Egyptian Geophysical Society
EGS Journal, Vol. 11, No. 1, 1-14 (2013)

USE OF THE GEOELECTRICAL TECHNIQUE TO DETECT THE SALINE-FRESH WATER INTERFACE IN THE COSATAL AREA BETWEEN SEDI ABD EL-RAHMAN - EL DABAA AREA, NORTHWESTERN COAST OF EGYPT

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استخدام تقنية الجيوكهربية لتحديد الحد الفاصل بين الماء العذب والمالح للمنطقة الساحلية

بين سيدى عبد الرحمن– الضبعة بالساحل الشمالى الغربى لمصر

الخلاصـة: تقع المنطقة بين سيدى عبدالحمن والضبعة بالساحل الغربى للبحر الأبيض المتوسط لمصر وتمتد بطول حوالى ثلاثين كيلومتر. تهدف تلك الدراسة لأستكشاف المياه الجوفية ومعرفة مدى تأثر المنطقة بتداخل مياه البحر. وقد تم عمل ٣٦ جسة جيوكهربية باستخدام توزيع شلمبرجير وبطول أقطاب كهرية (أب) وصل الى ١٠٠٠ متر بالأضافة الى ثمانية بروفيلات تخريط كهربية ثنائيةالأبعاد.

وقد أوضحت نتائج التفسير الكمى أن التتابع الجيوكهلربى بالمنطقة يتكون من خمسة طبقات، وقد تم عمل خرائط المقاومة الكهربية، عمق السطح العلوى للطبقة الحاملة للمياه وسطح الحد الفاصل بين المياه المتوسطة الملوحة والمالحة وتساوى السمك. وقد تم عمل ستة قطاعات جيوكهربية، أربعة منها موازية لشاطىء البحر وأثنين عموديين عليه.

وقد أتضح من هذا العمل، أن السطح العلوى للحجر الجيرى البطروخى يمثل الخزان الجوفى الضحل بالمنطقة ويمكن تمييزه الى نطاقين. النطاق العلوى مشبع بمياه متوسط الملوحة بينما النطاق السفلى يكون مشبعة بالمياه المالحة نظرا لتداخل مياه البحر. أمكن توضيح الحد الفاصل بين الماء المالح والمتوسط الملوحة من خلال القطاعات التى نأخذ أتجاه شمال – جنوب. وقد وجد أن الخزان الجوفى من النوع الحر. وقد سجل تداخل مياه البحر خلال كل من الجسات وقطاعات التخريط الكهربى ثنائى الأبعاد. وقد وجد أن سطح الماء يقع على عمق من ٣,٥ الى ٢٤ متر. وتبع لذلك فأن أفضل المواقع لحفر آبار للمياه تم تحديدها. وقد وجد أن تداخل مياه البحر تتركز بالجزء الشمالى للمنطقة.

عمق سطح الماء وسمك الطبقة الحاملة للمياه الجوفية تزداد جنوبا وأيضا العمق للسطح الفاصل بين الماء المتوسط الملوحة والمياه المالحة تزداد فى نفس الاتجاه. حفر آبار المياه تكون مناسبة أكثر بالمنطقة الجنوبية نظرا لأن سمك الطبقة المتوسطة الملوحة والعمق لسطح الماء تزداد جنوبا.

ABSTRACT: *The area between Sedi Abd El Rahman and El-Dabaa lies at the western Mediterranean coastal zone of Egypt and extends for about 30 km long. The aims of the present study are to explore the groundwater and to know the effect of seawater intrusion on the freshwater aquifer. Thirty-six Vertical Electrical Soundings using Schlumberger array with maximum AB/2 = 500 m and eight 2-D imaging electrical profiles were carried out.*

Based on the interpreted results, five geoelectric layers have been detected in the area. Iso-rsistivity, depth to water, depth to brackish/saline water interface and isopach contour maps beside 6 geoelectric cross-sections (four from them are parallel to the Mediterranean shoreline and the other two are normal to the Mediterranean shoreline) have been constructed.

Interpretation of these maps and sections indicated that the Oolitic limestone represents the shallow groundwater aquifer which can be distinguished into two zones, the upper zone is brackish, while the lower one is the saline due to salt-water intrusion. The interface between brackish and saline water was distinguished along the interpreted N-S geoelectric cross sections. The geoelectric succession reveals that, the aquifer is of free type. The saline water intrusion was recoded in both the soundings and the electrical 2-D imaging profiles. The depth to water is presented at depth ranging between 3.5 m and 24 m. Consequently, the best sites for groundwater exploitation has been chosen. The sea water intrusion is restricted to the northern strip of the area.

The depth to water and the thickness of the brackish water increase towards the southern part, also the depth to the brackish/saline water interface increases in the same direction. Drilled wells are more suitable at the southern parts of the studied area because the depth to *brackish water and the its thickness increase southwards. The safe yield was calculated for each sounding station.*

INTRUDCTION

The water and soil resources are considered as the most important constitute topics for sustainable development. So, the water resource studies as a national aim have special importance. The importance of this study comes from that; the aquifer may be affected by seawater intrusions especially at the northern and eastern parts. The agricultural and touristic activities in this region need more water sources to face the increasing in water demand.

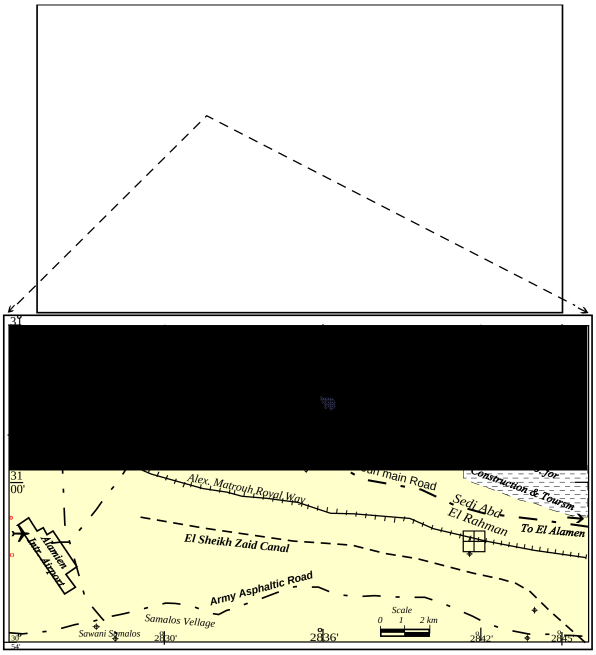


Fig. (1) Location map of the study area.

The investigated area between Sedi Abd El Rahman at the east and El Dabaa at the west extends along the Northern Western Coastal zone and lies between Latitudes 30°56′00"- 31°02′00"N and Longitudes 28°28′32″- 28°42′00"E (Fig. 1). The area extends southward to about 2 km from the coast with an area of about 200 km^2. The area is accessible from Alexandria thought Alexandria-Matruh road.

The aims of this study are to delineate the groundwater aquifers distribution, delineation of water-bearing formation and saltwater / brackish water interface. To achieve these aims, the electric soundings and 2-D, electrical Tomography were used.

The climatic condition along the NW coastal strip indicates hot summer. The rainy season extends from October and ends almost in March. December and January are the rainiest months with an average of 35 mm/months. Spring is dry and receives only 10% of the total rainfall.

GEOMORPHOLOGY, GEOLOGY AND HYDROGEOLOGY

Many geomorphological and geological studies were carried out along the study area and its vicinities, Shata (1971), Said (1962), Abdallah (1966), Hammad (1966), Selim (1969), and El Shamy et al (1968), Korny (1975), Hilmy et.al, (1978), El Maghraby (1997), and others are among these studies. The geomorphological and geological features that distinguish the study area are given here under:

Geomorphologically, the study area, as a part of the region lying to the south of the Mediterranean coastal region, exhibits three main geomorphologic units, according to Selim (1969), from the south to north direction; the southern tableland, the piedmont plain and the coastal plain. This zone, occupying the northern extremity of the great "Marmarican Homoclinal Plateau" displays geomorphological features which reflect the effect of both arid and wet climatic conditions, dominating the north Egypt and affected by the Mediterranean climate. There is no noticeable drainage system (Said, 1962).

- The southern elevated tableland (or structure plateau) is the most outstanding land feature in the northwestern littoral zone of Egypt that extends southwards to the Qattara Depression. It reaches a maximum altitude of about 130m, it is characterized by a broad gentle sloping surface of about 2m/km. It is bounded on its northern side by an escarpment facing the coastal plain. This plateau acts as major water shed area feeding the lower areas. The outlets of the drainage lines that pass to the coastal plain from high intake areas usually dissect the bounding table land slopes. Its surface is mostly rocky and is occasionally covered with thin mantle of sandy soils, moreover, it is found to be jointed and crusted.
- The piedmont plain in which the present study area is actually located extends to the north of the tableland and to the south of the coastal plain as a transitional zone, it characterized by low land and hills. It is partly rocky (degradation pediment plain) and locally covered with thick soils. The piedmont plain slopes generally towards the north 5m/km. and has an undulated surface.
- The broad coastal plain occupies a strip of land stretching adjacent to the Mediterranean Sea. It is generally occupied by elongated ridges and depressions. The ridges act as local water-shed areas, while the depressions act as collecting basins that are connected to the sea through several drainage lines outlets. At the approaches of the headlands protruding seawards from the tableland, the coastal plain may be missing or becomes very narrow. Wherever, the coastal plain is well developed, it displays features related to lithologic, structural conditions and fluctuation of sea level. Such features are mainly the alternation of low-lying elongate ridges separated by narrow lagoonal depressions.

Stratigraphically, the northwestern Mediterranean coastal zone is occupied by sediment and sedimentary rocks ranging in age from Tertiary to Quaternary and as reported in the near subsurface (Selim, 1969). In the study area, the Miocene deposits are represented and underliy the Quaternary deposits which are formed of thin cover of drift sands and loamy deposits covering mainly low-lying areas and the floors of narrow valleys dissecting the tableland as well as Pleistocene Oolitic and Cardium limestone followed by Miocene deposits which are represented by Marmarica and Moghra Formations. The upper limestone rocks (Marmarica Formation) is a shallow marine origin having a wide areal extension. It is formed of fracture white limestone and a lower grey calc-arenite with some shale intercalation that represent the saline water bearing formation.

Table (1): Stratigraphic succession of the study area (Hilmy et al., 1978).

AGE: Period	AGE: Epoch	Rock Unit (Formation and Member)	LITHOLOGY & DISCRIPTION	Average Thick (m)	HYDROGEOLOGY
RECENT	Deposits	Beach deposits	Loose yelow to brown quartiz sands mixed with, calcerious grains and shell fragments	Variable > 3 m.	
	Deposits	Alluvial deposits	Pale brown calcareous loam mixed with sand, shale fragments and organic mater.	= 10 m	
QUATERNARY	***PLEOSTOCENE***	Detrital OOlitic Limestone	Pale brown detrital oolitic limestone.	= 60 m	Main shallow aquifer widely distributed in the study area Unconfined
		Creamy massiv Limestone	Very hard limestone composed of consolidated aggregates of shells and gravels cemented by lime.	= 40 m	Partially saturated Limited distribution
	PLIOCENE	Creamy marly Limeston, shal and clay interbeds	Pale brown clay and fine sands with moderately hard creamy limestone at top.	< 70 m	Secondary aquifer reported in some basins west of the area
TERITARY	Miocene	Marmarecal limestone Formation	White to pale yellow fossiliferous L.S., marl and clays.	>1000 m	Main deep aquifer has a wide distribution - Perched
		Abu Subeiha and Moghra Formations	Yellow fine to coarse grain sandstone interbedded with shale and silts.		Main deep artesian aquifer

The groundwater bearing formations in the study area and its vicinities are classified from top downward into:

The Moghra Formation is represented by basal fluviatile to fluvio-marine deposits. It is composed of argillaceous limestone with sand and shale intercalation. This succession, has a thickness of about 190m. Table (1) shows the stratigraphic succession of the study area.

Structurally; the study area is a part of the Marmarica Homocline, which occupies the area north of the Qattara Depression. Local structural undulations are present in the form of gentle up fold and down fold structures, broad monocline structures and unconformities. Most of the folded structures are oriented NE-SW. Regionally, there are undetectable in the surface area, but the expected faulting in the subsurface with E-W strike and their down throw towards the north (Hilmy et.al., 1978).

Hydrogeologically; Korany (1975) concluded that, the water supplies in the studied area, as in many other localities along the Mediterranean Littoral zone, depend entirely on local natural supplies recharged by the available precipitation. These supplies include both surface and subsurface water, which are represented by successive drainage lines. The landforms as southern tableland, ridges, depressions, dunes, drainage lines control the distribution of surface runoff and consequently the groundwater accumulation and storage. No distinct line of demarcation between the coastal plain and the bordering tableland area to the south. The rocky surfaces are dominated by barren limestone rocks with regard to vegetation and soil. Such rocks constitute the parent material of all other types of non-consolidated soils (El Shamy et al., 1968).

Many hydro-geophysical investigations on the area of study and its vicinities are represented by the works of Sayed (1967), Abdel Latif (1973), El Maghraby. (1997), Fouad (2001), DRC (2005 & 2008) and Housny (2011).

Post Miocene aquifers; contain an upper unconsolidated coastal dune aquifer belongs to the Holocene, 2.5-8 m thick, and a lower consolidated detrital oolitic limestone aquifer of Pleistocene (Hilmy et al., 1978). The water in these aquifers exists under unconfined condition. These aquifers represent the main aquifers distributed along the study area which located at shallow depths from the ground surface. The groundwater was exploited along the Mediterranean cost. These aquifers are the main target of that work. The seaward seepages of the fresh water from the aquifer maintain the hydraulic equilibrium between the upper fresh water and the underlying intruded seawater (Korany, 1975).

In the study area, the post Miocene and Miocene aquifers are well developed into successive water bearing layers and are exposed in parts on the surface above the mean sea level. These aquifers have direct contact with the sea at different levels with different thicknesses. They are connected hydraulically with each other by a proper leaky connection. They have great intake areas of well defined characters, with adequate gradient for the groundwater movements (Hilmy et al., 1978).

Miocene aquifer: composed of a consolidated cavernous sandy limestone of Middle Miocene and a consolidated sandstone and sandy shale of Lower Early Miocene.

FILED MEASURMENTS AND INTERPRETATION

1- Geoelectric soundings:

The geoelectric measurements started with the execution of 36 Schlumberger sounding stations (VES'es), in the form of four profiles extending W-E direction (Fig. 2).

investigated sites. Depending on the obtained results from the 1-D resistivity soundings, eight 2-D images profiles were conducted in selected sites and far away from the sea coast about 500 m, at the sites of the VES's No. 2, 4, 5, 8, 12, 14, 17 and 25 respectively. Some of these profiles were conducted beside some boreholes with known water tables to delineate sea water intrusion and mapping fresh/saltwater boundary The 2-D

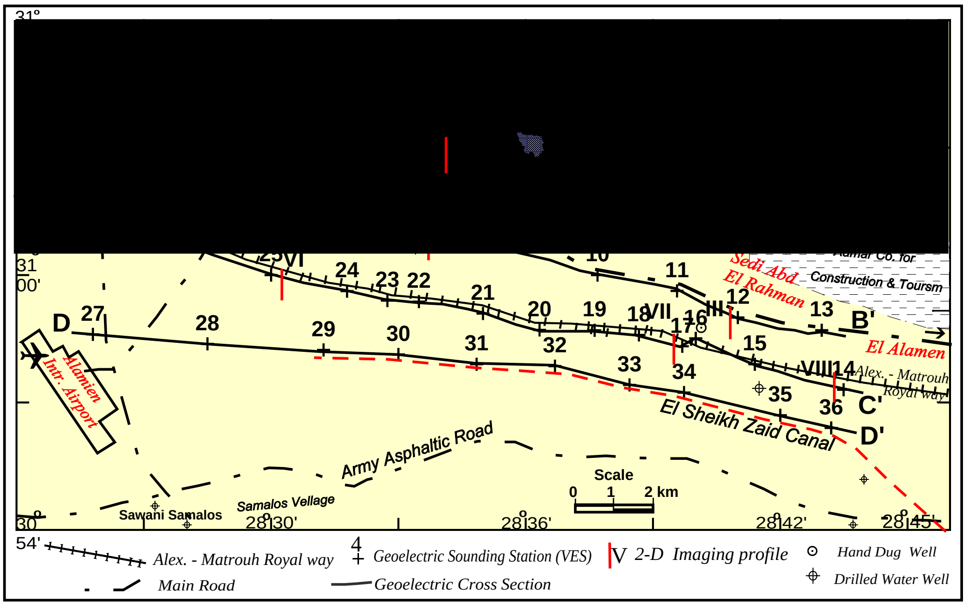


Fig. (2): Location of the Vertical Electric Sounding Stations, 2- D electric profiling and geoelectric cross sections at the study area.

For a reasonable penetration below sea level, the maximum spreading of the current electrodes (AB) was 400-1000m. The azimuth of the array (Schlumberger array) was always parallel to the strike of the formations, i.e. along W-E direction. The spacing between the successive soundings are 3 to 5 Km.

These resistivity soundings (VEs'es) were interpreted qualitatively and quantitatively. The computer program "RESIST" plus, V.2.39- by Van Der velpen (1988), was used for the quantitative interpretation. The data of the wells at sounding stations No. 4, 5, 8, 9, 16 and 35 were used in constructing the initial model parameters and assigning the lithology to the results of interpretation represented by geoelectric layers having particular resistivities and thicknesses. The interpretation results of the resistivity soundings (resistivities and thicknesses of subsurface layers) were used to construct geoelectric cross-sections and maps.

2- Two-dimensional resistivity imaging:

The saltwater intrusion in the shallow aquifer represents an important environmental problem along the whole northwestern coastal strip of Egypt (Gemail. 2002). The 2-D resistivity imaging records can be considered as a useful geophysical mapping tool for the delineation of the freshwater/saltwater zones as well as the intermediate zone and building a hydrogeological picture of the fissured Oolitic limestone aquifer in the resistivity profiling was carried out using Wenner arrays normal to the sea coast (N-S). The electrode spacing (a) was 10m in all of these profiles. The first two of these profiles were conducted to the north of Alamein-Matruh main road with length of 240m each while the other three profiles were conducted between the Alamein-Matruh main road and with a length of 160 m each and another three profiles were conducted south of the Royal way with a length of 30 m each. (Fig.2).

The direct current resistivity meter "Terrameter" model SAS 300C was used for measuring the resistance "R" with high accuracy. The topographic maps of scale 1:25,000 and GPS instrument were used to locate the VES stations and to determine their corresponding ground elevations.

For the quantitative interpretation of the 2-D imaging data, RES2DINV, Ver 3.4 computer program by Loke (1998) was used. It is a Windows-based computer program that automatically determines a two-dimensional (2-D) subsurface resistivity model for data obtained from electrical imaging surveys (Griffiths and Barker 1993).

DISCUSSION OF THE RESULTS

I- Interpretation of Vertical Electrical Soundins results

The qualitative and quantitative interpretations revealed the existence of five main geoelectric units as listed in Table (2). The interpreted sounding data were used to construct 6- geoelectric cross sections to identify the distribution of the resistivities, thicknesses, depth to water bearing layer as well as depth to brackish/saline water interface. Locations of these cross-sections are shown in figure (2).

Table (2):True resistivities, thickness and lithology of the obtained subsurface units in the studied area.

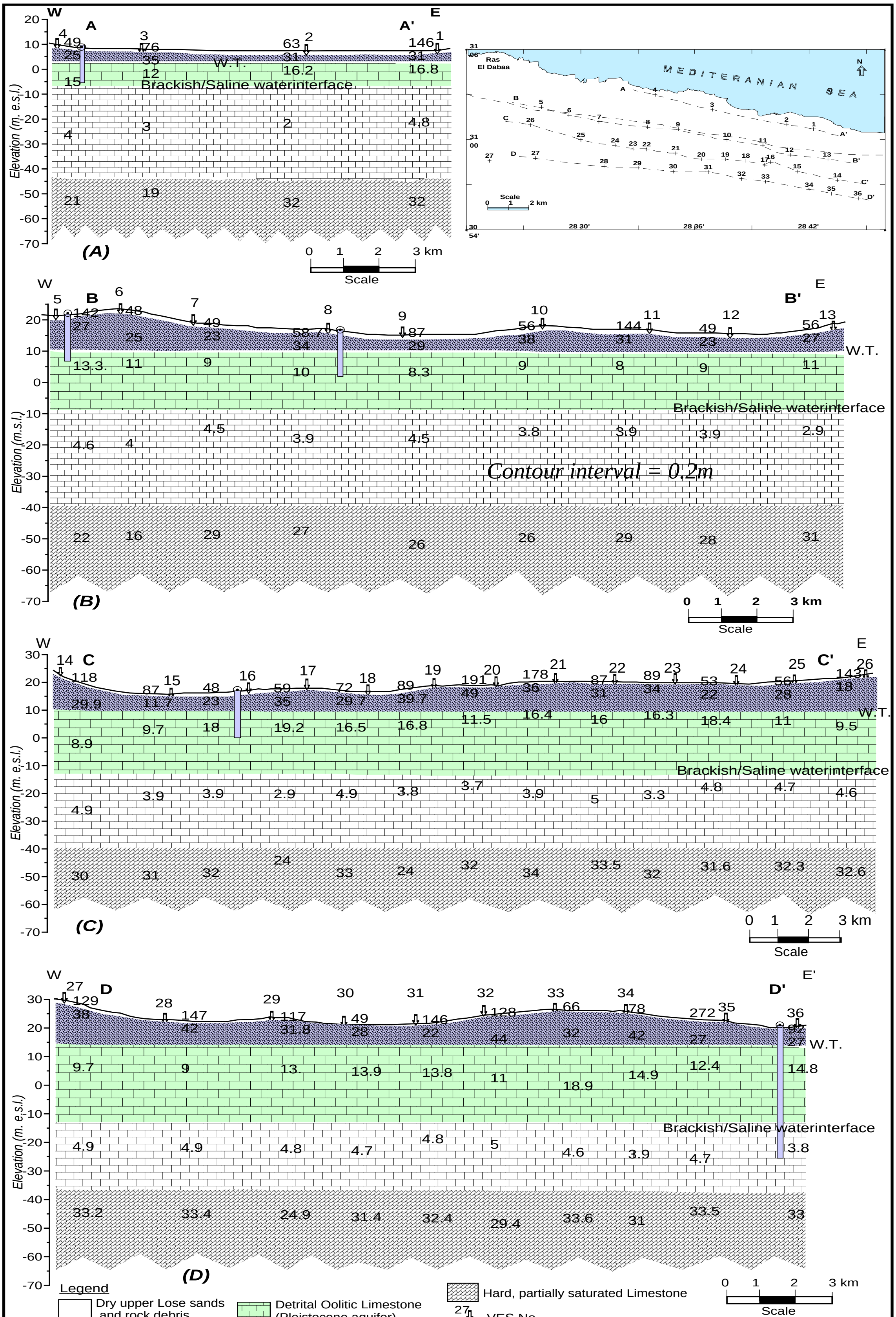
Lithological description	Resistivity (Ω m)	Thickness (m)
Alluvial deposits (calcareous sand, shell and rock fragments, silt and clay).	39 – 272	0.6 – 2.6
Dry calcareous loam, organic matter and Oolitic limestone.	22 - 49	3.5 - 23
Saturated oolitic limestone, sand and gravel.	8 – 19.5	8 – 26
Saturated, fractured oolitic limestone (saline water).	2 – 5	29 - 41
Massive to fractured oolitic limestone (partially saturated).	16 – 34	----

The major geoelectric units within these cross-sections were delineated based on the resistivity-lithological unit calibration. Four geoelectric resistivity cross-sections AA`, BB', CC` and DD` are extending nearly parallel to the Mediterranean Sea shoreline (Fig. 3), while the 5$^{th}$ and 6$^{th}$ cross-sections (E E' and FF`) were selected normal to the sea coast (Fig. 4). To avoid un-necessary repetitions in description of these cross sections, the flowing is a brief description of these layers from top downwards:

- The first top dry geoeectric layer consists of Holocene alluvial deposits (calcareous sand, shell and rock fragments, silt and clay). The resistivity of this layer varies widely from 39 Ω.m at VES 1 to 272 Ω.m at VES 27. The wide variation of resistivity can be attributed to the variations in moisture content and fine materials of this layer in some localities. Its thickness ranges from 0.6 m at VES 1 to 2.6 m at VES 35.
- The second geoelectric layer can be correlated with dry oolitic limestone (Pleistocene), that present above the water table in the study area. The resistivity values for this layer varies from 11.7 Ω.m at VES 15 to 49 Ω .m at VES 20 and its thickness ranges from 3.5 m at VES 1 to 23 m at VES 36. The lower boundary of this layer can be correlated with the brackish water table in the study area. Generally, the resistivity and the thickness of this layer decrease northwards.
- The third geoelectric layer is represented by the oolitic limestone saturated with brackish water. It has resistivity values ranging from 8 Ω .m at VES 11 to 19.5 Ω .m at VES 17 and its thickness varies from 8m at VES 2 to 26m at VES 26. The thickness of this layer increases gradually from north to south while, its resistivity decreases towards the north (Fig.5). The depth to the upper surface of this layer is considered as the depth to brackish water in the study area which ranges from 4.5m at VES 4 to 25m at VES 30 (from the ground surface), it increases southwards.
- The fourth geoelectric layer is correlated with the oolitic limestone saturated with saline water (indicating sea water intrusion on the shallow Pleistocene aquifer). It has low resistivity values which range from 2 Ω m at VES 2 to 5 Ω m at VES 27 and 33 (Fig.6), and its thickness varies from 29 m at VES 6 to 41m at VES 24. The depth to the upper surface of this layer that considered as depth to the brackish / saline water interface in the study area ranges from 8m at VES 2 to 43 m at VES 31as measured from the ground surface (increases from the north to the south.
- The fifth geoelectric layer is represented by Pleistocene massive to fractured oolitic limestone that is partially saturated by saline water. It is characterized by resistivity values ranging from 16 Ω. m, at VES 6 to 34 Ω .m at VES 31. It represents the lower aquifer along the coastal plain, which is exposed at the surface forming the Marmarican monocline of the southern tableland.
- **The depth to the brackish water contour map:** For practical purposes, the depth to the brackish water bearing layer contour map (Fig.7) was constructed. It displays the interpreted depth to top of the brackish water bearing formation which increases southward due to the change in topography of the area. This map is useful in predicting the depth to brackish water in the area where new water wells are intended to be drilled. It indicates that the northern part of the area is the place where a minimal depth to water (3.5m).
- **The depth to brackish/saline water interface contour map:** It was constructed by using the depth to the base of the third geoelectric zone (Fig.8). It gives the variation of depth to the brackish/saline interface, which increases southwards across the study area
- **Isopach map of brackish water bearing zone:** It was constructed by using the thickness of the third geoelectric zone which shown in figure (9). The

thickness of this zone ranges between 8m at VES 2 to 26m at VES 26 with general increase southward.

- **Isopach contour map of the Saline water bearing oolitic limestone layer:** Its thickness varies from 29 m at VES 6 to 41m at VES 24 with general decrease southwards (Fig. 10). According to the above discussion, the Pleistocene Oolitic Limestone is the main groundwater aquifer in the study area.



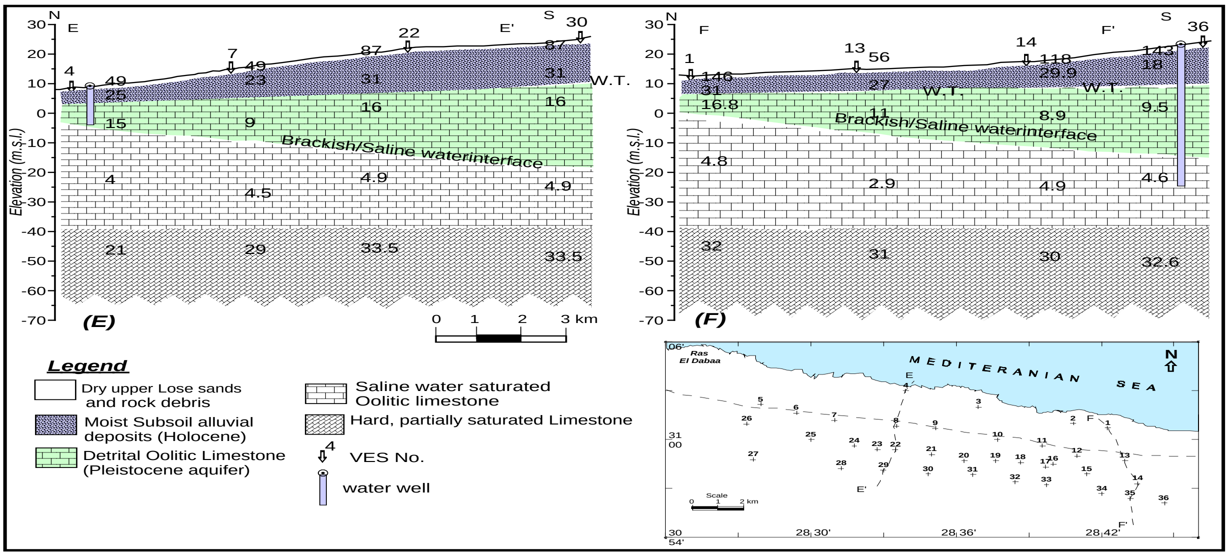


Fig. (4): Geoelectric cross sections E E' and F F' (N-S direction).

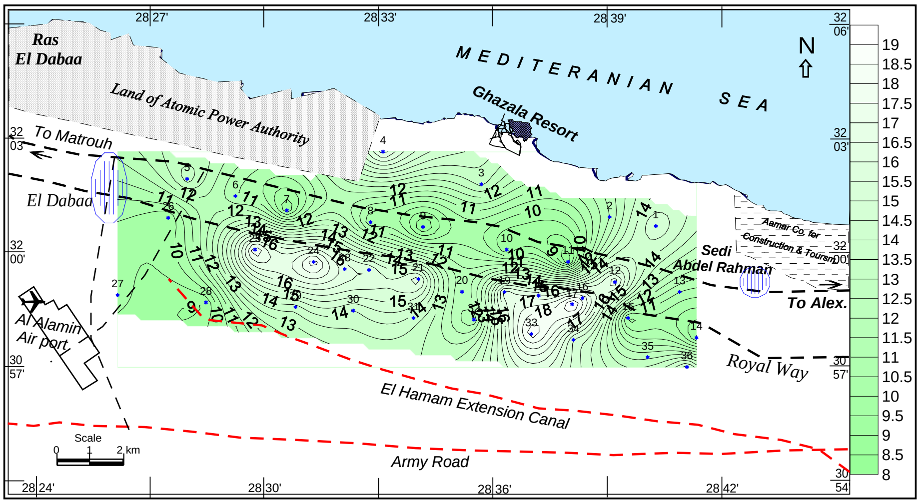


Fig. (5): Iso-resistivity contour map of the third geoelectric layer (brackish water bearing oolitic limestone).

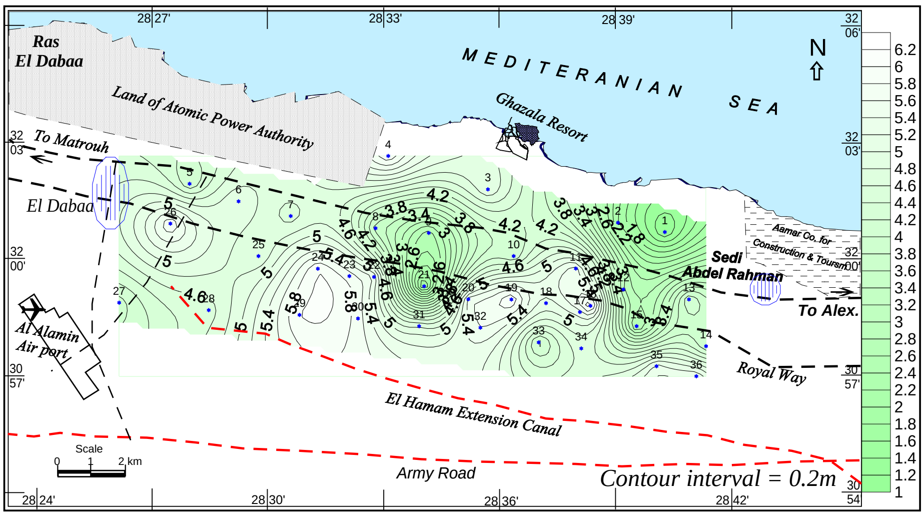


Fig. (6): Iso-resistivity contour map of the fourth geoelectric layer (saline water).

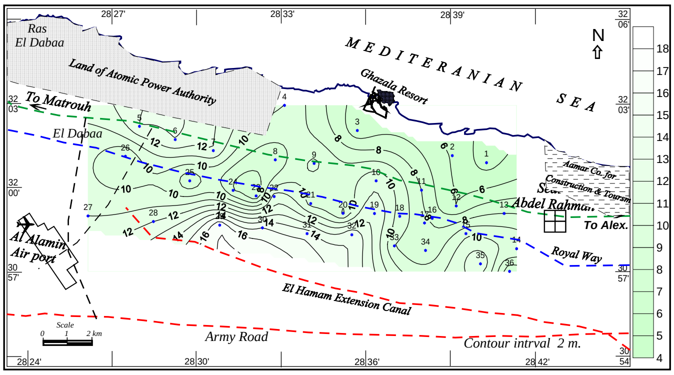


Fig. (7): Depth to brackish water bearing formation Contour map.

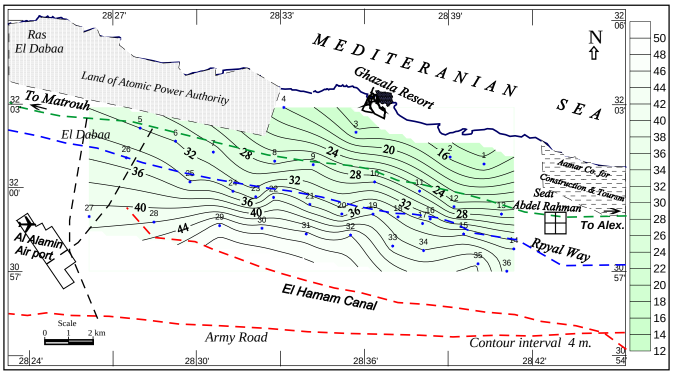


Fig. (8): Depth to brackish/saline water bearing formations interface contour map.

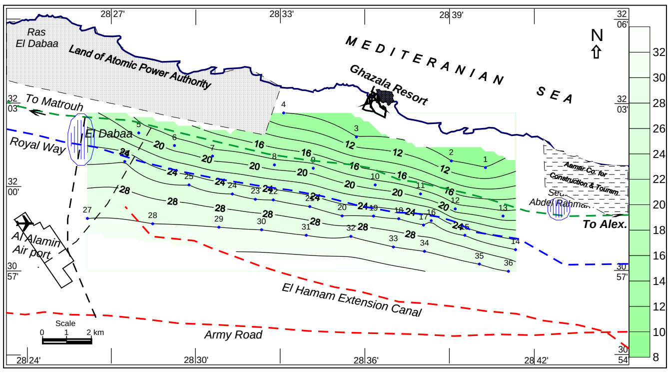


Fig. (9): Isopach contour map of the oolitic limestone (brackish water aquifer).

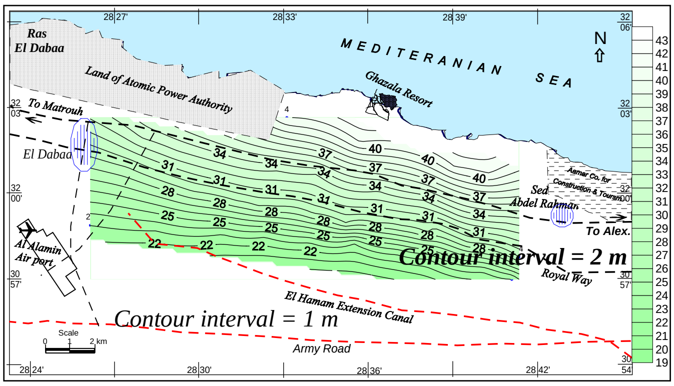


Fig. (10): Isopach contour map of the Saline water bearing oolitic limestone layer.

The upper part is represented by the fresh to brackish water accumulation. The water level of this aquifer is related to sea level, the water table is at small depths. The lower part is saturated with saline water representing the invaded sea water intrusion under the upper aquifer. The fresh/saltwater boundary in this aquifer was confirmed using 2-D resistivity imaging measurements within the eight selected sites.

II- Interpretation of Two Dimensional Resistivity imaging profiles:

A- The imaging profiles No's I and II (northern profiles):

These two profiles located at the northern part of the study area and the profile No.I lies beside a shallow dug well and VES No.4. The interpreted models of these two profiles indicate that the depth to water varies from 3.5 m at profile II to 5 m at Profile I and the depth to brackish/saline interface ranges from 6.5 m at profile I to 8m at profile II (Fig. 11). This indicates that the depth to water shows the same units, which were interpreted in the geoelectric reisitivity section A-A` (Fig.3, A). The comparison between them gives a good agreement, where high variations in resistivity values in this first unit, is observed it is divided into two zones. At the shallow one has relatively high resistivity values, while at the deep horizon has lower resistivity. The upper zone is characterized by high resistivity values and the second zone is characterized by relatively low resistivity values with relatively the same thicknesses. The third unit (saturated water bearing zone in the area), is characterized by relatively moderately resistivity values. The intermediate zone is characterized by low resistivity values ranged between 5 to 10 Ω.m and located between brackish water zone and low resistivity zone (< 5 Ω.m).

B- The imaging profiles No's III, VI and V (at the central zone):

These profiles were located at the sites of VES No.s 11, 8 and 5; respectively. The interpreted model of these 2-D profiles shows the same units, which were interpreted in the geoelectric reisitivity section B B` (Fig.3, B). Examination of these imaging profiles indicated that the upper parts are dominated by deposits of high resistivity that corresponds to dry alluvial deposits. Some low resistivity zones were observed near the surface that may represent wet finer materials. Fig 12 represents 2-D imaging profiles No. IV and V. The decrease of the resistivity values towards the northern part indicates an increase of water saturation in this direction (i.e. highly fractured limestone). The depth to water in the central part varies from 12 m at profile No.IV to 17 m at profile No.V and the depth to brackish/saline water interface varies from 20 m at profile No. III 3 to 32 m at profile No.V

C- The imaging profiles No.'s VI, VII and VIII (at the southern zone):

These profiles were located at the sites of VES No.'s 25, 17 and 14 respectively (of the geoelectric profile C C' Fig.3, C). Fig.13 represents the 2-D imaging profiles No. VII and VIII. The interpreted models of these profiles indicate that the depth to brackish water bearing formation varies from 20 m at profile No.VI to 24 m at profile No. VIII and the depth to brackish/saline interface varies from 32 m at profile No. VII to 39 m at profile No. VII.

HYDROGEOLOGICAL ASPECTS

Groundwater occurrence: In view of the above-mentioned discussion, it is obvious that groundwater occurrence is controlled by the existence of fractured zones within the Oolitic limestone layer. The interpretation of the sounding data (VES) allover the studied area revealed that the resistivity of some layers changes from one locality to another. The third geoelectric layer which represent the main water bearing layer is characterized by medium resistivity values (from 8 to 19.5 Ω.m). The available hydrogeological information of the investigated area indicates that a water-bearing layer is recharged directly through the peculation of the local precipitation and surface runoff. Generally, the resistivity values and the thickness of the aquifer increases towards the southern direction in the study area. This may be attributed to the increasing potentiality of water and water quality of wells in that direction. The middle portion of the concerned area was found the best site for locating production wells. All sites of the geoelectric sounding stations is favorable sites for wells with variable depths according to each location. The geoelectric succession revels that the aquifer is open where there is no confining layer, so this aquifer is unconfined (water table). The saline water intrusion from the north was detected in all soundings and the electric 2-D imaging profiles. The measured total salinity (TDS) of the groundwater samples which collected from drilled and dug wells, range from 1686 ppm to 3742 ppm

Safe Yield: When an aquifer contains an underling layer of saline water such as the area under study and is pumped by a well penetrating only the brackish water of the upper part of the aquifer, a local rise of the saline/brackish water interface below the well occurs (the up-coning phenomenon). This generally necessitates that the well has to be shutdown due to the influence of the intruded saline water. Up-coning phenomenon has been formulated for the design and operation of wells for skimming brackish water from the saline water. An approximate analytical solution for up-coning directly beneath a well, based on the Depute assumptions and Ghyben-Herzberg relation (Todd, 1980), was given by:

$$Z = Q/[2\pi\, d^2\, K\, (\Delta\rho/\, \rho_b)]$$

where $\Delta\rho = \rho_s - \rho_f$; ρ_s , ρ_f are the specific weight of saline and brackish water.

d = the distance between the end of the well and interface between saline and brackish water.

K = Hydraulic conductivity and Z = the critical rise.

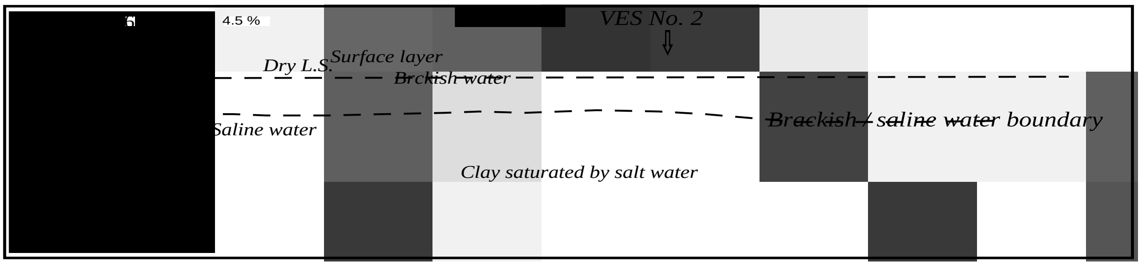


Fig. (11): 2-D inverted resistivity imaging profiles No.'s I and II (at the Northern part)

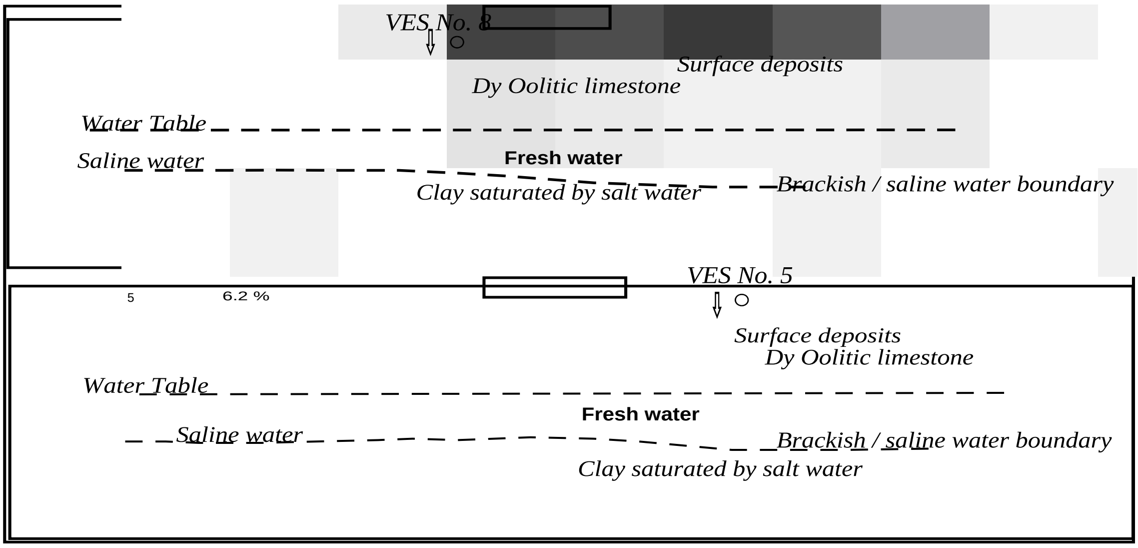


Fig. (12): 2-D inverted resistivity imaging profiles No.'s III, VI and V (at the central part)

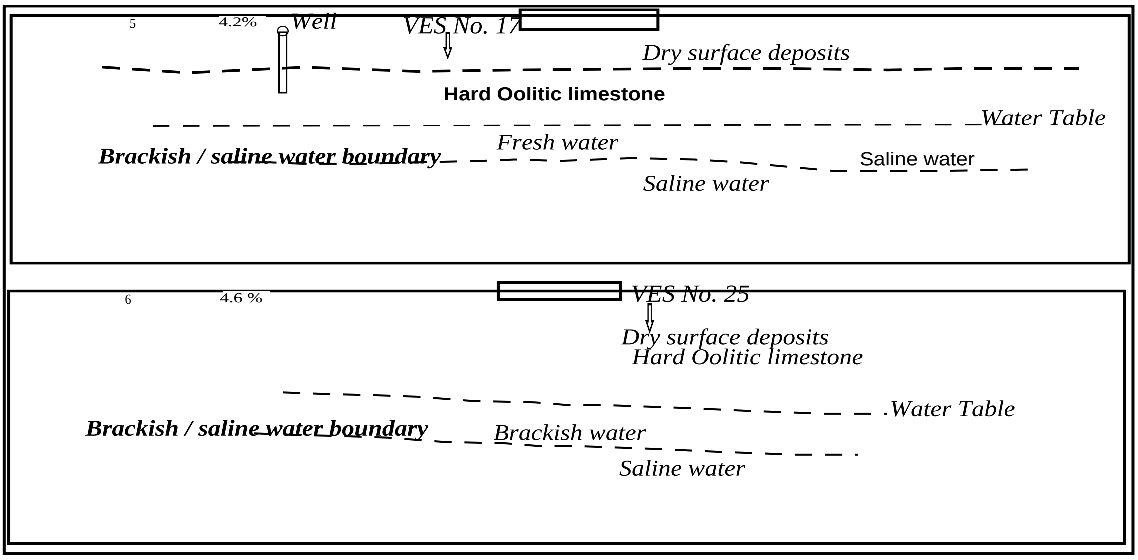


Fig. (13): 2-D inverted resistivity imaging profiles No.'s VI, VII and VIII (at the southern part).

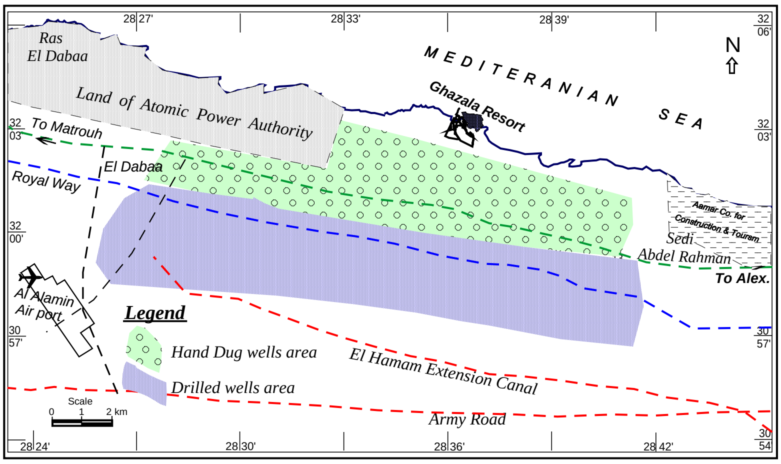


Fig. (14) Map of the recommended sites of hand dug and drilled wells.

Table (3): The depth to water, water table, depth to interface and interface level.

VES No.	Ground Eleve. m.a.s.l	Water Depth m. g.l.	Water Table m.a.s.l	Depth to Interf. m.g. l.	Depth to Interf. m.a.s.l.	Thick. of brackish w. b. f.	VES No.	Ground Eleve. m.a.s.l	Water Depth m.g.l.	Water Table m.a.s.l	Depth to Interf. m.g.l	Depth to Interf. m.a.s.l	Thick of brackish w. b. f.
1	7	4.6	2.4	14.6	-7.6	10	19	24.5	12	12.5	38	-13.5	26
2	7.3	5.9	1.3	15.6	-8.3	10	20	25	11.8	13.2	36.8	-11.8	26
3	8	6.3	1.7	16.3	-8.3	10	21	25	10.6	14.4	35.6	-10.6	26
4	10	7	3	20	-10	10	22	23	11.6	11.4	37.6	-14.6	26
5	14	9	5	32	-18	19	23	22	10	12	33	-11	26
6	17	12	5	32	-15	19	24	23	10	13	34	-11	26
7	15.5	11	4.5	31	-15.5	19	25	22	8.5	13.5	34	-12	26
8	16	8.3	7.7	27.3	-11.3	19	26	21	8	13	35	-14	26
9	15	10.3	4.7	29.3	-14.3	19	27	25	10.5	14.5	41	-16	30
10	17	11	6	30	-13	19	28	26	11	15	42	-16	30
11	16	8	8	27	-11	19	29	29	14	15	47	-18	30
12	15	6	9	25	-10	19	30	27	17	10	45.1	-18.1	30
13	17	8	9	27	-10	19	31	28.6	15.1	13.5	44.6	-16	30
14	22	10	12	35	-13	26	32	28	14	14	44	-16	30
15	22	9.8	12.2	33.5	-11.5	26	33	23	13	10	39	-16	30
16	22.5	7.5	14.5	34.5	-12	26	34	25	14.6	10.4	38	-13	30
17	20.8	8.7	12.1	34	-13.2	26	35	26	12	14	42	-16	30
18	21.6	9.5	12.1	34.5	-13.1	26	36	25	14.5	10.5	37	-12	30

Table (4): Design and safety yield of water wells.

VES No.	Design T.D.	Casing Length	Well Screen	D m	D^2 m^3	Q m^3/day	VES No.	Design T.D.	Casing Length	Well Screen	D m	D^2 m^3	Q m^3/day
1	9						19	38	11.5	20	8	64	24.3
2	8.5						20	36.8	16.8	20	9	81	23.7
3	9.5						21	35.6	15.6	20	7.5	57	21.6
4	12						22	37.6	17.6	20	5	25	9.3
5	15						23	33	13	20	7.5	57	21.6
6	14						24	34	14	20	3.5	12.3	4.7
7	17						25	34	14	20	7	49	18.6
8	17						26	35	15	20	10	100	38
9	19						27	41	21	20	14	156	59.3
10	13						28	42	22	20	19	361	137.2
11	17						29	47	27	20	22	484	183.9
12	15						30	45.1	25.1	20	20	400	152
13	17						31	44.6	24.6	20	11	121	46
14	35	17	20	13	169	64.2	32	44	24	20	5	25	9.3
15	33.5	17.5	20	7	49	18.6	33	39	19	20	14	156	39.3
16	34.5	20.5	20	4	16	6.1	34	38	18	20	18	324	123.1
17	34	23	20	6	36	14.5	35	42	22	20	15	225	43.3
18	34.5	18.5	20	8	64	19	36	37	17	20	13	169	64.2

Q max=3.14 x d^2 x 1.64 x 0.025 = 0.12874 m^3/day , K = 9.12 m^3/ day , $\Delta\rho$ = 0.025.

If the up-coning exceeds a certain critical rise, it accelerates upwards to the well. Critical rise has been estimated to approximate Z/d = 0.3 to 0.5. Thus, adopting an upper limit of Z/ d = 0.5 , it follows that the maximum permissible pumping rate without salt entering the well is: $Q_{max} \leq \pi d^2 K (\Delta\rho/ \rho_b)$.

where; K is the hydraulic conductivity of the Pleistocene Oolitic limestone aquifer is 9.2 m^3/day to 82 m^3.day (Hilmy 1978).

The depth to water, water table, depth to interface, thickness of the brackish water zone and interface level for every sounding site are given in table (3). According to the above equation, the drilled well design and the corresponding Q max (safe well yield) are calculated and registered in table (4). Safety yield (Q) for drilled wells varies from 4.7 to 183.9 m^3/hour. Drilled wells are more suitable in the southern parts of the area due to the increase in depth to water in that direction, and the thickness of the brackish water increases in the southern direction (9 to 32 m).

If the hand dug wells lies half diameter r = 2 meters and will dug under water level (Z) by two meters. The safe well yield Q is calculated by the equation: $Q= \pi r^2 Z$, then Q =3.14 x 4 x 2 = 25.12 m^3 /day if the water is pumped ones every day. From the tables No. (4), hand dug wells are suitable in the northern part of the study area due to low ground level, shallow water level and effect of the salt water intrusion. The recommended sites of both the hand dug and the drilled wells are shown in Fig. (14).

CONCLUSIONS AND RECOMMENDATIONS

Two geoelectric resistivity techniques were conducted through 36 Vertical Electrical Soundings and 8 Electric Tomographic (2-D) profiles in this study to evaluate the ground water potentiality and sea water intrusion in the area between Sedi Abdel Rahman and El Dabaa, Northwestern coast, Egypt. This study reveals the following conclusions:

1- The geoelectric succession in the area consists of five layers. The first two layers are dry, while the third layer is Pleistocene Oolitic Limestone saturated with brackish water. The fourth layer is saturated with saline water while the fifth layer is a partially saturated hard limestone. The 2-D electric profiles verify the lateral extension of the electric resistivity, and make a good confirmation with the VES data.

2- The water table possesses a smooth curved surface above the main sea level and follows the land topography. Depth to the water table varies from 3.5m near the coast (north) to 24 m at the south. The southern part of the study area is the best site for drilling new groundwater wells, because it has suitable thickness of the brackish water-bearing formation.

3- From the geoelectric sections and the 2-D imaging profiles, the sea water intrusion is restricted to the northern strip. The Pleistocene Oolitic Limestone aquifer is affected by sea water intrusion, where the denser saline water trends to intruded in-land below the brackish water. The brackish/saline water interface is located at depths varying from 9 m at the northern part to 36 m at the southern part. Its depth increases southwards (inland direction).

4- The degree of saturation ranged from massive dry limestone to partly saturated limestone depending on the density of fractures and voids.

5- The thickness of brackish water bearing bed ranges from 8 at the northern area to 26 m in the southern side of the investigated area, while the depth to water bearing zone ranges from 3.5 to 16m from the ground surface at all soundings.

6- The calculated safe yield of the VES sites reveals that the Safety yield for every hand dug well reach 25.12m^3/ day.(as discharge), while for drilled wells varies from 4.7 to 183.9 m^3/day.

From this study it can be recommended:

- The best location of the proposed for hand dug wells are recommended, at the sounding stations No. 2, 3, 4, 7, 8, 9 and 10 (in the middle portion of the study area). It is also recommended to drill new productive wells at the locations of the sounding stations No. 15, 16 and 36.

- The suitable techniques for drilling can be both the hand-dug wells in the northern parts and drilled deeper wells at the southern parts. Well logging of these wells is strongly recommended to the proper design as production wells and due to the saline water intrusion.

- The depth of the well ranges from 40 to 60m and also the pumping tests is highly important to avoid the over pumping or the depilation of the aquifer and rise of the brackish/saline water interface which causes salt water contamination.

- Detailed hydrogeological and hydrogeochemical studies are highly recommended in the whole area.

- The new cultivated land projects must be use modern irrigation system to save and consume the water demands.

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