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Hydrochemical Studies of Groundwater at Al Hassa Oasis, Eastern Region, Saudi Arabia

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Abstract: Al-Hassa Oasis is one of the important agricultural regions in the Kingdom of Saudi Arabia and covers an area of approximately 20000 ha. Approximately 8000 ha are irrigated with groundwater, which considers the main source of irrigation water in Al Hassa Oasis. This study was carried out to investigate the Hydrochemistry of groundwater of Al-Hassa Oasis, to evaluate it for irrigation purposes and to investigate the salt-water intrusion into the ground water and its impact on the main Aquifers at Al Hassa Oasis especially the Neogene Aquifer. To achieve the objectives of this study, one hundred and twelve water samples were collected from Al Hassa Oasis. The samples coordinates were recorded using Global Position System (GPS). Water samples were analyzed for total salt concentration, Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-. Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP, %), Soluble Magnesium Percentage (SMgP, %), Residual Sodium Carbonate (RSC, me/L) and Potential Salinity (PS) were calculated. The electrical conductivity for the collected ground water samples (ECiw) ranged from 1.37 to 12.28 dS/m. Moreover, Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Residual Sodium Carbonate (RSC) and magnesium hazard are relatively low in comparing with the critical level of irrigation water quality. In addition, the results showed that, some of the used groundwater for irrigation might cause one problem or another according to the quality of groundwater. According to the criteria used for interpreting water quality for irrigation purposes, the most domain problems are salinity hazard and potential salinity. According to U.S. salinity laboratory classification, the classification of the irrigation groundwater is high (C3) to very high (C4) salinity and low (S1) sodicity hazard. Additionally and based on the classification established by Wilcox for irrigation purposes, the water samples were located in three classes good to permissible, doubtful to unsuitable and unsuitable. Therefore, it is expected that continuous irrigation without good water management (leaching requirements) can led with time to severe problems from the salinity point of view. Moreover, Hydrochemical analysis of water samples indicated that there are a spatial variability in salinity levels, as reflected by the values of electrical conductivity (ECiw). These spatial variations in the salinity of groundwater may be attributed to the increases for salts dissolved during the passage of the groundwater through the aquifers, increasing salinity due to extensive abstraction of the groundwater and/or due to the direct and indirect recharge occurring to the Neogene aquifer that supplies the irrigation water in the Oasis. This shows that salt-water intrusion has already occurred largely in the region and appropriate steps need to be taken for checking this problem. Therefore, a monitoring program on groundwater quality should be established in selected sampling points, in order to improve the groundwater quality and avoid saltwater intrusion phenomena on a large scale in the coastal aquifer system of Al Hassa oasis.

Key words: Water chemistry · Water quality · Salt-water intrusion · Aquifers · 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 temperature close to freezing. The western and eastern regions are hot and humid in the

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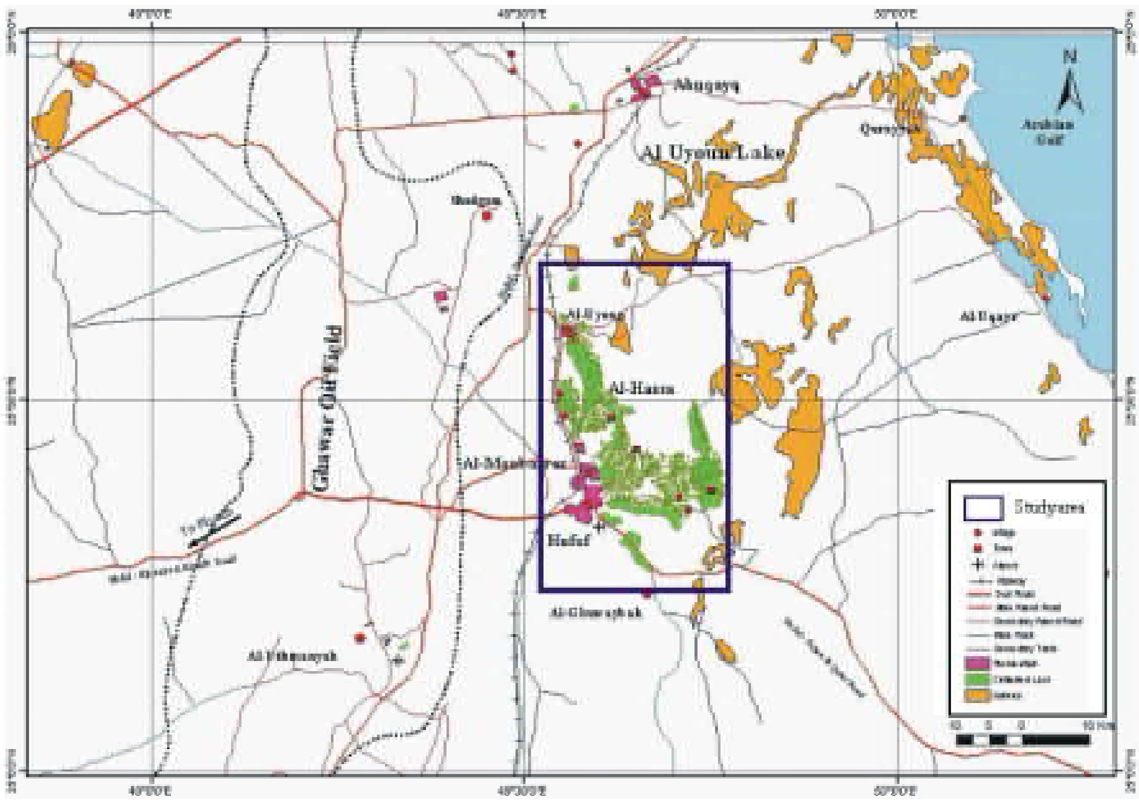

Fig. 1: Base map showing Al Hassa Oasis, Al Hassa, Eastern Province, KSA.

summer month, 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 [1]. The total irrigation use has increased from about 6.108 MCM in 1970 to about 19.074 MCM in 2000 [2, 3]. 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 in 1980 to about 21 Km^3 in 2006. The total surface water and groundwater withdrawal represented 943% of the total renewable water resources [4].

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 (Figure 1). 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-shaped. 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 southwestern corner of the Oasis. The overall area is considered as twin Oasis with an Oasis in the north and the other in the south. The climate is severely arid with an average annual rainfall of 72.1 mm [5]. Out of the (20000 ha), only 8000 ha irrigated with groundwater which considers 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 [1]. About 30 per cent of the total consumed water is being pumped from wells and springs in the region. The total production of groundwater within Al Hassa is about 10.125 m^3s^{-1}. About 90 percent of that quantity is used for irrigation an area of about 8000 hectares of the region.

Three aquifers (Neogene, Dammam and Umm-er-Radhuma) are the main source of ground water in Al Hassa Oasis. The aquifers are partly interconnected to each other. Because of intensive fracturing along the Ghawar anticline, preferential flow paths are developed.

The water quality varies within each aquifer as well as between aquifers. Neogene aquifer (Miocene-Pliocene) with an extent varying between 100 and 200 meters depth [6]. 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- Radhuma aquifer (Paleocene-Eocene) underlies the Khobar aquifer and consists mainly of massive dolomite and dolomitic limestone. Due to the rapid economic growth since the middle of the last century and then the aquifers at Al Hassa area have been overexploited to meet the increasing water demands. Because of the over exploitation of the resources, a decline in groundwater levels is observed. The famous springs in the Al Hassa oasis were running dry. Furthermore, a deterioration of groundwater quality is occurred, caused by seawater intrusion from Arabian Gulf and as well from up coning of deeper saline groundwater and the dynamic balance between freshwater and seawater will disturbed. Recently, the deterioration of water quality of the main aquifers at Al Hassa area due to saltwater infiltration into the freshwater aquifer has become a major concern.

Salt-water intrusion into coastal aquifers has become a major concern [7] because it constitutes the commonest of all the pollutants in freshwater, therefore, understanding of saline intrusion is essential for the management of coastal water resources [8]. Saltwater intrusion has been discussed [9, 10, 11] as a source of contamination. Salt-water intrusion can pose serious problems to coastal areas with freshwater aquifer having marine- aquifer hydraulic interaction. In natural condition, salt-water intrusion happens when the low density of freshwater groundwater interacts with the high density of salt-water. Other sources of saline contamination includes connate water of marine origin [12], saline water of canal and of river which hydraulically interacts with aquifer [13]. [14] investigated the salt-water intrusion problem in the coastal area of South Korea, they observed that salinization of fresh groundwater is highly associated with groundwater withdrawal. [15] showed that the deterioration of freshwater quality due to natural seawater infiltration affects the balanced life of the narrow coastal strip of Rhodes Island, USA. In-addition, [16, 17] observed that the discharge of a large volume of groundwater may allow saltwater intrusion into the freshwater aquifers and this potential saltwater contamination poses a threat to the sustainable development and economic well being of any coastal area. [18] reported that saline water intrusions into coastal aquifers have resulted in acute environmental problems in the past. They further confirm that the extent of saline water intrusion is influenced by the nature of geological formations present, hydraulic gradient, rate of withdrawal of ground water and its recharge.

The main goal of this paper is to study the chemistry of groundwater of Al Hassa Oasis and to evaluate it for irrigation purposes. In addition, to investigate the salt-water intrusion and its impact on the main Aquifers at Al Hassa Oasis especially of the Neogene Aquifer.

MATERIALS AND METHODS

The increase of salinity in irrigation water leads to the increase of its percentage in soil. This will lead to damage the growth and yield of the plants. Therefore, in the first phase of this study, 112 water samples were collected from different wells located at Al Hassa Oasis during the winter months of November and December 2010. The sample position was recorded using Global Position System (GPS). The water samples were collected in sterile plastic bottles, stored in icebox and transported immediately to the laboratory for analysis. Water classification, based on the chemical characteristics, was done according to the method described in Handbook 60 [19]. The concentrations of NO_3^- in collected ground water samples were determined by [20] method. The locations of the collected water samples, Al Hassa Oasis, are presented in Figure (2).

Quality of irrigation water was determined according to the following parameters [21, 22, 23].

- The salt concentration of water, which can be expressed in terms of electrical conductivity (ECiw, dS/m).
- The chemical composition of water, by determining the concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-. The quality parameters were calculated from as follows:

Sodium Hazard: Can be expressed in terms of Sodium Adsorption Ratio (SAR) or Soluble Sodium Percentage (SSP, %).

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

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

(The concentration of cations was expressed in me/L).

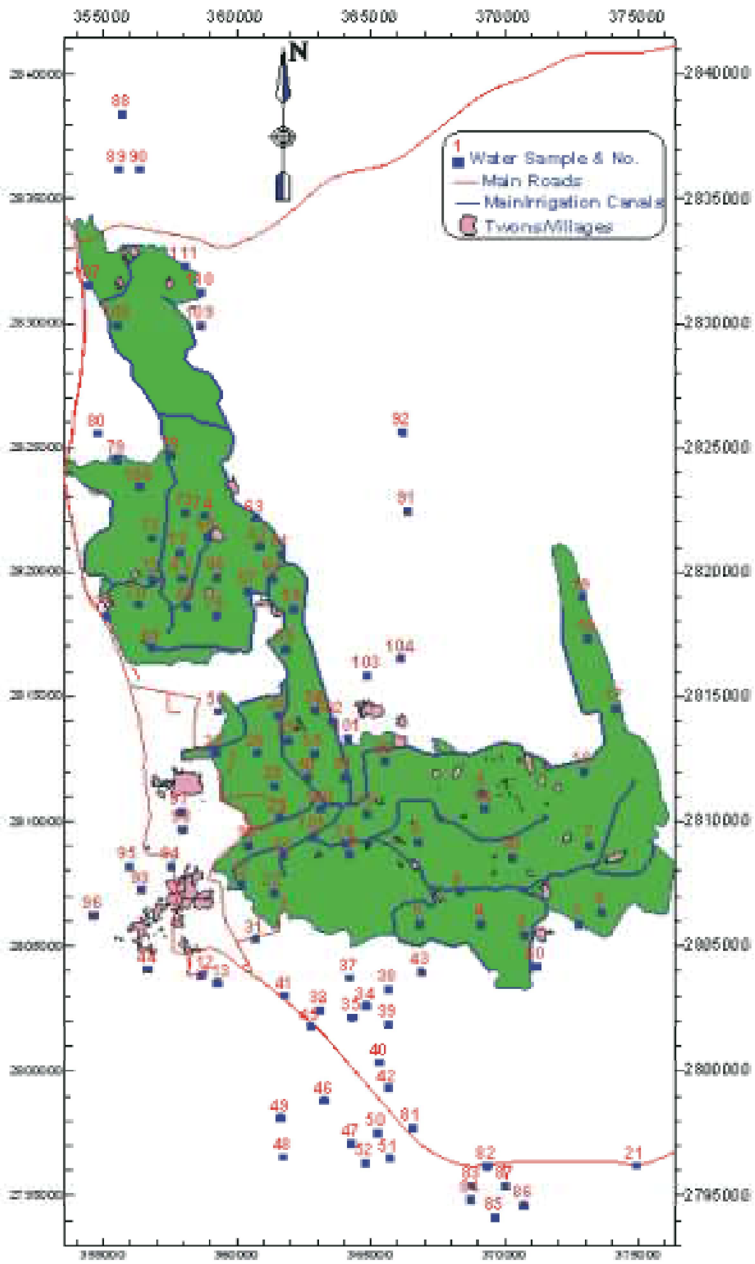

Fig. 2: Base map showing the locations of the collected water samples from wells, Al Hassa Oasis, KSA

Magnesium Hazard (SMgP): It can be expressed by the value of Soluble Magnesium Percentage (SMgP, %),

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

Bicarbonate Hazard: It can be expressed by the value of Residual Sodium Carbonate (RSC, me/L):

$$RSC = \left[CO_3^{2-} + HCO_3^-\right] - \left[Ca^{2+} + Mg^{2+}\right]$$

(The concentration of ions was expressed in me/L.)

3. The concentration of toxic compounds can be expressed by the values of:

a. Potential Salinity (PS):

$$PS(me/l) = Cl^- + 0.5 \times SO_4^{2-}$$

The Nitrate Concentration (NO_3^-, mg/L).

In the second phase of this study, investigated the salt-water intrusion and its impact on the main Aquifers at Al Hassa Oasis especially the Neogene Aquifer.

RESULTS AND DISCUSSION

Chemistry of Groundwater: The ranges of different water quality parameters were 1.37- 12.28 dS m^{-1} (EC), 4.05-39.56 meq L^{-1} (Ca), 2.82-27.09 meq L^{-1} (Mg), 5.21-52.05 meq L^{-1} (Na), 0.28- 4.10 meq L^{-1} (K), 3.40- 8.30 meq L^{-1} (HCO_3^-), 5.10-77.56 meq L^{-1} (Cl), 4.19- 37.66 meq L^{-1} (SO_4), 0.04-16.52 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^-. A significant correlation was found between Na and Cl ions (R^2 = 0.98) because Na and Cl were the dominant cation and anion, respectively in the groundwater of Al Hassa Oasis when compared with other cations/anions.

Quality of Groundwater: Data listed in (Table, 2) shows that all of ground water samples, the ECiw ranged from 1.37 to 12.28 dS/m. The critical level of ECiw to cause severe salinity problems is 3 dS/m as reported by FAO (1976). About 69 wells in the study area, where the values of ECiw are less than the critical limit and no problems have arisen concerning the permeability of the soil irrigated by this water. On the other hand, about of 43 wells the ECiw is more than the critical level that can be affected by salinity (Table 3). It could be considered relatively high and may cause severe salinity problems. Therefore, it is expected that continuous irrigation without good water management (leaching requirements) can led to severe problems from the salinity point of view.

The data presented in Table (2) also revealed that the SAR value of all ground water is relatively low in comparing with the critical level of sodium hazard (less than 10) as reported by [19]. Only sample No. 72 has SAR value exceeds the maximum critical level of sodium hazard.

With respect to the SSP as indicator for sodium hazard, the values of SSP for all ground water were ranged from 34.56 to 57.28%. The data revealed that all values of SSP were in the range of safety limit (< 60%) as reported by [21].

Magnesium hazard is one of the criteria of suitability of water for irrigation. In this respect, the values of SMgP tabulated in Table (2) indicated that all sources of groundwater have a values ranged from 31.03 to 49.56%. The values are less than the harmful level (50%). This means no problem of magnesium hazard.

The RSC value 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, too. The present values of RSC have a negative values, this means that $Ca^{2+} + Mg^{2+}$ is more than the $CO_3^{2-} + HCO_3^-$ resulted in no problem of sodium hazard.

Potential salinity (PS) for all groundwater ranged from 6.49 to 82.16 meq/L. The high values of PS over the critical level (5 meq/L) as reported by [19] may be due to high chloride and sulphate content in the irrigation water.

The nitrate contents (NO_3^-) in the analyzed groundwater samples are not exceed the critical limit (45 mg/L) that cause nitrate poisoning [21].

Generally, from the data previously presented, it appears that most of the groundwater used in the present study may cause one problem or another. By applying the criteria used for interpreting water quality for irrigation, the most domain problems are salinity hazard and potential salinity. [24] evaluating different types of irrigation water at Al Hassa oasis indicated that without applying leaching requirements, most of the domain problems are salinity hazard, potential salinity and soluble sodium percentage. Moreover, [25] evaluated 136 groundwater samples for irrigation purposes in Al-Hassa Oasis. He found that, the most domain problems are salinity hazard, potential salinity and magnesium hazard.

Evaluating of Groundwater According to Us Salinity Laboratory Method: The U.S. Salinity Laboratory Method for water quality evaluation for irrigation is based on evaluating the salinity versus SAR. The evaluation use a diagram that contains water quality classes based on EC (C) and SAR (S). There are four C-class from low salinity (C1) to very high salinity (C4) and four S-classes from S1 to S4. Collected water samples were evaluated according to the U.S. Salinity Laboratory Method (1954). Most of the samples were located in class C4-S1 (very high salinity hazard and low sodium hazard) and C3-S1 (high salinity hazard and low sodium hazard) (Figure 3). Additionally and based on the classification established by [26] for irrigation purposes, the water samples were located in three classes, good to permissible, doubtful to unsuitable and unsuitable (Figure 4). In order to represent the degree of severity of salinity an index is proposed which is the ratio of number of wells crossing particular salinity level to the total number of wells. Among 112 wells, 74.11% of wells are very high salinity and 25.89% of wells are high salinity. [26] evaluated 136 groundwater samples for irrigation purposes in Al-Hassa Oasis. According to U.S. salinity laboratory classification, he found that, the classification of the irrigation groundwater is high (C3) to very high (C4) salinity and low (S1) to medium (S2) sodicity hazard.

Table 1 Statistical analysis for chemical analysis of groundwater of Al Hassa Oasis

			Soluble cations				Soluble anions			
			Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	$SO_4^=$	NO_3^-
Analysis Value	pH	EC (dS/m)	meq/L							mg/L
Minimum	7.96	1.37	5.21	0.28	4.05	2.82	5.10	3.40	4.19	0.04
Maximum	6.65	12.28	52.05	4.10	39.56	27.09	77.56	8.30	37.66	16.52
Mean	7.33	3.54	15.72	0.72	10.93	7.99	19.31	5.20	10.61	4.37
SD*	7.36	4.16	18.42	0.86	12.79	9.66	23.79	5.32	12.93	5.41

SD* (Standard Deviation)

Table 2 Water quality parameters for Al Hassa water wells used as irrigation water for the present study.

pH	EC (dS/m)	SAR	SSP %	RSC meq/L	SMgP %	PS, meq/L	NO_3^-mg/L
1	2.04	4.61	49.07	-7.32	43.44	12.71	4.10
2	2.41	5.38	52.50	-7.13	38.72	13.19	0.94
3	2.05	4.44	47.77	-7.08	43.00	12.62	4.15
4	1.91	3.41	42.17	-5.89	48.04	11.00	0.71
5	1.43	3.47	45.64	-3.73	44.14	7.83	0.14
6	2.02	3.95	44.66	-7.10	46.43	11.68	0.57
7	1.98	3.82	43.00	-8.38	49.32	11.31	0.95
8	4.15	3.98	34.56	-21.13	48.55	26.29	5.90
9	2.10	4.26	46.72	-6.38	41.54	12.83	3.18
10	5.87	5.97	40.93	-28.09	46.87	40.18	3.46
11	1.87	3.32	39.80	-7.66	47.29	10.76	5.42
12	2.32	4.40	46.21	-7.61	37.61	14.20	5.18
13	5.24	5.02	37.74	-26.41	45.93	33.91	5.30
14	5.51	5.97	42.06	-25.53	43.99	36.79	4.38
15	2.89	3.59	36.55	-12.68	38.96	17.29	4.76
16	2.19	4.00	43.24	-7.05	39.15	12.10	1.70
17	2.63	4.21	42.92	-9.71	39.13	17.30	5.50
18	6.02	6.76	44.70	-27.72	47.23	46.08	3.72
19	2.72	4.51	44.31	-10.54	42.81	17.75	3.10
20	6.77	6.17	40.86	-30.88	46.26	47.48	11.22
21	2.15	3.90	43.75	-7.56	36.67	13.35	5.55
22	5.50	6.46	44.78	-22.25	44.62	36.03	6.14
23	4.34	4.94	39.90	-20.04	39.87	27.27	5.34
24	1.55	3.87	48.47	-3.69	38.22	8.04	3.60
25	3.08	3.90	39.42	-12.13	42.13	18.55	4.55
26	2.45	4.44	45.08	-9.15	33.41	15.12	4.15
27	2.53	4.96	48.46	-7.79	40.59	14.48	5.70
28	2.85	4.35	42.93	-9.86	40.49	17.27	4.80
29	2.55	4.58	45.62	-9.10	34.80	15.79	4.55
30	2.14	3.98	45.14	-6.15	42.49	11.89	0.59
31	5.87	6.96	46.21	-23.90	44.22	34.70	10.94
32	5.25	6.39	45.64	-20.04	44.75	32.59	9.52
33	8.64	6.39	38.12	-45.89	45.69	58.70	12.00
34	2.18	4.82	50.07	-5.85	41.12	13.01	0.40
35	3.23	5.54	48.26	-10.98	39.62	21.07	4.14
36	9.91	8.11	43.14	-48.34	41.08	59.86	12.85
37	8.74	9.12	48.88	-36.22	40.24	50.96	11.90
38	1.92	4.38	48.65	-5.21	43.69	11.59	0.40
39	8.45	7.29	42.30	-41.98	44.27	49.35	13.66
40	4.08	4.76	40.17	-19.40	41.88	24.38	9.10
41	9.31	6.19	36.11	-51.79	46.96	52.40	16.52
42	2.19	4.94	52.95	-4.83	46.69	13.57	0.68
43	2.76	4.40	43.66	-10.22	41.90	14.80	4.95
44	4.84	5.65	42.57	-22.02	45.75	28.64	9.08

Table 2: Continued

Serial No.	EC(dS/m)	SAR	SSP, %	RSC, meq/L	SMgP, %	PS, meq/L	NO_3(mg/L)
45	2.15	4.21	47.73	-5.56	47.58	13.30	0.84
46	10.15	8.70	44.54	-50.61	45.83	64.85	14.30
47	3.64	4.60	41.33	-16.00	43.31	21.10	5.55
48	3.11	4.24	41.13	-12.10	35.71	16.12	6.50
49	2.70	5.60	52.43	-6.76	38.24	17.40	3.50
50	5.36	7.24	49.38	-21.86	47.61	36.12	8.50
51	5.53	8.77	54.55	-20.20	44.32	37.58	8.12
52	2.63	4.41	44.53	-9.68	40.48	15.61	4.20
53	2.67	5.15	48.49	-9.42	37.93	16.18	4.10
54	2.74	3.94	40.43	-10.79	39.57	15.57	3.75
55	3.14	4.86	44.48	-11.19	42.02	17.23	3.55
56	2.76	3.90	40.54	-9.62	42.28	13.95	3.45
57	2.58	3.78	40.09	-9.02	43.37	15.19	3.80
58	2.53	5.77	53.55	-5.43	41.34	15.08	4.05
59	2.52	4.08	42.70	-8.69	37.78	16.04	3.05
60	2.47	4.81	48.42	-6.89	39.97	15.51	3.70
61	2.50	4.41	45.61	-7.45	32.91	15.41	3.55
62	3.42	4.77	42.34	-13.47	41.75	18.49	3.40
63	2.83	4.36	42.52	-10.90	35.64	17.18	3.35
64	2.44	4.55	46.24	-7.26	33.68	12.77	4.00
65	2.42	4.24	44.01	-7.98	33.39	13.62	3.55
66	2.50	4.48	45.80	-7.84	33.39	15.94	3.65
67	2.47	5.61	53.53	-5.53	39.84	15.00	3.60
68	2.48	4.29	44.32	-7.64	37.07	15.45	3.65
69	3.20	4.93	44.97	-11.68	37.69	22.07	4.10
70	2.61	3.93	41.28	-8.75	33.37	16.67	4.05
71	2.61	4.78	46.43	-8.68	36.40	15.99	3.65
72	10.23	10.00	48.68	-39.51	44.54	66.90	2.64
73	2.80	4.98	47.27	-8.85	37.12	17.19	3.75
74	2.84	4.51	44.55	-8.63	36.74	14.76	4.05
75	2.97	5.38	49.28	-8.23	35.51	18.49	2.85
76	3.56	5.40	46.98	-12.17	43.39	24.80	3.70
77	2.96	4.60	43.84	-10.23	35.40	18.50	3.55
78	3.54	5.00	43.66	-14.12	36.37	23.70	3.65
79	3.66	5.65	47.00	-13.66	44.23	23.12	0.06
80	1.80	4.11	48.40	-4.74	40.44	10.15	2.90
81	1.39	2.57	37.61	-4.31	38.53	6.49	0.06
82	1.77	2.84	37.06	-6.43	46.38	9.52	0.06
83	1.83	3.21	39.94	-6.62	44.68	10.01	3.85
84	1.46	2.66	38.42	-4.07	43.61	6.63	0.22
85	1.48	2.51	36.66	-4.29	42.16	6.86	0.17
86	1.37	2.86	40.66	-3.93	49.56	6.53	0.04
87	2.82	6.72	57.28	-5.79	39.58	17.66	1.60
88	3.35	6.17	51.97	-8.80	43.47	20.78	1.65
89	7.73	8.46	48.26	-31.85	46.06	52.43	6.76
90	12.28	9.19	43.65	-56.50	38.39	82.15	3.95
91	2.09	3.34	39.85	-6.81	41.10	11.57	4.65
92	2.02	4.23	47.60	-5.91	37.75	12.12	4.00
93	4.37	5.50	43.04	-19.04	44.19	27.25	9.44
94	2.74	4.43	44.95	-9.27	42.74	15.22	4.30
95	1.91	3.71	42.95	-6.37	40.29	10.96	4.15
96	2.50	4.40	45.02	-8.31	38.23	14.70	4.35
97	2.50	4.53	46.25	-7.99	42.65	15.96	4.30
98	5.37	6.62	46.23	-18.56	31.03	26.41	4.54
99	2.68	3.88	40.66	-10.28	44.09	14.84	4.70
100	3.68	3.95	36.31	-16.40	42.01	21.27	4.05

Table 2: Continued

Serial No.	EC (dS/m)	SAR	SSP %	RSC meq/L	SMgP %	PS, meq/L	NO_3^- mg/L
101	2.61	4.34	44.26	-8.61	40.62	15.77	4.45
102	6.62	7.58	46.80	-28.67	49.15	45.79	2.52
103	2.02	3.83	44.41	-5.69	44.55	12.02	4.65
104	3.99	7.24	53.45	-12.79	41.44	26.02	5.45
105	4.73	6.10	45.62	-18.68	47.47	31.35	4.30
106	3.32	5.35	46.17	-11.30	41.31	22.78	3.45
107	2.84	5.24	48.98	-6.77	37.59	18.12	2.10
108	2.20	3.50	40.17	-7.19	44.75	12.05	3.70
109	4.20	5.34	42.48	-16.70	43.13	27.07	3.95
110	3.95	5.53	45.58	-13.04	43.02	25.57	3.80
111	1.71	3.52	42.66	-6.30	46.86	8.76	0.20
112	1.50	2.90	39.88	-5.34	41.91	7.25	0.32

Table 3: Water sampling locations, which have EC, more than the critical limit (3 dS/m)

Serial No.	EC dS/m	Serial No.	EC dS/m	Serial N0.	EC dS/m	Serial No.	EC dS/m
8	4.15	33	8.64	50	5.36	90	12.28
10	5.87	35	3.23	51	5.53	93	4.37
13	5.24	36	9.91	55	3.14	98	5.37
14	5.51	37	8.74	62	3.42	100	3.68
18	6.02	39	8.45	69	3.20	102	6.62
20	6.77	40	4.08	72	10.23	104	3.99
22	5.50	41	9.31	76	3.56	105	4.73
23	4.34	44	4.84	78	3.54	106	3.32
25	3.08	46	10.15	79	3.66	109	4.20
31	5.87	47	3.64	88	3.35	110	3.95
32	5.25	48	3.11	89	7.73		

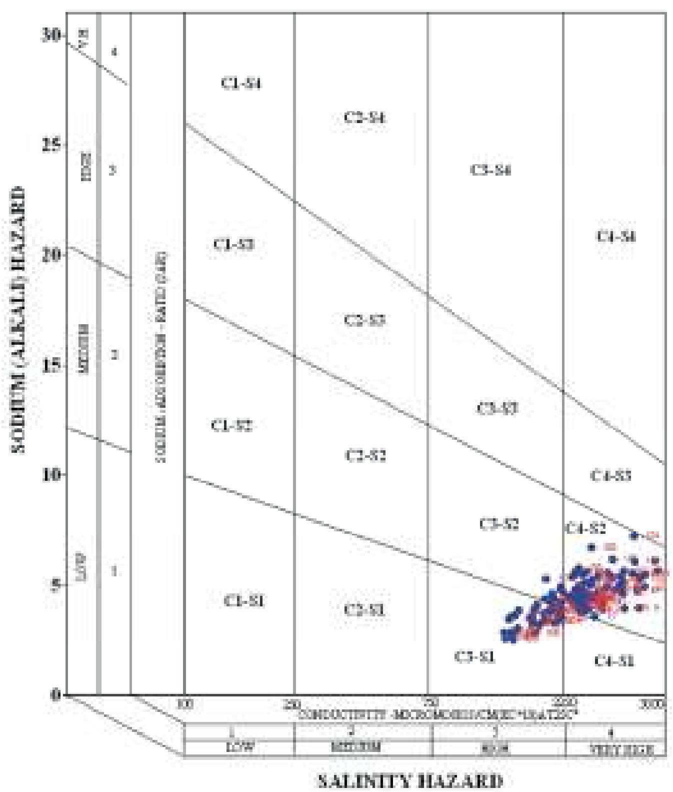

Fig. 3: The plot of the collected water samples in the study area, Al Hassa Oasis, KSA, using the Diagram of (U.S. Salinity Laboratory Staff; 1954)

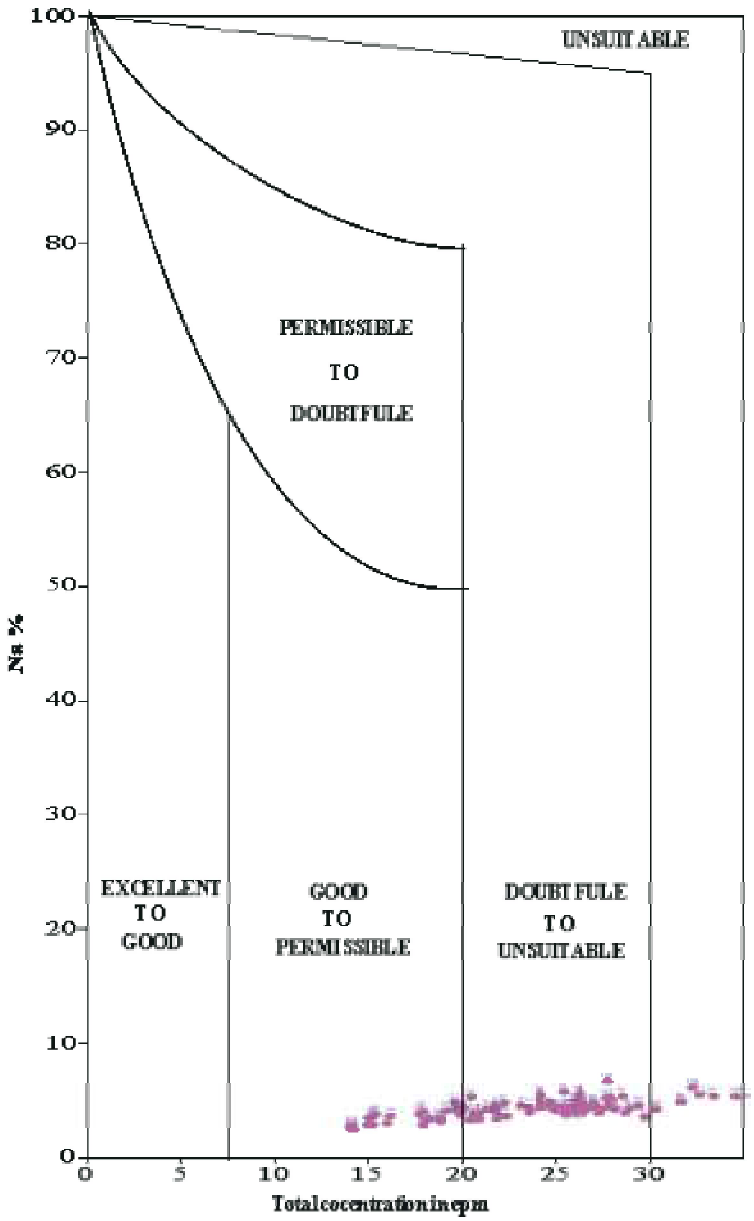

Fig. 4: Wilcox`s classification of irrigation water in the study area, Al Hassa Oasis, KSA

Saltwater Intrusion into Groundwater: From the constructed salinity map (Figure 5), it is found that the concentration of salinity ranged from 1.37-12.28 dS/m with an average 3.54 dS/m. Among 112 wells were 61.61% of wells the values of ECiw are less than the critical limits (3 dS/m) and 38.39% of wells the values of ECiw are more than the critical level. The wells, which have ECiw values higher than the critical limits, are: thirty two wells where the ECiw ranged from 3-6 dS/m are located in different parts from the oasis, two wells (Nos. 20 and. 103) where the ECiw ranged from 6-9 dS/m which located in southeast and central of the oasis and nine wells (Nos. 33, 36, 37, 39, 41, 46, 72, 89, 90) where the ECiw > 9 dS/m are located in south of the oasis except the wells No.72, 89 and 90 located in west, center and northwest of the oasis, respectively (Figure 5).

Based on those results, groundwater from 43 wells is unfit for irrigation purpose. The spatial variations in salinity of groundwater may be attributed to; a) the increases in the amount of salts dissolved during the passage of the groundwater through the aquifers, b) increasing salinity due to extensive abstraction of the

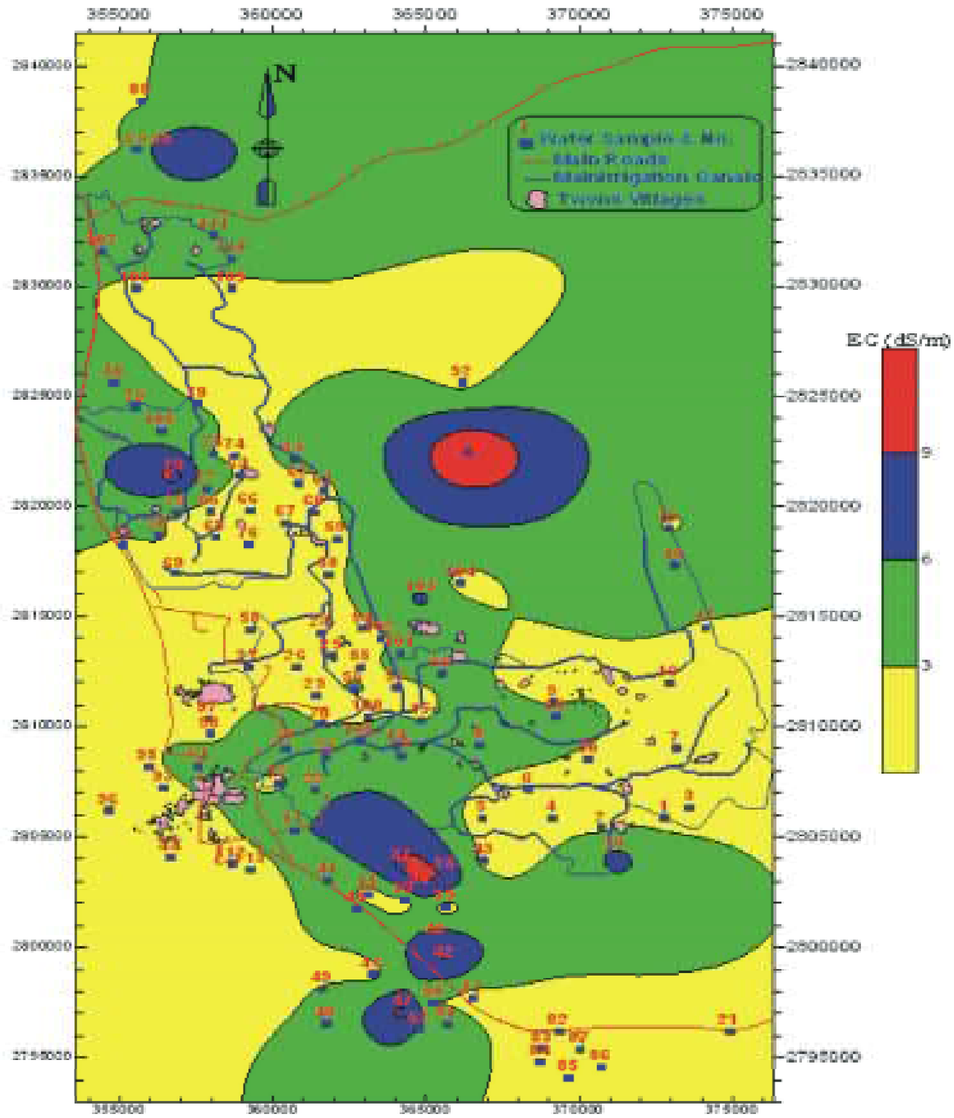

Fig. 5: Distribution map of the electrical conductivity for the collected water samples in the study area, Al Hassa Oasis, KSA

groundwater and/or due to the direct and indirect recharge occurring to the Neogene aquifer that supplies the irrigation water in the Oasis, c) the mixing of waters with other aquifers water in the oasis because the aquifers are partly interconnected to each other and d) eastern part of Al Hassa oasis may be affected by saltwater from Arabian Gulf as a result of the variation in the level of water table due to excess withdrawals from wells caused the intrusion of seawater into the groundwater. This result can be explained, the thickness of the fresh water zone decreases considerably in the farming areas at Al Hassa oasis and thus the degree of seawater intrusion increases.

The first possibility may be due to the groundwater in Neogene aquifer cut hundreds of kilometers from the recharge zones, which lies west of the oasis and down to the borders of the northern and north-eastern oasis [27, 6, 28, 29]. This flow of underground water occurs during Neogene aquifer, which consists mainly of conglomeratic sand, sandstone and heavily fissured limestone. With regard to the second probability, the studies carried out on the levels of water in the oasis showed that a decrease in groundwater levels as a result of extensive withdraws for the groundwater and also to a large quantities of water that lost by evaporation to sabkha [30, 31] indicated that Neogene aquifer in Al Hassa oasis exposure to two process, the first one direct recharge from rainfall which lead to improved its quality and the second one indirect recharge from intrusion irrigation water to it which lead to a deterioration its quality and raising its salinity. [32] investigated the spatial and temporal variations of irrigation groundwater quality and its chemical characterizations during the period 1994 to 2009 at Al-Hassa Oasis. He found that a temporal variability in salinity levels with time. The water salinity classified as high (C3) to very high (C4) salinity, with an average equal to 2.55 dS/m at 1994 and 3.2 dS/m at 2009. Moreover, the spatial changes analysis indicated that the quality of groundwater is deteriorating towards the east and to north along the oasis. These spatial variations in the groundwater properties may be attributed to the increases for salts dissolved during the passage of the groundwater through the aquifers as the groundwater flow is from west to east. While, the temporal variations of salinity is attributed to extensive abstraction of the groundwater and/or due to the shortage of direct and indirect recharge occurring to the Neogene aquifer that supplies the irrigation water in the Oasis.

This shows that salt-water intrusion has already occurred largely in the region and appropriate steps need to be taken for overcoming this problem. Therefore, a monitoring program on groundwater quality should be established in selected sampling points, in order to improve the groundwater quality and avoid saltwater intrusion phenomena on a large scale in the coastal aquifer system of Al Hassa oasis.

CONCLUSION

From this study, it can be concluded that at some locations of Al Hassa Oasis, the groundwater may cause one problem or another according to the quality of groundwater. According to the criteria used for interpreting water quality for irrigation, the most domain problems are salinity hazard and potential salinity. According to U.S. salinity laboratory classification (1954), the classification of the irrigation groundwater is high (C3) to very high (C4) salinity and low (S1) sodicity hazard. Additionally and based on the classification established by Wilcox (1955) for irrigation purposes, the water samples were located in three classes, good to permissible, doubtful to unsuitable and unsuitable. Therefore, it is expected that continuous irrigation without good water management (leaching requirements) can led with time to severe problems from the salinity point of view. Moreover, Hydrochemical analysis of water samples indicated that there are a spatial variability in salinity levels, as reflected by the values of electrical conductivity (ECiw). These spatial variations in the salinity of groundwater may be attributed to the increases of salts dissolved during the passage of the groundwater through the aquifers, increasing of salinity due to extensive abstraction of the groundwater and/or due to the direct and indirect recharge occurring to the Neogene aquifer that supplies the irrigation water at Al Hassa Oasis. In addition, salt-water intrusion may be occurred in the region due to the connection of Neogene aquifer with underlying aquifers. Thus, appropriate steps need to be taken for overcome this problem. Therefore, a monitoring program on groundwater quality should be established in selected sampling points, in order to improve the groundwater quality and avoid saltwater intrusion phenomena on a large scale especially the aquifer systems of Al Hassa oasis are quite near to Arabian Gulf.

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REFERENCES

1. FAO, 2007. Improvement of Irrigation Water Management in the Kingdom of Saudi Arabia. UTFN/SAU/011/SAU, Kingdom of Saudi Arabia.
2. Alamoud, A. and Y.Y. Aldakheel, 2003. The importance of renewable water in agricultural development in Saudi Arabia. Proceedings of the Symposium on Water as a Strategic Challenge Facing Humanity, (WSCFH03), Ministry of Electricity and Water and Ministry of Higher Education, Riyadh, KSA.
3. Al-Dakheel, Y.Y., 2005. Water governance as part of IWRM in arid regions: A case study of Saudi Arabia. Proceedings of the Seminar on Water Governance: Role of Stakeholders, November 14-15, 2005, Beirut, Lebanon.
4. MOWE, 2008. Department of economical studies and statistics: Agricultural Statistical Yearbook. Ministry of Water and Electricity, Riyadh, Saudi Arabia.

5. Leichtweiss Institute, 1979. The Water Potential of the Al-Hassa Oasis. LBID Publication No. 38.
6. BRGM, Bureau de Recheres Geologiques ET Miniseres, 1977. Al-Hassa Development Project Groundwaters Study and Management Programme. Final Report vol. 1, Groundwater Resources Development Department, Ministry of Agriculture and Water, Riyadh, KSA.
7. Batayneh, A.T., 2006. Use of electrical resistivity methods for detecting subsurface fresh and saline water and delineating their interfacial configuration: a case study of the eastern Dead Sea coastal aquifers, Jordan. Hydrogeol. J., 14: 1277-1283.
8. Ginzburg, A. and A. Levanon, 1976. Determination of a saltwater interface by electric resistivity depth soundings. Hydrogeological Sci., 21: 561-568.
9. Nowroozi, A.A., S.B. Horrocks and P. Henderson, 1999. Saltwater intrusion into the freshwater aquifer in the eastern shore of Virginia: a reconnaissance electrical resistivity survey. J. Appl. Geophysics, 42: 1-22.
10. Papadopoulou, M.P., G.P. Karatzas, M.A. Koukadaki and Y. Trichakis, 2005. Modeling the saltwater intrusion phenomenon in coastal aquifers- A case study in the industrial zone of Heraklio in Crete. Global NEST J., 7: 197-203.
11. Narayan, K.A., C. Schleeberger and K.L. Bristow, 2007. Modelling seawater intrusion in the Burdekin Delta Irrigation area, North Queensland, Australia. Agric. Water Manage., 89: 217-228.
12. Hing, T.T., 1995. Hydrochemistry of grounwater at Sahabat region, Sabah Proceedings of the Annual Geological Conference 1995, Geological Society of Malaysia Bulletin 38, Jun. 11-12, Kuala Terengganu, Malasia, pp: 63-70.
13. Mohamad, I.C., A.R. Samsuudin and A.G. Rafek. 2001. In conjunction used wih geophysical data and geology into alluvial coastal aquifer at Pekan Rompin, Pahang area. Proceedings of the annual Geological Conference 2001, Geological Society of Malaysia Bulletin 44, June 2001, Pangkor Island, Perak Darul Ridzuan, Malaysia, pp: 197-203.
14. Lee, J.Y. and S.H. Song, 2007. Evaluation of groundwater quality in coastal areas: implications for sustainable agriculture. Environ. Geology, 52: 1231-1242.
15. Frohlich, R.K. and D.W. Urish, 2002. The use of geoelectrics and test wells for the assessment of groundwater quality of a coastal industrial site. J. Appl. Geophysics, 50: 261-278.
16. Urish, D.W. and R.K. Frohlich, 1990. Surface electrical resistivity in coastal groundwater exploration. Geoexploration, 26: 267-289.
17. Frohlich, R.K., D.W. Urish, J. Fuller and M.O. Reilly, 1994. Use of geoelectrical method in groundwater pollution surveys in a coastal environment. J. Appl. Geophysics, 32: 139-154.
18. Choudhury, K., D.K. Saha and P. Chakraborty, 2001. Geophysical study for saline water intrusion in a coastal alluvial terrain. J. Appl. Geophysics, 46: 189-200.
19. USDA, 1954. Diagnosis and Improvement of Saline and Alkaline Soils. U.S. Dept. of Agric., Handbook No. 60. U.S. Government Printing Office, Washington, DC. USA.
20. Norman, R.J., J.C. Edberg and J.W. Stucki, 1985. Determination of nitrate and nitrite in soil extracts by ultraviolet spectrophotometry. Soil Sci. Soc. Am. J., 49: 1182-1185.
21. Wilcox, L.V., 1958. Determining Quality of Irrigation Water. US. Department of Agriculture Information Bulletin No. 194, USDA, Washington, Dc., USA.
22. FAO, 1973. Salinity, Irrigation and Drainage, pp: 177-204.
23. Ayers, R.S. and D.W. Westcot, 1976. Water Quality for Agriculture. FAO. Irrigation and Drainage Paper No.29.FAO, Rome, pp: 97.
24. Al-Dakheel, Y.Y., 2011. Assessing NDVI Spatial Pattern as Related to Irrigation and Soil Salinity Management in Al-Hassa Oasis, Saudi Arabia. J Indian Soc Remote Sens, 39: 171-180, [DOI 10.1007/s12524-010-0057-z].
25. Al-Naeem, A.A., 2011. Evaluation of groundwater of AI-Hassa oasis, eastern region, Saudi Arabia. Res. J. Environ. Sci., 5: 624-642.
26. Wilcox, L.V., 1955. Classification and Use of Irrigation Water U. S. A., Salinity Lab., Circulation No. 969.
27. Italconsult, 1969. Water and Agricultural Development Studies for Area IV: Final Report. A study prepared by FAO, Rome. Ministry of Agriculture and Water, Riyadh, Kingdom of Saudi Arabia.
28. HARC, Hofuf Agricultural Research Center, 1979. Water Resources of the Al-Hassa Oasis. A Report on the Work of the Leichtweiss-Institute Research Team, Technical University Braunschweig Prepared for Hofuf Agricultural Research Centre, KSA, Publication no. 38.

29. AL-Mahmoud, M.J., 1987. Hydrogeology of the Al-Hassa Oasis. M. Sc. Thesis, Faculty of the College of Graduate Studies, King Fahad University for Petroleum and Minerals, Dhahran, Saudi Arabia.
30. Othman, M.N., 1983. Water and the process of development in the Kingdom of Saudi Arabia. Tohama Press, Jeddah, KSA. In" Arabic".
31. Aldakheel, Y. and A.M. Al-Safarjalani, 2005). Study of historical pattern of changes in water quality of Al-Hassa oasis springs. Journal of Productivity and Development, 10(2): 211-225. In “Arabic”.
32. Al- Hobany, Kh.A., 2011. The spatial and temporal pattern of changes in ground water quality in Al-Hassa region. M. Sc. Fellowship, Soil and Water Dept., Faculty of Agriculture and Food Science, King Faisal University, KSA.