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# Geoelectrical Investigation of Groundwater at Northern Gaza Strip, Palestine

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**Abstract:**
A vertical electrical sounding survey was carried out in northern Gaza Strip (Gaza City, Jibalya, Bayt Lahya and Bayt Hanun), Palestine to study the groundwater conditions and evaluate its quality and distribution. The survey included twenty-six (26) traverses with variable lengths in the range 200-500 m. The geoelectrical survey revealed that the resistivity of the study area varies in a wide range mostly 9 to 850 Ωm, subdivided into three subsurface zones. The first zone represents the dry sandstone and alluvial that attains the highest resistivities (100-850 Ωm) with variable thicknesses in the range 26-80 m beneath the whole study area. This zone is characterized by the presence of thin layers of clay and silt in some localities that reduced the resistivity to 15-25 Ωm. The second zone represents the fresh water saturated calcareous sandstone (locally named Kurkur) with resistivities in the range 22 -39 Ωm). The thicknesses of this zone is about 55-70 m in the western part of the study area and increased to 110 m in the east. The surface of this zone shows a gentle westward gradient, which indicates a general flow of water towards the Mediterranean Sea. The third zone represents saline water saturation with low resistivities, mostly 9 Ωm -10 Ωm close to the Mediterranean shore, located at 60 m below sea level and 100 m beneath the eastern side of the study area. Beneath the eastern part of the study area, an anomalous low resistivity of 2-3 Ωm is observed within the fresh water zone, which indicates groundwater pollution near the buffer zone caused by agriculture activities and untreated pumped wastewater.

**Keywords:**

Geoelectrical, Resistivity, Schlumberger configuration, Gaza Strip, Seawater Intrusion.

## Introduction:

Water is the vital component for life sustainability, economic development and human survival. Scarcity in this crucial component is facing many parts of the world especially communities within coastal areas. The study area is located on the eastern coast of the Mediterranean Sea classified as a semi-arid climatic zone, with low precipitation and high evaporation. Groundwater forms the main source in Gaza. Water sector is affected strongly by excessive pumping, mismanagement, Israel occupation, lack of environment awareness and illegal human activities. Hydrogeological studies showed that water sector suffers from many problems in terms of its quantity and quality, and more than 90% of Gaza wells are not suitable for domestic use due to high proportion of chloride exceeding 2500 mg/l and Nitrate concentration more than 500 mg/l (Abu Heen, 1997; Abu Heen and Lubbad, 2005; Abu Heen, et al., 2008, Abu El-Naeem, *et al.* , 2009; Abu Mayla and Abu Amr, 2010). Over exploitation of costal aquifer causes destruction of natural barriers, and results in seawater intrusion forming a major water crisis in this coastal region.

Many geophysical techniques can be useful for exploration of subsurface aquifer conditions depending on AC and DC current. Among these techniques, electrical resistivity sounding (VES) and electrical resistivity imaging (ERI) surveys represent the main tools for mapping subsurface boundaries, structures, and hydrologic features of the groundwater aquifer (Gemail *et al.*, 2004; El – Isa, Z H., 2005; Khalil, 2006; Nejad, 2009, Nejad *et al.* 2011; Batayneh, *et al.,* 2010; Metwaly *et al.,* 2012; Abiola *et al.,* 2013; Basheer *et al.,* 2014 ; Mogren, 2015; Abu Heen and Muhsen, 2016, 2017a,b; Ramadain *et. al.,* 2018; El Waheidi *et al.,* 2020, Arunbose *et al.,* 2021; Agbemuko *et al.,* 2021 and Singh *et. al.,* 2021).

The problem of sea water intrusion in the aquifer is considered as one of the most important problems in the coastal areas, especially if it is accompanied by an increase in water withdrawal from the aquifer, a decrease in the quantities of falling water, urban development and an increase in demand for water for domestic, agricultural and industrial use.

According to the geographical location, the study area is located in arid to semi-arid region, where the average annual rainfall amounts to 300 mm, and this region suffers from an annual deficit in the annual water budget of about 50-60 million cubic meters.

There are many geophysical methods used to explore for groundwater, but the Vertical Electrical Sounding (VES) configuration is considered the best at all due to the low cost, effectiveness and ease of application in the field, as well as its different configurations that suit for different field conditions. The Schlumberger array is the most recommended technique that researchers use to search for groundwater exploration (Nejad, 2009; Nejad *et al.,* 2011; Egbai, 2011; Loke, 2011; Adeoti *et al*., 2010 and Oladapo, 2013).

The present research aims to determine the groundwater quality, the aquifer layer' thicknesses and resistivities to trace the water intrusion into the freshwater aquifer and drawing subsurface geological cross sections for the study area.

## Geographical and geological settings

Gaza strip is narrow strip located in southwest of Palestine with a total area of about 365 km$^2$ and its length is approximately 45 km along the coast line, width ranges from 6 to 13 km and divided to five Governorates: Northern, Gaza, Middle, Khan Younis, and Rafah. The study area forms the northern part of Gaza Strip. It is lies between latitudes 31°34'42.93"N-31°28'14.17"N and longitude 34°31'39.46"E- 34°24'22.48"E including Gaza Governorate and North Governorate (Jibaliya, Bayt Lahiya and Bayt Hanun (Figure 1).

Geology of Gaza Strip is a part of geology of Palestine. Several authors have described geology of Palestine (Gvirtzman *et al.,* 1972; Bartov *et al.,* 1980; Abed and Weshahy, 1999; Ubeid, 2010, 2011). Subsurface geology of the Gaza Strip was analyzed from oil and gas exploitation logs up to depth of about 2000m.

Geology of the study area consists of a sequence of geological formations ranging from upper Cretaceous to Holocene tertiary formations. The consist of Saqiya group (upper Eocene to Pliocene) that underlined by Eocene Chalks and Limestone (Figure 2). The Saqiya group composed of shallow marine impervious sediments of Shale, Clay, and Marl, with a thickness ranges from 400 m to 1000 m. The Quaternary deposits (of about 160 m) thick, throughout the Gaza Strip are overlain the Saqiya group, while at the east they overlain the Eocene Chalks and limestone. IT is represented by the coastal plain aquifer of Palestine, composed of loose sand dunes (Holocene age) and Kurkar group (Pleistocene). The Kurkar Group consists of marine and aeolian calcareous sandstone, reddish silty sandstone, silts, clays, unconsolidated sands, and conglomerates, distributed in a belt parallel to the coastline, from north of Haifa to the Sinai in the south.

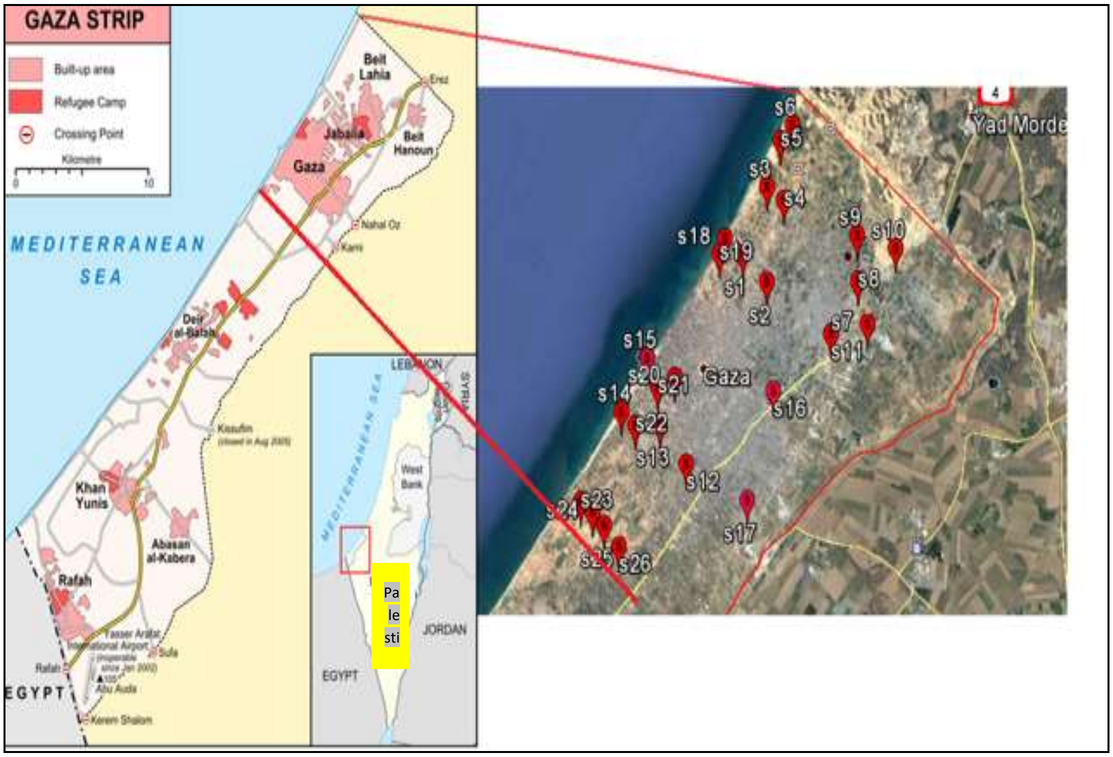



**Figure 1** ***Location map of study area and Vertical Electrical Soundings location.***

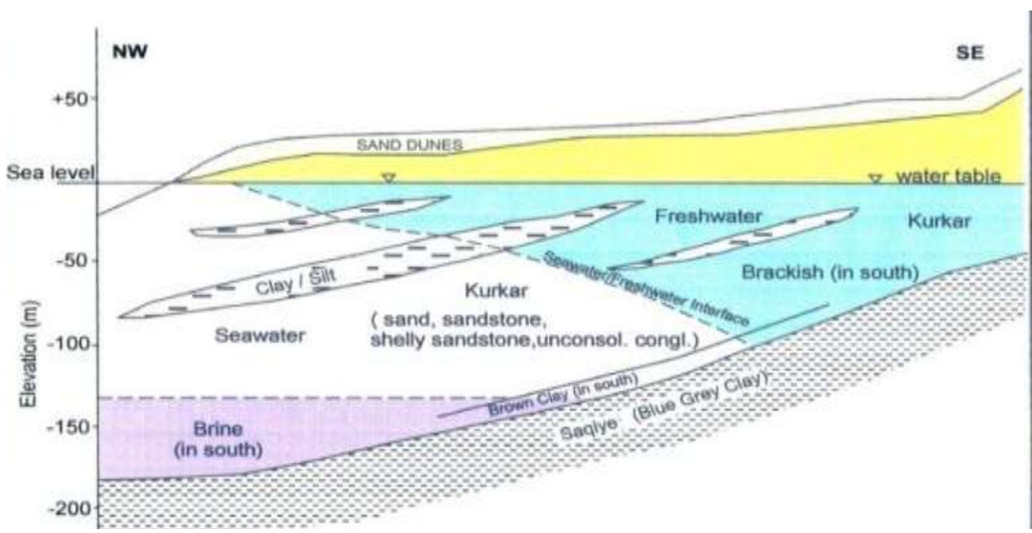



**Figure 2** ***Hydrogeological cross-section of the coastal aquifer (Metacalf and Eddy, 2009).***

## Material and Method

The practical method to measure the ground resistivity done by injected a direct currents (I) or very low frequency alternating current into the earth using pair of electrodes (A & B) and the measuring resulting potential differences (ΔV) between another pair of electrodes (M & N) at a multiplicity of locations at the surface (Figure 3), then these measurements are inverted into a distribution of electrical resistivity in the subsurface. The resistivity values are interpreted in terms of lithological boundaries, the foundation of this is Ohm's law (Kirsch, 2009).
Geoelectrical data are commonly expressed as apparent resistivity and given by the equation:

$$\rho_a = K\,(\Delta V/ I)$$

Where **ΔV** is the measured potential, **I** is the transmitted current, and **K** is the geometrical factor.

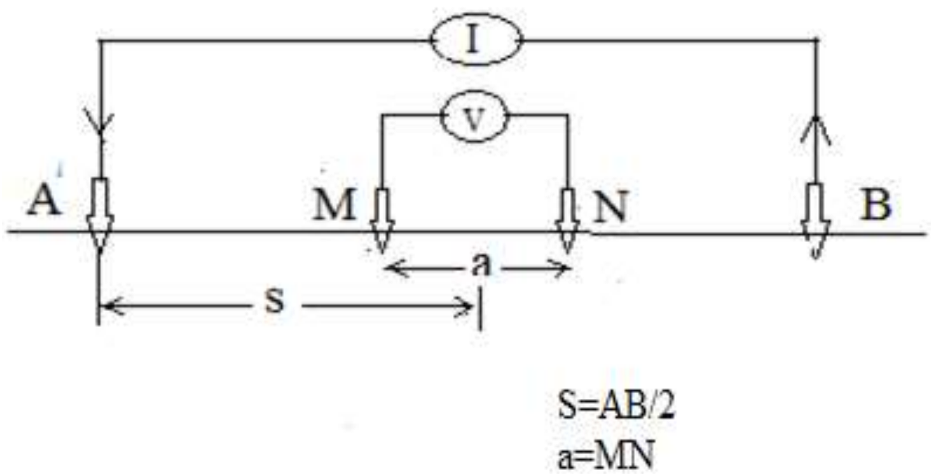



**Figure 3** ***Electrical resistivity Schlumberger configuration.***

The apparent resistivity (ρa) applying Schlumberger array can be written in the form:

$$\rho_a = \pi\,\Delta V/I * ((AB/2)^2 - (MN/2)^2) / MN],$$

$$OR,\ \rho_a = \pi\,\Delta V/I * (S^2/a) - (a/4)$$

In the present study, twenty six (26) vertical electrical soundings (VES) measuring points with Schlumberger array were carried out. SYSCAL Junior Switch24 resistivity meters of IRIS INSTRUMENT, France, with 24 electrodes is used. In the generalized Schlumberger array the distance between the potential electrodes (MN) is small compared to the distance between current electrodes (AB) and AB equal or more than 5MN. The selected distances between current electrode (AB/2) are: 2, 3, 4, 5, 6, 8, 10, 13, 16, 20, 25, 30, 40, 50, 60, 80, 100, 130, 160, 200, 250, 300, 400, 500 and 600 m.
Vertical electrical sounding (VES) interpretation is carried out automatically by using the (IPI2Win) Software (Bobachev, 2010). The field curves of the (VES) points can be interpreted into two types, qualitative and quantitative to get a good picture of the subsurface layers. Lithology data obtained from some boreholes provide a very important constrains on the results of the sounding data

interpretation. Figure 4 illustrates an example of 1D field curve data analysis as a result from IPI2Win software.

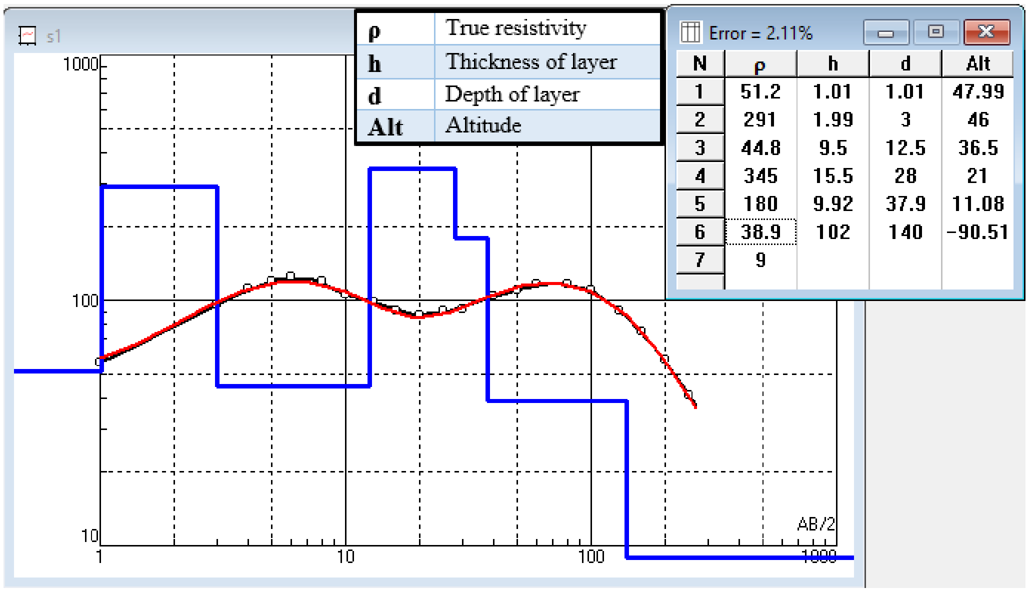



**Figure 4** ***An example of 1D field curve data analysis as a result from IPI2Win software.***

For better understanding the spatial variation of the resistivity values for the study area and aquifer thicknesses, some of six 2D cross sections from soundings have been constructed. Three cross sections (1,2 and 3) were constructed perpendicular to the shoreline and another three cross sections (4, 5 and 6) were constructed parallel to the shoreline (Figure. 5). Table 1 illustrates the total length of each cross section and its soundings involved.


**Figure 5** ***Location map of cross sections for the study area***

**Table 1** ***Cross sections lengths and soundings included.***

| Cross section No | Sounding No | Total length (m) |
|---|---|---|
| 1 | S14, 22, 13, 12, 17 | 5200 |
| 2 | S18, 19, 1, 2 | 2000 |
| 3 | S3, 4, 9, 8 | 4850 |
| 4 | S6, 5, 3, 18, 19, 15, 14, 23 | 13050 |
| 5 | S4, 1, 20, 21, 22, 24 | 11400 |
| 6 | S10, 8, 7, 11, 16, 17 | 9000 |

## Field Results, Discussion and Interpretation

### Cross-section 1:

This cross-section runs perpendicular to shoreline in an NW-SE direction, south of Gaza City and is compiled utilizing the final interpretation results of sounding: S14, S22, S13, S12 and S17 with a total length of about 5200 m (Figure 5). The section shows three major subsurface zones: dry zone, fresh water saturated zone, and saline water saturated zones (Figure 6a). The upper dry sands and sandstone with variable resistivities mostly in the range 100-750 Ωm. Its thickness ranges between 35-66 m. It includes thin layers of clay indicate low resistivities range (13-18 Ωm). The second zone is the fresh water-saturated with variable resistivities of about (25-35 Ωm). This zone occurs at a variable thickness in the range of 55 m in western part of the study area to 105 m in its eastern part, being shallower in the west close to the coastline indicates a general water flow towards the Mediterranean Sea. The third represents a saline water saturated zone with resistivities of about (9-15 Ωm). This zone extends down to a depth of about 90 m in the west to about 171 m beneath the eastern side. These geoelectrical layers and its resistivities are correlated well the interpreted electrical resistivity data analysis of Abu Heen & Muhsen, 2,016, 2017a, b for south of Gaza Strip.

### Cross-section 2:

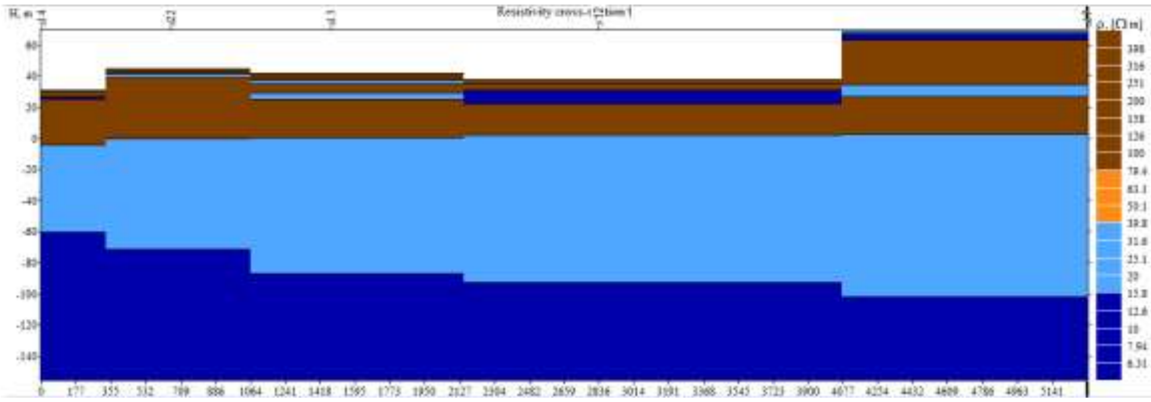
This cross-section parallels to cross section 1, located in north of Jabaliya City and compiled utilizing the final interpretation results of soundings: S18, S19, S1 and S2 (Figure 5), with total length of about 2000 m. The cross section consists of three major subsurface zones similar to the cross section one. The upper is dry sandstone with variable resistivities mostly in the range 100 Ωm to 350 Ωm (Fig. 6-b). Its thickness varies in the range (25-37 m) and is characterized by the presence of thin layers of silt mixed with clay. This is indicated by its resistivities (45-68 Ωm). The second zone is the fresh water-saturated with variable resistivities of about (29-38 Ωm). This zone occurs with a variable thickness in the range 66 m in western part of the study area to 115 m in its eastern part. This therefore indicates a general water flow towards the Mediterranean Sea. Saline water saturated zone with resistivities of the range (9-15 Ωm). is the third zone that observed on this cross section, that extends down to a depth of range (98-143 m) from the west to the east.

### Cross-section 3:

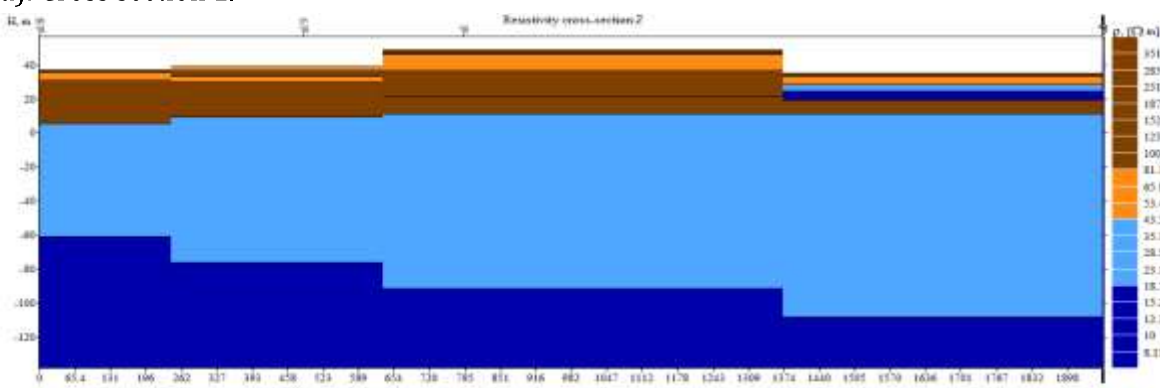
This cross-section paralleled to cross sections 1 & 2, north of Bait-lahiya with a total length of about 4850 m, and compiled utilizing the final interpretation results of soundings: S3, S4, S9 and S8 (Figure 5). The section consists of three major subsurface zones (Figure 6c). The first represents dry sandstone with variable resistivities in the range (100-1000 Ωm). Its thickness varies in the range (30-66 m). This zone is characterized by the presence of thin layers of clay with low resistivities in the range (14-31 Ωm). The second zone represents the fresh water-saturated with variable resistivities of about (22-31 Ωm). This zone occurs at a variable thickness in the range 66 m in western part of the study area to 115 m in its eastern part. This therefore indicates a general water flow towards the Mediterranean Sea. The third represents a saline water saturated zone with resistivities of the range (9-15 Ωm). This zone extends down to a depth of 98 m in the west to about 143 m to the east (Figure 4-C) with variable thickness in the range 60 m in western part of the study area to 114 m in the eastern part that indicates general water flow towards the Mediterranean Sea. The third layer represents a saline water saturated zone with resistivities of about 9 Ωm-10 Ωm. This zone extends down to a depth of about 102 m

### Cross-section 4:

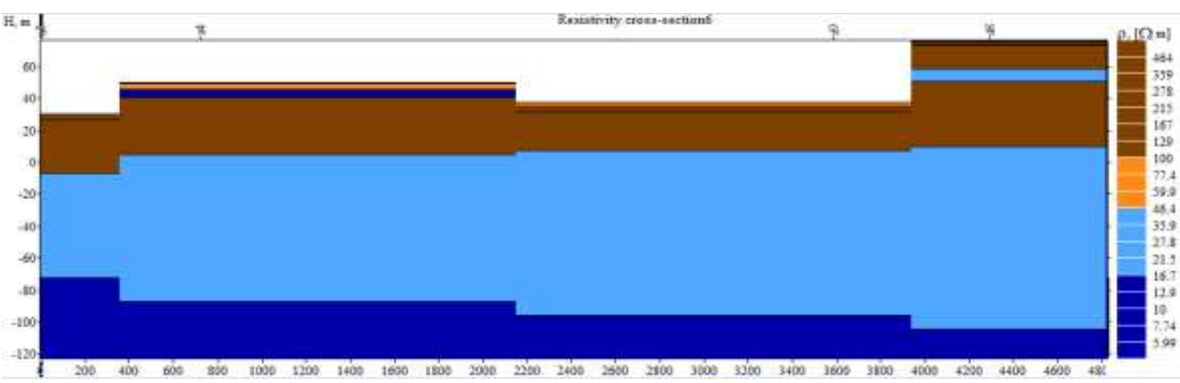
This cross-section is located close to the Mediterranean Sea some 400m east of the shoreline and parallels it, runs in a NE-SW direction with a total length of about 13050 m (Figure 5). It is combined utilizing the results of VES: S6, S5, S3, S18, S19, S15, S14 and S23. The interpreted 2D (Figure 7a) shows that this section consists of three major subsurface zones. The upper represents a dry sandstone with variable resistivities mostly in the range (100- 675 Ωm) with thickness range of about (13.5-42 m). It is interbedded by thin layers of silts mixed with clay as indicated by the resistivity range (50-60 Ωm). The second zone represents the fresh water saturated as indicated by its low resistivity (22-38 Ωm), with calculated thickness of about 69 m. The third zone represents a saline water saturated with resistivity of the range of (9-15 Ωm). This zone extends down to a depth of range (85-112 m). The interference zone between the saline-fresh water looks shallow and appears at 75 m below the Sea level.



a): Cross section 1.

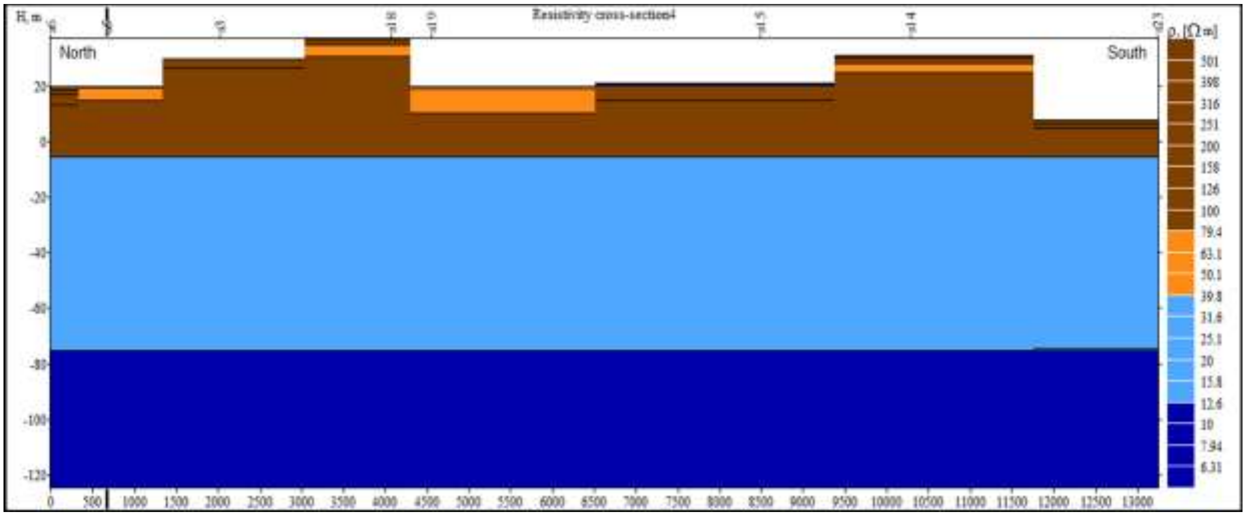


b): Cross section 2.

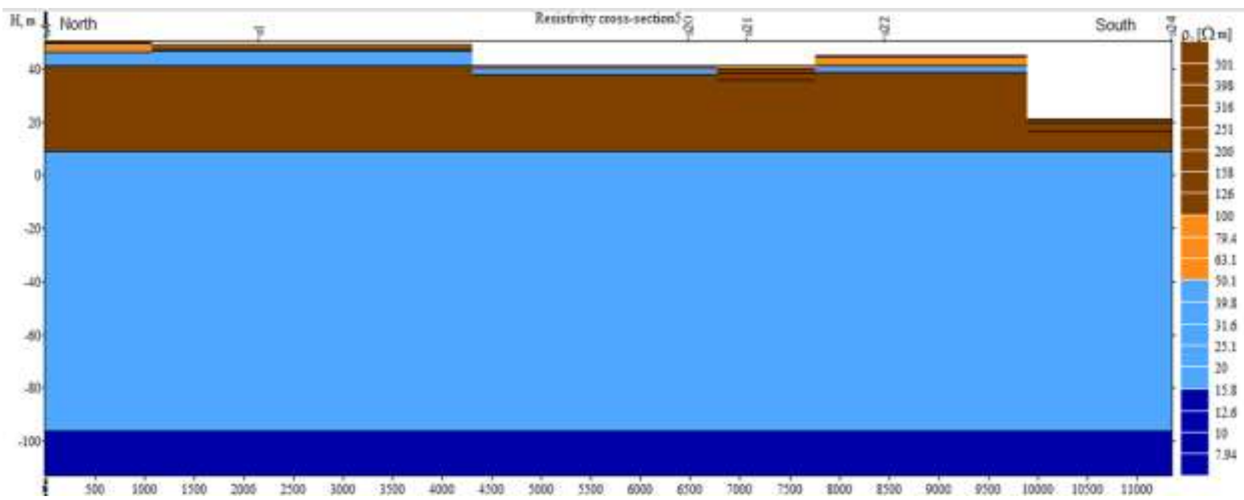


c): Cross section 3.

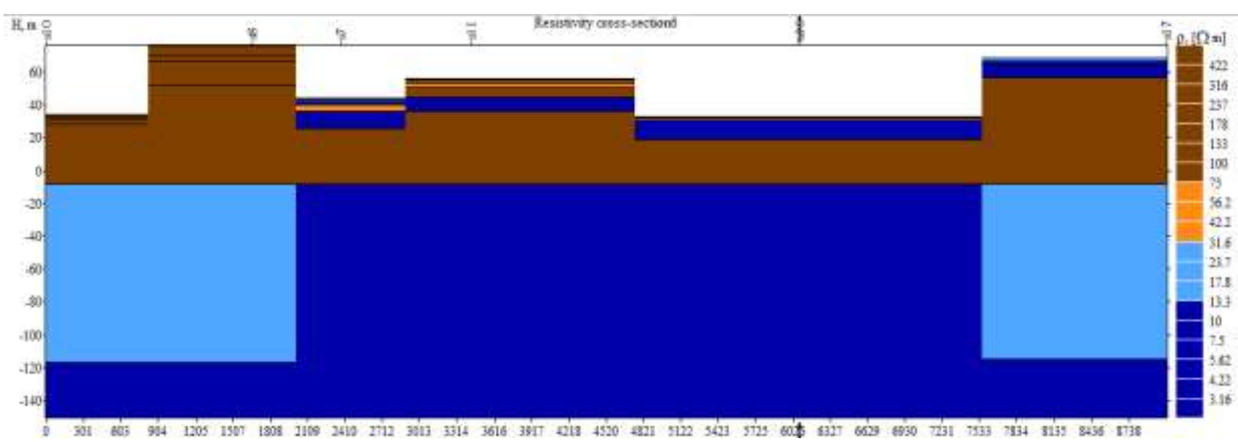
**Figure 6** ***2D geoelectrical models of cross sections: 1 (a), 2 (b) and 3 (c).***




a): Cross section 4.




b): Cross section 5.




c): Cross section 6.

**Figure 7** ***2D geoelectrical models of cross sections: 4 (a), 5 (b) and 6 (c).***

## Cross-section 5:

This cross-section is located some 1200 m east of cross-section 4, runs in a NE-SW direction parallel to the sea (Figure 5). It is combined utilizing the results of VES: S4, S1, S20, S21, S22, and S24 with total length of about 11400 m (Figure 5) . The section consists of three main subsurface zones (Fig, 7b). The upper represents dry sandstone with variable resistivities in the range (1007-50 Ωm), with thickness range of about (12-41 m). It is cut by thin layers of clay as indicated by the low resistivity range (15-35 Ωm). The second zone represents the fresh water-saturated as indicates by its resistivity (26-33 Ωm). Its thickness is about 105 m. The aquifer in this cross looks deeper than cross-section 4. The third zone represents a saline water saturated with resistivity of the range (9-15,8 Ωm). This zone extends down to a depth of range (117-145 m). The interference zone between the saline-fresh water appears at 96 m below the Sea level.

## Cross-section 6:

This cross-section is located near the buffer zone some 5800m east of the Mediterranean Sea coastline. It runs in a NE-SW direction parallel to the sea with total length of about 9000 m (Figure 5). It is constructed utilizing the results of VES: S10, S8, S7, S11, S16 and S17.The section consists of three major subsurface zones (Figure 7c). The upper zone represented by a dry sandstone with variable resistivities mostly in the range 100 to 3000 Ωm. Its thickness varies in the range (43-84 m) and interbedded by thin layers of clay and silt as indicated by their resistivities (10-55 Ωm). The second zone represents the fresh water-saturated aquifer as indicated by its resistivity (26-31 Ωm). Its thickness is about 105 m. The third zone represents a saline water saturated with resistivity of about (2-15 Ωm). This zone extends down to a depth of about (151-180 m) (Figure 7c). The interference zone between the saline-fresh water appears at 115m below the Sea level.

An anomalous low resistivity of about (2-3 Ωm) is observed within the fresh water zone in S7, S11 and S16. The resistivity of the similar zone in the previous six cross-sections was always of about (22-38 Ωm). This decrease in the resistivity levels indicates polluted ground water. Untreated sewage and agricultural return flows of gray water coupled with continued over-abstraction (Abu El- Naeem *et.al.,* 2009), has led to increased salinization of the aquifer. In addition to that, the Israeli Occupying Government dumps 100 $Mm^3$ of, allegedly, reclaimed wastewater to farmlands surrounding the Gaza Strip as a supply to the aquifer. That water originates as reclaimed water from the Dan wastewater treatment plant in South of Yafo, but it appears that this pumped water adds more pollution which means this water is not treated properly.

## Conclusion:

Some of 26 vertical electrical sounding (VES) surveys, with Schlumberger electrode configuration carried out in both Gaza Governorate and North Governorate (Jibaliya, Bayt Hanun & Bayt Lahya) to map the aquifer and groundwater potentiality. These soundings were constructed in six 2D cross sections, three of them were parallel to the shore line, whilst the other three cross sections were perpendicular to shoreline. In the study area of Gaza and the north Gaza strip, the Quaternary aquifer forms the major promising aquifer having generally fresh to saline water. It consists of sand stone, which intercalated with silt and clay deposits in some localities. From the geoelectrical survey, three geoelectrical layers were identified down to the depth of investigation. The resistivity of the first layer ranges between (100-850 Ωm) and are typically indicate of dry sandstone deposits, characterized by the presence of thin layers of clay and silt in some localities. The thickness of this layer ranges between (29-80 m). The second layer characterized by relatively low resistivity values (22-39 Ωm) indicates of fresh water saturated and reflects the maim fresh water aquifer in Gaza Strip. The thickness of this layer varies between (55-110 m). The resistivity of the third layer ranges between (2-16 Ωm) and is interpreted as saline water saturation sand stone, occurs at (60-105 m) below sea level. An anomalous low resistivity of (2-3 Ωm) is observed within the fresh water layer in the NE of study area close to the buffer zone indicates groundwater pollution caused by untreated sewage and agricultural return flows of gray water coupled with continued over-abstraction.

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