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Conjunctive Use of DC Resistivity Method and Hydrochemical Analysis for Groundwater Potentiality of Wadi El Natrun Area, Egypt

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Abstract: Resistivity method has shown its effectiveness for groundwater investigations in many areas. In this paper twenty discrete electrical resistivity soundings, with maximum AB/2 of 750m, have been carried out in the area west Wadi El-Natrun, northwest of the Nile Delta, Egypt using Schlumberger array for studying the stratigraphic sequence of the different aquifers and delineating the factors affecting groundwater potentialities and movements. On the other hand, complete hydrochemical analysis of thirty six water samples collected from the available drilled wells have been carried out to assess the quality of groundwater and study the factors affecting its potentiality and extent of contamination. The analysis of electrical soundings delineated that there are different water bearing zones with varying thicknesses. The integration of these results with the available hydrogeological data indicated existence of four main aquifers distributed in the study area. Moreover, the water table contour maps of these aquifers through different periods indicate a frequent change in water level. The analysis of hydraulic parameters indicated that these aquifers in some parts are connected since the area is structurally controlled. The analysis of water samples illustrated that the main aquifer has been contaminated due to the effect of surface water irrigation.

Key words: Resistivity · Hydrochemical · Groundwater · Aquifer · Potentiality

INTRODUCTION

A lot of hydrological problems face many reclamation projects in Wadi El-Natrun area, such as water logging, water depletion and groundwater salinity and groundwater pollution. Etc. Therefore, great efforts and many investigations have been carried out taking in consideration avoiding the different side effects of development.

The western Delta region where Wadi El-Natrun is located, is one of the first regions in Egypt where land reclamation projects started in the late fifties on Nile water diverted through a set of main and secondary canals. Growing of reclamation projects of this area takes place with variable rates from fifties to update. So, the hydrological and hydro chemical conditions have been influenced with these new variables.

The direct current (DC) resistivity method, which is one of the most impotent geophysical methods, was applied to evaluate the sedimentary section and to detect the groundwater aquifers.

About 26 soundings were conducted and investigated to a depth of about 250 m. The resistivity of rock units, which depends on porosity, permeability, water content and temperature, was measured at different profiles using the vertical electrical sounding technique.

The lateral and vertical distribution of resistivity reflected the lateral and vertical changes in lithologic conditions at each profile.

Location: The area under investigation occupies the northwestern portion of Egypt (Figure 1). It lies between 30°.00′. 00′: 31°00′ 00″, north and 30°00′00″: 31° 00′ 00″, east. The area includes lands belonging to four govern orates; Behira, Menofia, Giza and small part of Gharbia govern orate. Almost the new reclamation projects of the last four governorates are included in the study area among the cultivated lands which lies east Rosetta branch.

Topography: The investigated area exhibits a great variation in ground levels; the maximum ground level recorded is 250 m amsl, whereas the minimum ground level

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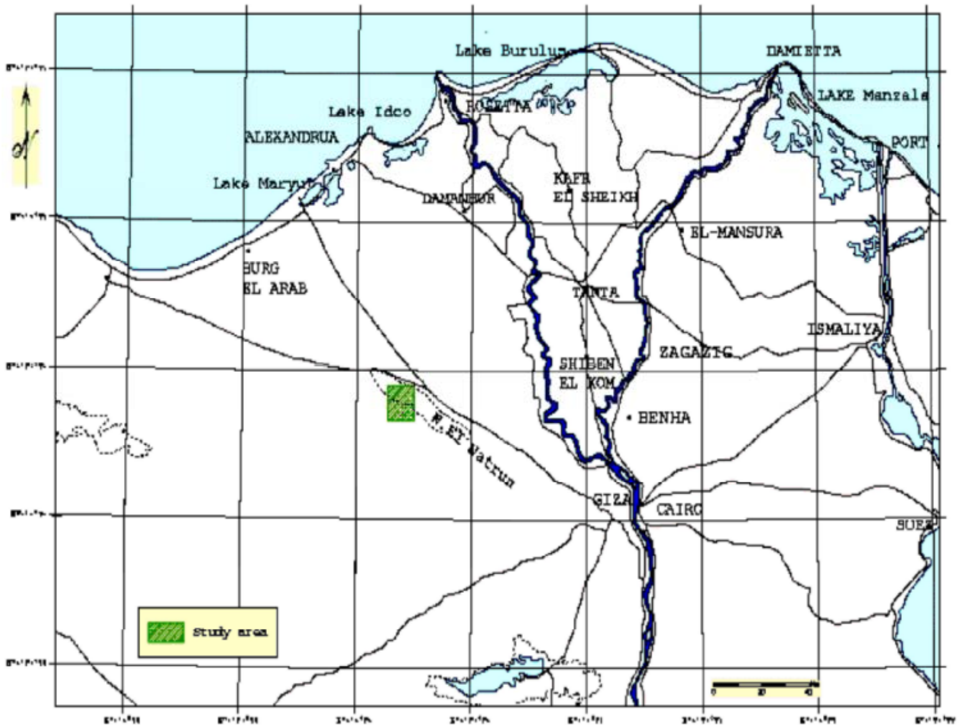

Fig. 1: Location map of the study area

is several meters below sea level. This variation is effective factor in distribution of recharge and discharge areas. The change in ground levels is gradually, from the southwestern portion, where the maximum ground level recorded to northern portion, where the minimum ground level recorded.

Geomorphology: The geomorphologic units of the western Nile Delta where the study area is located reflect the geologic structures, lithologic features and land forms processes. The geomorphologic units can be grouped according to their regional trends into:

The Young Fluviatile Plain: Occupying the northern and eastern portion of the study area. It is flat plain; its elevation ranges from three meters to twelve meters Figure (2) above mean sea level. In many places, brackish lakes and water-logged areas are present. This plain underlain by thin silt clay layer, which change locally into calcareous loamy layer, deposited during successive floods of the Nile.

The Old Fluviatile Plain: Occupying the central portion of the area and extends northwest-southeast direction Figure (2). Holocene and Pleistocene gravel and coarse sand with minor intercalation of clay underlie the old fluviatile plain. The surface is dissected by shallow channels directed either to the Delta or to the depression of Wadi El Natrun.

The Structural Plain: Occupying the south and west Wadi El Natrun . The surface is almost flat and locally affected by the northwest terminus of Wadi El Natrun depression, where the ground elevation is fifteen meters below mean sea level. The plain is underlain by sands and limestone and is occupied by multitude of channels of dry desert wadis and a series of elongated dunes “Seif” in the southwest.

The Mediterranean Foreshore Plain: Represented in very small area in the northwest corner of the study area. Landforms represented in this plain include the wetland areas of the main lakes, the sabkhas, or evaporites consisting of gypsum, halite and clays mixed quartz and silt. The evolution of foreshore plain was influenced by succession of transigressive and regressive phases.

Geologic Setting: Many authors studied the geology of Wadi El-Natrun area, among them; Farag, [1], Shata, [2] and Said, [3]. The area of study constitutes a portion of the great arid belt covering Egypt.

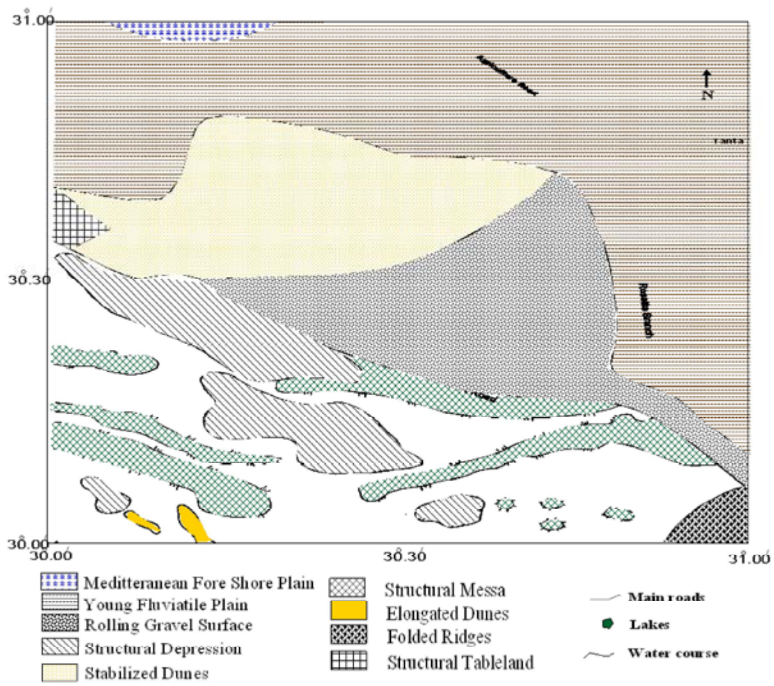

Fig. 2: Geomorphologic map northwestern part of the Nile delta

This belt characterized with low average annual rainfall, degradation of the surface and accumulation of sand dunes. Other landforms reflect less arid conditions like old drainage lines, which are relatively short and their beds are filled with young sediments.

Deep wells drilled in this area shown apparently geologically, simple structure made by the thin sediments conceals beneath it an intricate geological structure made up of large number of swells and basins.

The sedimentary section in the study area is very thick ranging from Pre-Cambrian age to Holocene age. The exposure formations in west delta are dominated by a sedimentary succession ranging from Lat Cretaceous to Quaternary. The sedimentary column starts from bottom by Oligocene sediments.

Stratigraphy: The staratigraphy of the area will be discussed according to their sequence of sedimentation from bottom to top as follows:

Oligocene: Thickness of Oligocene sediments in the study area is about 390 m. The Oligocene sediments are represented by some horizons of red, violet and yellow ferruginous sandstone and sands, sometimes with gravels and occasionally indurate into quartzite. The Oligocene formation "Gabel Ahmer formation" is well exposed at Gabel Ahmer and at Abu Roash areas in the environs of Cairo.

Pliocene: The well-developed thickness of Pliocene sediments is about 200 m. The Pliocene age represented by Gabel El Hadid formation which occupies high terraces capping Early Miocene rocks at Gabel El Hadid to the west of Wadi El Natrun. This formation is constituted of gravel and sands.

Gabel Hamza formation is formed of sandstones, sandy marl and parcellaceous lime stones and covered sometimes with red silts. It is associated also with calcareous materials and clay and is characterized by medium gray color and medium texture. This formation outcrops in the southeastern direction of study area.

Pleistocene: The well-developed section of Pleistocene deposits is 1000 m thickness. It mainly distributed west of Rosetta branch and east of Wadi El Natrun. Gabel El Basur formation of Pleistocene age is a young Pleistocene terrace covered by sands and gravels.

Pleistocene to Holocene: During this period, different erosional processes produce different types of deposits as follows;

Alluvial Deposits Derived from Miocene Rocks: These deposits composed of almost homogeneous calcareous loam, sometimes associated with concretionary gypsum.

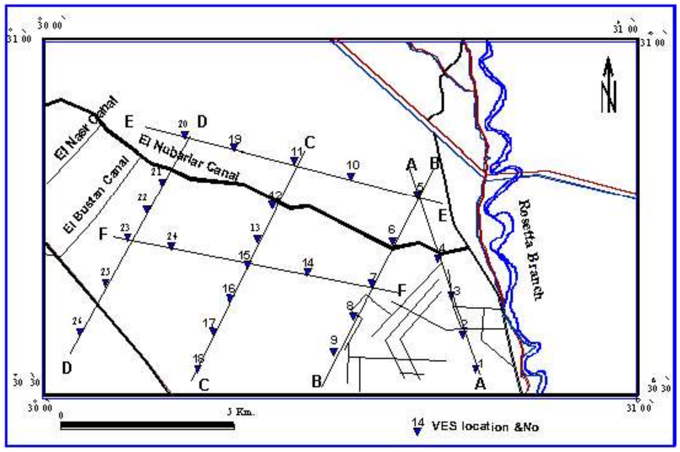

Fig. 3: Location of resistivity sounding profiles.

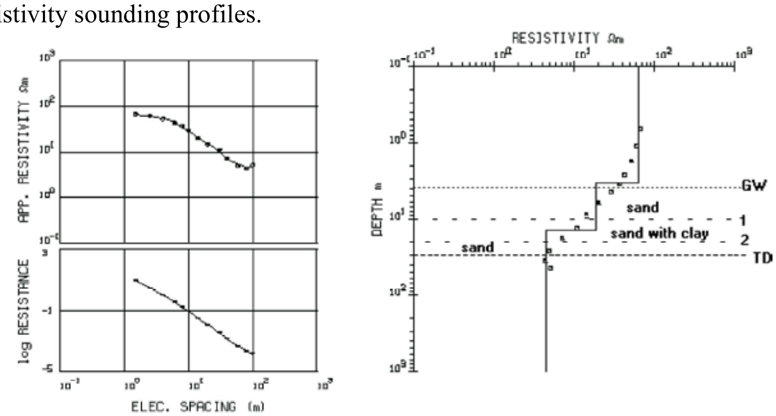

Fig. 4: Selective example of 1-D inverse modeling results at VES3 using Meju program (1994).

Alluvial Deposits Derived from Pliocene Rocks: The well-developed thickness of these deposits is about 2 m. They occur northeast to Wadi El Natrun depression and extend in northwest direction. They are characterized by light gray and very fine texture.

Sand Dunes: The thickness of these deposits range from 10 to 30 m. Sand dunes belts with certain direction to become mostly NNW-SSE, are present to the south of Wadi El Natrun.

Deltaic Deposits: The thickness of these deposits reach about 300 m in the Nile Delta, areas covered by inland and deltaic deposits exist.

Marshes and Sabkhas: The thickness of these deposits reaches 18 m and observed in Wadi El Natrun depression.

DC Resistivity Investigation: Electrical resistivity measurements has been used significantly in groundwater prospecting [4, 5, 6]. The geophysical survey described in this work is represented by DC resistivity soundings. A geoelectrical resistivity survey in the form of twenty discrete vertical electrical soundings was carried out in the considered area (Figure 3). The well-known Schlumberger configuration with current electrode spacing (AB) starting from 3 m up to 1000 m, in successive steps, is selected and applied. Five profiles were surveyed. The field survey was conducted using the ABEM SAS 4000 Resistivity Meter.

The data was initially processed using 1-D (one dimensional) modeling program [7]. Processing of 1-D initiated first with forward modeling using an initial model based on a simple resistivity-depth transformation of the raw data [7] and geological information from the available boreholes. Then and for getting a better fit, the inverse modeling has been iteratively processed. Figure (4) shows an example of the 1-D inversion results at site no. 3. Calibration of the VES's results with the available boreholes revealed that the resistivity values are governed mainly by the hydrogeological and lithological conditions. The 1-D inversion results have been collated in the form of 6 Geoelectric sections. Three of them are shown in Figures (5, 6 and 7).

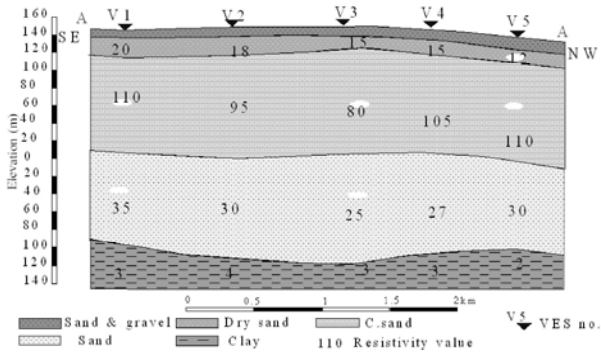

Fig. 5: Geoelectric cross section A-A

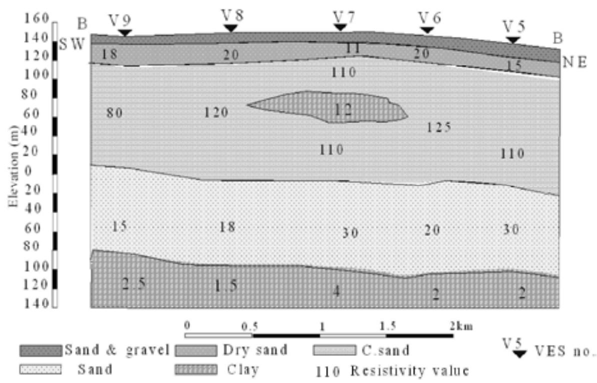

Fig. 6: Geoelectric cross section B-B

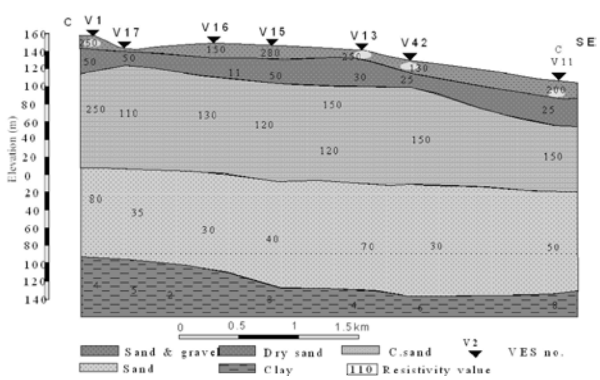

Fig. 7: Geoelectric cross section C-C

These geoelectric sections portrayed five geoelectric layers representing the investigated sedimentary sequence; the top one has resistivity values ranged between 35 and 150 ohm-m. This resistivity range indicates that this geoelectric layer might have fresh to brackish water-bearing formation almost at the bottom zone when compared with the depth to water recorded from the available water wells drilled in the study area. This upper geoelectric layer is underlined by a conductive zone of resistivity values 5-30 ohm-m and. The third geoelectric layer having resistivity values of between 80-250 ohm-m and which can be considered as water bearing layer corresponding to the Pliocene sediments. It has thickness of about 80 m. the fourth layer has lower resistivity between 15 and 39 ohm.m and great thickness and interpreted as sandy layer of brackish water potentiality. These four layers rest over a lower resistivity conductive layer which separates the upper water bearing zones from the deeper aquifers of Miocene and Oligocene. Generally, this one dimensional geoelectric inversion results along the three profiles (A- A-, B-B- and C-C-) indicates the presence of lateral and vertical variations in the investigated area.

Surface Water System: Irrigation in the study area depends mainly on the surface water diverted from Nile water through main canals and their secondary channels. The surface water system includes Rosetta Branch, El Nubariya canal and El Nasr canal, Figure (3). These canals between Rosetta branch, as well as surface drainage system play an important role in the water regime of the study area. The existing surface water systems mainly cut through sands and therefore, a direct connection between the surface water and groundwater exists.

The seepage from surface water to groundwater and vice versa depends on water levels in both. In Rosetta branch, the water levels varies from 5.56 m amsl to 3 m amsl, whereas the groundwater levels in adjacent area varies from 7 m amsl to 5 m amsl. This means that Rosetta branch act as drain for the groundwater in this area [8]. In Wadi El Natrun, the lowest water levels all over the study area existed. Therefore, Wadi El Natrun is the main discharge area.

El Nasr canal was constructed in 1966 as a branch of El Nubariya canal at km 57.5 in the left bank. It carries irrigation water to the cultivated lands in new reclaimed areas (El Nubariya area).

Groundwater System: Inventory of the available water wells drilled in the study area helped in analyzing the different water bearing formations. About 41 well data were collected and used for calibrating the results of DC resistivity results although the resistivity sections investigated to depth of about 250 m geologically, it was clearly noticed that the groundwater conditions in the study area are greatly affected by structural features especially faulting, litho logical nature of aquifers as well as the drainage pattern. Therefore, studying the lithological conditions through geoelectic cross sections is of prime importance for deciphering groundwater problems. According to stratigraphic sequence of water bearing formations with other geological and hydrological conditions of the study area, groundwater aquifers can be classified into:

Table 1: Hydraulic characteristics of the Pleistocene aquifer in the study area

Author	Area	T (m^2/day)	K (m/day)	S
Said [3]	Eastern Alex. Rd at W.N.	1291.7	52.98	$3.95 * 10^{-3}$
Said [3]	South El Tahrir	2161	10.8	$8.4 * 10^{-2}$
GPC [14]	East Wadi El Natrun	2600	26.0	$3.9 * 10^{-3}$
Abd El Baki [15]	Along El Nassr Canal	4619	49.68	$2.52 * 10^{-3}$
Ismail *et al*. [16]	El Bustan	3560	-	$2.32 * 10^{-3}$
Gomma [9]	El Bustan	2276.3	-	$4.5 * 10^{-3}$
Ahmed [17]	East Wadi El Natrun	1925	-	-

Table 2: Hydraulic characteristics of the Pliocene aquifer in the study area

Author	Area	T (m^2/day)	K (m/day)	S
Said [3]	East Wadi El Natrun	395.5	38.9	$1.35 * 10^{-3}$
Saad [18]	Northern Wadi El Natrun	1180.8	-	$2.65 * 10^{-3}$
Saad [18]	At El Hamra lake	95.04	-	$7.5 * 10^{-4}$
RIGW [10, 11]	Wadi El Natrun	500	9.8	$1.7 * 10^{-2}$
Mostfa [19]	East Wadi El Natrun	943	47	$7 * 10^{-4}$
Ahmed [17]	Northern Wadi El Natrun	1043.9	-	-
Ahmed [17]	Southern Wadi El Natrun	1660.2	-	-

- Nile Delta aquifer (Quaternary aquifer)
- Pliocene aquifer
- Miocene aquifer

Nile Delta Aquifer: It is composed of two zones: a) the upper zone of recent age which has limited distribution of sandy deposits with calcareous intercalations of Aeolian origin, filling the low lands in Wadi El Natrun depression. The thickness of this zone ranges between 4 m to 10 m exists under free water table conditions at depths ranging from 2.4 m to 4.3 m from ground surface [9]. b) the lower zone of Pleistocene is the main water bearing formation occupies the northern and northeastern portion of the study area. It is highly productive aquifer [10, 11]. This aquifer is made up of successive layers of sand and gravels with occurrence of clay lenses of fluviatile origin. Total thickness of Pleistocene-Holocene deposits ranges between 300 and 80 m. Close to Wadi El Natrun, the aquifer thickness varying between 60 to 80 m.

Hydraulic parameters of Pleistocene aquifer has been dealt by many authors and Table (1) shows some authors and values of hydraulic parameters calculated:

Pliocene Aquifer: This aquifer is restricted in Wadi El Natrun area, where most of deep wells drilled recognized two water-bearing horizons of sandy facies included in Pliocene clay of great thickness [12, 13]. The thickness of this aquifer attains 140 m with saturated thickness equal 90 m. The thickness increases from west to east and from south to north Figure (9).

The uppermost horizon is mainly composed of loose sand and sandstone having a thickness about 15 m developed into clay facies with interbeds of sandy facies in the eastern part of Wadi El Natrun. The lower water-bearing horizon is represented by sandy facies with thickness range between 1-to 10 m. This horizon is restricted in Wadi El Natrun depression. The uppermost horizon bearing groundwater under semi-confined conditions whereas, the lower one bearing groundwater under confined conditions.

The groundwater quality of Pliocene aquifer varies from fresh water to brackish water, where fresh water observed in the southern and eastern portion of Wadi El Natrun, whereas the brackish one observed in the central portion.

Miocene Aquifer: Miocene aquifer, which represented as Moghra formation of early Miocene age, covers a wide area in the west of the study area. It is mainly composed of sand, sandstone with clay intercalation of fluviatile and fluviomarine origin. The aquifer thickness varies in different areas, it attain 75 m in the eastern, 150 m in Wadi El Farigh area, 250 m at Wadi El Natrun area and gradually increase in the northwest direction to attain the maximum thickness (900 m) at Qattara depression Figure (10).

The groundwater exists mainly under free water table conditions. In Wadi El Natrun depression, impervious Pliocene clay covers the aquifer. Therefore, the groundwater exists under confined or semi- confined conditions.

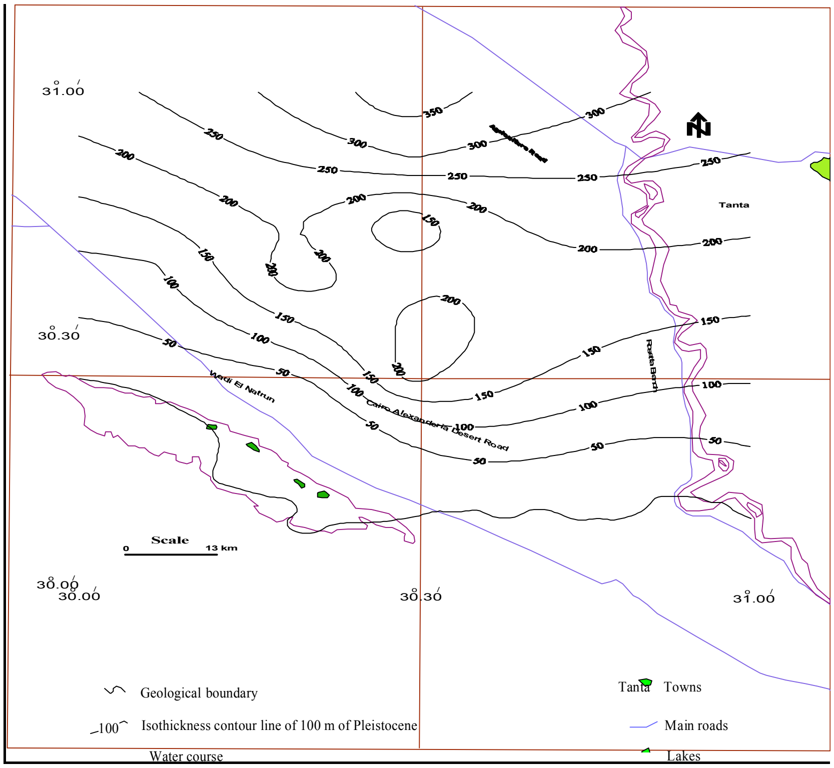

Fig. 8: Thickness map of Pliestocene aquifer

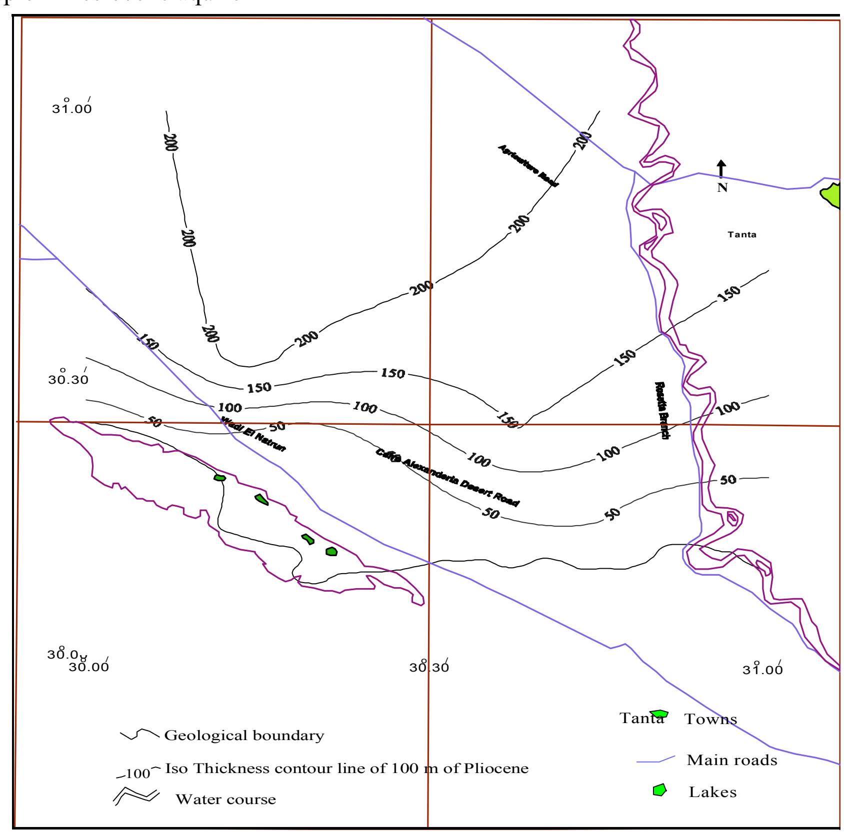

Fig. 9: Thickness map of Pliocene aquifer

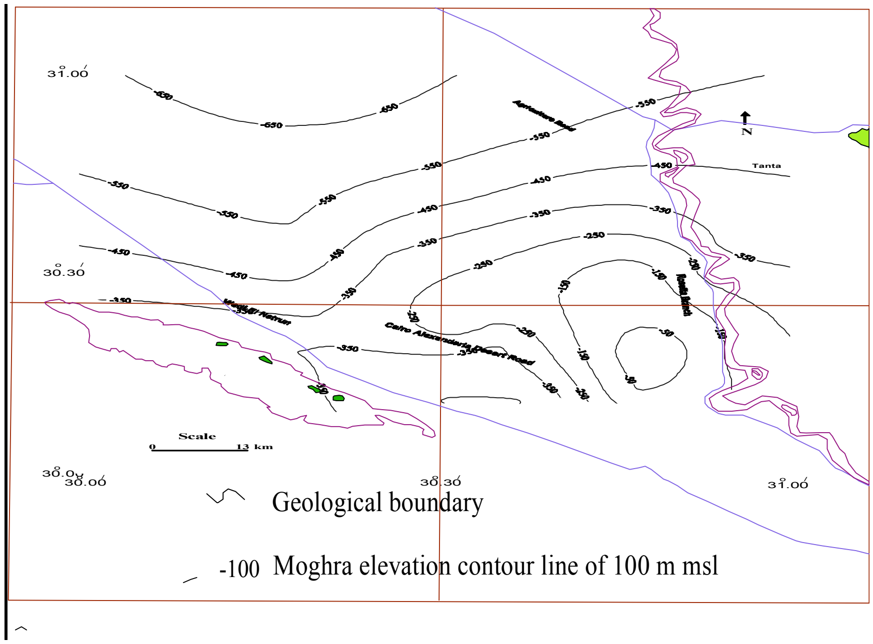

Fig. 10: Thickness map of Miocene aquifer.

Table 3: Assessment of groundwater vulnerability

Clay thickness (m)	Recharge (mm/d)	Depth to gw table (m)	Vulnerability
		<5	High
	>1	5-15	High
No clay		>15	High
		<5	High
	<1	5-15	Medium
		>15	Medium
		<5	High
	>1	5-15	Medium
0-2		>15	Medium
		<5	Medium
	<1	5-15	Medium
		>15	Low
		<5	Medium
	>1	5-15	Medium
2-10		>15	Low
		<5	Medium
	<1	5-15	Low
		>15	Low
		<5	Medium
	>1	5-15	Low
>10		>15	Low
		<5	Low
	<1	5-15	Low
		>15	Low

Eventually, the southeast - northwest flow direction from south of the Delta Barrages towards the study area across the Cairo-Alexandria desert road is doubtful, since the geological structure and type of sediments mainly govern the existence of groundwater through this direction.

Hydrochemical Aspects: The subsurface environment of groundwater is characterized by a complex interplay of physical, geochemical and biological factors that govern the release, transport and fate of a variety of chemical substances. The impact of natural groundwater recharge and discharge processes on distributions of chemical constituents is understood for only a few types of chemical species. In addition, these processes may be modified by both natural phenomena and man's activities for their complicated apparent spatial or temporal trends in water quality.

Thirty six water samples were analyzed for elements and parameters that exceed the standard limits of drinking and irrigation. The following elements are exceeding the standard limits of drinking and irrigation. The groundwater vulnerability assessment illustrated in Table (3) helped in scanning for elements and parameters that exceed the standard limits of drinking and irrigation. The following elements are exceeding the standard limits of drinking and irrigation.

Salinity: The dominant ones are NaCl and $CaSO_4$ due to the high solubility of chloride and sulfate minerals. Obscure geological environments can host high salinity ground waters with some rather unusual geochemical facies.

Chloride: NaCl facies dominate in sedimentary basin brines, where Cl^- concentration can exceed 100,000 mg/l leaching of marine sediments is also a source of NaCl salinity. Less common is $CaCl_2$ salinity, although this facies dominates in brines from crystalline basement rocks where feldspar alteration is the source of Ca^+.

The chloride concentration increases northwestward. The minimum concentration of chloride, all over the study area is in the eastern portion, whereas the maximum concentration is in Nubariya in the northwest.

Sodium Concentration in the Study Area: The sodium concentration increases northwestward. The minimum concentration of sodium, all over the study area is in the eastern portion, whereas the maximum concentration is in Nubariya in the northwest.

The trend of change of sodium is coinciding with the trend of change of salinity and chloride. Increasing the sodium, salinity and chloride contents of groundwater are due to either mixing with seawater or leaching soil salts. The improvement of soil salinity and groundwater quality is so clear in small area within Nubariya.

Sulfate Reduction at Depth: The sulfate concentration increases northwestward reached its maximum in Bustan area. The minimum concentration of sulfate, all over the study area is in the eastern portion, whereas the maximum concentration is in Bustan in the northwest corner. The trend of change of sulfate is coinciding with the trend of change of salinity.

Nitrate: The nitrate concentration increases northwestward reached its maximum value in north Wadi El Natrun. The minimum concentration of nitrate, all over the study area is in the eastern portion, whereas the maximum concentration is in north Wadi El Natrun close to Cairo-Alexandria desert road. The trend of change of nitrate is coinciding with the trend of change of salinity. Increase the salinity and nitrate contents of groundwater are due to applying fertilizers in reclamation areas.

Manganese: The maximum concentration of manganese in the study area was reported in eastern portion east Rosetta branch. The manganese concentration increases eastward reached its maximum in Ashmon. The minimum concentration of manganese, all over the study area is in the western and northwestern portions, whereas the maximum concentration is in eastern portion east Rosetta branch. The fore mentioned area is a tradionally-cultivated land with clay cover and presence of clay minerals is the main cause of increasing manganese. The trend of change of manganese is coinciding with the trend of change of Iron. Increase the Manganese and Iron contents of groundwater are due to presence of clay minerals.

Fluorine: The maximum concentration of fluorine in the study area was reported in north Wadi El Natrun close to Cairo-Alexandria desert road and in Nubariya. Fluorine concentration increases northwestward reached its maximum in north Wadi El Natrun close to Cairo-Alexandria desert road and in Nubariya. The minimum concentration of fluorine, all over the study area is in the eastern portion, whereas the maximum concentration is in north Wadi El Natrun close to Cairo-Alexandria desert road and in Nubariya. The fore mentioned area is a new reclamation area and applying fertilizers is the main cause of increasing Manganese.

Iron: The maximum concentration of iron in the study area was reported in eastern portion east Rosetta branch. The iron concentration increases eastward reached its maximum in Ashmon. The minimum standard limit of Iron for drinking is 0.1 ppm whereas the maximum standard limit of iron for drinking is 0.5 ppm.

Summary: Direct current resistivity method has been evaluated for mapping groundwater potentiality. Data sets of twenty six vertical electrical soundings were collected. The data were processed and interpreted and the results illustrated that the technique has shown its effectiveness for differentiating the water bearing strata when compared to the available information from water wells. Furthermore, it has also shown a limited fresh water bearing horizon above the saltwater bearing zone. The study area, groundwater aquifers can be classified into:

- Nile Delta aquifer (Quaternary aquifer)
- Pliocene aquifer
- Miocene aquifer

Hydrochemically, the major elements of water exceeds the permissible limits of drinking and irrigation.

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