

**PHYSICAL AND CHEMICAL CHARACTERISTICS  
OF GROUNDWATER IN SOUTH BARIS-EL  
KHARGA AREA AS RELATED TO THE  
PREVAILING DIFFERENT AQUIFER SYSTEMS,  
WESTERN DESERT, EGYPT.**

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The study area which is a real desert is, solely, depending on the groundwater as the only source of development, where neither surface water nor rainfall are available. This area is characterized by two different physical systems of groundwater occurrence; the unconfined condition in Baris oasis, where the water table is shallow and free, and the confined one in El Kharga oasis, where the water is under artesian pressure. The total energy contained in each of the water systems depends on three components: pressure, velocity and elevation head and, hence, affects greatly the water characteristics in such system. The present work is a trial to differentiate between the physical and chemical properties of groundwater exists under different conditions in the middle part of the western desert aiming to understand the relationship between groundwater occurrence and its quality. In Baris oasis (unconfined aquifer system), data of 32 groundwater samples were collected and used to assess the water quality of the aquifer. The analysis reveals that low dissolved oxygen (DO) values and high iron contents are detected. Meanwhile, values of the oxidation-reduction (Eh) potential show that the groundwater is in a reduction condition. The groundwater salinity shows a general trend of increase from northeast (El-Kharga) to southwest (Baris) with a fresh to slightly fresh water classes. The study also indicates that the groundwater in the area is of mixed origin, possibly pure meteoric but occasionally affected by marine deposits. Analyses of minor and trace constituents show that their concentrations are in the acceptable limits for different uses, except for higher iron and manganese concentrations. In El-Kharga oasis (confined aquifer system), literatures show that the groundwater is characterized by lower pH, DO, salinity, iron and manganese

contents but higher Eh and temperature as compared with the conditions in Baris oasis.

**Keywords:** Physico-chemical characteristics, groundwater occurrence, Baris-Kharga, Western Desert, Egypt.

As Egypt is a desert land, a great consideration is given to land reclamation activities based on the available groundwater resources. Baris-El Kharga area (western desert), is one of these areas that have water potential for agricultural plans. The only water resource in this area is the groundwater supply from the so called Nubian Sandstone aquifer. The need of sufficient quantities of high quality water in this area is a must, where the increase in the content of some hazardous components is a serious problem. The unplanned drilling of water wells; the mis-use of groundwater in irrigation and the high concentration of iron and manganese in the water have complicated the problems that affect the development activities in the study area. In the present study, 32 samples were collected from different water points during November 2004 from Baris oasis, where two kinds of samples were obtained:-

One liter samples were collected for major constituents determination, while other samples were collected in 100 ml acid-washed polyethylene bottles for heavy metal content.

The main issues that will be addressed by this study include: 1- the physical and chemical properties of the groundwater and their mutual relationship in the study area, 2- the possible impact of the groundwater occurrence upon its quality, 3- the correlation between the shallow groundwater in Baris and the deep groundwater in El-Kharga from the quality point of view.

The Baris area is located at the western desert between longitudes  $30^{\circ} 30'$  to  $30^{\circ} 50'$  and latitudes  $24^{\circ} 30'$  to  $24^{\circ} 50'$  covering an area of about  $900 \text{ km}^2$  (Fig. 1). Meanwhile, El-Kharga oasis located between longitudes  $30^{\circ} 30'$  to  $30^{\circ} 50'$  and latitudes  $24^{\circ} 15'$  to  $24^{\circ} 45'$  covering an area of about  $2000 \text{ km}^2$ .

#### **Aquifer System**

The Nubian Sandstone aquifer is the main water source in Baris-El Kharga Oases. Nubian Aquifer is formed by predominantly continental sediments, (mainly sandstone and shale layers), which contain an enormous groundwater mass. The groundwater of the Nubian sandstone aquifer was formed by local infiltration during the past wet periods. The aquifer attains a thickness more than 400m below Baris and 1000 m below El-Kharga.

In Baris area, the Nubian aquifer is unconfined and the depth to groundwater varies from 25 to 40m from ground surface (Fig. 2). Further, northward in El-Kharga oasis, the aquifer is overlain by impervious shales

and the groundwater is considered confined and springs are issued as a result of the upward movement under great pressure.

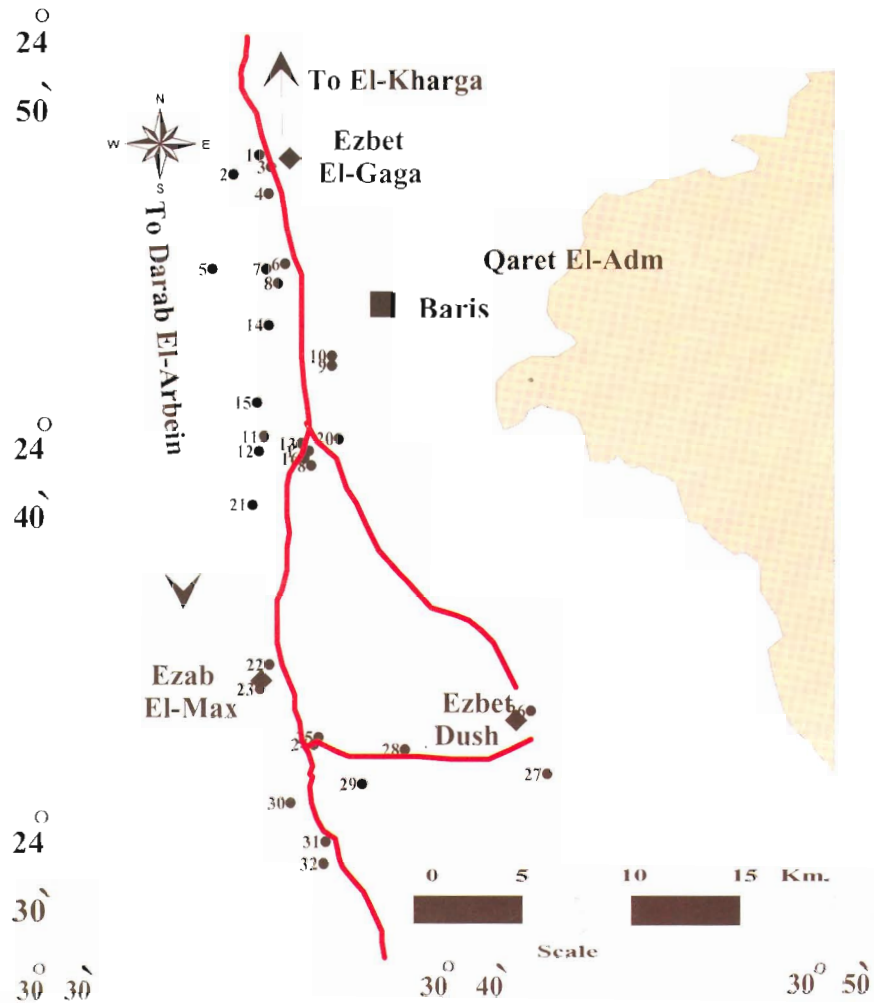


Fig. (1). Location map of Baris oasis.

Confined aquifer in El Kharga area is overlain by an impermeable layer that prevents recent recharge by rainfall or irrigation water. So, this aquifer is said to be under high pressure or artesian. Unconfined aquifer in Baris area is overlain by a permeable, unsaturated zone that allows surface water to percolate down to the water table. Therefore, the unconfined aquifer is under atmospheric pressure i.e., free water table.

The total daily discharge of wells in the area of study enormously decreased in the past 50 years probably due to the drop in the piezometric pressure of the confined aquifer, which caused by drilling of plenty of wells and also by the extensive exploitation of deep wells. As a consequence of this general drop of the hydrostatic pressure, the shallow wells stopped flowing.

Concerning the age of groundwater in the western desert, Shata *et al.* (1962) found that the water of Baris and Mahariq deep wells has an age of about 25000 years ago. Using He/Ar method, Himida, (1967) estimated the average age of about 541000 years for the deep groundwater in El Kharga Oasis.

By using krypton (Kr) gas dubbed as "atom trap trace analysis" (ATTA), the age of the groundwater in the Nubian Sandstone aquifer in the Western Desert was found to be about 0.5 million years (Du *et al.* 2004).

#### **Hydrochemical characteristics of the groundwater**

This work is based on the results of physical and chemical analyses of 32 groundwater samples collected from production wells in Baris area. Collected water samples were analyzed for major and minor dissolved chemical constituents (TDS,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ,  $\text{I}^-$ ,  $\text{Br}^-$ ,  $\text{F}^-$ ,  $\text{PO}_4^{3-}$ , and  $\text{SiO}_2$ ). Other water samples were in-situ acidified for the analysis of trace and soluble heavy and non metals including;  $\text{Al}^{3+}$ ,  $\text{B}^{3+}$ ,  $\text{Cd}^{2+}$ ,  $\text{Co}^{2+}$ ,  $\text{Cr}^{3+}$ ,  $\text{Cu}^{2+}$ , total Fe,  $\text{Mn}^{2+}$ ,  $\text{Mo}^{2+}$ ,  $\text{Pb}^{2+}$ ,  $\text{Sr}^{2+}$ ,  $\text{V}^{2+}$ ,  $\text{Zn}^{2+}$ , and  $\text{Se}^{2+}$ .

Laboratory measurements were carried out by EC meter (Orion model 150A<sup>+</sup>), pH meter (Jenway model 3510), flame photometer (Jenway model PFP7), ion-selectivity meter (Orion model 940), uv/visible spectrophotometer (Thermo-Spectronic model 300). Atomic absorption hydride system (Thermo-Electronics model Solaar MQZ<sub>environmental</sub>) was used for Se determination and Plasma Optical Emission-Mass Spectrometer (Thermo Jarrell Ash model POEMS III) was used for heavy metals determination. All the analyses were conducted according to the methods adopted by ASTM, (2002). The results of the chemical analysis are illustrated in tables (1 and 2).

Analytical data of 38 groundwater samples from El-Kharga are from the literatures, e.g. Shawky *et al.* (2006) and El-Sheikh, (2007).

#### **1. Physical characteristics of the groundwater**

The physical properties may change considerably within limited time after sample collection due to the unstable nature of physical constituents in groundwater. Therefore, immediate analysis in the field is required if dependable results of these parameters are to be obtained. Among the physical parameters that investigated and determined are; temperature, pH, dissolved oxygen (DO) and oxidation reduction (redox) potential.

**TABLE (1). Results of the chemical analysis of groundwater samples in Baris area.**

No.	pH	Temp (°C)	Eh (mV)	EC (µS/cm)	TH (mg/l as CaCO <sub>3</sub> )	PCO <sub>2</sub>	Concentration in mg/l													
							DO	TDS	Ca <sup>++</sup>	Mg <sup>++</sup>	Na <sup>+</sup>	K <sup>+</sup>	CO <sub>3</sub> <sup>==</sup>	HCO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>==</sup>	Cl <sup>-</sup>	NCS			
1	7.2	35.9	-79	573	119.3	5.6 x 10 <sup>-3</sup>	0.7	308.5	23.8	14.5	54	26	0	85.4	38.5	108.9	23.4			
2	7.2	33.1	-61	641	134.2	4.5 x 10 <sup>-3</sup>	1.6	363	27.8	15.7	60	29	0	72.5	80.3	113.8	64.4			
3	7.3	37.1	-80	619	134.2	4.6 x 10 <sup>-3</sup>	1.4	342.9	27.8	15.7	60	25	0	85.4	52.8	118.8	36.3			
4	7.6	34.7	-73	557	124.2	2.7 x 10 <sup>-3</sup>	1.3	311.2	25.8	14.5	52	26	8.4	93.9	33.5	103.9	19.1			
5	7.3	34	-70	606	124.2	4.3 x 10 <sup>-3</sup>	1.1	331.9	25.8	14.5	56	26	0	85.4	60.4	106.4	45.6			
6	7.5	35.8	-84	594	129.5	2.7 x 10 <sup>-3</sup>	1.3	323.5	22	18.1	54	26	0	81.1	58.9	103.9	44.5			
7	7.6	37.5	-75	577	114.5	2.9 x 10 <sup>-3</sup>	1.0	303.3	25.8	12.1	52	26	0	102.4	29.6	106.4	14.8			
8	7.6	34.8	-96	592	124.2	2.2 x 10 <sup>-3</sup>	1.8	332.4	27.8	13.2	56	28	8.4	72.5	58.6	103.9	44.2			
9	7.8	36.3	-64	665	124.2	1.6 x 10 <sup>-3</sup>	1.5	371.4	31.8	10.8	72	22	4.2	89.6	64.4	121.2	47.5			
10	7.8	34.8	-70	698	124.5	1.5 x 10 <sup>-3</sup>	1.5	348.0	27.8	13.3	66	25	4.2	85.4	57.7	111.1	42.3			
11	7.7	33.6	-77	706	169.4	1.8 x 10 <sup>-3</sup>	0.9	437.2	28	24.1	72	29	4.2	85.4	123.2	113.8	107.4			
12	7.2	33.1	-87	660	154.1	5.5 x 10 <sup>-3</sup>	1.1	384.2	33.8	16.9	62	26	4.2	85.4	94.7	103.9	80.2			
13	7.4	31.3	-56	661	149.1	3.7 x 10 <sup>-3</sup>	1.9	382.9	33.8	15.7	62	25	4.2	89.6	93.4	103.9	79.0			
14	7.1	32.4	-60	619	174	4.1 x 10 <sup>-3</sup>	1.7	357.9	39.8	18.1	46	30	0	81.1	62.1	121.2	45.3			
15	7.4	34.6	-67	642	144	3.5 x 10 <sup>-3</sup>	1.9	365.0	35.82	13.2	64	26	0	85.4	48.6	134.6	29.9			
16	7.5	32.6	-63	742	149.1	3.0 x 10 <sup>-3</sup>	1.2	451.1	35.82	14.5	94	22	46.2	46.9	93.9	121.2	77.0			
17	7.5	34.6	-86	658	164	2.8 x 10 <sup>-3</sup>	1.4	377.5	39.8	15.7	58	26	0	85.4	70.6	124.7	53.3			
18	7.4	35.2	-82	659	179	3.4 x 10 <sup>-3</sup>	1.9	388.2	39.8	19.3	52	29	0	81.1	86.3	121.2	69.4			
19	7.1	34.9	-73	672	198.8	4.6 x 10 <sup>-3</sup>	1.5	405.2	41.78	22.9	52	28	4.2	81.1	82.1	133.6	63.5			
20	7.3	34.5	-70	682	203.7	4.3 x 10 <sup>-3</sup>	1.6	409.2	45.76	21.7	50	29	0	85.4	98.7	121.2	81.9			
21	7.5	33.2	-54	716	179.4	2.9 x 10 <sup>-3</sup>	1.9	412.6	38	20.5	62	26	8.4	81.1	113.2	103.9	98.7			
22	7.3	32.8	-70	752	203.8	4.2 x 10 <sup>-3</sup>	1.8	438.5	47.76	20.5	60	30	0	85.4	108.4	129.0	90.5			
23	6.9	34.9	-62	696	169.9	3.8 x 10 <sup>-3</sup>	1.7	404.4	40	17.0	58	29	0	85.4	113.8	103.9	99.3			
24	7.2	33.4	-54	694	184.4	5.8 x 10 <sup>-3</sup>	1.2	385.5	40	20.5	50	30	8.4	85.4	90	103.9	75.5			
25	7.2	33.4	-51	646	198.8	4.1 x 10 <sup>-3</sup>	1.8	393.7	43.7	21.7	44	26	4.2	93.9	103.1	103.9	88.6			
26	7.4	31.7	-64	704	208.7	4.2 x 10 <sup>-3</sup>	1.9	414.4	47.7	21.7	54	28	4.2	102.4	85.9	121.6	69.0			
27	7.6	31.7	-113	1045	144.9	3.7 x 10 <sup>-3</sup>	1.9	597.5	36	13.3	150	25	8.4	140.9	61.6	232.6	29.3			
28	7.1	35	-60	691	199.4	2.3 x 10 <sup>-3</sup>	1.5	398.7	44	21.7	50	28	0	106.7	100.1	101.4	86.0			
29	7.7	32	-51	819	189.8	2.5 x 10 <sup>-3</sup>	1.8	423.9	52	14.5	68	23	8.4	115.2	74.0	126.2	56.5			
30	7.6	31.7	-52	751	189.8	2.5 x 10 <sup>-3</sup>	1.9	424.7	42	20.6	58	28	4.2	93.9	111.1	113.8	95.3			
31	7.2	31.2	-56	1079	269.8	2.2 x 10 <sup>-3</sup>	1.7	625.8	62	27.9	108	23	8.4	115.2	145.9	192.9	119.1			
32	7.6	32.2	-52	744	193.6	2.6 x 10 <sup>-3</sup>	1.4	432.3	49.7	16.9	59	28	0	102.4	108.7	118.8	92.2			

Eh = oxidation-reduction potential, EC = electrical conductivity, TH = total hardness, PCO<sub>2</sub> = partial CO<sub>2</sub>, DO = dissolved oxygen, TDS = total dissolved salts, NCS = non-cyclic sulphate.

*i) Temperature*

The temperature of groundwater is controlled by heat flow from the earth's interior and by chemical reactions in the aquifer system.

In Baris area, groundwater temperatures are ranged between 31.1 and 37.5 °C with a mean value of 33.8 °C. Meanwhile, in El-Kharga the groundwater temperatures are varied from 33.7 to 43.4 °C with a mean value of 36.8 °C. In general, the temperature of groundwater varies greatly with the aquifer depth and geological structures.

*ii) pH*

The hydrogen-ion activity in an aqueous solution is controlled by interrelated chemical reactions that produce or consume hydrogen ion. Therefore, pH of the water sample can be affected by dissolved gases such as; CO<sub>2</sub>, H<sub>2</sub>S and SO<sub>2</sub> as well as oxidation of dissolved ferrous iron. The pH value of the groundwater in Baris area ranges from 6.9 to 7.8 with a mean value of 7.4. On the other hand, lower pH values varied from 5.8 to 7.4 with

a mean value of 7.1 were detected in El Kharga area. On the other hand, the lower value of pH in El-Kharga water samples reflecting the influence of H<sub>2</sub>S gas exists in the groundwater.

iii) *Dissolved Oxygen (DO)*

Low concentrations of dissolved oxygen are common in groundwater. The primary source of dissolved oxygen in groundwater is precipitation that recharges the aquifer (Hem, 1989). Winograd and Robertson (1982) reported groundwater more than 10,000 years old, that had traveled up to 80 km from their point of recharge and still rich in oxygen.

Values for DO in water may be given in milligrams per liter or as a percentage of saturation at the temperature of measurements. DO concentrations in groundwater generally decrease over time as the oxygen in the water reacts with minerals. Hence, the abundance of higher DO concentration in the aquifer system indicates groundwater recharge or the lack of reactive minerals in the aquifer.

**TABLE (2). Results of minor and trace constituents of the groundwater samples in Baris area.**

No.	Concentration in mg/l							
	Fe	Mn	SiO <sub>2</sub>	PO <sub>4</sub> <sup>-3</sup>	B	I <sup>-</sup>	Br <sup>-</sup>	F <sup>-</sup>
1	1.464	0.2014	10.83	0.18	0.0175	0.0003	0.98	0.41
2	1.932	0.2698	10.76	0.16	0.0215	0.0003	0.57	0.37
3	1.703	0.1956	13.71	0.17	0.0208	0.0005	0.61	0.39
4	1.355	0.2434	7.13	0.12	0.0183	0.0004	0.61	0.39
5	1.854	0.3082	10.45	0.26	0.0197	0.0004	0.52	0.37
6	1.462	0.2318	1.38	0.14	0.0152	0.0004	0.61	0.38
7	0.8822	0.3079	1.48	0.34	0.0173	0.0005	0.82	0.41
8	2.946	0.3228	8.81	0.24	0.0184	0.0005	0.62	0.48
9	0.7982	0.2370	11.38	0.22	0.0131	0.0004	0.74	0.54
10	1.147	0.1826	2.74	0.20	0.0166	0.0004	0.62	0.42
11	3.664	0.2460	N.D	0.17	0.0222	0.006	0.52	0.21
12	3.695	0.3245	N.D	0.01	0.0183	0.0004	0.76	0.26
13	1.986	0.2516	N.D	0.07	0.0191	0.0004	0.48	0.37
14	2.256	0.3496	N.D	0.09	0.0264	0.0004	0.61	0.53
15	1.518	0.2599	1.76	0.07	0.0228	0.0005	0.75	0.71
16	2.163	0.1719	2.72	0.05	0.0506	0.0003	0.58	0.35
17	2.387	0.3131	0.15	0.58	0.0263	0.0003	0.53	0.62
18	3.645	0.3112	3.98	0.05	0.0316	0.0003	0.47	0.54
19	2.754	0.3052	23.96	0.08	0.0293	0.0004	0.67	0.42
20	4.125	0.2002	19.43	0.10	0.0404	0.0004	0.65	0.39
21	3.109	0.1132	21.42	0.16	0.0416	0.0006	0.44	0.27
22	4.442	0.2075	19.33	0.39	0.0443	0.0004	0.55	0.29
23	2.948	0.2515	15.24	0.06	0.0321	0.0005	0.73	0.43
24	4.184	0.1534	7.31	0.06	0.0408	0.0005	0.67	0.33
25	3.077	0.2664	17.97	0.04	0.0313	0.0003	0.42	0.33
26	2.407	0.3117	N.D	0.06	0.0311	0.0007	0.63	0.41
27	6.461	0.3091	22.68	0.06	0.0633	0.0032	1.65	0.52
28	3.084	0.1503	8.01	0.12	0.0339	0.0007	0.53	0.45
29	1.349	0.0645	23.20	0.05	0.0586	0.0005	0.57	0.51
30	4.366	0.0940	12.62	0.09	0.0451	0.0004	0.48	0.32
31	0.1023	0.0082	0.84	0.14	0.0600	0.0003	0.86	0.41
32	3.100	0.1226	1.03	0.20	0.0412	0.0004	0.51	0.32

N.D = not detected

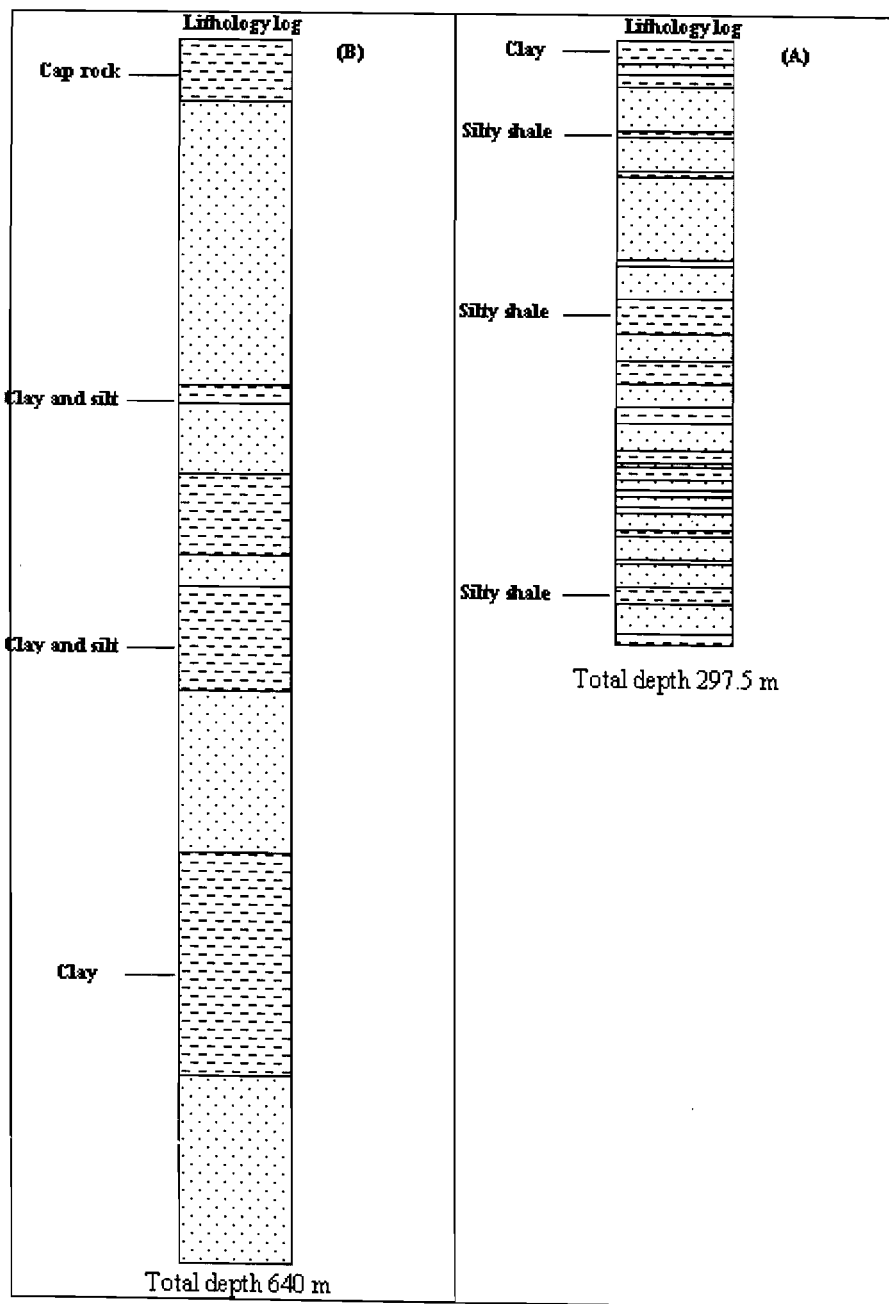


Fig. (2). Representative wells showing: (A) Free water table condition in Baris area, (B) Artesian water condition in El-Kharga area. (after Shata, 1962)

Field measurements of the DO concentration of the groundwater samples in the study area varies from 0.7 to 1.9 mg/l with a mean value of 1.5 mg/l. Meanwhile, at El-Kharga content in the groundwater are decreased to be ranged from nil to 1.2 with a mean value of 0.5 mg/l. The higher contents in the dissolved oxygen reflect the unconfined "free water table" in the study area compared with the confined condition in the north (Table 3).

*iv) Oxidation-Reduction potential*

The oxidation-reduction (redox) potential  $E_h$  is a numerical index of the intensity of oxidizing or reducing conditions within a system expressing in (mV). Positive potentials indicate that the system is relatively oxidizing and negative potentials indicating that it is relatively reducing. Only few elements are important in the natural redox system (e.g., Fe, Mn, S, and C).

Redox potentials of the groundwater samples from the area of study were ranged from -113 to -51 mV with a mean value of -79.6 mV indicating weakly reducing conditions (Beaucaire, 1987). Lower reducing condition was found in the north with the values varied from -111 to -26 mV with a mean value of -63.3 mV.

**TABLE (3). Comparison between the hydrochemical constituents of groundwater in the unconfined (Baris) and confined (El-Kharga) aquifer systems.**

Characteristics	Unconfined			Confined		
	Low	High	Mean	Low	High	Mean
pH	6.9	7.8	7.4	5.8	7.6	7.0
Temperature (°C)	31.2	37.5	33.8	33.7	43.4	36.8
Eh (mV)	-113	-51	-79.6	-111	-26	-63
DO (mg/l)	0.7	1.9	1.52	0	1.2	0.58
TDS (mg/l)	303.3	625.8	395.2	177	512	251.3
Fe (mg/l)	0.1	6.46	2.38	0.17	3.73	1.1
Mn (mg/l)	0.008	0.34	0.22	0.04	0.7	0.17
SiO <sub>2</sub> (mg/l)	0	23.9	9.2	0	34.3	9.7
TH (mg/l)	114	269	165	60	138	91
B (mg/l)	0.013	0.069	0.031	0.01	0.3	0.05
PO <sub>4</sub> (mg/l)	0.01	0.58	0.14	0.008	0.6	0.12
I (mg/l)	0.0003	0.006	0.0006	0.00004	0.0015	0.0005
Br (mg/l)	0.42	1.65	0.66	0.22	8	0.85
F (mg/l)	0.21	0.71	0.41	0.28	1.1	0.56
NCS	14.8	119	64.7	0	59	11.5
% NCS	4.9	24.5	16	0	16	3.7
PCO <sub>2</sub>	1.5 x10 <sup>-3</sup>	5.83 x10 <sup>-3</sup>	3.47 x10 <sup>-3</sup>	2.67 x10 <sup>-3</sup>	9.86 x10 <sup>-3</sup>	5.68 x10 <sup>-3</sup>

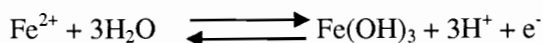
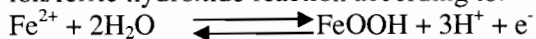
Eh = oxidation-reduction potential, TH = total hardness, DO = dissolved oxygen, TDS = total dissolved salts, NCS = non-cyclic sulphate.

It is well known that the main source for Fe<sup>2+</sup> in groundwater is the dissolution of Fe(II)-bearing minerals like magnetite, ilmenite, pyrite, siderite, and Fe<sup>2+</sup>-bearing silicates, like amphiboles, pyroxenes, olivine, biotite, glauconite and clay minerals such as smectites and the reduction of Fe-oxyhydroxides present in the sediments. So, a higher reduction potential



measured may reflect a higher concentration of iron reduced into the groundwater.

In this case the concentration of  $Fe^{3+}$  in solution is so low that the reaction:  $Fe^{3+} + e^{-} \rightleftharpoons Fe^{2+}$  is very unlikely in groundwater, except for oxidizing acidic environment. At that point, it may be considered that ferrous iron is dominant in solution. *Doyle (1968)* has shown that the redox potentials of natural waters often follow the Nernst equation for the ferrous ion/ferric hydroxide reaction according to:



With,  $E_{h,calc.} = E_0 - 0.18pH - 0.0592 \log a(Fe^{2+})$

Where, a = activity of ferrous ions and  $E_0 = 0.98$  Volt

Figure (3) illustrates the relationship between Eh values measured in the field and Eh values calculated with Nernst equation. The results show a little variation between the two sets of data. There are two reasons for this variation; lack of equilibrium between different redox couples in the same water sample (Lindberg and Runnells, 1984) and/or analytical difficulties in measuring with Pt-electrode (Stumm and Morgan, 1981). The latter include lack of electroactivity at the Pt-surface, as for  $O_2$ , mixing potentials, and poisoning of the electrode. Since in our case, the only redox couple is ferrous/ferric. Therefore, a slight poisoning may be caused as a result of the precipitation of FeOOH on the Pt surface when the electrode is immersed in an anoxic,  $Fe^{2+}$  - rich sample because of  $O_2$  adsorbed on the electrode surface. In the lower Eh, the relatively higher deviation between measured and calculated values could be attributed to the higher  $Fe^{2+}$  concentration.

In order to study the different factors that may affect the value of Eh, a statistical analysis was made for the physical and chemical constituents of the groundwater from the area of study. A regression equation between the dependent variable (Eh) and the independent variables; TDS, pH, Fe, temperature, DO and  $SiO_2$  was made as follows:

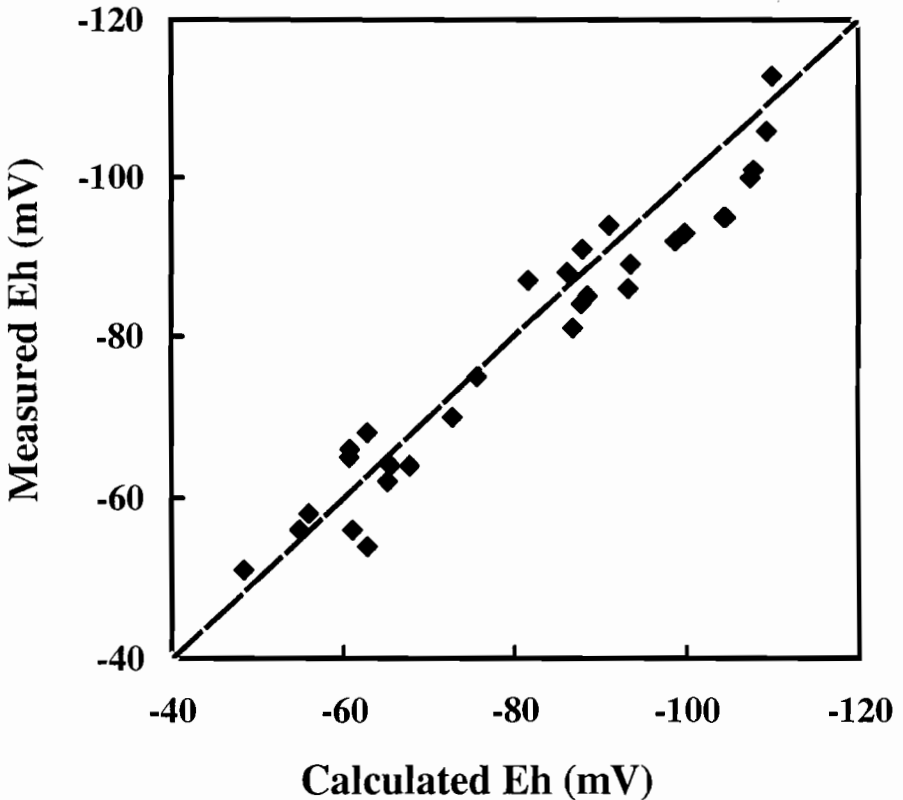
$$Y = -111.56 + 0.019X_1 - 3.34X_2 - 6.21X_3 + 0.916X_4 + 27.98X_5 + 0.16X_6$$

{1.304}
{0.487}
{0.37}
{2.87\*\*}
{0.66}
{2.89\*\*}
{0.68}

Where; Y = Eh,  $X_1$  = TDS,  $X_2$  = pH,  $X_3$  = Fe,  $X_4$  = Temperature,  $X_5$  = DO,  $X_6$  =  $SiO_2$ , Correlation coefficient ( $R^2$ ) = 0.73, Significant (F) = 11.42, \* Significant (P < 0.05), \*\* Highly significant (P < 0.01)

The equation shows that both Fe and DO have significant effect on the dependent variable (Eh), as both variables have high ratios; they are significant at the level of 1%. The  $R^2$  value of 0.73 points to the fact that the mentioned variables explain about 73% of the variance of Eh, meanwhile, the significant (F) value of the model that reached 11.42 points to the overall significance of the model. The coefficient of (Fe) factor that reached -6.213

points to a generally decreasing attitude which means that every unit increase in Fe leads to a decrease in Eh by 6.213 (i.e. the increase in Fe concentration, decreases the oxidation-reduction potential, at these conditions, and the groundwater is in a reduction process). In contrary, a reverse behavior is found for the effect of DO on Eh, as it follows a generally increasing attitude where any increase in DO value leads to an increase in Eh value by 27.98 (i.e., in lower DO value, the groundwater is in a reduction condition and by increasing DO values, the Eh values increase going to oxidation conditions).



**Fig. (3). Correlation between measured and calculated Eh (mV) in Baris area.**

The above mentioned results were confirmed by the correlation coefficients between Eh, TDS, pH, Fe, temperature, DO and  $\text{SiO}_2$  (Table 4).

**TABLE (4). Correlation coefficients between different constituents processed from groundwater**

	<i>Eh</i>	<i>TDS</i>	<i>pH</i>	<i>Fe</i>	<i>Temp</i>	<i>DO</i>	<i>SiO<sub>2</sub></i>
<i>Eh</i>	1						
<i>TDS</i>	-0.0591	1					
<i>pH</i>	0.1867	-0.0252	1				
<i>Fe</i>	-0.7592	0.3408	-0.3508	1			
<i>Temp</i>	0.0607	-0.6489	0.022	-0.1785	1		
<i>DO</i>	0.7709	0.1892	0.1709	-0.63	-0.1504	1	
<i>SiO<sub>2</sub></i>	-0.179	0.0909	-0.3861	0.347	0.005	-0.2218	1

*Eh* = oxidation-reduction potential, *TDS* = total dissolved, *DO* = dissolved oxygen salts

## 2. Chemical characteristics of the groundwater

The groundwater chemical characteristics and their distribution in the studied area are discussed under the following topics:

### *i- Total salinity*

In Baris area, the total salinity of the groundwater samples varies from about 303 mg/l (well no. 7) to 625 mg/l (well no. 31) with a mean value of 395 mg/l, reflecting a fresh water type (Chebotarev, 1955). Figure (4) shows TDS contour map of the groundwater in the studied area from which it can be seen that the high value of TDS at the southern parts is 620 ppm and decrease rapidly to the northern parts of the study area.

Fresher groundwater type was found at the north (El-Kharga) than at the south (Baris) as water salinity is ranged from 177 to 512 mg/l, with a mean value of 293 mg/l.

Statistical analysis was made to figure out which of the major cations and anions are affecting TDS values in both areas. Form which it can be seen that in the unconfined zone  $\text{Na}^+$ ,  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  are the most affecting ions, and this convert to be  $\text{Na}^+$  and  $\text{HCO}_3^-$  in case of the confined zone.

Concerning the chloride-sulphate relationships in the waters, the calculated values of  $\text{Cl}/\text{SO}_4$  ratio are not very meaningful. However, if it is assumed that all sulphate in excess of that expected on the basis of  $\text{Cl}/\text{SO}_4$  ratio of 7.2 for sea water is of "non-cyclic sulphate", a very coherent picture emerges.

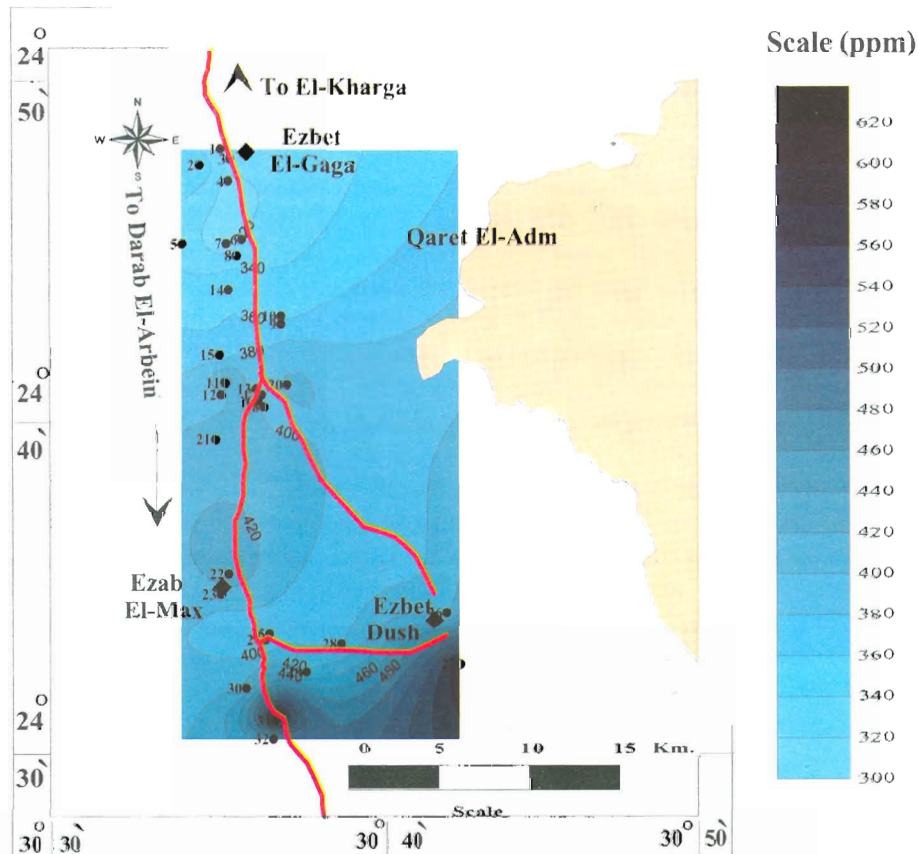
It can be observed form the calculated Noncyclic Sulphate (NCS) =  $\text{SO}_4^{2-}$  (mg/l) -  $\text{Cl}^-$  (mg/l)/7.2, that it ranged from 14.8 to 119 mg/l with a mean value of 64.7 mg/l and from 0 mg/l to 59 mg/l with a mean value of 11.5 mg/l in case of the unconfined and confined zones, respectively. The results also show that 17% of the samples in the confined zone have 0 NCS, i.e., having only cyclic sulphate.

NCS represents from 4.9 to 24.5% of the TDS values with a mean value of 16% in the unconfined aquifer. Meanwhile, it represents from 0 to

16% with a mean value of 3.7% in case of the confined aquifer (Fig. 5). Generally, the values of the calculated NCS increase as the salinity of the groundwater increases. Therefore, the data of NCS reveals that; in the unconfined zone, groundwater is mostly affected by terrestrial source (such as gypsum and anhydrite).

*ii- Total hardness*

In Baris area, the value of the total hardness (T.H) in the groundwater is ranged from 114 to 269 mg/l with a mean value of 165 mg/l as  $\text{CaCO}_3$ , 65% of these samples are moderately to hard water while 35% are classified to be very hard according to Durfor and Becker (1964). 56% of the samples show permanent hardness rather than temporary hardness.



**Fig. (4). Iso-Salinity contour map of the groundwater in Baris oasis.**

The results also show that the total and permanent hardness increase with increasing water salinity, meanwhile, temporary hardness increase with decrease of water salinity. This is may be attributed to the effect of leaching and dissolution of salts leading to an increase in hardness with particular

importance to the effect of NaCl concentration (effect of ionic strength) on increasing the solubility of  $Ca^{2+}$  and  $Mg^{2+}$  in groundwater, Richards, (1954), Freeze and Cherry (1979) and Hem, (1989). This does not exclude longer residence time of the groundwater and cation exchange processes.

The obtained ratio for the percentage of T.H. to the value of TDS, is 36.7% representing the permanent and temporary salts in the groundwater. This result reveals that 63.3% of the increase in the water salinity is due to the increase in soluble salts ( $NaCl$  and  $Na_2SO_4$ ) while 36.7% of the increase is due to the permanent and temporary hardness ( $MgCl_2$ ,  $CaCl_2$ ,  $MgSO_4$ ,  $CaSO_4$ ,  $Mg(HCO_3)_2$  and  $Ca(HCO_3)_2$ ). This is confirmed by the salt assemblages (I, II, III and IV)

While, all samples in the south (Baris) are classified to be from moderately to very hard samples; with 56% of the samples showing permanent rather than temporary hardness, most of the groundwater samples in the north (El-Kharga) are found to be moderately hard (T.H. ranged from 60 to 138 mg/l, with a mean value of 91 mg/l) with the disappearance of permanent hardness.

**Partial pressure of carbon dioxide ( $PCO_2$ ) in groundwater**

The computed  $PCO_2$  values in the groundwater are ranged between  $1.5 \times 10^{-3}$  to  $5.83 \times 10^{-3}$  with a mean value of  $3.47 \times 10^{-3}$  in Baris and between  $2.67 \times 10^{-3}$  to  $9.86 \times 10^{-3}$  with mean value of  $5.68 \times 10^{-3}$  in El-Kharga. Although these values suggest closed system conditions in both zones ( $PCO_2$  is more than that in the earth's atmosphere  $0.32 \times 10^{-3}$  bars), the higher values in El-Kharga reflecting more disequilibrium condition with the atmospheric  $CO_2$  in this zone (Fig. 6).

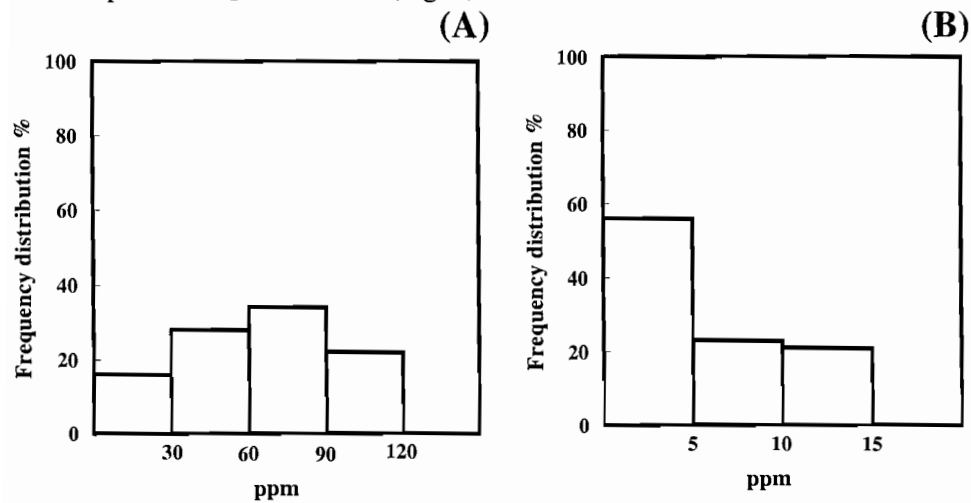


Fig. (5). Frequency distribution % of NCS in: Unconfined aquifer (Baris), Confined aquifer (El-Kharga)

iii- Ion dominance

Concerning the ion dominance in the groundwater for Baris area, four sequences are recognized:

**Group I:**  $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^- > \text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$ , in 53% of samples.

**Group II:**  $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} / \text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$ , in 47% of samples.

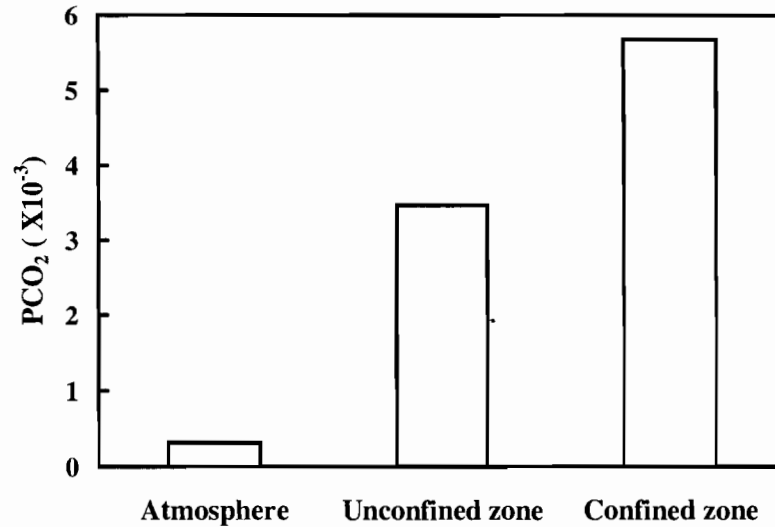


Fig. (6). The mean values of PCO<sub>2</sub> in the unconfined and confined aquifers with regard to earth's atmosphere.

Group II indicates the intermediate stage of hydrochemical evolution of the groundwater. Thus, 47% of the groundwater samples exhibit a less advanced stage of mineralization where the metasomatic sequence is;  $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-}$ . This is may be due to leaching and dissolution of marine and continental deposits.

Group I reflects an advanced stage of hydrochemical evolution, where the metasomatic sequence is;  $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$  (53%). Water types in all groups are Cl-Na indicating that all groundwaters are of meteoric origin and affected by continental events.

Meanwhile, the ion dominance in the groundwater for El-Kharga area shows two groups:

**Group III :**  $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$  and  $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+}$ , in 82% of samples.

**Group IV :**  $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$  and  $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$ , in 18% of samples.

While the ion dominance reflects an intermediate and advanced stages of hydrochemical evolution with all the samples has Cl-Na type in Baris, this converted to be an indication of the initial stage of evolution in El-Kharga with HCO<sub>3</sub>-Na type in 100% the samples.

*iv- Hypothetical salt assemblages*

According to the chemical aspects mentioned in the ion dominance, the following groups of salts assemblages are formed in the groundwater of Baris area as follows:

**Assemblage I:** NaCl, Na<sub>2</sub>SO<sub>4</sub>, MgSO<sub>4</sub>, Mg(HCO<sub>3</sub>)<sub>2</sub>, Ca(HCO<sub>3</sub>)<sub>2</sub> (22 % of samples).

**Assemblage II:** NaCl, Na<sub>2</sub>SO<sub>4</sub>, MgSO<sub>4</sub>, CaSO<sub>4</sub>, Ca(HCO<sub>3</sub>)<sub>2</sub> (22% of samples).

**Assemblage III:** NaCl, MgCl<sub>2</sub>, MgSO<sub>4</sub>, Mg(HCO<sub>3</sub>)<sub>2</sub>, Ca(HCO<sub>3</sub>)<sub>2</sub> (12% of samples).

**Assemblage IV:** NaCl, MgCl<sub>2</sub>, MgSO<sub>4</sub>, CaSO<sub>4</sub>, Ca(HCO<sub>3</sub>)<sub>2</sub> (44% of samples).

Assemblages I and II which represents 44% of groundwater samples, reflecting the effect of leaching and dissolution of terrestrial salts (continental facies) (El-Sayed *et al.* 2001). The presence of two bicarbonate salts in assemblages I and III reflects the effect of old rain water on the groundwater.

Some groundwater samples (12%) are characterized by assemblage salt III (fresh water type). This assemblage represents the meteoric origin of water which confirmed by the presence of Mg(HCO<sub>3</sub>)<sub>2</sub>.

Assemblages I and II are dominated by rNa/rCl ratio more than unity and the presence of Na<sub>2</sub>SO<sub>4</sub> salt indicating meteoric water. While the assemblage III is considered as transitions stage between assemblages I and IV.

44% of the groundwater samples are characterized by assemblage IV regardless of total salinity (Freeze and Cherry, 1979). This assemblage represents an advanced stage of chemical development reflecting the effect of marine salt pollution (marine facies groundwater types) with possible contribution of cation exchange phenomenon resulting from the presence of the clay intercalated with the Nubian sandstone aquifer.

The hypothetical salts show two assemblages in El-Kharga area:

**Assemblage V:** NaCl, Na<sub>2</sub>SO<sub>4</sub>, NaHCO<sub>3</sub>, Mg(HCO<sub>3</sub>)<sub>2</sub>, Ca(HCO<sub>3</sub>)<sub>2</sub> (86 % of samples).

**Assemblage VI:** NaCl, Na<sub>2</sub>SO<sub>4</sub>, MgSO<sub>4</sub>, Mg(HCO<sub>3</sub>)<sub>2</sub>, Ca(HCO<sub>3</sub>)<sub>2</sub> (14% of samples).

Therefore, groundwater in El-Kharga is characterized by the presence of three bicarbonate salts in 86% of the samples and two bicarbonate salts in 14% of the samples. Therefore, an early stage of evolution was found in the El-Kharga, meanwhile, the four hypothetical salt

assemblages in Baris reflects to a great extent the effect of marine deposits pollution.

*v- Ion ratios*

Ion ratios are important for possible determination of the origin of groundwater and various processes contributing in water quality development. The significance of these ratios in the concerned areas can be evaluated as follows (Table 5):

*Sodium-Chloride ratio ( $rNa^+/rCl^-$ )*

The values of ( $rNa^+/rCl^-$ ) for most groundwater samples in Baris (72% of the total samples) and in 38% of samples in El-Kharga are less than values of seawater (0.87). The decrease in the concentration of  $Na^+$  ions may be attributed to the adsorption of sodium ions on the fine argillaceous sediments. Meanwhile, 28% and 62% of the groundwater samples in Baris and El-Kharga areas, respectively has the values of ( $rNa^+/rCl^-$ ) more than that of seawater, reflecting meteoric and deep meteoric water recharge with a great extent in confined aquifer (El-Kharga) rather than unconfined (Baris).

**TABLE (5). Comparison between ion ratios of groundwater in the unconfined (Baris) and confined (El-Kharga) aquifers.**

Ion ratios	Unconfined			Confined		
	Low	High	Mean	Low	High	Mean
$(rNa^+/rCl^-)$	0.58	1.19	0.8	0.46	2.49	1.2
$(rSO_4^{2-}/rCl^-)$	0.19	0.8	0.5	0.02	0.88	0.28
$(rCa^{2+}/rMg^{2+})$	0.7	2.1	1.3	0.41	1.98	0.85
$(rCl^-/r(HCO_3^-+CO_3^{2-}))$	1.6	2.8	2.34	0.38	1.98	0.77
$Na^+/K^+$	1.5	4.7	2.41	0.5	5.7	1.79

*Sulphate-Chloride ratio ( $rSO_4^{2-}/rCl^-$ )*

The mean values of ( $rSO_4^{2-}/rCl^-$ ) ratio increase as the salinity of groundwater samples increases in both areas. This means that the solubility of sulphate mineral components gradually increased in the hydrochemical composition by moving towards the recharge area. The values of ( $rSO_4^{2-}/rCl^-$ ) are more related to the value of rainwater (0.5), which reflected the meteoric rainwater origin of groundwater.

*Calcium-Magnesium ratio ( $rCa^{2+}/rMg^{2+}$ )*

In most of investigated groundwater samples in Baris area,  $Ca^{2+}$  exceeds  $Mg^{2+}$  (regardless of water salinity). On the other hand,  $Mg^{2+}$  exceeds  $Ca^{2+}$  in most groundwater samples in El-Kharga. So, the data reveals that; groundwater in the unconfined aquifer is mostly affected by terrestrial source (such as gypsum and anhydrite) confirming the results obtained from NCS.

Meanwhile, the values of ( $rCa^{2+}/rMg^{2+}$ ) are more related to the value of rainwater in both areas (2.16), which also reflects the meteoric rainwater origin of groundwater.



*Chloride-Bicarbonate and Carbonate ratio ( $rCl/r(HCO_3^-+CO_3^{2-})$ )*

Simpson, (1946) and Todd, (1959) categorized groundwater according to this ratio as follows: normal good groundwater (less than 1), slightly contaminated water (more than 1 and less than 2), moderately contaminated water (2-6), seriously contaminated water (6-15) and highly contaminated water (more than 15). The values of  $rCl/r(HCO_3^-+CO_3^{2-})$  ratio in the groundwater samples at Baris are ranged from 1.6-2.8, which is less than that in seawater (220) and more than rainwater (0.68). These values reflect slightly to moderately contaminated water, and that the groundwater in this area have meteoric water origin probably affected, to less extent, by traces of marine deposits.

Ion ratios also show a better groundwater quality in the north (El-Kharga) as the values of  $rCl/r(HCO_3^-+CO_3^{2-})$  in 82% of the samples are less than 1 and between 1-2 in 18% of the samples.

*Sodium-Potassium ratio ( $Na^+/K^+$ )*

The ratio of Na/K (in mg/l) is very important, since it points out the extent to which leaching of shally deposits rich in adsorbed Na takes place. K ion concentration in the groundwater of both areas derived from the alteration of the acidic granitic rocks highly enriched with K-feldspars. The values of Na/K are varied from 1.5 to 4.69 with a mean value of 2.41, and 0.5 to 5.7 with a mean value of 1.79 in the unconfined (Baris) and confined (El-Kharga) aquifers, respectively. The constant values of K ions in Baris and El-Kharga areas (mean values of; 26.6 and 26.8, respectively) point out to that the increase in Na/K is due to the increase in Na ion concentration. Therefore, the increase in Na/K ratio in the unconfined aquifer may be attributed to leaching and dissolution of deposits rich in Na ions.

**Chemical classification**

For the classification of the chemical data, samples are plotted on Piper's diagram (Fig. 7). In general, fresh groundwater samples will land near the area labeled as "fresh" while pure seawater will plot near the "sea" label. Water that results from conservative mixing (mixing without ion exchange reactions) between the fresh water and seawater would plot along the line labeled "mixing". Also, leaching may occur between fresh groundwater and aquifer with marine conditions.

Thus, ion exchange reactions will often occur between the groundwater and the aquifer materials, which alter the chemical composition of the water. This change in chemical composition results in a deviation from the conservative mixing line on the Piper's diagram, moving the point upward into the upper portion of the diamond during leaching with the aquifer material, and downward toward the lower portion of the diamond during freshening.

So, Piper's diagram suggested that leaching and dissolution of fresh water with marine deposits mostly affect the groundwater samples in Baris oasis. Meanwhile, fresh water type is found in case of El-Kharga oasis.

These results suggested that the energy of the groundwater plays an important role in the differentiation between chemistry of the unconfined and confined waters. As in case of unconfined aquifer, groundwater is a "free water table" i.e., in dynamic state, having high energy to move up and down, therefore, can interact easily with aquifer matrix. But in case of confined aquifer, groundwater is in static condition having low energy to move and therefore, low possibility to interact with aquifer matrix.

#### **Minor and trace constituents in the groundwater**

For a better judgment on the water quality, a complete analyses for minor and trace constituents of the groundwater samples in Baris area were made. These include halogens (Br<sup>-</sup>, I<sup>-</sup> and F<sup>-</sup>), phosphate, silicate, boron and all the available heavy metals (Al<sup>3+</sup>, Cd<sup>2+</sup>, Co<sup>2+</sup>, Cr<sup>3+</sup>, Cu<sup>2+</sup>, Mo<sup>2+</sup>, Pb<sup>2+</sup>, Sr<sup>2+</sup>, Mn<sup>2+</sup>, total Fe, V<sup>2+</sup>, Zn<sup>2+</sup>, and Se<sup>2+</sup>). The results of these analyses are summarized in table (2), from which the following can be conducted:

The concentrations of Br<sup>-</sup> and I<sup>-</sup> in the samples are less than that of seawater (Br<sup>-</sup> = 172 and I<sup>-</sup> = 0.48 mg/l). The very low concentrations of these elements (average; Br<sup>-</sup> = 0.66 and I<sup>-</sup> = 0.00069 mg/l) indicating meteoric origin of the groundwater samples.

Fluoride on the other hand has a chemical behavior different to that of the other halogens, and some of these differences are evident in its behavior in natural water (Hem, 1989). It is almost all tied up in rock minerals, and only a small percentage of the total is contained in seawater. Therefore, the existence of fluoride ions may be due to leaching and dissolution with rock riches with fluoride minerals. The concentration of fluoride is varied from 0.21 to 0.71 mg/l with an average value of 0.41 mg/l.

Phosphate concentrations are ranged from 0.01 to 0.58 mg/l with an average value of 0.14 mg/l indicating very low contents of such constituents in the groundwater.

A very low concentration of boron content ranged from 0.013 to 0.069 mg/l (with an average value of 0.031 mg/l) is found in the groundwater samples.

On the other hand, the concentration of the above constituents did not show a significance change in the north part (El-Kharga).

The concentrations of Al<sup>3+</sup>, Cd<sup>2+</sup>, Co<sup>2+</sup>, Cr<sup>3+</sup>, Cu<sup>2+</sup>, Mo<sup>2+</sup>, Pb<sup>2+</sup>, Sr<sup>2+</sup>, V<sup>2+</sup>, Zn<sup>2+</sup>, and Se<sup>2+</sup> in both areas are very low; generally bellow the acceptable limits for pollution according to WHO guideline.

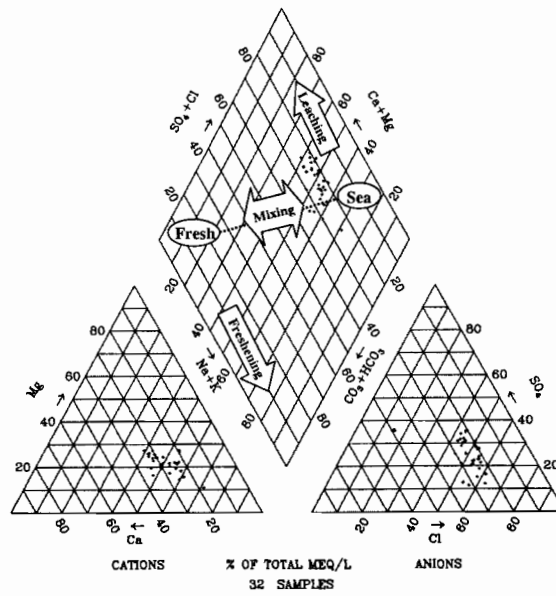
The concentration of silicate in the groundwater samples is varied from nil up to 23.9 mg/l with a mean value of 9.2 mg/l in Baris. Meanwhile, a slightly higher concentration of silicate was found in El-Kharga (SiO<sub>2</sub>

ranges from nil to 34.3 mg/l with mean value 9.7 mg/l). The mineralogical composition of the materials in contact with the groundwater is the most important factor controlling the amount of silicate in water. Therefore, the higher concentration of silicate found might be attributed to that the groundwater is in equilibrium with clay minerals, some amorphous silica and siliceous rock-forming minerals. Also, the higher silicate in El-Kharga may be due to the higher temperature of the confined aquifer rather than the unconfined one.

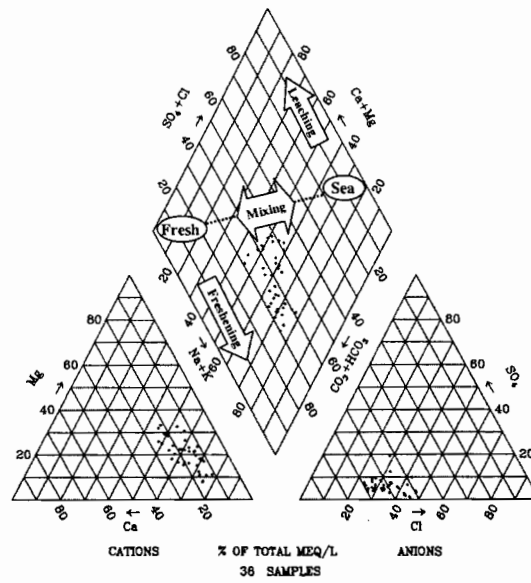
Groundwater in Baris has slightly higher concentration of  $Mn^{2+}$  and a higher concentration of total Fe. Manganese contents ranged from 0.008 to 0.35 mg/l, while that of iron is from 0.1 to 6.5 mg/l. The higher concentration of iron may be attributed to the interaction between groundwater and minerals of aquifer matrices, which leads to the release of soluble iron ion. Iron presents in igneous rocks, sulfide minerals (pyrite) and oxides minerals (magnetite). In sandstone iron oxide, carbonate and hydroxide are often present in the cementing material in acceptable percentages. Iron is present in the form of oxide carbonate and sulfide in shales and as a minor impurity in most carbonate rocks. In addition to solution from such natural sources iron may be added to groundwater from contact and/or corrosion with well casing, pump parts, piping and other iron objects that may be in contact with the water.

The concentration of manganese and iron is generally low in El-Kharga (mean; 0.17 and 1.1 mg/l, respectively) compared with Baris. This is confirmed by the higher Eh values found in the north (El-Kharga) rather than the south (Baris). Meanwhile, concentrations of 8.1 and 32.1 mg/l for manganese and iron, respectively, are detected in Genah area (located in the border between the two areas). These higher concentrations are followed by a higher sulphate content (320 mg/l) and lower pH value (5.8), revealing a source of pyrite located in El-Kharga. Thus, the reduction of this pyrite in the aquifer will be followed by higher iron concentration, also, when pyrite is oxidized, as the groundwater reaches the atmosphere, higher sulphate concentration and lower pH will be found.

(a)



(b)



**Fig. (7). Piper's diagram for the plotted chemical data of: (a)Unconfined aquifer (Baris), (b)Confined aquifer (El-Kharga, After El-Sheikh, 2007).**

## CONCLUSION

In the present study, the physical and chemical characteristics of the groundwater are used to differentiate between the groundwater under unconfined aquifer in Baris oasis and the groundwater under confined system in El-kharga oasis in the Western Desert of Egypt. Groundwater in the unconfined aquifer is characterized by:

1. Relatively low temperatures (mean value; 33.8°C), low Eh (mean value; -79.6 mV), low  $\text{PCO}_2$  (mean value;  $3.47 \times 10^{-3}$ ) and low silicates (mean value; 9.2 mg/l).
2. High pH (mean value; 7.4), high DO (mean value; 1.52 mg/l), high salinity (mean value; 395.2 mg/l), high NCS (mean value; 64.7 mg/l), high iron (mean value; 2.38 mg/l) and high manganese (mean value; 0.22 mg/l).
3. Classified according to TH to be from moderately to very hard samples; with 56% of the samples showing permanent rather than temporary hardness.
4. Ion dominance, hypothetical salt assemblage and ion ratios show intermediate and advanced stages of hydrochemical evolution of the groundwater with Cl-Na water type suggesting the effect of leaching and dissolution of fresh water with marine deposits mostly affecting the groundwater in this aquifer.
5. According to Piper's diagram groundwater is classified as secondary salinity.

Meanwhile, the confined aquifer is characterized by:

1. Relatively, high temperatures (mean value; 36.8°C), high Eh (mean value; -63 mV), high  $\text{PCO}_2$  (mean value;  $5.68 \times 10^{-3}$ ) and high silicates (mean value; 9.7 mg/l)
2. Low pH (mean value; 7.0), low DO (mean value; 0.58 mg/l), low salinity (mean value; 251.3 mg/l), low NCS (mean value; 11.5 mg/l), low iron (mean value; 1.1 mg/l) and low manganese (mean value; 0.17 mg/l).
3. Classified according to TH to be moderately hard with the disappearance of permanent hardness.
4. Ion dominance, hypothetical salt assemblage and ion ratios show initial stage of hydrochemical evolution of the groundwater with  $\text{HCO}_3$ -Na water type suggesting fresh water in this aquifer.
5. According to Piper's diagram groundwater is classified as primary alkalinity.

Also, better groundwater quality was found in El-Kharga rather than Baris, as the groundwater in both areas has meteoric origin, but it is mostly highly affected by leaching and dissolution with marine and continental deposits in Baris.

These results may be attributed to energy of the groundwater which plays an important role in the chemistry difference between the unconfined and confined waters. In the unconfined aquifer, groundwater has a "free water table" i.e. in a dynamic state, having high energy to move. Therefore, groundwater can readily interact with dissolvable salts. This leads to specific characteristics of the unconfined aquifer.

But in case of confined aquifer, groundwater is almost in static condition having low energy to move and therefore, low possibility to interact with aquifer matrix. Therefore, groundwater has better quality.

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## الخواص الطبيعية والكيميائية للمياه الجوفية في منطقة جنوب باريس - الخارجة وعلاقتها بنظم الخزانات الجوفية المختلفة، الصحراء الغربية- مصر

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تعتمد منطقة الدراسة كمنطقة صحراوية اعتمادا كبيرا على المياه الجوفية كمصدر وحيد للتنمية حيث لا توجد مياه سطحية أو مياه أمطار كمصدر للمياه. تتميز هذه المنطقة بحالتين مختلفتين للمياه الجوفية وهما الحالة الحرة ممثلة في واحة باريس والحالة المغلقة ممثلة في واحة الخارجة. محتوي الطاقة الكلي في كل حالة يعتمد على ثلاث عوامل وهي الضغط وسرعة المياه والأرتفاع الرأسى مما يؤثر بشدة على خواص المياه في كل حالة. تحاول هذه الدراسة ايجاد علاقة بين وجود المياه الجوفية و جودتها عن طريق التفريق بين الخواص الطبيعية والكيميائية للمياه الجوفية في الجزء الأوسط من الصحراء الغربية حيث تم تجميع ٣٢ عينة مياه جوفية من واحة باريس واستخدمت لتقييم جودة مياه الخزان الجوفي وأظهرت نتائج التحاليل ما يلي:

١. وجود نسبة منخفضة من الأكسجين المذاب بينما أظهرت قيم جهد الأكسدة والأختزال أن المياه الجوفية في حالة أختزال.
  ٢. التركيز المنخفض من الاكسجين المذاب والتركيز العالي من الحديد يؤيدان إلي زيادة حالة الاختزال.
  ٣. ملوحة المياه الجوفية تزداد في الاتجاه من الشمال الشرقي (منطقة الخارجة) إلي الجنوب الغربي (منطقة باريس) و تنتمي إلي نوعية المياه العذبة والمياه طفيفة العذوبة.
  ٤. المياه الجوفية في منطقة الدراسة ذات أصل مختلط ربما تكون قارية خالصة متأثرة بترسيبات بحرية.
  ٥. تركيزات العناصر الصغرى والثقيلة في الحدود المسموح بها للاستخدامات المختلفة باستثناء وجود الحديد والمنجنيز بتركيزات كبيرة.
- وبقارنة هذه النتائج مع واحة الخارجة نجد أن منطقة الدراسة تتميز بارتفاع قيمة الأس الهيدروجيني والاكسجين المذاب والملوحة وتركيز كلا من الحديد والمنجنيز مع انخفاض قيمة كل من جهد الأكسدة والأختزال ودرجة الحرارة.