Geochemistry of Quaternary Aquifer Groundwater in Burg El Arab Area and its Suitability for Irrigation

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Abstract: The ground water in the Burg El Arab area exists under free water table condition. The general gradient is towards the Mediterranean Sea. The total dissolved solids (TDS) range from 1562 to 8813 mg/l, indicating possibly fresh to saline water classes. Sodium, chloride and sulphate ions display a relatively linear increase with increasing salinity. The main groundwater genetic type is Na_2SO_4, reflecting a meteoric water affinity. The groundwater in the Quaternary aquifer is unsuitable for irrigation under normal condition. Further action for salinity control is required in remediation such a problem. It can be managed by improving irrigation management technologies and by using salt-tolerance plants.

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1. Introduction

Water availability in Egypt is highly constrained due to many reasons, such as a fixed national share of the Nile River, and the population growth. The increasing demand for fresh water and over-exploitation of the existing reserves has encouraged the studying of groundwater as a vital source for agricultural and developmental activities in the area. Burg El Arab area represents one of potential localities for future developments in the northwestern coast of Egypt. It is subjected to regional development projects including land reclamation, new factories and many economic, scientific and recreation center.

Burg El Arab area is located to the west of Alexandria city, within the northwestern-coastal zone of Egypt between latitudes 30^o 50' and 30^o 57' N and longitude 29^o 25'and 29^o 38' E (Fig. 1). It is geographically bounded by the Mediterranean Sea to the north, the tableland to the south, El Amerya area to the east, and El Hammam area to the west (Fig. 1). Generally, the Mediterranean climate is characterized by high relative humidity, unstable rainy winter, warm dry stable summer and small diurnal temperature variations. The Alexandria region receives an average rainfall of 170 mm per year, but precipitation varies greatly from year to year. Rains are seasonal: almost all rain occurs between December through February, whereas between June and August it is essentially none. Annual evaporation potentials of 1.5 mm far exceed precipitation (Warne and Stanley, 1993). The absolute water levels vary from -4.48 m to +5.10 m. The hydraulic gradient is of the order of 4.5×10^{-4} towards the sea and 6.7×10^{-4} towards Mallahet Maryut (Abdel Mugheith, 1968).

Agriculture is the essential sector in the economy of the northwestern coast of Egypt. It accounts for approximately 70 % of the total employment (El Asmar *et al*., 2012). The main objective of the present study is to assess the geochemical characteristics of groundwater and its suitability for agricultural uses in the Burg El Arab area.

Methodology:

Nineteen groundwater samples from tube- and dug-wells tapping the Quaternary aquifer were collected during April (2011), in addition to four surface water samples (Fig. 1). The collected samples were chemically analyzed for the major cations and anions besides nitrates and phosphates. Unstable parameters such as pH and electrical conductivity (EC) were measured in the field using pH meter (CONSORT P903, after Richards, 1954) and EC meter (Cyberscan Conductivity Meter CON 100). Sodium and potassium contents were determined by using Flame

Photometer (Rhoades, 1982). Calcium and magnesium contents were determined by EDTA titration using Eriochromeblack-T as an indicator (Jackson, 1958). Chloride concentration was measured by silver nitrate titration using Volhard's method. Sulphate was measured using a turbidity method (Adams, 1990). Carbonate and bicarbonate contents were measured by acid-base titration (Nelson, 1982). Nitrate and nitrite ions were determined colorimetrically by using UV/visible Spectrophotometer (Harrison and Perry, 1986). Phosphate was determined colorimetrically based on hydroquinone method described by Snel and Snel (1967).

Land cover classes are typically mapped from digital remote sensing data through the process of a supervised digital image classification (Campbell, 1987; Thomas, *et al.*, 1987). The overall objective of the image classification procedure is to automatically categorize all pixels in an image into land cover classes or themes (Lillesand & Kiefer, 1994). The land cover map was done by using the programs ENVI 4.7 and GIS 9.3, and the Enhanced Thematic Mapper (ETM+) image (with path/row 178/39) acquired in 2003.

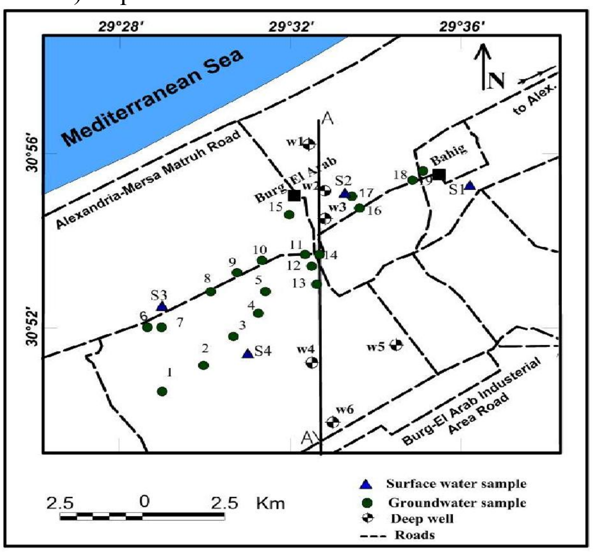

Fig. (1): Location map of the collected water samples in Burg El Arab area, NW Egypt.

Geologic setting:

The surface of the Mediterranean coastal area is built mainly of various Tertiary and Quaternary sedimentary deposits (El Shazly *et al.,* 1975; Swanberg *et al.,* 1984; Gindi and Abd-Alla, 2000). The strata of hydrological importance are essentially of Quaternary age.

The study area is characterized by a series of three parallel Pleistocene limestone ridges ranging in elevation up to 35 m separated by shallow depressions. The ridges are the coastal ridge, El Max-AbuSir ridge, and Gebel Maryut ridge (Fig. 2). The study area is located in the Frontal Plain between Gebel Maryut ridge to the north and Maryut Tableland (up to +100 m in elevation) to the south. The Frontal Plain varies in width from 300 to 1750 m. It is covered by calcareous soil accumulations overlaying an evaporite series of alternating thin gypsum and clays (Guindy, 1989).

Burg El Arab area is a part of the rapidly developing northwestern coastal zone of Egypt. Economic gypsum deposits are known in El-Gharbaniate area in the lagoon separating the third and the fourth ridges (Adindani *et al.*, 1975). El-Sharabi (2000) described the gypsum in this region as elongated lenses of variable widths and thickness that gradually changes at the outer edges to gypsiferous limestone and limestone.

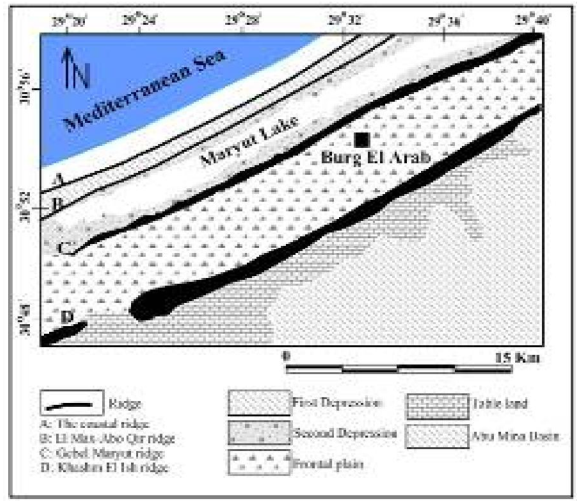

Fig. (2): Geomorphologic map of Burg El Arab area (after Guindy, 1989).

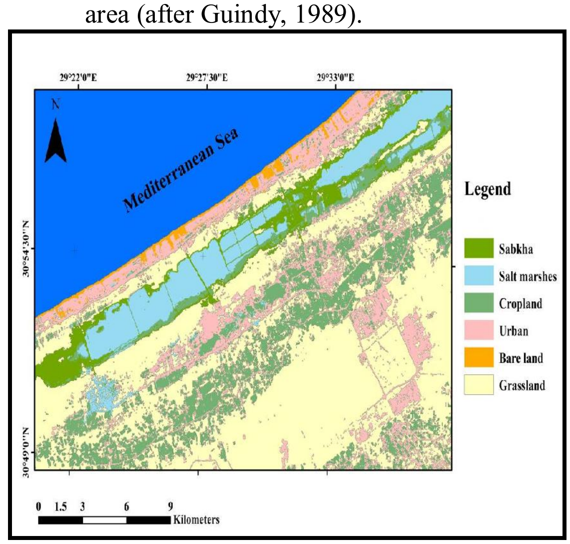

Fig. (3): Land use-land cover map of Burg El Arab area.

Land use involves the management and modification of natural environment or wilderness into built environment such as fields, pastures, and settlements. Supervised classification was done using ground checkpoints in the study area. The area was classified into seven main physiographic classes (Fig. 3): sea water, salt marshes, sabkha, cropland, grassland, bare land and urban. Description of these land cover classes is presented in Table 1.

The new reclaimed lands, which mainly irrigated from the Nile water of the lining canals, represent most of the cropland class in Burg El Arab area.

Land degradation caused by water logging which results from mismanagement of irrigation. The main problems associated with irrigation schemes are their wasteful use of water, with application rates exceeding possible plant uptake as well as poor drainage system and leading to problems associated with water logging; salinization and alkalinization. Wind and water erosion led to the removal of the relatively fertile topsoil and this could lead to desertification (Shalaby and Tateishi, 2007).

According to El Shazly, *et al.,* 1975; and the Ministry of Irrigation, Desert Irrigation Department, 1976, the stratigraphy of the exposed rocks is described from top to bottom as the following:

1. Holocene beach sediments and sand dunes that are characterized by a yellow color and fine- to very-fine texture. The sediments are limy in composition. They have fresh groundwater floating on top of salt water. The thickness of the freshwater zone is being controlled by its height above sea level and the distance from the sea as well as the amount, of rain water that recharges this aquifer through direct infiltration.
2. Holocene alluvial loamy deposits: It is composed of almost homogenous calcareous loam and concretionary gypsum.

Table (1): Description, areas and percentages of different land cover classes in the study area.

Class	Area (km^2)	%	Description
Sea water	160.03	27.19	Mediterranean Sea
Sabkha	21.90	3.72	The inter-ridge lagoonal sabkha depressions are filled with calcareous deposits, gypsies deposits and less (Hassouba, 1995).
Salt marshes	40.36	6.86	The salt marshes in the study area are separated from the sea by lime rocks.
Cropland	72.11	12.25	Areas cultivated with annual crops, vegetables, or fruit. These crops are irrigated mainly from the water of the river Nile and/or ground water. Most of the cultivated area is newly reclaimed.
Urban	66.11	11.23	Includes construction activities along the coastal dunes (summer resorts) as well as sporadic houses of the bedouins within the local villages and some governmental buildings as well as the main cities.
Bare land	6.45	1.10	Land areas of exposed soil surface as influenced by human impacts and/or natural causes. It contains sparse vegetation with very low plant cover value as a result of overgrazing, woodcutting, etc.
Grassland	221.51	37.64	The plants of the study area can be classified into nine life forms: annuals, perennial grasses, perennial herbs, evergreen succulent perennial sub-shrubs, evergreen non-succulent perennial sub-shrubs, partially deciduous perennial sub-shrubs, evergreen succulent perennial shrubs, evergreen non-succulent perennial shrubs and deciduous perennial shrubs. (Kasparek, 1993)
Sum	588.47		

3. Pleistocene Alexandria Formation; composed of Oolitic limestone, which has a fine to coarse texture and mostly light to gray colors. The Alexandria Formation includes gypsum and clays (calcareous gypsum with soluble salts) forming pockets to the south of the Mediterranean coast (10- 12 km) at Burg El Arab.
4. The Miocene-Pliocene rock units: These units form isolated brown compact sandy limestone with some gypsiferrous limestones on top of small hills.

Hydrogeology:

In the study area, the Quaternary deposits constitute the main groundwater source in the area. The winter rainfall varies seasonally with an annual mean intensity of precipitation of 170 mm (El Arabi and Fekry, 2009) representing the main recharging source to such formations. The groundwater exists under free-water table condition. The cross section (Fig. 4) Represents the main characteristics of this aquifer. The saturated thickness of the coastal aquifer is about 30 m in the Oolitic limestone. The hydraulic conductivity of this aquifer is about 19 m/day (Hilmy *et al.*, 1977). Most recharge to the aquifer takes place through the precipitation falling directly on the area. Some recharge may occur through excess irrigation water, seepage from irrigation canals and their subsidiaries, and the Mediterranean Sea. The groundwater discharged naturally to Mallahet Mariut, coastal marshes, and northward to the Mediterranean Sea. It's also discharged through evaporation, evapotranspiration and pumping. The depth of water level from the ground surface varies from 3m to 25m. Ridges and depressions in the Burg El Arab area control the groundwater flow pattern. The flow of groundwater in this aquifer is due north and northeast (Guindi, 1989 and Atwia *et al.,* 2012).

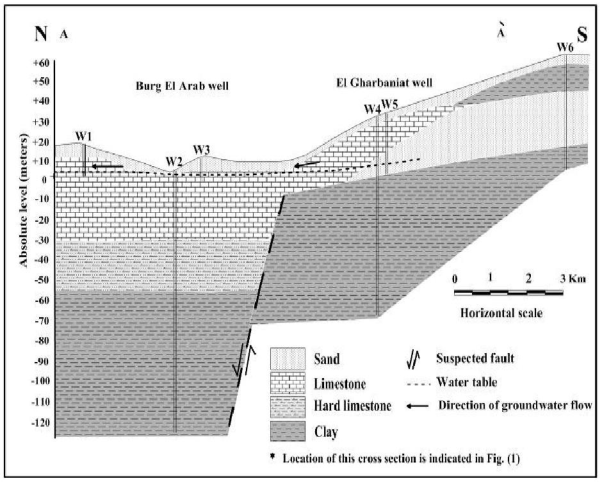

Fig. (4): Hydrogeological cross section along the direction A-A\ (modified after Guindy, 1989).

Geochemical properties of Quaternary aquifer:

Based on the chemical analyses given in Tables 2 and 3, the geochemical properties of the studied Quaternary aquifer are summarized and discussed:

The pH values of groundwater mostly reflect slightly acidic to alkaline condition. The total dissolved solids (TDS) range from 1562 to 8813mg/l (Table 4). According to Chebotarev' s classification (1955), about 53% of the collected water samples belong to a saline water class (4000->7000 mg/l), while 47% of the collected water samples belong to possibly fresh to brackish water class (1500-4000 mg/l) (Fig. 5).

Sodium represents the dominant cation in the analyzed groundwater samples (Fig. 6). It varies between 385 and 2535mg/l, with an average value of 1460 mg/l (Fig. 8 & Table 4). Potassium is the least dominant cation; ranging from about 13 to 59 mg/l, with an average value of about 36 mg/l (Fig. 6 & Table 4 shows the relatively high potassium content in the groundwater of the coastal aquifer is mainly due to invasion of the seawater (Atta *et al.,* 2007).

Table (2): Results of chemical analyses for the collected surface water samples in Burg El Arab area, Egypt (April, 2011).

				Cations				Anions					Water parameters				
Ser. No.	EC	TDS	pH	K^+	Na^+	Mg^{++}	Ca^{++}	Cl^-	SO_4^{--}	HCO_3^-	NO_3^-	PO_4^{-3}	SAR	Na^+ %	MH %	RSC	TH
1	5.62	5397	8.20	27.0	945.3	90.6	132.6	1341.9	732.6	170.8	11.60	1.97	15.5	73.7	52.9	-11.3	704
2	7.56	4838	7.28	29.0	1237.5	133.5	193.8	2492.1	192.4	61.0	8.13	0.22	16.7	71.5	53.1	-19.7	1033
3	4.85	3104	7.52	29.0	779.60	88.0	128.6	958.5	831.0	243.8	4.75	0.33	13.0	70.2	53.0	-9.7	683
4	0.71	454	8.58	10.0	122.00	24.00	32.5	190.0	68.0	146.0	6.43	0.04	4.0	57.9	54.7	-1.2	180

Table (3): Results of chemical analyses for the collected groundwater samples of the Quaternary aquifer in Burg El Arab area, Egypt (April, 2011).

				Cations				Anions					Water parameters				
Ser. No.	EC	TDS	pH	K^+	Na^+	Mg^{++}	Ca^{++}	Cl^-	SO_4^{--}	HCO_3^-	NO_3^-	PO_4^{-3}	SAR	Na^+ %	MH %	RSC	TH
1	2.89	1850	8.65	18.0	492	44.2	67.4	447.3	694.0	110.0	0.78	0.21	11.4	74.2	51.9	-5.2	350
2	8.16	5222	8.64	56.0	1297.2	152.2	224.4	2172.6	833.7	183.0	4.14	0.08	16.4	69.1	52.8	-20.7	1187
3	6.92	4429	8.56	33.0	1210.3	99.4	148.0	1757.3	861.2	97.6	6.28	1.26	18.9	76.2	52.5	-13.9	779
4	9.90	6336	8.81	36.0	1851.4	96.5	173.40	2236.5	1556.0	158.6	2.20	0.56	27.9	82.1	47.8	-14.0	830
5	7.43	4755	8.09	34.0	1196.0	133.7	204.0	1917.0	848.2	146.4	7.60	1.05	16.0	70.2	51.9	-18.8	1060
6	3.03	1939	7.32	22.0	483.2	52.1	79.6	493.6	668.8	122.0	8.45	1.18	10.3	70.4	51.9	-6.3	413
7	2.44	1562	7.22	13.0	385.3	47.3	68.4	479.3	388.2	170.8	5.65	0.23	8.8	68.7	53.2	-4.5	341
8	4.35	2784	7.33	25.0	768.3	58.1	86.8	1214.1	314.7	146.4	6.75	0.13	15.7	77.4	52.4	-6.7	456
9	11.00	7040	8.95	41.0	2023.9	126.2	188.8	2811.6	1308.9	146.4	7.63	ND	28.0	80.8	52.4	-17.4	991
10	12.59	8057	8.13	41.0	2058.5	213.8	326.4	2939.4	1923.5	97.6	4.60	0.08	21.7	71.9	51.9	-32.3	1695
11	5.78	3699	8.60	21.0	989.0	86.9	132.6	1341.9	831.4	134.2	7.00	0.27	16.4	75.0	51.9	-11.57	689
12	3.53	2259	9.06	42.0	581.9	61.2	87.8	766.8	576.5	134.2	1.50	0.29	11.7	70.7	53.5	-7.2	471
13	8.09	5177	8.01	58.5	1193.7	170.9	255.0	2076.8	965.8	97.6	4.35	ND	14.2	64.7	52.5	-25.2	1340
14	13.77	8813	7.20	29.0	2534.6	166.6	234.0	3692.0	1456.8	122.0	7.00	0.48	30.9	80.8	54.0	-23.4	1270
15	5.20	3334	6.18	28.0	832.6	94.9	142.8	1278.0	646.6	146.4	4.70	0.70	13.2	69.8	52.2	-12.5	747
16	4.84	3098	7.27	30.8	823.4	77.3	106.0	1214.1	559.2	146.4	6.40	0.20	14.8	74.2	54.6	-9.3	583
17	8.20	5248	6.85	22.0	1247.1	167.0	254.0	1917.0	1200.0	134.2	9.12	3.13	14.9	66.8	52.0	-24.2	1321
18	6.03	3859	7.51	23.0	1021.2	93.6	142.8	1278.0	979.2	207.4	7.95	1.55	16.3	74.2	51.9	-11.4	742
19	7.54	4826	7.07	44.1	1269.6	120.3	183.6	1917.070	931.7	122.0	7.18	0.53	17.9	73.2	51.9	-17.0	953

Units in mg/l except pH, Electrical Conductivity (EC) in mmhos/cm at 25°C, Sodium Absorption Ratio (SAR) and Residual sodium carbonate (RSC) in epm, Total Hardness (TH) in mg/l, 1 mg/l of nitrate-N is equivalent to 4.5 mg/l of nitrate-NO_3 (Bauder *et al.,* 2004). Magnesium hazard (MH) % = (Mg^{2+}×100)/ (Ca^{2+}+Mg^{2+}), where all ionic concentration expressed in equivalent per million (epm), according to Szabolcs and Darab (1964). Na % = (Na^+) x 100/ (Ca^{2+} + Mg^{2+} + Na^+ + K^+), where the concentrations of ions are expressed in epm (Wilcox, 1955). TDS are the summation of anions and cations.

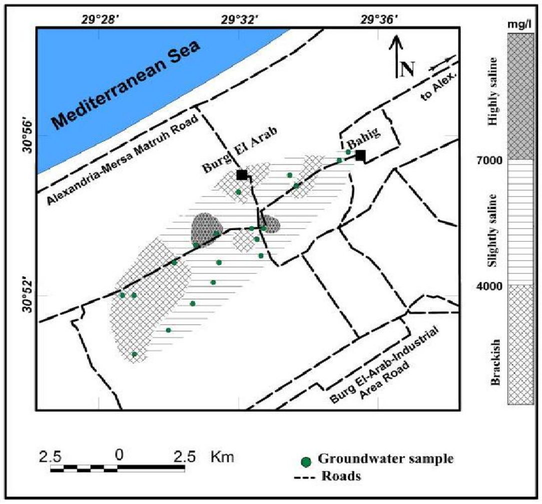

Fig. (5): Iso-salinity zonation map of the Quaternary aquifer in Burg El Arab area, Egypt (April, 2011).

Magnesium ranges between about 47 and 214mg/l, with an average value of about 131mg/l. Calcium ranges between 67 and 326 mg/l with an average value of 196 mg/l. In the majority of the collected groundwater samples, calcium percentage is slightly higher than that of magnesium. This may be explained by the abundance of carbonate minerals that composed the water-bearing formations as well as ion exchange processes and the precipitation of calcite.

Table (4): Concentration ranges for the measured constituents, water parameters and hydrochemical ratios of the collected groundwater samples of the Quaternary aquifer in Burg El Arab area, Egypt.

		Min.	Max.	Av.
pH value		6.18	9.06	7.62
E.C. (mmhos/ cm)		2.44	13.77	8.11
TDS (mg/l)		1562	8813	5188
Ions (mg/l)	**K^+**	13.0	58.5	35.8
	Na^+	385.3	2534.6	1460.0
	Mg^{+2}	47.3	213.8	130.6
	Ca^{+2}	67.4	326.4	196.9
	Cl^-	447.3	3692.0	2069.7
	SO_4^{-2}	314.7	1923.5	1119.1
	HCO_3^-	97.6	207.4	152.5
	PO_4^{-3}	0.08	3.13	1.61
	NO_3^-	0.78	9.13	4.96
Water parameter	**SAR**	8.76	30.92	19.84
	Na^+ %	64.71	82.13	73.42
	MH%	47.77	54.55	51.16
	RSC	-4.50	-32.40	-19.45
	TH	340.58	1694.98	1017.78
Hydrochemical	**rNa/rCl**	0.89	1.70	1.30
	rSO_4/rCl	0.19	1.15	0.67
	rCa/rMg	0.83	1.09	0.96
	rCl/ ($rHCO_3$+rCO_3)	4.82	52.00	28.41

SAR: Sodium absorption ratio in epm, RSC: Residual sodium carbonate in epm, MH: Magnesium hazard in %, TH: Total hardness in mg/l.

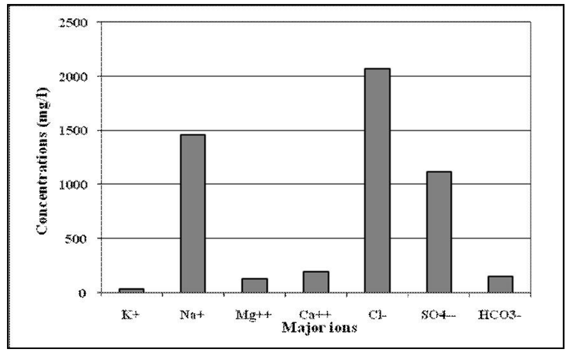

Fig. (6): Average values of major ions (mg/l) for the groundwater samples of the Quaternary aquifer, Burg El Arab area, Egypt.

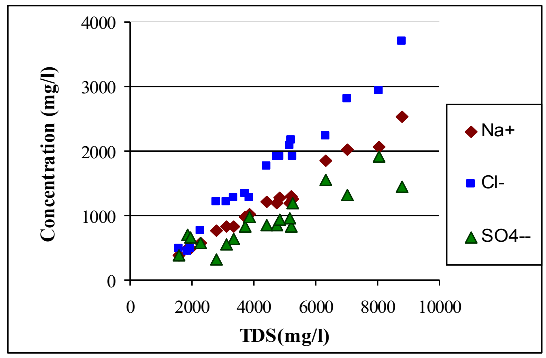

Fig. (7): Relationship between chloride, sodium, sulphate concentrations and salinity (mg/l) for the groundwater samples of the Quaternary aquifer in Burg El Arab area, Egypt.

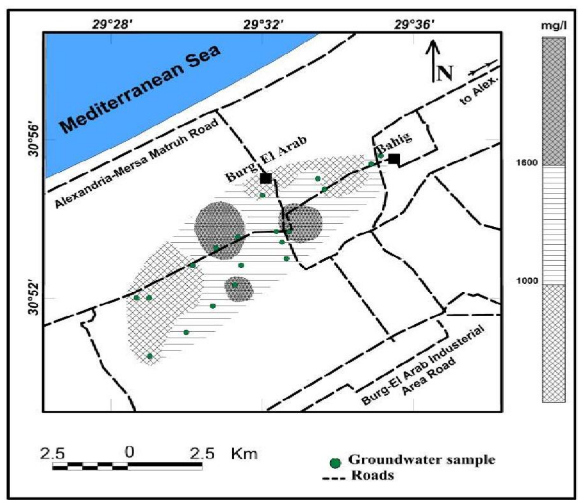

Fig. (8): Iso-sodium zonation map of the Quaternary aquifer in Burg El Arab area, Egypt (April, 2011).

Chloride content in the collected groundwater samples shows a wide range (from 447 and 3692 mg/l) with an average value of about 2070 mg/l (Fig. 9). Most of the samples have relatively high chloride concentrations that are greater than

1000 mg/l, indicating seawater intrusion (Atta *et. al,* 2007).

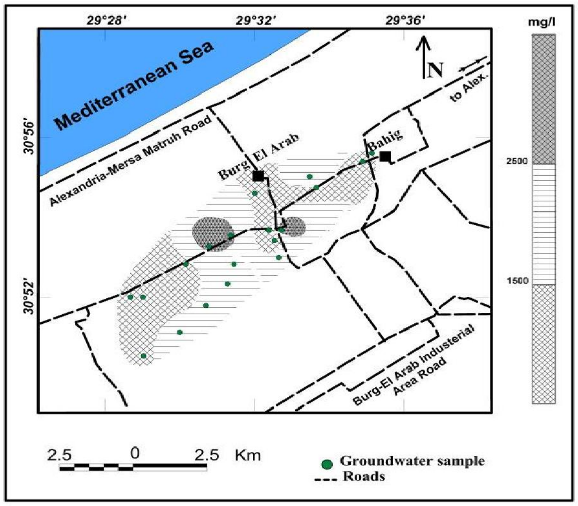

Fig. (9): Iso-chloride zonation map of the Quaternary aquifer in Burg El Arab area, Egypt (April, 2011).

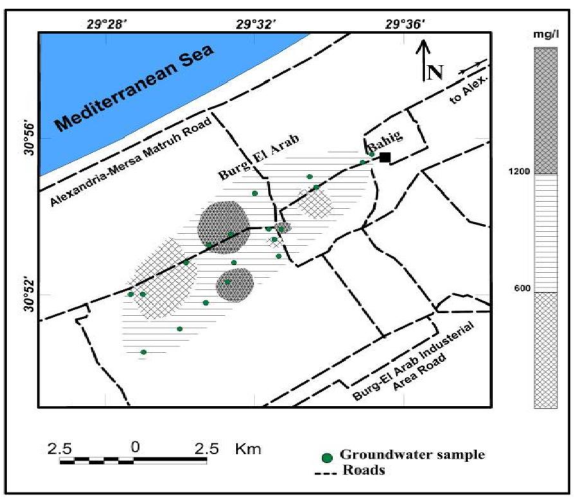

Fig. (10): Iso-sulphate zonation map of the Quaternary aquifer in Burg El Arab area, Egypt (April, 2011).

Sulphate content varies from 314 to 1924 mg/l with an average value of 1119mg/l (Fig. 10). High sulphate concentration may be due to seepage from excess irrigation water and dissolution processes of sulphate minerals rich in aquifer matrix. Sodium, chloride and sulphate ions display a nearly linear increase with increasing salinity of Quaternary groundwater (Fig. 7).

Carbonate ions (CO_3^{2-}) are not detected in the groundwater, while bicarbonates range from 98 to 207 mg/l, with an average value of about 152 mg/l. The concentrations of nitrate vary between 0.78 and 9.13 mg/l with an average of 4.96 mg/L. The concentration of phosphate ions (PO_4^{3-}) ranges between 0.08 and 3.13 mg/l, with an average value of 1.61mg/l. In comparison with the Nile water, nitrate and phosphate ions in the coastal aquifer are higher than those of the Nile water, which are recorded by Ismail and Ramadan (1995) as 0.25 and 0.1 mg/l, respectively. These relatively high concentrations suggest an influence of nitrate sources in the rural localities. However, it has a problem of loading nutrients from excess fertilizers in the new reclaimed lands in the environ of Burg El Arab area.

Chloride-sodium is the main water type that represents about ninety percent of the collected groundwater samples of the Quaternary aquifer in Burg El Arab area. Sulfate-sodium is a secondary type, which is represented by only two samples.

The degradation of water quality in Burg El Arab area is due to irrigation return flows. The agricultural inputs of nitrogen, phosphorus and salts found in the water draining from irrigation and direct deep drainage which entering groundwater aquifer adversely affect its quality.

From Piper's diagram (Piper, 1944), The groundwater samples occupy the subzone (7). In this area, the water is characterized by primary salinity character where Na^+ and K^+ exceeds SO_4^- and NaCl salt prevails compared to sea water (Fig. 11).

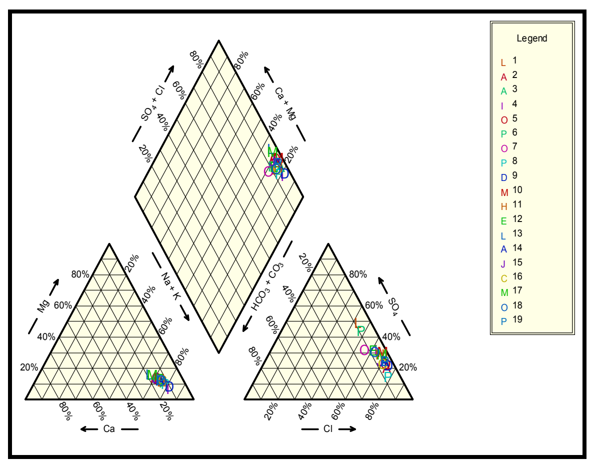

Fig. (11): Plots of the analyzed groundwater samples on Piper trilinear diagram, Burg El Arab area, Egypt.

According to the Sulin's classification (1948), about eighty four percent of the groundwater samples are located in the lower quadrant of Sulin's diagram (Fig. 12). They are characterized by $Na\text{-}SO_4$ genetic water type, indicating meteoric water mixed with sea water. The rest of the samples are located in the upper quadrant within the lower triangle, where (recall$^-$-rNa^+) /rMg^{++}<1 and $MgCl_2$ genetic salts are formed. It shows marine water genesis, which indicates recently salt water intrusion.

The ion ratios are important evidence to clear up the relationship between surface water and groundwater resources in the study area. These ratios are helpful in detecting the hydrochemical processes affecting water quality such as mixing, leaching, and ion exchange.

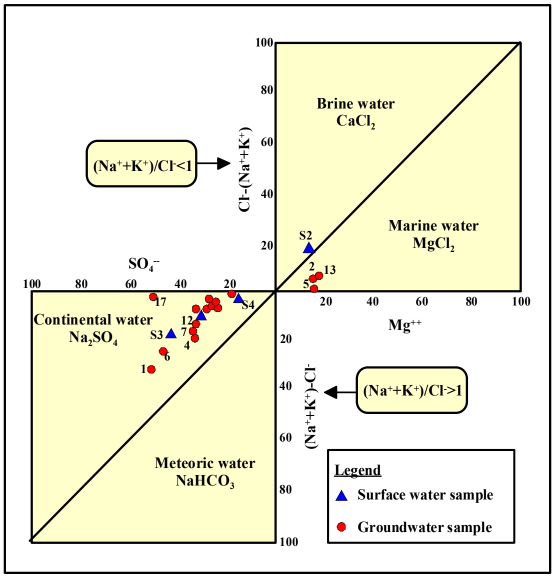

Fig. (12): Hydrochemical classification of the examined surface and groundwater samples using Sulin's (1948) diagram of the Burg El Arab area, Egypt

The rNa/rCl ratio in the groundwater of the Quaternary aquifer of Burg El Arab area varies from 0.89 to 1.70 with an average value of 1.3 (Table 4). The rNa/rCl ratio is generally more than unity. Sodium exceeds chloride in about seventy nine percent of the samples, which refers to the influence of fresh water. Meanwhile, the rNa/rCl ratio is less than unity in twenty one percent of the collected groundwater samples, which refers to the marine water effect and possibly the effect of sediments of marine origin.

The excess of sulphate ratio rSO_4/rCl is useful in determining the influence of solution of halite, gypsum, or anhydrite from aquifer material or from contaminant sources. This ratio in the groundwater samples of the Quaternary aquifer in Burg El Arab area varies from 0.19 to 1.15 with an average of 0.67 (Table 4). It is generally less than unity referring to low sulphate relative to chloride in about ninety percent of the samples.

Since magnesium present in seawater is much greater than calcium, the rCa/rMg ratio is recommended as a parameter for determining the salt-water contamination. If the ratio is less than one, the groundwater is considered to be affected by salt water intrusion. For groundwater samples, (rCa/rMg) ratio is less than one in all samples except one; this is an indication of saltwater contamination in the area.

The rCl/ $(rHCO_3+rCO_3)$ ratio is one of the criteria to evaluate the presence of seawater intrusion. For the Mediterranean Sea, the rCl/ $(rHCO_3+rCO_3)$ value ranges from 200 to 500 (Custodio and Bruggeman, 1987). The rCl/ $(rHCO_3+rCO_3)$ ratio of the groundwater of the Quaternary aquifer ranges from about 5 to 52, with an average of about 28 (Table 4, Fig 13). According to Simpson (1946) classification, fifty eight percent of the groundwater samples lie in the sea water class and thirty seven percent of the samples are located in the highly contaminated groundwater class.

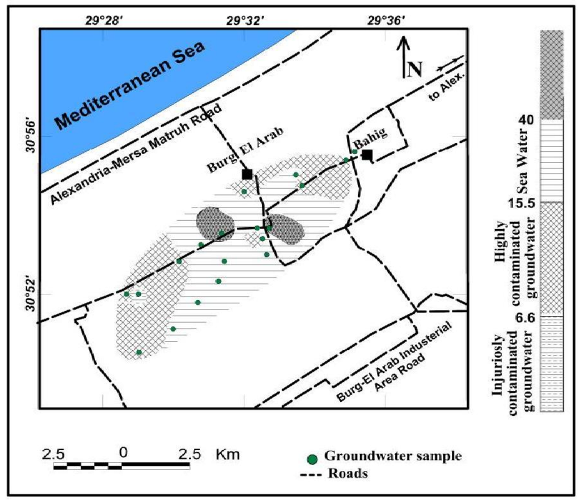

Fig. (13): The rCl/ $(rHCO_3+rCO_3)$ ratio zonation map of the Quaternary groundwater samples, Burg El Arab area.

Evaluation of Groundwater Quality for Irrigation Purposes:

Several parameters, which affect both the plant and the soil, are used to assess the suitability of the Quaternary aquifer of Burg El Arab area for irrigation purposes.

Salinity Hazard:

High salinity water can limit the growth of plants physically by restricting the taking up of water through modification of osmotic processes. According to Fipps classification (Table 5), most of the collected groundwater samples (84%) are unsuitable for irrigation and require high leaching before their usage. Regarding the relative tolerance of crop plants to groundwater salinity (Table 6), twenty six percent of the analyzed groundwater samples are suitable for irrigation of moderately salt-tolerant crops. Thirty seven percent of the samples can be used to irrigate salt-tolerant crops such as, sunflower, oats, soybean, zucchini, broccoli, olive and peach.

Twenty six percent of the samples can be used to irrigate very salt-tolerant crops such as, cotton, sugar beet, sorghum and wheat. Only eleven percent of the water samples are recommended to irrigate saline-tolerant crops such as barley (grains) and tall wheat grass (Table 5).

Table (5): Classification of collected groundwater samples based on salinity hazard (Fipps, 1996).

Classes of water	Samples	%
Class 1, Excellent (TDS<175 mg/l)	-	-
Class 2, Good (TDS=175 -525mg/l)	-	-
Class 3, Permissible(TDS=525-1400 mg/l)	-	-
Class 4, Doubtful (TDS=1400-2100 mg/l)	1, 6, 7	16
Class 5, Unsuitable (TDS>2100 mg/l)	2, 3, 4, 5, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18 , 19	84

Sodium hazard:

Groundwater may be classified according to the sodium percent (e.g. Wilcox, 1955). All the analyzed groundwater samples of the Quaternary aquifer in Burg El Arab area (Table 7, Fig. 14) have sodium percent greater than 60%. This high sodium percent may cause sodium accumulations, which lead to a breakdown in the physical properties of soil (Fipps, 1996).

Table (6): Relative tolerance of crop plants to groundwater salinity, Burg El Arab area, Egypt (adapted from Ayers and Westcot, 1976; and NWQMS, 2000).

Classes of crops	**Samples**	**%**	**Remarks**
Class 1, Sensitive crops (EC< 0.95 mmhos/cm)	-	-	-
Class 2, Moderately sensitive crops (EC=0.95-1.9 mmhos/cm)	-	-	-
Class 3, Moderately salt tolerant crops (EC= 1.9-4.5 mmhos/cm)	1, 6, 7, 8, 12.	26	**Field crops**: Groundnut, rice, safflower. **Vegetables**: Beet. **Forages:** Tall fescue, barley hay, trefoil (small), harding grass. **Fruits**: Date palm.
Class 4, Salt tolerant crops (EC= 4.5-7.7 mmhos/cm)	3, 5, 11, 15, 16, 18, 19.	37	**Field crops**: Sunflower, oats, soy bean. **Vegetables**: Zucchini, broccoli. **Forages:** Bermuda grass, wheat grass. **Fruits:** Olive, peach.
Class 5, Very salt tolerant crops (EC= 7.7-12.2 mmhos/cm)	2, 4, 9, 13, 17.	26	**Field crops**: Cotton, sugar beet, sorghum, wheat.
Class 6, Generally too saline crops (EC> 12.2 mmhos/cm)	10, 14.	11	**Field crops**: Barley (grains). **Forages:** Tall wheat grass.

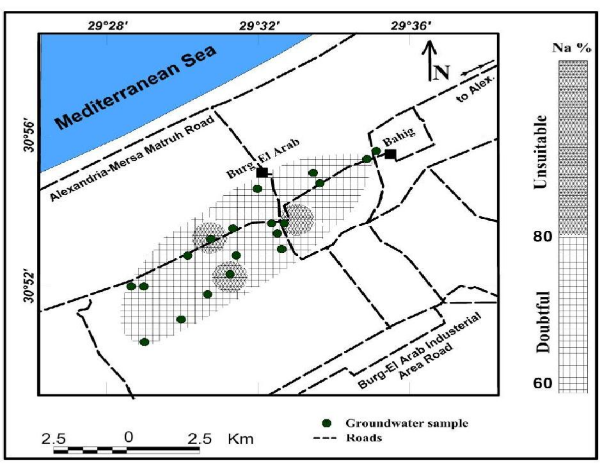

Fig. (14): Sodium percent (Na %) zonation map of the Quaternary groundwater samples, Burg El Arab area (categories classified according to irrigation purposes after Wilcox, 1955).

Table (7): Classification of groundwater samples based on the soluble sodium percent after (Wilcox, 1955), Burg El Arab area, Egypt.

Water class	**Na%**	**Samples**	**%**
Excellent	<20	-	-
Good	20-40	-	-
Permissible	40-60	-	-
Doubtful	60-80	1, 2, 3, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, 17, 18, 19	84
Unsuitable	>80	4, 9, 14	16

High salt content (high EC) in the studied water leads to formation of saline soil, and the development of an alkaline soil. Irrigation with Na-rich water results in ion exchange reactions: uptake of Na^+ and release of Ca^{++} and Mg^{++} (Khodapanah *et al.*, 2009). This causes soil aggregates to disperse, reducing its permeability (Tijani, 1994). Sodium adsorption ratio (SAR) of the groundwater samples ranges from 2 to 35 epm (Table 4). Medium to high SAR values; causing alkali hazard, are recorded in seventy nine percent of the analyzed samples (Table 8and Fig. 15).

Table (8): The sodium hazard of groundwater based on SAR Values (Fipps, 1996).

Water class	SAR values	Remarks	Samples	%
Low	1-10	Use on sodium sensitive crops such as avocados must be cautioned.	7	5
Medium	10-18	Amendments and leaching needed.	1, 2, 5, 6, 8, 11, 12, 13, 15, 16, 17, 18 &19	68
High	18-26	Generally unsuitable for continuous use.	3& 10	11
Very high	>26	Generally unsuitable for use.	4, 9 & 14	16

The relation between SAR and salinity (Fig. 16) reveals the following: **1) Water of very high salinity and very high SAR (C4S4),** this class includes three samples**; 2) Water of very high salinity and high SAR (C4S3),** this class is represented by two samples. These water samples are generally unsuitable for continuous use in irrigation of most soils and require special soil management and high leaching; **3) Water of very high salinity and medium SAR (C4S2),** this class contains sample No. 7 only. This water category is satisfactory for salt tolerant crops and soils of good permeability with special leaching. The rest of the samples are out of range.

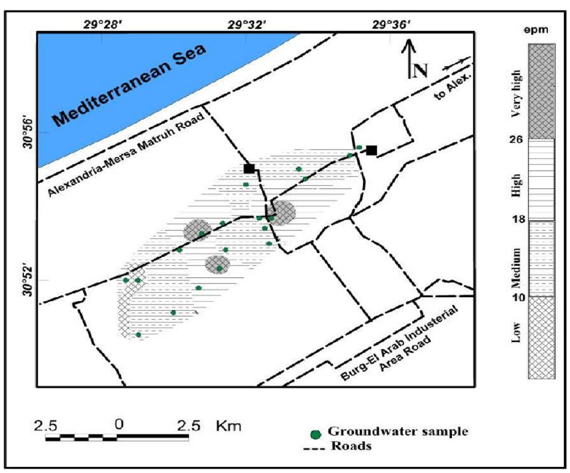

Fig. (15): Sodium adsorption ratio (SAR) zonation map of the Quaternary groundwater samples, Burg El Arab area (categories classified according to irrigation purposes after Fipps, 1996).

Magnesium hazard (MH):

Although calcium and magnesium ions are essential for plant growth, they may associate with soil aggregation and friability (Khodapanah *et al.*, 2009). Magnesium hazard (MH) must be less than 50% to ensure safe and suitable water for irrigation (Khodapanah *et al*., 2009). In the study area, the MH values range between about 48% and 55%. Ninety five percent of the analyzed groundwater samples are unsuitable for irrigation from this point of view (Table 4).

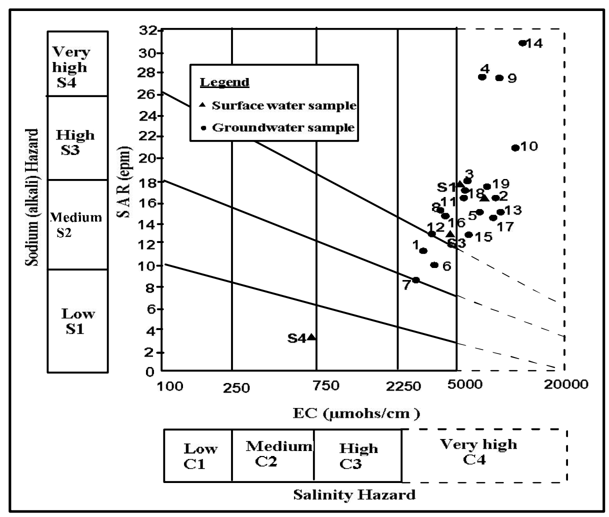

Fig. (16): Classification of the examined water samples for irrigation based on the U.S. Salinity Laboratory Staff (1954), Burg El Arab area, Egypt.

Residual sodium carbonate (RSC):

Residual sodium carbonate (RSC) has been calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purposes. In waters having high concentration of bicarbonates, there is a tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. As a result, the relative proportion of sodium in the water increases in the form of sodium bicarbonate (Sadashivaiah *et al.,* 2008). All the analyzed water samples (surface- and ground-water) fall in the suitable class for irrigation purpose according to the classification of Eaton, 1950; (RSC< 1.25) (Tables 2 & 3).

Total hardness (TH):

Water with hardness less than 150 mg/l (based on Todd's classification, 1980) is considered desirable for plant growth. All the analyzed surface- and ground-water samples exceed the permissible limit (150 mg/l) (Tables 2 & 3).

Nitrates (NO_3^-):

Nitrate ion (NO_3^-) is the common form of combined nitrogen in natural water. Nitrogen in irrigation water especially nitrate-nitrogen (NO_3-N), which often occurs at higher concentrations than ammonia in irrigation water and causes quality problems in crops such as barley and sugar beets and excessive vegetative growth in some vegetables (Bauder *et al.,* 2004). However, these problems can usually be overcome by good fertilizer and irrigation management. Regardless of the crop, nitrate should be credited toward the fertilizer rate especially when the concentration exceeds 10 mg/l NO_3-N (Bauder *et al.,* 2004). In the study area, all the analyzed surface and groundwater samples are within the safe limit, less than 45 mg/l (Tables 2 & 32).

Phosphate (PO_4^{--}):

Phosphate (and nitrate) in surface and groundwater are generally associated with the usage of nitrogen and phosphorus fertilizers. The acceptable limit for phosphate concentrations in the irrigation water is between 0-2 mg/l (Shahinasi and Kashuta, 2008). All surface water samples and groundwater samples fall in the permissible class except one sample, which exceeds 2 mg/l. (Tables 2 & 3).

Excess chloride:

Excess chloride deposited on leaves cause foliar burn (Hopkins *et al.*, 2007). Based on Ayers (1975), chloride concentrations less than 142 mg/l show no chloride toxicity problems which increase if the chloride concentration ranges between 142-335 mg/l. Irrigation water with a chloride concentration exceeds 335 mg/l causes severe problems of chloride toxicity in most plants. All the analyzed groundwater samples of the Quaternary aquifer in Burg El Arab area suffer from chloride toxicity as chloride concentrations exceed 355 mg/l (Tables 2 & 3).

Summary and conclusions:

The Quaternary aquifer in Burg El Arab area is dominated by carbonate facies and tapped by hundreds of wells for agricultural and domestic purposes. The groundwater exists under free water table conditions, and the general gradient is towards the Mediterranean Sea. The source and amount of recharge, type of sediment, and groundwater flow are mainly affecting the geochemical characteristics of the Quaternary aquifer in Burg El Arab area. The Quaternary groundwater is mainly fairly fresh to saline in character, with TDS range from 1562 to 8813 mg/l. The percentage of chloride, sodium and sulphate increases with salinity increasing. Generally, the groundwater belongs to the Na-SO_4 genetic water type, indicating meteoric water genesis mixed with sea water.

The majority of the analyzed samples is unsuitable for irrigation under normal condition and requires special soil management and high leaching. Thus, for agricultural development special management of salinity control and certain kind of plants with good salt tolerance should be considered. Twenty six percent of the analyzed groundwater samples are suitable for irrigation of moderately salt tolerant crops. Thirty seven percent of the samples can be used to irrigate salt tolerant crops such as sunflower, oats, soybean, zucchini, broccoli, olive and peach. Twenty six percent of the samples can be used to irrigate very salt tolerant crops such as cotton, sugar beet, sorghum and wheat. Only eleven percent of the water samples are recommended to irrigate saline tolerant crops such as barley (grains) and tall wheat grass.

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