Egyptian Journal of Geology, v.49, 2005, p.109-131

HYDROGEOCHEMICAL AND ENVIRONMENTAL ISOTOPIC EVALUATION OF GROUNDWATER OF THE AREA LOCATED TO THE NORTHWEST OF THE GULF OF SUEZ COAST, EGYPT

ABDEL SAMIE S. G.* AND ELEWA, H. H.**
***National Center for Nuclear safety and Radiation Control, Atomic Energy Authority**
E-mail: sgamal55@yahoo.com
**** National Authority for Remote Sensing and Space Sciences (NARSS), e-mail: hossh2@yahoo.com**

ABSTRACT

Water resources in Ain El Sukhna area play an important role in providing a source of potable water for land use and construction of new settlements. Hydrogeology, geochemistry and environmental isotopes were integrated in this study to assess groundwater resources recharging. The structural setting of the study area affected to a great extent the hydrogeological regime of the aquifer systems of the study area and resulted in the initiation of fracture or flowing springs. This same setting, especially the deep-sated faults, was responsible for the hydrochemical and isotopic composition of the groundwater of the study area. The water level at the area of the Miocene aquifer in the northern parts of the study area is higher than that of the Quaternary aquifer areas. This means that, the Miocene aquifer is the main source of recharge to the Quaternary aquifer. The main flow of water in the study area is directed from west, northwest and south to east and southeast. This gave evidence that the main recharge is coming from the upland areas, which lead to rainfall water storage in the sediments of these areas.

Chemical measurements on groundwater indicate significant variations in solute content. Its lowest values were detected at delta W. Ghaweibba and gradually increase toward the Gulf shore. The general trend of increasing salinity is directed eastward. All samples coincide with the prevalence of Cl-Na as dominant ions and one salt assemblage (NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$, and Ca $(HCO_3)_2$). The increase in Ca^{2+} ions concentration is mainly attributed to the saturation conditions in most water samples with respect to calcite and dolomite minerals. The isotopic results of O-18, D, C-13 and C-14 dating reveal three distinct recharge sources replenishing the Quaternary aquifer with different mixing ratios: 1. Paleowater from older formation (the Nubian Sandstone aquifer) seeping eastward via geological structures in Gebel El Galala El Bahariya represented by the issuing water samples (this water is denoted by isotopic depletion, old age (11,240 yr. B.P), and relatively high salt content), 2. Groundwater of Ain El Sukhna thermal flowing water with less isotopic depletion and age determination of 7000 yr. B.P and, 3. Recent recharge by infiltration of flash floods water after rainstorms over the hydrographic basins replenishes the aquifers directly on a short travel time. This water is isotopically enriched and has the signature of the Mediterranean Sea precipitation. C-13 measurements provided another confirmation of the diversity of recharge sources, where the issued water samples flow through aquifers less in carbonate minerals content (depleted in C-13). Whereas the groundwater samples are in contact with carbonate minerals cause a relative enrichment in C-13 isotopes. Marine residual deposits from the sequential regression and transgression of sea water are the main source of mineralization which is evidently observed from the low difference in isotopes with respect to salt content.

Keywords: Water resources, geochemistry, stable isotopes dating, saturation indices

INTRODUCTION

In the last few years, the West Gulf of Suez area represents one of the most strategic important areas, received considerable attention by the Egyptian Government to become one of the mega national projects regions. Ain El Sukhna is a part of the area occupies the western part of the Gulf of Suez (Figure 1). This area represents the natural extension for Cairo Suez Cities for planning projects and the construction of new settlements. Ambitious plans are being devoted to implement national projects for development of the northwest Suez Gulf area development depending on the availability of its natural resources. Almost 90% of its current water consumption is extracted from the shallow groundwater in the Quaternary and Miocene aquifers.

The rapid growth of the industrial projects (cement, ceramic, iron steel, petrochemical, and electronics beside the new Al Ain El Sukhna Harbor) through the last few years causes serious shortage in fresh water resources. Nowadays, groundwater is being excessively pumped in the coastal zone through a number of hand-dug wells by the citizen and investors. These water resources are subjected to spatial diverse and temporal variations; this policy affects the aquifer dependability as a continuous source of

water and may eventually deteriorate its water quality due to the liability of the coastal zone to sea water intrusion problems.

Location of the study area

The study area lays northwest coastal zone of Gulf of Suez. It represents a desert region located between Gebel Al Galala Al Baharyia and Gebel Ataqa at Cairo-Suez district (Figure 1). The area extends between latitudes 29° 20′00′′ and 30° 00′ 00′′ N and longitudes 31° 50′ 00′′ and 32° 30′ 00′′ E and covers about 4750 km^2. It includes five main hydrographic basins (W. Ghweibba, W. Badaa, W. Hagul, W. Hammtih and W.South Hagul). The area is already accessible by important highway roads (Cairo-Ain Sukhna, Cairo-Suez and Red Sea coastal road).

Climatic conditions

The climatic conditions prevailing in the area are typically of the arid province of the North Africa. The meteorological data are collected from the nearby stations (e. g. Suez, Qattamyia and Helwan Stations). The following is the summary of the data for period from 1978 to 1998 (Table 1).The Annual values of air temperature are 22.94°C, 21.06°C and 21.6°C at Suez, Qattamyia and Helwan, respectively. In the winter months, the temperature ranges between 11.8 and 14.9°C, whereas in the summer months, it ranges between 28.3°C and 37.3°C. In Suez Station the maximum mean annual intensity is 4.1 mm (March), whereas the minimum intensity of rain is 0.1 mm (June). The isoheytal map of the study area is shown in Figure 2. Dry drainage lines dissect the surface of the study area, which are directed into the major basins to the Gulf of Suez. Such wadis become occasionally active, when the area is affected by rainstorms.

GEOMORPHOLOGIC FEATURES

The highly complex and varied relief phenomena are reflecting the rock composition and the effect of geological structure processes of the northwest Gulf of Suez region. Moderated relief characterizes the study area at the northwest Gulf of Suez with elevations varying from sea level to + 1200 m. The landform features have a direct impact on the surface water conditions of the concerned area. They are demonstrated by watershed areas, hilly areas, drainage basins and coastal plain (Figures. 3 and 4).

The geomorphologic units were discernment upon the landsat TM image (taken in the 1995). The main geomorphologic features of the study area are summarized below (Figure. 4):

The uplands (watershed areas) constitute very prominent and scenic land features in the investigated area. The high tablelands unit occupies the central, west central, northwestern, south and northern parts of the study area. It covers large part of the northwest Gulf of Suez region. The central and northwestern parts of the study area are formed by the tops of G. Akheider, G. E1 Ramliya (+ 367m), South Akheider Plateau (+ 269m), G. Abu Trail (+ 512m), G. Um Zeita (+355m), G.EI Noqra (+ 460m), G. Um Arqoub (+ 467m), G. A1 Kahaliya (+ 577m) and G. Um Remella (+ 431m). The northern upland is G. Ataqa tableland (+ 987m), which is mainly composed of various strata of different geological ages, starts from Jurassic to Eocene. It is a bold mountain block forming an impressive feature at the entrance to the Gulf of Suez on the northern side of the study area, where it ends in high vertical scarps; on the other side, the southern part of study area, El Galala El Baharyia (Northern Galala) tableland has a maximum height of + 1274 m. It is the most impressive topographical features in the northern part of the Gulf of Suez. It extends as high plateau bounded by a scarp that rises as shear vertical cliffs from the water body of the Gulf, and is hanging on the north and south by the wide depressions of Ghweibba and Araba, respectively. The highlands are greatly sculptured by the drainage lines and draining their water through the internal main wadis (Wadi Ghweibba, W.Badaa, W.Hagul, W.Hammtih, and W.South Hagul) or directly into the Gulf of Suez, through W. Abu Darag, W.Quseib, W.A1 Abair, and W.Gammal (Figures. 3 and 4).

The hilly area extends westwards from the coast of the Gulf of Suez, where it covers a large part between the main wadis and their fringes. It shows a rugged topography including hills ranging in elevations from few meters to hundreds of meters above sea level. The hilly areas are almost flat-topped benches and isolated pinnacles of variable composition and extension. Lithologically, they are mainly covered by the Quaternary clastic sediments and extensive thick gravelly sand deposits forming a gently seaward sloping plain (Alluvial plain). The hilly area is mainly composed of Upper Eocene clay, sand with limestone, Oligocene gravels, shally sand and Miocene deposits.

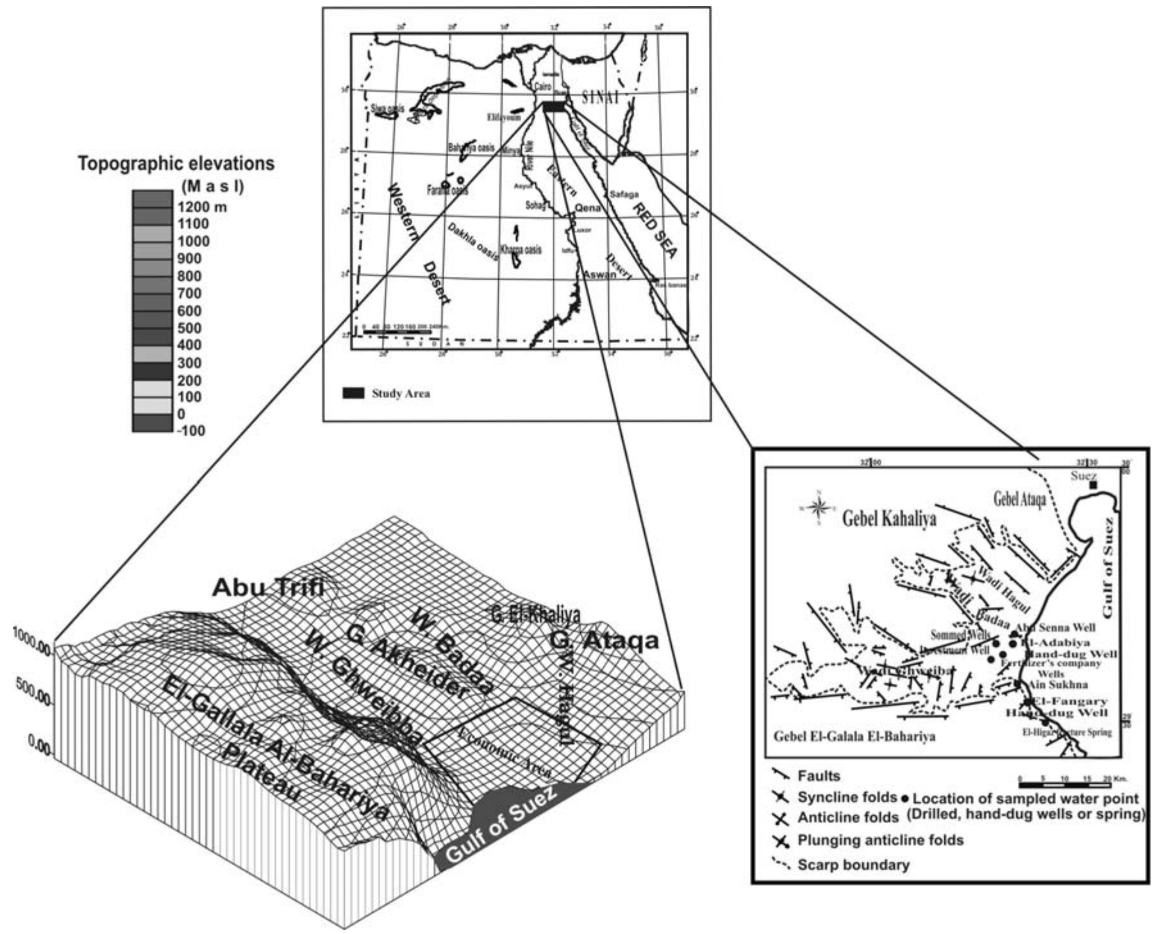


Fig. 1. Location map and wire-frame 3d model of the study area.

Table 1. Annual mean of the climatic data of the study area (1978 - 1998)

Station	JAN	FEB	MAR	APR	MAY	JUN.	JUL	AUG	SEP	OCT	NOV	DEC	Mean
Temperature (1978-1998)													
Suez	14.9	15.4	18.0	22.6	25.0	27.9	29.4	29.2	27.4	24.9	20.3	20.3	22.94
Qattamyia	11.8	13.5	15.9	20.2	23.5	26.2	37.3	26.9	25.1	22.0	17.1	13.3	21.06
Helwan	13.8	14.8	18.0	21.8	24.5	27.1	28.3	28.1	26.4	24.1	18.9	14.2	21.6
R. Humidity (1978-1998)													
Suez	59.4	56.6	54.4	46.7	43.5	48.0	54.9	54.7	56.1	57.8	60.1	60.9	54.4
Qattamyia	63.2	57.9	55.4	46.7	47.7	40.9	52.2	56.8	56.4	61.5	63.7	66.2	55.7
Helwan	65.1	57.15	54.6	44.5	42.5	46.1	53.2	56.1	58.3	58.8	61.9	63.1	54.9
Evaporation (1978-1998)													
Suez	5.31	6.4	7.91	9.76	11.5	12.2	11.4	9.5	9.6	7.61	5.97	4.92	8.51
Qattamyia	6.06	7.61	9.48	11.8	13.6	13.9	13.3	11.3	9.88	8.37	6.51	5.6	9.78
Helwan	6.2	7.7	9.6	12.4	14.7	13.5	11.8	10.5	9.35	8.45	6.77	9.43	10.1
Rainfall (1978-1998)													
Suez	3.72	3.8	4.13	0.93	0.37	0.09	0.00	0.00	0.24	0.73	1.40	2.40	1.48
Qattamyia	1.36	1.68	1.78	0.89	0.60	0.00	0.00	0.00	0.00	0.19	0.80	1.17	0.71
Helwan	1.25	1.64	1.82	0.57	0.13	0.00	0.00	0.00	0.00	0.04	2.6	1.03	0.75

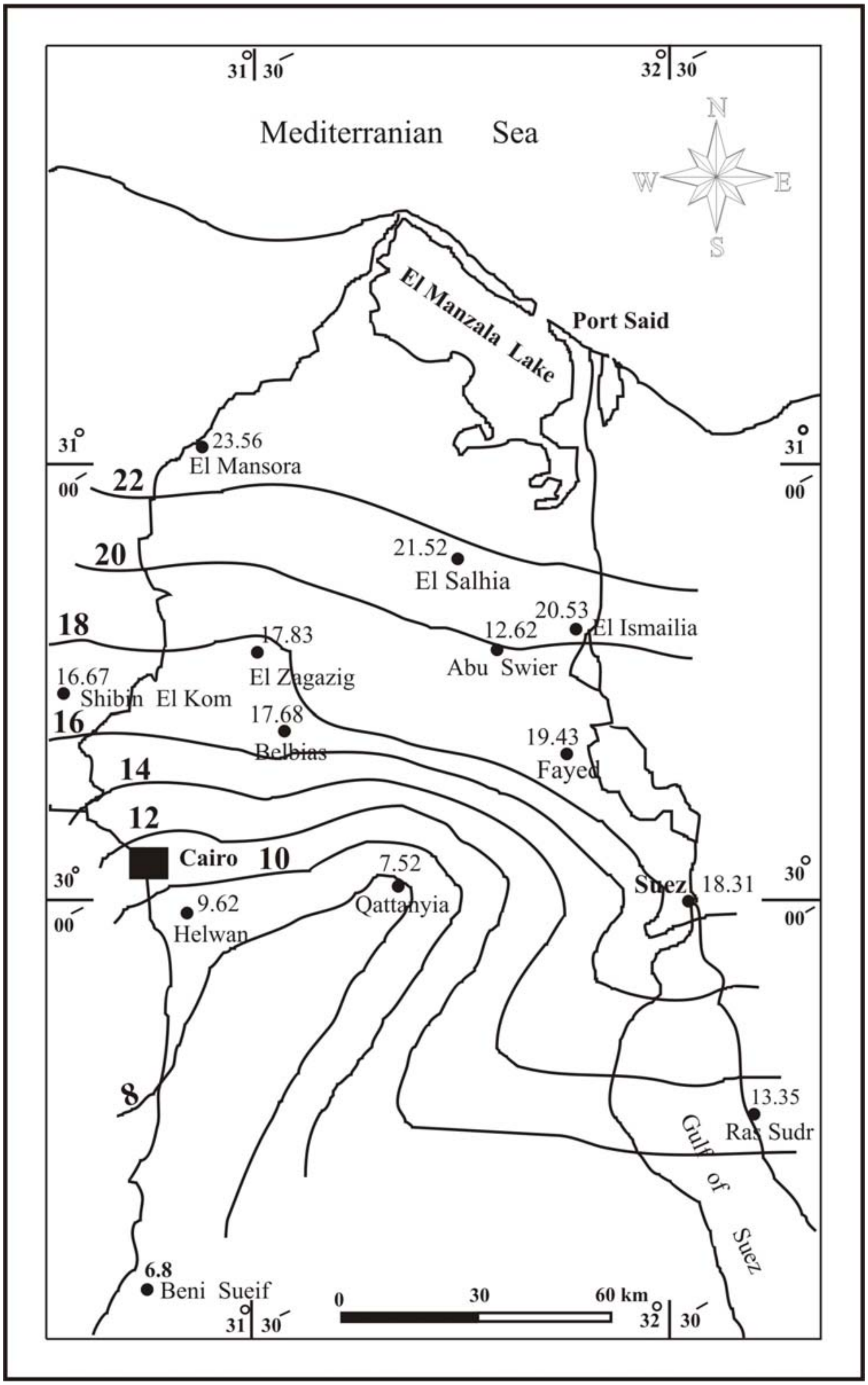


Fig. 2. Isoheytal map of the annual rainfall intensity (mm) of the study area.

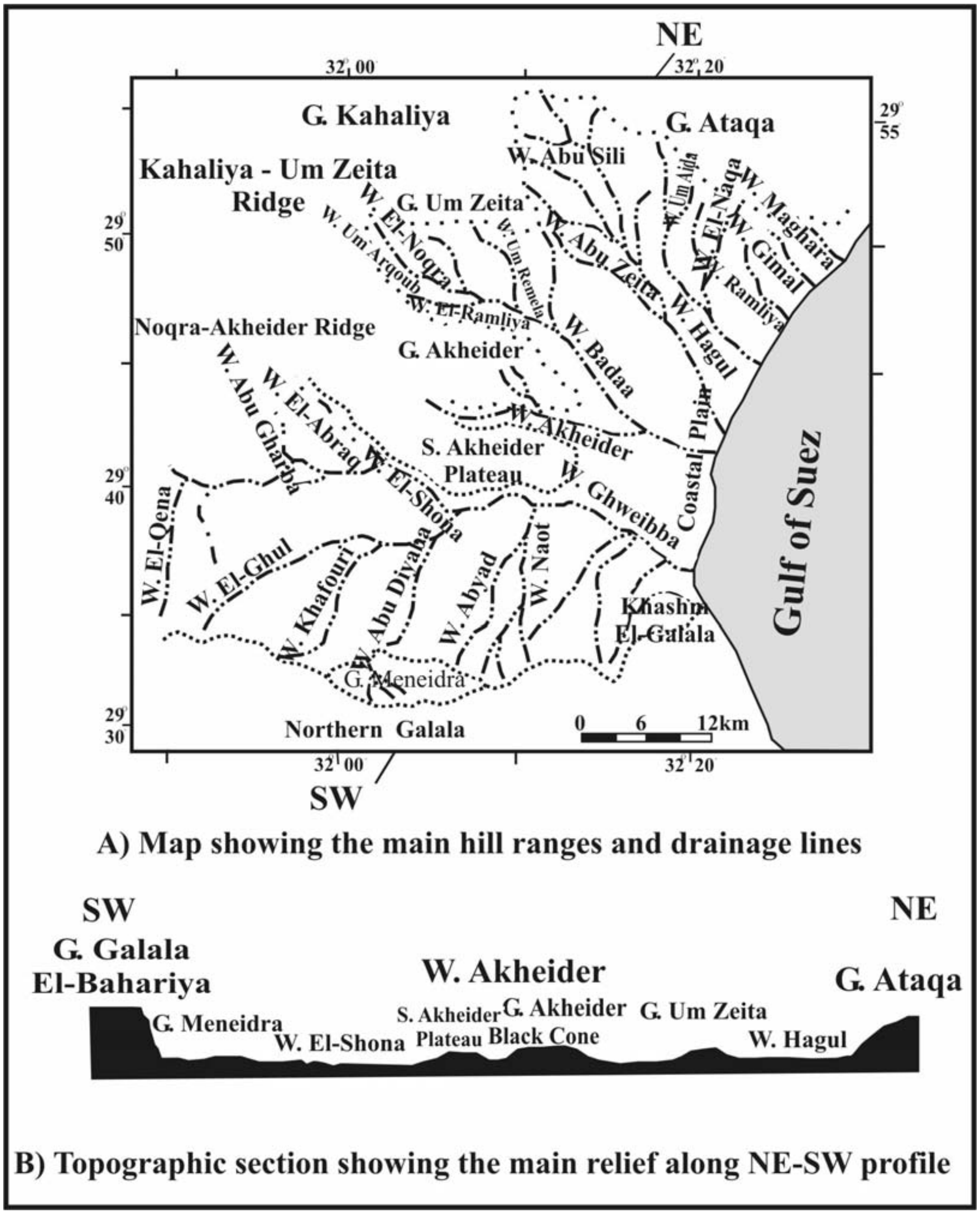
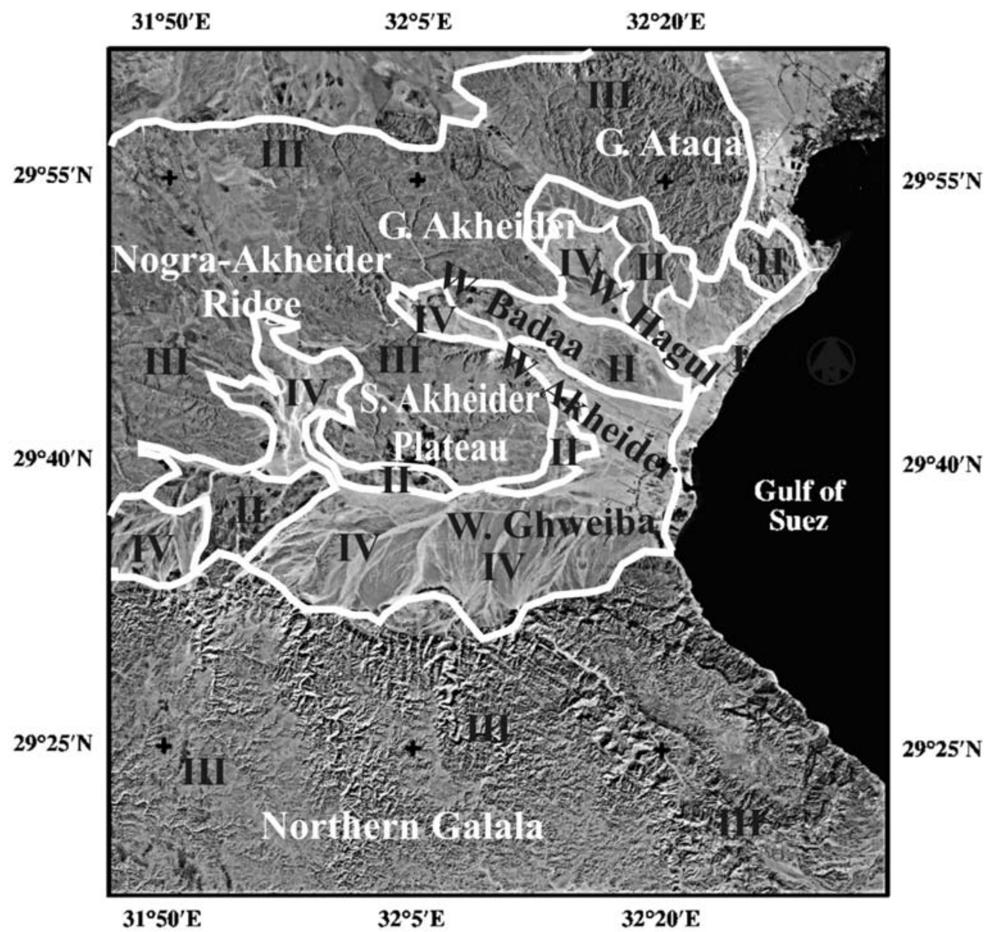


Fig. 3. The main topographic features in the area between G. Ataqa and Northern Galala (after Sadek, 1926).



Legend:

I Coastal areas II Hilly areas III Watershed area
IV Main wadis

Fig. 4. Geomorphologic units of the study area (interpretated from landsat TM image, 1995).

The coastal plain is bounded from the eastern side by Gulf of Suez water body and the continuous bedrock exposures from the west. It extends in NW-SE direction parallel to the Gulf of Suez. The elevation of the land in coastal plain ranges between few maters to + 27 m above sea level. The elevation decreases generally from northwestern to southeastern direction with some local sabkha deposits, which is accumulated and the occasionally wet at the northeastern parts of Khashm El Galala, at Ain Sukhna area. The coastal plain at the mouth of the major steams of the main wadis (i.e. W.Ghweibba, W.Badaa, W.Hagul ...etc) is characterized by an increase of the width far from the Gulf of Suez. It is about 11 km width at the mouth of W.Ghweibba and decreases steadily towards the north and south.

GEOLOGIC SETTING

The sedimentary rock units belonging to Carboniferous, Jurassic, Cretaceous, Eocene, Oligocene, Miocene, Pliocene, and Quaternary occupy the area located to the northwest of the Gulf of Suez (Figure 5) (Said, 1962). The coastal plain is covered mainly by the Quaternary sediments, which form a gently seaward sloping plain. These sediments are distinguished into two types. The first is represented by the Quaternary terraces, which constitute the greater part of Wadi Ghweibba and Wadi Badaa plains and are composed of gravels (limestone clastics) reaching a thickness of 5 m. The second is represented by the Quaternary alluvial sediments, which occupy the actual course of wadis terraces and the whole of the Sukhna plain forming disconnected deltas-like sediments. These are composed of relatively fine and loose materials. The low-lying hills range in height from a few tens of meters to more than 100 meters. They involve exposures of Pliocene, Miocene, Oligocene, and/or Upper Eocene rocks.

The exposures of Pliocene rocks have been described from various locations north of Wadi Badaa, Wadi Ghweibba and the coastal plain. The Pliocene rocks on the surface are mainly covered by the Quaternary deposits (Said, 1962). The Miocene rocks cover the greater parts of the low land in the district between Gebel Ataqa and El Galala El Baharyia plateaus. They are restricted to the northeastern, southern and southwestern reaches of the project area.

The Oligocene beds are similar to those at Gebel Ahmar near Cairo and overlie unconformably the Upper Eocene beds in Ataqa and El Galala El Baharyia Depression (Sadek, 1926). They occur in two facies being of sedimentary and volcanic origin. The Eocene rocks are represented by the Nummulitic limestone, which forms the main part of Ataqa and Galala, as well as the faulted blocks of Akheider, Naqra, Um Zeita and Kahaliya like wising the top of the fault block of Khashm El Galala and the low faulted plateau of El Menidra. The Cretaceous rocks overlie the Jurassic deposits, forming the middle part of Khashm El-Galala and exhibits a prominent (protruding) rocks in the lower part of the main Galala Scarp forming a thin strip extending over 10 km eastward. These rocks occur in the lowermost part of the eastern scarp of the fault block of El-Galala El-Baharyia Plateau. This formation measures about 170 m in thickness. Paleozoic rocks are exposed between Wadi Aheimer and Abu El-Darag, just south Ain Sukhna spring. The outcrops are strongly controlled by the considerable vertical tectonic movements.

The transgression and regression of Tethys Sea played an important role for sedimentation in the study area (Abd Ellatief et al, 1997). The first main transgression occurred in the Middle Carboniferous which was followed by continental ones in the second half of Carboniferous, Permian, Triassic and the beginning of Jurassic. The second main transgression of the Tethys Sea occurred in the Jurassic period, where the sea was oscillating, and leaving deep and shallow water facies interbedded with continental sandstones. At the beginning of the Cretaceous, back retreated northward took place which was persisted well into Eocene and massive beds of limestone and dolomites originated to these seas. The great plateau of Galala, Akheider and Ataqa mountains are to great extent built up of Eocene formations. Middle Eocene marked the final major influence of this northern sea (Tethys). In the Oligocene, a series of events changes the quiet geological picture dramatically. Faulting in the Oligocene was accompanied to some extent by minor intrusion and extrusions of basalt. The Miocene sediments support the idea of two stages opening of the Red Sea, separated by a long period of quiescence. The last stage started in Pliocene- Pleistocene. Sometimes, during the early Pliocene the Red Sea became part of the world rift system.

HYDROGEOLOGICAL BACKGROUND

Aquifers geometry

To investigate the aquifer extension and its thickness, the data from different wells are used to construct a cross section (Figure 6). This section was drawn between some selected wells (Figure 7). The section gives a clear picture of the vertical and horizontal extension as will as the thickness of the water-bearing formations in the area.

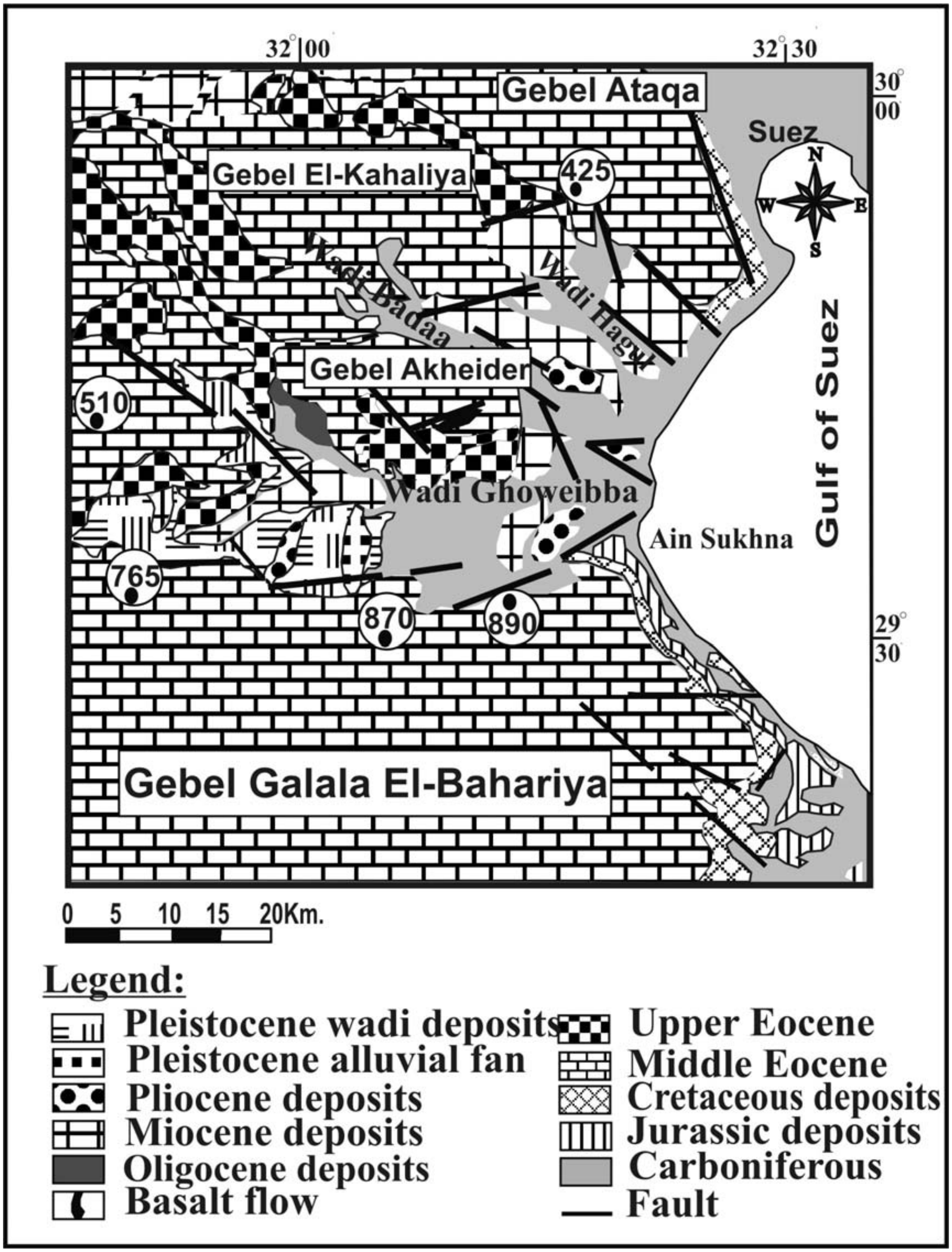


Fig. 5. Geological map of the study area (based on CONOCO, 1987 and landsat TM image, 1995)

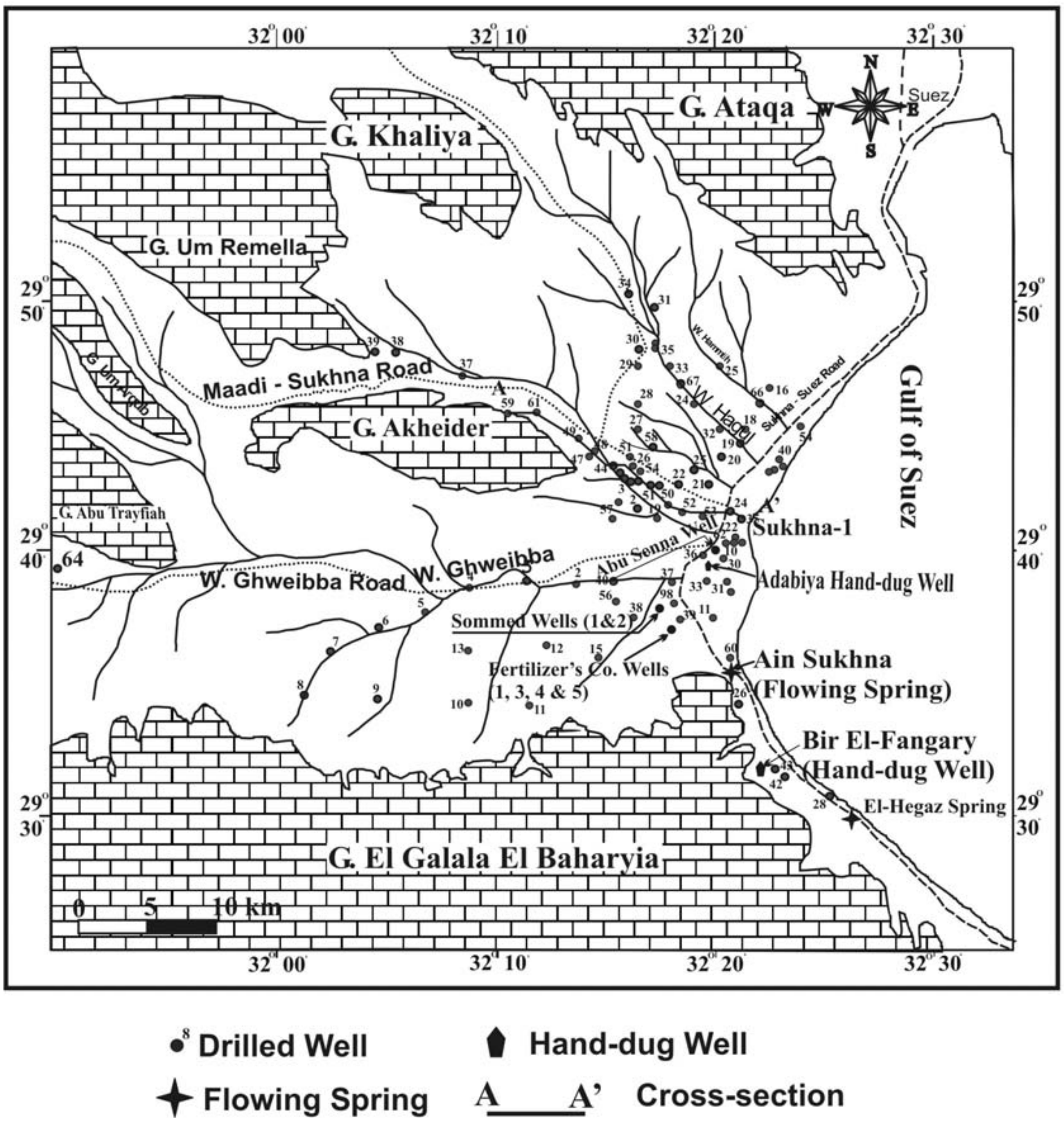


Fig. 6. Location map of water wells of the study area.

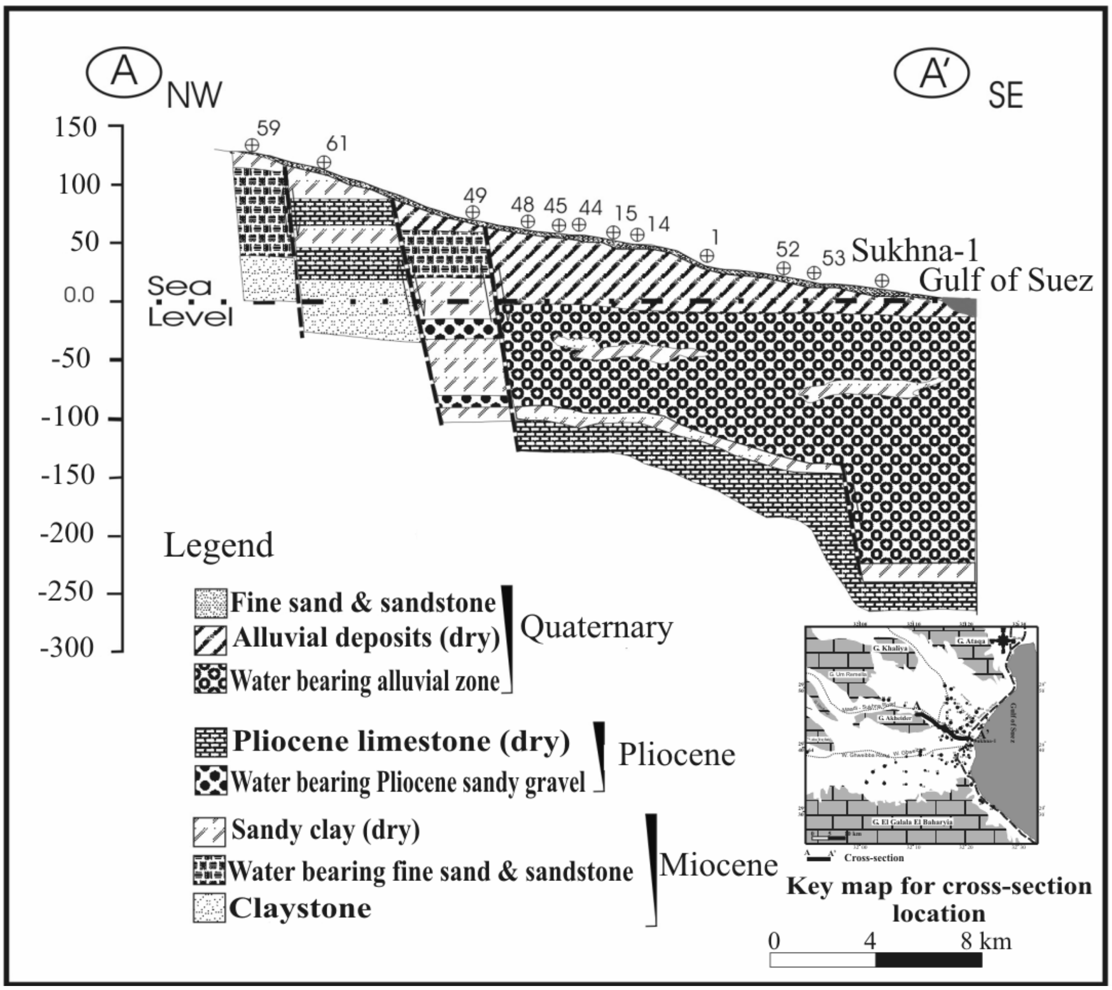


Fig. 7. Hydrogeological cross section across NW-SE direction of the study area.

The cross section was constructed along the course of Wadi Badaa. It extends from northwest to southeast with a length of about 25 km. This section passes by the Wells nos. 1, 14, 15, 44, 45, 48, 49, 52, 53, 59, 61 and Sukhna-1.

The A-A′ cross-section reveals a wide variation of lithologic composition, which is attributed to the effect of many normal step faults. The first fault influences the area between Well no. 59 and Well no. 61, where the up-thrown side is the dry Miocene sediments and the down thrown side is the dry Pliocene deposits (sand, limestone and claystone). The second fault exists between Well no. 61 and Well no. 49 and influences the Pliocene sediments. However, the Pliocene deposits in the area of Well no. 49 includes low saturated zone of groundwater (very low productivity). The third fault is found between Well no. 49 and Well no. 48. This fault brought the Pliocene sediments opposite to the Quaternary sediments. There is another fault influences the area between Well no. 53 and Sukhna-1 Well. Due to this fault, the Quaternary deposits are increasing in thickness. At the start of the section (at northwest), the Eocene, Miocene and Pliocene deposits are water-bearing formations (sand, gravel with marl). These formations are found below the Quaternary deposits (clayey sand, gravel with sandy clay lenses). They are fully penetrated by the Wells nos. 48, 45, 44, 15, 1, 52, 53 and Sukhna-l and overly the dry layer of the Pliocene clayey limestone. The thickness of the Quaternary water-bearing layer is gradually increasing towards the southeast (towards the Gulf of Suez) with the down throwing of the step faults and varying from 60 to 250 m thick.

The dry layer is composed of gravely sand and clay and its thickness ranges from 5 m to 64 m from the southeast to northwest, respectively. The water level in this section varies from 0.0 to + 3.10 m. The salinity of the water ranges from 2459.78 ppm to 6681.52 ppm.

Groundwater levels

In order to detect the groundwater flow from the areas of recharge to the areas of discharge, a detailed depth to water surveying has been carried out .The main water level contour map of northwest Gulf of Suez area is based on the available hydrogeological data from the existing water wells.

The depth to water is topographically controlled, where the higher elevated areas have the greater depth to water (>100m) and the low areas have depth to water of less than 5m below ground surface. In order to evaluate the potentiality of the groundwater and its extension, the directions of groundwater flow and the elevation of the water surface should be known and referred to some datum, preferably mean sea level. From the analysis of the groundwater map (Figures. 8 and 9), one can deduce the following:

a) **Generally, the water levels vary from west and northwest to east and southwest. The groundwater level decreases gradually from more than 100 m (towards the upstream of wadis) to few centimeters above the sea level near to the shoreline.**
b) **This low level of the groundwater is due to the low relief of the coastal plain in the deltas of the drainage basins.**
c) **The water level at the area of the Miocene aquifer in the northern parts of the study area is higher than that of the Quaternary aquifer, where the two aquifers are highly influenced by faulting. This suggests the hydraulic connection between them. The Miocene aquifer acts as a source of recharge to the Quaternary aquifer.**
d) **At the southern part of the study area, the water level is higher than the water level in the middle parts, which is due to the higher ground level beside El Galala El Baharyia Plateau.**
e) **The intensive contours of potentiometric surface in the Miocene flow net are attributed to the influence of geologic structures (Figure 9).**
f) **The direction of groundwater flow in the Miocene aquifer in the studied area was interpreted from the flow net map, where the flowlines were drawn orthogonal to the equipotential lines (Figure 9). The trends of the groundwater flow in the studied area indicate the following:**
g) **Adjacent to El Galala El Baharyia Plateau, the groundwater flows from the southwest to northeast with low hydraulic gradient. Also, at the northern part (beside G. Ataqa) the ground water flows from northwest to southeast, which is attributed to the effect of the step faults.**
h) **The main flow of water in the study area is directed from west, northwest and south to east and southeast. This gives evidence that the main recharge is coming from the upland areas, where the watersheds are located and the rainfalls are draining due east, northeast and southeast.**
i) **At the northern territories of the study area, the groundwater in the Miocene aquifer moves towards the southeast. The equipotential lines are not coincided with the equipotential lines of the Quaternary aquifer (at W. Badaa), where the groundwater moves to the east.**

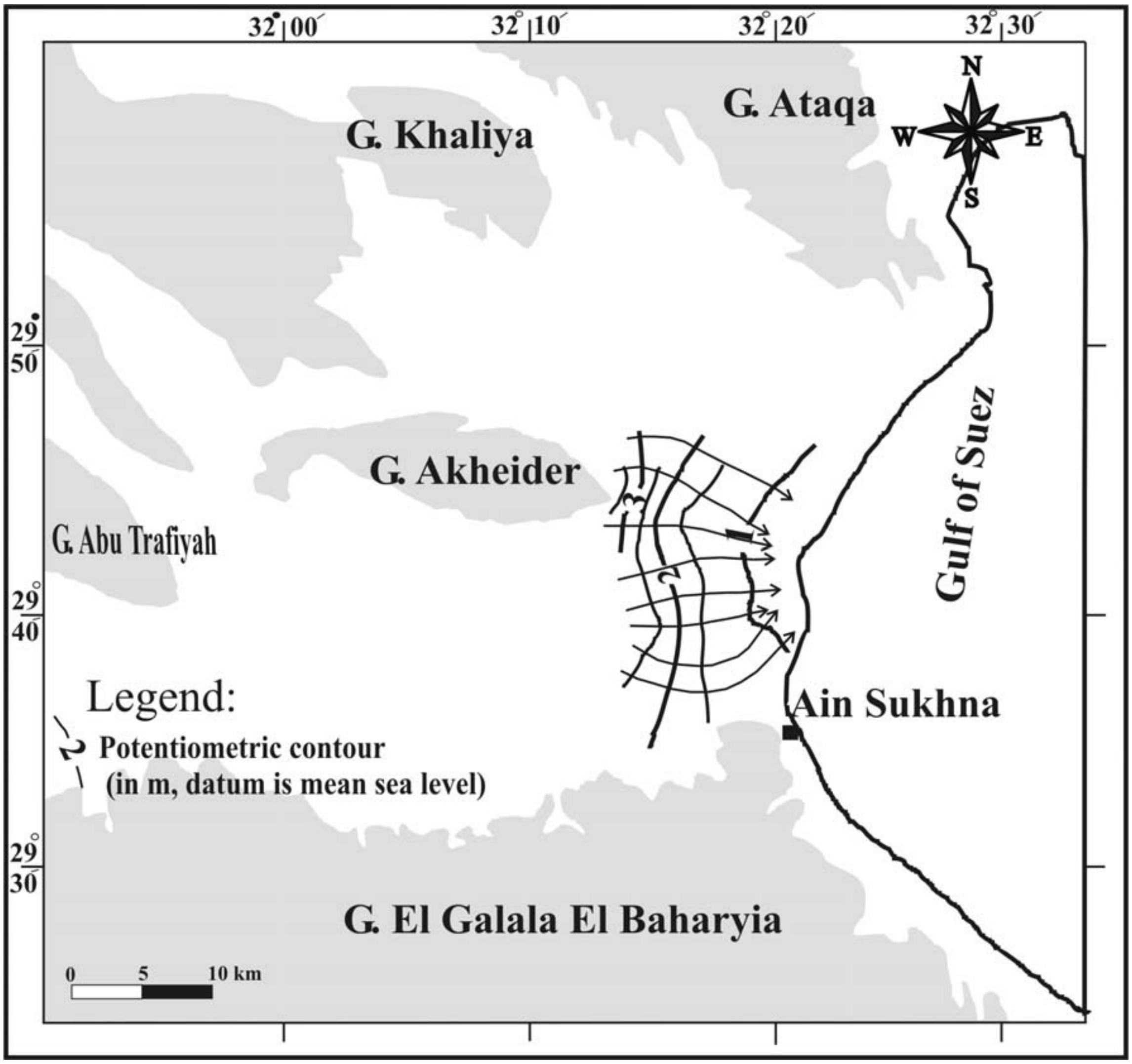


Fig. 8. Flow net map of the Miocene aquifer of the study area.

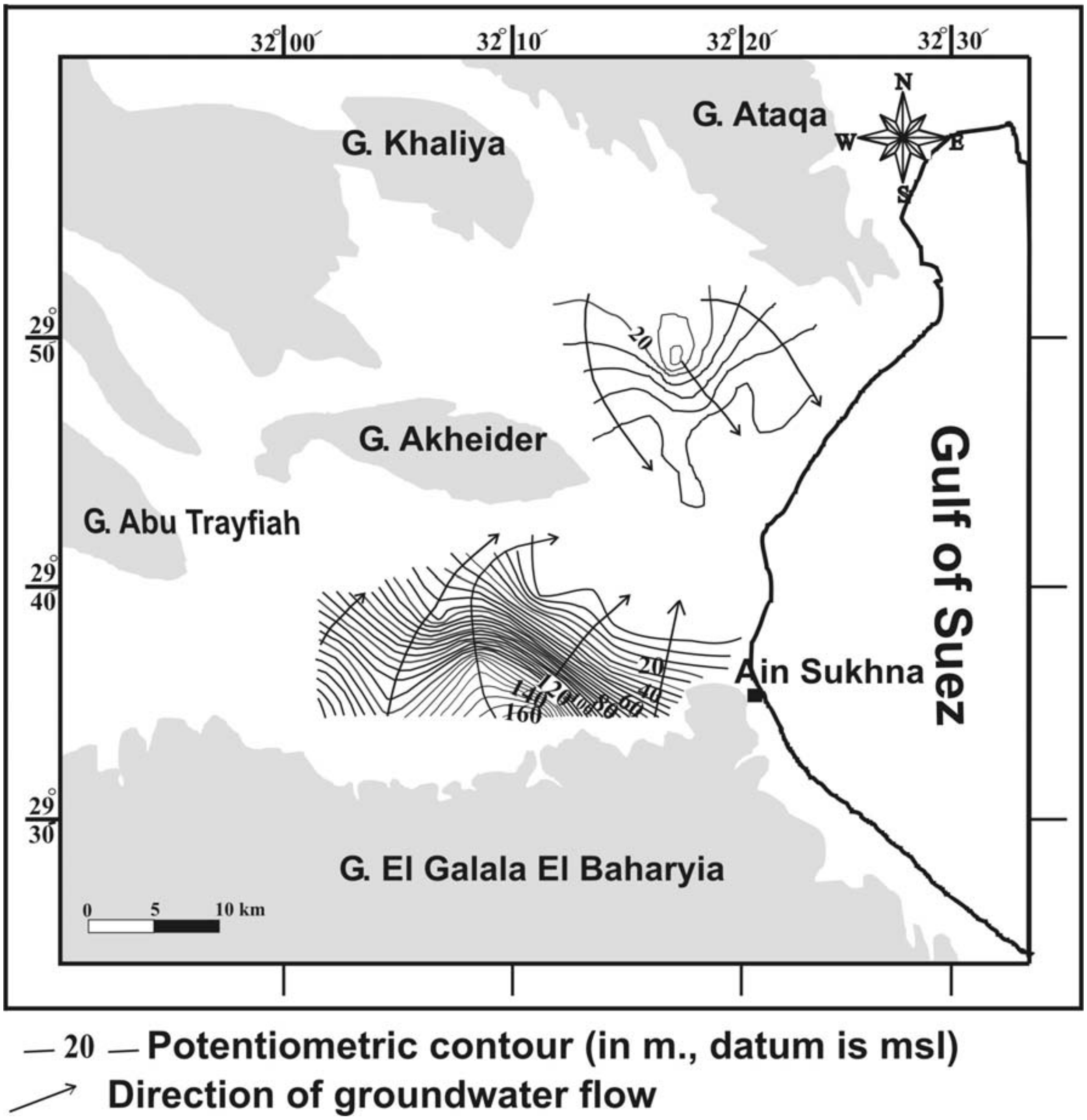


Fig. 9. Flow net map of the Miocene aquifer of the study area.

FIELD AND LABORATORY WORKS

Fourteen water samples were collected during the field work of the present study (Figure. 6). These samples represent two aquifers (Quaternary alluvial deposits and the Miocene sandstone). They comprise; five naturally issuing water samples were collected from the coastal plain of Gulf of Suez. Two of them occur as fracture springs at about 1.5 m below the ground level (El-Fangarry and El-Addabia), and the others are flowing springs (El-Hegaz, Wadi Qusseb and Ain El-Sukhna). Eight groundwater samples are tapping the Quaternary aquifer were collected from the drilled wells in the concerned area. One sample was taken during the rain event which took place during the field work. This sample was collected from the accumulated water in wadi floor. Dissolved inorganic carbon was precipitated by adding $BaCl_2$ salt to adequate volume of water sample at higher pH value, followed by adding O-H_3PO_4 to liberate CO_2 in a vacuum line. Small volume was taken to measure ^{13}C stable isotope, while the remaining volume continued for benzene synthesis to measure C-14 by Liquid Scintillation Counter. Stable isotopes of ^{2}H, ^{18}O were measured by the Isotopic Ratio Mass Spectrometer by equilibration method according to the procedure described by Epstein and Mayeda (1953), and Horita, (1988). The results obtained are expressed as δ notation, which represents the deviation in part per thousand (o/oo) of the isotopic value of the sample with respect to the international reference value (SMOW for O-18 & D in case of water samples) and PDB for C-13 in dissolved inorganic carbon (DIC).

Hydro chemical characteristics

Field and laboratory measurements of pH, temperature and major ions are given in Table 2. The chemical characteristics of the collected water samples could be outlined as follows:

The hydrogen ion activity characterizes water samples from neutral to a mild basic media (7.03 to 7.92). It depends on the type of weathered rocks. The issued water sample taken from the Miocene aquifer acquires the highest salt content (8173 mg/l) and a temperature (33°C) with respect to the other flowing water from the Quaternary aquifer (3866- 5930 mg/l). Whereas, the exploited water from the Quaternary aquifer exhibits two different solute concentrations; high concentration were found in Fertilizer and Abu Senna wells, which have similar salt content as that of the issued waters. On the contrary, fresh water is abstracted from the Investment, Addabia and Sumid wells at depths of about ≤50m. The range of this salinity is from 1035 to 1500 mg/l, which may reflects a direct replenishment from the westward watershed area (from Gebel Akheider), where these wells are located at the downstream of Wadi Ghweibba that receives the discharge of surface runoff through the main channel.

The chemical measurements indicate a relative enrichment of salt content in rain water sample implying a fast leaching of salts present at the soil in a short time of contact with it.

Despite the quantitative variations of salt content in the collected water samples, the arrangement of the ions concentration follows mostly one main order: Na> Ca> Mg / Cl > SO_4 > HCO_3, where Ca and Mg are alternatively in the cationic sequence, while anions have the same order. The Cl & Na are the dominant ions, and the water type is predominantly chloride–sodium in all samples. As well as, the calculated values of the hypothetical salt combination gave one salt assemblage arranged as: NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$, and Ca $(HCO_3)_2$. The coincidence of salts present in all samples from the two aquifers (Quaternary and Miocene) by only one assemblage designates the hydraulic connection between them.

The mineralization sources could be estimated from the ion ratios calculations, whether they are related to marine or meteoric origin. Six ion ratios were calculated as indicated in Table 3 and correlated with those of the same ratios in rain and sea waters. rNa/rCl shows higher chloride content than sodium, and ranges from 0.62 to 0.88. This ratio is less than the value of rain water and more or less than the value of sea water, which indicates the absorption of Na ions on the rock matrices and release of calcium ions to attain the cationic equilibrium. The presence of $MgCl_2$ salt in parallel with the depletion in rNa/rCl ratio reflects that the main source of water mineralization is mainly attributed to the marine sources. According to the calculated values of rCl-(rNa+rK), the predominance of Cl^- ions with respect to Na^+ and K^+ ions that was attained from the positive results of this parameter; reinforces the marine genesis of the Quaternary and Miocene waters. The occurrence of these wells adjacent to the Gulf of Suez water could affect their mineralization by its salts in aqueous or dry form.

On the other hand, the increase of rCa/rMg more than one in most samples confirms the presence of calcareous facies within the aquifer matrices enhancing the leaching processes by increasing calcium concentration. Also, the increase of rSO_4/rCl, rCa/rCl and rMg/rCl ratios relative to the sea water adds

other weathering sources could be gypsum, calcite and dolomite that prevail in the host rock. The solubility amplitude of these minerals in accordance with their ions concentration and pH values were calculated using Solmineq Program (Khavaka et al 1988) as presented in Table 4. The concentration of calcite and dolomite exceeds equilibrium (>0) and reach the saturation, except samples nos.6 and 7, which are less than the saturation level of calcite (-ve), (Figures 10 and 11). In addition, the dissolution of the other minerals (Anhydrite, Gypsum, and Halite) is still active till their concentrations attain the saturation level.

Figure 10 shows the increasing of saturation indices as ionic strength increase. The dependency of saturation index of each mineral on its solubility product is clear, where calcite and dolomite have the lowest solubility product, so they tend to precipitate firstly. They are followed by gypsum, anhydrite and halite, which have the highest solubility product that tend to precipitate at higher ionic strength. The good coincidence of the concentration of some ions species against the saturation indices of some minerals (i.e. HCO_3 against total inorganic carbon (TIC), Ca against calcite-dolomite, and SO_4 against gypsum and anhydrite) implies that these ions species are mainly derived from the dissociation of these minerals (Fig. 11).

Stable and radioactive isotopes

The results obtained from the isotopic measurements of the collected water samples are shown in Table 5. The isotopic results of the collected samples range from -8.2 to -1.91o/oo for oxygen-18 and from -57.2 to -6.67o/oo for deuterium. Water issued near the ground level or naturally flowing from the Quaternary and Miocene aquifers (samples 1, 2, 3, and 4) are isotopically lighter relative to the other samples. These springs are located at the foot slope of the upland area of Gabel El Galala El Bahariya (catchment area) in the narrow coastal plain.

Plotting the data points with respect to the Global Meteoric Water Line (GMWL) in the conventional relationship of δO-18 and δD. Figure 12 demonstrates that; the distribution of the points along the global meteoric line reflects the meteoric origin of water, without significant mixing with sea water. Meanwhile, the isotopic oscillation along this line with different d-excess parameter ($d^*=\delta D-8\delta^{18}O$) indicates different recharge sources feeding the aquifers, having a signature of paleo and recent meteoric waters. These values could be classified into three groups. Two groups of samples are characterized by lower d* less than 10 (slope of the GMWL $\delta D=8\delta^{18}O+10$).

The first group (samples 1, 2, 3 and 4) is isotopically depleted and distributed below that line at the lower depleted end and closer to the mean value of the Western Desert paleowater (δO-18= -10o/oo, δD=-78o/oo) (Sadek,1996). The second group is represented by the groundwater samples (7, 11 and 12) with lower d-parameter and enriched in isotopes. This isotopic enrichment implies different stages of evaporation during surface runoff of down stream water prior infiltration. The third group (samples 5, 6, 8, 10, 13) has d* values higher than 10 and is distributed at higher slope than 8, as that of the GMWL, which reflects the direct replenishment by recent precipitation in a short travel time, with minimal evaporation.

The increment in d* parameter of rainwater sample around 17 refers to the Mediterranean Sea air masses (d*=22) (Dansgaard, 1964), where the condensed moisture moving from the north to the south direction causing the precipitation over the area. These air masses are characterized by high difference in both oxygen-18 and deuterium, which is due to the kinetic isotopic fractionation in a partially closed basin and temperate area leading to such enrichment in d* relative to the GMWL (d*=10).

When taking the regression line of these samples (except samples 7, 9, 11 and 12), it follows a linear relationship with a slope of 9.93 and intercept 23. This line passes through the average point of the Nubia Sandstone paleowater, and passing through the Miocene water represented by Ain El Sukhna sample. Meanwhile its extrapolation meets the evaporated rain point representing the other end member of that line. It represents a mixing line of three components with two end members, where the location of each point on the line represents a distinct ratio of each component (proportional to the relative amounts contributed be each end member). Though it could be considered that, the paleowater is the main component of the issued water samples (1 and 2) that seeps from older formations mixed with a somewhat low percentage of the Miocene water. Furthermore, this is confirmed by the higher age obtained from the C-14 measurements in sample-1 (11,240 yr.b.p.) and lower d*.

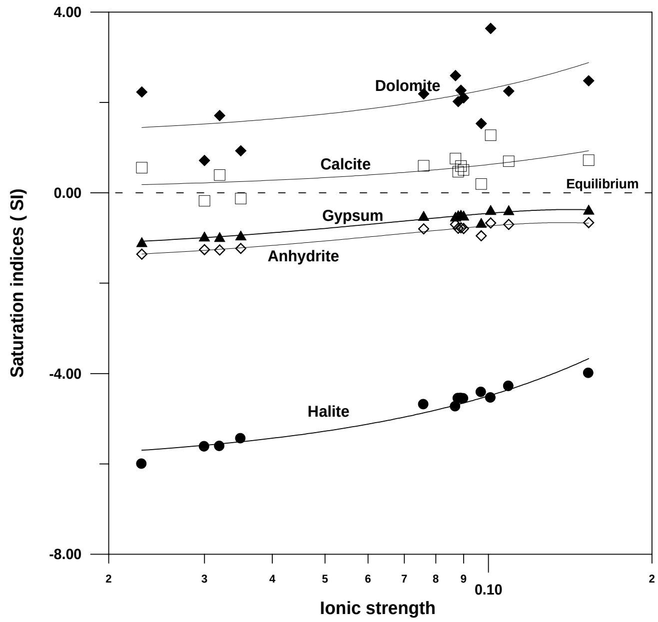


Fig. 10. Ionic strength (IS) as a function of saturation of calcite, dolomite, anhydrite, gypsum and halite.

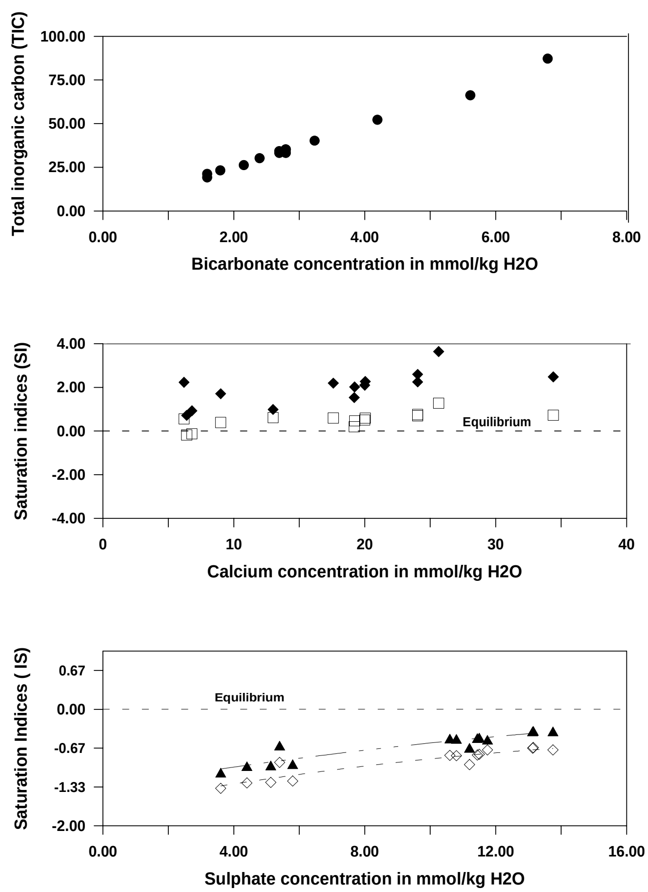


Fig. 11. Relationship of HCO_3 against TIC, Ca against SI and SO_4 against SI.

Table 2: Chemical results of the collected water samples in the studied area

S.No	S. name	Aquif.	Depth (m)	pH	EC mS/cm	TDS mg/l	Na epm	K epm	Mg epm	Ca epm	Cl epm	SO_4 epm	HCO_3 epm
1	El Fangarry sp.	Quat.	1.5	7.5	9.23	5907	55.8	2.0	13	24.04	66.5	27.5	4.2
2	El Heggaz sp.		Flowing	7.03	6.04	3866	27.5	1.1	22	23.8	44.2	23.5	6.8
3	Wadi Qossib sp.			7.4	7.36	4710	37.2	0.3	24	25.7	53.9	26.3	5.6
4	Ain El Sukhna sp.	Mioc.		7.5	12.77	8173	76.0	1.3	27	32.4	104.3	26.9	3.2
5	Investment well	Quat.	25	7.4	1.72	1105	10.9	0.8	6	6.4	12.3	10.3	1.6
6	El Addabia well		Flow	7.4	2.14	1370	13.5	0.4	8.2	6.8	15.4	11.6	1.8
7	Sumid-1 well		50	7.6	2.41	1542	9.7	0.3	6.4	9	14.1	8.8	2.7
8	Sumid-2 well		50	7.9	1.62	1035	6.1	0.3	6.4	6.2	8.8	7.1	2.8
9	Fertilizer-1 well		70	7.2	8.13	5203	43.4	1.1	22	19.2	59.9	22.4	2.8
10	Fetilizer-3well		70	7.5	7.01	4486	37.2	0.6	18	19.2	49.5	22.9	2.8
11	Fertilizer-4 well		70	7.7	6.12	3917	33.2	0.6	14	17.6	40.9	21.5	2.7
12	Fertilizer-5 well		70	7.5	7.00	4480	38.0	0.7	19	20	49.9	23	2.6
13	Abu Senna well		19	7.4	7.05	4512	35.6	0.7	20	20	52.5	21.2	2.2
14	Rain water		-	8.1	1.95	1248	7.4	0.2	0.6	13	7.7	10.8	1.6
15	Gulf of Suez water		Surf.	7.6	64.5	41301	544	9.8	130	29.66	652	68.17	2.2

Table 3: Ions ratio and water quality parameters (Na, SAR, T.H.)

S.No.	S. Name	rNa/rCl	rMg/rCl	rCa/rCl	rSO_4/rCl	rCa/rMg	rCl-(rNa+rK)	Na%	SAR	Total Hardness
1	El-Fangary	0.84	0.20	0.36	0.41	1.79	8.65	60.71	12.97	1841
2	El Heggaz sp.	0.62	0.50	0.54	0.53	1.08	15.82	38.15	5.74	2299
3	Wadi Qusseb sp.	0.69	0.44	0.48	0.49	1.07	16.45	43.05	7.47	2466
4	Ain El Sukhna sp.	0.72	0.26	0.31	0.26	1.20	21. 81	55.69	13.97	2448
5	Investment well	0.88	0.49	0.52	0.83	1.07	0.63	48.53	4.38	615
6	El Addabia well	0.88	0.53	0.44	0.75	0.83	1.46	48.17	4.93	743
7	Sumid-1 well	0.69	0.46	0.64	0.63	1.41	4.08	39.30	3.5	765
8	Sumid-2 well	0.69	0.73	0.70	0.81	0.97	2.40	33.68	2.43	625
9	Fertilizer-1 well	0.72	0.37	0.32	0.37	0.87	15.37	51.89	9.56	1847
10	Fertilizer-3 well	0.75	0.37	0.39	0.46	1.05	11.67	50.23	8.63	1869
11	Fertilizer-4 well	0.82	0.34	0.43	0.53	1.28	6.82	51.91	8.36	1334
12	Fertilizer-5 well	0.76	0.38	0.40	0.46	1.05	11.25	49.75	8.60	1983
13	Abu Senna	0.68	0.38	0.38	0.40	1.00	16.21	47.58	7.96	1984
14	Rain water	1.09	0.08	1.69	1.40	21.67	-0.86	38.63	2.83	680
15	Red Sea water	0.85	0.04	0.20	0.05	4.72	132.20	76.55	60.93	7879

Table 4: Ionic strength and saturation indices of some minerals in water samples

S.No.	S.Name	I.S.	Calcite	Dolomite	Anhydrite	Gypsum	Halite	TIC	PCO_2
1	El-Fangarry	0.109	0.701	2.243	-0.699	-0.381	-4.283	52.24	61×10^{-4}
2	El Heggaz sp.	0.087	0.758	2.597	-0.698	-0.525	-4.735	87.46	158×10^{-4}
3	Wadi Qusseb sp.	0.101	1.276	3.637	-0.667	-0.379	-4.538	66.07	28×10^{-4}
4	Ain El Sukhna sp.	0.153	0.725	2.470	-0.659	-0.372	-3.995	39.88	41×10^{-4}
5	Investment well	0.030	-0.178	0.716	-1.257	-0.966	-5.622	20.57	34×10^{-4}
6	El Addabia well	0.053	-0.125	0.931	-1.232	-.943	-5.441	23.05	37×10^{-4}
7	Sumid-1 well	0.032	0.394	1.711	-1.266	-0.977	-5.613	33.77	39×10^{-4}
8	Sumid-2 well	0.023	0.336	2.233	-1.588	-1.089	-6.004	30.02	17×10^{-4}
9	Fertilizer-1 well	0.097	0.197	1.535	-0.951	-0.663	-4.415	36.92	82×10^{-4}
10	Fertilizer-3 well	0.088	0.468	2.021	-0.785	0.496	-4.55	35.01	42×10^{-4}
11	Fertilizer-4 well	0.076	0.599	2.193	-0.798	-0.509	-4.687	34.51	30×10^{-4}
12	Fertilizer-5 well	0.090	0.592	2.269	-0.773	-0.485	-4.551	33.09	29×10^{-4}
13	Abu Senna	0.09	0.506	2.103	-0.791	-0.503	-4.556	26.48	24×10^{-4}

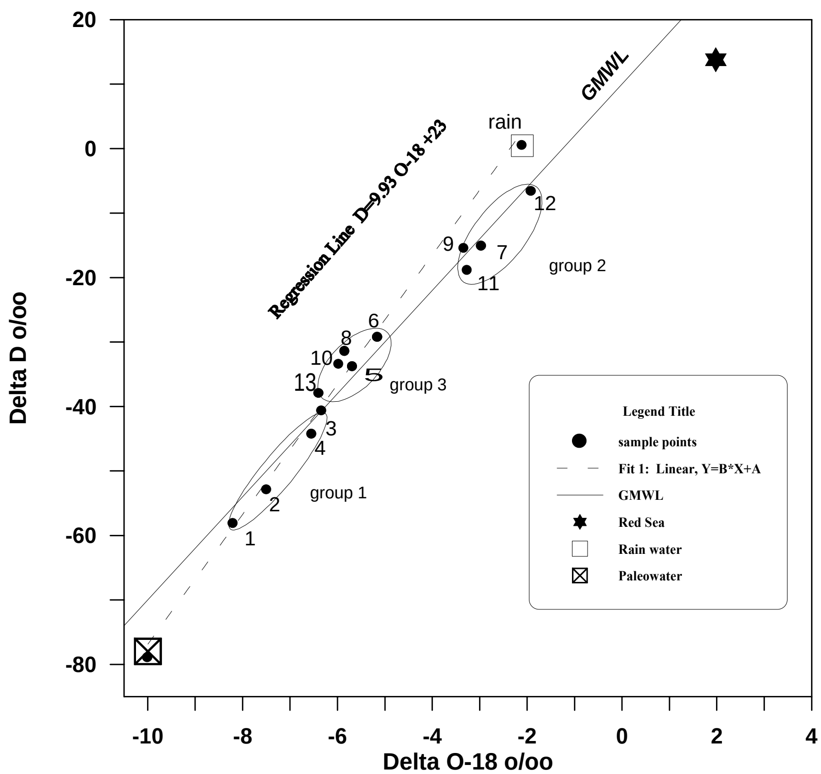


Fig. 12. Delta O-18 vs Delta D.

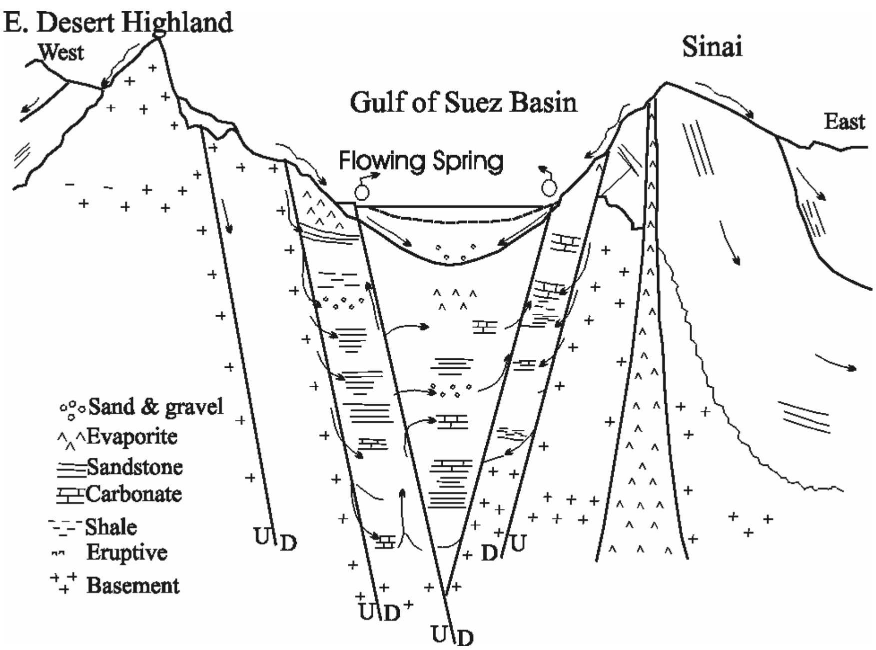


Fig. 13. Thermal springs and mineralized water in the Gulf of Seuz (Tatheogenetic basin), northeast Egypt (after Shata, 1990).

Although the isotopic content of the water samples (3, 13) is close to Ain El Sukhna thermal spring, there is no thermal gradient measured in these samples. It seems to be caused by convective heat transfer from thermal groundwater ascending under artesian pressure along fault zones from the deep-seated fault with different subsurface flow path. The emanating thermal water is formed by mixing of old water with deeply circulating meteoric water along the regional faults of the Gulf of Suez structural province (Darwish et al; 1993) (Figure 13). The deep–seated structural elements cause temperature elevation (about 100ºC, Sturchio et al, 1993), with gradual losses till the discharge point (to reach 33ºC). Age determination for this thermal water indicates about 7000 yr.b.p. as nearly as sample-13 (7420 yr.B.p.). The mixing ratio of recent precipitation is gradually increased in samples (5, 6, 8 and 10) as indicated by, higher d* and C-14 measurement of water sample-10 (6711 yr.B.p.).

This difference in flow path and recharge mechanism between the issued and groundwater samples is obviously confirmed by the C-13 results (Table 5), where the former acquires lower C-13 content indicates water circulates within low-carbonate aquifer content a long flow path and residence time. Meanwhile the significant enrichment in C-13 values of the groundwater samples implies fast flow through the aquifer rocks enriched with carbonate content. It is also confirmed by the fact that the deep percolated water is one of the recharging sources of the Quaternary aquifer, as previously mentioned.

The isotopic depletion associated with high salt content that were obtained from the collected water samples, and the deviation of the regression line from the sea water point; give no evidence for mixing with sea water point (enriched in isotopes and salt content). Though, dissolution is the main process for water mineralization as a result of the sequential regression and transgression of Red Sea water during several geological ages.

Water Quality Evaluation for different uses

According to the International standards of drinking water reported by the World Health Organization (1998), when taking the total salinity and total hardness into consideration (Table 1), despite the relative depletion in salt content in the exploited water samples from the shallow layers, there are high values of total hardness categorize the water in the undesirable form. Whereas for irrigation Na%, SAR, fall in the permissible category (<60%, <10 respectively), and the TDS within the range 1000-2000mg/l are involving hazards. At higher TDS (3000-7000), it can be used only with leaching and perfect drainage. For industrial purposes, high values of Total Hardness characterize these waters in the very hard class, which precipitate as dense scales around the walls of heating boilers and industrial equipments. Also in cleaning processes it can form calcium and magnesium precipitate. The drilled Quaternary water wells by the industrial companies (Investment Well, El Addabia Well, Sumid-1 Well, Sumid-2 Well) are somewhat suitable for using in boiler-feed water. The other drilled water wells could be used in oil refining industries in cooling, laundering, and steel manufacturing (Tables 6 and 7).

CONCLUSION

The structural setting of the Gulf of Suez province has its own bearing on the hydrochemical and isotopic composition of the groundwater aquifers of the study area. The water level at the area of the Miocene aquifer in the northern parts of the study area is higher than that of the Quaternary aquifer, where the two aquifers are highly influenced by faulting. This suggests the hydraulic connection between them. The Miocene aquifer acts as a source of recharge to the Quaternary aquifer. Only one water type of Cl-Na was distinguished, with one salt assemblage (Na Cl, Mg Cl_2, Mg SO_4, Ca SO_4 and Ca $(HCO_3)_2$, revealing the extreme influence of the Red Sea environment on the hydrochemical composition of groundwater aquifers of the study area. Besides, the prevalence of one water type and one salt group designates to the hydraulic connection between the Miocene and Quaternary aquifers. The environmental isotopes referred to a comprehensive isotopic depletion, which designates to the old paleowater. This result also confirms the hydraulic connection between the Quaternary and Miocene aquifers, side by side with the existence of an old water recharging source. However, this view is also confirmed by the results of C^{14} dating, which denotes a relatively old age (11.240 yr. B.P.) of the paleowater signature. The C^{13} measurements reflected the mechanism of recharging, whether the host mediums are carbonate or detrital rocks. The depleted C^{13} content was obtained from the issued water samples (El-Fangary, W. Qusseib, Adabiya, and Ain El-Sukhna springs), referring to their Nubian sandstone recharging source. The enrichment in C^{13} values in the drilled Quaternary water wells indicates the contribution of the Miocene limestone water in the aquifer with a long residence time.

Table 5: Stable and radioactive isotopes results of the measured samples

S.No.	S. Name	δO-18 o/oo	δD o/oo	d* o/oo	$\delta^{13}C$ DIC	C-14 (yr.B.P.)
1	El-Fangary	-8.20	-57.20	8.40	-7.77	11,240
2	El Hegaz	-7.49	-52.97	6.95	-8.10	
3	Wadi Qusseb	-6.33	-40.72	9.92	-11.92	
4	Ain El Sukhna	-6.54	-44.36	7.96	-8.20	6900*
5	Investment area	-5.97	-33.50	14.26	--	
6	El Addabia	-5.15	-29.32	11.88	--	
7	Sumid-1	-2.96	-15.16	8.52	-6.04	
8	Sumid-2	-5.84	-31.50	15.22	-6.83	
9	Fertilizer-1	-3.33	-15.53	11.11	-6.44	
10	Fertilizer-3	-5.68	-33.87	11.57	-6.62	6711
11	Fertilizer-4	-3.26	-18.94	7.14	-6.28	
12	Fertilizer-5	-1.91	-6.67	8.61	-6.64	
13	Abu Senna	-6.39	-38.01	13.11	-6.78	7420
14	Rain water	-2.10	0.46	17.26	--	
15	Red Sea	1.98	13.8		--	

*C-14 value obtained by personal communication

Table 6: Tolerance limits for boiler-feed water (mg/l) Walton (1970)

Item	Pressure (psi)^2			
	0-150	150-250	250-400	Over 400
Total dissolved solid	3000-500	2500-500	1500-100	50
Bicarbonate	50	30	5	0
Total hardness as$CaCO_3$	80	40	10	2
pH	8	8.4	9	9.6
Sulphate carbonate ratio Na_2SO_4/ Na_2CO_3	1/1	2/1	3/1	3/1

Table 7: Suggested water quality tolerance for industrial uses (allowable limits in mg/L

Industry on use	Total dissolved solid	Hardness as $CaCO_3$	Alkalinity as $CaCO_3$	pH
Carbonated beverage	850	250	50-100	……..
Cooling	…..	50	……..	…….
Laundering	……	50	……..	……
Plastics, clear paper &pulp	200	………		
Steel manufacture	……..	50	……..	……..
Tanning texta			50-135	135
Rayon(viscose) Pulp production	100	8	50	…….
Dyeing	200	…….	……..	……..

REFERENCES

Abd Ellatief T. A., Galal G. H. and Youssef (1997): " Structural and lithological impacts on the groundwater occurrences along wadi El-Naqra-wadi Badaa area" E.G.S. proc. of the 15th Ann. Meet, March 1997. 107-124.

Appelo C. A. J., Pastma D., (1993): "Geochemistry, Groundwater and Pollution" A.A.Blkema, Rotterdam, Brookfield, USA

Bartelli, L. J., ed. (1966): Soil Surveys and planning; Soil Sciences Society of America, Madison, WI, 196 p.

Dansgaard W., (1964): "Stable isotope in precipitation" Tellus,.16, 436-468.

Darwish, M., El Kiki M.F., and El Araby A. (1993): " Geochemical characteristics of the connate oil waters in the Gulf o Suez petroleum Province as possible indicators for the migration nd entrapment of oil " Egypt J. Geol., 37-2, 347-374.

Epstein S. , Mayeda T. K. (1953): "Variation of $^{18}O/^{16}O$ ratio in natural water". Geochem. Cosmochem. Acta, 4, 213.

Horita J. (1988): "Hydrogen isotope analysis of natural water using an H2-water equilibration method: a special implication to brines. Chem. Geol (isotope Geosci.Sect.), 72, 89-94.

Khavaka Y. K., Gunter W. D., Agrawal P. K., Perkins E. H., and De Brl J.D. (1988): "Solmineq 88 : A computer program for geochemical modeling of water rock interactions. U.S. Geological Surv. Water Resources investigations. Report 88-4427.

Klingebiel, A. A. and Montgomery, P. H. (1961): Land capability classification; Agricultural handbook No. 210, Soil Conservation Service, U. S. Department of Agriculture, Washington, DC, 21 p.

Sadek, H. (1926): The geography and geology of the district between Gebel Ataqa and Gebel El-Galala El-Bahariya, Gulf of Suez". Geol. Surv. Egypt, Cairo, 120 p.

Said, R. (1962): The geology of Egypt. El-Sevier Publ. Co., Amsterdam and New York, 377 p.

Sadek M. A. H. (1996): "Hydrological and environmental isotopes in the Nubian aquifer in scattered regions at the Western Desert, Egypt" Ph.D. Theses. Faculty of Science, Ain Shams University, Cairo.

Shata, A.A.(1990): " Thermal springs and mineralized water in Gulf of Suez Tatheogentic basin north east Egypt" International conference on water resources in the mountainous regions, Lausnne, Swizerland.

Sturchio N. C., Arehart G. B., Sultan M., Sanyo Y., Abo-Kamar Y. and Sayied M., (1996): "Composition and origin of thermal waters in the Gulf of Suez area, Egypt"Applied Geochemistry, 11, 471-479.

Walton, W. C. (1970): Groundwater resource evaluation. Mc Graw – Hill, New York 664 p.

World Health Organization (WHO), (1998): "Guide line for drinking water quality" 1, Recommendation second edition, Geneva, 188p.

تقييم الهيدروجيوكيمياء والنظائر البيئية لمياه الجوفية للمنطقة الواقعة الى الشمال الغربي من ساحل خليج السويس، مصر.

سوسن جمال عبد السميع* و حسام حمدي عليوه**
* هيئة الطاقة الذرية
**هيئة الإستشعار عن بعد وعلوم الفضاء

الملخص

يؤثر الوضع التركيبي لخليج السويس على التركيب الهيدروجيوكيميائي والنظائر البيئية لخزانات المياه الجوفية بتلك المنطقة. توجد المستويات البيزومترية لخزان المياه الجوفية بصخور الميوسين أعلى من تلك الخاصة بمناسيب المياه الجوفية بصخور العصر الرباعي، وذلك بالجزء الشمالي لمنطقة الدراسة، حيث تتأثر تلك الخزانات بشدة بالعديد من الفوالق العميقة مما يفترض معه وجود إتصال هيدروليكي بينهما. فقد تم تحديد نمط وحيد للمياه هو Cl- Na بمجموعة ملحية مكونة من Na Cl, Mg Cl_2, Mg SO_4, $CaSO_4$ and Ca $(HCO_3)_2$، والتي تعكس الأثر الشديد لبيئة البحر الأحمر (خليج السويس) على التركيب الهيدروكيميائي لخزانات المياه الجوفية بالمنطقة. بالإضافة الى ذلك فإن سيادة نمط وحيد للمياه مع وجود مجموعة ملحية واحدة يشير إلى وجود إتصال هيدروليكي بين خزاني المياه الجوفية بصخور الميوسين والرباعي. بينما تشير النظائر البيئية إلى قيم منخفضة تعزى إلى مياه قديمة. وهذه النتيجة أيضا تؤكد وجود إتصال هيدروليكي مابين خزاني المياه الجوفية للميوسين والرباعي بالإضافة إلى وجود مصدر آخر لشحن المياه الجوفية القديمة (الحجر الرملي النوبي). وهذه النتيجة تم تأكيدها أيضا من خلال تحديد عمر المياه الجوفية بإستخدام الكربون-١٤ والتي تشير إلى عمر قديم نسبيا (١١,٢٤٠ سنة). وتحدد قيم الكربون -١٣ ميكانيكية الشحن الجوفي لخزانات المياه سواء كانت الصخور الحاملة للمياه كربونية أم فتاتية، حيث وجدت القيم المنخفضة للنظير كربون-١٣ في عينات المياه المأخوذة من (عيون الفنجري، وادي قصيب، الإدابية والعين السخنة)، والتي تشير إلى أصل الشحن الجوفي من خزان المياه بالحجر الرملي النوبي. بينما عينات المياه المأخوذة من الآبار المحفورة بصخور العصر الرباعي تحتوي على قيم مرتفعة من الكربون-١٣ والتي تشير إلي إختزان المياه بصخور الميوسين الكربونية لفترة زمنية كبيرة.