NRIAG Journal of Astronomy and Geophysics 7 (2018) 377–389

Contents lists available at ScienceDirect

NRIAG Journal of Astronomy and Geophysics

journal homepage: www.elsevier.com/locate/nrjag

Full length article

Application of geoelectrical measurements for detecting the ground-water seepage in clay quarry at Helwan, southeastern Cairo, Egypt

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ARTICLE INFO

Keywords:
Quarry problems
Geoelectrical resistivity
Groundwater seepage

ABSTRACT

Clay is considered one of the most important raw materials in cement industry. It is the most common rich source of silica and alumina. During the quarrying process a few months later, a new feature of water accumulation appeared on the quarry floor and many water pools were formed during excavation process. In order to detect the source and extension of the ground-water seepage, geoelectrical resistivity technique in the form of vertical electrical soundings was applied. Fifteen vertical electrical soundings with AB/2 from 1 to 150 m have been executed.

Geoelectrical resistivity measurements are applied in Helwan clay quarry to understand the source of the groundwater accumulated recently on the floor of quarry. The results indicate the passage of groundwater from the adjacent areas through channel ways formed as a result of the excavation process. All over the measured area, there are some sand lenses intercalated with clays & during the excavation process, some channels formed and the groundwater started to percolate through these channels forming many water pools along the quarry floor.

1. Introduction

The study area is located between latitudes 29°46′22.24″N & 29°46′45.35″N and longitudes 31°21′23.48″E & 31°21′44.32″E (Fig. 1). The investigated clay quarry is located about 42 Km and 19 Km to the south-east of Cairo and Helwan cities respectively. The altitude of the floor of study area is approximately 50 m above sea level. At the northeast; the ground elevation is around 63 m above sea level, decreasing gradually to the southwest, down to 60 m above sea level. The region is characterized by a dry climate with warm winter and hot summer with an average daily temperature ranges from 14° to 31 °C. The average long-term rainfall is about 25.7 mm/year, evapotranspiration rate ranges from about 256 mm/year in winter to about 5746 mm/year in summer and relative humidity from 50 to 70% (Elminir et al., 2005).

From 1955 to 1975, Helwan city and its environs were considered one of the most important industrial zones in Egypt with all the negative side effects related to the environment in particular. This is due to the presence of some large national industrial facilities like cement, iron, steel, cement, automobile manufacturing, coal industry and red brick factories. Industries consume large amounts of water and in many cases return highly polluted wastewater directly to the environment. Furthermore, the region has some tourist activities because of the presence of the Helwan (mineral and sulphurous) springs.

The aim of this study is to determine the shallow subsurface geologic interfaces to delineate the extension of the groundwater accumulations in clay quarry at the southeastern part of Helwan area and know the causative sources for these accumulations by using vertical electrical sounding technique which is extensively used in hydrogeology to define horizontal zones of porous strata and to delineate different subsurface geoelectrical layers, subsurface structure and its influence on the general hydrogeological conditions (Lashkaripour et al., 2005; Oseji et al., 2006; Khalil, 2010). In addition to, VES technique is widely attempted for the exploration of groundwater resources (Kumar et al., 2007; Soupios et al., 2007; Hodlur and Dhakate, 2009; Balaji et al., 2010; Khalil, 2010).

2. Geological setting

Geologically, the Helwan clay quarry, the exposed rocks consist of Pliocene conglomeratic sands, sandstone and gravels (Fig. 2). These Pliocene sediments belong to the Nile Valley sediments consist of a

Peer review under responsibility of National Research Institute of Astronomy and Geophysics.

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https://doi.org/10.1016/j.nrjag.2018.04.003
Received 8 February 2018; Received in revised form 17 April 2018; Accepted 20 April 2018
Available online 30 April 2018

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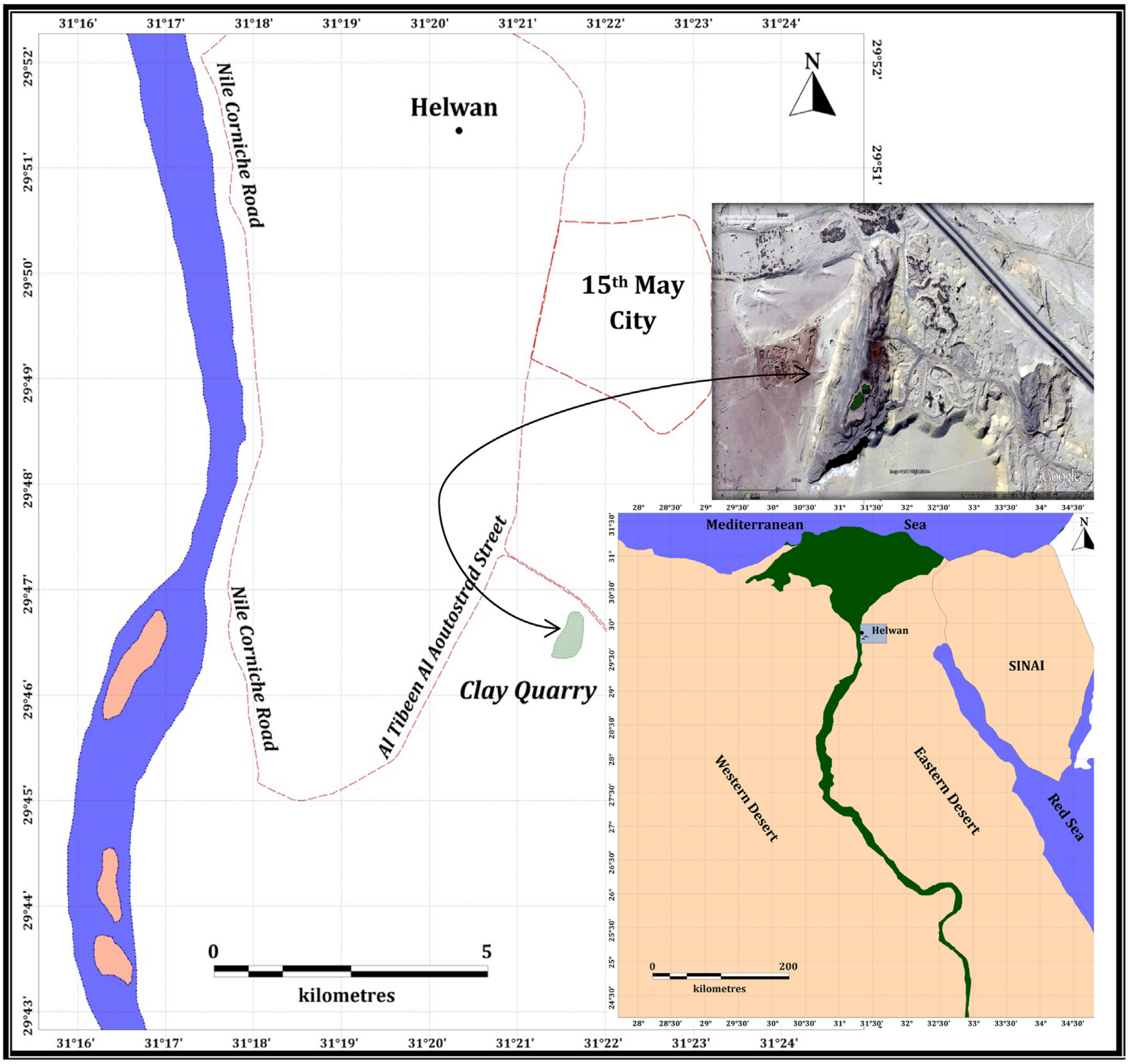


Fig. 1. Location map of the Helwan clay quarry.

lower marine sequence of Early Pliocene age and an upper fluviatile sequence of Late Pliocene age (Conoco, 1987, Hermina & Lindenberg, 1989, Said, 1990; Swedan, 1991).

Early Pliocene Marine Sequence: The type section of the marine Pliocene deposits of the Nile Valley is at Kom El-Shelul, where it is made up of a basal 10 m oyster bed made almost of Ostrea cucullate shells. This is followed by a 2 m sandstone bed crowded with Pecten benedictus and Chlamys scabrella. Upon this lies a sandstone bed of 50 cm thick full of remains of Clypeaster aegyptiacus casts of large gastropods, the same pectens in the underlying bed, and many other fossils. Then follows a 10 m bed of unfossiliferous yellow quartzose sand and brownish sandstone with large flint pebbles. The top of the section is covered by Pliocene-Pleistocene gravels.

Late Pliocene Fluviatile Sequence: The onset of more humid conditions in the Late Pliocene time converted the marine gulf of the Nile into veritable river channel. Sediments belonging to this river system consist of a long series of interbedded red-brown clays and thin fine grained sands and silts laminae which crop out along banks of the Nile.

3. Objective

The objective from the present work is delineating the source and extension of the accumulated water zone on the clay quarry floor, where a water pool is recently formed during the excavation process in few months. Probably, there are some sand lenses filled with water and during the excavation, seepage is occurred and the water accumulated forming pools in many places on the floor of the quarry or maybe there is another reason explaining these accumulations. However, there is a good resistivity contrast because the water will reduce the resistivity values of the saturated rocks compared to the unsaturated surrounding rocks.

There are different arrays which can be applied to detect the resistivity anomalies created by these lenses. There are many factors (like the use of the optimum combination of electrode spacing, interval between successive stations in addition to the site conditions) which control in the probability of success by any method. In order to resolve the anomalies sought, numerous surveys are carried out with an interval too large.

It is important to delineate the sources of the accumulated water on the quarry floor. The water seepage started through channels & after that the amount of water is increased forming many pools along the quarry floor (Fig. 3). In order to solve the problem and prevent the increasing of this water, it is necessary to know and detect the sources of the water seepage on the quarry floor. In this respect, it is required to carry out a number of vertical electrical soundings to know the detailed information about the sources of water seepage.

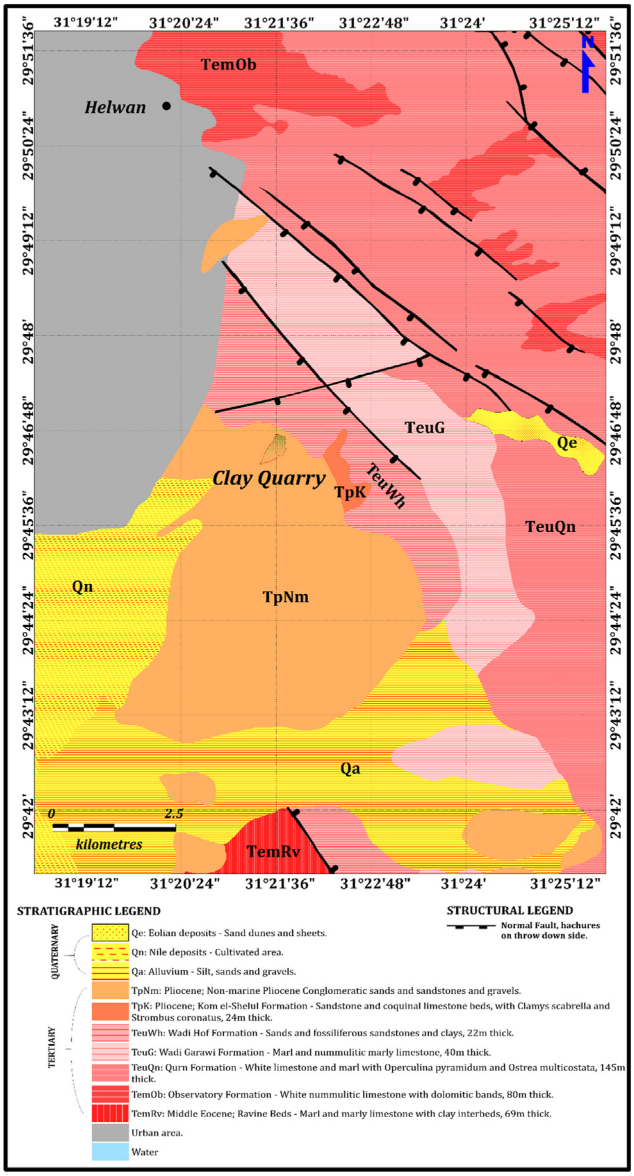


Fig. 2. Geological map of the study area (Modified after the Egyptian Geological Survey and Mining Authority, 1983).

Fig. 3. Photo shows the water pools on the clay quarry floor.

4. Geoelectrical data acquisition

Resistivity surveys are made to satisfy the needs about knowing the water sources. These needs are represented in understanding the resistivity changes with depth, reflecting more or less horizontal stratification of earth materials. Therefore, apparent resistivity measurements are done at a single location or around a single centre point with systematically varying electrode spacings. This method is called vertical profiling or vertical electrical sounding (VES).

In the field, resistivity surveys can be carried out with simple equipment. It consists of a high tension battery pack as the source of current, four metal stakes, a voltmeter & four reels of insulated cable. An alternating current (AC) or a direct current (DC) source can be used for the resistivity measurements. The unwanted potentials such as caused by polarization of electrodes or by natural earth currents can be avoided when AC is used in the resistivity measurements. To avoid the rapid decrease of the current intensity with depth, and consequently a decreased depth of investigation, a low-frequency AC source should be used for measuring field data. The using of DC source may be necessary for greater depth penetration. With using DC source, the generation of electrochemical potentials between the ground and the metal electrode should be prevented by using non-polarizing electrodes.

Fifteen VES with AB/2 from 1 m to 150 m have been made. VES's (No. 1, 2, 3, 4, 5, 9, 13, 14 & 15) are measured above mountain surrounding the quarry to know the source of water which appears in the base of the quarry. Six vertical electrical soundings (No. 6, 7, 8, 10, 11 & 12) are measured inside the quarry to try to follow up the water if it is extended under the quarry. The measured vertical electrical soundings locations in the form of Schlumberger configuration are shown in Fig. 4.

5. Geoelectrical data processing and interpretation

Many studies are applied to interpret the electrical resistivity data by several authors as Keller and Frischknecht (1966), Dohr (1981), Barker (1989 and 1990), Bisdorf (1982 and 1996), Zohdy (1989, 1993), Zohdy and Bisdorf (1989), Ward (1990), Zohdy and Martin (1993), Parasnis (1997), Van Overmeeren and Ritsema (1988), Chistensen and Sorensen (1998), Dahlin and Zhou (2004), Wisen et al. (2005), Sorensen et al. (2005), Ernstson and Kirsch (2006) and others.

The aim from vertical electrical sounding data interpretation is determining the true resistivities and thicknesses of the successive strata below the different stations utilizing the measured field curves. The interpretation of geologic data is used to translate the quantitative values into a realistic picture within the known geologic framework. In the area under study, the interpretation of geoelectrical resistivity data is performed by using fifteen vertical electrical sounding curves. The interpreter uses the technique to convert the values of AB/2 and ρa into a multilayer model, is that of Geosoft (2004). Winsev 6.0 is simply a program provided by Geosoft Company. The interpreter is using this program to interpret the vertical electrical sounding curves because it is a forward and inverse modelling program for interpreting resistivity sounding data in term of a layered earth (1-D) model. In order to perform this step, sounding curves will be entered as apparent resistivity versus (AB/2) for Schlumberger sounding.

The user can calculate a synthetic resistivity sounding curves for a model with up to twenty plane layers by using forward modelling. He can also determine the layered model directly from the data curve, without having to construct the numbers of layers and the resistivity and the thicknesses of the layers manually by applying direct inversion. In addition to, the applying of inverse modelling will be helpful to construct a model which best fit the data in a least square sense. All of these steps are done by using ridge regression to adjust the parameters

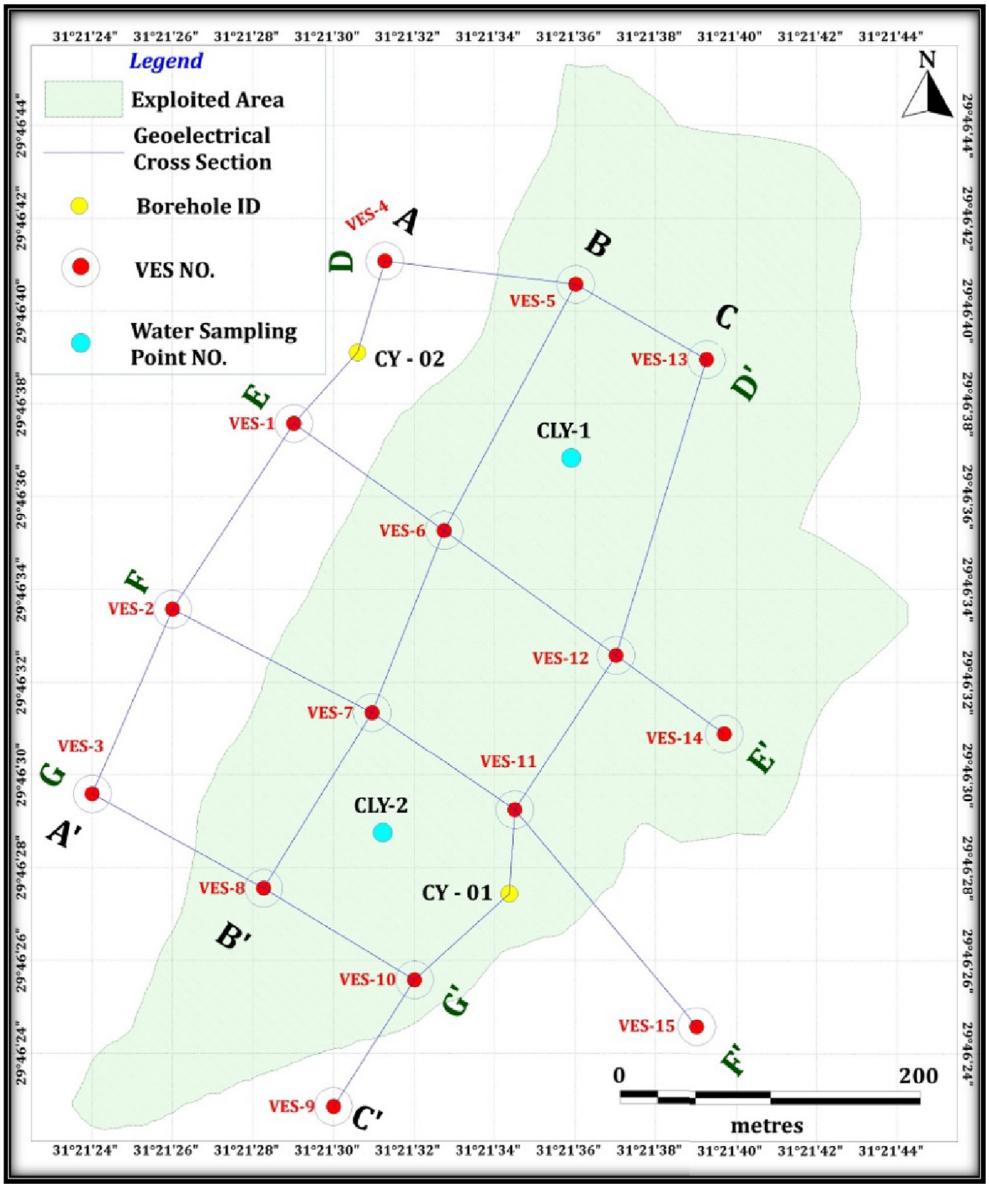


Fig. 4. Vertical electrical sounding location map of the study area.

of a starting model supplies by the user in an iterative manner.

Fig. 5 shows the interpretation of vertical electrical sounding curves of the Helwan clay quarry. From the interpretation of theses curves, it is clarified that there are relative very low-intermediate range resistivity values (from 1 Ω m. to more than 170 Ω m). There are four interpreted geoelectrical units. Table 1 shows the true resistivities and the layer thicknesses. The field observation indicates clay on the quarry floor. In addition to, there are two exploratory boreholes (CY-01 & CY-02) which will be used to obtain the lithology of the study area & their locations are shown in Fig. 4. These boreholes were drilled in the exploration stage to know the thickness of clay layer. The depth of first borehole CY-01 is 20 m while the second borehole CY-02 depth is 30 m. At all location, vertical electrical sounding curves interpretation was correlated with each other and with the geological information which obtained from the boreholes in the study area.

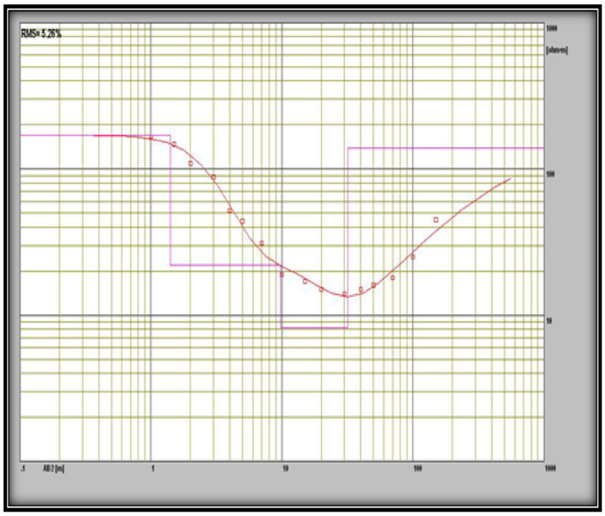
There are three geoelectrical cross-sections that are constructed in the northeast-southwest directions (A-A′, B-B′ and C-C′). In addition to, four geoelectrical cross-sections are created in the northwest-southeast directions (D-D′, E-E′, F-F′ and G-G′).

The geoelectrical cross-section (A-A′) is located at the western part of the study area and above the mountain surrounding the quarry. It includes VES's 1, 2, 3, 4 plus the shallow borehole CY-02 (Fig. 6). The second geoelectrical cross-section (B-B′) is constructed in the middle of the area under study including VES's 5, 6, 7 & 8 (Fig. 7). The last NE-SW cross-section (C-C′) is located at the eastern part of the study area including VES's 9, 10, 11, 12, 13 in addition to the borehole CY-01 (Fig. 8).

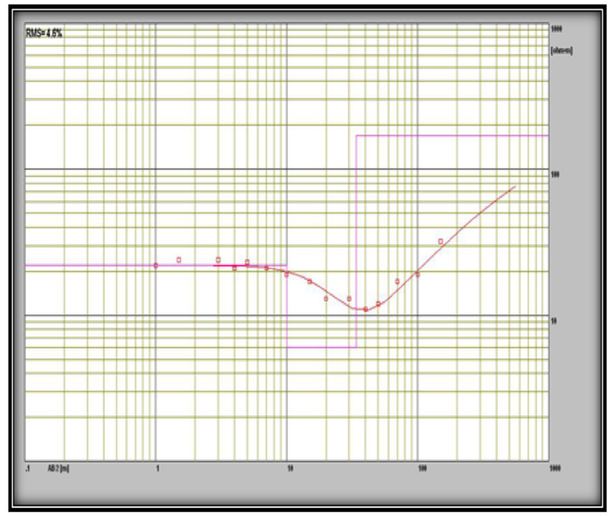
In the northern part of the area under consideration, cross-section (D-D′) is constructed between VES's 4, 5 and 13 (Fig. 9). Towards the south direction, cross-section (G-G′) is built along VES's 3, 8 &10 (Fig. 10). The other NW-SE geoelectrical cross-sections (E-E′) & (F-F′) are located in the middle of the study area including respectively VES's 1, 6, 12 & 14 (Fig. 11) & VES's 2, 7, 11 & 15 (Fig. 12).

It can be summarized from constructing the geoelectrical cross-sections that:

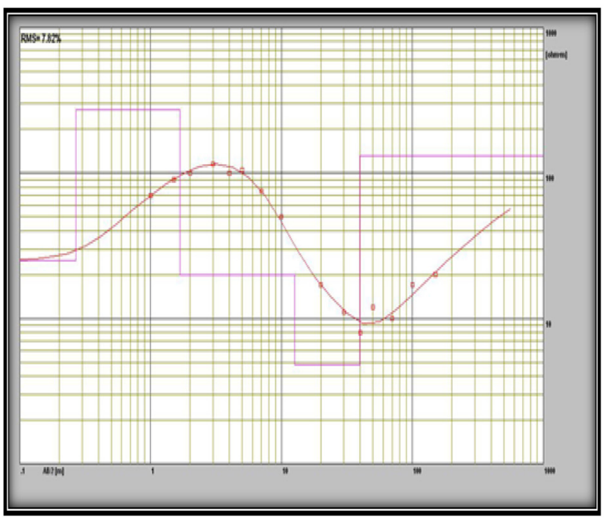
(1) The first geoelectrical unit is characterized by relatively high electric resistivity value ranging between 140 Ω m (VES No. 4) to more than 250 Ω m (VES's No. 3, 14 & 15). This unit thickness is varying between 1.4 m (VES's No. 1, 4, 13 & 14) and 2 m (VES's No. 9 & 15),



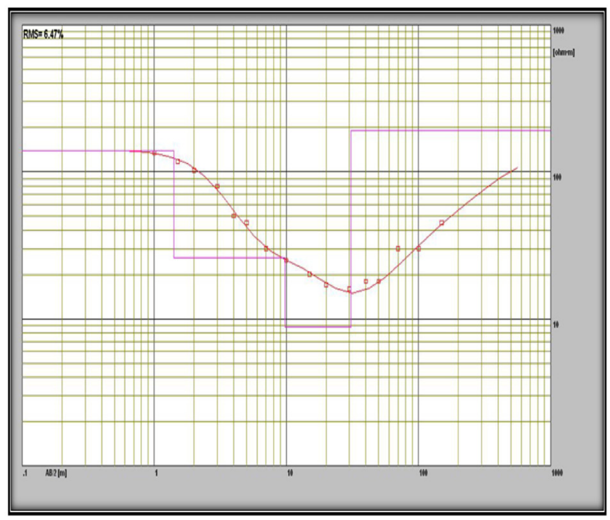
Vertical Electrical Sounding No. 1.



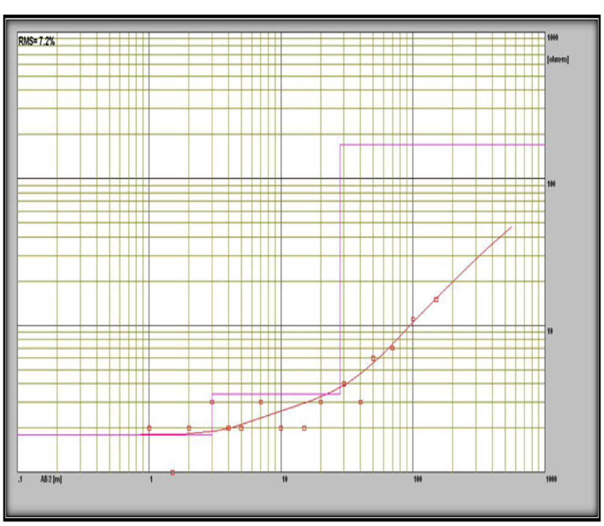
Vertical Electrical Sounding No. 2.



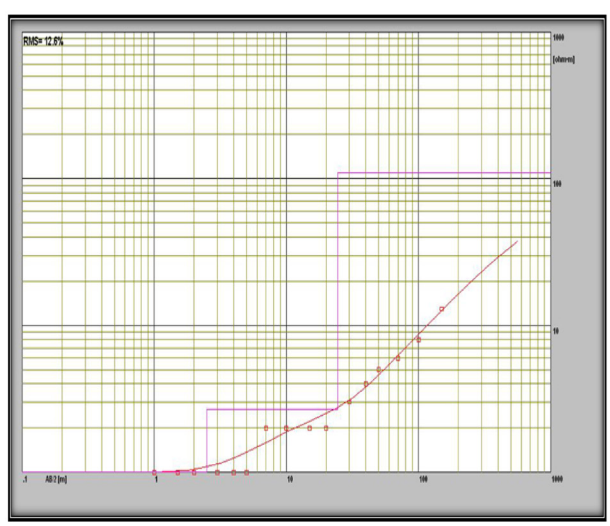
Vertical Electrical Sounding No. 3.



Vertical Electrical Sounding No. 4.

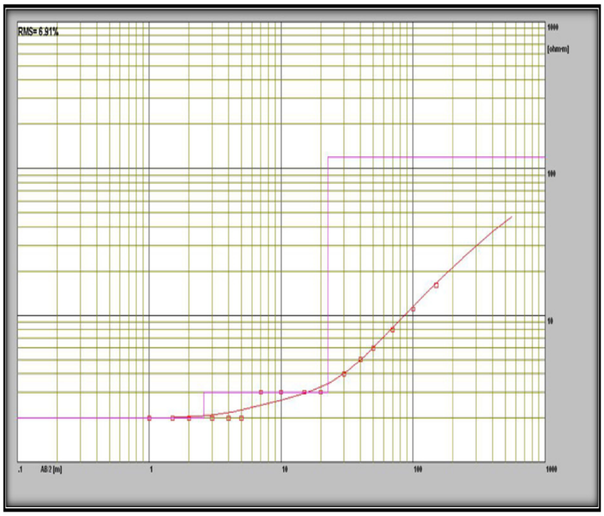


Vertical Electrical Sounding No. 5.

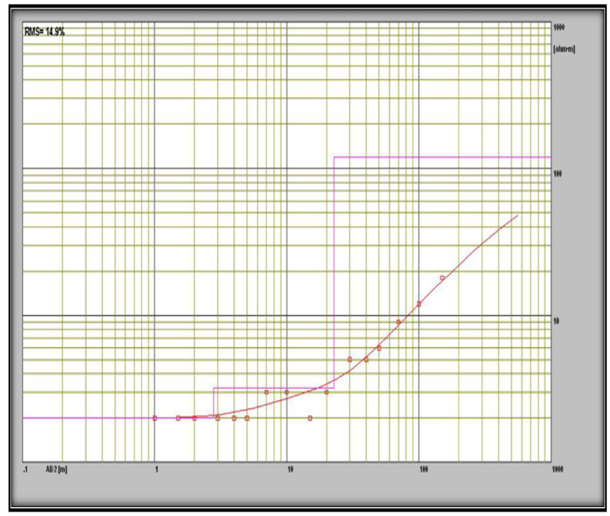


Vertical Electrical Sounding No. 6.

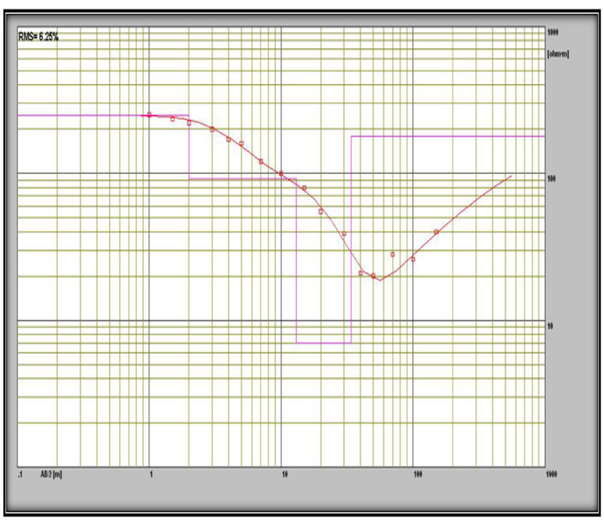
Fig. 5. Interpretation of Vertical Electrical Sounding curves of the Helwan clay quarry.



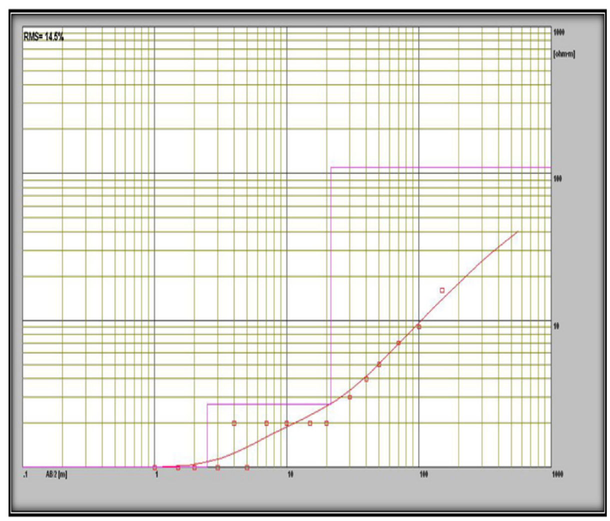
Vertical Electrical Sounding No. 7.



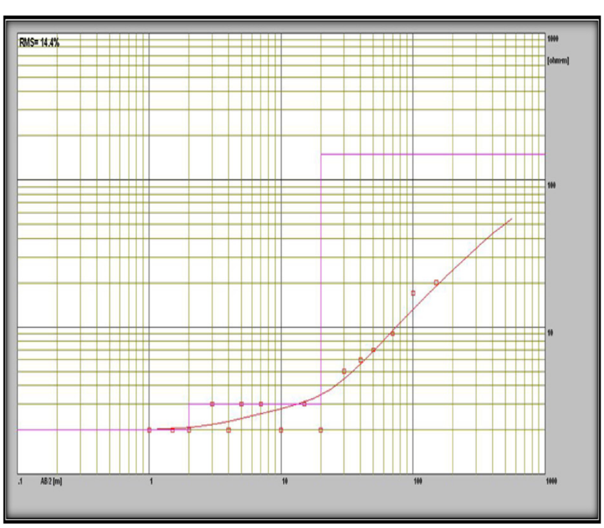
Vertical Electrical Sounding No. 8.



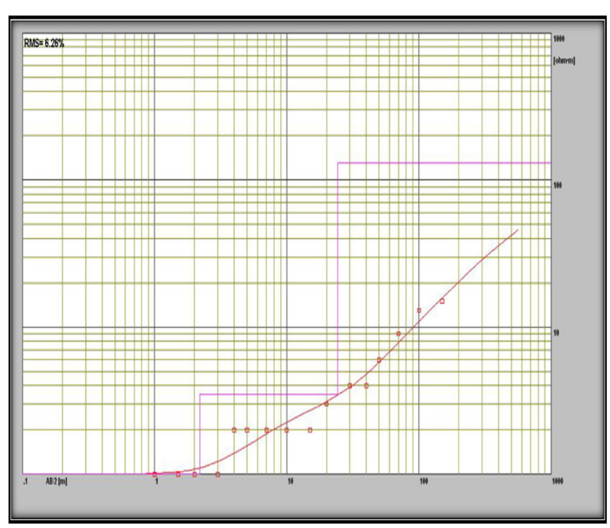
Vertical Electrical Sounding No. 9.



Vertical Electrical Sounding No. 10.

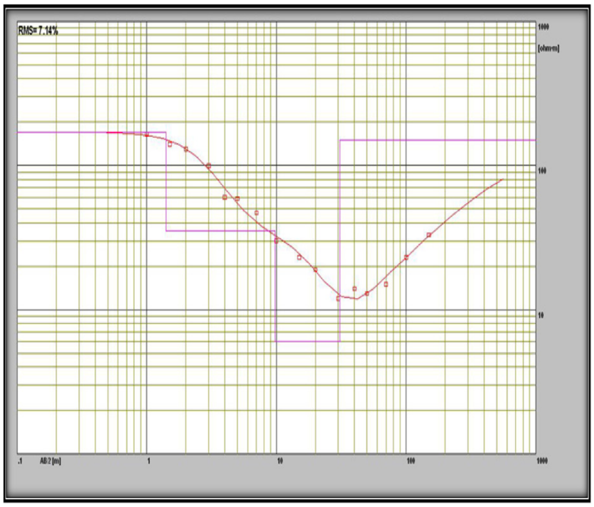


Vertical Electrical Sounding No. 11.

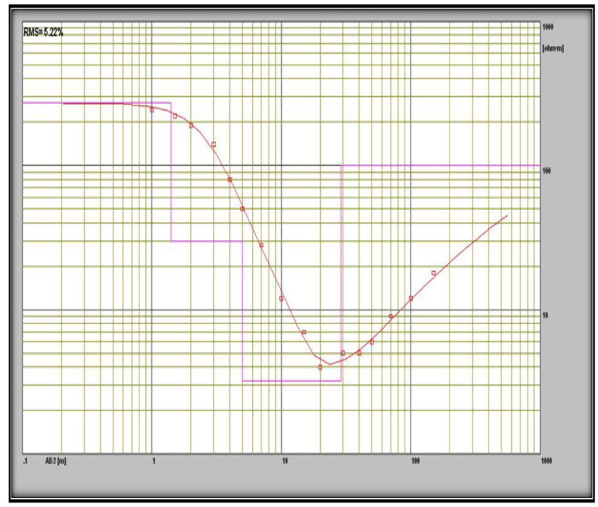


Vertical Electrical Sounding No. 12.

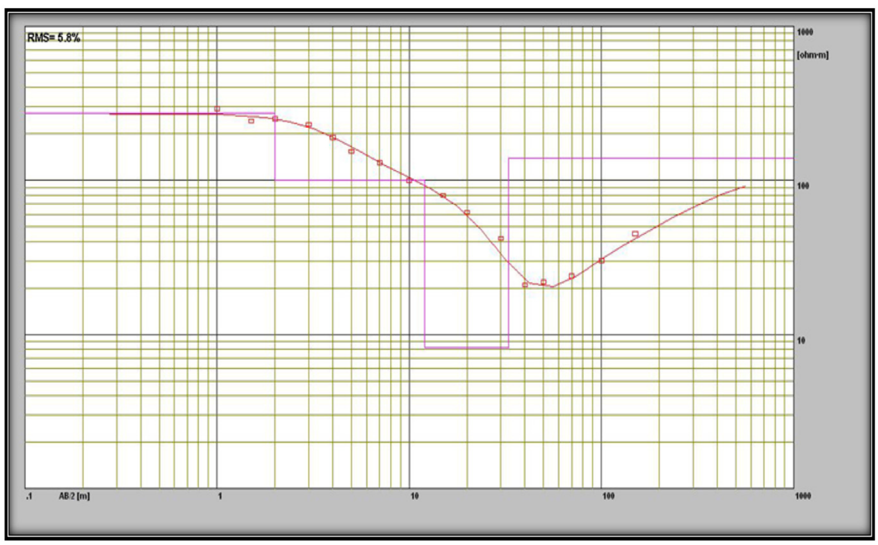
Fig. 5. (*continued*)



Vertical Electrical Sounding No. 13.



Vertical Electrical Sounding No. 14.



Vertical Electrical Sounding No. 15.

Fig. 5. (*continued*)

Table 1
Vertical electrical sounding interpretation of Helwan clay quarry.

VES No.	Resistivity (ρ) Ω m						Thickness (H) m				
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	H_1	H_2	H_3	H_4	H_5
1	170	22	8.2	140	140	–	1.4	8.4	22	18.2	–
2	22	6	170	170	–	–	10	24	16	–	–
3	25	270	20	4.8	130	130	0.27	1.4	11	27	10.3
4	140	26	8.8	190	190	–	1.4	8.4	21	19.2	–
5	1.8	3.4	170	170	–	–	3	25	22	–	–
6	1	2.7	110	110	–	–	2.5	22.5	25	–	–
7	2	3	120	120	–	–	2.6	20.4	27	–	–
8	2	3.2	120	120	–	–	2.8	20	27.2	–	–
9	250	92	7	180	180	–	2	11	21	16	–
10	1	2.7	110	110	–	–	2.5	19	28.5	–	–
11	2	3	150	150	–	–	2	18	30	–	–
12	1	3.5	130	130	–	–	2.2	22.5	25.3	–	–
13	170	35	6	150	150	–	1.4	8.4	21	19.2	–
14	270	30	3.2	100	100	–	1.4	3.6	24	21	–
15	270	100	8.2	140	140	–	2	10	21	17	–

which corresponds to the surface thin gravel lenses. This unit vanishes towards the quarry floor and exists only on the mountain surrounding the quarry.

(2) The second geoelectrical unit is characterized by relatively intermediate electric resistivity value varying between 20 Ω m (VES No. 3) and 100 Ω m (VES No. 15). This unit thickness ranges between 3.6 m (VES No. 14) and increasing to 11 m (VES's No. 3 & 9), which corresponds to sand unit. Sand unit disappears on the quarry floor.

(3) The third geoelectrical unit is characterized by relatively low electric resistivity value ranging between 1.0 Ω m (VES's No. 6, 10 & 12) and increasing with depth to 8.8 Ω m (VES No. 4). This unit thickness ranges between 20 m (VES No. 11) and 27 m (VES No. 3), which corresponds to the clay unit. On the quarry floor, this unit is divided into two zones (upper & lower); the upper zone is affected by the groundwater so the resistivity values are very low compared to the resistivity values of the lower zone. Consequently, the resistivity values for this unit are increasing with depth.

(4) The fourth geoelectrical unit is characterized by relatively high electric resistivity value varying between 100 Ω m (VES No. 14) and

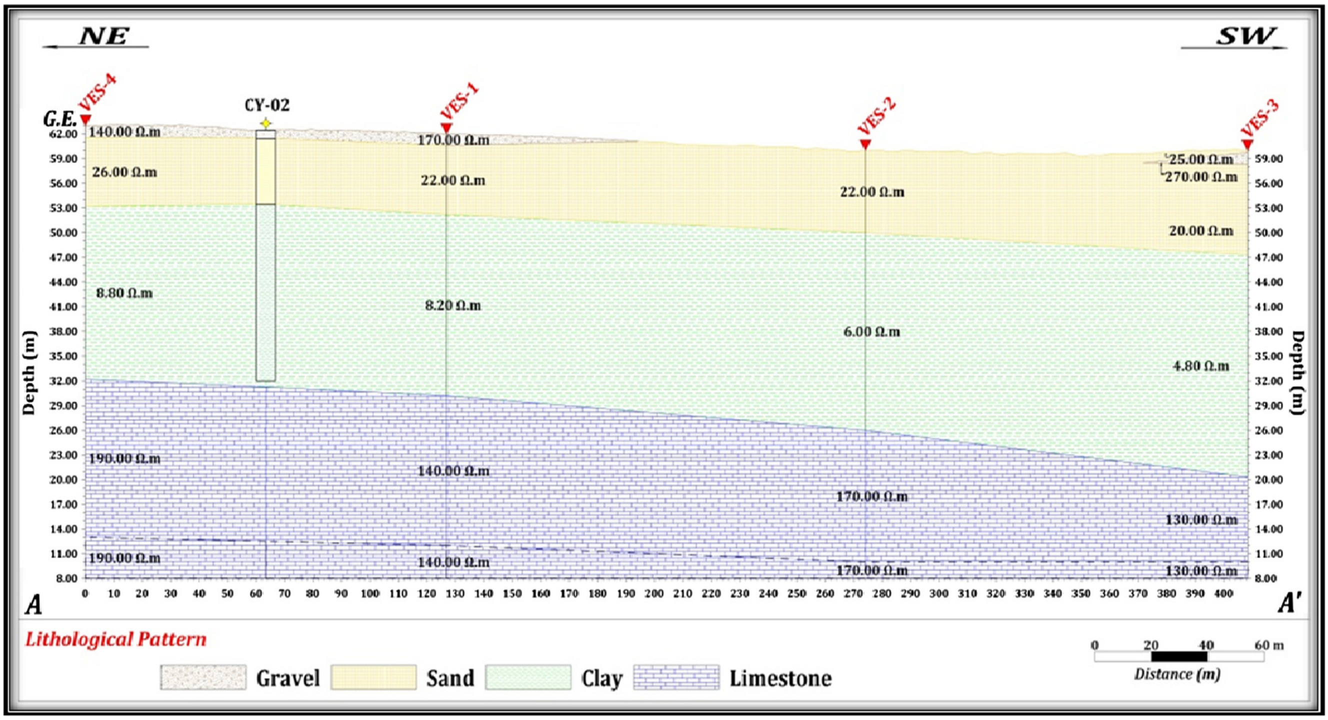


Fig. 6. Geoelectrical cross-section along the profile A-A′.

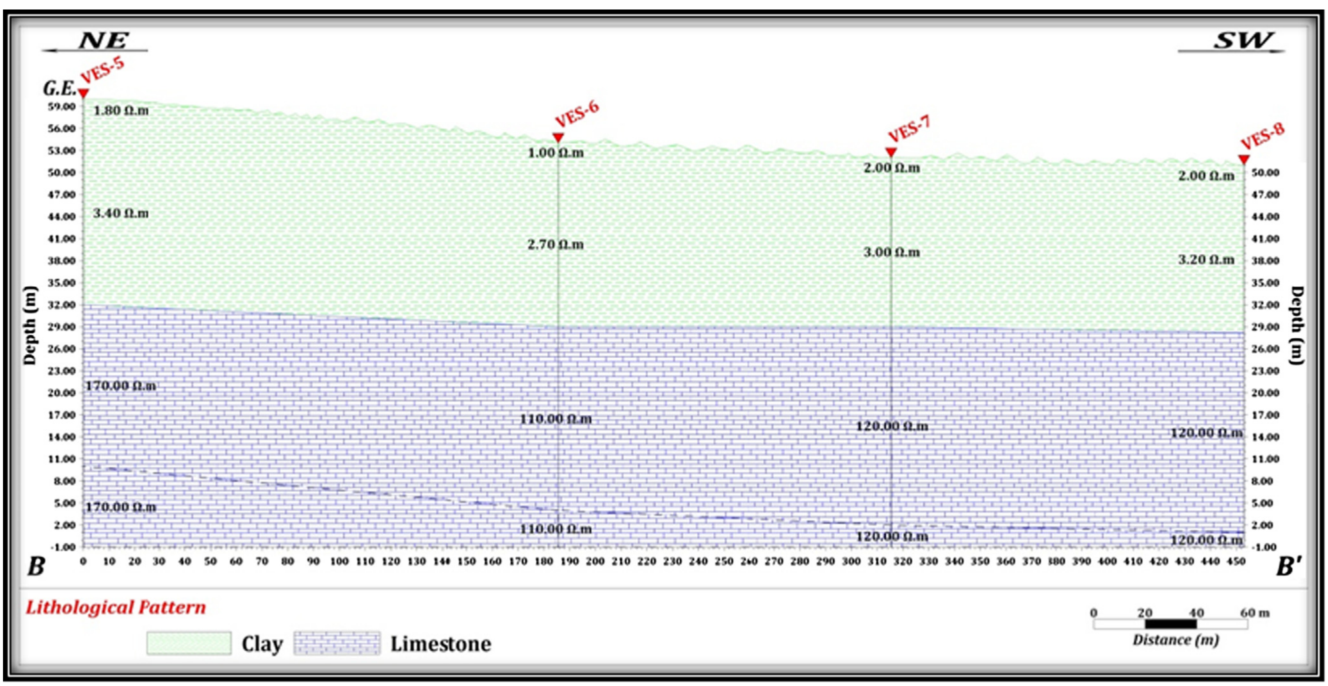


Fig. 7. Geoelectrical cross-section along the profile B-B′.

more than 170 Ω m (VES's No. 4 & 9) which corresponds to dry limestone unit. The bottom of this unit is represented by dashed line in all geoelectrical cross-sections. The minimum and maximum thicknesses are recorded respectively at VES No. 3 (10.3 m) & VES No. 11 (30 m).

6. Hydrochemical Aspects

The objective from the study of the chemical characteristics of groundwater is considered so important in order to know useful information about the geologic history of the enclosing rocks, sources of recharge, the direction & velocity of water movement. It is probably that the chemical composition of groundwater is subjected to significant changes because of admixture of other waters, natural biological process in aquatic plants and animals, and the direct or indirect results of man's activities. According to the lithological characteristics and geo-climatic conditions, the groundwater may be subjected to dynamic change.

Hydrogeologically, the aquifers from bottom to top are (summed after Abdel- Daiem, 1971; RIGW, 1978; Idris, 2000; Sadek and Abd El-

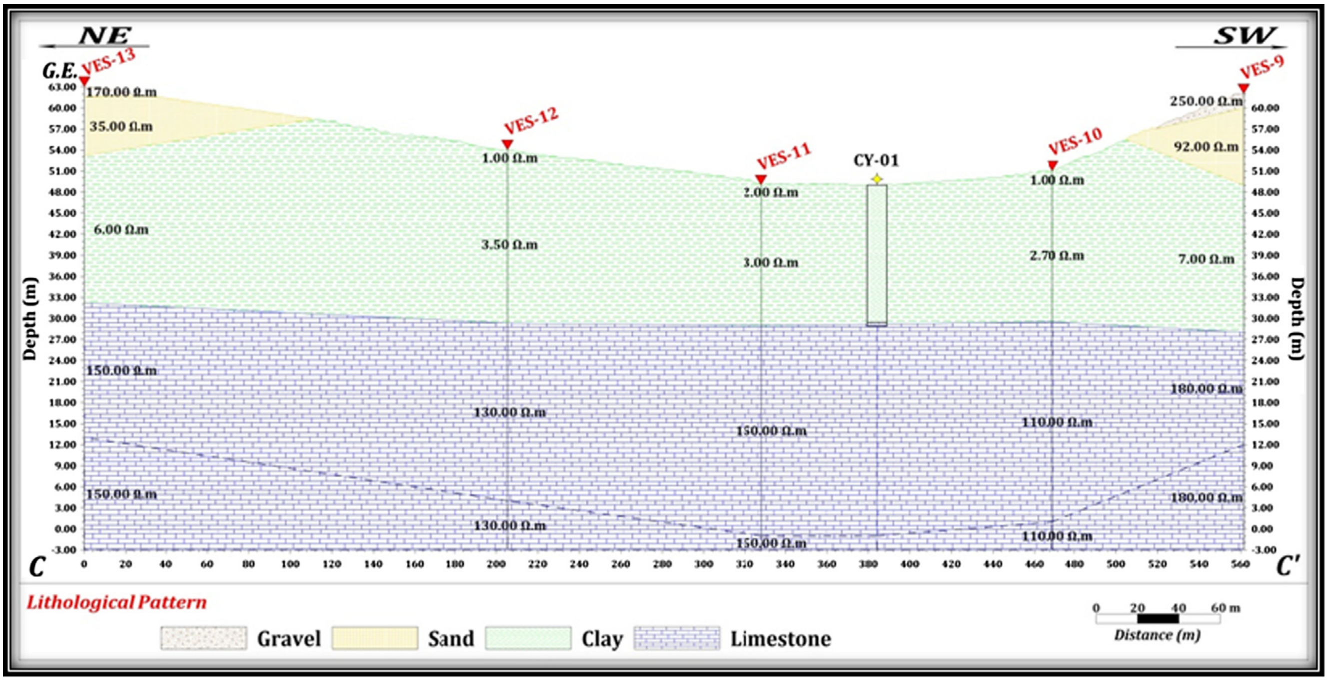


Fig. 8. Geoelectrical cross-section along the profile C-C′.

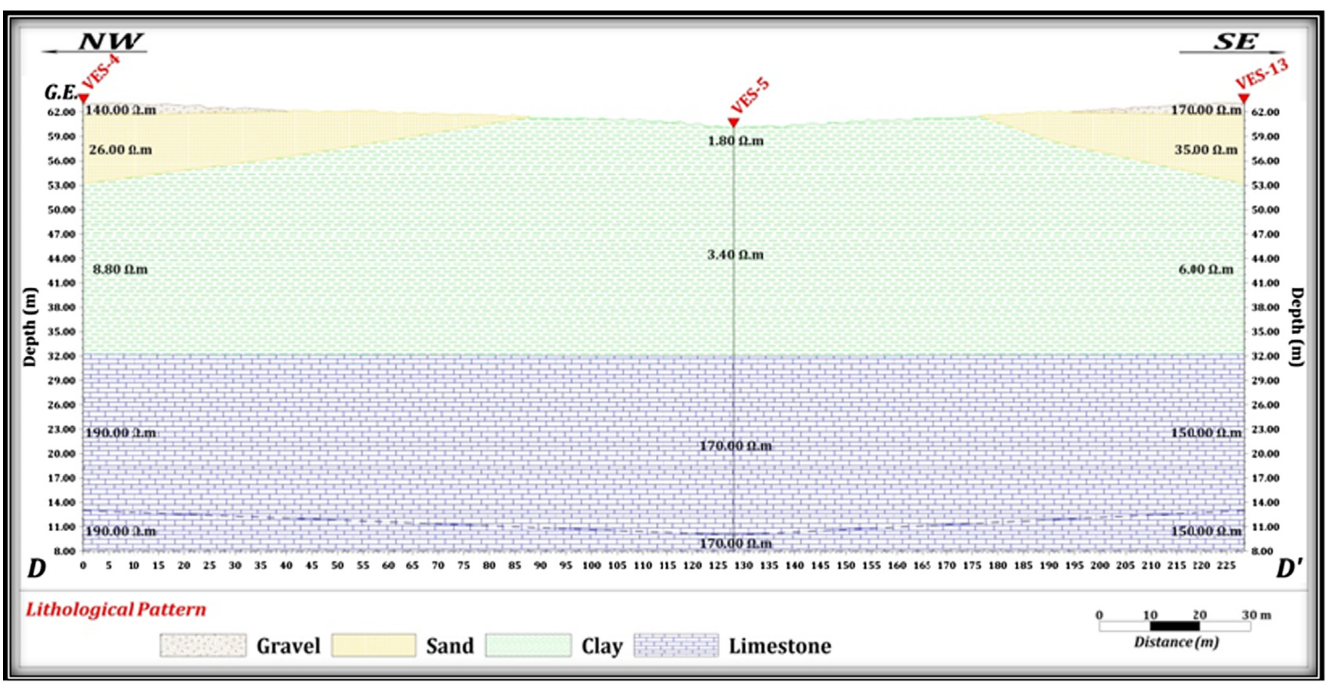


Fig. 9. Geoelectrical cross-section along the profile D-D′.

Samie, 2001) the following:

(1) *Eocene Aquifer:* In the Helwan area, there is a wide distribution for the fractured Eocene limestone on surface and in subsurface. The thickness of Eocene limestone within the region varies among 400 & 800 m and overlay unconformably the Cretaceous Nubian sandstone aquifer (Idris, 2000). In limestone aquifers, the secondary porosity is much more common than the primary porosity. The karstic features in the Eocene fissured and cavernous limestone are played an important role for the egression of groundwater to many warm mineral springs within the Helwan region forming a good medium for chemical reactions. These springs are fed by upward water leakage from the underlying main Nubian sandstone aquifer through crevices, cracks, underground channels & fault planes in the Eocene fractured and cavernous limestone.
(2) *Pliocene Aquifer:* It is mainly consisted of clays, fine to medium sands, argillaceous and calcareous sediments. The main recharge origin to this aquifer is upward infiltration from Eocene cavernous and fissured limestone aquifer and the downward leakage of water from irrigation drains and canals.

The interpretation of hydrochemical data carried out for the present work involving the analysing of two water samples chemically in terms of mineral constituents to define the origin of the implied water. The

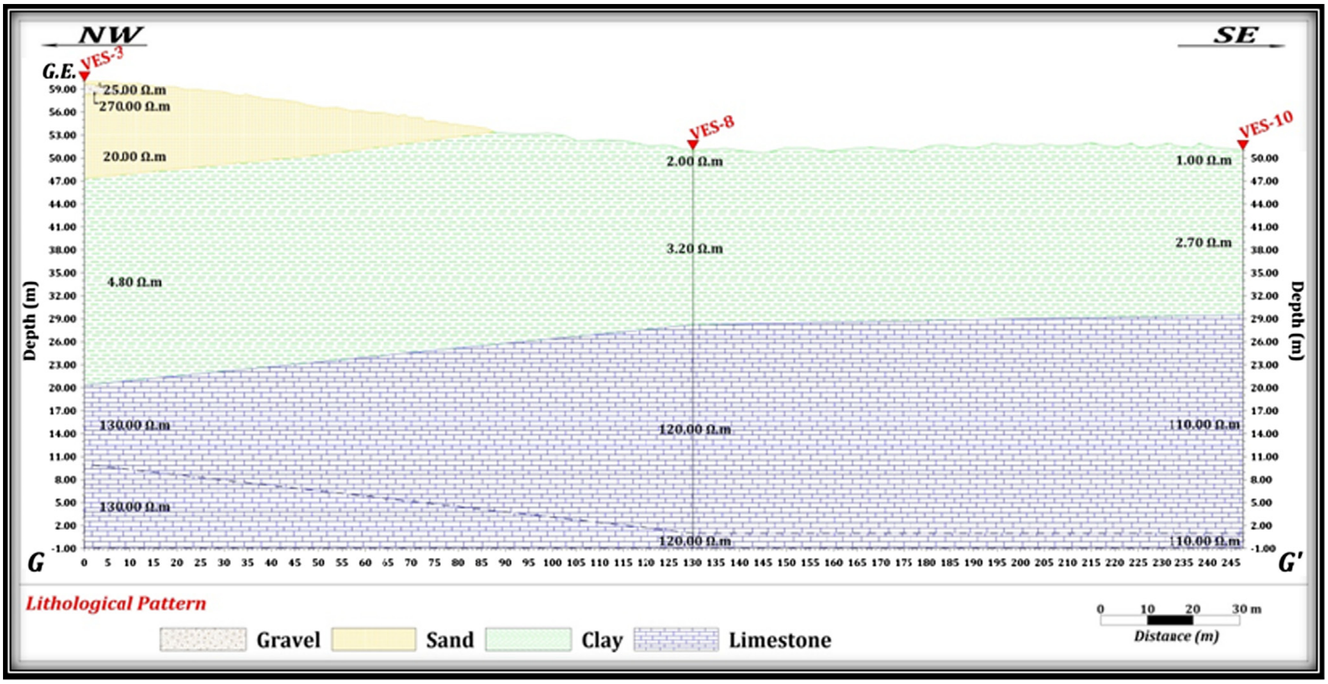


Fig. 10. Geoelectrical cross-section along the profile G-G′.

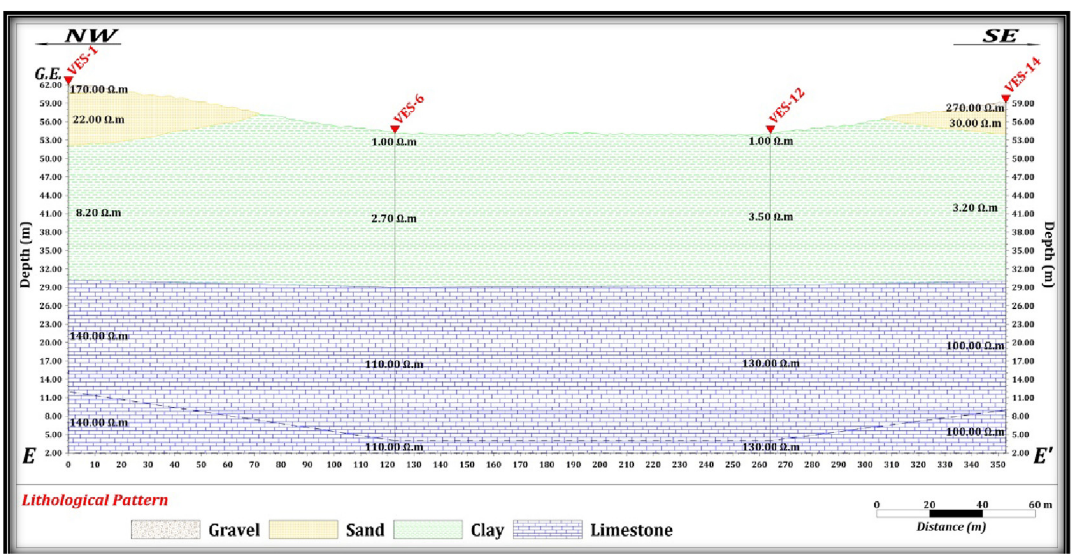


Fig. 11. Geoelectrical cross-section along the profile E-E′.

water samples (CLY-1 & CLY-2) belong to moderately saline water class depending on the water salinity classification of USGS (Heath, 1983). T.D.S of the first water sample (CLY-1) is 3936 mg/L while the total dissolved solids of the second water sample (CLY-2) are 5133 mg/L. The chemical analysis for the water samples in Helwan clay quarry are shown in Table 2. The results of chemical analysis are entered, checked and interpreted by using AquaChem 4.0 software.

In the study area, genesis of the groundwater has been defined by figuring the hydro-chemical ratios rNa/rCl, rCa/rMg & rCa/rSO_4 (meq/L) and comparing these parameters with the standard values of normal sea water (Table 3).

The rNa/rCl ratio shows the sources of salinity during groundwater flow (Cartwright and Weaver, 2005). Two samples indicated that sodium ions exceed chloride ions. The high concentration of sodium in groundwater shows addition of sodium to water through the dissolution and ion exchange processes which withdraws Ca and gives Na to the solution. The presence of clay and marl intercalations (exchange sites) promotes the suggested ion exchange and dissolution processes. The long residence time also favours cation exchange between Ca and Na on the exchange sites.

The ratios of rCa/rMg indicate the dissolution of dolomite and calcite present in the materials of aquifer. Generally, when the values are close to unity, this will be an indication for the dissolution of dolomite (Maya and Loucks, 1995). The rCa/rMg ratio for the first water sample (CLY-1) is very close to unity while the second water sample showed higher ratio which explained as being because of greater calcite or gypsum dissolution.

In order to understand the geochemical evolution of the groundwater and determine the chemical types of water in the area under study based on their chemical composition, Piper trilinear diagram (Piper, 1944) will be used to plot the concentration of major cations and anions (Fig. 13). According to Furtak and Langguth (1967), the water

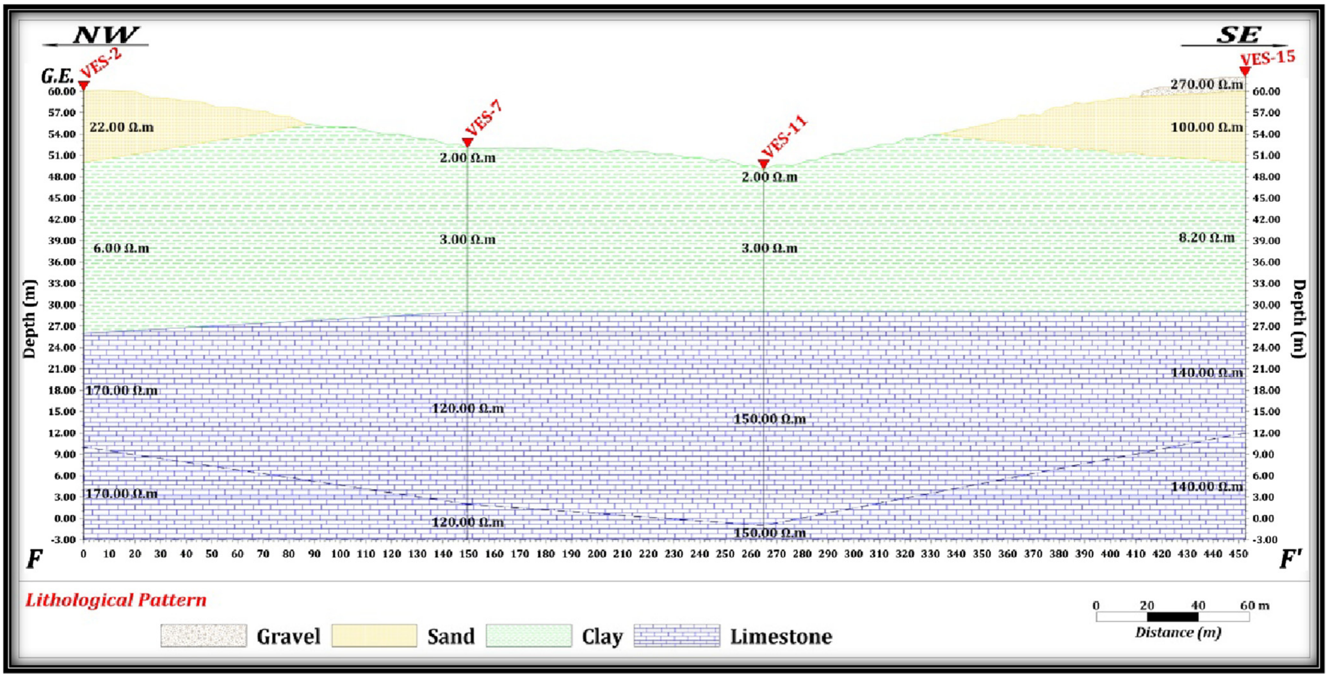


Fig. 12. Geoelectrical cross-section along the profile F-F′.

Table 2
The chemical analysis of the surface water samples in the area under study.

Sample ID	Major Cations (mg/L)				Major Anions (mg/L)				TDS (mg/L)
	Ca^{+2}	Mg^{+2}	K^{+}	Na^{+}	HCO_3^{-}	$CO3^{-2}$	$SO4^{-2}$	Cl^{-}	
CLY-1	125.6	77.9	12.52	995	122	Nil	592	1375.51	3935.6
CLY-2	246.8	109.8	19.53	1020	134	Nil	1285	1539.87	5132.8

Table 3
The comparison between calculated ion ratios for water samples in Helwan clay quarry and equivalent standard of sea water.

Ion Ratio	Sea Water	Water Points	
		CLY-1	CLY-2
rNa/rCl	0.858	1.12	1.02
rCa/rMg	0.194	0.98	1.36
rCa/rSO_4	0.364	0.51	0.46

samples are alkaline water with prevailing sulphate and chloride.

Durov diagram (Durov, 1948) is another method of data presentation. It has advantage over Piper diagram because it displays some possible geochemical processes that could affect the water genesis. Depending on the Lloyd and Heathcote (1985) divisions, both of samples are located in the most upper right zone (Cl^- and Na^+ dominant frequently indicate end point waters) as shown in Fig. 14. This agrees with the results of Piper plot which displays these samples in the field of alkaline water with prevailing chloride and sulphate. Actually, in the aquifer matrix; the exchange of Ca^{2+} for Na^+ induces the Na–Cl water type, therefore the Na^+ concentrations increases in the groundwater. This happens through the cation exchange mechanism on clay minerals.

The water genetic type can be determined by using Sulin (1946) diagram. His diagram consists of two equal squares. The lower left one displays the meteoric water genesis ($NaHCO_3$ & Na_2SO_4) and the (rNa/rCl) ratio > 1 while the upper right square shows the marine water genesis ($MgCl_2$ & $CaCl_2$) and the ratio (rNa/rCl) < 1. Every square is divided diagonally into two triangles. The results of the chemical analysis of the water samples are plotted on Sulin's diagram (Fig. 15). It is obtained that the Na_2SO_4 salt, type of meteoric genesis ((rNa/rCl) > 1), ((rK + rNa) - rCl)/rSO_4 < 1), reflects the hydrochemical composition of the samples in Helwan clay quarry. The hypothetical salt combination of this water type is (K + Na)Cl, Na_2SO_4, $MgSO_4$, $CaSO_4$ and Ca$(HCO_3)_2$. The Na_2SO_4 water type corresponds to deep meteoric water percolation.

7. Conclusions

The application of geoelectrical resistivity method in Helwan clay quarry helps to understand the source of the groundwater accumulated recently on the floor of quarry. The results indicate the passage of groundwater from the adjacent areas through channel ways formed as a result of the excavation process. All over the measured area, there are some sand lenses intercalated with clays & during the excavation process, some channels formed and the groundwater started to percolate through these channels forming many water pools along the quarry floor.

From the interpretation of the hydrochemical data, it is concluded that the groundwater in Helwan clay quarry is alkaline in nature & Na-Cl-SO_4 type. This water is of meteoric genesis. The main rechargeable sources for this water are from Eocene limestone and Pliocene aquifers.

The level of groundwater can be reduced a few meters from the quarry floor; if the amount of water pumped out from the quarry area exceeds the recharge rate through the channels. For dewatering the quarry area; it is recommended to drain the waters in a circular pool much deeper than the quarry floor. The pool walls must be perforated and its core is filled by coarse sands and gravels. For maintaining groundwater at a certain level; the pumping time and rate can be adjusted by monitoring the groundwater level through a piezometer.

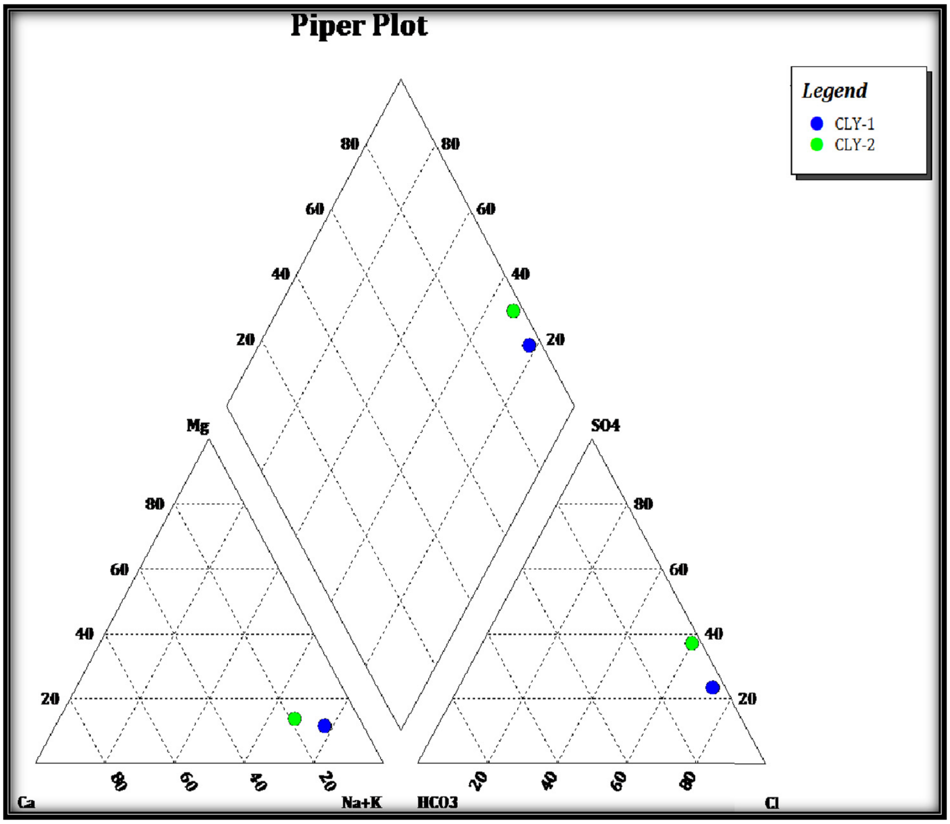


Fig. 13. Piper diagram of the analysed water samples in Helwan clay quarry.

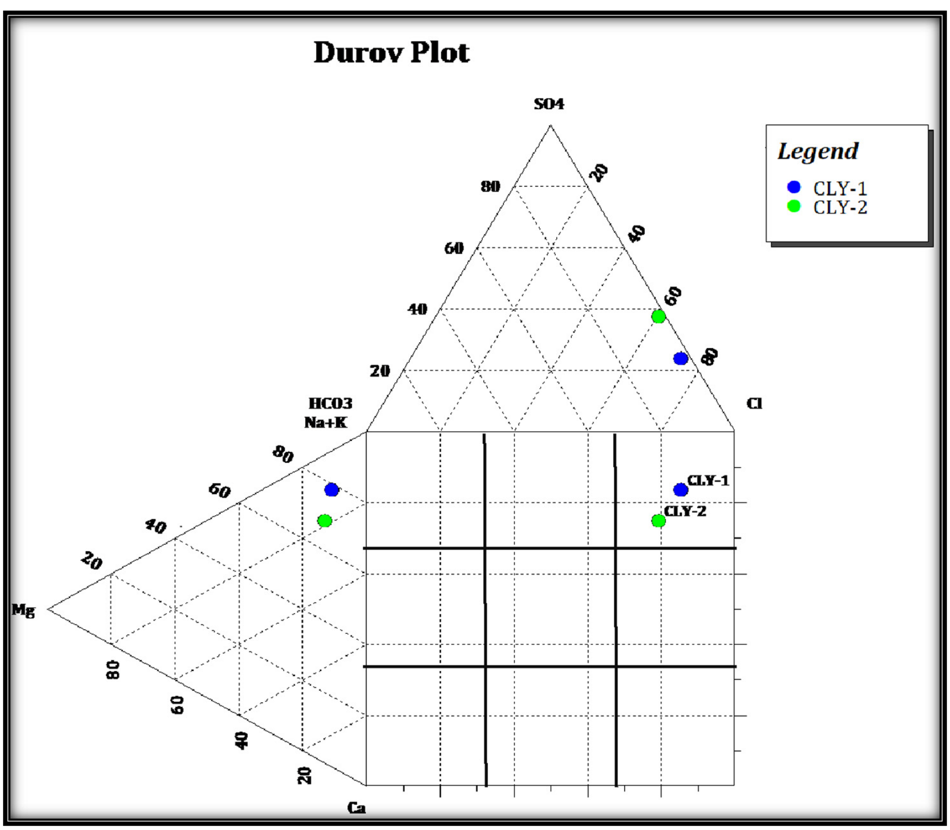


Fig. 14. Durov classification of groundwater of Helwan clay quarry (Divisions after Lloyd and Heathcote, 1985).

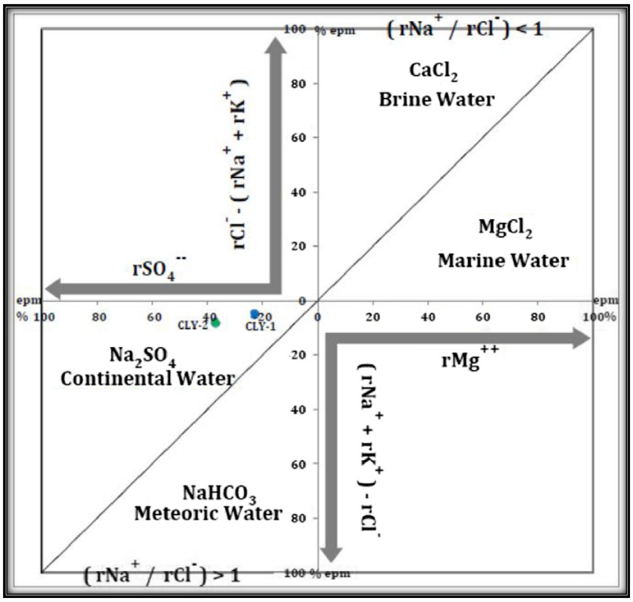


Fig. 15. Sulin's graph classification of groundwater of Helwan clay quarry.

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