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The hydrogeological conditions in Sahel Hasheesh, Eastern Desert, Egypt

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Abstract The groundwater development in Egypt in the present time is of a vital importance than in past few years. A comprehensive plan for new land reclamation projects has been recently established. To achieve these plans new sources of water must be available. This has been done by conducting a number of VES'S where interpreted by a comparison with the existing drilled borehole soil samples. The optimum resistivity model is obtained by matching method using "IPI2Win" Moscow State University 2000 software computer programs for resistivity interpretation. The results of the quantitative interpretation of the resistivity curves has been represented as geoelectric sections, showing the thickness and true electric resistivity values of the different geoelectric layers. The results of quantitative interpretation of the vertical electrical soundings show subsurface five geoelectric units and the aquifer system belongs to lower Miocene and the total salinity of 2451.2 ppm. The depth to water surface is 88.05 m and the total dissolved solids are 2451.2 ppm (Mekhemer well). The salt assemblages in Sahel Hasheesh are NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$, Ca $(HCO_3)_2$. This marine water is of brackish sodium chloride water type (NaCl).

1. Introduction

Development of the Eastern Desert of Egypt is a main target to strengthen the National Economy plan in Egypt. This is being emphasized in the Eastern Desert by developing the water resources.

The area of study is located in the western part of the Red Sea in the Eastern Desert, south of Hurghada by about 25 km between latitude 26°56′00″, 27°07′00″N and longitude 33°36′00″, 33°55′00″E (Fig. 1).

The present study deals with the exploration and evaluation of the groundwater potentiality by using geological, geophysical, hydrogeological and chemical tools. This work started in the summer of 2006 and continued until the summer of 2008. This area covers an area of about 1200 km^2. Development of Sahel Hasheesh was the topic of several research works

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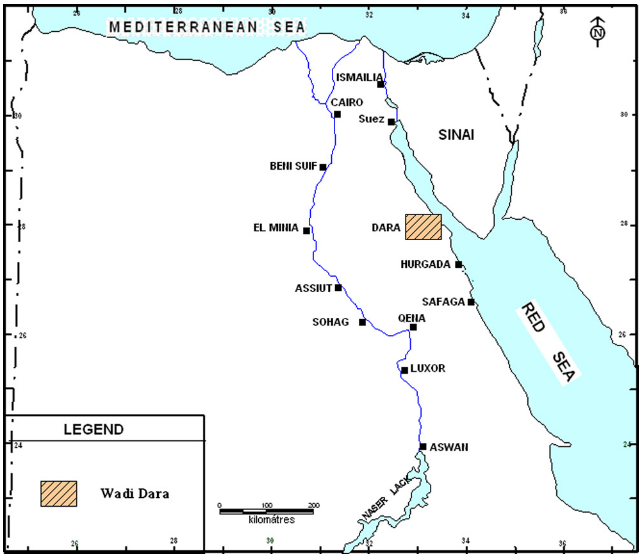


Figure 1 Location map of the study area.

including the construction of storage dams or and drilling boreholes. Previous studies showed that a relatively large amount of flood water is lost every year to the Red Sea. Therefore, the operational objectives of the current project are to utilize this flood water for ground water recharge. Twenty vertical electrical sounding (VES) were measured by using Schlumberger configuration in the study area.

2. Previous work

The areas of study, western side of the Red Sea Coastal plain were studied by several authors; Hume (1921), El Ramly (1972), Issawi (1983), Said (1990), El Sharabi (1993), (1983), Aggur and Sadek (2001).

2.1. Aim of the study

The main objectives of the study are as follows:

1. Study the surface and subsurface lithological.
2. Studying the subsurface structural setting and its effect on movement and accumulation of the groundwater.
3. Delineating the aquifer configuration and the subsurface structural complex in the study area. and
4. To calculate the hydraulic parameters of the aquifer.
5. The chemical analysis of the available groundwater samples to evaluate their suitability for the different use purposes.

3. Geomorphology and geology in the study area

The investigated area is subdivided into three geomorphologic units, Said (1962) as shown in Fig. 2. The high lands are represented by Red Sea mountainous shield (Basement Complex). These high lands are Shayieb El Banat (2185 m), Umm ‘Anab (1660 m), Abu Dalf (1235 m), Loman (1122 m), Umm Araka (1310 m), Umm Nife’I (1735 m), Abu ’Abid (1900 m), Umm Gidri (1070 m), Abu Bidun (755), Umm Fahm (375) and represent the main watershed areas.

The low land is represented by sedimentary tablelands and widespread along the sides of wadis and low lands. It consists of relatively thick section of loose sands and gravels. The area is intersected by a number of wadis draining from the high lands. The tributaries of these wadis spread westwards and collecting rain water down to the main streams and eastward to the Red Sea. The main wide wadis included in the catchments of the study area are Wadi Faliq El-Sahl, Wadi Nakhra, Wadi Abu Makhadiq and Wadi Umm Enab. The coastal plain occupies the eastern part of the study area with a low topographic feature of an irregular longitudinal strip of land running parallel to the Red Sea Coast. The lowermost area bounding the sea shore form narrow strip of sabkha lands as shown in Fig. 2 which are dominated by salt tolerant plants cover including Nitraia Retusa, Zyophyllum album and Tamarix mannifera (El Sharabi, 1993). The emerged shoreline is locally represented by the soft sandy shore such as in Sharm el-’Arab, Marsa Abu Makhadiq, and Dishet El Dhaba.

3.1. The geology of the study area

The sedimentary sequence overlies the Precambrian basement rocks and extends to recent sands and gravels. The geology of Sahel Hasheesh is dominated by a sedimentary succession ranging in age from lower Miocene (Ranga formation) to Recent (post-rift succession) as shown in Fig. 3. Post-Rift Succession (Post-Miocene units): Pliocene (Shagra F.) to Recent and Syn-Rift Succession (Miocene units The Upper Miocene (Umm Gheig Formation) – The Middle Miocene (Umm Mahara Formation) – The Lower Miocene Ranga Formation).

4. Measurements and interpretation of vertical electrical soundings

Schlumberger array is the most widely used technique in electrical prospecting. Four electrodes are placed along a straight line on the earth’s surface. The outer electrodes are for the current and the in-between electrodes are for the potential. The separating distance between the potential electrodes is small compared with the total length of the array, usually less than one fifth of total length.

4.1. Data acquisition

The field geoelectric survey comprises 20 VES in Sahel Hasheesh using Schlumberger electrode configuration. The centers of these spreads are shown in Fig. 4. At each VES location, the distance between the potential electrodes (MN) was increased only few times (0.5–200 m) while the current electrode separation (AB) was increased from 1 up to 1000 m.

4.2. The qualitative interpretation of electrical resistivity data

The main purpose of the qualitative interpretation of the geoelectric resistivity sounding is to determine the number of geoelectric layers in terms of thicknesses (or depth) and relative resistivity. This is done by plotting the field measured apparent

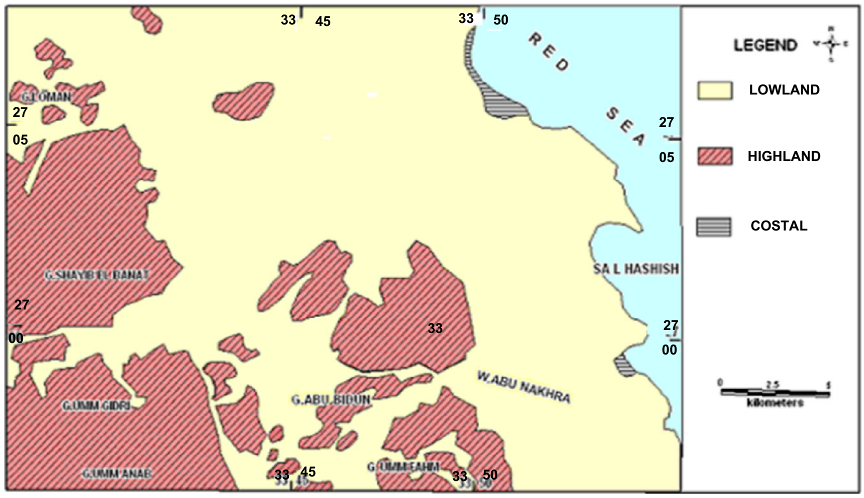


Figure 2 The main geomorphological units of the study area (after Conoco, 1989).

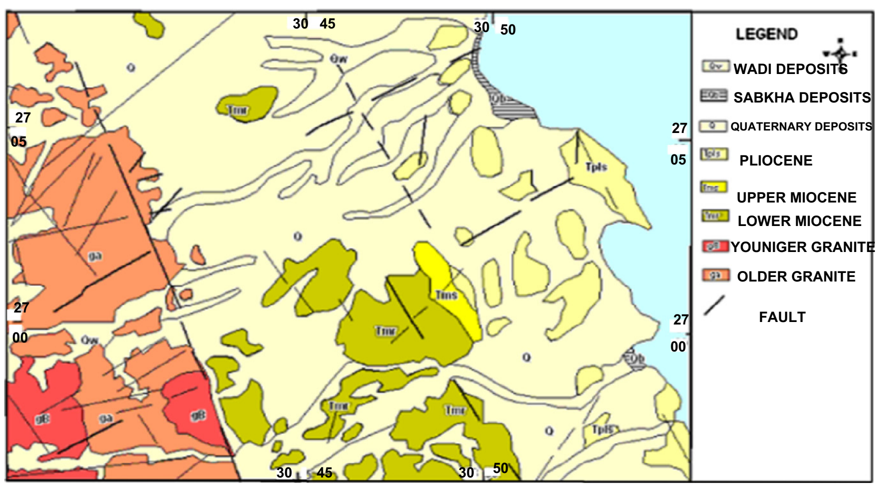


Figure 3 Geological map of the study area (after Conoco, 1989).

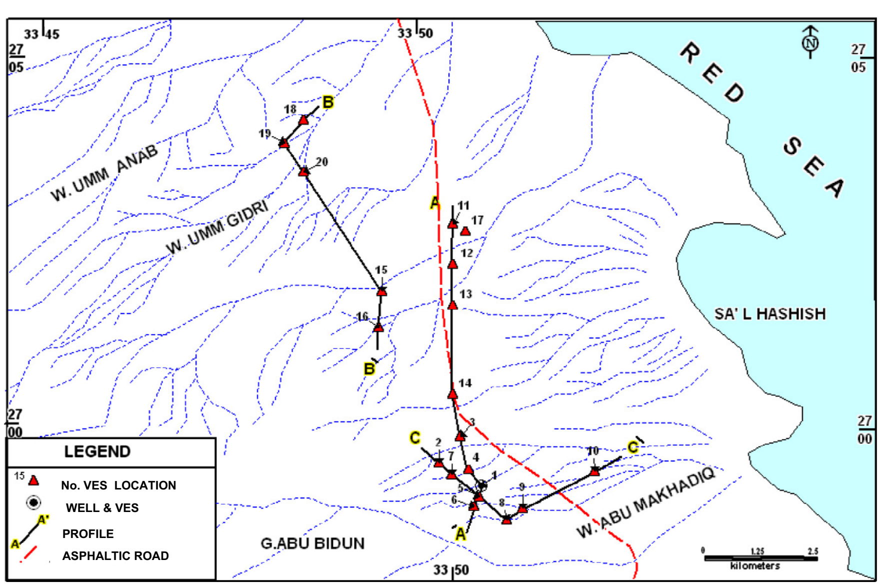


Figure 4 Base map for Wells & VES's locations and profiles in Sahel Hasheesh.

resistivity data (ρa) against half-current electrode spacing (AB/2) and construction of the filed curves (VES curves), which guide the subsequent process of quantitative interpretation.

4.3. The quantitative interpretation of electrical resistivity data

The quantitative interpretation of the vertical electrical soundings (VES) aims principally, to determine the thickness (or depth) and true resistivity of the interpreted geoelectric layers. This can be done graphically or analytically. The graphical interpretation can be performed by using master curves and utilizing the curve matching technique (Koefoed, 1976 and, Orellana and Mooney, 1966). The quantitative interpretation is an analytical technique which can be performed in electrical soundings using computerized software constructed for such purposes. In the present study, the vertical electrical sounding has been interpreted using the software "IPI2win" Moscow State University (2000). This program compares the field data with the data calculated for initially assumed layer model. The initial model was constructed based on the lithological succession from the available wells drilled in the investigated areas. These interpretation results in the form of layer resistivity and thicknesses from the measures (VES) in Sahel Hasheesh as shown in Fig. 5.

4.4. Calibration of the sounding data with the borehole information

The interpretation of the vertical electrical soundings has been correlated with available boreholes Sahel Hasheesh as shown in Fig. 6. Thus, a reliable control can be achieved for portraying the subsurface picture in the area of study to help in constructing geoelectric cross sections based on layer thicknesses and their corresponding litho-resistivity ranges. The results of such interpretation, in the form of layer thicknesses and true resistivities, are illustrated in geoelectric cross-sections, from which some isoparametric maps can be portrayed, told delineate the subsurface geologic and hydrogeologic aspects.

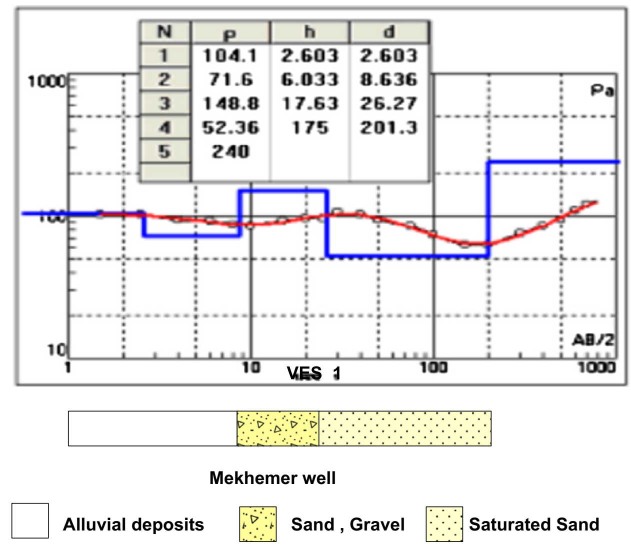


Figure 6 The calibration of the interpreted VES No. 1 with data of Mekhemer Well.

4.5. Geoelectric cross sections

The geoelectric cross-section reflects the subsurface rock units based on resistivity layering obtained from the interpreted VES curves, together with the available borehole lithological information. The interpreted geoelectric layers with their own resistivities depend mainly on water and ionic contents, clay percentage and to some extent, on the granular framework of the rock. Thus, the vertical electrical sounding technique is, sometimes, termed as electric drilling that helps with some borehole data to build geoelectric sections. In the present study, three geoelectric cross-sections have been constructed along profiles across the study areas Fig. 5. Therefore, we can recognize through critical inspection of these three geoelectric cross-sections in Sahel Hasheesh as shown in Figs. 7–9.

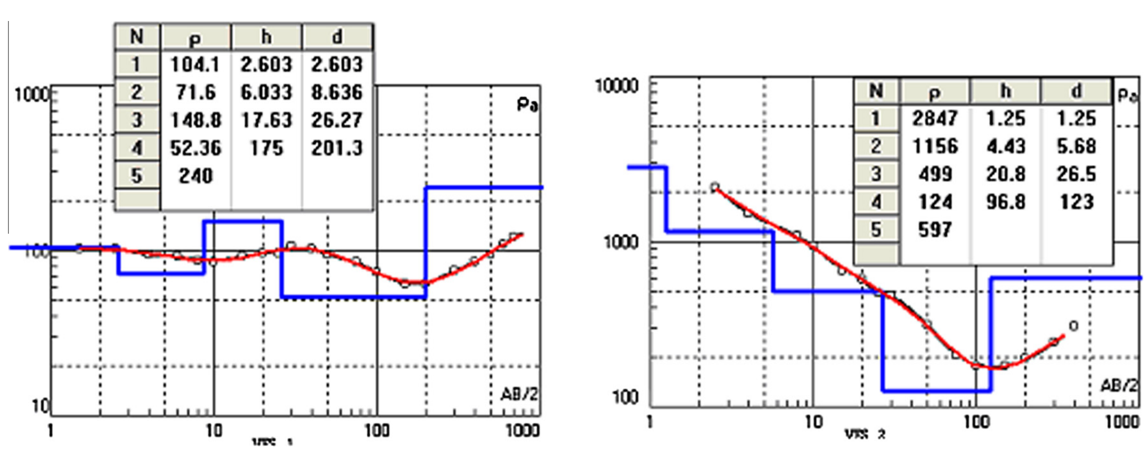


Figure 5 The quantitative interpretation of VES'S No. 1, 2 in Sahel Hasheesh.

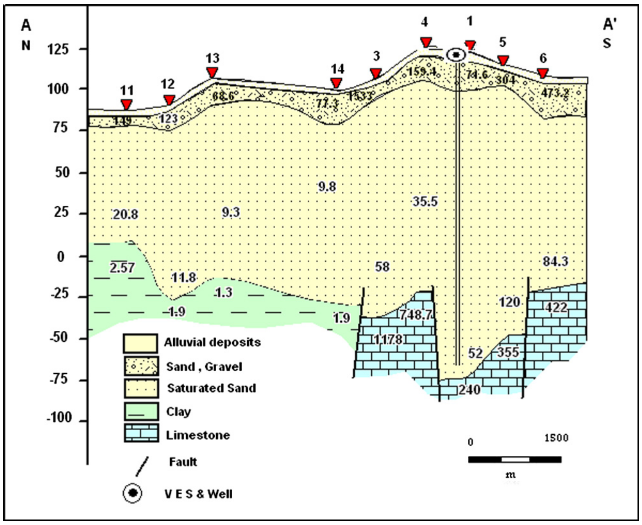


Figure 7 Subsurface geoelectric cross section along the profile A–A′ in Sahel Hasheesh.

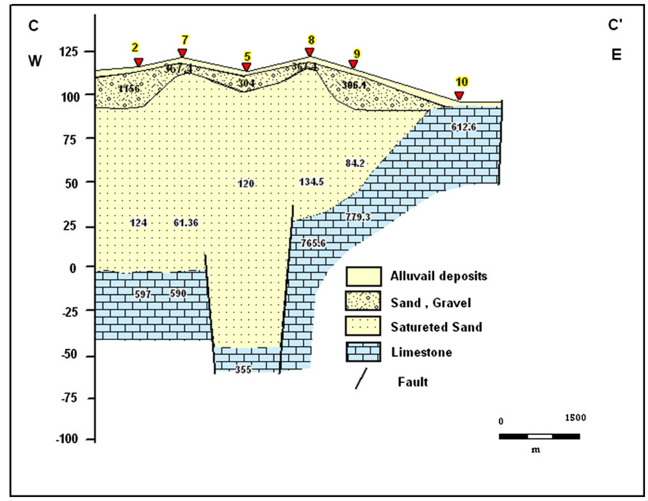


Figure 9 Subsurface geoelectric cross section along the profile C–C′ in Sahel Hasheesh.

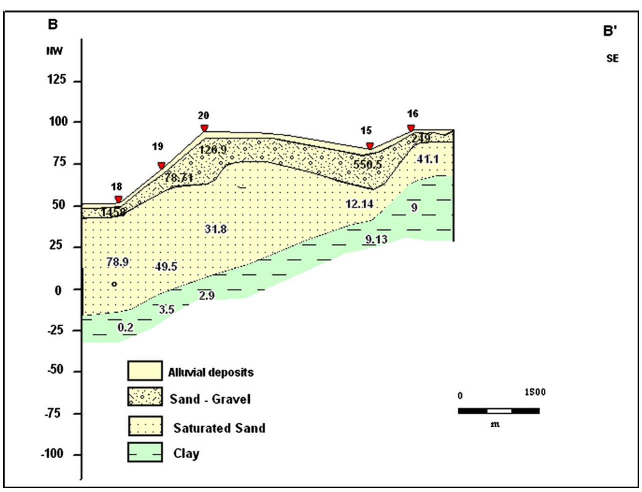


Figure 8 Subsurface geoelectric cross section along the profile B–B′ in Sahel Hasheesh.

The quantitative interpretation of subsurface section consists of five geoelectrical units (A, B, C, D, and F).

4.5.1. Geoelectric layer "A"

The electrical resistivities of this layer range from 47.9 to 5054 Ohm m. This layer has a thickness ranging from 0.5 to about 3.4 m with erratic distribution pattern along the studied sections as shown in Figs. 7–9 due to the effect of lithological, topographical and structural elements. Interpretation of these resistivity values indicate finer lithologic facies of this unit consist of recent deposits.

4.5.2. Geoelectric layer "B"

The second geoelectric layer has resistivity values ranging from 68.6 to 550.5 Ohm m. This layer has a thickness range from 4.2 to about 25.2 m with erratic distribution pattern along the studied sections. This layer composed of gravel, sands and clays. The high resistivity value of the layer is due to the presence of dry sediments and low resistivity value can be attributed to the presence of wet fine sediments and clay.

4.5.3. Geoelectric layer "C"

The resistivity values for this layer ranging from 9.33 to 134.5 Ohm m, which can be interpreted as water bearing sand and gravels with some, evaporates. Correlation of these results with the hydrogeological data from borehole as shown in Fig. 7, confirm the resulted result interpretation. The low resistivity values (< 10 Ohm m) indicate saline groundwater conditions, and/or clay content, while the relatively moderate values (up to 134.5 Ohm m) suggest marginal fresh water condition. The third geoelectric layer represents the saturated lower Miocene (Ranga formation composed of gravel and sand with some evaporates). On the other hand, the thickness of this water bearing strongly varies along the surveyed profile, which ranges from 19.6 to about 201.3 m. The maximum thicknesses are recorded at the sites of the VES No. 1 and 5. however, sudden absence of this unit due to local faulting cause lateral lithologic discontinuity along some profiles in the study area as shown in Figs. 7 and 9. These sedimentological, structural and stratigraphical characteristics of this layer suggest subsurface lateral inhomogeneity that controls the groundwater potentiality in the study area. Generally normal faulting is affecting the bottom of the aquifer.

4.5.4. Geoelectric layer "D"

The fourth geoelectric layer has resistivity values ranging from 0.2 to 9.13 Ohm m, which can be interpreted as clay.

This unit is underlain the base of the water bearing layer “C”, represented in VES’es No. (11, 12, 13, 14, 15, 16, 18, 19, and 20).

4.5.5. Geoelectric layer “E”

The fifth geoelectric layer has resistivity values ranging from 240 to 1178 Ohm m. This layer can be interpreted as hard, massive limestone facies. This layer is underlain the base of the water bearing layer “C”, represented in VESes No. (1, 2, 3, 4, 5, 6, 7, 8, 9, and 10).

5. Hydrogeological and hydrochemical investigation

The present hydrogeologic studies are based on the following foundations the evaluation and interpretation of the available previous data and the results of the present investigations such as hydrogeologic inventory of one water point.

5.1. The aquifer characteristics

The Lower Miocene Ranga aquifer composed of gravel and sand with some evaporates.

In order to confirm the geoelectrical results one test well (Mekhemer well) has been drilled at the site of VES–1). As shown in Table 1, this well has been penetrated with a total depth of 200 m with completed lined depth of 195 m. The screen intervals are from 147 to 153 m., 159–171 m and 177–189 m. The depth to water is 88.05 m and the specific discharge (Q/S) is 6.38 m^3/h/m (where $Q = 37.7\ m^3/h$ and $S = 5.9$ m). The setting position of the pump is 120 m from the ground surface.

Well and aquifer pumping tests have been conducted on the well to extrapolate each of well equation and hydraulic parameters of the water bearing formation. The analysis of step drawdown test gives the following well equation:

$$S = 0.1079Q + 0.0013Q^2$$

The analysis of continuous pumping test reveals that the value of transmissivity (T) is 415 m^2/day and the hydraulic conductivity is 13.83 m/day.

5.2. Hydrochemical characteristics of Sahel Hasheesh

In Sahel Hasheesh all the tourist resorts depends on desalinated water. Mekhemer well is the first exploratory well tapping the Miocene aquifer. So that only one sample is available to evaluate the chemical characteristics of this new aquifer. The results of chemical analysis are represented in mg/L, meq/L, and e%. The measured values of total dissolved solids (TDS) and hydrogen concentration (pH) are 2451.2 mg/1 and 7.3 respectively. The chemical composition reflects Sodium Chloride water type (NaCl) as shown in Table 2.

pH = 7.3 EC at 29 °C = 3.83 m mhos/cm
TDS = 2451.2 mg/L

$$X = \text{Ions} \quad Y = \frac{\text{cL} - (\text{K} + \text{Na})}{rMg}$$

Table 3 Hydrochemical ratios of sea water.

Hydrochemical parameter	rK/rCl	rNa/rCl	rMg/rCl	rCa/rCl	$r$$SO_4$/$r$Cl	Na/K
Sea water	0.0181	0.8537	0.1986	0.0383	0.103	40

Table 1 Hydraulic characteristics of Mekhemer Well.

TDS (m)	Com.D. (m)	Screen interval (m)	Depth to water (m)	Specific discharge (m^3/h/m)	B (h/m^2)	C (h/m^5)	T (m^2/day)	K (m/day)
200	195	147–153 159–171 177–189	88.05	6.38	0.1079	0.0013	415	13.8

Where: the value 0.1079 h/m^2 is the formation loss coefficient (B) and the value 0.0013 h/m^2 is the well loss coefficient (C).

Table 2 Results of chemical analysis of water sample and calculated parameters.

Concentration of ions				Hydrochemical ratios				HT (mg/l)	HYP. Salt comb. (%)	Saturation index	
ions	meq/l	mg/l	e%	r^* tcl	Y (meq/l)	Na/K	SAR			mineral	l.la p/kt
K	0.7	27.37	1.8	0.04	0.01	14.7	31.5	1004.6	Na + K (47.5)	Calcite	0.31
Na	17.5	402.3	45.7	0.96					$MgCl_2$ (24.7)	Gypsum	0.72
Mg	9.7	117.95	25	0.53					$MgSO_4$ (24.7)	Aragonite	0.17
Ca	10.4	208.4	27	0.57					$CaSO_4$ (14.6)	Dolomite	0.66
Cl	18.3	643.7	47.8	–					$Ca(HCO_3)^2$ (12.9)	P. CO_2	1.9
SO_4	15.05	722.85	39.3	0.82							
HCO_3	4.95	302.01	12.9	–							

The hydrochemical parameters which are: $\frac{rK}{rCl}, \frac{rNa}{rCl}, \frac{rMg}{rCl}, \frac{rCa}{rCl}, \frac{rSO_4}{rCl}, \frac{rCl-r(K+Na)}{rMg}$ and $\frac{Na}{K}$ have been calculated to trace the genetic origin (meteoric or marine or contaminated by highly mineralized water). The different hydrochemical processes affecting the water composition of the aquifer can be recognized by comparing with the chemical composition of sea water as shown in Table 3. The ratio rK/rCl is higher than that of sea water due to leaching processes for shale and clay by percolated water and/or in the direction of groundwater flow.

The ratios rNa/rCl and $\frac{rCl-r(K+Na)}{rMg}$ are less than 1 and reflect marine $MgCl_2$ water type. In this reaction the residual chloride ions in solution after the formation of sodium chloride salts is lesser than the total concentrations of magnesium. The ratios rMg/rCl, $rCal/rCl$ and SO_4/rCl attain concentrations greater than that of the normal sea water. This increase may be due to the leaching process of calcareous materials and evaporates during groundwater flowing.

The calculated hydrochemical parameter Na/K is smaller than that of the similar parameter given for the normal sea water. This means that the water of meteoric origin leaching clays and shale of continental sediments derived from the decomposition of acidic granite (K-field). These hydrochemical ratios reveal that water in the aquifer of marine origin and diluted by rain water. Table 3 shows the percent values of hypothetical salt combinations in the area of study. These hypothetical salt combinations are represented by NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$. The presence of magnesium chloride ($MgCl_2$) in minor concentration confirms that the water of marine origin is diluted by fresh water.

The total hardness is 1004.6 mg/L as shown in Table 2. This means that, this water is classified as very hard. So one can say this water can be used for washing purposes only by using special types of soap. It used with constrains in boilers for industrial purpose where it will reduce the efficiency of boilers after forming scale on the inner surface.

According to U.S Salinity laboratory staffs classification (1954) this water is classified as high salinity and very high sodium water. So that can be used for irrigation with salt tolerant crops on soils of good drainage with special leaching, also adding Gypsum ($CaSO_4$) to the soil helps considerably.

The ionic activities of ions and the saturation indices of minerals have been calculated by using Aquachem program. The results of ionic activities indicate that, among cations sodium is the most active ion while among anions chloride is the most active ion. This means that the sodium and chloride ions have the ability to form salts such as NaCl, $NaSO_4$, $MgCl_2$, and $CaCl_2$ in appreciable amounts. The rest ions are characterized by its low activities. This means that these ions have the ability to form salts such as $MgCl_2$, $MgSO_4$, $Mg(HCO_3)_2$, $CaCl_2$, $CaSO_4$, and Ca $(HCO_3)_2$ but in minor amounts. Table 2 shows the calculated values of saturation indices of different minerals existing in this water. The results show that, minerals of Calcite, Aragonite and Dolomite are supersaturated, this means that these minerals are going to precipitate causing problem of scaling in pump pipe line and well casing. Gypsum and CO_2 exist in under saturation state. This means that, Gypsum minerals are going to dissolve causing corrosion for pump pipe line and well casing. The presence of CO_2 in under saturation state may be due to exhaustion of the CO_2 in some chemical reactions in the aquifer. This aquifer is structurally controlled, so that the consumed gas can't be compensated from other resource.

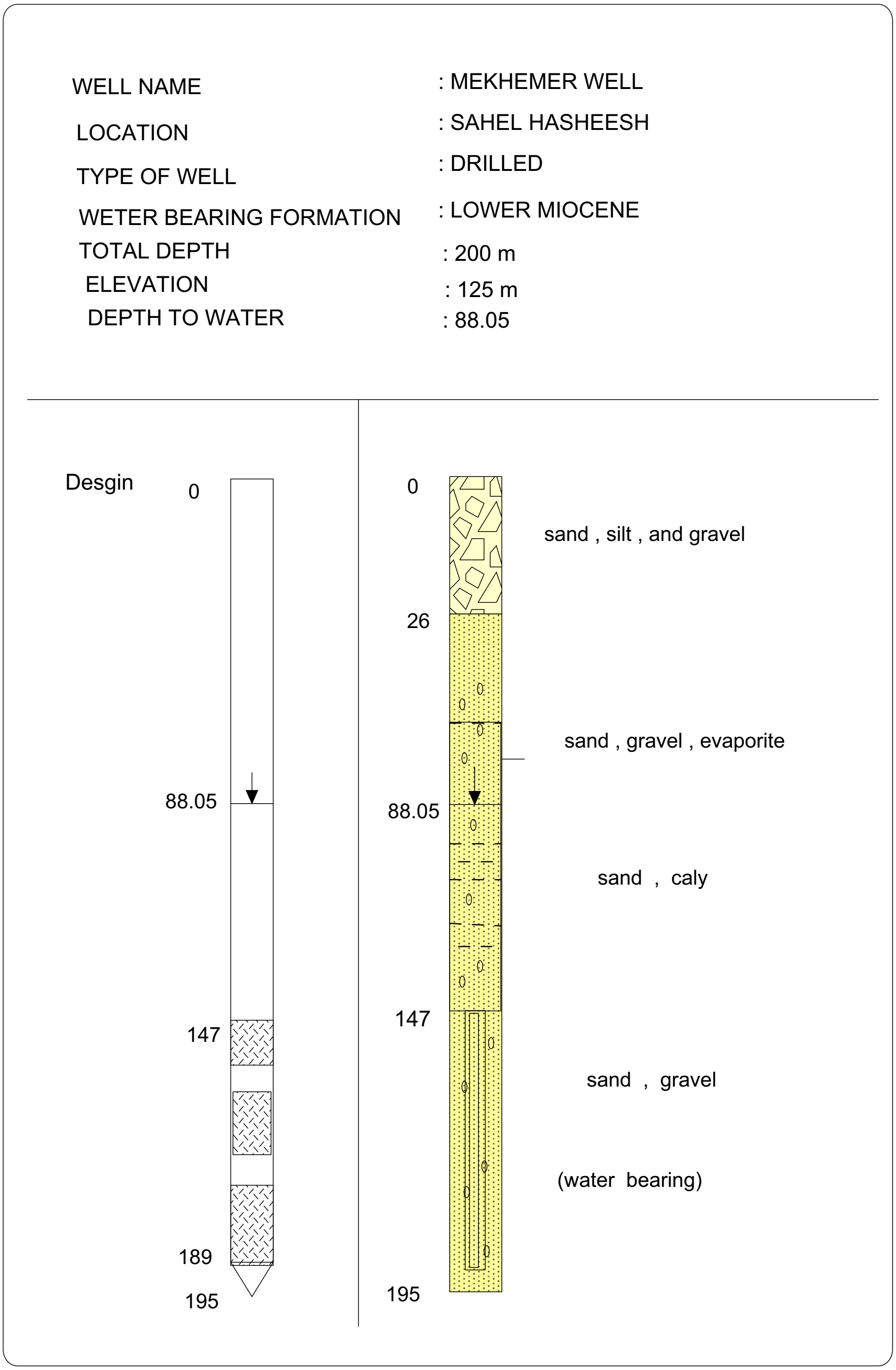
6. Conclusion

The results of the research show that the lower Miocene in the study area is promising. The quantitative interpretation of the vertical electrical soundings in the study area is showing five geoelectrical layers. The groundwater in the study area is available from an aquifer system belonging to Lower Miocene times. The depth to water table is 88.05 m. in study area (Mekhemer well). The total salinity is 2451.2 ppm in the study area (Mekhemer well). One group of salt assemblages is identified in Sahel Hasheesh NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$, $Ca(HCO_3)_2$. The Chemical classification of the groundwater accordingly reflects marine and brackish sodium chloride water type (NaCl) in the study area.

7. Recommendations

- Detailed surface and subsurface investigations including geophysical, geological and hydrogeological studies should be carried out at Sahel Hasheesh.
- A number of observation wells must be drilled to monitor the aquifer system in Sahel Hasheesh.
- A number of production wells can be drilled in Sahel Hasheesh to added new amount to the Egyptian water budget.
- Detailed chemical analysis program should be planned for the surface and groundwater resources. This can be done by annual sampling and complete analysis for all surface and groundwater resources in Sahel Hasheesh.

Appendix A



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