.2	4.64	C3S1
6	7.0	2.64	1824	7.78	6.00	15.85	0.63	2.84	18.68	8.83	16.80	1.3	6.04	C4S2
7	6.9	2.45	1692	8.78	4.93	13.53	0.72	2.84	16.93	8.25	16.50	1.5	5.17	C4S2
8	7.1	2.80	1836	8.78	5.64	15.66	0.68	3.04	20.54	7.13	25.70	1.0	5.83	C4S2
9	7.0	2.10	1624	8.58	6.00	13.13	0.45	3.87	14.60	7.97	24.90	1.2	4.86	C3S2
10	7.0	2.07	1480	7.98	5.60	10.53	0.52	3.08	14.23	7.29	25.70	1.2	4.04	C3S1
11	7.7	2.00	1328	7.98	4.40	9.94	0.45	3.16	13.12	6.46	27.30	1.1	3.99	C3S1
12	7.2	2.10	1398	8.78	4.40	9.81	0.45	3.12	13.32	6.59	27.30	1.1	3.82	C3S1
13	6.9	2.64	2084	10.78	7.42	15.94	0.67	2.84	22.79	9.17	28.50	1.1	5.29	C4S2
14	7.1	2.09	1382	7.19	5.60	9.85	0.50	3.36	13.29	6.34	26.60	1.1	3.90	C3S1
15	6.8	5.05	3566	15.37	12.88	31.33	0.89	3.04	43.66	13.88	21.30	1.2	8.34	C4S3
16	7.1	2.28	1578	8.38	6.00	11.53	0.53	2.96	16.80	6.84	20.70	1.1	4.30	C4S2
17	7.5	1.84	1372	6.39	6.00	10.24	0.45	3.08	13.84	6.51	6.80	1.5	4.12	C3S1
18	7.3	1.84	1302	5.99	5.60	9.89	0.44	3.20	12.92	6.09	6.40	1.5	4.11	C3S1
19	7.5	2.40	1504	7.29	5.20	12.11	0.52	2.96	15.94	6.56	8.40	1.2	4.85	C4S2
20	7.1	4.09	2948	16.47	10.79	21.33	0.73	2.84	31.26	15.08	28.60	1.2	5.78	C4S2
21	7.6	1.23	952	4.39	4.80	6.09	0.45	3.24	7.27	5.57	5.80	2.5	2.84	C3S1
22	7.3	1.95	1352	6.99	4.80	10.27	0.50	3.04	13.99	5.96	6.30	1.7	4.23	C3S1
23	7.2	3.30	2386	10.68	10.39	18.47	0.61	3.08	25.56	11.42	31.30	1.1	5.69	C4S2
24	7.2	3.73	2416	11.88	6.49	21.31	0.69	2.96	26.17	10.96	37.50	1.2	7.03	C4S2
25	7.6	3.40	3262	29.54	13.19	6.98	0.53	2.64	5.77	42.03	6.20	2.7	1.51	C4S1
26	6.9	1.60	1104	6.39	6.00	6.09	0.26	3.20	9.43	6.14	9.20	1.3	2.45	C3S1
27	7.6	1.81	1294	6.19	5.44	9.58	0.48	3.08	12.76	6.17	6.50	1.6	3.97	C3S1
28	7.2	1.99	1336	6.89	4.96	9.95	0.46	3.16	12.75	6.65	7.40	1.7	4.09	C3S1
29	6.7	3.40	3452	31.94	12.79	9.65	0.45	3.70	10.70	39.48	6.00	3.0	2.04	C4S1
30	7.4	1.99	1360	6.79	6.00	9.68	0.50	3.20	12.30	6.90	26.00	1.3	3.83	C3S1
31	7.1	2.80	2396	17.17	11.19	9.83	0.48	3.04	12.85	22.82	13.60	1.8	2.61	C4S1
32	7.3	3.50	2394	8.88	6.32	23.67	0.78	2.84	26.57	10.11	29.10	1.4	8.59	C4S3
33	7.3	2.70	1902	8.38	6.13	16.46	0.73	2.84	21.16	7.75	23.70	1.5	6.11	C4S2
34	7.3	2.56	1854	8.33	6.13	15.93	0.70	3.28	20.03	7.76	21.40	1.5	5.93	C4S2
35	6.8	2.62	1764	8.23	6.13	14.61	0.70	3.04	19.13	7.38	18.90	1.0	5.45	C4S2
36	7.7	2.61	1786	8.58	6.16	14.53	0.73	3.00	19.64	7.42	17.20	1.1	5.35	C4S2
37	6.6	2.61	1720	7.98	6.00	14.80	0.76	2.84	18.68	7.05	19.60	1.1	5.60	C4S2
38	6.8	2.52	1720	7.98	6.00	14.72	0.73	2.88	18.79	7.09	19.80	1.1	5.57	C4S2
39	6.8	3.71	2726	11.58	11.59	22.63	0.70	3.08	30.24	12.91	5.80	1.8	6.65	C4S2
40	7.5	3.61	2724	11.28	10.82	23.24	0.76	2.84	29.62	12.60	47.20	1.5	6.99	C4S2
41	7.8	3.72	2670	11.18	9.99	23.40	0.71	2.84	29.12	11.99	49.60	1.5	7.19	C4S2
42	2.1	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	6.9	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	7.0	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	7.2	2.10	1442	6.91	4.75	11.76	0.48	2.80	14.67	6.35	28.90	1.0	4.87	C3S2
46	7.0	2.20	1362	6.79	3.77	10.80	0.47	3.08	13.27	6.15	28.20	1.1	4.70	C3S2
47	7.1	2.30	1366	6.79	4.59	10.93	0.47	3.04	13.52	6.08	28.30	1.2	4.58	C3S2
48	7.0	2.10	1392	6.71	5.00	10.97	0.48	3.04	14.03	6.04	27.50	1.0	4.53	C3S2

Table 1: Continued

Sample No.	pH	EC (dS m^{-1})	TDS (dS m^{-1})	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	F	SAR	Water class
				--------------(Meq L^{-1})------------------							----(mg L^{-1})---			
49	6.9	2.10	1396	7.12	4.90	10.85	0.47	3.04	14.11	6.02	25.80	1.0	4.42	C3S2
50	7.1	2.20	1428	7.30	4.18	11.69	0.48	2.76	14.67	6.17	24.70	1.0	4.88	C3S2
51	7.2	3.10	1890	8.53	5.49	17.15	0.55	2.80	22.63	6.36	27.60	1.1	6.48	C4S2
52	7.2	3.00	1924	7.98	5.99	18.10	0.59	2.84	22.69	6.54	29.00	1.1	6.85	C4S2
53	7.1	3.00	1938	8.38	5.73	17.93	0.57	2.88	22.72	6.75	29.70	1.1	6.75	C4S2
54	7.2	2.80	1756	8.34	5.17	15.46	0.58	2.92	19.35	6.71	27.80	1.1	5.95	C4S2
55	7.0	2.80	1720	7.86	5.24	15.24	0.58	2.80	19.47	6.26	25.80	1.1	5.95	C4S2
56	7.2	2.70	1720	7.86	5.24	15.30	0.59	2.80	19.24	6.37	27.10	1.1	5.98	C4S2
57	7.2	2.60	1742	9.00	5.16	14.70	0.59	2.80	17.06	8.39	19.40	1.4	5.52	C4S2
58	6.9	2.80	1702	8.35	4.83	14.88	0.55	3.00	18.62	6.46	26.80	1.1	5.80	C4S2
59	6.8	2.85	1754	8.59	5.16	15.03	0.58	3.00	18.62	7.30	28.00	1.1	5.73	C4S2
60	6.9	2.93	1746	8.67	5.16	14.88	0.59	3.00	18.76	7.05	27.50	1.1	5.66	C4S2
61	7.0	2.50	1710	8.76	5.41	13.92	0.56	3.00	16.82	8.29	20.60	1.2	5.23	C4S2
62	7.1	2.72	1808	8.84	5.82	14.77	0.58	3.00	17.94	8.81	16.80	1.3	5.45	C4S2
63	7.3	2.82	1922	8.18	5.49	18.12	0.65	2.96	21.45	7.62	16.00	1.4	6.93	C4S2
64	7.0	3.20	1980	8.35	5.57	18.68	0.63	3.00	21.38	8.52	15.80	1.3	7.08	C4S2
65	7.0	2.98	1848	8.02	5.49	17.08	0.60	2.88	20.23	7.63	16.30	1.3	6.57	C4S2
66	6.6	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	6.7	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	7.1	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	7.3	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	7.4	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	7.2	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	7.0	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	6.7	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	7.0	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	7.1	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	7.2	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	7.3	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	7.3	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	7.2	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	6.8	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	7.2	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	7.1	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	7.2	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	7.4	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	7.5	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	7.2	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	7.2	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	6.9	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	7.3	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	7.1	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	7.1	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	6.8	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	6.8	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	7.1	2.20	1684	9.06	4.00	15.23	0.32	3.72	16.02	7.66	24.10	1.2	5.96	C3S2

Table 1: Continued

Sample No.	pH	EC (dS m^{-1})	TDS (dS m^{-1})	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	F	SAR	Water class
				--------------(Meq L^{-1})-------------------							----(mg L^{-1})---			
96	7.0	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	7.0	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	7.0	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	7.3	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	7.2	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	7.3	2.20	1276	6.39	6.00	9.36	0.32	3.36	11.99	6.14	26.10	1.0	3.76	C3S1

Data Source: Al-Zarah (2008)

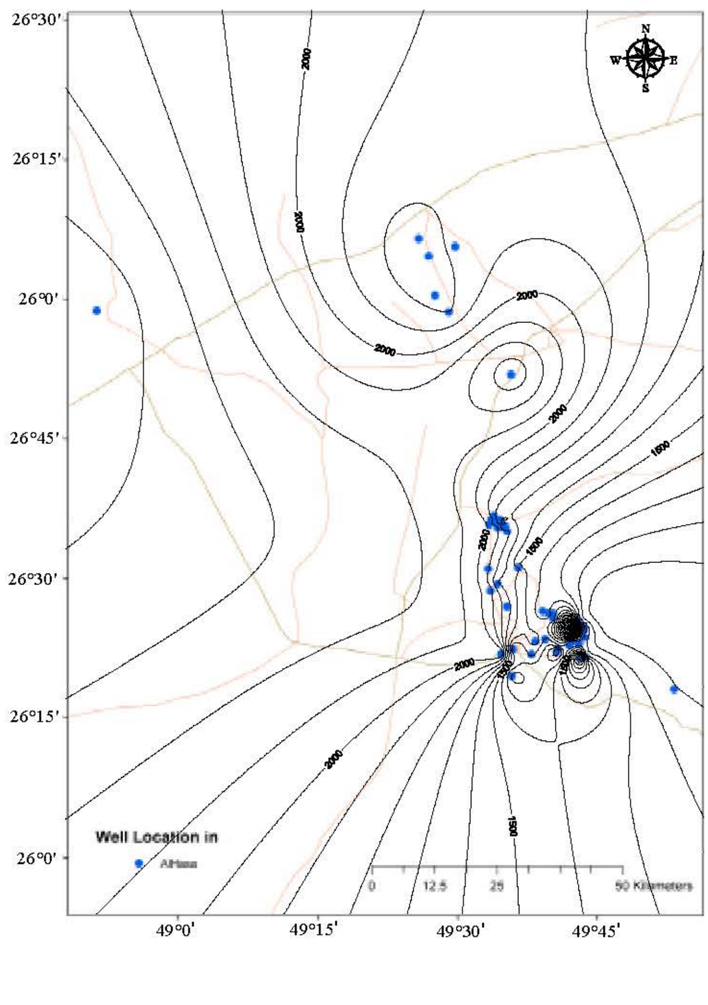

Fig. 3: Contour map of groundwater salinity of Al-Ahsa Oasis. Al-Zarah (2008)

The contour map of groundwater salinity (Al-Zarah, 2008) showed that the groundwater salinity varies from 4400 mg L^{-1} (total dissolved solids, TDS) along the Gulf coast on the eastern side to around 1800 mg L^{-1} on the western side of Al-Ahsa oasis (Fig. 3). The high TDS on the eastern side could be due to: (1) High pumping rate deteriorated the groundwater quality by extracting a mixture of freshwater and saline water from the aquifer, because freshwater layer is on the top of saline water and (2) Possibility of seawater intrusion into the adjoining aquifer through natural drainage to equilibrate the depleting zone. Overall, the TDS of groundwater decreased from East to West direction, but improved in the middle (Western part) and the South-East corner of Al-Ahsa Oasis. The improvement in total salinity (TDS) of groundwater could be attributed to shallow well depth and the minimum influence of seawater intrusion. The groundwater is dominant by Na ion followed by Mg, Ca and K in descending order. Whereas, the anion concentration order is $Cl>SO_4>HCO_3$ (Table 1). Overall, Na and Cl ions dominate the total salinity of the groundwater.

Total hardness: Mean hardness ranged from 460-1420 (mg L^{-1}) in the groundwater of AlAhsa Oasis at different locations (Table 1). Overall, the groundwater is unsuitable for drinking and other purposes according to WHO (1984) drinking water quality standards and household uses unless hardness is either totally removed or minimized to the recommended safe limits. The concentration of $CaCO_3$ dissolved in water by its degree of hardness is presented below:

Degree of Hardness	mg L^{-1} as $CaCO_3$
Soft	0-60
Moderately hard	60-120
Hard	120-180
Very Hard	Greater than 180

Nitrate (NO_3) concentration: Mean nitrate concentration (mg L^{-1}) ranged from 5.3-78.6 in the groundwater of Al-Ahsa Oasis (Table 1). The maximum permissible limit of nitrate concentration in water for various purposes especially for drinking is 50 mg L^{-1} according to WHO (1984). Overall, most of the groundwater samples contain low level of nitrate which is within permissible limits and will not create health hazards upon consumption.

Fluoride (F) concentration: Mean fluoride concentration (mg L^{-1}) ranged from 1.0-2.7 in the groundwater of Al-Ahsa Oasis (Table 1). The WHO (1984) guidelines suggested that in warm climate regions, the 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 in groundwater of Al-Ahsa Oasis is within permissible limit according to WHO (1984). The Saturation Indice (SI) value of fluorite mineral is negative in the groundwater of Al-Ahsa Oasis at four different locations.

Saturation indices: Groundwater chemistry is influenced by various dissolution and precipitation reactions occurring in the soil during rock-water interaction. Because the concentration of many ions 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 groundwater samples from Al-Ahsa Oasis using the speciation code WATEQ4 (Ball and Nordstrom, 1992) and the PHREEQC model developed by Parkhurst (1995). Mean saturation indices of different minerals are given in Table 2. 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

Table 2: 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	Un-Saturated	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	$CaSO_4.2H2_O$	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

Source: Al-Zarah (2008)

specified solid-phase mineral. However, the minerals with positive SI will precipitate and adversely affect the aquifer properties. Similarly, the minerals with negative SI will dissolve aquifer rock during groundwater flow which will increase its porosity and permeability.

Chemistry of spring water: Many researchers have investigated the chemistry of free flowing spring waters (Anonymous, 1979; Hussain and Sadiq, 1991; Al-Naeem, 2008). The total salinity (EC dS m^{-1}) of spring waters ranged between 2.1-2.6 (1975), 2.02-3.35 (1991) and 2.90-4.24 (2002) between 1975 and 2002. The data showed a significant change in the total water salinity over a period of 25 years or more (Table 3). This temporal variability in the total water salinity could be attributed to (1) over exploitation of the groundwater which deteriorated the water quality and (2) possibility of seawater intrusion from the Southeast side in order to fulfill the depleting aquifer from Al-Oqair region.

Hussain and Sadiq (1991) classified all the spring waters as C3S1 to C4S2, i.e., high salinity and low sodium to very high salinity and medium sodium waters according to Ayers and Westcot (1985) water classification scheme for crop irrigation. The TDS of spring waters ranged between 1293 and 2144 mg L^{-1}. The TDS range suggests that the springs were drawing waters from aquifers with variable salinity. Sodium was the most abundant cation in all water samples followed by Ca, Mg, Sr and K in descending order. The concentration of all trace and heavy metals was below 0.1 mg L^{-1}. Thermodynamics calculations revealed that a significant fraction of Ca and Mg in spring waters was associated with SO_4 and HCO_3. However, most of the Na and Cl were found in free form. Thermodynamics calculations showed that Ca and Mg would preferentially precipitate as their CO_3 followed by SO_4.

Chemistry of umm-khurisan spring: Al-Mohandis (1991) studied the geochemistry of Umm-Khurisan spring located near Jamal Al-Qarah, Al-Ahsa Oasis. He found high concentrations of total hardness, total dissolved solids, Cl, NO_3 and F and the high values of the electrical conductivity of the spring water are above the safe limits recommended by the WHO (1984) standards with respect to potability. The concentrations of other minor constituents are around these limits. The Umm-Khurisan water is a saline water with medium sodium hazard and should be used only on soils of moderate to good permeability. The Umm-Khurisan spring water is of

Table 3: Temporal changes in spring water salinity

	ES (dS m^{-1})		
Spring	1975[a]	1991[b]	2002[c]
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: HIDA (1984) [b]Source: Hussain and Sadiq (1991). [c]Al-Hawas (2002)

Table 4: Chemical analyses of Umm-Khurisan spring water

		Maximum permissible limits	
Parameter	Concentration	WHO	NASNAE
Na	600	---	---
K	44	---	---
Ca	180	200	---
Mg	110	150	---
Cl	984	600	250
SO_4	202	400	250
HCO_3	427	---	---
NO_3	48	45	---
pH	7.1	6.5-9.2	---
TH (mg L^{-1}) as $CaCO_3$	1680	---	---
EC (dS m^{-1})	1735	---	---
TDS (mg L^{-1})	3060	1500	1500

WHO: World Health Organization, NASNAE: National Academy of Science and National Academy of Engineering

meteoric origin of deep percolating water (Table 4). The concentration of all the cations/anions in the spring water are within the maximum permissible limits for use in agriculture except Cl, NO_3, pH and TDS which are higher than the permissible limits. The high concentration of these cations/anions can create soil salinity, Cl ion toxicity in plants (citrus). Also the high NO3 contents defines this water as unsuitable for drinking purpose.

Table 5: Elemental concentration (mg L^{-1}) of Umm-Khurisan spring water

Element	Concentration	Maximum permissible limits	
		WHO	NASNAE
Antimony	<0.040	---	---
Arsenic (As)	<0.010	0.05	0.01
Barium (Ba)	0.010	---	1.0
Boron (B)	0.680	---	---
Bromide (B)	<0.010	---	---
Cadmium (Cd)	<0.001	0.01	0.01
Chromium Cr)	<0.003	0.05	0.50
Cobalt (Co)	<0.010	---	---
Copper (Cu)	<0.010	1.0	---
Fluorine (F)	1.600	0.8	---
Iodine (I)	<0.010	---	---
Lead (Pb)	0.100	0.05	0.05
Manganese (Mn)	<0.003	0.10	---
Molybdenum (Mo)	<0.100	---	---
Nickel (Ni)	<0.050	0.05	---
Selenium (Se)	0.010	0.01	0.01
Silicon (Si)	34.000	---	---
Tin (Sn)	0.070	---	---
Vanadium (V)	<0.010	---	---
Zinc (Zn)	0.82	5.0	5

WHO: World Health Organization, NASNAE: National Academy of Science and National Academy of Engineering

The concentration of trace elements and heavy metals is presented in Table 5. The concentration of all the trace elements and heavy metals is within the permissible limits according to WHO (1984) except Pb, NO_3 and F which are higher than the recommended limits of WHO (1984) whereas the Selenium and Arsenic are equal or less than the established standards of WHO (1984). The relatively high nitrate concentration could be due to the application of nitrogen fertilizer to crops around the spring or to the biological activity of nitrogen fixing bacteria. The level of fluoride must not exceed the optimum level, i.e., 0.5-1 mg L^{-1} in drinking water, because it is harmful to children and develops F related problems.

Micro-elements in spring waters: Hussain and Sadiq (1991) reported that the concentration of trace elements and heavy metals in the spring waters is very low and is within permissible limits according to WHO (1984) standards for drinking water and other purposes (Table 6).

Ain Umm sabah spring: Recently, Al-Naeem (2008) reported the trace elements and heavy metal composition of Ain Umm-Sabah natural spring (Table 7). Presently, the spring is not flowing naturally and a shallow pump is installed at the site of spring for pumping water to the main water reservoir. The data indicate that the concentration of trace elements and heavy metals is very low as compared to the permissible limits of WHO (1984) for drinking and other uses. Also, the concentration of trace and heavy metal ions was within safe limits for drinking water when compared to the established standards of European Countries Guidelines for drinking water and other uses.

Table 6: Concentration of micro-elements

Description	Concentration (mg L^{-1}) Fe	Cu	Mn	Zn
Ain Al-Hara	0.015	ND	ND	ND
Ain Al-Hawarat	ND	ND	ND	ND
Ain Um-Sabaa	ND	ND	0.055	ND
Ain Mansoor	ND	ND	0.101	1.640
Ain Nasser	0.054	ND	0.126	0.027
Ain Al-Jawahriya	ND	ND	0.139	0.033
Ain Al-Khadood	ND	ND	0.162	0.036
Ain Al-Lawami	ND	ND	0.084	0.023
Ain Al-Manna	ND	ND	0.109	0.016
Ain Um-Allif	ND	ND	ND	0.031
Ain Bahjah	0.111	ND	0.196	ND
Ain Brabar	0.060	ND	ND	ND
Ain Bastiat	-------	-------	-------	-----
Ain Um-Dali	0.123	ND	ND	0.037
Ain Kmmara	ND	ND	0.029	0.039
Ain Rasseb	ND	ND	0.230	0.026
Um-Qurash	ND	ND	ND	0.037
Um-Saif	ND	ND	0.303	ND
Ain Bari mann	ND	ND	0.124	0.030
Ain Sahla	0.06	ND	0.737	0.030
Ain Al-Bahriya	ND	ND	0.226	0.079
Ain Al-Hawarat	ND	ND	0.248	ND

ND: Not detectable (beyond detection limit of mg L^{-1})

Ain al-khadoud spring: Fathi and Al-Khahtani (2009) studied the water quality of Al-Khadoud spring and concluded that after receiving water from the outlets either treated sewage water or of re-use drainage water, the spring water had an obvious increase in electrical conductivity, COD, total alkalinity, nitrates, phosphorus, chloride and potassium. These features indicated pollution with organic wastes, increased salinity and deteriorated oxygenated state. Based on this, it can be concluded that all these factors could affect both the soil and plants cultivated in the area of Al-Hassa. The physio-chemical characteristics of spring water are shown in Table 8.

Classification of groundwater for irrigation: The groundwater was classified on the basis of chemical composition of water samples from Al-Ahsa Oasis for irrigation by following the guidelines according to Ayers and Westcot (1985). The groundwater falls in the category of C3S1 to C4S3, i.e., high salinity and low sodium to very high salinity and medium sodium waters (Fig. 4).

Infiltration rate of soils: The groundwater of Al-Ahsa Oasis was classified for its effect on the infiltration rate of soils after irrigation (Fig. 5). The data show that the Al-Ahsa groundwater is moderate to highly saline with low to medium sodicity hazards after irrigation. Generally, high salinity of irrigation helps the flocculation process of soil particles which improves the soil structure thus resulting in high rate of water infiltration and enhance aeration to plant roots for optimal

Table 7: Mean metal concentration (mg L^{-1}) of water of Ain Umm Sabah spring in Al-Hassa, Eastern Province as compared to the WHO (1993) standards

Treatment	Mean element concentration	International specifications permission in upper level
Cr	0.018	0.05
Co	0.005	0.1
Al	0.090	0.2
As	0.005	0.05
Ba	0.017	1
Cd	0.005	0.001
Cu	0.005	1.5
Fe	0.008	1
La	0.005	----
Mn	0.005	0.1
Mo	0.006	0.01
Ni	0.005	0.1
Pb	0.005	0.05
Se	0.005	0.001
Si	9.060	----
Sr	2.250	----
V	0.012	0.1
Zn	0.005	5
Sb	0.040	10
I	0.010	----
B	0.570	1**
Br	0.010	----
F	1.340	1.8

**EEC (European Countries Guidelines)

Table 8: The physico-chemical characteristics of Al-Khadoud spring water during the investigation period

	Seasons/sites							
	Summer				Autumn			
Parameters	1	2	3	4	1	2	3	4
Temperature (°C)	24.2	24.9	22.8	22.5	20	21	20.8	21.1
pH	7.95	7.65	7.71	8	7.88	7.9	7.89	8.22
Conductivity (mS)	2.31	2.96	5.2	55 5	2.2	2.3	4.39	4.44
TDS (g L^{-1})	1.38	1.77	3.11	3.42	1.38	1.37	2.64	2.66
Dissolved O_2 (g L^{-1})	9	5.8	6.23	7.5	6.5	4.2	4	8
Alkalinity (mg L^{-1})	129	124	101	137	67	4.2	191	194
Chloride (mg L^{-1})	454	412	562	976	434	472	658	1160
Nitrate-N (mg L^{-1})	2.1	2.7	2.5	4.2	1.7	2	2.7	1.90
Phosphate-P (mg L^{-1})	0.75	0.73	0.78	0.38	0.35	0.75	2.75	2.75
Sulphate-S (mg L^{-1})	298	299	322	348	301	295	308	335
Sodium (mg L^{-1})	255	254	412	455	237	240	324	362
Potassium (mg L^{-1})	39.5	38.4	25.8	27.1	31.3	32	21.5	26.4
Calcium (mg L^{-1})	172	176	150	143	165	166	154	154
Magnesium (mg L^{-1})	71.4	70	71.1	68.2	65.4	62.5	67.1	66.4
COD (mg L^{-1})	10.1	11.2	25.5	40.4	10.5	12	22.5	30.3

Table 8: Continued

	Seasons/sites							
	Winter				Spring			
Parameters	1	2	3	4	1	2	3	4
Temperature (°C)	18.6	18.8	18	18.1	19.2	19.2	19.4	19.2
pH	8.02	7.75	7.74	7.92	8	7.99	7.72	8.01
Conductivity (mS)	2.36	2.35	4.55	4.54	2.66	2.2	4.56	4.76
TDS (g L^{-1})	1.42	1.41	2.76	2.72	1.12	1.38	2.78	3.29
Dissolved O_2 (g L^{-1})	9.21	6.64	6	8.2	14.2	10.5	10.7	12.3
Alkalinity (mg L^{-1})	90	115	129	134	53	130	142	169
Chloride (mg L^{-1})	434	444	538	960	450	452	742	1240
Nitrate-N (mg L^{-1})	2.1	2.3	3.74	2.4	1.9	1.92	4.7	3.6
Phosphate-P (mg L^{-1})	0.52	0.52	2.75	2.75	0.75	0.75	2.14	2.14
Sulphate-S (mg L^{-1})	295	290	314	355	288	287	312	350
Sodium (mg L^{-1})	229	234	315	357	234	235	315	425
Potassium (mg L^{-1})	23	22	21	21.5	25.2	25.2	27.4	25.2
Calcium (mg L^{-1})	158	157	158	151	162	160	161	163
Magnesium (mg L^{-1})	69	68.7	68	65.8	70.6	70.5	71	70.2
COD (mg L^{-1})	10	11.8	22.8	27.2	9.9	10.2	26.1	33.9

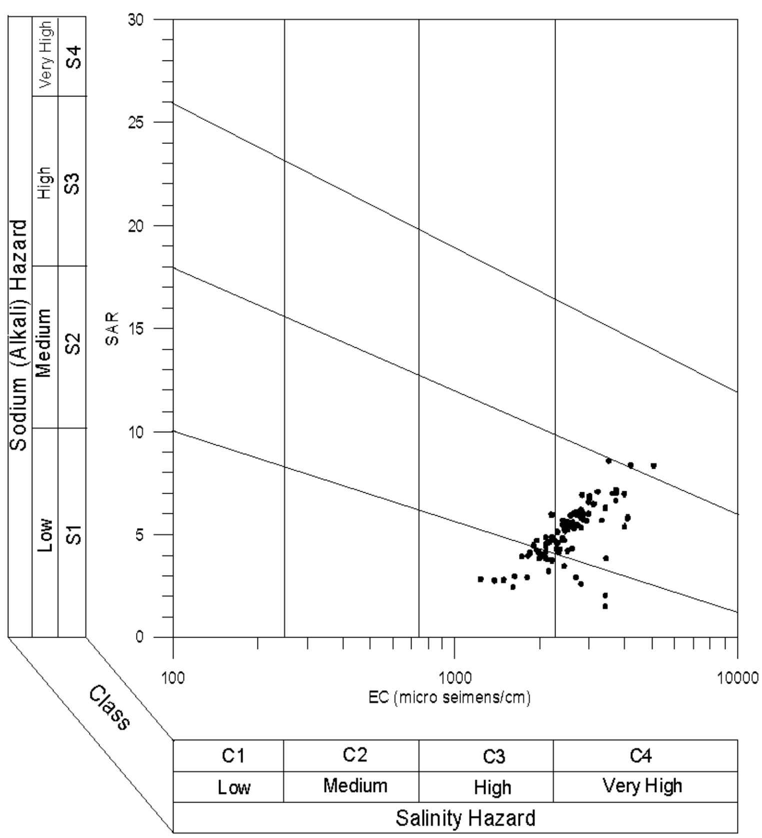

Fig. 4: Irrigation water classification according to USDA (1954)

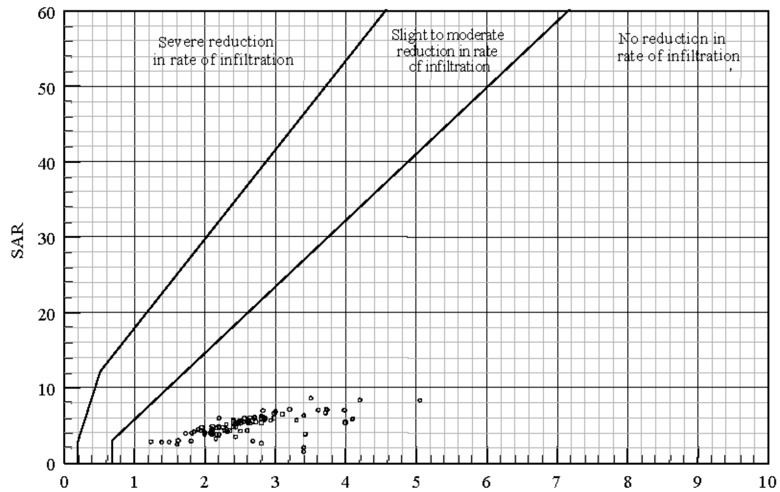

Fig. 5: Groundwater classification for infiltration rate of soils according to Ayers and Westcot (1985)

growth. On the other hand, irrigation water with low salinity results in deflocculation of soil structure due to hydrolysis process and deteriorates the soil structure. This will considerably affect the soil productivity. Therefore, It was noticed that the groundwater will not affect the infiltration rate of soils after irrigation according to the FAO Guidelines (Ayers and Westcot, 1985). Because, the groundwater is of moderate salinity with medium sodicity hazards and falls in the category of no-reduction zone with respect to infiltration of soils.

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