Hydrogeochemistry and Quality Assessment for the Groundwater of the Nubian Sandstone Aquifer of the Bahariya Oasis, Western Desert, Egypt

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ABSTRACT

Groundwater is considered as one of the most important natural resources, on which a complete dependence for all human consumption, industrial and agricultural activities in El-Bahariya Oasis. Unfortunately, the increased reliance on groundwater resources without any scientific pre-plans has caused some negative hydrogeological impacts such as: rapid decline in groundwater potentiometric levels and groundwater salinization. The hydrogeochemical aspects of El-Bahariya Oasis are thoroughly evaluated in the present work based on chemical analysis of 59 groundwater samples, representing the main aquifer system (Nubian Sandstone Aquifer). Most of water wells drilled in the study area range from 600 to 1200 m in depth. The groundwaters from the Nubian Sandstone Aquifer in El-Bahariya Oasis have mixed types of mineralization, i.e., pure meteoric water that vertically infiltrated and settled in the aquifer materials during the past Pluvial times and those affected through groundwater flow by relics of marine water. It has been found that the majority of the groundwater samples of the Nubian Sandstone Aquifer of El-Bahariya Oasis is suitable for drinking, domestic uses, irrigation, livestock and poultry and some industrial purposes.

Keywords: Nubian Sandstone Aquifer– Bahariya Oasis – Hydrogeochemistry -Quality assessment- Egypt.

INTRODUCTION

El-Bahariya Oasis is a natural depression approximately located in the heart of the Western Desert of Egypt (Fig.1). It is located between latitudes 27°48′ and 28°30′N and longitudes 28°35′ and 29°10′E, about 370 km southwest of Cairo and around 190 km west of Samalut town in the Nile Valley. It occupies an area of about 1800 Km^2.

The groundwater-bearing horizons in the investigated area follow two aquifer systems. These are, from top to bottom: a) The Post-Nubian Sandstone Aquifer System, which occurs to the north of latitude 26^0 in the Western Desert of Egypt (CEDARE, 2001). It is composed of marine sediments, mainly consist of clay, marl and limestone, overlain by continental clastic sediments, which exhibit noticeable facies variation in the northern parts of Egypt to pass laterally into carbonate facies. This sequence ranges in age from Late Cenomanian to Recent. b) The Nubian Sandstone Aquifer System, which represents the main water-bearing horizon in the study area. It consists of continental clastic sediments, mainly sandstone alternating with shale and clays.

In El-Bahariya Oasis, the extraction of excessive quantities of groundwater has resulted in progressive depletion of the storage (Nubian Sandstone Aquifer) and continual decline of potentiometric level (Abd El-Latif, 2007). This leads to increasing cost of pumping even with a reduction in well yield. Other associated adverse consequences would be deterioration of groundwater quality. Accordingly, a major concern in managing groundwater resources is whether or not water quality variables have changed over time or space.

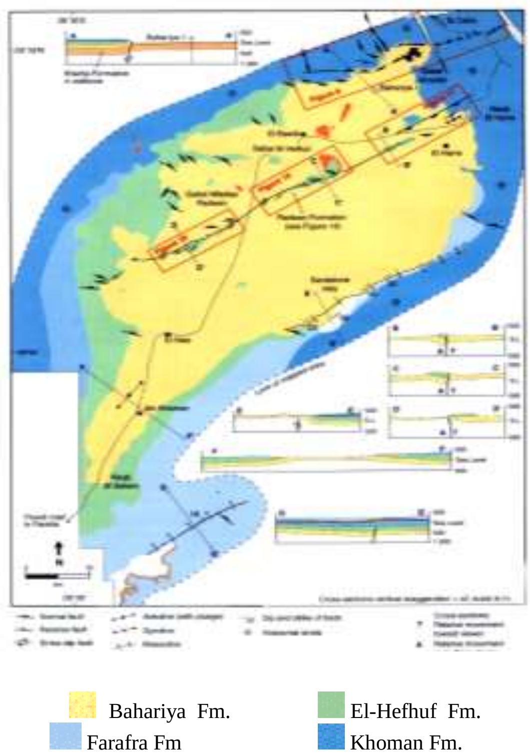

Fig.1. Simplified geological mapand cross-sections of El-BahariyaOasis (after Moustafa et al., 2003)

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MATERIALS AND METHODS

The collected groundwater samples were chemically analyzed for the major cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}) and anions (HCO_3^-, SO_4^{--}, Cl^-) and minor (Br^-, I^-, SiO_2 and B) and trace elements (Al, Cd, Co, Cr, Cu, Zn, Fe, Mn, Ni, Pb, and Sr), in order to determine the hydrochemical facies and assessment of groundwater quality (Table 1).

The procedures of Rainwater and Thatcher (1960) were applied on the collected groundwater samples. Temperature (^oC), pH and electrical conductivity (EC, µS/cm) of the groundwater samples were measured in the field at the time of collection. Each water sample was stored in two polyethylene bottles. Water in one of the bottles was acidified upon collection with ultrapure concentrated nitric acid (HNO_3) to pH<2. Acidification stops most bacterial growth, blocks oxidation reactions and prevents adsorption or precipitation of cations. Whereas, water in the second bottle was kept unacidified for Cl^-, SO_4^{--} and alkalinity determinations. The samples were analyzed for the cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}) and the anions (HCO_3^-, $SO_4^{--}$and Cl^-). Calcium and Magnesium were determined by titration against a standard EDTA solution by complexometric method using murexide and eriochrome black-T indicators in presence of suitable buffer, respectively. Sodium and Potassium (Na^{+} and K^{+}) were determined using a flamephotometer Jenway Model pep7 (UK). Bicarbonate (HCO_3^-) was determined titrimetrically against sulphuric acid by neutralization method. Sulfate (SO_4^{--}) was determined by turbidimetric method using UV/Visible Spectrophotometer, Unicam model UV4-200 (UK). Chloride (Cl^-) was volumetrically determined against a standard solution of silver nitrate using potassium chromate as indicator. Silica (SiO_2) was determined by colorimetric method using UV/Visible Spectrophotometer, Unicam model UV4-200 (UK). Bromide (Br^-) was determined by ion selective electrode using Ionometer, Orion-930. Minor and trace elements, which include aluminum (Al), boron (B), cadmium (Cd), cobalt (Co), lead (Pb), chromium (Cr), copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), nickel (Ni) and strontium (Sr) were determined using Atomic Absorption Spectrophotometer, Unicam model Solaar 929. Total dissolved solid (TDS) was calculated from the summation of cations and anions. The accuracy of the analysis can be estimated from the ionic balance (B), which may be expressed, as follows:

$$\mathbf{B\%} = \frac{(\Sigma \text{cations} - \Sigma \text{anions})}{(\Sigma \text{cations} + \Sigma \text{anions})} \times 100$$

Where cations and anions are expressed as meq/l. Groundwater samples should lie within an errors of ± 5%. The ionic balance (B) for all the groundwater samples of El-Bahariya Oasis lies within the standard error limit (± 5%)

Hydrogeochemistry

The groundwater temperature in El-Bahariya Oasis ranges from 22 ^oC to 55 ^oC with an average temperature of 41 ^oC, where the highest and lowest temperatures were recorded for samples No.55 and No.38, respectively. Therefore, thermal groundwaters (hot springs) are found in the study area, where the temperature gradient profile is normal. The original reservoir temperature was estimated using Giggenbach (1988)'s geothermometer method (Table 2), as follows:

$$T^{o}C = \frac{4410}{14 - \log \frac{C_k^2}{C_{Mg}}} - 273 \qquad \text{(in mg/l)}$$

The quotient ($\frac{C_k^2}{C_{Mg}}$) adjusts much faster and to low temperatures (< 100 ^oC). From Table (2), the groundwater temperature in the study area is described as normal geothermal gradient not as a result of the effect of the hydrothermal solutions (Abd El-Latif, 2007). Geothermal waters, which are generally accepted to be of meteoric origin, represent groundwaters that have percolated deep into the ground and gained heat through contact with hot rock (Magnusdottir et al., 1992). Most of the groundwater that found in El-Bahariya Oasis has pH ranges from 7.02 to 8.5 (i.e. neutral to slightly alkaline), but seldom to be below 6.5 (Table 1).

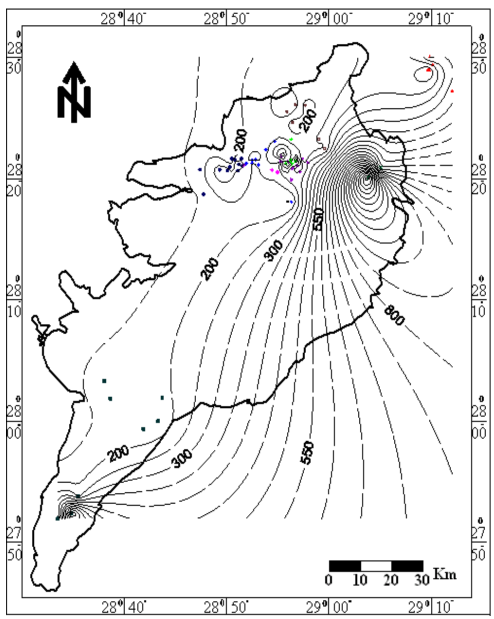

Fig.2. Iso-salinity contour map of El-Bahariya Oasis

Table 1. Chemistry of groundwater from the Nubian Sandstone Aquifer, Bahariya Oasis ((Abd El-Latif, 2007)

No			T	E.C	TDS	T.H.	Cations (mg/l)				Anions (mg/l)			Br
	Well name	pH	^{0}C	µS/cm	mg/l	mg/l	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO3^{-}	SO4^{--}	Cl^{-}	mg/l
1	Ain Halfa	7.55	47	282	202.86	75.0	20	6.08	27	18	29.55	33	69.23	0.626
2	Bawiti drink	8.08	37	380	273.87	95.5	20.24	10.94	32	30	65.28	53	62.41	0.582
3	El-American	7.55	47	371	230.44	72.5	14.03	9.12	37	25	29.55	26	89.74	0.954
4	El-Matar	7.55	47	342	251.37	77.5	15.03	9.73	39	25	27.82	63	71.79	0.762
5	Dehqema	8.07	47	312	260.76	95.0	16	13.37	38	20	24.34	67	82.05	0.742
6	El-Abida	7.26	48	276	185.34	65.0	12	8.51	27	18	31.29	27	61.54	0.449
7	El-Qeles	8.05	44	447	269.57	86.5	17.64	10.34	45	27	34.77	22	112.82	1.3
8	Beshmo	7.29	48	287	188.45	63.5	14.83	6.44	28	19	26.08	30	64.10	0.565
9	Gevara	7.81	43	215	142.92	55.0	16	3.65	18	12	29.55	15	48.72	0.159
10	Mine-4	8.45	30	499	414.22	125.0	28	13.37	80	19	62.59	101	110.26	1.19
11	Mine-8	8.15	38	399	308.34	105.0	22.04	12.16	53	16	57.96	60	87.18	0.971
12	Mine-6	7.85	45	282	197.38	83.0	24.05	5.59	26	12	34.77	36	58.97	0.488
13	Mine-7	7.67	48	274	204.68	82.5	18.04	9.12	25	17	29.55	47	58.97	0.401
14	Mine-1	6.16	32	708	433.46	246.0	42.08	34.29	39	15	54.91	161	87.18	0.797
15	Ain Shawer	8.41	32	329	220.40	120.0	30.06	10.94	15	15	39.99	53	56.41	0.232
16	Waled	7.62	51	321	247.82	110.0	30	8.51	29	17	34.77	67	61.54	0.648
17	Meftela	8.45	46	350	227.23	85.0	24.05	6.08	31	16	56.13	35	58.97	0.808
18	Shroey	7.81	46	477	334.52	130.0	30	13.37	47	24	43.46	69	107.69	1.37
19	Dedela	7.92	32	242	153.12	70.0	19.04	5.47	14	16	27.46	25	46.15	0.154
20	Ain Embash	8.01	36	313	208.44	106.0	27.45	9.12	16	15	41.72	53	46.15	0.203
21	El-Ayon	7.59	46	421	277.48	100.0	20	12.15	44	23	34.77	41	102.56	1.05
22	Tabaneia	8.37	37	466	286.93	92.5	19.04	10.94	37	29	71.28	53	66.67	0.499
23	Barakat	8.3	30	301	178.79	85.0	24.05	6.08	14	17	36.51	35	46.15	0.25
24	Mady	7.17	33	256	156.26	76.0	12.02	11.19	14	14	29.90	29	46.15	0.203
25	Ain El Seer	7.53	48	346	216.78	65.5	11.02	9.24	39	20	32.34	18	87.18	0.926
26	Tobela	7.44	42	418	312.58	135.0	17.64	22.13	43	22	38.25	67	102.56	1.31
27	El-Kebier	8.16	41	407	271.36	90.0	12.42	14.35	42	23	41.49	74	64.10	0.976
28	Ain Hamra	8.47	40	428	257.83	85.0	17.64	9.97	43	23	39.66	22	102.56	1.14
29	Maesera	7.23	40	274	176.47	65.0	10	9.72	26	17	26.08	21	66.67	0.488
30	El-Gazaier	8.26	43	393	246.25	88.0	13.23	13.38	40	21	34.77	29	94.87	0.926
31	Segam	7.36	43	363	262.32	101.5	19.64	12.77	36	21	51.86	39	82.05	0.742
32	Qubala East	7.51	46	511	316	122.0	21.64	16.54	50	21	33.56	63	110.26	0.887
33	Qubala West	7.62	47	202	187.72	47.5	10.02	5.47	34	16	30.51	43	48.72	1.44
34	Abu Singo (new)	7.03	42	231	191.63	87.5	13.03	13.37	20	14	34.77	58	38.46	0.084
35	El Ghaba -	7.46	30	709	483.38	239.0	57.31	23.35	53	28	30.51	163.0	128.21	1.01
36	Sidi Ahmed	7.4	33	247	184.70	90.0	28	4.86	14	17	19.12	53	48.72	0.983
37	Mehebes	6.86	31	242	162.91	70.0	16	7.29	18	16	24.34	30	51.28	0.121
38	Tablamon	7.86	22	230	155.87	61.5	12	9.72	15	15	43.93	30	35.90	0.078
39	Ain El-Ezza	7.55	42	222	161.55	70.0	13.23	11.55	20	15	24.34	50	46.15	0.176
40	Ain Qara	7.85	53	228	180.27	80.5	16.63	24.68	20	19	31.73	84	61.54	0.226
41	Khamaan	7.96	38	470	257.58	143.0	78.36	29.18	120	59	26.08	166.0	302.56	2.85
42	Badr Farm	7.52	29	1267	781.18	315.5	20.04	15.81	6	33	52.15	63	41.03	…
43	New (El-Heiz)	8.52	44	291	231.03	115.0	16.63	8.75	44	26	32.95	19	107.69	0.943
44	Aguz West	7.78	43	424	255.02	77.5	13.03	13.37	20	14	34.77	58	38.46	0.084
45	Aguz East	7.59	47	254	207.73	60.0	16.03	4.86	34	13	33.56	55	51.28	0.247
46	El-Magaria	7.52	47	300	205.12	75.0	12	10.94	27	21	26.08	44	64.10	0.461
47	El-Habasi	8.18	35	337	289.49	100.0	18	13.37	34	31	52.15	82	58.97	0.373
48	Mehibes	7.69	43	480	345	140.0	40	9.72	44	23	43.46	72	112.82	0.964
49	Kom Shada	8.36	32	772	528.07	112.0	37.88	4.26	136	20	34.77	87	208.16	1.53
50	Ain Ghard	7.18	28	874	546.01	210.0	40.08	26.75	94	23	34.77	171.0	156.41	1.35
51	Ain El Qasr	7.52	52	284	221.98	100.0	20	12.15	25	17	31.29	55	61.54	0.384
52	Qassa-1	7.62	45	400	283.44	105.0	20	13.37	39	24	52.15	58	76.92	0.68
53	Qassa-2	7.81	40	425	275.65	95.0	14.03	14.59	39	25	67.11	39	76.92	0.578
54	Qassa-3	7.27	52	286	182.69	55.0	18	2.43	29	18	31.29	25	58.97	0.391
55	El-Dolab	7.02	55	268	179.57	65.0	16	6.08	27	14	26.08	34	56.41	0.461
56	Qassa-4	7.33	45	338	238.70	83.5	14.43	11.55	35	21	41.49	46	69.23	0.966
57	Gemaha (new)	8.23	40	388	265.71	117.5	23.65	14.23	31	20	54.91	45	76.92	0.787
58	Ain El-Bahariya	8.1	31	986	636.45	260.0	57.11	28.57	106	27	76.27	111.0	230.50	2.52
59	Ain Hadad	7.02	29	2425	1478.07	665.0	94.19	104.6	222	60	79.32	457.0	460.99	4.26

EC: Electrical Conductivity TDS: Total Dissolved Solids T.H.: Total Hardness

Table 2. Calculated reservoir temperature according to Giggenbach (1988)'s method (Abd El-Latif, 2007)

No.	Total Depth (m)	Measured T°C	Calculated T°C	No.	Total Depth (m)	Measured T°C	Calculated T°C
1	1111	47	86	31	660	43	81
2	500	37	92	32	999	46	78
3	300	47	90	33	713	47	84
4	990	47	89	34	1123	42	71
5	811	47	79	35	291	30	80
6	1200	48	82	36	347	33	88
7	768	44	90	37	220	31	80
8	1082	48	87	38	1100	22	75
9	820	43	83	39	210	42	76
10	600	30	78	40	100	53	74
11	1000	38	74	41	371	38	70
12	1003	45	78	42	N.D.	29	97
13	1117	48	80	43	800	44	90
14	500	32	62	44	794	43	91
15	799	32	75	45	1040	47	81
16	651	51	80	46	1054	47	83
17	1051	46	83	47	498	35	90
18	840	46	84	48	770	43	87
19	807	32	84	49	670	32	94
20	250	36	77	50	500	28	75
21	807	46	84	51	N.D.	52	76
22	652	37	91	52	780	45	84
23	335	30	84	53	654	40	84
24	301	33	72	54	200	52	98
25	N.D.	48	84	55	N.D.	55	80
26	781	42	75	56	324	45	82
27	746	41	82	57	N.D.	40	78
28	750	40	86	58	816	31	77
29	305	40	78	59	206	29	81

The groundwater in the study area varies from non-saline to slightly saline water. An exception is found in one groundwater sample, No.59, which is considered slightly saline (Abd El-Latif, 2007).

In general, the salinity of groundwater increases gradually in the direction of flow (SW-NE) (Fig.2). The increase in the salinity of groundwater in the aforementioned direction may be attributed to the following factors:

1) the changes in lithology and structural pattern of the water-bearing formation,

2) slow groundwater velocity and long distance from the southern to the northern part of the study area, and

3) long residence time.

All ions concentration (Ca^{++}, Mg^{++}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{--} and Cl^{-}) show noticeable increase in the same direction of the regional flow of the Nubian Sandstone Aquifer (SW-NE) (Table 1).

Hydrochemical coefficients

Hydrogeochemical parameters, which are commonly used for identification of groundwater bodies, should be based on and confirmed by hydrogeochemical indicators such as ionic ratios. The cationic and anionic concentrations in these ratios are calculated according to their equivalent concentrations (meq/l). The important ionic ratios which influence the hydrochemical model of the study area are highlighted in the following paragraphs:-

Na / Cl

Groundwater flowing through the normal and active hydrological cycle is characterized by Na/Cl ratios of 0.86-1.0 range (0.86 is the ratio of seawater) (Schoeller, 1956, and Hem, 1989). Figure (3) show that Na/Cl ratio of groundwater samples from the study area decreases as the salinity increases. The Na/Cl ratio in the majority of groundwater samples (59% of the samples) in the study area are more than those of sea water (0.86) (Fig.3).

Neal and Kirchner (2000) concluded that the Na/Cl ratio in groundwater is higher than the seawater ratio when salinity is low and lower when salinity is high. This behavior is consistent with ion exchange buffering of sodium in the water-bearing formation (Neal and Kirchner, 2000). The Na/Cl ratio could reach unity due to mixing of seawater and freshwater, which has a Na/Cl ratio greater than unity (Vengosh and Rosenthal, 1994 and Ghabayen et al., 2006). Mercado (1989) suggested that dissolution of $CaCO_3$ might raise the calcium content in water which is further exchanged with Na ions, thus causing an increase in Na/Cl ratio. In addition, Mercado (1989) suggested that reactions with clays might lead to the exchange of sodium for calcium and/or magnesium ions. By such processes, groundwater may be either enriched or depleted in Na with the Na/Cl ratio changing accordingly (Uliana and Sharp Jr., 2001).

On the other hand, the decrease of Na concentration in some groundwater samples (41% of the samples) may be attributed to cation exchange and mixing with relics of marine water enriched in chloride ions. The equivalent Na/Cl ratio for the groundwater samples of the study area indicates that the influence of marine water as a main source of salinization is limited (Abd El-Latif, 2007).

The effect of cation exchange was evaluated by calculating the base exchange index (BEX) (Stuyfzand, 1999) which is defined as follows:

$$BEX = (Na + K + Mg) - 1.076Cl \text{ in meq/l}$$

Significantly positive sign of BEX indicates freshening and significantly negative sign indicates salinization and value near zero occurs at equilibrium (Stuyfzand, 1999). The calculated BEX values of the majority of the groundwater samples (93% of the samples) of El-BahariyaOasis have significantly positive sign referring to freshening (Table 3).

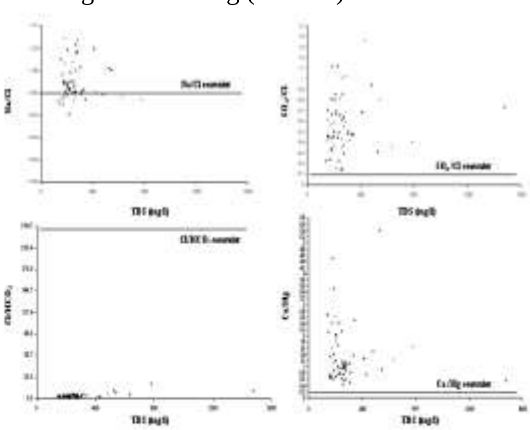

Fig. 3. Relations between salinity and different ionic ratios of groundwater samples of El-Bahariya Oasis

SO_4 / Cl

The salinization has been characterized by studying the content of a series of ionic relationships (SO_4/Cl, B/Li, Na/Cl, Cl/Br) (Martos et al., 2002 and Ghabayen et al., 2006). Sulfate/chloride and magnesium/calcium ratios showed significant variations in relation to lithological controls and assisted delimitation of continental and marine facies in the aquifer construction and can be taken as a guide for sulfate mineral dissolution. The SO_4/Cl ratio is not influenced by base-exchange reactions, adsorption onto clay minerals, carbonate-dissolution-precipitation processes and it is considered conservative tracer (Vengosh and Rosenthal, 1994; Vengosh et al., 1994 and Vengosh et al., 1999). Since, dissolution of evaporite leads to an enrichment in sulfate, so the ratio of SO_4/Cl can be used as a natural tracer (Oliman, 1995; Perry et al., 1995).

About 93 % of the groundwater samples have SO_4/Cl ratio less than unity but more than that of seawater (0.1) (Fig.3). This indicates the predominance of chloride ions. The dominance of chloride ion is probably due to the leaching of some marine salts from the fluvio-marine sediments which dominate the water-bearing formation or due to mixing with deep-seated salt water that leaks upward along fractures (Abd El-Latif, 2007).

Ca / Mg

This ratio usually indicates seawater contamination (Ca/Mg is about 0.2) or meteoric water mixing (Ca/Mg is about 1.07) in the groundwater bodies. High values of this ratio possibly indicate anhydrite dissolution, meteoric water mixing or CO_2-$CaCO_3$ interaction. Ghabayen et al. (2006) concluded that high values of Ca/Mg ratio and high values of Na/Cl ratio, relative to seawater, may be caused by dissolution of $CaCO_3$. This raises the Ca content that is further exchanged with Na^+ ions thus causing an increase in the Na/Cl ratio (Vengosh and Rosenthal, 1994).

In addition, high Ca/Mg ratio may be more pronounced in older waters than in modern waters (Sidenvall, 1981). However, the Ca/Mg ratio decreases as the total salinity increases (Fig.3) and is highly influenced by the activity of base exchange processes.

The values of this ratio for groundwater from the Nubian Sandstone Aquifer in the study area (range from 0.14 to 5.4 with an average of 1.4) are higher than that of seawater (Fig.3), thus indicating meteoric water mixing. In general, high TDS values and low Ca/Mg ratio characterize the northeastern part of the study area (Abd El-Latif, 2007).

Table 3. Hydrochemical coefficients of groundwater from the Nubian Sandstone Aquifer in El-Bahariya Oasis (Abd El-Latif, 2007)

No.	BEX	Na/Cl	SO_4/Cl	Ca/Mg	Cl/Br	No.	BEX	Na/Cl	SO_4/Cl	Ca/Mg	Cl/Br
1	0.03	0.84	0.36	2.00	110.59	**32**	0.73	0.87	0.42	0.79	124.30
2	1.18	1.24	0.63	1.12	107.24	**33**	0.87	1.38	0.66	1.11	33.83
3	0.28	0.89	0.22	0.93	94.07	**34**	1.16	1.14	1.11	0.59	457.87
4	0.95	1.15	0.65	0.94	94.22	**35**	1.06	0.84	0.94	1.49	126.94
5	0.76	0.93	0.61	0.73	110.58	**36**	-0.06	0.74	0.80	3.50	49.56
6	0.47	0.94	0.33	0.86	137.06	**37**	0.20	0.80	0.44	1.33	423.82
7	0.07	0.83	0.14	1.04	86.78	**38**	0.83	1.18	0.70	0.68	**….**
8	0.29	0.95	0.34	1.40	113.46	**39**	0.75	1.02	0.61	0.75	460.22
9	-0.11	0.78	0.22	2.66	306.40	**40**	0.80	0.96	0.81	0.69	262.24
10	1.72	1.28	0.68	1.27	92.65	**41**	1.51	0.78	1.01	0.41	272.29
11	1.06	1.10	0.50	1.10	89.78	**42**	-0.05	0.79	0.40	1.63	106.16
12	0.12	0.87	0.45	2.61	120.85	**43**	1.16	0.96	1.12	0.77	….
13	0.50	0.92	0.58	1.20	147.07	**44**	0.03	0.85	0.13	1.15	114.20
14	2.25	0.85	1.36	0.74	109.38	**45**	0.68	1.27	0.80	2.00	207.62
15	0.22	0.65	0.69	1.67	243.15	**46**	0.67	0.95	0.50	0.67	139.05
16	0.52	0.97	0.81	2.14	94.97	**47**	1.56	1.36	1.02	0.82	158.11
17	0.45	1.05	0.44	2.40	72.99	**48**	-0.12	0.79	0.47	2.50	117.03
18	0.49	0.88	0.47	1.36	78.61	**49**	0.45	1.09	0.31	5.40	136.05
19	0.03	0.76	0.41	2.11	299.70	**50**	2.15	1.07	0.80	0.91	115.86
20	0.43	0.83	0.85	1.83	227.36	**51**	0.65	0.88	0.66	1.00	160.26
21	0.39	0.86	0.29	1.00	97.68	**52**	1.07	1.06	0.55	0.91	113.12
22	1.23	1.25	0.59	1.06	133.60	**53**	1.20	1.08	0.37	0.58	133.08
23	0.14	0.80	0.56	2.40	184.62	**54**	0.13	1.04	0.32	4.49	150.83
24	0.48	0.74	0.46	0.65	227.36	**55**	0.33	0.97	0.44	1.60	122.36
25	0.32	0.90	0.15	0.72	94.15	**56**	0.91	1.05	0.49	0.76	71.67
26	1.14	0.84	0.48	0.48	78.29	**57**	0.70	0.86	0.43	1.01	97.74
27	1.63	1.32	0.85	0.53	65.68	**58**	0.66	0.82	0.35	1.21	91.47
28	0.17	0.85	0.16	1.07	89.97	**59**	5.80	0.86	0.73	0.55	108.21
29	0.34	0.83	0.23	0.62	136.61						
30	0.50	0.85	0.22	0.60	102.45						
31	0.66	0.91	0.35	0.93	110.58						

Cl / Br

The cationic and anionic concentrations in this ratio is calculated according to its milligram concentrations (mg/l). The Cl/Br ratio was previously identified to differentiate between sources of salinization (Starinsky et al., 1983; Richter et al., 1990; Vengosh and Rosenthal, 1994; Davis et al., 1998; Martos et al., 2002, Edmunds, 1996; Edmunds et al., 2003 and Ghabayen et al., 2006). The Cl/Br ratio is not influenced by base-exchange reactions, adsorption onto clay minerals, carbonate-dissolution-precipitation processes and it is considered a conservative tracer (Carpenter, 1978; Stoessell and Carpenter, 1986; Whittemore, 1988, Vengosh and Rosenthal, 1994; Vengosh et al., 1994 and Vengosh et al., 1999). The ratio of Cl/Br can be classified into three types: rock salt type (Cl/Br ratio of 2500 or more), secondary salt type (288-2500) and rain water type (288 or less) (Imaizumi et al., 2001). According to this classification, the majority of the groundwater samples (91%) from the study area have Cl/Br values less than 288 (Fig.4), which indicates that the groundwater is of rain water type (meteoric origin). On the other hand, some groundwater samples (9%) have Cl/Br values (>288 to 460), indicating the involvement of traces of marine water.

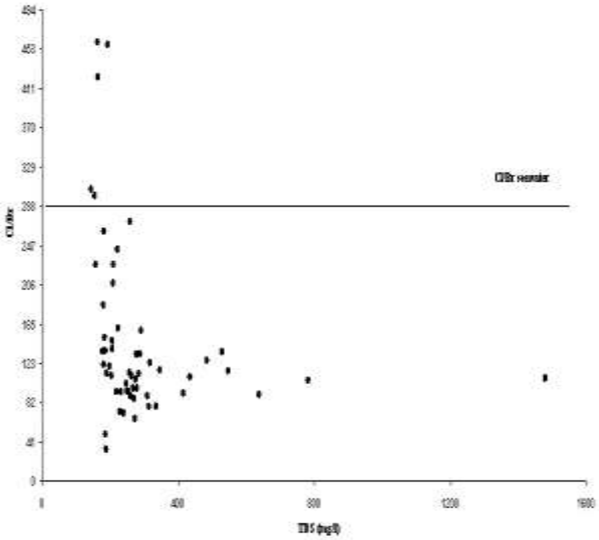

Fig. 4. between salinity and Cl/Br ratio of groundwater samples of El- Bahariya Oasis (after Abd El-Latif, 2007)

Hydrochemical facies and genetic classification of groundwater

The trilinear plotting classification method Piper's (1944) diagram

Piper's diagram for groundwater samples of the study area (Fig.5) illustrates that most of groundwater samples (61%) are located within sub-area 9, while other groundwater samples 20% and 19% lie in sub-area 7 and sub-area 6, respectively. The samples located within sub-area 9 (i.e. No one cation-anion pair > 50%) are shown to be more influenced by meteoric replenishment in the past time, while those located within sub-area 7 and sub-area 6 are shown to be more affected by marine water and non carbonate hardness "secondary salinity" > 50%, respectively. Finally, this diagram suggests that the groundwater from the Nubian Sandstone Aquifer in El-Bahariya Oasis have mixed types of mineralization, i.e., pure meteoric water that vertically infiltrated and settled in the aquifer materials during the past Pluvial times and those affected through groundwater flow by relics of marine water (Abd El-Latif, 2007).

Sulin's (1948) diagram.

Sulin's (1948) diagram is usually used to reveal the water genesis and the type of water from the hydrochemical composition. Plotting of the groundwater samples from the Nubian Sandstone Aquifer on Sulin's diagram (Fig.6) shows that more than 50% of the collected samples are of marine origin (Cl-Mg type), where the rest are of SO_4-Na type (i.e. meteoric origin).

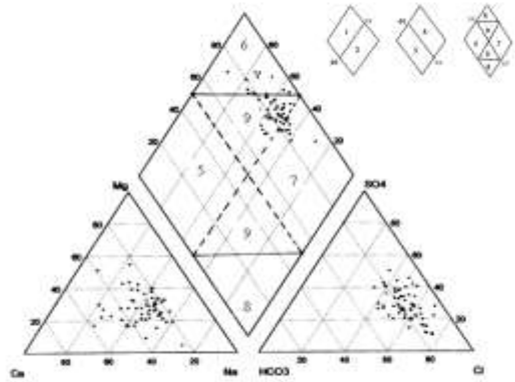

Fig.5. Piper's diagram for groundwater samples of the Nubian Sandstone Aquifer in El-Bahariya Oasis

However, it is noteworthy to mention that the genetic classification of groundwater according to the Cl/Br ratio which indicates that the majority of the groundwater samples (91%) is of rain water type (meteoric origin) is more reliable than that of Sulin's diagram classification (i.e. >50% of the collected samples are of marine origin, Cl-Mg type). This may be attributed to the conservative nature of Cl and Br in the groundwater system (Abd El-Latif, 2007), whereas Sulin's classification involves non-conservative ions like Na, Ca and Mg which are strongly affected by hydrogeochemical processes of cation exchange and dissolution-precipitation reactions.

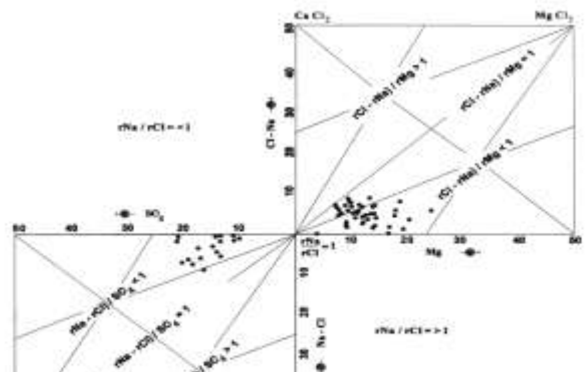

Fig.6. Sulin's diagram for ground-water samples of El-Bahariya Oasis

Durov's (1948) diagram

Evidence of cation exchange and reverse cation exchange in the Nubian Sandstone Aquifer system can be revealed from the Durov's diagram (expanded) (Fig.7). It shows evolutionary trends and hydrochemical processes occurring in the groundwater system. The significance of each of the nine fields on the expanded Durov diagram is as follows (Lloyd, 1985):

Durov's field	Characteristics
Field 1	: Indicates recharging waters
Fields 2&3	: Indicate ion exchange
Fields 4&5	:Indicate waters exhibiting simple dissolution or mixing
Field 6	:Indicates probable mixing influences
Fields 7&8	:Indicate that groundwaters may be related to reverse ion exchange
Field 9	: Indicates end-point waters

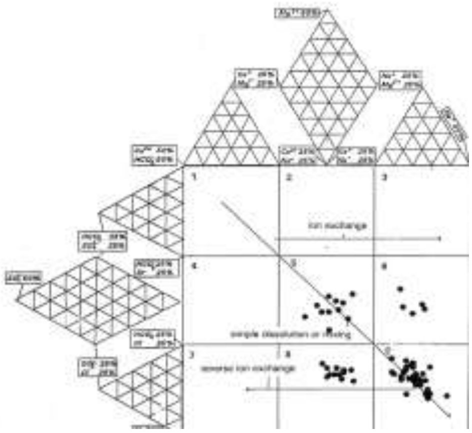

Fig.7. Expanded Durov's diagram for different water types of the collected groundwaters of El-Bahariya Oasis

The arrows in Fig.7 indicate possible process paths, such as ion exchange or dissolution. From the Durov's diagram, it is obvious that most of the groundwater samples representing the Nubian Sandstone Aquifer in El-Bahariya Oasis are plotted in field 9 (Cl-Na type) which indicates end-point water (i.e. more developed stage of mineralization) (Abd El-Latif, 2007). Some of the plotted groundwater samples (20%, 19% and 8%) are located in fields (8, 5 and 6) of Cl-Mg, SO_4-Mg and SO_4-Na type, respectively. These waters represent less advanced stage of mineralization. It is also clear that the groundwaters of the study area have a mixed origin (pure meteoric water affected to less extent by traces of marine water). Therefore, the groundwater acquires its quality from mixing, cation exchange and dissolution of salts by interaction with clays, shales, carbonates and sulfates in the aquifer matrix.

Quality Assessment

The main aquifer is the highly productive artesian Nubian Sandstone Aquifer. This groundwater is being, and will be, used as an essential source of water for agricultural expansion, as well as for industrial development and domestic usages, particularly in the newly established communities and industrial zones. In fact, greater residential development and population density brings greater potential for human effects on water quality (Eckardt and Stackelberg, 1995; and Thomas, 2000). Therefore, water resource management and water availability are among the most important political, social and economical issues of the 21st century (Harsh et al. 1989 and Krug, 1989) as water quality assessment is becoming a major concern in El-Bahariya Oasis.

1) Assessment for drinking and domestic purposes

Water-quality standards published by various agencies are used for drinking and domestic uses owing to evaluate the suitability of water for public supply. Accordingly, the majority of groundwater samples of the Nubian Sandstone Aquifer of El-Bahariya Oasis are suitable for drinking and domestic uses under normal conditions except for iron and manganese.

The concentrations of the trace elements are far below the drinking water permissible limits, except for aluminum where 25% of groundwater samples have higher concentrations. Therefore, most of groundwater samples are suitable for human drinking (Abd El-Latif, 2007).

2)Assessment for irrigation and salinity management

One of the most widely advocated water management objectives in Egypt is the improvement of water-use efficiency in agriculture. Irrigation is the most effective mean of increasing food production in Egypt. Therefore, the main purpose of irrigation is to assure a given quantity and quality of water being made available at a given place and at a given time (Hall, 1976).

Generally, irrigation water requirements depend on three factors, climate, plant type, and drainability of soil. Thus, rigorous universal standards for these water requirements can not be formulated, and what may be poor quality under certain conditions could be quite acceptable under other conditions.

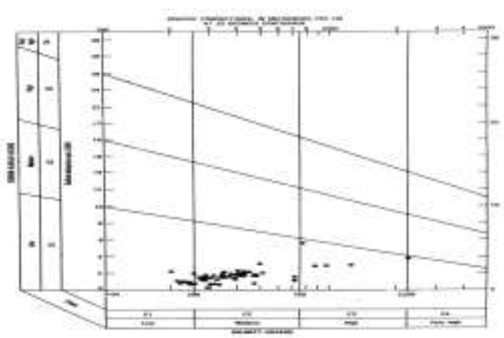

Fig.8. Classification of groundwater samples from El-Bahariya Oasis according to US Salinity Laboratory Staff, 1954

i) The U.S. Salinity Laboratory (1954) classification

The U.S. Salinity Laboratory classification is widely used normogram for evaluating waters for irrigation purposes (Table 4). Accordingly, the waters are divided into four classes on the basis of salinity (C_1, C_2, C_3, & C_4) and four classes on the basis of sodium adsorption ratio (S_1, S_2, S_3, & S_4) giving a total of sixteen possible quality classes (C_1-S_1, C_1- S_2 ….etc.) (Table 4).

The sodium adsorption ratio has been introduced by Richards (1954) as follows:

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}} \qquad \text{(in meq/l)}$$

The concentration of sodium, calcium and magnesium are expressed in meq/l. High SAR (sodium hazard) leads to the breakdown in the physical structure of the soil. Such soils can crust badly and swell or disperse thus reducing the soil permeability (Buckman and Brady (1967), Chen and Banin (1975), Ayers and Westcot (1976), Frenkel et al. (1978), Hardy et al. (1983), Miller and Donahue (1995), Hanson et al. (1999), Falstad (2000), Van de Graaff and Paterson (2001), Bauder (2001), Bauder and Brock (2001), Ali et al. (2002) and Barbiéro et al., 2004). Sodium is adsorbed, replacing calcium and magnesium (cation exchange reaction) and becomes attached to soil particles which becomes hard and compact when dry. The interaction of clay surface with ions has great influence on physicochemical behavior of soils. The types and concentration of ions in soil solution govern the dominance of attracting and repelling forces and the resulting flocculation or deflocculation of clays. Divalent exchangeable cations result in flocculated clay systems while monovalent exchangeable cations produce dispersed or deflocculated systems (Aydin et al., 2000 and Aydin et al., 2004). In other words, by replacing the Na adsorbed on the clay with Ca, the thickness of the electrical double layer is reduced and thus soil colloids flocculate. From the plotted samples on the normogram (Fig.8), the major classes of the groundwater of El-Bahariya Oasis are given in Table (5). Concerning salinity and sodium hazards, groundwater in El-Bahariya Oasis is considered as good class (76% C_2-S_1, 15% C_1- S_1, 7% C_3-S_1 and 2% C_4-S_1).

Thus, groundwater samples from the Nubian Sandstone Aquifer are suitable for irrigation under normal condition (Abd El-Latif, 2007)

ii) Wilcox's (1948) classification

It suggests the definition of sodium percentage relative to common cations percentage as shown in the following equation:

$$Na\ \% = \frac{Na \times 100}{Ca + Mg + Na} \qquad \text{(in meq/l)}$$

Wilcox classification is essentially based on the relation between Na and salinity, which defines the suitability of water for irrigation and the potential for plant toxicity. In the study area, 92% of the groundwater samples (Table 6 and Fig.9) are plotted in the field of excellent to good water class (i.e. suitable for irrigation) while 5%, 2% and 1% of water samples varying from good to permissible, permissible to doubtful, and doubtful to unsuitable class, respectively.

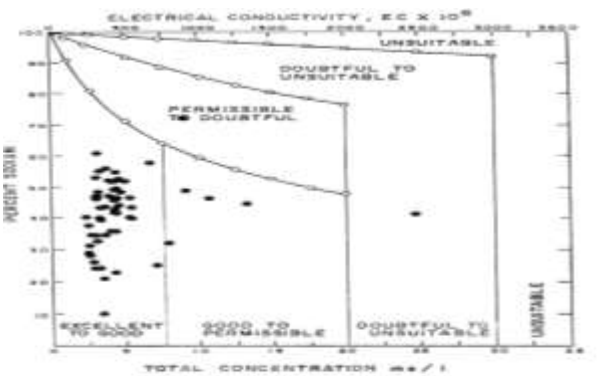

Fig.9. Classification of groundwater samples from El-Bahariya Oasis based on Wilcox's (1948)

Table 4. Water quality-class according to .S. Salinity Lab. (1954)

EC class	Water Quality	Range EC (us/cm)	Us age	SAR class	Water Quality	Range	Us age
C_1	Low salinity	100-250	Can be used for irrigation with most crops on most soils	S_1	Low sodium	0.10	Can be used for all soils
C_2	Medium salinity	250-750	Can be used if moderate leaching occurs	S_2	Medium sodium	10-18	Preferably used with good permrability
C_3	High salinity	750-2250	Cannot be used with restricted drainage	S_3	High sodium	18-26	Can produce a harmful effects
C_4	Very high salinity	>2250	Not suitable for irrigation under ordinary conditions	S_4	Very high sodium	26-100	Unsuitable for rrigation expect at low & medium salinity

Note: 1- The C_2 S_2 and C_3 S_3 water can be improved by adding gypsum to the soil peciodically.

2- the $C_{4\ S4}$ may be improved by addition of gypsum to the water

iii) Eaton's (1950) classification

Some water, when used for the irrigation of crops, has a tendency to produce alkalinity/sodicity hazards, depending upon the absolute and relative concentrations of specific cations and anions.The alkalinity is generally measured in terms of the sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and adjusted SAR (Tyagi, 2003). In fact, the effect of bicarbonate ions on the increase of soil alkalinity and on lime accumulation is very important. Concerning the bicarbonate content of the water, Eaton (1950) was the first to introduce the residual sodium carbonate (RSC) value expressed by the equation:

$$RSC = (CO_3 + HCO_3) - (Ca + Mg) \ \text{(in meq/l)}$$

According to the residual sodium carbonate, the irrigation water can be divided into three classes as follows:

i) Safe, if RSC < 1.25 meq/l (i.e. negative values indicate no problem);

ii) Marginal, if RSC ranges from 1.25 to 2.5 meq/l, and

iii)Unsuitable, if RSC > 2.5 meq/l

Since, high concentration of bicarbonate is associated with an increase in the pH values which causes the dissolution of the organic matter (FAO, 1985). Moreover, high concentration of bicarbonate in irrigation water leads to its toxicity and effects the mineral nutrition of many plants. Generally, carbonate and bicarbonate can also affect infiltration (FAO, 1985).

Table (7) shows that the RSC values of the groundwater samples of the study area are less than 1.25, indicating that the groundwater of the Nubian Sandstone Aquifer can be safely used for irrigation (Abd El-Latif, 2007).

iv) Boron content

Boron is an essential micro-nutrient to proper plant nutrition and required only in very small amounts, however, greater concentration of boron in soil and in irrigation water are harmful (i.e. toxic to some plants) (Hem, 1989). Sprague (1972) mentioned that boron in natural waters exists primarily as undissociated boric acid with some borate ions. Leeden and Todd (1990) introduced limits of boron in irrigation water depending upon the boron requirements for different types of crops as shown in Table (8):

In El-Bahariya Oasis, the groundwater samples of the Nubian Sandstone Aquifer have boron contents range from 0.010 to 0.076 mg/l with an average of 0.043 mg/l. Based on this classification, all the groundwater samples in the study area can be grouped into the excellent classes for different kinds of crops including sensitive, semitolerant and tolerant (Abd El-Latif, 2007)

Table 7. Calculated values of RSC for the groundwater of El-BahariyaOasis

Well No.	RSC	Assessment	Well No.	RSC	Assessment
1	-1.01	Safe	31	-1.18	Safe
2	-0.84	Safe	32	-1.89	Safe
3	-0.97	Safe	33	-0.45	Safe
4	-1.09	Safe	34	-1.18	Safe
5	-1.50	Safe	35	-4.28	Safe
6	-0.79	Safe	36	-1.48	Safe
7	-1.16	Safe	37	-1.00	Safe
8	-0.84	Safe	38	-0.58	Safe
9	-0.61	Safe	39	-0.68	Safe
10	-1.47	Safe	40	-1.21	Safe
11	-1.15	Safe	41	-2.34	Safe
12	-1.09	Safe	42	-5.88	Safe
13	-1.17	Safe	43	-1.45	Safe
14	-4.02	Safe	44	-1.01	Safe
15	-1.74	Safe	45	-0.65	Safe
16	-1.63	Safe	46	-1.07	Safe
17	-0.78	Safe	47	-1.14	Safe
18	-1.88	Safe	48	-2.08	Safe
19	-0.95	Safe	49	-1.67	Safe
20	-1.44	Safe	50	-3.63	Safe
21	-1.43	Safe	51	-1.48	Safe
22	-0.68	Safe	52	-1.24	Safe
23	-1.10	Safe	53	-0.80	Safe
24	-1.03	Safe	54	-0.59	Safe
25	-0.78	Safe	55	-0.87	Safe
26	-2.07	Safe	56	-0.99	Safe
27	-1.12	Safe	57	-1.45	Safe
28	-1.05	Safe	58	-3.95	Safe
29	-0.87	Safe	59	-12.00	Safe
30	-1.19	Safe			

Table 8. Limits of boron in irrigation wateraccording to Leeden and Todd (1990)

Class of water	Permissible Limits (Boron in mg/l) Crop group		
	Sensitive	Semitolerant	Tolerant
Excellent	< 0.33	< 0.67	< 1.0
Good	0.33 to 0.67	0.67 to 1.33	1.0 to 2.0
Permissible	0.67 to 1.0	1.33 to 2.0	2.0 to 3.0
Doubtful	1.0 to 1.25	2.0 to 2.5	3.0 to 3.75
Unsuitable	> 1.25	> 2.5	> 3.75

v) Minor and trace elements

The terms "minor" and "trace" are commonly used for substances that always or nearly always occur in concentration less than 1.0 mg/l (Hem, 1989).

In general, the most important minor elements are boron, iron and nitrate. Recommended maximum limits for constituents in irrigation water presented by the National Academy of Sciences and National Academy of Engineering (1972) and Rowe and Abdel-Magid (1995) are given in Table (9).

Assessment of the groundwater quality of the study area for safe irrigation is carried out through the determination of two minor elements (B and Fe) and nine trace elements (Al, Cd, Cr, Co, Cu, Pb, Mn, Ni, and Zn) in 58 groundwater samples that were collected from El-Bahariya Oasis in December 2002 (Table 11).

Table 9. Recommended maximum limits (mg/l) for minor and trace elements in irrigation water according to NAS-NAE (1972)and Rowe and Abdel-Magid (1995)

Const.	Long-term use [(a)] (mg/l)	Short-term use [(b)] mg/l)[b]	Const.	Long-term use [(a)] (mg/l)	Short-term use [(b)] (mg/l)
Alumi num	5.0	20.0	Iron	5.0	20.0
Arseni	0.1	2.0	Lead	5.0	10.0
Berylli	0.1	0.5	Lithium	2.5	2.5
Boron	0.75	2.0	Manganese	0.2	10.0
Cadmi	0.01	0.05	Molybdenu	0.01	0.05
Chrom	0.1	1.0	Nickel	0.2	2.0
Cobalt	0.05	5.0	Selenium	0.02	0.02
Coppe	0.2	5.0	Vanadium	0.1	1.0
Fluori	1.0	15.0	Zinc	2.0	10.0

[a]For water used continuously on all soils. [b]For water used for a period of up to 20 years on fine-textured neutral or alkaline soils.

The permissible iron content in irrigation water is 5 mg/l, whereas the iron content, in the investigated groundwater samples (Tables 10 and 11), ranges between 0.01 to 10.29 mg/l with a mean value of 1.87 mg/l. Therefore, the majority of the groundwater samples (95%) have iron content below the permissible level for irrigation while 5% exceed the recommended value.

Several classifications and standard limits are used to assess the suitability of the groundwater of the study area for irrigation. A complete water quality management will define the suitability of water for irrigation, which associated with soil nature and crop type, and the potential for plant toxicity. For irrigation, water quality is related to its effect on soils and crops, and on the management that may be necessary to control or compensate for the water quality related problems (Ayers and Westcot, 1976). Depending upon the above mentioned classifications, the majority of groundwater sample of El-Bahariya Oasis can be used for irrigation under ordinary circumstances with little exception that leads to the optimum level of the expected productivity(Abd El-Latif, 2007).

Table 10. Results of chemical analysis of minor elements (mg/l) of the groundwater samples of El-Bahariya Oasis

Well No.	B	*Fe*	Well No.	B	*Fe*
1	0.0200	0.0110	**31**	0.0521	1.5100
2	0.0402	0.0150	**32**	0.0425	2.0500
3	0.0311	0.5839	**33**	0.0340	1.5420
4	0.0236	0.0101	**34**	0.0325	0.2212
5	0.0258	0.2816	**35**	0.0573	5.9370
6	0.0228	1.3080	**36**	0.0337	3.3180
7	0.0482	1.4140	**37**	0.0282	0.8687
8	0.0209	2.2290	**38**	0.0301	0.4912
9	0.0195	2.5020	**39**	0.0341	1.6060
10	0.0710	1.5150	**40**	0.0439	2.2720
11	0.0670	0.6617	**41**	0.0274	0.5868
12	0.0315	3.7760	**42**	0.0377	4.9820
13	0.0146	0.3367	**43**	0.0284	0.4536
14	0.0446	10.2900	**44**	0.0548	2.1630
15	0.0109	3.1460	**45**	0.0386	3.1590
16	0.0208	2.8080	**46**	0.0362	1.3950
17	0.0213	2.5090	**47**	0.0585	0.0430
18	0.0341	2.7510	**48**	0.0544	0.1751
19	0.0099	2.7720	**49**	0.0513	1.4520
20	0.0140	4.2790	**50**	0.0450	0.5343
21	0.0717	2.3490	**51**	0.0328	0.7139
22	0.0755	0.4819	**52**	0.0449	0.0152
23	0.0431	3.1420	**53**	0.0455	0.2030
24	0.0432	4.5110	**54**	0.0383	0.1823
25	0.0635	7.0390	**55**	0.0331	2.2380
26	0.0600	2.3190	**56**	0.0361	0.1526
27	0.0587	1.7820	**57**	0.036	0.153
28	0.0522	0.4292	**58**	0.0670	0.2161
29	0.0481	4.5680	**59**	…	…
30	0.0508	1.8290			

Table 11. The range and mean values of trace elements (mg/l) of the groundwater samples of Bahariya Oasis

Concentration in mg/l									
Al		Cd		Cr		Co		Cu	
Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
0.03 to 0.3374	0.0138	0.0002 to 0.0045	0.0003	0.0007 to 0.0328	0.0043	0.0001 to 0.0122	0.0004	0.0008 to 0.495	0.021

Concentration in mg/l							
Pb		Mn		Ni		Zn	
Range	Mean	Range	Mean	Range	Mean	Range	Mean
0.0008 to 0.032	0.0064	0.0028 to 1.398	0.449	0.0002 to 0.743	0.006	0.0002 to 0.72	0.0296

3)Assessment of groundwater for industrial purposes

In the study area, plentiful groundwater supply from the Nubian Aquifer is considered to have played an important role in the province's socio-economic development. From the economic viewpoint, it may be necessary to site water consuming industries in areas where there is an abundant natural supply of suitable water (Matthess, 1982). Water required for industrial purposes depends on the requirements of particular industry; some may need water to be more pure than domestic, whereas others may require some specific minerals to be absent. For instance, the water quality for food and medicinal drug industries must be at least as that of drinking water. For textile industries, water should be low in iron, manganese, other heavy metals, total salts and hardness. There are many quality parameters that must be considered when using water resources for industry:

1) Total Dissolved Solids (TDS):

High TDS levels (> 500) result in excessive scaling in water pipes, water heaters, boilers, and household appliance such as kettles and steam irons (Tihansky, 1974 and McQuillan and Spent, 1976). Such scaling can shorten the service life of these appliances.

2) Total Hardness:

Hardness of water is defined as its content of metallic ions which react with soaps to produce scuds or scummy residues; and which react with negative ions when water is evaporated in boilers to produce solid boiler scale and is expressed, as follows:

$$\text{Total Hardness} = 50 \times (\text{Ca} + \text{Mg}) \ \text{in meq/l} \ (\text{Hem,1989})$$

Durfor and Becker (1964) gave the following hardness classification (Tables 12 and 13):

Based on the above classification (Table 12), the groundwater samples of El-Bahariya Oasis can be classified as follows:

Description	Groundwater samples %
Soft	5 %
Moderately hard	75 %
Hard	10 %
Very hard	10 %

Table 12. Hardness classification according to Durfor and Becker (1964)

Description	Hardness range (mg/l of $CaCO_3$)
S	0 – 60
M.D	61 – 120
H	121 – 180
V.D	> 180

Table 13. Classification of total Hardness of the ground-water of El-Bahariya Oasis according to Durfor and Becker (1964)

Well No.	Total Hard-ness	Descri-ption	Well No.	Total Hardness	Descri-ption
1	75	M.D	31	102	M.D
2	96	M.D	32	122	H
3	73	M.D	33	48	M.D
4	78	M.D	34	87	M.D
5	95	M.D	35	239	V.D
6	65	M.D	36	90	M.D
7	87	M.D	37	70	M.D
8	64	M.D	38	61	M.D
9	55	S	39	70	M.D
10	125	H	40	81	M.D
11	105	M.D	41	143	H
12	83	M.D	42	316	V.D
13	83	M.D	43	115	M.D
14	246	V.D	44	78	M.D
15	120	M.D	45	60	S
16	110	M.D	46	75	M.D
17	85	M.D	47	100	M.D
18	130	H	48	140	H
19	70	M.D	49	112	M.D
20	106	M.D	50	210	V.D
21	100	M.D	51	100	M.D
22	93	M.D	52	105	M.D
23	85	M.D	53	95	M.D
24	76	M.D	54	55	S
25	66	M.D	55	65	M.D
26	135	H	56	84	M.D
27	90	M.D	57	118	M.D
28	85	M.D	58	260	V.D
29	65	M.D	59	665	V.D
30	88	M.D			

M.D: Moderately hard S: Soft H: Hard V.H:

High total hardness values in the study area may be attributed to over pumping and the effect of leaching and dissolution of salts that increase the solubility of calcium and magnesium in water (Richards, 1954, Freeze and Cherry, 1979, and Hem, 1989). Depending on the interaction of other factors, such as pH and alkalinity, water with hardness above approximately 200 mg/l may cause scale deposition in the distribution system. In contrast, soft water with hardness less than 100 mg/l has a greater tendency to cause corrosion of pipes (National Research Council, 1977). According to Moustafa et al. (2003), Bahariya Depression may offer opportunities for potential hydrocarbon reserves. Thus, several projects are expected to be established in the future, many of which are petroleum industries. NAS-NAE,1972 introduces the quality requirements of water at point of use for some industries, as shown in Table 14.

Table 14. The quality requirements of water at point of use for some industries according to NAS-NAE (1972)

Characters	Paper	Textile	Petroleum
pH	….	….	6 - 9
TDS (mg/l)	200 - 500	100 – 200	3500
Alkalinity	75 – 150	50 – 200	500
Hness	100 - 200	0 – 50	900
K+Na	….	….	230
Mg	….	….	85
SO_4	….	100	900
Cl	0 - 200	100	1600
Silica	20 – 100	25	85
Iron	0.1 – 1.0	0.0 – 0.3	15
Copper	….	0.01 – 5	….

Based on the above classification (Table 14), the use percent of the groundwater samples of the study area for some industries, can be classified, as follows:

	% of ground water sample to use		
	Paper	**Textile**	**Petroleum**
pH	….	….	100 %
TDS (mg/l)	92 %	29 %	100 %
Alkalinity	100 %	100 %	100 %
Hardness	90 %	17 %	100 %
K+Na	….	….	98 %
Mg	….	….	100 %
SO_4	….	88 %	100 %
Cl	93 %	75 %	100 %
Silica	100 %	93 %	100 %
Iron	42 %	20%	100 %
Copper	….	100 %	….

It can be concluded that the groundwater of El-Bahariya Oasis can be used for petroleum and paper industry under ordinary conditions (Abd El-Latif, 2007) but not suitable for textile industry (Serag El-Din, 1999), where high iron contents should be removed prior to use**.**

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الملخص العربي

هيدروجيوكيميائية وحساب جودة المياه الجوفية لخزان الحجر الرملى النوبى فى الواحات البحرية، الصحراء الغربية، مصر

ابراهيم حسن حميدة، حنفى محمود هليل، مُحَّد ناصر شعبان، انور عبد العزيز الفقى و رمضان مُحَّد عبد اللطيف

تعتبر المياه الجوفية واحدة من أكثر الموارد الطبيعية الهامة والتي يعتمد عليها جميع الانشطة البشرية والأنشطة الصناعية والزراعية اعتمادا كاملا . ولكن للأسف تسبب زيادة الاعتماد على موارد المياه الجوفية بمنطقة الواحات البحرية من دون أي خطط علمية مسبقة فى حدوث بعض الآثار الهيدروجيولوجية السلبية مثل الهبوط السريع في مستويات المياه الجوفية وتملحها. ويهتم هذا البحث بالدراسات الهيدروجيوكيميائية للمياه الجوفية بمنطقة الدراسة.

وتعتمد هذه الدراسات على التحليل الكيميائي لعينات المياه المختلفة للمنطقة واستخدام نتائجها لتقييم وإدارة مياه الخزان في أغراض التنمية المختلفة. ولتحقيق ذلك فقد تم جمع 59 عينة مياه جوفية ممثلة للمنطقة وتحليلها كيميائياً و معرفة اصل المياه الجوفية و تقييم صلاحية عينات المياه الجوفية الممثلة لمنطقة الواحات البحرية للاستخدام بغرض الشرب الآدمي والحيواني والاستخدام المنزلى وفى الزراعة والصناعة.