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Hydrogeochemical evaluation of the area between El Daba'a and Ras El hekma, North western coast, Egypt

Mohammed Ahmed Gomaa, Gilan Abdelwahab Omar

Desert Research Center, Matariya, Cairo, (EGYPT)

E-mail : gomaa_57@hotmail.com

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ABSTRACT

The objective of this paper is to evaluate the present hydrogeochemistry of the area between El Daba'a and Ras El Hekma. Two main water-bearing formations are recognized, the first is the Pleistocene at both El Daba'a and Ras El Hekma areas, while the second is the Miocene aquifer at El Daba'a only. The recharging source is the rainfall. The groundwater flow direction is mainly northward. Fifty groundwater samples were chosen to evaluate aquifers' quality. The investigated groundwater varies from fresh to saline, moderately hard to very hard. The groundwater salinity and the concentration of major constituents increase in the same direction of the groundwater flow, particularly in the Miocene groundwater. The main water type is Cl-Na, reflecting the mature phase of groundwater metasomatism. The study of ion ratios as well as the hypothetical salts reflects the impacts of marine sediments rich in Ca and Mg on groundwater quality. The investigated water is super saturated with carbonate minerals, which cause a scale formation. Some recommendations are given.

INTRODUCTION

Now-a-days, great attention is paid by different authorities for the establishment of the new settelments and land reclamation projects, to overcome the over population crisis, which represent the greater challenge to Egypt's future. In this respect, priorities are given to the northwestern coastal zone of Egypt, which is considered a promising strip due to its nice weather, mild topography, easy accessibility as well as the availability of the favorable precipitation and soil. The investigated area lies between El Daba'a and Ras El Hekma (longitudes $27^0 40'$ and $28^0 40'$ E and latitudes $30^0 50'$ & $31^0 30'$ N), (Figure 1). It is geographically bounded by Mediterranean Sea due north, the elevated plateau due south, El Alamain area to the east and Mersa Matruh to the west. The study area is characterized by mild climatic condition. Rainfall is considered as the main source of recharge to groundwater aquifer and affects greatly the amounts of water stored in such aquifers. The mediterranean coastal zone of Egypt receives noticeable amounts of rainfall especially in winter, and the rainfall in the coastal zone is usually restricted to the coastal, but may extend few kilometers inland. The maximum annual rainfall recorded 274.6 mm during 1989 and 1990. The annual mean of rainfall is about 139.2 mm[14].

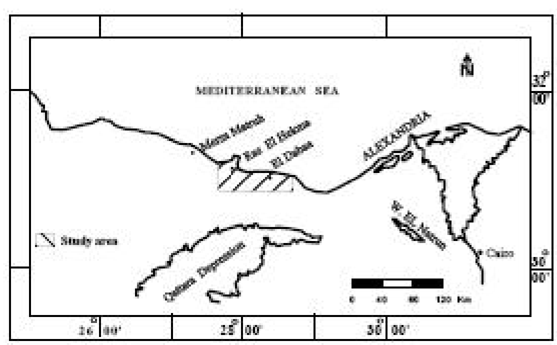

Figure 1 : Key map

Hdrogeomorphology

The area is dominated by mild topography. It is divided into two main geomorphic units; the coastal plain and the elevated plateau (Figure 2).

The coastal plain occupies the northern narrow strip adjacent to the present mediterranean shore line. It slopes gradually due north and exhibits elevation ranging from the mean sea level up to about +60 m. It displays different morphologic features due to the influence of local physiographic and lithologic conditions. The land forms represented within this plain are the foreshore dunes, which constitute the out standing land feature stretched at several localities (e.g. El Daba'a, Fuka and Baqqush). The foreshore dunes act as a water-bearing at El Daba'a and Baqqush localities. The lithic nature of the binding material accelerates the infiltration of rainwater, forming a fresh groundwater lenses above the main water TABLE.

The coastal plain is dominated by several elongated ridges, which form gentle sweeping curves running sub-parallel to the present coast. Such ridges are partially covered by foreshore dunes and mainly composed of oolitic loose limestone possessing different degrees of hardness as well as indurated surfaces. According to their hydrologic response, the ridges are distinguished into the northern near-shore ridges and the southern inland ridges. The former ridges are built up from friable cemented limestone, interbeded by loose carbonate sand lenses. The latter ridges are mainly composed of moderately hard to hard oolitic limestone. The outer portion of these ridges is developed into very hard siliceous crust, which minimizes the vertical percolation of rain water into the ridges. Accordingly, these ridges act as water divides, where the surface water seeps towards the low hollows and depressions. The coastal depressions are located between the elevated ridges and constitute the elongated shallow topographic depressions. The surface of these depressions is plate to gently undulated and slopes gently northward. Such depressions are occupied by the alluvial deposits intermixed with variable amount of carbonate and quartz sands. The depressions are considered as collectors for surface water runoff.

The elevated plateau constitutes a prominent geomorphic unit bounding the coastal plain at its southern

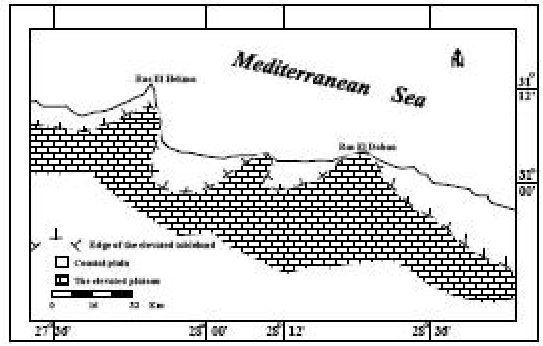

Figure 2 : Geomorphological map (Modified after Said, 1962)

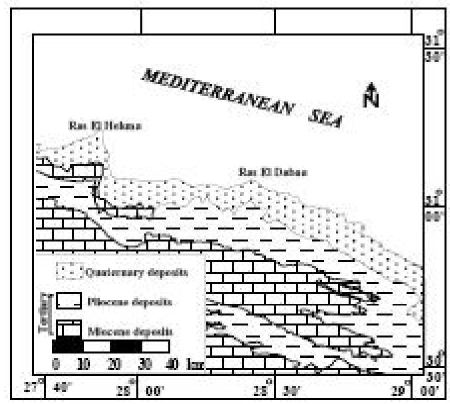

Figure 3: Geological map (simplified after CONOCO, 1986)

side. It rises to about +100 m above the mean sea level and regionally slopes northward. Such plateau is built up of fissured limestones. Its top portion is highly weathered and developed into a very hard pink crust. The elevated plateau represents the watershed area in the western coastal zone (Figure 2).

Geology

In the western mediterranean coastal zone, the exposed rocks are entirely of sedimentary origin ranging in age from Tertiary to Quaternary (Figure 3).

Tertiary deposits

Tertiary rocks are represented by Miocene and Pliocene sediments (Figure 3). Miocene sediments exhibit great facies changes with a large number of conformities, reflecting the nature of the tectonically formed basins in which they were formed. In the investigated area, Miocene deposits are discriminated into two horizons. The lower one is Mamura Formation (lower Miocene), which can be traced along the northern margin of El Qattara Depression with 900 m thick[9]. The upper horizon is the Marmarica Formation (Middle Miocene) with a platform features, and exhibits lateral and vertical facies changes. It is composed of shallow marine limestone (distinguished into upper white fossiliferous limestone member, middle white chalk member and a lower member of alternating cross-bedded carbonates and fossil shale with marls). It is worthmentioning that, the Miocene sediments along the north littoral part of Egypt have a composite thickness of about 400 m.

Pliocene sediments are of limited distribution in the investigated area (Figure 3). Local Pliocene exposures are recognized at some localities as Mersa Matruh[5], Ras El Hekma[7] and El Daba'a[4]. These deposits are composed of white shallow marine limestone, interbedded with marl, grading into pink marly limestone towards El Daba'a area. In the subsurface, Pliocene sediments are dominated by creamy limestone and calcareous sandstone with shale.

Quaternary deposits

The Quaternary deposits are related to Pleistocene and Holocene times. Pleistocene deposits have a wide distribution in the area. These deposits are differentiated into pink and cardium limestones. Pink limestone is exposed at the topmost portion of the northern edge of the elevated plateau, where it overlies Marmarica Formation. On the other hand, cardium limestone exposes locally at El Daba'a, Ras El Hekma and Mersa Matruh localities with a thickness not more than one meter (Figure 4).

Holocene deposits are represented by a variety of unconsolidated deposits, differentiated into alluvial, aeolian as well as beach deposits. Alluvial deposits are predominant in the shallow topographic conditions composed of quartz, sands, silt and clay, showing enrichment in carbonate grains due north and rock fragments, pebbles with gravel due south. Aeolian deposits are recognized as the coastal dunes of carbonate nature or as the inland dunes composed of quartz sands. Beach deposits occupy a narrow strip along the shore and composed of loose white carbonate sand grains intermixed with few quartz grains as well as fossil remains.

Hydrogeology

Two water-bearing formations are recognized in the investigated area. The first is the Pleistocene oolitic limestone aquifer, while the second is the Miocene limestone aquifer (Marmarica Formation), which is developed as a secondary aquifer in the area (Figure 5).

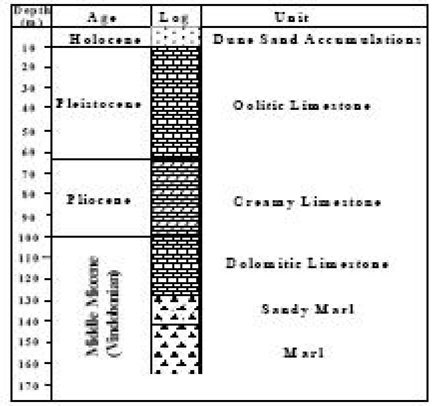

Figure 4 : Idialized stratigraphic section at El Daba'a area, (After El Shamy, 1968)

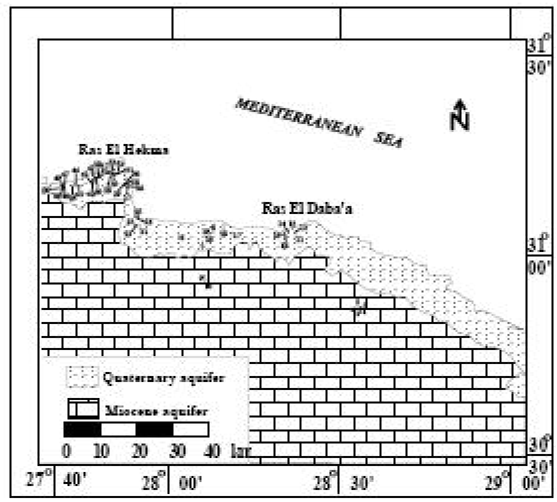

Figure 5 : Map showing wells' locations and aquifers' distribution

Pleistocene oolitic limestone aquifer

The most important aquifer along the coastal strip. It has a wide distribution and extends about 10 km southward. The foreshore oolitic limestone ridges are characterized by less cementing materials if compared with the inland ridges, which acquire the former one more porous nature. Also, the flanks of the ridges are covered by loose foreshore sand accumulations, which permit a direct infiltration and percolation of rainfall. Such foreshore sand accumulations are witnessed as noticed at El Daba'a and Baqqush localities. The investigated aquifer is recharged through infiltration of annual rainfall on the oolitic limestone ridges and/or from the rainwater falling on the elevated tableland area. The groundwater exists as a free water table (phreatic condition). The groundwater table attains altitude close to the mean sea level. It is a result of the local percolation in the coastal plain and the inflow from sea water.

At El Dabaa locality, the direction of groundwater flow is due north and south. The hydraulic gradient is gentle in the northern part (0.0002), while at the southern one it records (0.0003)[2]. At Ras El Hekma locality, the investigated aquifer is characterized by permeability (0.0015 m/min), Transmissivity (0.03 m^2 /min) and storativity (6.31×10^{-6})[8].

Miocene limestone aquifer

Marmarica Formation is developed as a secondary aquifer along the coastal area to the west of Alexandria and is explored at El Daba'a, Fuka, Matruh and El Sallum localities. It is composed of limestone, dolomite and shale sequences related to the Middle Miocene. This formation is largely fractured and exists in successive horizons separated by impervious clays with occasional bands of sandstone.

The groundwater in this fractured limestone exists in the form of thin sheets accumulating at the contact with the impervious clay and depends on its supply by local rainfall (semi confined water). The groundwater of the Marmarica aquifer is naturally discharged upward through the flowing springs and by subsurface flow into the Mediterranean Sea due north. The lateral and vertical facies changes affect the productivity of the aquifer, particularly along the coastal area. However, the transmissivity of the Marmarica aquifer ranges between 10^{-4} and 10^{-2} m^2/sec[1].

Methodology

Fifty groundwater samples were collected from the investigated area. The depths to the groundwater surface were measured using an electric line sounder (Richter measuring tool, 100-200 m) and wells' locations were estimated using a field GPS instrument (Magellan colour trak). Samples were collected using a peristaltic pump at the surface. Samples for analyses were immediately filtered through 0.45 micrometer cellulose membrane filters. The performed chemical analyses included the determination of E.C, pH, T.D.S, Ca, Mg, Na, K, Alkalinity, SO_4, Cl, I and Br. Hydrochemical analyses were carried out at the central lab of Desert Research Center according to the methods adopted by[6,10]. The instruments used were a pH meter, EC meter, Flame photometer, Spectrophotometer and Ion Selective Electrode (Orion), Plasma Optical Emission-Mass spectrometer (POEMS III).

RESULTS AND DISSCUSION

At El Daba'a area, two aquifers are recognized, Miocene and Pleistocene. Miocene is represented by ten samples (Nos. 1-10, inclusive) and Pleistocene aquifer is represented by ten samples (Nos. 11-20, inclusive). At Ras El Hekma area the Pleistocene aquifer is represented by thirty samples (Nos. 21-50, inclusive), (Figure 5).

1. Groundwater salinity

Pliestocene aquifer

At El Daba'a area, the groundwater quality varies between fresh to saline (Chebotarev, 1955) where it ranges between 523.86 ppm (No.20) and 7484.7 ppm (No.15) (TABLE 1) with an average of 3238 ppm.. About 20% of the groundwater samples is fresh (Figure 6), where it ranges from 523 mg/l (No.20) to 852 mg/l (No.17) with an average value of about 688 mg/l, 60% is brackish, where it ranges from 1930 mg/l (No. 18) to 4760 mg/l (No.11) with an average value of about 3059 mg/l, and 20% of the total samples is saline, where it ranges from 5170 mg/l (No.12) to 7484 mg/l (No.15) with an average value of about 6327ppm. Iso-salinity contour map (Figure 7), indicates that the

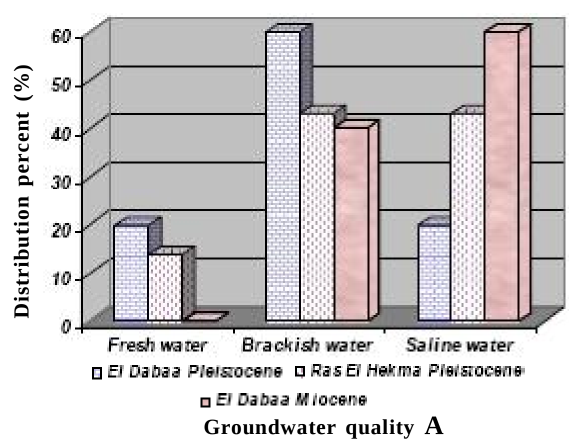

Figure 6 : Groundwater quality distribution

TABLE 1 : Chemical analysis data in ppm

Well no.	salinity	Hardness	Alkalinity	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl
Pleistocene aquifer (El Daba'a area)											
11	4760.22	1377.403	466.9876	132.65	254.15	1233.33	54	32	504.26	400	2401.96
12	5170.462	1275.505	416.9588	81.632	260.35	1449.86	71	28	451.4	750	2303.92
13	2622.54	765.1847	306.872	81.63	136.37	650	65	28	317.2	400	1102.94
14	3320.508	1020.342	650.4438	81.63	198.36	850	48	32	727.9	325	1421.568
15	7484.745	1571.279	316.8666	155.1	287.63	2200	72	36	313.13	950	3627.45
16	2722.63	867.2643	510.3446	81.63	161.17	650	64.5	40	540.86	450	1004.9
17	852.871	50.9952	413.6118	8.16	7.438	300	13	36	431.066	160	112.74
18	1930.608	152.9873	880.6027	20.4	24.79	671.42	31	68	935.33	157.143	490.19
19	2999.6	407.9885	296.8483	81.63	49.59	950	42	40	280.6	250	1446.08
20	523.85	203.9612	193.4597	40.81	24.79	108	11	20	195.2	104	117.65
Pleistocene aquifer (Ras El Hekma area)											
21	3525.986	918.2736	366.877	91.836	167.37	925	47	56	333.46	675	1397.05
22	1499.165	459.0531	300.1787	61.22	74.38	350	43	40	284.66	200	588.235
23	3257.825	749.9788	150.0736	60	145.8	900	64	32	117.93	600	1397.06
24	3063.14	999.5339	206.793	216.32	111.58	750	42	28	195.2	200	1617.64
25	7038.565	1683.398	340.2236	204.08	285.15	2000	66	32	349.73	600	3676.47
26	3286.83	918.2382	246.8138	102.04	161.17	900	33.5	32	235.86	200	1740.19
27	3639.79	1061.131	250.1551	106.12	193.41	1000	25	28	248.06	325	1838.23
28	14125.76	1877.159	160.0998	306.12	270.31	4500	140	16	162.66	1500	7312
29	14266.03	2602.106	303.5174	142.85	545.5	4450	115	40	288.73	660	8168.316
30	8578.41	1377.58	433.6018	81.63	285.15	2700	110	56	414.8	800	4338.23
31	4596.95	1199.99	343.5674	88	238.14	1300	51	24	370.06	333.33	2377.45
32	5919.945	1549.944	240.1446	128	298.89	1700	57	32	227.73	600	2990.19
33	3723.565	979.6177	263.4859	61.22	200.85	1000	43	40	239.93	542.85	1715.68
34	4655.88	1346.931	490.3237	102.04	265.32	1266.66	62	48	500.2	333.33	2328.43
35	6755.46	1530.633	270.1658	102.04	309.95	2050	48	36	256.2	650	3431.37
36	1820.149	714.2586	473.6359	44.89	146.29	428.57	18	52	471.73	85.714	808.82
37	7023.035	1632.556	243.4701	142.85	309.95	2100	46	40	215.53	600	3676.47
38	3695.36	959.07	313.5386	102.04	171.09	1000	38.5	32	317.2	600	1593.13
39	3770.192	918.37	226.8113	61.22	185.97	1050	42	24	227.73	700	1593.137
40	5151.135	1306.027	356.8982	118.36	245.48	1400	37	36	361.93	633.33	2500
41	7122.04	1556.062	273.4805	122.44	303.75	2050	51	48	235.86	875	3553.92
42	3522.23	1520.257	313.5437	151.02	277.71	750	16.5	24	333.46	200	1936.27
43	637.788	336.6078	286.0958	59.18	45.87	110	19	24	300	50	179.738
44	676.51	351.9402	340.4451	48.97	55.79	112.5	20	32	350	95	137.25
45	593.04	265.2271	163.0479	36.73	42.15	110	8.5	24	150	130	166.66
46	7726.58	1887.916	547.0033	71.42	415.33	2050	140	68	528.66	1500	3217.5
47	6870.36	2142.876	250.1658	132.65	440.12	1750	120	24	256.2	550	3725.49
48	5195.01	2112.182	253.4912	163.26	414.09	966.66	97	32	244	1600	1800
49	1698.047	612.1874	253.5096	65.31	109.102	400	29	16	276.53	235	705.37
50	25594.99	6378.029	233.5121	285.71	1376.17	7500	205	0	284.66	1625	14460.78
Miocene aquifer (El Daba'a area)											
1	3855.507	1624.24	240.1629	270	230.78	800	42	20	252.133	700	1666.66
2	5360.645	2040.099	190.1368	367.34	272.75	1083.33	45	8	215.53	1466.66	2009.8
3	3785.895	2294.853	130.0736	510.2	247.96	312.5	25	20	117.93	1925	686.27
4	3736.354	2295.032	150.1052	448.979	285.15	375	29	8	166.73	1600	906.86
5	4350.887	1734.059	166.7772	326.53	223.16	816.66	40	16	170.8	1250	1593.137
6	36007.89	7141.597	220.1605	918.36	1177.81	10750	160	8	252.13	3750	19117.65
7	9509.3	1019.963	286.8562	204.08	123.97	3125	62	28	292.8	1187.5	4632.35
8	22758.49	4336.858	153.4173	265.31	892.65	6875	190	24	138.26	2187.5	12254.9
9	14309.63	4298.552	146.7556	780	571.05	3700	42	20	138.266	3000	6127.45
10	11335.98	3315.039	216.806	653.06	409.13	3000	40	20	223.66	2200	4901.96

groundwater salinity increases generally from west to east. This is mainly due to the presence of fresh water lenses over the saline water body. The presence of saline groundwater in the northern area in the Pleistocene aquifer is mainly attributed to salt water encroachment as a result of the over pumping in addition to the decrease of fresh water lenses due north.

At Ras El Hekma area, the groundwater salinity

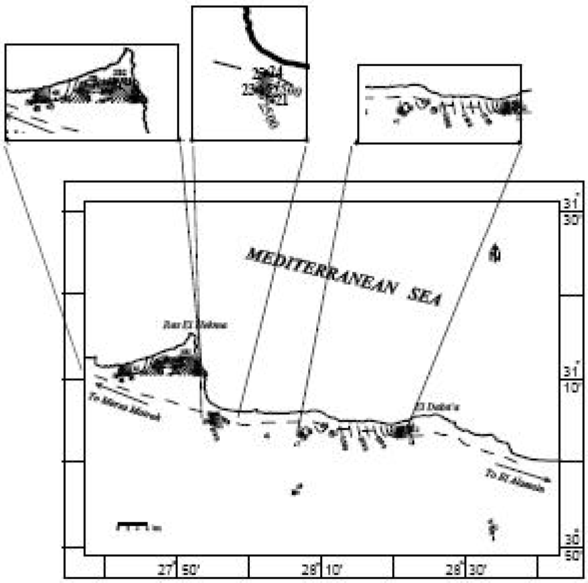

Figure 7 : Iso-salinity contour map of the pleistocene groundwater

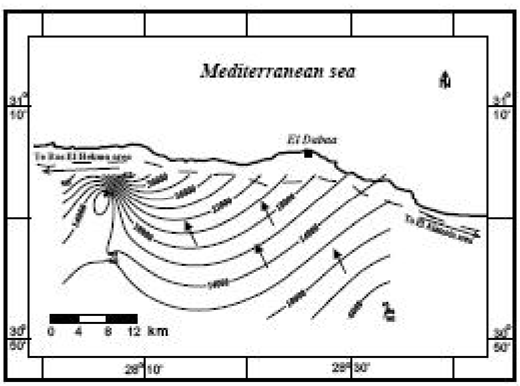

Figure 8 : Iso-salinity contour map of the miocene groundwater

reflects a wide variation, where it varies between 593.04 ppm (No.45) and 25594 ppm (No.50). About 14% of the total samples is fresh (Figure 6), where it ranges from 593 mg/l (No.45) to 1499 mg/l (No.22), with an average value of about 851 mg/l. About 43% is brackish, it ranges between 1698 mg/l (No.49) and 4655 mg/l(No.34) with an average value of about 3404mg/l. The rest 43% of the samples reflects saline quality, where it ranges between 5151 mg/l (No.40) and 25595 mg/l (No.50) with an average value of about 9335 mg/l (Figure 6). According to the iso-salinity contour map (Figure 7), it is clear that the groundwater salinity in Fuka area (Nos. 21- 25, inclusive) increases northward in the same direction of groundwater flow, while at Ras El Hekma area, the water points are located within the southern flank of the fore-shore ridge which acts as a local watershed area of low salinity than the surrounding areas of low relief. So the precipitated rainwater causes leaching and dissolution, and consequently groundwater salinity increases southward. Furthermore, at Ras El Hekma area, the hydraulic gradient in the northern depression is of order 0.006, so the effect of groundwater coming from the tableland could be neglected.

Miocene aquifer

As mentioned before, Miocene aquifer was detected as a water-bearing formation at El Daba'a area. 40% of the investigated groundwater samples is brackish (Figure 6), where it ranges between 3736 mg/l (No.4) to 4350 mg/l (No.5) with an average value of 3932 mg/l. The rest of samples 60% is saline water, where it ranges from 5360 mg/l (No.2) to 36007 mg/l (No.6) with an average value of about 16546 mg/l (TABLE 1). According to the constructed iso-salinity contour map (Figure 8), the groundwater salinity of the Miocene aquifer increases northward in the same direction of

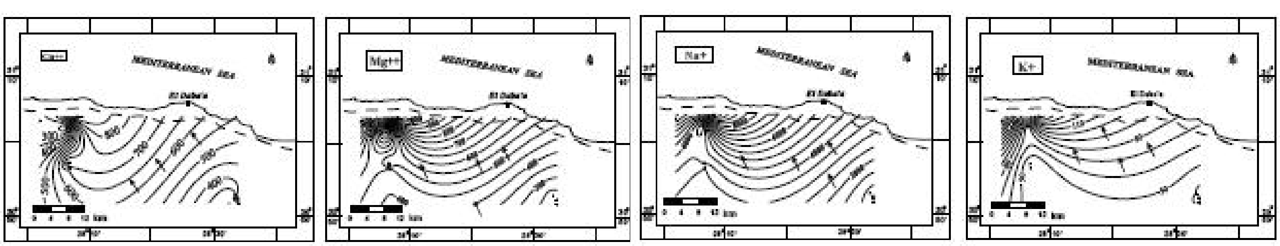

Figure 9 : (a) Iso-contour maps of the miocene groundwater, El Daba'a area (May, 2004).

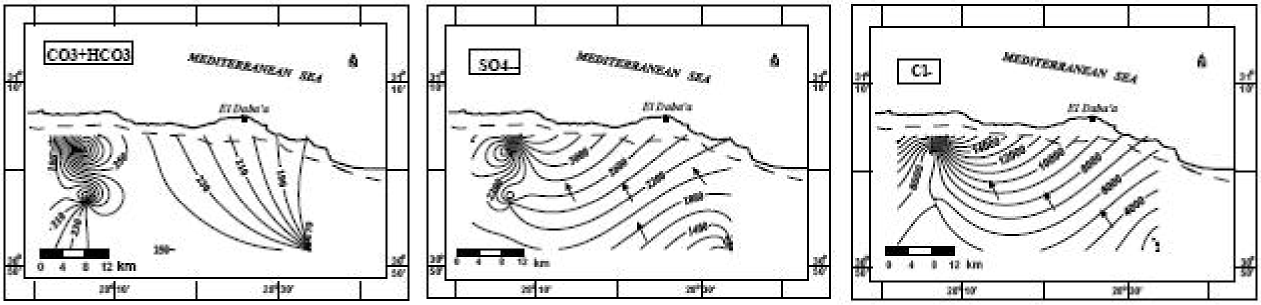

Figure 9 : (b) Iso-contour maps of the miocene groundwater, El Daba'a area (May, 2004)

groundwater flow. This reflects the most important role of leaching and dissolution for aquifer sediments during water movement.

In the study area, the concentrations of major constituents are mostly correlated with groundwater salinity (Figures 9 (a and b), confirming the effective role of leaching and dissolution processes. Carbonate and bicarbonate concentrations have no definite trend since their concentrations are mainly controlled by the complicated geomorphologic nature of the area as well as the local precipitation, which acts as one of the main source of carbonate and bicarbonate in the groundwater.

Generally, Na concentration records high values in the investigated groundwater due to cation exchange process (The area is dominated by marine deposits rich in sodium). Close to the intake area, water has low salinity, due to free carbonic acid, which begins to react with the aquifer sediments to form calcium and magnesium bicarbonates. Calcium and magnesium ions are then removed from solution and replaced by sodium ions as a result of cation exchange.

2. Chemical water type

Pleistocene aquifer

At El Daba'a area, the majority of the Pleistocene groundwater samples (70%) are characterized by categories I and V so, the chemical water type is Cl-Na (TABLE 2) and the rest of the samples exhibit category VI showing HCO_3-Na type. The bicarbonate type reflects the initial phases of groundwater metasomatism. On the other hand, at Ras El Hekma area, four category are recognized (TABLE 2). The majority of the samples (93.3 %) are characterized by categories I, II and III. So, the chemical water type is Cl-Na which indicates advanced stage of groundwater metasomatism. Only 6.7 % of samples have Na-HCO_3 type (category VI) reflecting the effect of dilution due to rainfall precipitation.

TABEL 2: Ion dominance and chemical water type at the study area

Category	Ion dominance	Chemical water type	Well no	Percent %
The peistocene aquifer (El Daba'a area)				
I	$Cl^->SO_4^{--}>HCO_3^-$ $Na^+>Mg^{++}>Ca^{++}$	Cl-Na	12,13,15	30%
V	$Cl^->HCO_3^->SO_4$-- $Na^+>Mg^{++}>Ca^{++}$	Cl-Na	11,14,16,19	40%
VI	$HCO_3^-> Cl^->SO_4^{--}$ $Na^+>Mg^{++}>Ca^{++}$	HCO_3-Na	18,17,20	30%
The pleistocene aquifer (Ras El Hekma area)				
I	$Cl^->SO_4^{--}>HCO_3^-$ $Na^+>Mg^{++}>Ca^{++}$	Cl-Na	21,23,25,26, 27,28,29,30, 31,32,33,35, 37,38,39,40, 41,46, 47,48,50	70 %
II	$Cl^->HCO_3^->SO_4^{--}$ $Na^+>Mg^{++}>Ca^{++}$	Cl-Na	22, 34, 36, 42, 45, 49	20 %
III	$Cl^->SO_4^{--}>HCO_3^-$ $Na^+>Ca^{++}>Mg^{++}$	Cl-Na	24	3.3%
IV	$HCO_3^->Cl^->SO_4^{--}$ $Na^+>Mg^{++}>Ca^{++}$	HCO_3-Na	43, 44	6.7%
Groundwater in the miocene aquifer				
I	$Cl^->SO_4^{--}>HCO_3^-$ $Na^+>Mg^{++}>Ca^{++}$	Cl-Na	1, 2, 5, 6, 8, 9, 10	70%
II	$Cl^->SO_4^{--}>HCO_3^-$ $Na^+>Ca^{++}>Mg^{++}$	Cl-Na	7	10%
III	$SO_4^{--}>Cl^- >HCO_3^-$ $Ca^{++}>Mg^{++}> Na^+$	SO_4-Ca	3	10%
IV	$SO_4^{--}>HCO_3^-> Cl^-$ $Mg^{++}>Ca^{++}> Na^+$	SO_4-Mg	4	10%

Miocene aquifer

In the Miocene aquifer, 80% of the samples are characterized by categories I and II so, the chemical water type is Cl-Na, reflecting a mature stage of groundwater metasomatism , 10 % exhibits category III representing Ca-SO_4 type and 10 % exhibits category IV

TABLE 3: Assemblages of the hypothetical salts of the study area

Assemblage category	The hypothetical salts assemblage	Well no.	Percent %
Pleistocene aquifer (El Daba'a area)			
I	NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$,$Ca(HCO_3)_2$	15	10%
III	NaCl, $MgCl_2$, $MgSO_4$, $Mg(HCO_3)_2$,$Ca(HCO_3)_2$	11,12, 13,14	40%
IV	NaCl, Na_2SO_4, $MgSO_4$, $Mg(HCO_3)_2$,$Ca(HCO_3)_2$	16,19,20	30%
V	NaCl,Na_2SO_4,$Na(HCO_3)$ $Mg(HCO_3)_2$,$Ca(HCO_3)_2$	17,18	20%
Pleistocene aquifer (Ras El Hekma area)			
I	NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$,$Ca(HCO_3)_2$	25,26,28,29, 32,37,41,42, 47,48,50	36.7%
III	NaCl, $MgCl_2$, $MgSO_4$, $Mg(HCO_3)_2$,$Ca(HCO_3)_2$	27,30,31,33, 34,35,36, 38, 40, 49,	33.3%
IV	NaCl, Na_2SO_4, $MgSO_4$, $Mg(HCO_3)_2$,$Ca(HCO_3)_2$	21,22,33, 39 43,44,45,46	26.7%
VI	NaCl, $MgCl_2$, $CaCl_2$, $CaSO_4$,$Ca(HCO_3)_2$	24	3.3%
Miocene aquifer (El Daba'a area)			
I	NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$,$Ca(HCO_3)_2$	1, 2, 3, 4, 5, 6, 8, 9, 10	90%
II	NaCl, Na_2SO_4, $MgSO_4$, $CaSO_4$,$Ca(HCO_3)_2$	7	10%

showing Mg-SO_4, which represent intermediate stage of groundwater evolution.

Conclusion: The percent of the samples having Cl-Na chemical water type in Miocene aquifer is greater than that of Pleistocene aquifer, reflecting the less advanced stage of the groundwater evolution in the latter, and the appearance of 30% of the samples with Na-HCO_3 type in the Pleistocene aquifer is mainly due to precipitation.

3. Hhypothetical salts assemblages

Pleistocene aquifer

At El Daba'a area, 90% of the Pleistocene groundwater samples are characterized by assemblages III, IV and V which contain two or three bicarbonate salts, reflecting the dilution effect of precipitation. Assemblage II contains three sulfate salts, indicating a transition stage between assemblages {I} and {III,IV and V}. On the other hand, at Ras El Hekma area, about 73.3 % of the samples contain two or three chloride salts (groups I, III and VI) reflecting salt water intrusion, about 26.7 % contain two bicarbonate salts reflecting the effect of rainfall on the aquifer quality. Group III shows mixed water, since it contains two chloride and two bicarbonate salts (TABLE 3).

Miocene aquifer

In the Miocene aquifer, 90% of the groundwater samples are related to group I (TABLE 3), which contains two chloride salts (especially $MgCl_2$) reflecting the effect of marine salt dissolution and two sulfate salts showing the effects of leaching and dissolution of terrestrial salts (continental groundwater) due to the local precipitation with some contribution of cation exchange process.

Conclusion: The groundwater of Pleistocene aquifer is in the earlier stage of chemical development (dominated by two or three bicarbonate salts) than that water of Miocene aquifer, which is in more advanced stage (two chloride salts are recognized), (TABLE 3).

4. Groundwater hardness (TABLE 1)

At El Daba'a area, the total hardness of the Pleistocene groundwater ranges between 50.99 mg/l (No.17) to 1571.27 mg/l (No.15) with an average value of 769 mg/l as $CaCO_3$, while at Ras El Hekma area, the Pleistocene groundwater has total hardness ranges between 265 mg/l (No.45) and 6378 mg/l (No.50) with an average value of 1398.28 mg/l as $CaCO_3$. In the Miocene groundwater it ranges between 1019.96 mg/l (No.7) and 7141.59 mg/l (No.6) with an average value of 3010 mg/l as $CaCO_3$. In general, the investigated groundwater varies from soft to very hard water. This is mainly due to leaching and dissolution of limestone deposits rich in Ca & Mg. Total and temporary hardnesses relative to the total salinity decrease according to the change of water type from fresh to saline due to the increase of soluble salts.

5. Groundwater alkalinity(TABLE 1)

At El Daba'a area, the alkalinity of Pleistocene groundwater ranges between 193.45 mg/l (No. 20) and 880.62 mg/l (No. 18) with an average value of 445.29 mg/l as $CaCO_3$. At Ras El Hekma area, the Pleistocene groundwater has alkalinity ranges between 150 mg/l (No. 23) and 547 mg/l (No. 46) with an average value of about 296.48 mg/l as $CaCO_3$. At El Daba'a area, the alkalinity of the Miocene groundwater ranges between 130.07 mg/l (No.3) and 286.85 mg/l (No.7) with

TABLE 4: The values of the ions ratios of the study area

N0.	rNa^+/rCl^-	rCa^{++}/rMg^{++}	rSO_4^{--}/rCl^-	$(Cl^- - Na^+)/rCl^-$	R (Cl^-/Br^-)	R (I^-/Br^-)
Pleistocene aquifer (El Daba'a area)						
11	0.79	0.32	0.12	0.21	94	0.1
12	0.97	0.19	0.24	0.03	70	0.01
13	0.91	0.36	0.27	0.09	93	0.08
14	0.92	0.25	0.17	0.08	73	0.02
15	0.94	0.33	0.19	0.06	113	0.01
16	1	0.31	0.33	0	67	0.02
17	4.1	0.67	1.05	-3.1	63	0.01
18	2.11	0.5	0.24	-1.11	76	0.03
19	1.01	1	0.13	-0.01	79	0.01
20	1.42	1	0.65	-0.42	85	0.04
Pleistocene aquifer (Ras El Hekma area)						
No.	rNa^+/rCl^-	rCa^{++}/rMg^{++}	rSO_4^{--}/rCl^-	$(Cl^- - Na^+)/rCl^-$	R (Cl^-/Br^-)	R (I^-/Br^-)
21	1.02	0.33	0.36	-0.02	88	0.02
22	0.92	0.5	0.25	0.08	84	0.02
23	0.99	0.25	0.32	0.01	78	0.01
24	0.72	1.18	0.09	0.28	75	0.01
25	0.84	0.43	0.12	0.16	74	0.01
26	0.8	0.38	0.08	0.2	84	0
27	0.84	0.33	0.13	0.16	89	0
28	0.95	0.69	0.15	0.05	92	0
29	0.84	0.16	0.06	0.16	103	0
30	0.96	0.17	0.14	0.04	101	0
31	0.84	0.22	0.1	0.16	94	0.01
32	0.88	0.26	0.15	0.12	97	0
33	0.9	0.18	0.23	0.1	109	0.01
34	0.84	0.23	0.11	0.16	86	0.01
35	0.92	0.2	0.14	0.08	108	0
36	0.82	0.19	0.08	0.18	78	0.01
37	0.88	0.28	0.12	0.12	84	0.01
38	0.97	0.36	0.28	0.03	96	0.01
39	1.02	0.2	0.32	-0.02	92	0
40	0.86	0.29	0.19	0.14	95	0.04
41	0.89	0.24	0.18	0.11	81	0.01
42	0.6	0.33	0.08	0.4	84	0.01
43	0.94	0.78	0.21	0.06	65	0.02
44	1.26	0.53	0.51	-0.26	81	0.18
45	1.02	0.53	0.58	-0.02	65	0.04
46	0.98	0.1	0.34	0.02	69	0.01
47	0.72	0.18	0.11	0.28	89	0.01
48	0.83	0.24	0.66	0.17	46	0.04
49	0.87	0.36	0.25	0.13	68	0.02
50	0.8	0.13	0.08	0.2	99	0
Miocene aquifer (El Daba'a area)						
N0.	rNa^+/rCl^-	rCa^{++}/rMg^{++}	rSO_4^{--}/rCl^-	$(Cl^- - Na^+)/rCl^-$	r(Cl^-/Br^-)	R (I^-/Br^-)
1	0.74	0.71	0.31	0.26	88.00	0.00
2	0.83	0.82	0.54	0.17	93.00	0.01
3	0.70	1.25	2.07	0.30	84.00	0.00
4	0.64	0.96	1.30	0.36	78.00	0.01
5	0.79	0.89	0.58	0.21	80.00	0.00
6	0.87	0.47	0.14	0.13	96.00	0.01

an average value of about 190.12 mg/l as $CaCO_3$. According to the obtained results of alkalinity, it is clear that, the alkalinity of the Miocene groundwater is lower than that of the Pleistocene groundwater in the investigated area. This is mainly due to the higher salinity of the former one.

6. Hydrochemical coefficients

rNa^+/rCl^-

At El Daba'a area, 60% of the Pleistocene groundwater samples have values less than unity and 40% of the samples are more than unity (TABLE 4). The increase in sodium concentration reflects meteoric and deep meteoric water recharges. At Ras El Hekma area, about 86.7% of the Pleistocene groundwater samples have values less than unity, 10% approximately equal unity and 3.3% is more than unity, reflecting the effect of marine salts. On the other hand, Miocene groundwater has 90% of samples with rNa^+/rCl^- value less than unity, reflecting marine salt leaching and 10 % nearly equal unity (No.7)

rCa^{2+}/rMg^{2+}

At El Daba'a area, the Pleistocene groundwater has ratio ranges between 0.19 and 0.99 with a mean value of 0.49. At Ras El Hekma area, rCa^{2+}/rMg^{2+} is ranged between 0.1 and 0.78 (except No. 19 has ratio equal 1.17). About 56.7% of the samples have rCa^{2+}/rMg^{2+} <or = 0.29 reflecting salt water contamination. On the other hand, Miocene groundwater has ratio ranges between 0.18 and 0.99 with an average value of about 0.8, reflecting the impact of sediments rich in dolomite within the aquifer sediments.

rSO_4^{2-}/rCl^-

At El Daba'a area, the Pleistocene groundwater has ratios ranging between 0.12 and 0.65 (except No. 17 has a value of 1.04). At Ras El Hekma area, the values of the ratio range between 0.05 and 0.65 with an average value of about 0.21. This means that the groundwater is more comparable with sea water than in case of rainwater. On the other hand, Miocene groundwater has ratio ranges between 0.13 and 0.58 (except Nos. 3 and 4 have values 2.07 and 1.3, respectively), reflecting that 80% of the samples have values less than or equal 0.58 which is more closed to

TABLE 5: Classification of the water corrosion potential based on the calcite (SI) values and recommended treatment

Saturation indices (SI)	Describtion	General recommendations	Saturation indices (SI)	Describtion	General recommendations
-5.0	Sever corrosion	Treatment recommended	0.5	Some faint coating	Treatment typically not needed
-4.0	Moderate corrosion	Treatment recommended	1.0	Mild scale forming	Some aesthetic problems
-3.0	Moderate corrosion	Treatment recommended	2.0	Mild scale foming	Some aesthetic-considered
-0.2	Moderate corrosion	Treatment should be considered	3.0	Moderate scale forming	Treatment should be considered
-1.0	Mild corrosion	Treatment should be considered	4.0	Sever scale forming	Treatment probably required
-0.5	Mild corrosion	Treatment probably not needed	5.0	Sever scale forming	Treatment required
0.0	Balanced	Treatment typically not needed	0.5	Some faint coating	Treatment typically not needed

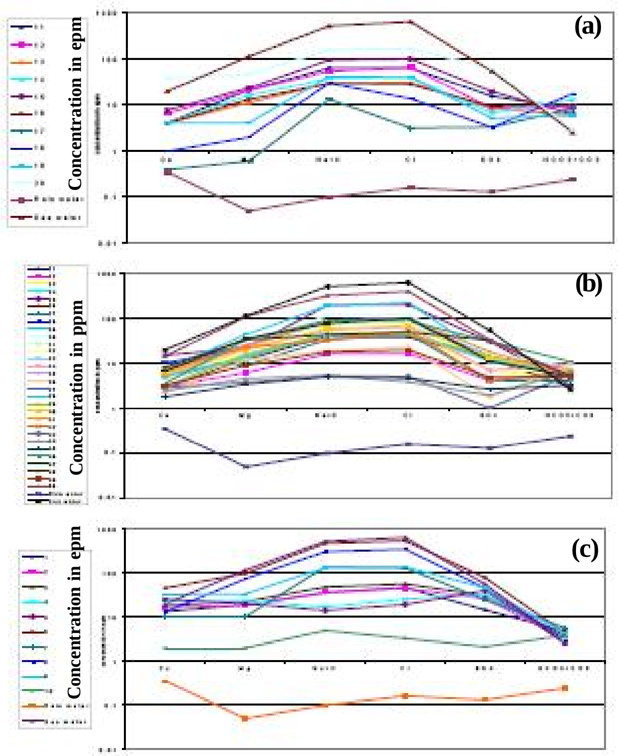

Figure 10 : (a) Semi logarithmic graph of the pleistocene groundwater, El Dabaa area (May 2004); (b) Semi logarithmic graph to the pleistocene aquifer, Ras El Hekma area (May 2004); (c) Semi logarithmic graph of the Miocene groundwater, El Dabaa area (May 2004)

the sea water rather than to the rainwater.

$rCl^-/r(HCO_3^-+CO_3^{2-})$

At El Daba'a area, 30% of the Pleistocene groundwater is characterized by normal good groundwater, 30% are moderately contaminated water, 30% are seriously contaminated water and 10% are highly contaminated water. At Ras El Hekma area, about 6.7% of the groundwater samples are normal good water, 3.3 % of the groundwater samples are slightly contaminated, 13.3 % of the groundwater samples are moderately contaminated, 46.7 % of the groundwater samples are seriously contaminated, 30 % of the groundwater samples are high contaminated. The Pleistocene groundwater in Ras El Hekma area have less percent of the normal good water due to the presence of the alluvium deposits in the depression between the first two ridges in which the most of the wells are located. On the other hand, 50% of the Miocene groundwater is characterized by seriously contaminated water (7.44-14.9) and the rest are highly contaminated water.

The high percent of normal good groundwater in the Pleistocene groundwater is due to the effect of the rainwater rich in carbonate and bicarbonate which dissolve from the air during precipitation. The absence of good groundwater in the Miocene groundwater is due to the leaching and dissolution of the aquifer matrix rich in marine deposits, which increase chloride salts.

rCl^-/rBr^- and rI^-/rBr^-

At El Daba'a area, the Pleistocene groundwater has bromide concentration ranging between 1.39 ppm (No.20) and 32.9 ppm (No.12) with an average value of about 16.47 ppm. The concentration of iodide ranges between 0.0085 ppm (No.17) and 0.29 ppm (No.14) with an average value of about 0.18 ppm (except No.13 has a value of 0.92 ppm). The average value of $r(Cl^-/Br^-)$ ratio is 81.3 ppm, reflecting sea water impact. The average value of $r(I^-/Br^-)$ ratio in the Pleistocene groundwater is 0.03 ppm (more close to the sea water). At Ras El Hekma area, bromide concentration ranges be-

TABLE 6: Classification of theinvestigated ground based on its tendency to be corrosive

Well no.	(SI) calcite	corrosivity	Well no.	(SI) calcite	Corrosivity	Well no.	(SI) calcite	Corrosivity	Well no.	(SI) calcite	Corrosivity
1	0.66	Mild scale forming	14	1.49	Mild scale forming	27	0.66	Mild scale forming	40	1.03	Mild scale forming
2	-0.66	Mild corrosion	15	0.91	Mild scale forming	28	0.48	Mild scale forming	41	0.78	Mild scale forming
3	0.83	Mild scale forming	16	1.48	Mild scale forming	29	0.58	Mild scale forming	42	1.53	Mild scale forming
4	0.64	Mild scale forming	17	0.42	Mild scale forming	30	0.82	Mild scale forming	43	1.11	Mild scale forming
5	-0.15	Mild corrosion	18	1.35	Mild scale forming	31	0.8	Mild scale forming	44	1.15	Mild scale forming
6	0.67	Mild scale forming	19	0.81	Mild scale forming	32	0.8	Mild scale forming	45	0.53	Mild scale forming
7	0.7	Mild scale forming	20	0.68	Mild scale forming	33	0.68	Mild scale forming	46	0.99	Mild scale forming
8	0.43	Mild scale forming	21	0.97	Mild scale forming	34	1.08	Mild scale forming	47	0.83	Mild scale forming
9	0.64	Mild scale forming	22	0.92	Mild scale forming	35	0.62	Mild scale forming	48	1.01	Mild scale forming
10	0.8	Mild scale forming	23	0.25	Mild scale forming	36	1.04	Mild scale forming	49	1.02	Mild scale forming
11	1.45	Mild scale forming	24	0.82	Mild scale forming	37	0.78	Mild scale forming	50	0.66	Mild scale forming
12	0.95	Mild scale forming	25	0.87	Mild scale forming	38	1.01	Mild scale forming			
13	1.09	Mild scale forming	26	0.68	Mild scale forming	39	0.62	Mild scale forming			

tween 1.7 ppm (No.44) and 49.4 ppm (No.25) with an average value of about 24.17 ppm (except Nos.29, 28 and 50 which have values equal 79.4, 79.7 and 146 ppm, respectively). Iodide concentration ranges between 0.04 ppm (No.43) and 1.38 ppm (No.48) with an average of about 0.28 ppm. The average value of r(Cl^-/Br^-) is 85.13 ppm which is more close to the sea water indicating groundwater contamination. The average value of r (I^-/Br^-) ratio is 0.01 ppm, which is intermediate value between sea water and rainwater. On the other hand, Miocene groundwater has bromide concentration ranges between 8.21 ppm (No.3) and 48.1 ppm (No.9) with an average value of about 26.83 ppm (except Nos.6 and 8 have bromide concentration equal 200 and 122 ppm, respectively). The concentration of iodide ranges between 0.026 ppm (No.3) and 0.32 ppm (No.7) with an average value of about 0.15ppm (except No. 12 has iodide concentration of 1.02 ppm). The average value of r (Cl^-/Br^-) ratio is 96.7 ppm which is more closed to sea water than the Pleistocene groundwater due to the dilution effect of rainwater on the latter. The average value of r (I^-/Br^-) ratio is 0.0045 ppm which is less than that of the rainwater and more than that of the sea water.

7. Schoeller's diagram (1962)

Plotting of the concentrations of the chemical constitutents in the study area on the semi-logarithmic graphs (**Figures 11(a-c)???**) reveals two dominant geochemical processes:

1. Groundwater acquires its quality from leaching and dissolution of the aquifer material through direct rainfall or subsurface runoff.
2. Groundwater of marine facies, resulting due to salt water intrusion.

8. Geochemical modeling

Saturation indices of major mineral phases in the investigated groundwater samples were calculated using the software package (WATEQ-F). They show a super-saturation with respect to the main carbonate minerals (aragonite, calcite, dolomite, magnesite and huntite nearly in all water samples as these minerals compose the main aquifer matrix in the study. Also, the saturation indices were used as an indicator of water agressivity or scale forming. (TABLE 5) presents a typical range of SI of calcite that may be encountered in drinking water and a description of the nature of the water and general recommendations regarding treatment (Wilkes University, 2002). According to the obtained results, it is clear that the investigated groundwater ranges between mild corrosion (Nos.2 and 5), balanced (Nos.42 and 44) and most of the samples (93.5%) are mild scale forming (TABLE 6). This may (by the time) leads to clog the pipes which transport the water to the inhabitants. So, it is recommended to be treated before use.

CONCLUSION

Investigation of the Pleistocene and Miocene aquifers at El Daba'a and Ras El Hekma areas reveals the following:

1. The Quaternary deposits represent the main water-bearing formation (Pleistocene aquifer) while the Tertiary deposits act as secondary aquifer (Miocene aquifer) in the study area.
2. Regionally, the groundwater flow direction is northward. The recharging source is the meteoric water.
3. The groundwater salinity in the Pleistocene aquifer ranges from fresh to saline, whereas in the Miocene aquifer it varies from brackish to saline. Generally, the salinity of the pliestcene groundwater is less than that of Miocene groundwater.
4. The hardness of the Pleistocene groundwater ranges from soft to very hard, while in the Miocene groundwater it ranges from hard to very hard. High hardness values at both aquifers are strongly attributed to the predominance of Ca^{+2} and Mg^{+2} minerals within the aquifers matrix.
5. The main chemical water type is Na-Cl, reflecting the mature stage of groundwater evolution.
6. From shoeller's diagram, it is concluded that the groundwater acquires its salinity from leaching and dissolution of the aquifer materials.
7. Application of WATEQ-F model indicates that, the investigated groundwater in both aquifers are super-saturated with calcite, aragonite, magnesite, dolomite and huntite minerals.
8. Comparing the saturation indices of calcite with standard values, it is found that 93.5% of the investigated groundwater samples are mild scale forming and should be treated before use.

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