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Study of Seawater Intrusion in Tajoura Area

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دراسة تداخل مياه البحر والمياه الجوفية في منطقة تاجوراء

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مركز بحوث الطاقة النووية، تاجوراء، طرابلس، ليبيا

Abstract

The aim of this study is to know the extent of seawater intrusion into groundwater. The geo-electrical method was used to measure the resistivity of subsurface layers. Field measurements were conducted using a resistivity device with a Schlumberger array. Variable electrodes were spread with a maximum distance of 400 m. Readings of 18 Vertical Electrical Soundings were taken in the area of study which has several wells that were formerly studied using chemical analysis method of well samples. Electrical data were analyzed and interpreted and horizontal and vertical sections of apparent resistivity were drawn, also contour maps of iso-resistivity lines were constructed. It has been clearly shown that seawater intruded into groundwater in the study area.

Keywords: *Intrusion, Seawater, Geo-electrical, Resistivity.*

الملخص

تم دراسة منطقة تاجوراء بهدف معرفة مدى تداخل مياه البحر مع المياه الجوفية وأستخدم في الدراسة طريقة قياس المقاومة النوعية للطبقات التحت سطحية وتمت القياسات في الحقل باستخدام جهاز قياس المقاومة النوعية وبترتيب شلمبرجير وبواقع نشر أقطاب تيار كهربائي متغيرة مساوية إلى مسافة قصوى 400 متر وأخذت قراءات لثماني عشر 18 جسة كهربائية داخل منطقة الدراسة التي بها مجموعة أبار تمت دراستها سابقا بطريقة التحليل الكيميائي لعينات الابار وقد تم تحليل وتفسير المعطيات الكهربائية ورسم المقاطع العمودية والخرائط الكنتورية لخطوط تساوي المقاومة النوعية وقد تبين بشكل واضح تداخل مياه البحر بمنطقة الدراسة.

الكلمات الدلالية: التداخل، مياه البحر، الكهروكيميائية، المقاومة.

1. Introduction

Geo-Electrical method is one of the important methods in geophysical prospecting. It deals with the electrical condition of earth and it investigates samples, electrical properties of rocks and minerals under different geological circumstances. It employs principles of the Earth‘s electricity to construct geological maps of subsurface structures, also, to investigate and explore bodies, mineral veins and oil. This method helps in solving problems related to geological engineering and ground water. There are several kinds of Geo–Electrical methods, but the most important one is electrical resistivity (Dobrin and Savit, 1976). This method uses direct or alternating current with very low frequency; these currents are induced into the ground by a pair of electrodes spread at certain distances. The difference in potential between a pair of electrodes and that one for a current unit is measured and the resistivity is considered as a function of the geometry of electrodes and electrical parameters Wenner array and Schlumberger array (Telford *et al*., 1990). There are two methods to measure the Field Electrical Resistivity:

- Electrical Profiling Survey
- Vertical Electrical Sounding Survey

1.1. The Aim of This Study

Determining the separating limit between fresh and salt water - affected water and comparing this to previous studies. Previous seawater studies demonstrated intrusion front by chemical analyzing well samples in 2005 as shown in Figure (1), (General Authority of water, 2005).

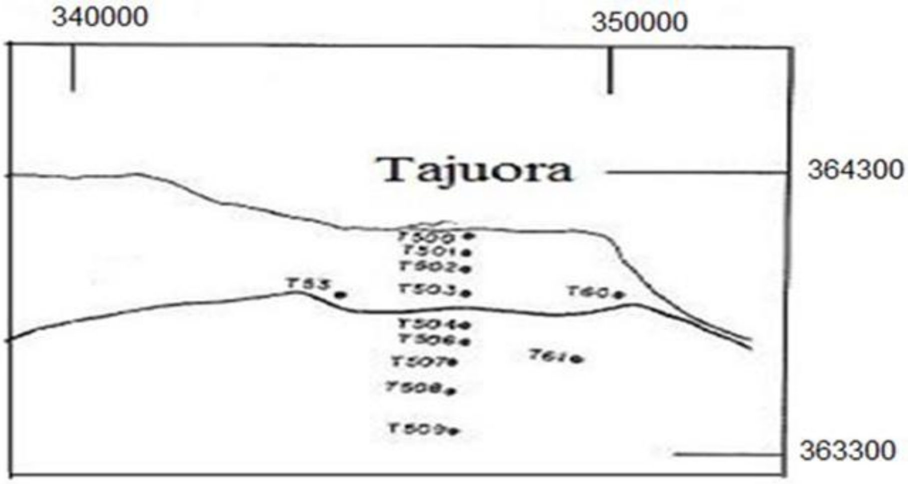
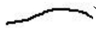


Figure 1. () Intrusion front (2005) in the study area, T60 Well NO.

Expanded study of seawater intrusion that used remote sensing and samples from wellsT500, T501, T502, T503, T504, T505, T506, T507, T508, T509 in addition to T60, T61 and T62 and doing chemical analysis and conductivity as shown in Figure (2), (Goboda, 2008).

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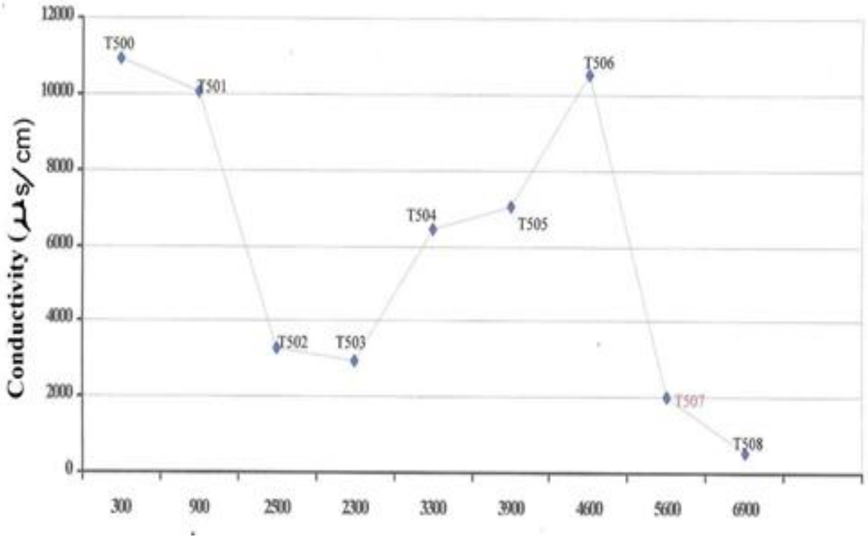

Figure 2. Conductivity micro Siemen/Centimeter, T500: Well NO, distance from seashore (*m*)

Also, the soluble salts group TD5 as shown in Figure (3), (Goboda, 2008)

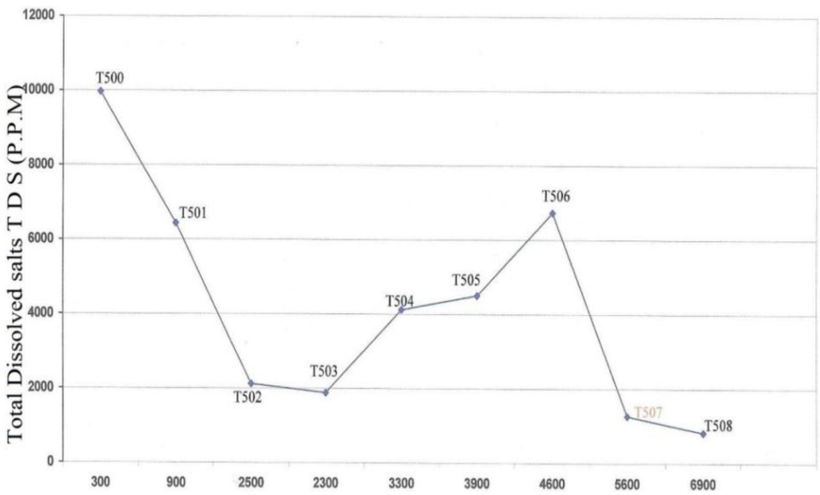

Figure 3. Total Dissolved Salts (P. P .M), T502: Well NO, distance from seashore (*m*)

Also, the degree of salinity as in Figure (4), (Goboda, 2008).

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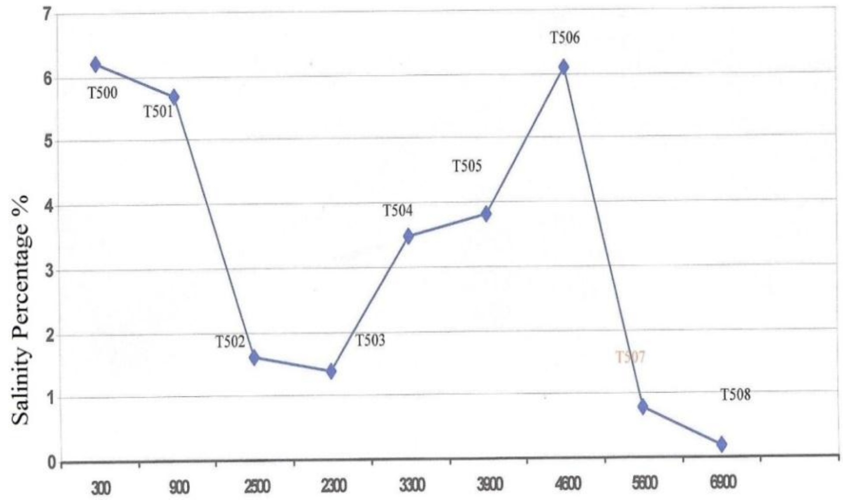

Figure 4. Salinity percentage %, T503 Well NO., distance from seashore (m)

In 2008, intrusion front was as shown in Figure (5), (Goboda, 2008).

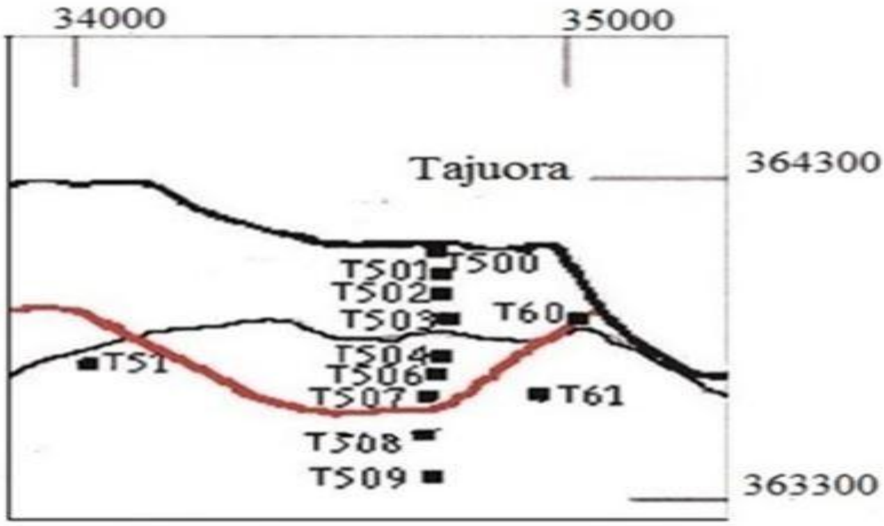

Figure 5. ( )Intrusion front, T509: Well NO, (Goboda, 2008)

1.2. Phenomenon of Sea Water Intrusion

Salt water intrusion occurs in coastal freshwater aquifers when the different densities of both the saltwater and freshwater allow the sea water to intrude into the freshwater aquifer. These areas are usually supporting large populations where the demanding groundwater withdrawals from these aquifers are exceeding the recharge rate. Figure (6) gives a rough illustration of what an overdrawn aquifer may look like. This can cause lateral and vertical intrusion of the surrounding saltwater, (USGS, 2007). Also, when groundwater levels in aquifers are depleted faster than they can recharge. This is directly related to the position of the interface and

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determines the amount of saltwater that can intrude into the freshwater aquifer system. Since saltwater intrusion is directly related to the recharge rate of the groundwater, this allows for other factors that may contribute to the encroachment of seawater into the freshwater aquifers. Climatic variables, such as precipitation, surface runoff, and temperature can play a big role in affecting saltwater intrusion. With lower precipitation amounts and warmer temperatures, the recharge rate will be much less due to lack of groundwater present and increased evaporation (Ranjan, 2007). Along with this, other factors may influence the groundwater recharge rate indirectly. An example of this would be the rising carbon dioxide emissions in the atmosphere. Increasing carbon dioxide levels can lead directly to an increase in average surface temperatures, indirectly increasing the evaporation rate and affecting the recharge of freshwater into the coastal aquifers.

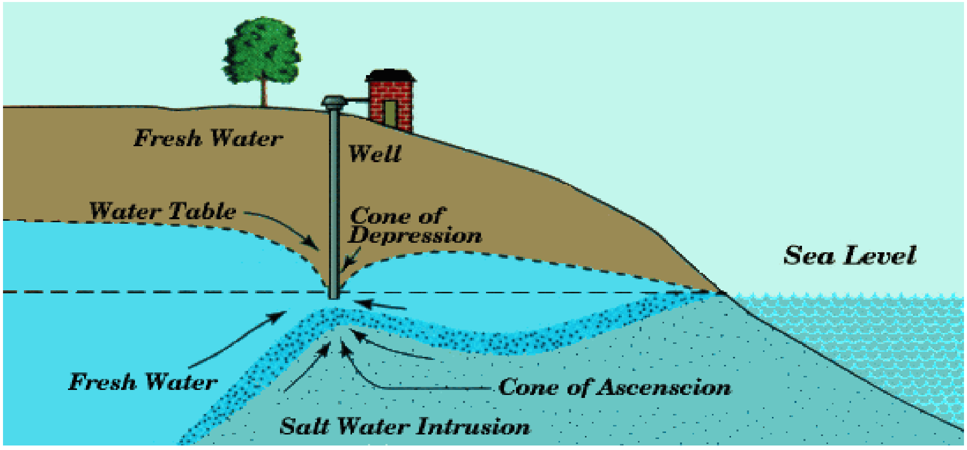

Figure 6. Salt water intrusion

1.3. Location of the Study Area

Area of study is located in Tajoura, 15 *km* east of Tripoli, south of the coastal highway in the Factories Zone. Latitude (36333000 - 3637000), Longitude (346000- 352000). Figure (7), shows the study area.

1.4 Geology and Hydrology of Study Area

Geological formations of the study area are the latest geological formations belonging to the fourth geologic time which is Pleistocene residues based on the rock component of marine Miocene rocks basis and represented by Gergarish formation and sediments of Aljafara formation, in addition to the sandy beach dunes. The most important geologic reservoirs which considered the main carrier of groundwater and already exploited is the Surface aquifer and the Quarterly aquifer that belong to the fourth and third time rocks Pliocene and upper Miocene, which consists of limestone with a bit of sandstone and clay and its thickness is in the limits of 200 *m* and water saturated thickness ranging between 5-160 *m*.

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2. Materials and Methods

According to previously acquired data from old wells, as displayed Figure (7), which were studied using chemical analysis of well samples, electrical surveying points have been configured almost as grid in the vicinity of these wells and taking into consideration some obstructions confronted in the area such as buildings and others obstacles that hinder electrical surveying should be bypassed.

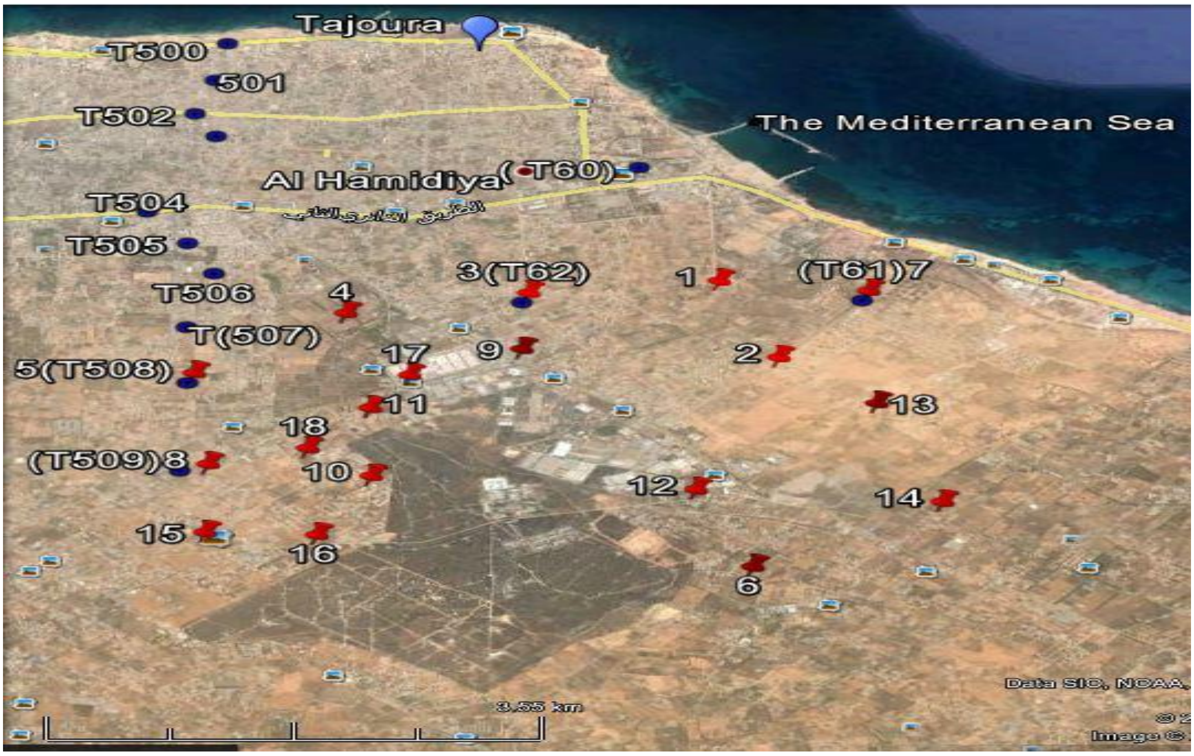

Figure 7. Location of the study area, (12): VES NO, (T60): Well NO.

2.1. Field Work and Measurements

The work was done using Vertical Electrical Sounding survey method with electrodes configuration as Schlumberger Array as illustrated in Figure (8), and the apparent resistivity measurements were taken using SARIS Resistivity Meter as shown in Figure (9). The field work and measurements were carried out by a team belonging to the Department of Prospecting. Eighteen Vertical Electrical Soundings were measured and the maximum distance between variable electrodes for each sounding was 400 *m*.

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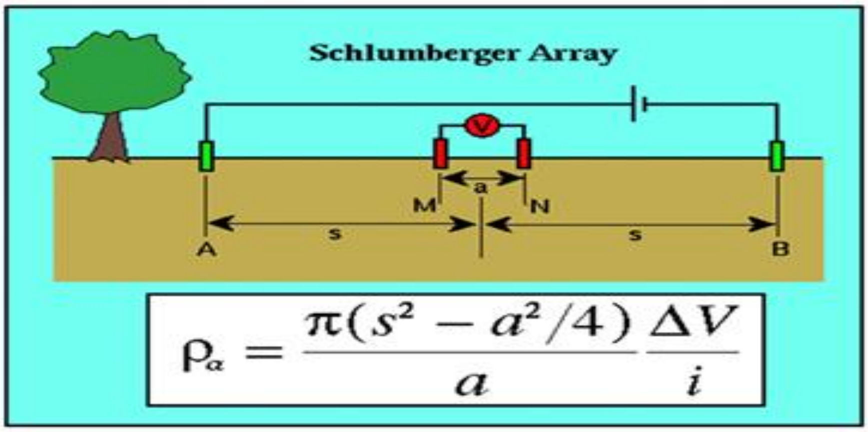

Figure 8. (ρ_a): Apparent Resistivity, (π): 3.14, (*S*): Distance between point (*VES*) and current electrode, (*ΔV*): potential Difference, (*i*): Current, (*AB*): Distance between Current Electrodes, (*MN*) = (*a*): Distance between potential Electrodes.

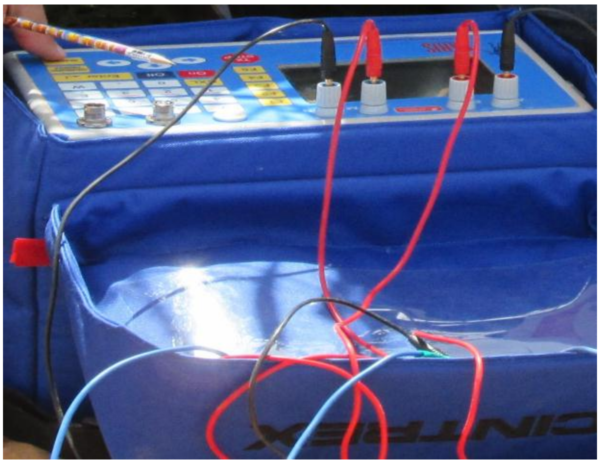

Figure 9. SARIS Resistivity Meter

3. Electrical Data Analysis and Interpretation

All 18 Vertical Electrical Soundings were manually drawn on dual logarithmic paper (62.5), where X-axis represents, *AB* is the distance between current electrodes while *Y*-axis is the apparent resistivity (ρ_a).

Variations in apparent resistivity were observed for each sounding and a relationship was practically derived that depth is almost between *AB*/4 and *AB*/3.

Using (IpI2Win+ip) software data were entered that include readings of variable distances between current electrodes *AB* and variable distances between potential electrodes *MN* for each sounding.

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Figure 10. ( ) Profiles, (6) VES NO, T(500): Well NO

Table 1. Profiles and Electrical Verticals Soundings

Profile No	Vertical Electrical Soundings				
VES 14	Profile – 1	VES 7	VES 13	VES 14	
Profile -2	VES 1	VES 2	VES 12	VES 6	
Profile – 3	VES 3	VES 9	VES 10	VES 16	
Profile – 4	VES 3	VES 17	VES 11	VES 10	VES 16
Profile – 5	VES 4	VES 18	VES 16		
Profile – 6	VES 5	VES 8	VES 15		

Profiles have been taken in the direction perpendicular to the intrusion front, which were previously studied in order to know the extent of seawater intrusion as shown in Figure (10), and with the help of software (Ip I2wint+ Ip), profiles have been interpreted separately.

Each profile as shown in Table (1), can be interpreted separately by reference to the Table (2), which displays the relation between formation resistivity and groundwater quality.

Table 2. Relation between formation resistivity and groundwater quality

Ground water quality group	Total Dissolved Salt TDS (mg/l)	Formation resistivity ρ (ohm meter), 11 ℃
Very fresh (VF)	< 200	**>200**
Fresh (F)	200 - 400	200 – 100
Moderately Fresh (MF)	400 - 800	100 -50
Weakly Fresh (WF)	800 – 1,600	50 – 25
Moderately Brackish (MB)	1,600 -200,3	25 – 12.5
Brackish (B)	3,200 – 6,400	12.5 – 6.25
Very Brackish (VB)	6,400 -12,800	6.25 – 3.12
Moderately Salt (MS)	12,800 – 25,600	3.12 – 1.56
Salt (S)	> 25,600	1.56<

4. Results and Discussion

4.1. Results Gained by Ip I2wint+Ip Software

Depending on profiles have been drawn in Figure (11), the upcoming results has been approached:

The lowest resistivity obtained in Profile (1) is shown in Figure (11). At VES 7. The resistivity value was (10-25 *Ohm meter*) at depth around (6-180 *m*). Depending on Table (2) and gained resistivity value, the TDS of water at this VES is ~(1,600–3,200 *mg/l*); which means it is slightly effected by Sea Water.

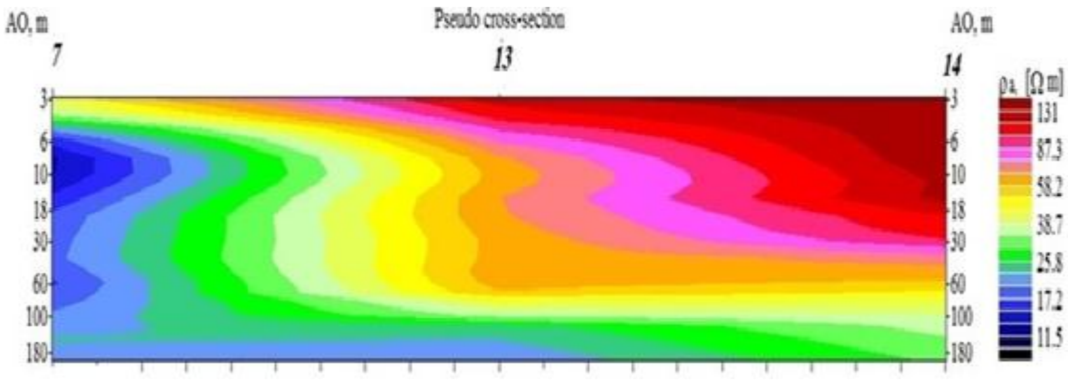

Figure 11. Profile (1), VES (7, 13, 14) , AO: depth (*m*)

The lowest resistivity obtained in Profile (2) is shown in Figure (12). At VES 1, the resistivity value was (0-10 *Ohm meter*) at depth around (60-180 *m*). Depending on Table (2) and gained resistivity value, the TDS of water at this VES is ~ (3,200 – 6,400 *mg/l*), which

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means it is highly affected by sea water. It is clear from the figure that the area between VES1 and VES2 has a high salinity, while the blank area after VES 2 was difficult to measure under (120 *m*) depth due to some obstacles.

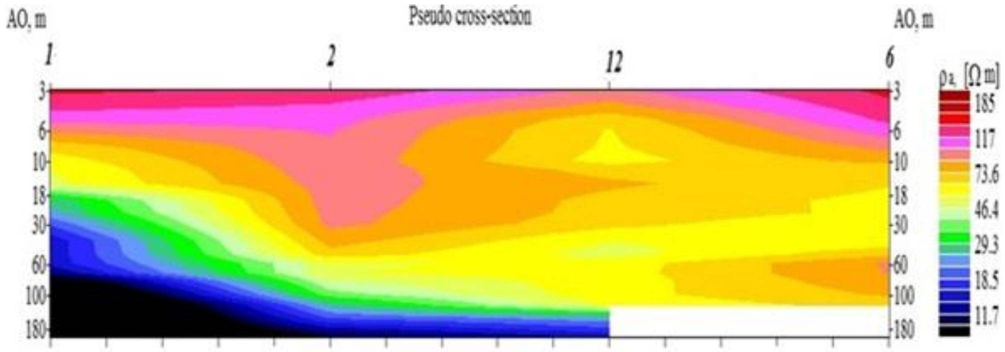

Figure 12. Profile (2), VES (1, 2, 12, and 6), AO: depth (*m*)

The lowest resistivity obtained in Profile (3) is shown in Figure (13). At VES 3, VES9 and VES16, the resistivity value was (10-25 *Ohm meter*) at depth around (80-180 *m*). Depending on Table (2) and gained resistivity values, the TDS of water at this VES is ~ (1,600–3,200 *mg/l*), which means it is highly affected by sea water. At VES10, the resistivity value was (0-10 *Ohm meter*) at depth around (100-180 *m*). Depending on Table (2) and gained resistivity values, the TDS of water at this VES is (3,200-6,400 *mg/l*), which means it is highly affected by sea water.

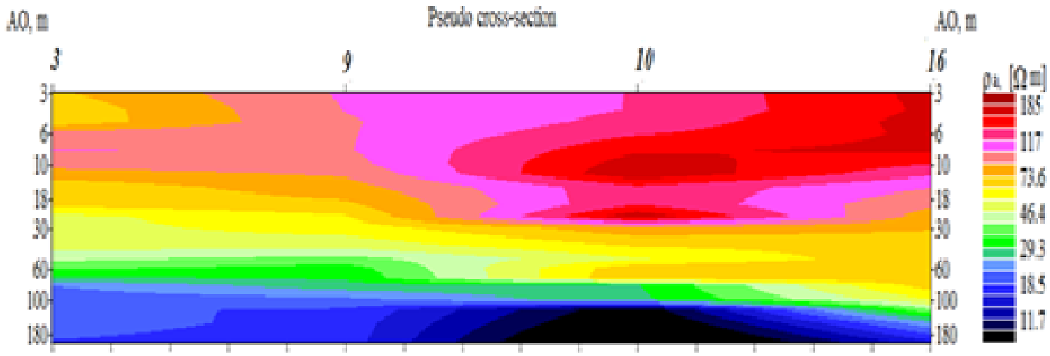

Figure 13. Profile (3), VES (3, 9, 10, and 16), AO: depth (*m*)

Profile (4) is shown in Figure (14), due to some obstacles, the area between VES17 and VES10 could just be measured till about (120 *m*) depth. It is clear from the figure that VES17 and VES11 are not affected by sea water.

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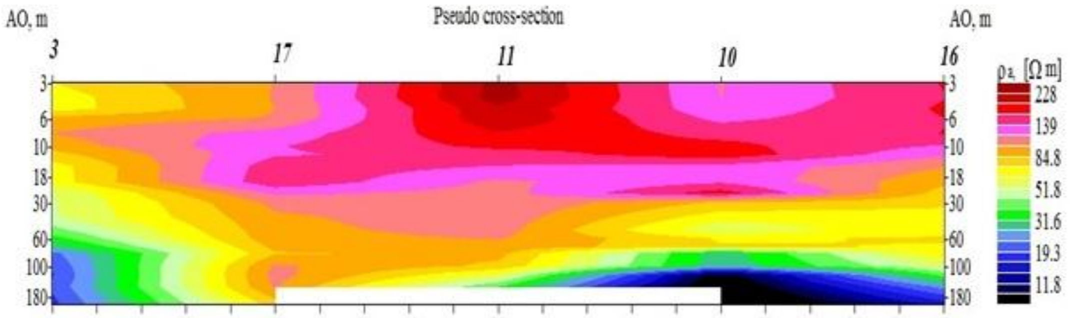

Figure 14. Profile (4), VES (3, 17, 11, 10, and 16), AO: depth (*m*)

As shown in Figure (15), Profile (5) could just be measured till about (160 *m*) due to some obstacles. The lowest resistivity obtained at the profile was VES 4. The resistivity value was (0-10 *Ohm meter*) at depth around (60-180 *m*). Depending on Table (2) and gained resistivity value, the TDS of water at this VES is ~(3,200–6,400 *mg/l*), which means it is highly affected by Sea Water.

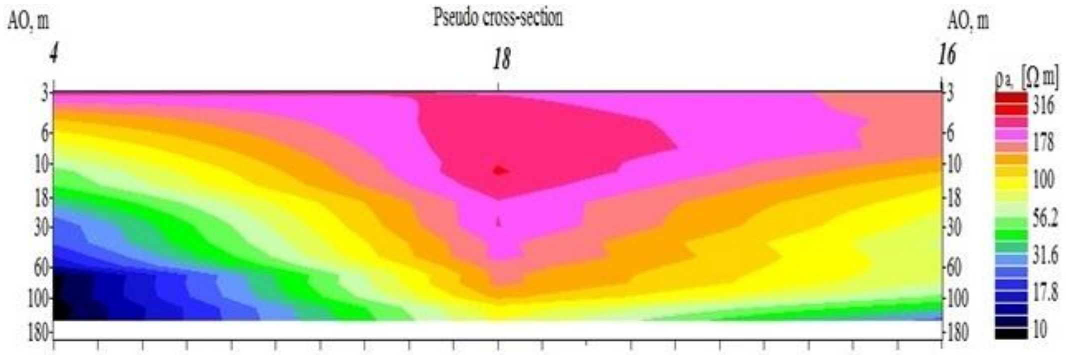

Figure 15. Profile (5), VES (4, 18, and 16), AO: depth (*m*)

The lowest resistivity obtained in Profile (6) is shown in Figure (16). At VES 5, the resistivity value was (0-25 *Ohm meter*) at depth around (160-180 *m*). Depending on Table (2) and gained resistivity value, the TDS of water at this VES is ~(1,600-6,400 *mg/l*), which means it is highly affected by sea.

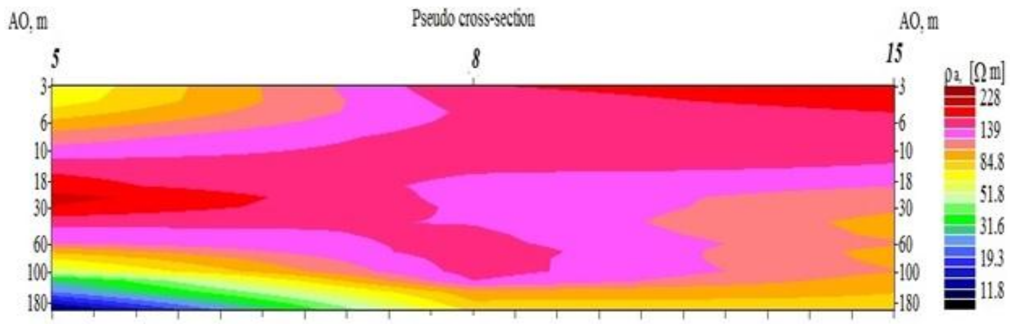

Figure 16. Profile (6), VES (5, 8, and 15), AO: depth (*m*)

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By interpreting previous profiles, very low resistivity was obtained for VES's (10-5-4-3-1-7) with values less than (10 *Ohm meter*) which means they are affected by highly sea water.

Iso-resistivity maps were drawn for different distances between current electrodes which equals (100, 240, 300, and 400 *m*) in the whole study area. These maps show differences in resistivity at fixed depths as shown in Table (3). Also, can be interpreted by reference to the Table (2), which displays the Relation between formation resistivity and groundwater quality.

Table 3. Apparent resistivity values (Ω*m*) at AB =(100, 240, 300, and 400) *m*, (x,y): UTM

V.E.S	x	y	ρ_a at AB=100 *m*, Ω*m*	ρ_a at AB=240 m, Ω*m*	ρ_a at AB=300 *m*, Ω*m*	ρ_a at AB=400 *m*, Ω*m*
1	350544.64	3637082.68	19.44	3.03	6.05	13.22
2	350968.07	3635989.77	66.71	25.96	19.13	10.12
3	349131.8	3636961.84	33.48	9.61	10.07	9.28
4	347777.68	3636722.92	14.25	9.01	9.34	12.28
5	346659.87	3635916.75	121.70	26.38	21.00	10.25
6	350727.73	3633108.45	70.96	77.91	73.89	75.90
7	351650.03	3636902.44	14.95	1.05	17.20	32.90
8	346766.88	3634650.8	143.30	137.20	93.40	75.70
9	349074.77	3636172.54	37.63	13.01	10.78	12.58
10	347959.74	3634444.77	53.60	8.70	7.80	6.30
11	347954.73	3635386.9	144.00	65.69	42.95	54.32
12	350330.35	3634177.25	50.71	85.02	17.53	248.70
13	351674.18	3635324.53	63.30	23.49	22.32	28.11
14	352125.52	3633945.69	68.81	35.34	157.80	61.07
15	346747.12	3633711.51	97.37	92.56	85.88	82.54
16	347562.84	3633649.62	70.26	18.19	19.55	15.34
17	348246.11	3635835.89	404.60	346.00	395.90	301.20
18	347495.46	3634845.93	163.40	101.80	93.13	93.15

Figure (17), shows iso-resistivity lines where distance between current electrodes equals (AB=100 *m*) and depth was practically between (AB/3, AB/4), and that is between (25- 33 *m*). Resistivity in the region is low in the direction of north and ranging between (0-40 *Ohm. meter*), it is defined in light blue.

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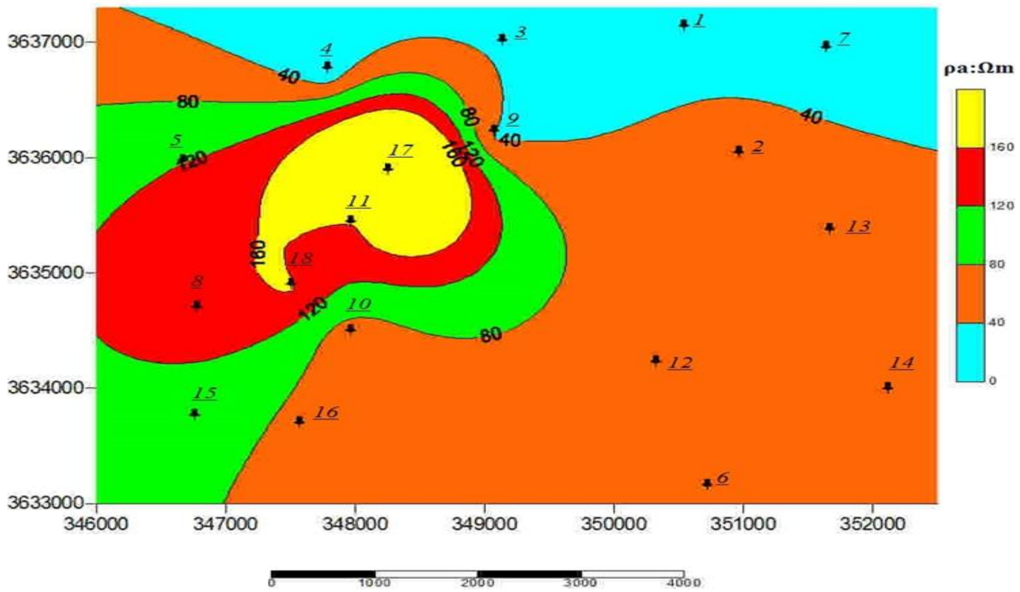

Figure 17. Iso –Resistivity contours map, (AB=100 *m*), Contour NO 15 Ω*m* , (15) : VES NO

Figure (18) shows lines of iso-apparent resistivity of the area where distance between electrodes was (AB=240 *m*), which range in depth (60-80 *m*). It has been found that the resistivity grades from north (0-10 *Ohm meter*) which means that ground water is affected by seawater at soundings (4-3-2-7), and it is defined in dark blue.

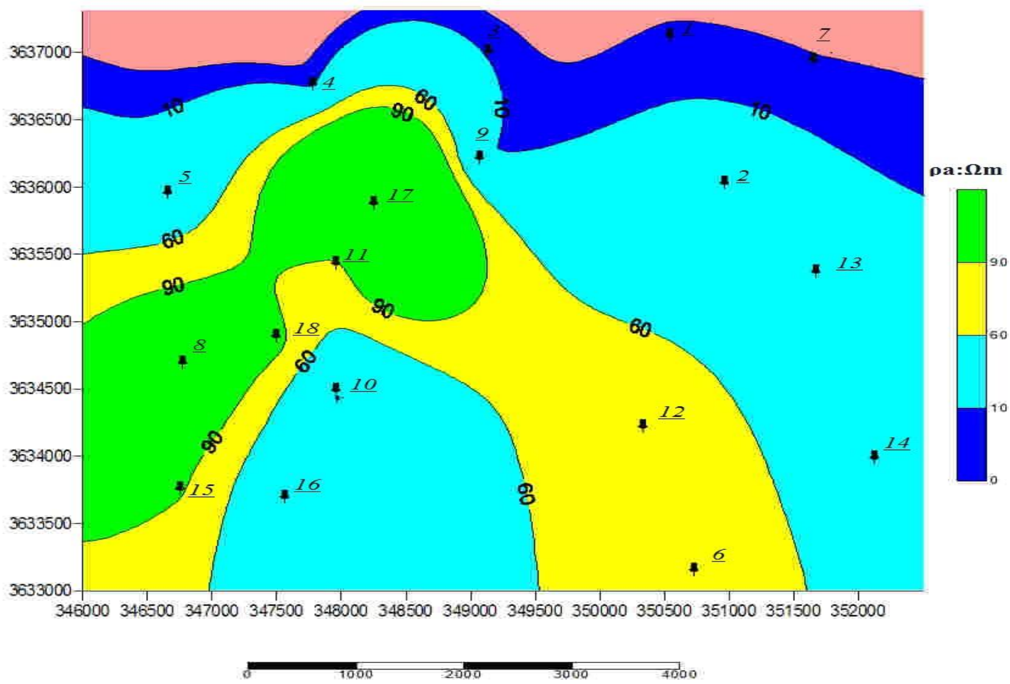

Figure 18. Iso-resistivity contours map (AB=300 *m*), (10) contour NO.: 10 Ω*m* , (12): VES NO

In Figure (19), it has been found that lines of iso-resistivity in the north of the study area is

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less than (0-10 *Ohm meter*), which located at soundings VES (1-2-3-4), and shown in dark blue and at depths around (75-100 *m*).

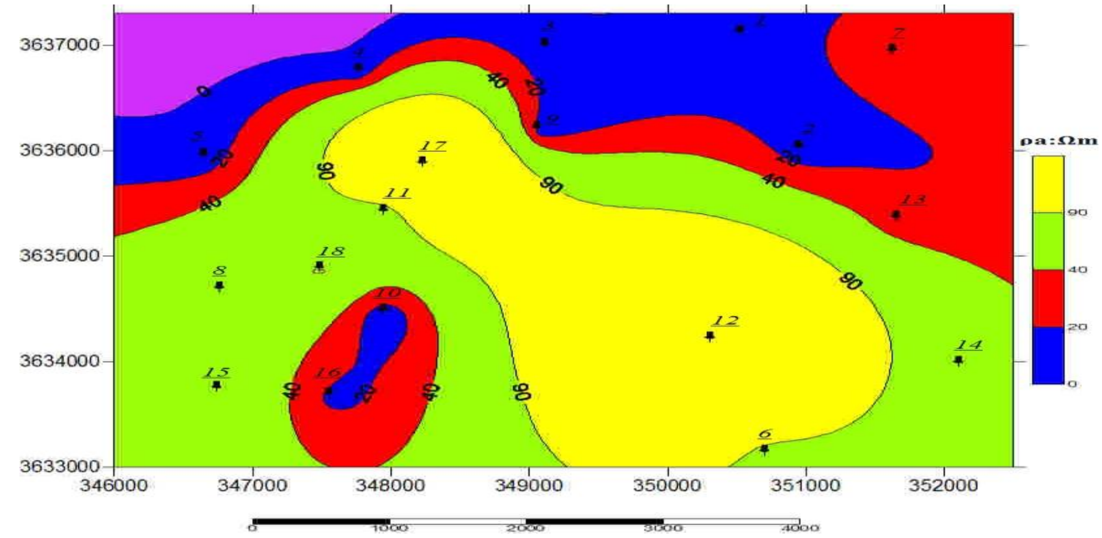

Figure 19. Iso- Resistivity contours map, (AB =300 *m*), (80), contour NO. 80 Ω*m*, (6): VES NO

In Figure (20), it has been observed lines of iso-resistivity where distance between electrodes (AB=400 *m*), and at depths ranging between (100-133 *m*), it is observed resistivity is less at north and in ranges (0-20 *Ohm meter*). It is defined in dark blue and located at (VES 1-2-3-4) and also at VES's (10-16) It needs further study.

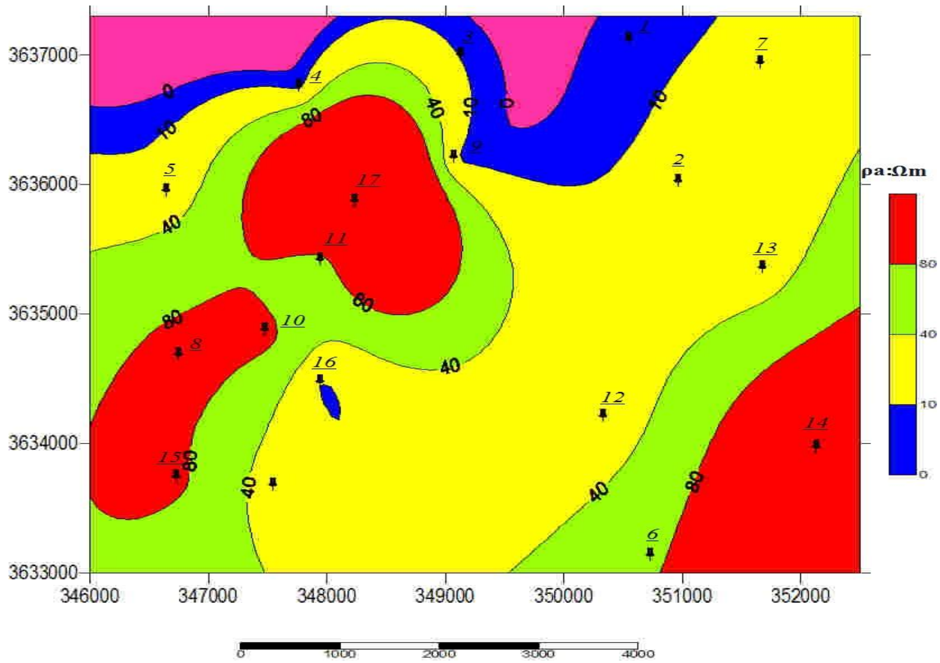

Figure 20. Iso- Resistivity contours map (AB= 400 *m*), (20) contour NO 80 Ω*m* (14): VES NO

5. Conclusion

By comparing profiles and iso-apparent resistivity maps, seawater intrusion can be determined in places where resistivity less than (10 *Ohm meter*), and also intrusion front can be known in the study area. By comparing the latest studies available to this study, it can be concluded that the intrusion front has slightly increased in the direction from north to south and was located between VES's (7 and 13) and also VES's (3 and 9) and pass through VES 4 and also at VES 5 as shown in blue in Figure (21).

Figure 21. ( ) Intrusion front (2015), (6): VES NO, (T509): Well NO
( ) Intrusion front (2008), and ( ) Intrusion front (2005)

6. Recommendations

It is advisable to construct Iso-resistivity contour maps for near sea areas utilizing Geo-Electrical method and taking well samples and chemically analyzing them and continuously monitoring these samples to get a clear picture of positions of fresh water and salt affected water, also raising awareness among people about this phenomenon via multimedia and urging farmers not to use water unwisely and if possible irrigating their lands at night to decrease the percentage of evaporation.

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