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Application of Vertical Electrical Sounding for Delineation of Sea Water Intrusion into the Freshwater Aquifer of Southern Governorates of Gaza Strip, Palestine

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Abstract

Vertical Electrical Sounding (VES) proved to be an important tool for mapping the freshwater-saltwater interface. Seawater intrusion is serious problem especially in coastal areas. 14 Vertical electrical soundings with Schlumberger array were carried out (perpendicular to the coast) in southern part of the coastal aquifer in Gaza Strip (Khan Younis and Rafah Governorates) to study the subsurface geologic formation and delineation of seawater intrusion into freshwater aquifer. Lithology and hydrochemistry data from 12 bore holes were used to integrate the results. The results reveals that 50% of the total sounding are interpreted of 3 layer modes, while the other 50% are of 4 layers model. Interpreted 2D geoelectrical models (in two cross sections parallel to the coast line) showed that seawater intrusion with electrical resistivity less than 2Ωm is dominant along the section parallel to coast line at 400m east of it and for shallow depths (3-10m depth), while in the other section (1000m) east of the coast line seawater intrusion is detected in some places while the other parts still have brackish/fresh groundwater with resistivity more than 10Ωm at different depths (26-50m).

Keywords:
Vertical electrical sounding; VES; sea water intrusion; geoelectrical; Gaza Strip; Palestine

1. Introduction:

Securing water for sustainable development is a major challenge facing the global community. At present, developing countries face environmental pressure induced by high population community, rapid urbanization, and deficient water sector services reflecting on improper management of water resources (UN, 2003; WHO, 2006).

The intrusion of saltwater into coastal aquifer is a wide spread phenomena, especially in Mediterranean regions where semi-arid conditions lead to excessive pumping, high extraction rate and low recharge and associated with urban area (Petalas et al., 2009; Oladapo et al., 2013).

The problem of the salinization of groundwater aquifers arises in coastal areas, where the excessive pumping of unconfined coastal aquifers by water wells leads to the intrusion of sea water. This negative effect of human activity has been recorded in many areas of the world. Hence, this problem is likely to arise in areas like Gaza Strip that has poor water resources (low precipitation and high evaporation) and has mismanagement of water resources (Abu Heen 2005; Abu Heen et al., 2005; Abu Heen et al., 2008; Abu Mayla et al., 2010;). Gaza Strip is classified as a semi-arid region and suffers from water scarcity. Ground water is the main source of water in Gaza Strip. Water analysis results revealed that more than 90% of the water wells unsuitable for domestic uses according to WHO Standards. The water sector suffers a lot of problems in terms of quantity and quality. (Abu El-Naeem et al., 2009)

Water demand in the Gaza Strip is increasing continuously due to economic development and population increase resulting from natural growth and returnees, while the water resources are constant or even decreasing due to urban development (Hamdan, 2006).

Palestinian Water Authority (PWA) reports (2015a, b, and c) published a recent salinity maps for Gaza Strip. The maps show that all the area adjacent to the coast characterizes by high salinity values, especially the Southern Governorates (Khan younis and Rafah) where these two governorates characterized by dense agricultural activities, so water salinization will have serious negative impacts. Identification and modeling of seawater intrusion of the Gaza Strip aquifer has been studied and proposed by Qahman, 2004, and Qahman et al., 2001, 2003, and 2005.

DC surface resistivity methods have been used for groundwater research for many years. It can be used to map the freshwater-saltwater interface and for studying conductive bodies of hydrogeological interest (Keller and Frischknecht, 1966; Zohdy et al., 1974; Goldman et al., 1991; Loke, 2000; Gemail et al., 2004; Stampolidis et al., 2005; Sherif et al., 2006; Aletabe, 2007; Sinha et al., 2009; De Franco et al., 2009; Capizzi et al., 2010; Batayneh et al., 2010; Chitea et al., 2011; Satriani et al., 2011; AL-Khersan, 2012; Olympia et al., 2012, 2013; Thabit et al., 2014; Basheer et al., 2014; Kalisperi et al., 2015; Mogren, 2015).

Vertical electrical sounding (VES) with Schlumberger array as a low-coast technique and veritable tool in groundwater exportation is more suitable for hydrogeological survey of sedimentary basin (Nejad, 2009; Nejad et al., 2011; Egbai, 2011; Adeoti et al., 2010).

The main goals of the present research are to determine the subsurface aquifer layers thicknesses and resistivities of the Southern Governorates of Gaza Strip (Khan younis and Rafah), to delineate the sea water intrusion into the freshwater aquifer in the study areas and drawing subsurface geological cross sections for the study area.

2. Geological and Hydrogeological Setting of the Study Area:

Khan Younis and Rafah governorates are the southern part of Gaza Strip. Gaza Strip is a narrow coastal strip along the Mediterranean Sea plain between Egypt and Palestinian occupied territories in the south-eastern coast of the Mediterranean Sea, between longitudes 34° 2" and 34° 25" east, and latitudes 31° 16" and 31° 45" north (figure 1).

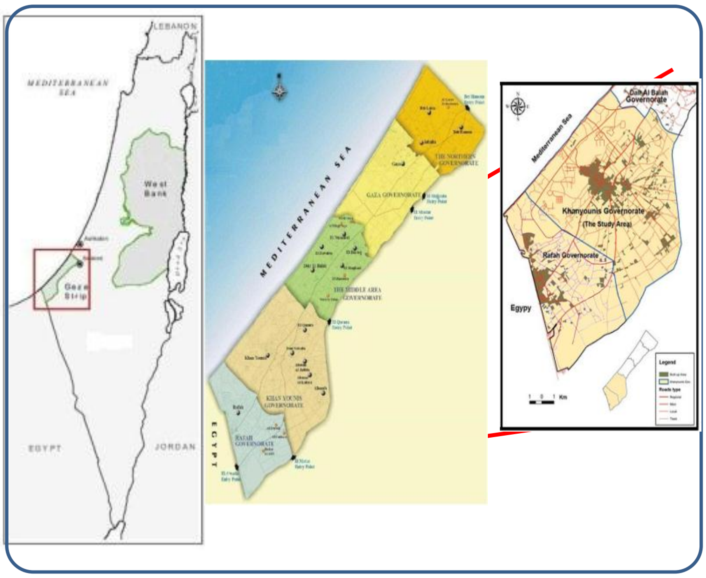

Fig (1): Location map of the study area (Khan Younis and Rafah Governorates)

The total area of Gaza Strip is about 365 km^2 and its length is approximately 45 km along the coast line and its width ranges from 6 to 13 km. Gaza Strip includes five Governorates: Northern, Gaza, Middle, Khan Younis, and Rafah.

The total population in 2015 is 1,819,982 inhabitants. The population is growing by density of about 4822 capita/km^2 annually, making it one of the most overcrowded areas in the world, to be about 2.27 Million inhabitants by the year 2020 (PCBS, 2015).

Rafah and Khan Younis located in the southern part of Gaza Strip with a surface area of 170.5 km^2, representing 45% of the total area of Gaza Strip, with a population of about 557.853 inhabitants (31.16% of the total the total population in Gaza Strip).

Geology of Gaza Strip is a part of geology of Palestine. Several authors have described geology of Palestine (Picard, 1943; Gvirtzman et al., 1972; Bartov et al., 1981; Frechen et al., 2004; Al-Agha and El-Nakhal, 2004; Galili et al., 2007; Ubeid, 2010; Ubeid, 2011). Abed and Al Wishahi (1999) summarized the geology of Palestine in his titled book (Geology of Palestine).

The studied area is a shore plain gradually sloping to the west as shown in figure (2). It is underlain by a sequence of geological formations ranging from upper Cretaceous to Holocene. The main formations known were composed in the last two system periods, Tertiary formation called “Saqiya formation” of about 1200-meter thickness, and the Quaternary deposits of about 160 meters thickness and cover Saqiya formation.

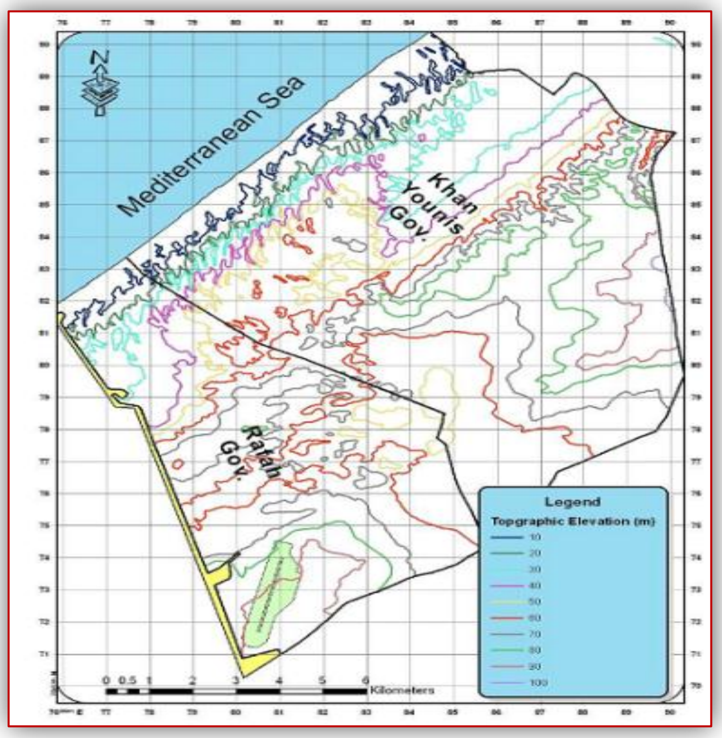

Fig (2): Topographic countering map of the studied area

Tertiary formations consist of Saqiya group (upper Eocene to Pliocene) underlined by Eocene Chalks and limestone as shown in figure (3). The Saqiya group composed of shallow marine impervious sediments of Shale, Clay, and Marl. The thickness of this group ranges from 400 m to 1000 m. This group wedged out rapidly to the east. The Quaternary deposits throughout the Gaza Strip are overlain the Saqiya group, while at the east they overlain the Eocene Chalks and limestone. Quaternary formations are represented by the coastal plain aquifer of Palestine. The coastal aquifer composed of loose sand dunes (Holocene age) and Kurkar group (Pleistocene). The Kurkar group composed of marine and aeolian calcareous sandstone (locally known as "kurkar") reddish silty sandstone ("hamra"), silts, interlayers of clay deposited during the Last Glacial stage and during the Holocene, unconsolidated sand and conglomerates. The surface morphological features of the Kurkar group are three elongated hills known as "kurkar ridges," located in clusters extends parallel to the shoreline. These belts extend about 15-20 km inland. They unconformable overlied Eocene limestone and chalks deposits to the east and upper Eocene-Pliocene age of the Saqiye group to the west throughout the Gaza Strip.

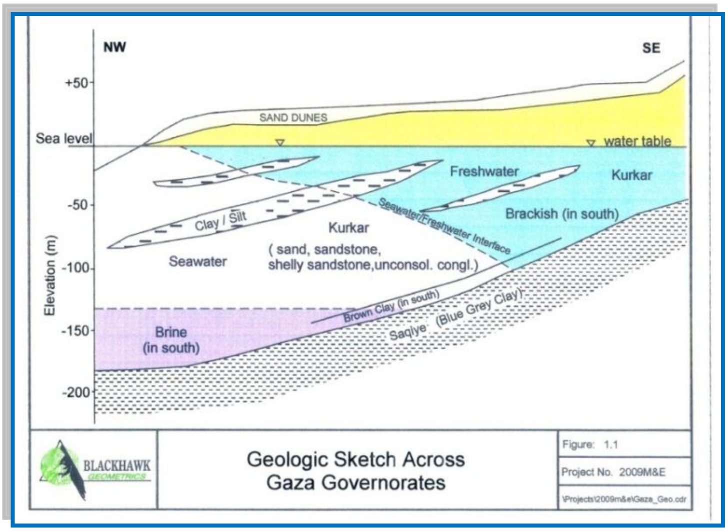

Fig (3): Hydrogeological cross-section of the coastal aquifer (Metacalf & Eddy, 2009).

Close to the present shoreline, the sequence of the Kurkar Group attains an average thickness of 200 m in the south and around 120 m in the north. Holocene deposits are found at the top of the Pleistocene formation with a thickness up to 25m.

3. Materials and Methods:

3.1 Hydrochemistry:

Sea water intrusion and intensive exploitation of groundwater have resulted in increased salinity in the most areas in Gaza Strip. Salinity levels (Chloride concentrations) have thus risen well beyond guidelines by the World Health Organization (WHO) for safe drinking water, the highest along the Gaza border in the middle and south areas with concentrations exceeding 1000 mg/l. The best water quality is found in the sand dune areas in the north, mainly in the range of 50-250mg/l (PWA, 2013a,b, 2014 and 2015a, b and c).

Chloride level in the groundwater in Khan Younis and Rafah governorate varies from less than 250 mg/l in some western areas to more than 2000 mg/l in the eastern area, as shown in figure (4). Chloride concentration increase at the north and south of study area along coastal line.

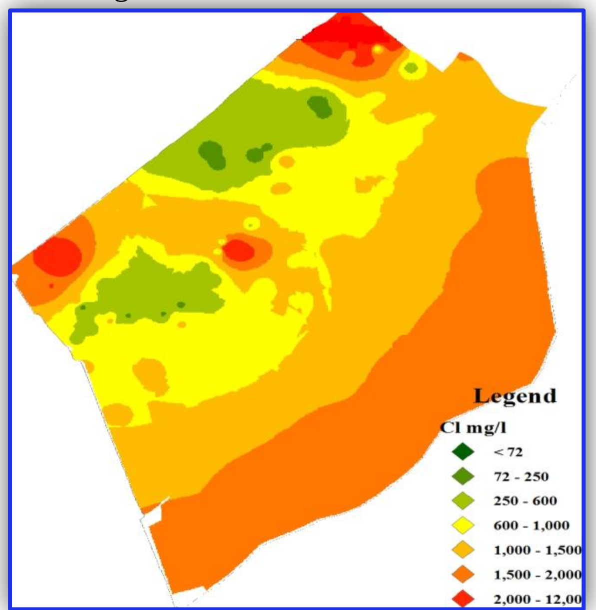

Fig (4): Chloride concentration in Rafah and Khan Younis (PWA, 2015c)

3.2 Geophysics:

3.2.1 Basic resistivity theory:

Resistivity of the ground is measured by injected a direct currents or very low frequency alternating current into the earth by means of pair of electrodes and the measuring resulting potential differences between another pair of electrodes at a multiplicity of locations at the surface. These measurements are inverted into a distribution of electrical resistivity in the subsurface. The resistivity boundaries are interpreted in terms of lithological boundaries, the foundation of this is Ohm's law.

The general field layout is sketched in (figure 5). Two pairs of electrodes are required, A and B are used for current injections, while M and N are for potential difference. In a homogeneous ground (half space) the current flow radially out from the current source and the arising equipotential surfaces run perpendicular to the current flow lines and form half spheres. In the common situation with both a current source and a current sink the current flow lines and the equipotential surfaces become more complex (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.

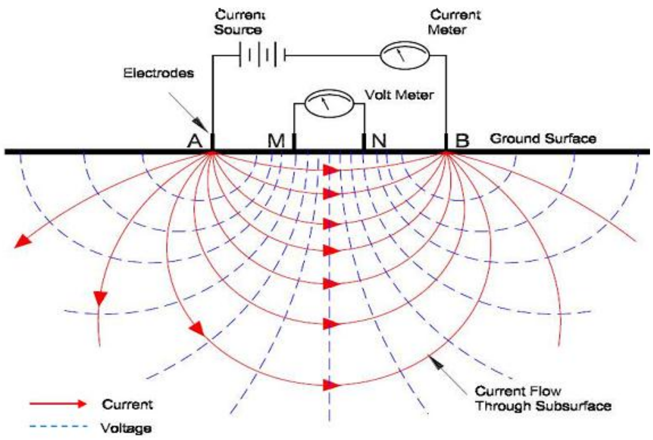

Fig (5): Simplified current flow line and equipotential surfaces arising from a set of current electrodes

Many electrode configurations have been proposed for electrical resistivity survey. The choice of the “best” array for a field survey depends on the type of structure to be mapped, the sensitivity of the resistivity meter and the background noise level. In practice in 1-D sounding survey, the arrays that are most commonly used for hydrogeology surveys are the Schlumberger and Wenner arrays (Dahlin and Zhou, 2004; Loke, 2011).

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

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

Vertical electrical sounding survey (VES) is used to determine the resistivity variation with depth. It’s common in the geoelectrical hydrogeological studies to use the Ohm resistivity meter as a field instrument and Schlumberger configuration as a ground electrodes array. Fourteen (14) vertical electrical soundings (VES) measuring points with Schlumberger array were carried out in the study area using the instrument SYSCAL Junior Switch-24 resistivity meters of IRIS INSTRUMENT, France, with 24 electrodes. Data arranged in seven lines (2 VES for each line) with a NW-SE direction, in order to determine the number of the underlying layers, depths, thicknesses and their conductivity. VES points for each line are separated by a distance of 500m spacing between each point, with line length of about 1km from the shore line (figure 6). 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 and 130m.

To construct a 2D images from sounding, two cross sections (H1, H2) has been selected from north to south. Every cross section has 7 VES soundings.

The interpretation of vertical electrical sounding (VES) points is carried out automatically by using the (IPI2Win) Software (Bobachev, 2002). 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. Litholgy data obtained from 12 boreholes, where these lithological data provide a very important constrains on the results of the sounding data interpretation. To study the hydrochemical parameters of the groundwater of the study area, ten chemical analyses water samples results were collected from ten agriculture groundwater bores to confirm the VES results. The analytical chemistry of groundwater in general was tested for TDS, EC and Chloride concentration and sodium (Table 1). The chemical data were analyzed to show the variation in water composition at different locations. In most cases water analyses were carried out by Ministry of Agriculture (MOA) and Coastal Municipalities Water Utility CMWU.

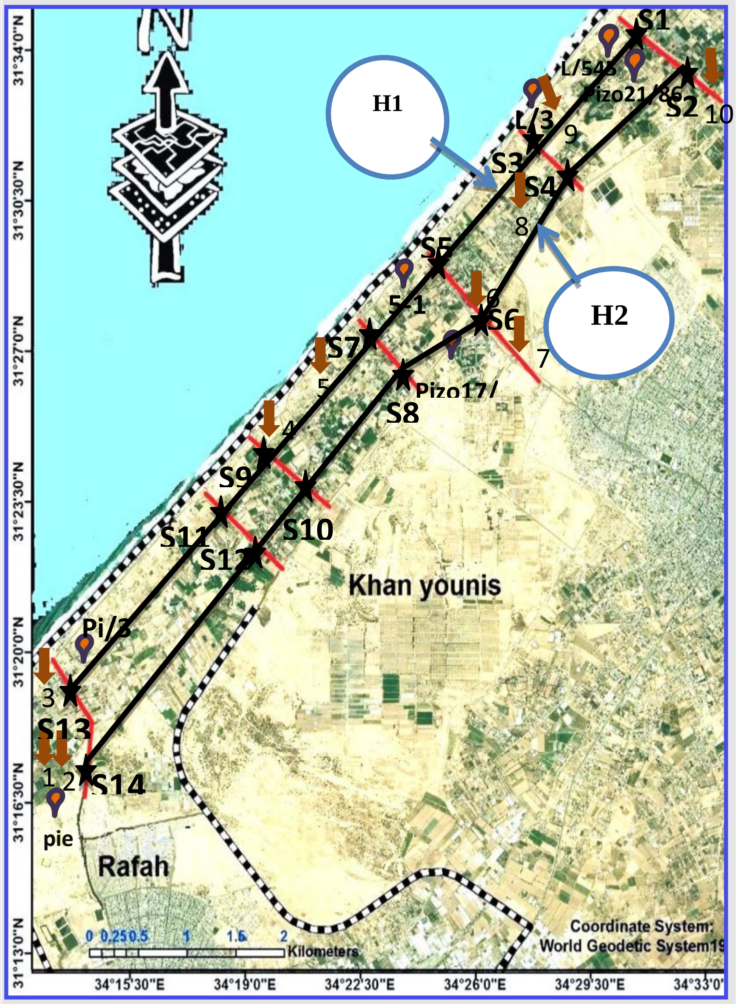

Fig (6): Location map of VESs and cross section H1 and H2

Table (1): Results of hydrogeochemical analysis of groundwater in the study area

VES	Well location		EC µS /cm	TDS mg/l	CL mg/l	Na mg/l
	Northern	Eastern				
VES 2	31° 22′ 53.47"	34° 17′ 56.95"	3440	1973	625	-
VES 3	31° 22′ 28.93"	34° 16′ 56.93"	9370	4766	2900	-
VES 4	31° 22′ 12.95"	34° 17′ 02.54"	4530	2430	788	460
VES 5	31° 21′ 25.62"	34° 16′ 48.72"	950	603.2	189.9	99.2
VES 6	31° 21′ 33.29"	34° 16′ 31.66"	1000	670	154.4	-
VES 7	31° 21′ 23.71"	34° 15′ 44.22"	8700	5829	2024.4	-
VES 9	31° 21′ 02.37"	34° 15′ 22.52"	6080	3360	1597	1100
VES 13	31° 18′ 34.46"	34° 13′ 33.03"	7900	5016	2149.3	906.9

4. Results and Discussion:

4.1 Qualitative and quantitative interpretation:

The results of a resistivity sounding survey can be interpreted both qualitatively and quantitatively. Qualitative interpretation of resistivity sounding data, involves the study of the types of sounding curves obtained, such curves are K, H, A and Q or a combination of two or three curves type e.g. KH, KHA, etc. (Keller and Frischknecht, 1966). The results reveal that 50% of the total soundings are interpreted of 3 layer modes, while the other 50% are of 4 layers model. All soundings in the study area are descending types, which mean decreases the layer resistivities as depths increased. Both Q and QQ curve type have about 92.86% of the total soundings, while KQ types occupied by 7.14% of the total soundings. Figures (7&8) represent 14 soundings curve carried out in Khan Younis and Rafah governorates.

The main purpose of quantitative interpretation of vertical electrical sounding (VES) is to determine the resistivity and thickness of different electrical horizons of the subsurface. The procedure of such interpretation depends on comparing the field curve with borehole logs and previous geophysical studies in the study area. However, there are several methods used in the quantitative interpretation of electrical sounding, but the most used methods are analytical (using computer program).Quantitative interpretation results for (14) VESs are presented in table (2).

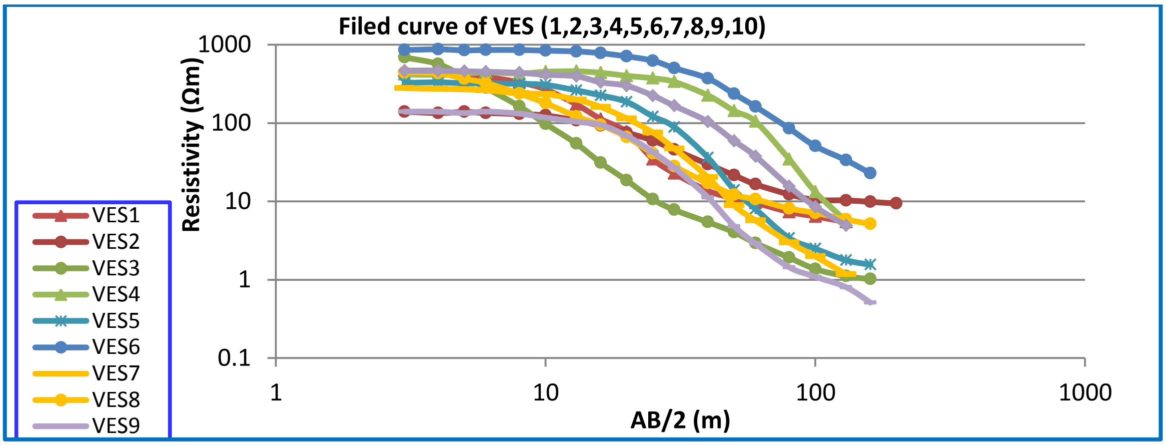

Fig (7): Sounding curves carried out in Khan Younis governorate

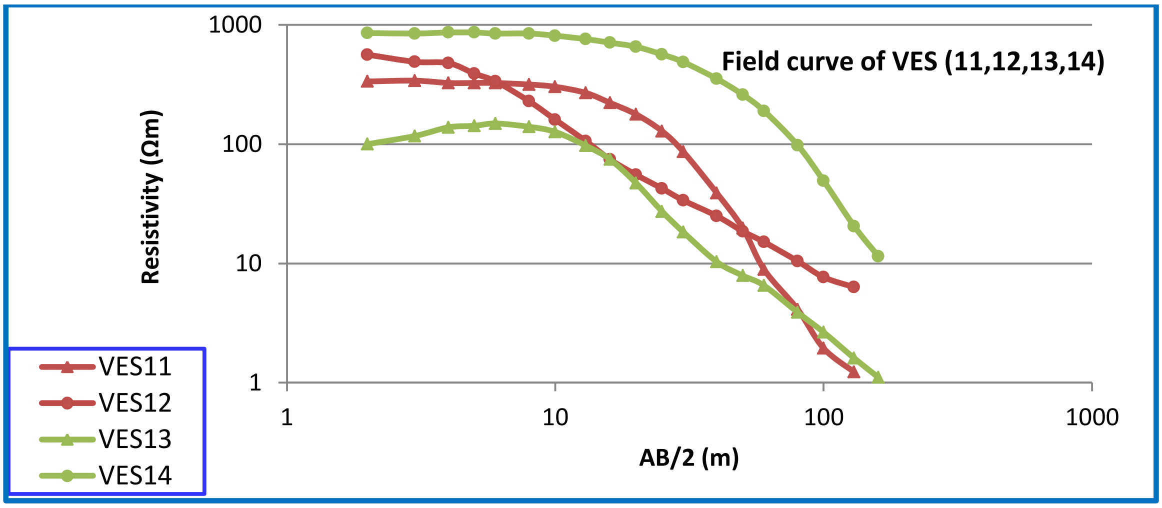

Fig (8): Sounding curves carried out in Rafah governorate

Table (2) Quantitative interpretation of VES soundings of the studied area

VES Point	RMS %	Electrical resistivity (ρ) in (Ohm.m) and thickness (h) in meter								Curve type
		Layer 1		Layer 2		Layer 3		Layer 4		
		ρ1 (Ωm)	h1 (m)	ρ2 (Ωm)	h2 (m)	ρ3 (Ωm)	h3 (m)	ρ4 (Ωm)	h4 (m)	
VES (1)	2.14%	479	4.75	134	4.2	12.3	30	4.3	-	QQ
VES (2)	1.33%	141	8.39	41.4	13	11.1	-			Q
VES (3)	2.07%	919	2.2	99.2	4.94	7.53	22.1	0.938	-	QQ
VES (4)	1.95%	491	2.71	474	18.5	5.41	-			Q
VES (5)	2.67%	332	11.6	3.94	34.6	0.949	-			Q
VES (6)	2.13%	866	17.9	46.7	44	9.9	-			Q
VES (7)	2.20%	272	9.84	6.45	33.5	0.553	-			Q
VES (8)	2.37%	484	3.35	107	8.19	10.9	38.3	4.09	-	QQ
VES (9)	2.92%	141	10.4	7.3	23.5	0.0.464	-			Q
VES (10)	2.22%	465	10.9	46.2	24.9	2.46	-			Q
VES (11)	1.16%	336	10.5	41	10.1	3.4	29.3	0.789	-	QQ
VES (12)	1.95%	561	3.38	62.6	11.6	15.8	27.4	5.34	-	QQ
VES (13)	3.06%	84.7	1.6	359	2.58	4.64	23	0.698		KQ
VES (14)	1.06%	860	10.1	434	17.5	62	27.9	4.49	-	QQ

4.2 Vertical electrical soundings cross section interpretation:

VESs soundings were interpreted individually (1D). For better understanding the distribution of the electrical resistivities in 2D view, and to delineate the effect of sea water intrusion in the fresh groundwater aquifer eastward, two resistivity cross sections were constructed (H1 and H2) using IPI2Win software (fig.5). Each section holds several soundings, with N-S trending and parallel to each other and parallel to the coastal line. H1 cross section distant about 400m east of the coastal line, while H2 cross section distant of about 1000m east of the coastal line. The interpreted geoelectrical pseudosections are shown in figures (8&9). The following are interpretation of these cross sections:

4.2.1 Geoelectrical cross section H1:

Geoelectrical cross H1includes several soundings (S1, S3, S5, S7, S9, S11, S13) extends to about 8.2 km from Khan Younis north (S1)to Rafah south (S13) in the western side of the study area and close to the coastal line and parallel to it (fig. 9). Inspection of contouring map of figure (8) reveals the following:

a) A high resistivity values (more than 300 Ωm) is observed at small AB/2 in Khan Younis Governorate between sounding S1 and S5 extend to about 2500m and another high resistivity anomalies also observed southwards in Rafah Governorate (S11). Resistivities between (100-300 Ωm) are observed along the cross section from north to south that may reflect unsaturated coastal shallow aquifer.

b) The resistivity values change horizontally and vertically.

c) At small AB/2 spacings, the apparent resistivities change horizontally which reflect the change in top soil layers, according to soil heterogeneity and water content.

d) As AB/2 spacing increased, the apparent resistivities decrease. It is well observed that at intermediate of AB/2 spacings, the resistivity values reflect the kurkar aquifer with different degree of salinity (with resistivity values between 5-100 Ωm).

e) At large AB/2 spacings, the low resistivity value (less than 2 Ωm) reflect the seawater intrusion. Seawater intrusion is observed clearly in all the section from north to south, but at different depths.

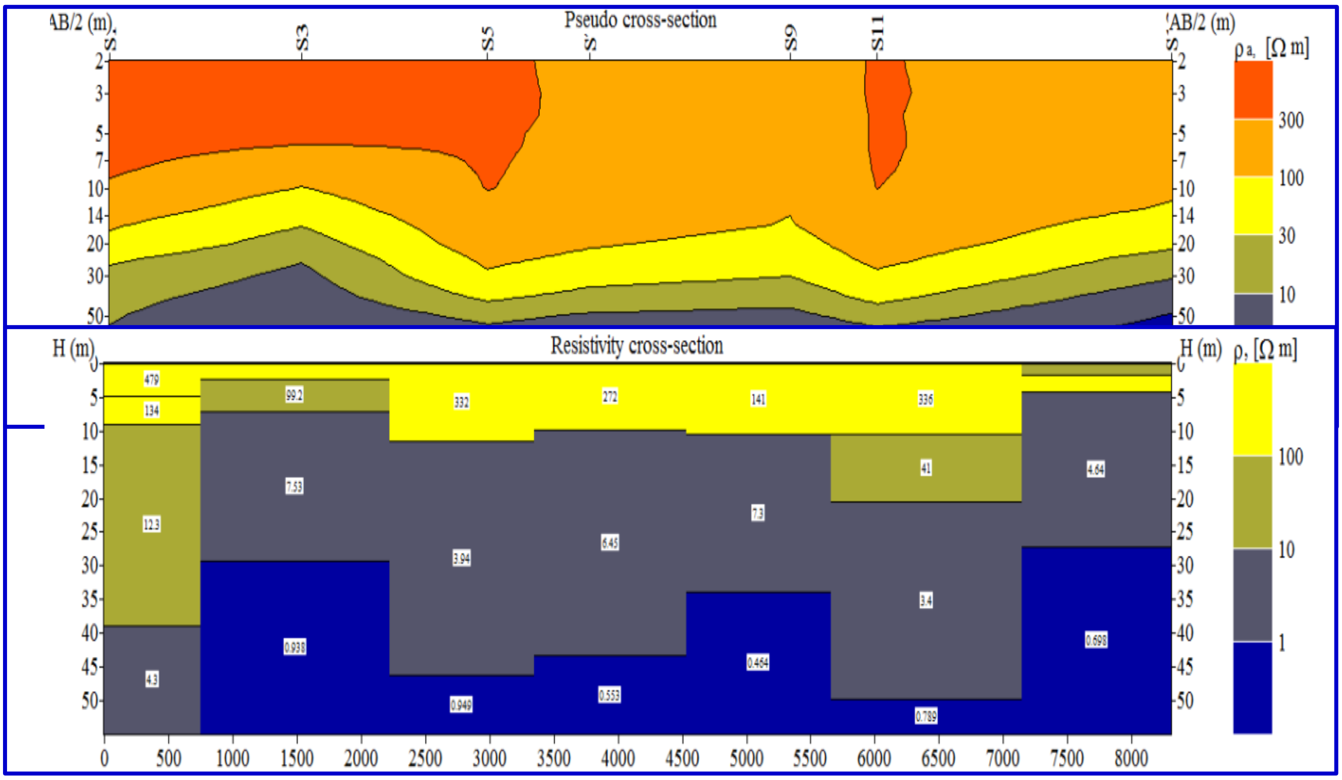

Fig (9): Pseudosection and Interpreted geoelectrical cross-section H1

The interpreted geoelectrical models of cross section H1 shows a top soil layer with resistivities range between 100 to more than 500Ωm with different depths along the cross section. The calculated depth for the top soil layers range between a few meters to about 20m at Rafah (S11). This top soil layer overlying a more conductive layer with resistivity ranges between 3.94 Ωm and 12.3 Ωm that represents the kurkar Aquifer saturated with brackish water at different depths. The Aquifer thickness in the south (S13) is about 27m increased to about 50m northwards (from S11 to S5), then the thickness decreases to about 30 m depth under S3 to increase again at Khan younis Governorate (S1) to about 39 m depth. Some shallow aquifer with fresh water could be observed in Khan younis (S1) and in Rafah (S11) with resistivities between 12-41 Ωm at shallow to intermediate depths.

The figure shows that the brackish Kurkar layer overlay a more conductive layer with resistivity values less than 2 Ωm that represents seawater intrusion in the aquifer at different depths. In Khan younis Governorate (S1) seawater intrusion not observed up to depth of about 55m but it was confirmed by chemical analyses for the nearby agriculture water well no.(10), where high TDS value about 1973 mg/l , EC about 3440 µS /cm and Chloride (CL) content about 625 mg/l. At S3 (1500 m south S1) seawater intrusion observed at 30 m depth that increased to about 50 m and then the depth decreased to about 27 m in Rafah (S13).

4.2.2 Geoelectrical cross section H2:

Geoelectrical cross section H2 was selected to parallel cross section H1 ad distant about 500 m eastwards and including sounding: S2, S4, S6, S8, S10, S12 and S14. Pseudosection and interpreted geoelectrical model for H2 cross section is presented in figure (10).

Inspection of pseudosection map of figure (9) reveals that H2 cross section in general has higher resistivity values than H1. This may be due to the fact that H1 cross section is very close to the coastal line, so that the layer resistivities are lower than that of H2 cross section.

Two high resistivity anomalies are well shown (500-1000 Ωm). The first one extends from S6 to S8 with extension of about 2500m in Khan Younis, while the other is located in Rafah between sounding S12 and S14 with extension of about 2000 m long. As AB/2 spacing increased the apparent resistivity decreased up to about 4 Ωm at the lower layers of section H2.

Pseudosection H2 illustrates that at shallow and intermediate depths, the observed resistivity values are higher than resistivities of H1 for the same spacing. The resistivity values of H1 cross section from the surface to AB/2 equal 70 m range between (3 Ωm- 500 Ωm), while for H2 range between (20 Ωm-1000 Ωm). At the bottom section H1, seawater intrusion is observed (less than 2 Ωm), while in H2 section it is not observed, it was confirmed at VES 6 by chemical analyses for the nearby agriculture water well no. 7, high TDS value about 670 mg/l , EC about 1000 µS /cm and Chloride (CL) content about 154.4 mg/l. A structural fault can be proposed in the area between S2 and S4 in Khan Younis, and other faults could be proposed under sounding S6, S8, S10 and S12.

The interpreted geoelectrical model of H2 cross section (Fig.10) shows that top soil layer characterized by high resistivity values, that, in general, increased from north to south (from S1 to S14). This top soil cover overlaying another layer represents the shallow aquifer at different depths with different resistivity values according to water content, salinity degree and soil mixture. Under this shallow aquifer, the deep Kurkar aquifer is characterized by low resistivity values that reflect more salinity content (brackish to saline water). However, the model show that no seawater intrusion observed in this section except under sounding S10, where resistivity values reach to about 2.46 Ωm that reflect seawater intrusion in the area.

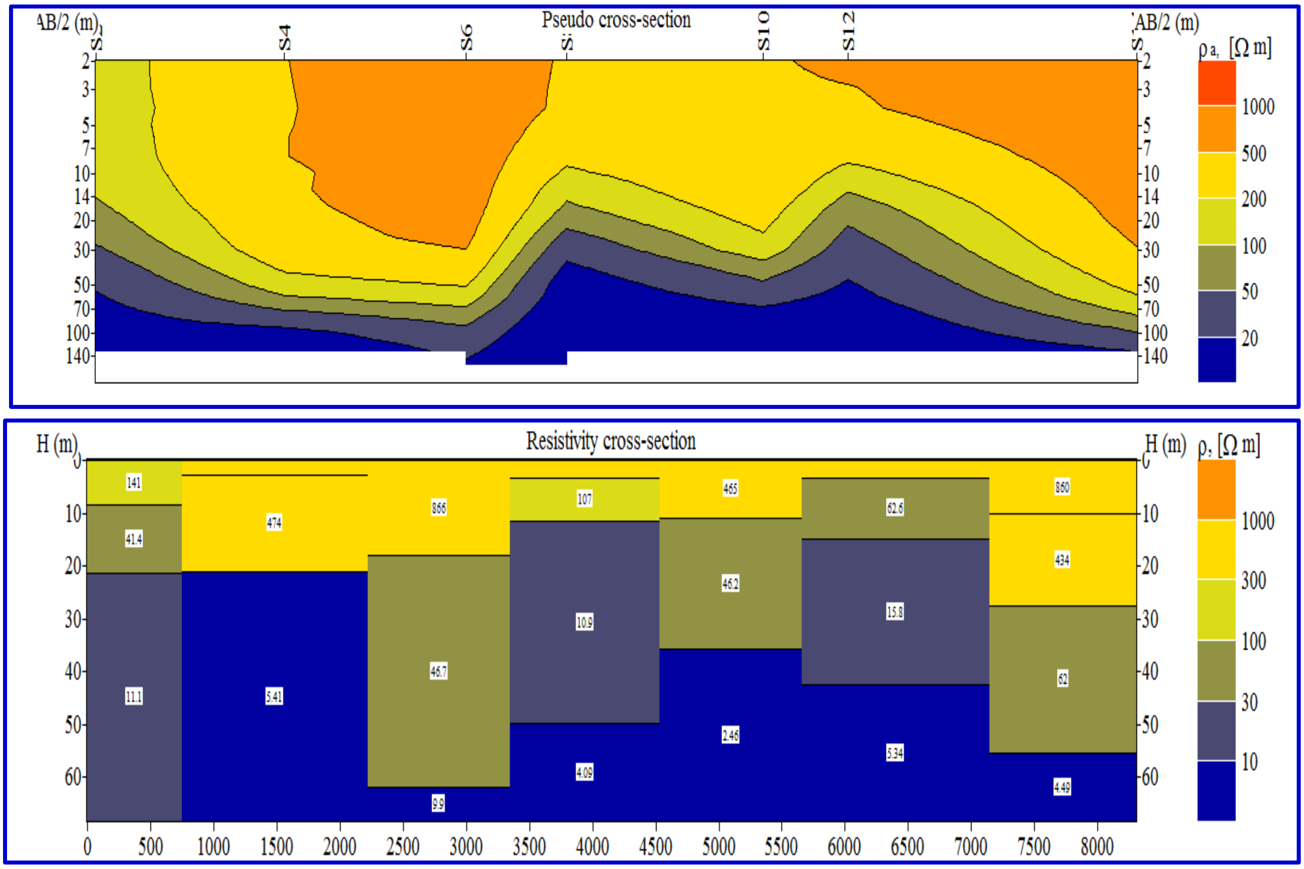

Fig (10): Pseudosection and interpreted geoelectrical cross-section H2

Comparison geoelectrical model of H1 and H2 reveals the following points:

a) The top soil at H1 is characterized with electrical resistivities lower than that of H2 section. This may be due to soil type and water salinity.
b) The second layer (sub aquifer) at H1 geoelectrical section is characterized by resistivities lower than that of H2 section and with layer thickness more than that of H2 section, because it more close to the coastal line.
c) The fresh water aquifer almost is absent in H1 section. All the aquifer layers are saturated with saline water except the upper most layers. Seawater intrusion appeared at all the section at few meter depth in Rafah to about 30 m depth in Khan younis.
d) Fresh aquifer layers in H2 cross section is characterized by medium resistivity values and much layer thickness than that of H1 aquifer. This means that the aquifer is still have fresh water but could be polluted by seawater intrusion.

5- Conclusions:

Vertical Electrical Sounding (VES) proved to be important tools for mapping the freshwater-saltwater interface and for studying conductive bodies and subsurface geological structural. According to the nature of electrical field curves, qualitative interpretation (1D) was applied and three types were classified, which are QQ, Q, and KQ. It reveals that 50% of the total soundings are interpreted of 3 layer modes, while the other 50%

are of 4 layers model. All soundings in the study area are descending types, which mean decreases the layer resistivities as depths increased. Both Q and QQ curve type have about 92.86% of the total soundings, while KQ types occupied by 7.14% of the total soundings. Fresh water zone which lies at the eastern part of the study area, where the aquifer thickness in the south (S13) is about 28m increased to about 50m northwards (from S11 to S5), then the thickness decreases to about 28 m depth under S3 to increase again at Khan Younis Governorate (S1) to about 38 m depth. Shallow aquifer with fresh water observed in Khan Younis (S1) and in Rafah (S11) with resistivities between 12-48 Ωm at shallow to intermediate depths.

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الملخص باللغة العربية:

اثبتت طريقة المقاومة الكهربائية العمودية (VES) فعاليتها فى تحديد الحدود الفاصلة بين المياه العذبة و المالحة . تعتبر مشكلة تداخل المياه المالحة فى مياه الخزان الجوفى العذب مشكلة ذات اهمية و خاصة فى المناطق الشاطئية. لقد تم تنفيذ 14 مجسة كهربائية عمودية بأستخدام تشكيل شلمبرجير بشكل قطاعات عمودية على على الساحل الجنوبى لقطاع غزة (محافظات خانيونس و رفح) و ذلك بهدف دراسة التركيب الجيولوجى للخزان الجوفى و تحديد مدى تداخل مياه البحر فيه . كما تم الاستعانة بالمعلومات الليثولوجية و الهيدروكيميائية من 12 بئرمياه فى مناطق الدراسة. اظهرت النتائج ان 50% من منحنيات المقاومة الكهربائية المقاسة تمثل نموذج لثلاث طبقات جيولوجية بينما 50% تمثل اربع طبقات. تم اختيار قطاعين متوازيين و موازين لشاطئ البحر، يبعد الاول 400 م عن الشاطئ بينما الاخر يبعد 1000م عنه لدراسة تغيرات المقاومة فى بعدين. أظهرت النتائج ان مياه البحر ذات المقاومة الكهربائية أقل من 2 أوم.متر تسود على طول القطاع القريب من الشاطئ و لاعماق ضحلة (3-10 م)، بينما فى القطاع الثانى و الذى يبعد 1000م شرقا تم تحديد أمكن تداخل مياه البحر المالحة فى بعض الاماكن و لم يتم تحديدها فى أماكن أخرى مما يفسر على ان تلك المناطق لا زالت تحتوى على مياه عذبة/ مالحة ذات مقاومة كهربائية اكبر من 10 أوم.متر و على أعماق تتراوح بين 26-50 متر .