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Determination of the saline water intrusion zone and its contamination with ground water in the Dibddiba aquifer using vertical electrical sounding technique at Basrah Governorate, southern Iraq

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Abstract - Thirty Vertical Electrical Sounding (VES) measuring points (Schlumberger array) were carried out in order to determine the number of the underlying layers, depths and their thicknesses, as well as ground water table and its influence by the saline water coming from the sea or even underlying layer. These points were distributed within five profiles, 500 m spacing between points. The length of each profile is 3 km and the distance between profiles is 2 km. These points were chosen at Basrah Governorate, southern Al-Zubair district. Qualitative interpretation was applied to study the type of the electrical field curves, which were classified to HKQQ, KQQ, KQQQ, QQQ and QQ. Five apparent resistivity sections and eight isoresistivity contour maps were drawn. Quantitative interpretation was carried out using five geoelectrical sections which were drawn along the selected profiles. Number of the underlying layers, depths, thicknesses and depth of ground water table were determined for each VES point along the investigated profiles. Also, decreasing of the apparent resistivity values with depth was noticed especially at the groundwater bearing intervals. This is because of the increasing of salinity in ground water at these intervals especially at the mid-way of all considered profiles. The rise of saline water belong to the lower part of the Dibddiba aquifer towards the brackish or fresh water existed in the upper profile due to the unprogramm able pumping processes which may cause mixture between them and make the resultant water more saline. Large reduction in the apparent resistivity values was also observed at the eastern parts of the study area near Khor Al-Zubair boundaries which indicate high electrical conductivity values. This is led to the increasing of saline water that probably comes from the sea. This fact is certainly approved by the interpretation of the isoresistivity contour map plotted for the upper part of aquifer and by comparing hydrochemical analysis for ten wells with the above result.

Keywords: Saline water, ground water, Dibddiba aquifer, Basrah.

Introduction

Electrical resistivity methods have been widely used to study groundwater contamination. The decrease in resistivity caused by salinity of groundwater helps to identify the contaminant zones. Coastal aquifers that are prone to saline water intrusion are identified by relatively low resistivity value, indicating salt water intrusion (Zohdy and Jakson, 1969; Zohdy *et al.*, 1974). Monitoring of well data provides information on contaminant concentration where wells are absent. Thus, they offer a limited constraint on the spatial variability of the locations, the extent of the contaminant, the depth and degree of contamination. Under these conditions, geoelectrical techniques find useful application in the evaluation of groundwater contamination. In earlier studies, electrical methods have been used in groundwater quality evaluation of coastal aquifers (Urish and Frohlich, 1990; Mc Donald *et al.*, 1998; Gnanasundar and Elango, 1999 and Sang-Ho *et al.*, 2002). In this paper, geoelectrical sounding data were analyzed as a part of the ongoing investigation of groundwater contamination in the eastern part of the Dibddibba aquifer located at Basrah Governorate, southern Iraq.

Study area:

The study area lying just south-western part of Basrah Governorate, southern Al-Zubiar district, is enclosed by salt water on eastern side by Khor Al-Zubiar chanal between longitudes 47° 48´, 47° 53´E and latitudes 30° 6´, 30° 10´N with an area of 24 km^2 (Fig. 1).

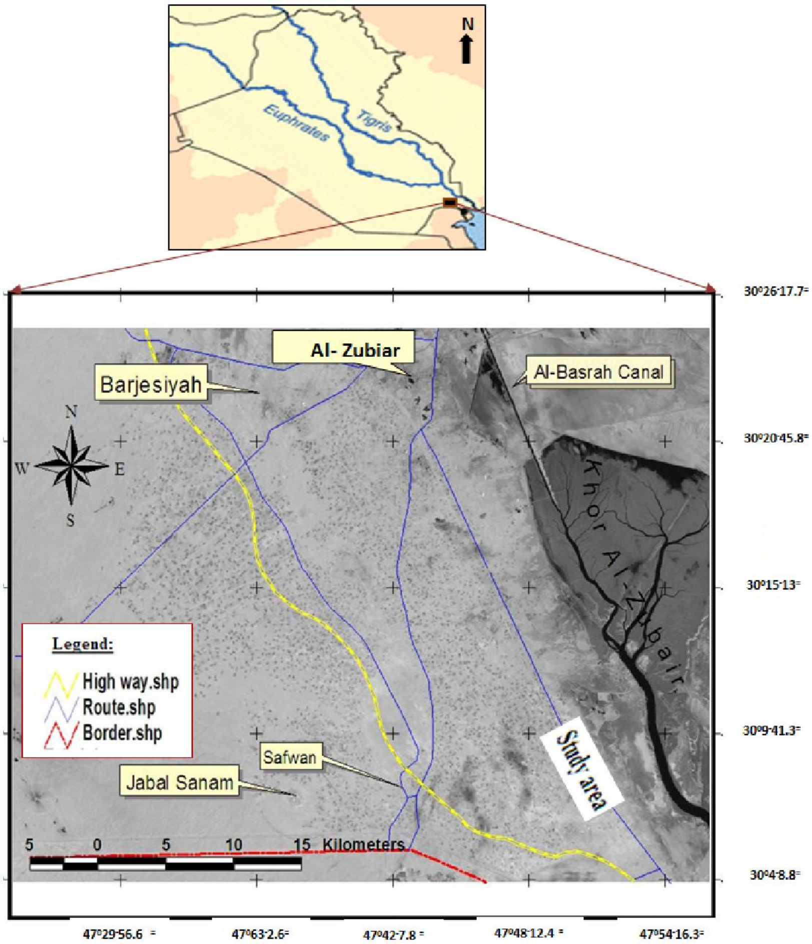

Figure 1. Location map of the study area.

There are many wells drilled in the study area for agriculture purposes and due to improper pumping from the wells located at the eastern side of the study area near Khor Al-Zubiar region, this part of aquifer is under a constant threat of saline water intrusion.

The study area has a terrain elevation ranging between 5 and 10m above sea level with a semi arid climate hot, dry climate and high wind velocity in summer, and cold, humid and little to moderate rainfall in winter. Also, there are significant differences in temperature between summer and winter seasons.

Hydrogeology:

The study area was considered as part of Dibddibba sediment basin. Dibddibba aquifer has acquired its name from Dibddibba Formation which is composed of unconsolidated deposits, i.e. alluvial, often represented by the most common exploited aquifer. This formation is highly permeable, direct recharge within rainstorms, accessibility and association with soils suitable for cultivation (Lanen and Rivera, 1998). Owing to the hydraulic properties variation, the Dibddibba aquifer is divided into two hydrogeological units; i.e. subaquifers, one of them is unconfined (Quaternary) and the other is semi-confined (Tertiary) (Al-Kubaisi, 1999).

At present, the unconfined; i.e. the upper aquifer, represents the exploited groundwater, which is characterized by the brackish groundwater. On the other hand, undesired saline groundwater is flux based on the semi confined aquifer. The thickness of Quaternary hydrogeological unit extents from 15 to 20m with an average of 15m. It is mainly composed of sand, gravel and interbeded with clay lenses recognized by its lateral discontinuity within unsaturated zone. According to Haddad and Hawa (1979)، the clay lenses from the perched aquifer, especially at the western parts of the study area (Jojeb), layer is hard pebbly, silty sandstone and has thickness ranges from 2 to 4m. It was recognized at 35m in depth, as well as it gradually vanishes out east and southeast causing deterioration of groundwater in the upper aquifer due to the hydraulic connection between the two parts of aquifer (Al-Suhail, 1999). Though the direct rainfall recharge is discontinued, it is considered as the main source in the study area.

Geoelectrical Survey:

The electrical resistivity technique is one of the geophysical methods that enable the determination of subsurface resistivity by sending an electric current into the ground and measuring the potential field generated by the current (Battacharya, and Patra, 1968; Griffiths and King, 1981). Thirty vertical electrical sounding (VES) measuring points (Schlumberger array) were carried out using the instrument SAS-300A, in order to determine the number of the underlying layers, depths and their thicknesses. However, groundwater table and its influence by the saline water coming from the sea or even underlying layer were also determined. These points were distributed within five profiles AA¯, BB¯, CC¯, DD¯ and EE¯(Fig. 2), 500m spacing between each point, 2 km distance between each profile and 3km the length of each profile. These points were chosen as completed recovery for a region located at Basrah Governorate \ southern Al-Zubair district, maximum electrode half spacing (AB/2) ranged from 1.5 to 250m.

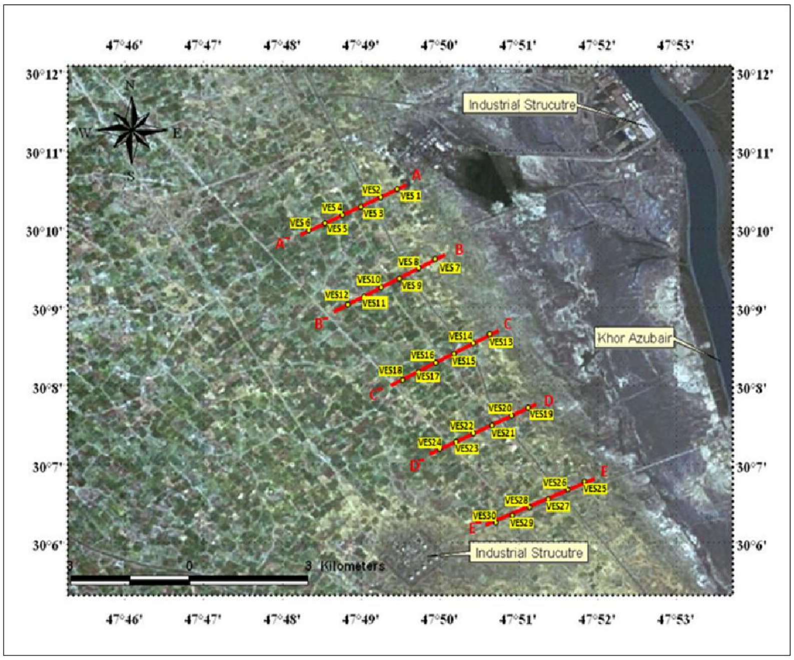

Figure 2. Location of VES points and profiles for the study area.

Interpretation:

1- Qualitative Interpretation:

Analysis and interpretation of VES curves:

Electrical field curves had been plotted depending on the apparent resistivity values for all mentioned measuring points. These curves show lateral and vertical changes of sediment layers, and the intensity of this change may indicate the nature of sedimentation in the region (Parasins, 1972; Griffiths and King, 1981). The qualitative interpretation of the curves showed that the sediments in this area has a wide range of resistivity value due to the fact of the agricultural operations as well as ground water and the proximity to the surface have a significant role at the apparent resistivity of the sediments and so the different values of groundwater salinity. According to the nature of these curves, qualitative interpretation was applied and five types of electric resistivity curves were classified, which are (QQ, QQQ, KQQ, KQQQ and HKQQ), these types are as illustrated in (Fig. 3). Among the five types of curves, type QQ, QQQ curves were similar in shape, type KQQ, KQQQ curves were similar too in their shapes.

The analysis of each type of curve in the study area is discussed in the following sections.

1- QQQ this type of curves shown in 19 points and QQ type of curves shown in one point. The first and second layers are within the top layer, have relatively high values of resistivity in the first layer because of the dry sand and gravel content in this layer, followed by the presence of unsaturated sand of varying grain size with less moisture content, third layer is the first aquifer. The fourth layer is the layer of transition between the first and second aquifers, the values of resistivity in this transitional layer which is influenced by the underlying layer because it is contain more salt, and therefore the resistivity values are low in this layer. The fifth layer is the second aquifer of low resistivity in this layer because of its salty water.

2- KQQQ this type of curves is shown in 4 points and KQQ type of curves shown in 4 points also, the first and second layers represent the top soil layer, the third layer has low resistivity due to the high clay content, the fourth and fifth layers represent the first aquifer, the sixth layer represents the second aquifer.

3- HKQQ this type of curves is shown at 2 points, the first and second layers within the top soil layer, with high resistivity in the first layer because of dry soil, and less resistivity in the second layer due to moisture in the lower part of the soil layer, the third layer gravel layer has relatively high resistivity, the fourth and fifth layers represent first aquifer, sixth layer is the second aquifer.

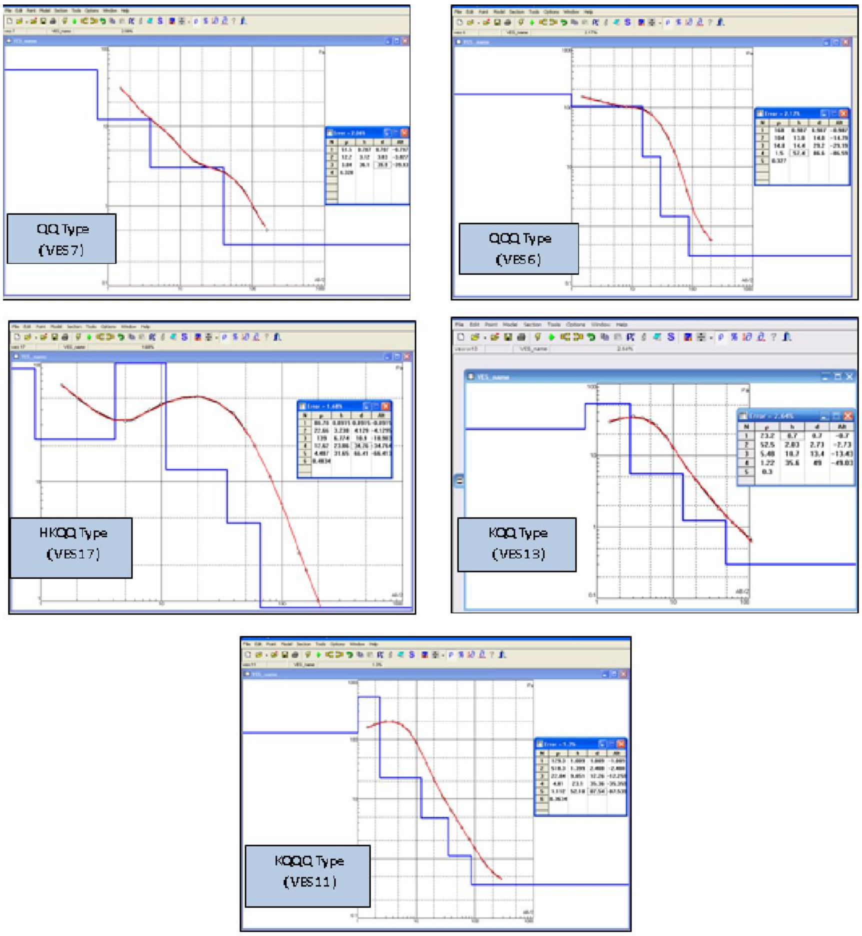

Figure 3. Some type of field curves in the study area.

Iso-apparent resistivity contours:

The iso-apparent resistivity (ρ_a) maps that are plotted for eight (AB/2) show that contour patterns almost parallel to the coast north-south trend with decreasing values to the east (Fig. 4). In the west, the apparent resistivity values were high when compared with the eastern margin. This clearly indicates the presence of a brackish water ridge in the western portion of the study area.

The high value of apparent resistivity (200-600) ohm.m observed for AB/2 at 10m and 20m are attributed to the presence of unconsolidated, dry sand and gravel at this depth. The apparent resistivities with AB/2 at 40 and 60m show relatively low apparent resistivity values. Similarly, the (ρa) values for AB/2 at 80, 100, 120 and 160m are observed to be very low, this indicates that the ρa values decrease with increasing in the depth of investigation. A sharp decrease in ρa values for AB/2 at 20m, this clearly shows that unconsolidated, dry sand and gravel exists from the surface to a few meters below ground surface followed by sand containing groundwater. The groundwater along the western portion of the study area is brackish water as observed from the (ρa) values. Very low resistivity values less than 12 ohm.m, exist along the eastern margin of the study area and they are indications of permeable sand formations with saline water. In previous investigations (Zohdy *et al.*, 1974; Prasad *et al.*, 1983; Sathymurthy and Banerjee, 1985; Gnanasundar and Elango, 1999), it has been reported that the zones saturated with salt water show a very low resistivity of less than 10 ohm.m. The saline groundwater along the eastern margin attributed to sea water intrusion. Clay lenses along the study area are also responsible for low apparent resistivity.

Apparent resistivity space section:

It is another method of qualitative interpretation to make initial idea about the variation of resistivity value with different distance AB/2 that reflects the type of sediment, at the bottom of the survey points, the preparation of the space section, from the locate of the survey points to the x-axis, while the y-axis is the measured resistivity values dropping below each point and corresponding to the value of AB/2, which is measured, then connect the contour values of equal lines resistance, the result of this section. Five pseudo sections to the profiles were drawn at this study by using the computer program (IPI2WIN), the distances from AB/2 in these sections are1.5m to 250m, they are initially linked with the geological and hydrogeological information available in the study area, and the sections are AA¯, BB¯, CC¯, DD¯and EE¯, these section shown in Fig. (5).

The interpretation of the above plotted sections gives an idea that large variations occurred in the apparent resistivity values especially at the commenced spreading distances when AB/2 is small. It represents the existence of surface layer that characterized by its moisture content and the presence of dry sediments such as sand, gravel and few sediments of gypsum which spreading laterally. Also, decreasing of the apparent resistivity values with depth is noticed especially at the groundwater bearing intervals.

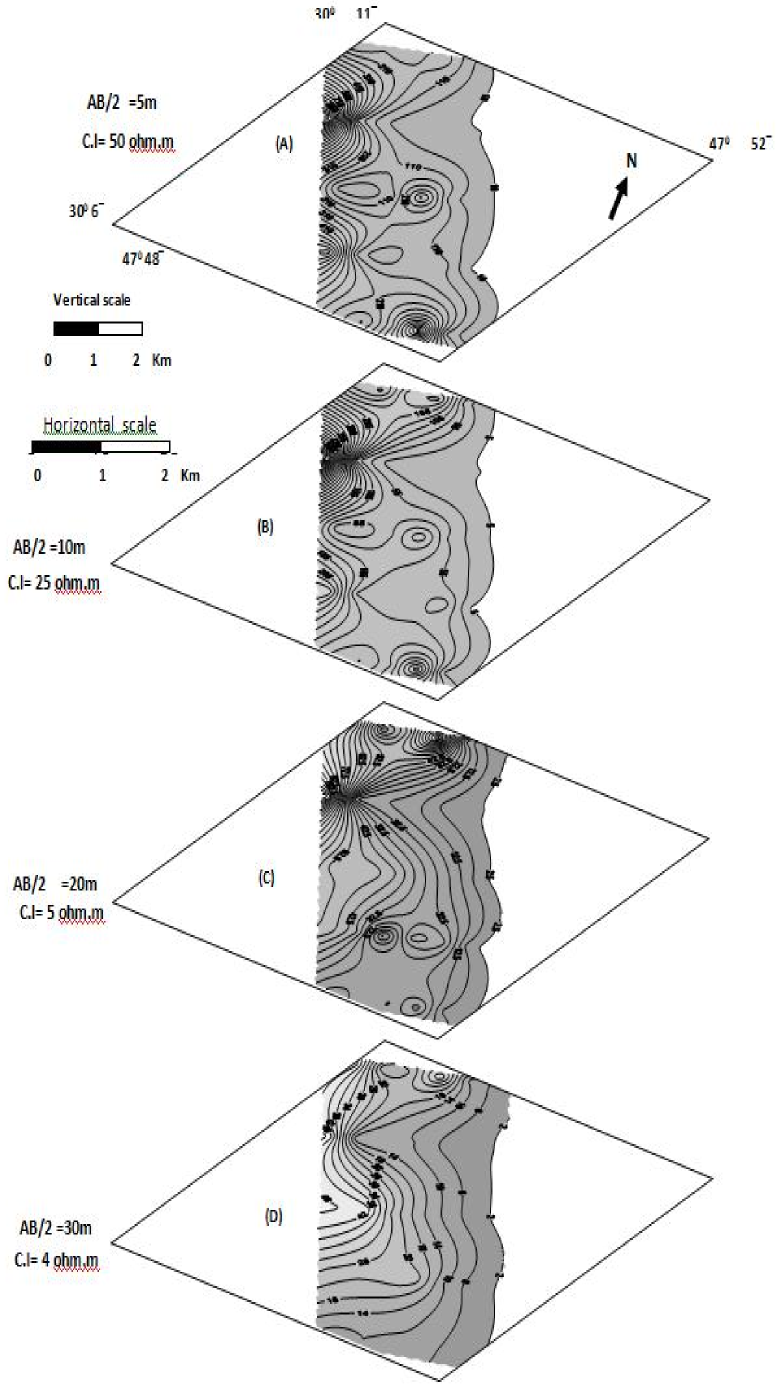

Figure 4. The isoresistivity maps of the studied area.

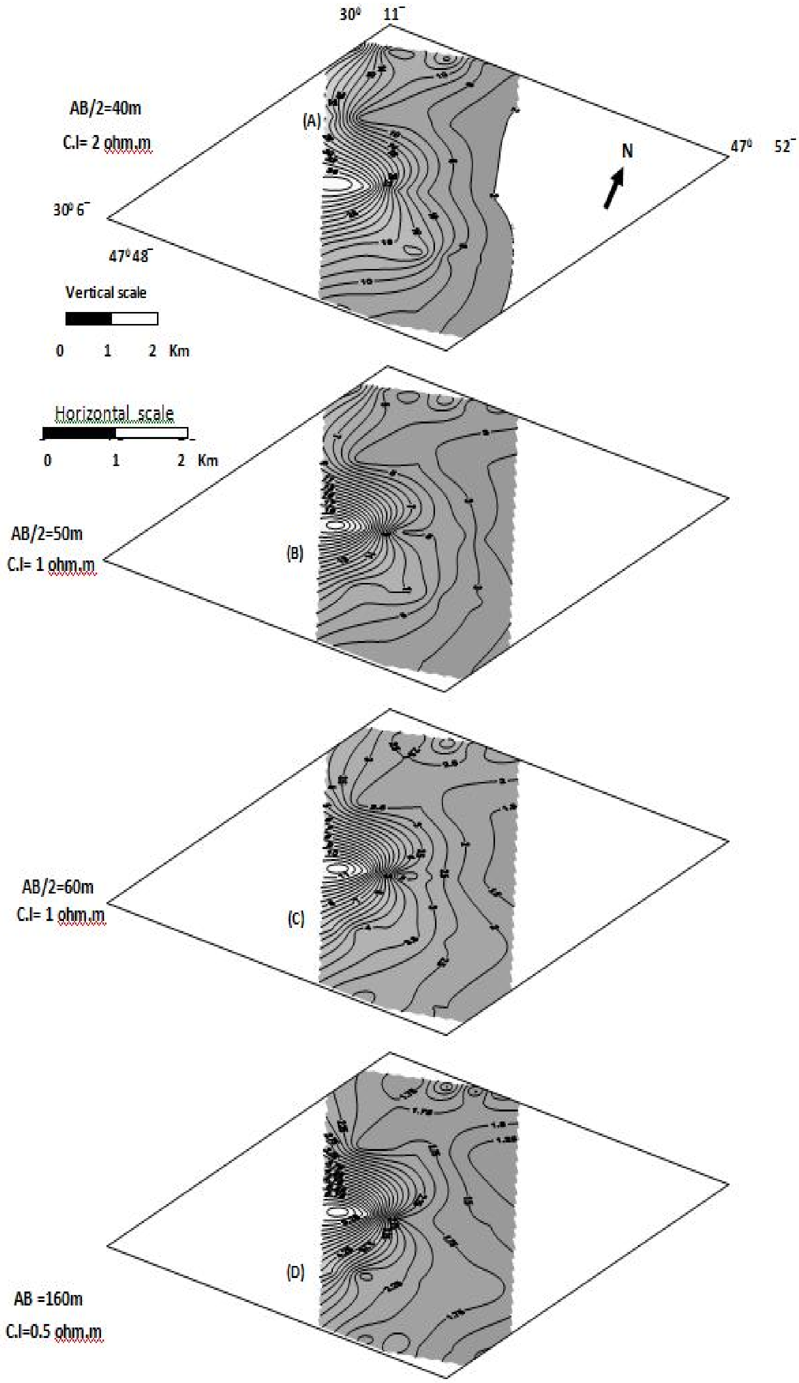

Figure 4. Continued.

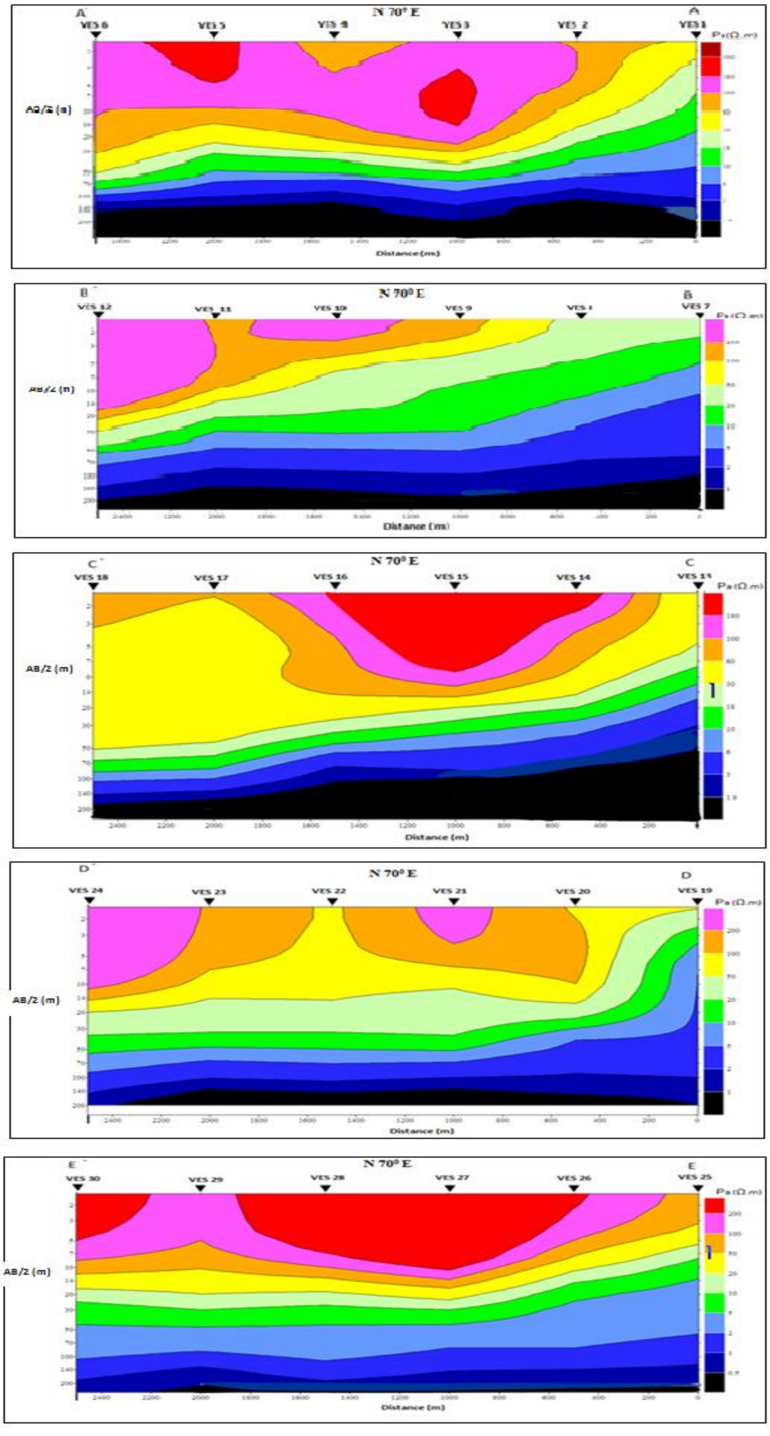

Figure 5. Space section along all profiles.

2- *Quantitative Interpretation:*

Five geoelectrical sections were drawn along the selected profiles and manually quantitative interpretation was carried out using partial curve matching method (Ebert technique). On the other hand, IPI2WIN program was used to complete the quantitative interpretation (Bobachev *et al.*, 2001), all profile directions are N 70° E.

Number of the underlying layers, depths, thicknesses and ground water table were determined for each VES point along the investigated profiles. The interpretation of the plotted sections gives large values and large variations occurred in the true resistivity values especially at the commenced of spreading distances when AB/2 is small, this is due to the large heterogeneity in the type of dry sediment surface layer, lethology and groundwater level were studied from three wells drilled in the area for correlate with geoelectrical sections (Fig. 6).

These sections represent existence of surface layer which is characterized by its moisture content and the presence of dry sediments such as sand, gravel and few sediments of gypsum which are spreading laterally. Also, decreasing of the apparent resistivity values with depth is noticed especially at the groundwater bearing intervals. This is because of the salinity increasing occurred in groundwater at these intervals especially at the mid-way of all considered profiles. The rises of the saline water belong to the lower part of the Dibddiba aquifer towards the brackish or fresh water existed in the upper one due to the unprogrammed pumping processes which may cause mixture between them and make the resultant water more saline and more contaminant, as shown in Fig. (7).

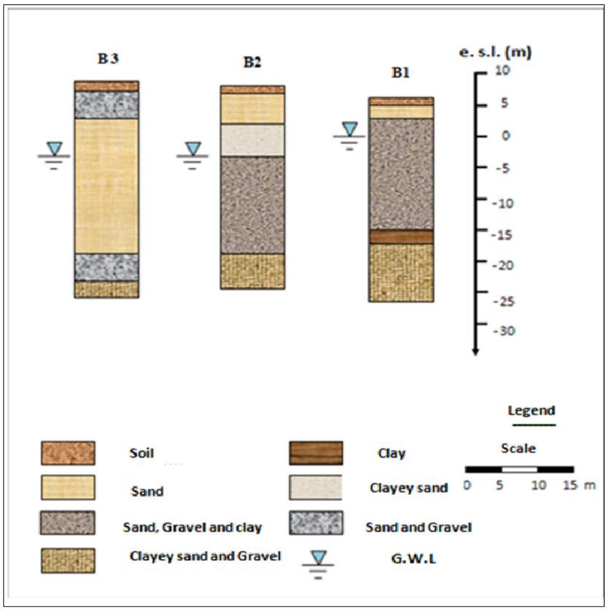

Figure 6. Lethology and groundwater for the study area.

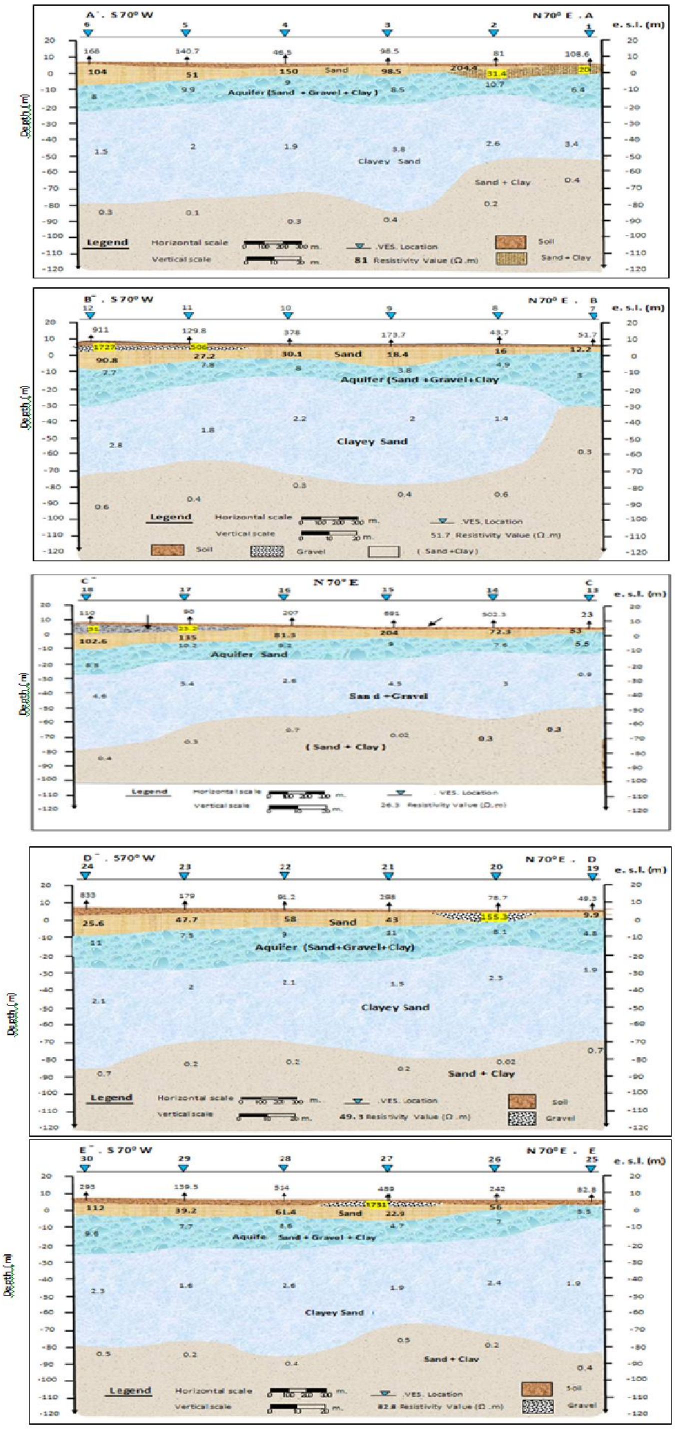

Figure 7. The geoelectrical sections for all profiles

Also, geoelectrical sections indicate that the area under investigation consists of three beds saturated with groundwater.The thickness of the first bed varies between 10.6-26m with resistivity values ranges between 3-11Ω.m., the thickness for the second bed varies between 30.2-66m with resistivity values ranges between 1-5.4Ω.m. and the average resistivity of the third layer is 0.3Ω.m. decreasing in the true resistivity values which is also observed at the eastern parts of the study area near Khor Al-Zubair chanal. This fact is certainly approved by the interpretation of the isoresistivity contour maps that plotted for first aquifer which is saturated with groundwater understudy for agricultural purposes; this map is shown in Fig. (8).

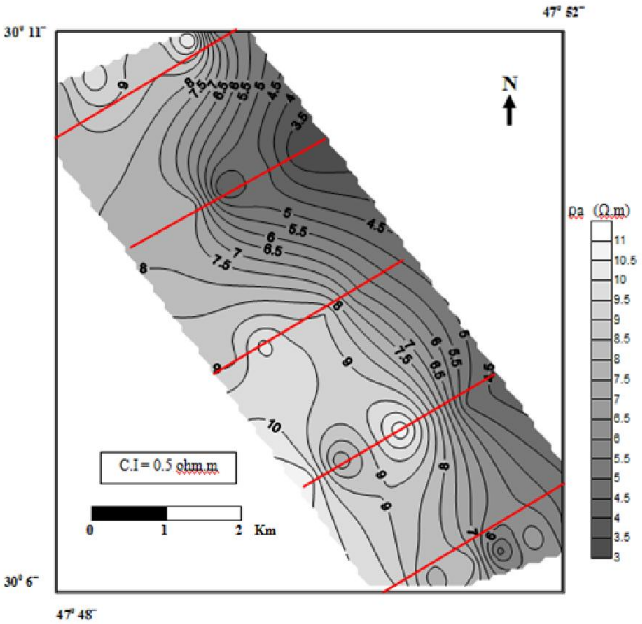

Figure 8. The isoresistivity map of the first aquifer.

Hydrogeochemical Analyses:

Type and the source of the groundwater were studied depending upon the performed chemical analyses for several samples extracted from ten wells drilled in the area under study for agriculture purposes, these analyses shown in Table (1) and their well locations shown in Fig. (9). It shows that the type of the water existed in the wells away from Khor Al-Zubair area is brackish, while the saline type present at the nearest wells. In the wells located at the eastern parts of the study area near Khor Al-Zubair region, the source of the ground water is mainly related to chloride group with marine origin. Moreover, the continental origin, and the rises of the saline water from lower part of Dibddiba aquifer are towards the upper one. Mixture and contamination between both saline and brackish or fresh water might be happened due to the extensive pumping processes and low rainfall in the area.

Table 1. Hydrogeochemical analyses for ten wells.

Well No.	PH	(EC) µmoh	(TDS) ppm	(ρw) Ω.m	ppm epm%							Accuracy	Water table m(b.s.l.)	Type of water
					Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	$SO_4^{=}$	Cl	HCO^{-3}			
1	7.5	11870	7500	0.84	600 30	537 47.3	650 28.3	18 0.49	1255 25.6	2201 62.2	549 9	4.8	1	MgCl
2	7.4	10370	6640	0.96	720 36	437 36	651 28.4	20.6 0.51	1847 38.5	1983 56	610 10	1.7	1	MgCl
3	7.9	12270	7805	0.81	620 31	650 6.53	630 27.5	16.3 0.28	1931 40	1775 11	671 11	5.1	1	MgCl
4	7.3	11250	7191	0.89	640 32	462 38.1	680 29.6	20 0.41	1858 38.8	1775 10	610 10	0.6	0.5	MgCl
5	7.6	12300	7900	0.81	640 32	340 28	698 30.4	20 0.51	1627 34	1846 52.2	549 9	2.3	3	CaCl
6	7.9	11180	7158	0.89	650 32.5	316 26	750 32.7	19.4 0.49	1960 35.3	1773 50.2	488 8	0.9	3	NaCl
7	7.3	11100	7111	0.9	590 29.5	340 28	650 28.4	19.4 0.5	1633 34.1	1775 50.1	671 11	4.8	2	CaCl
8	7.4	10700	6881	0.93	720 36	219 18	708 309	19 0.5	1739 36.3	1598 45.2	610 10	3.4	4	CaCl
9	7.8	14700	10191	0.88	640 32.1	218 18	1312 57.3	23 0.6	1609 33.7	2304 65.3	366 6	4.4	1.4	NaCl
10	8.4	16550	10550	0.66	640 32	515 42.6	1237 54.1	25.1 0.77	1857 38.9	3195 90.6	393 13.1	4.7	0.5	NaCl

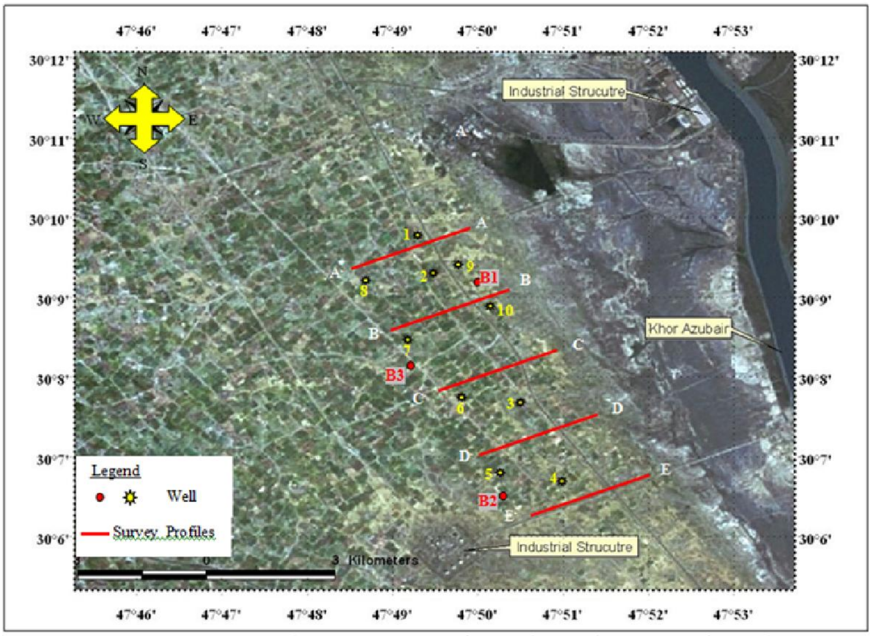

Figure 9. Location of wells and profiles fo the study area.

Conclusions:

According to the nature of electrical field curves, qualitative interpretation was applied and five types were classified, which are HKQQ, KQQ, KQQQ, QQ and QQQ. Moreover, five pseudo-sections, iso-apparent resistivity (ρa) maps that plotted for eight (AB/2) and five geoelectrical sections were drawn along the selected profiles that used to complete the quantitative interpretation.

The interpretation of the above results gives that there are large variations occurred in the apparent resistivity values especially at the commenced spreading distances when AB/2 is small. It represents the existence of surface layer that characterized by its moisture content and the presence of dry sediments such as sand, gravel and few sediments of gypsum which spread laterally. Also, decreasing of the apparent resistivity values with depth is noticed especially at the groundwater bearing intervals. This is because of the salinity increases occurred in ground water at these intervals especially at the mid-way of all considered profiles. The rises of the saline water belong to the lower part of the Dibddiba aquifer towards the brackish or fresh water existed in the upper one due to the un-programming pumping processes which may cause mixing and contamination between them which made the resultant water more saline. Decreasing in the apparent resistivity values is also observed at the eastern parts of the study area. Decreasing in the true resistivity values is observed at the eastern parts of the study area near Khor Al-Zubair boundaries which indicates high electrical conductivity values; however, this is due to the increasing of the saline water that probably comes from the sea. This fact is certainly approved by the interpretation of the isoresistivity contour maps that plotted for first aquifer saturated with ground water understudy for agriculture purposes. The chemical analysis shows that the water in the wells away from Khor Al-Zubair area is brackish and source of ground water is mainly of marine origin because they are enriched by chloride groups.

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تحديد نطاق تداخل المياه المالحة مع المياه الجوفية في خزان الدبدبة في محافظة البصرة / جنوب العراق باستخدام تقنية الجس الكهربائي العمودي

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المستخلص - تضمن العمل الحقلي القيام بمسح كهربائي عمودي باستخدام ترتيب شلمبرجر في 30 نقطة جس كهربائي باستخدام جهاز المقاومة الكهربائية SAS-300A، تم اختيارها على أساس مبدأ التغطية المتكاملة لعموم المنطقة قيد الدراسة والواقعة جنوب قضاء الزبير ضمن محافظة البصرة وذلك لتحديد عدد الطبقات تحت السطحية وأعماقها وسماكاتها فضلا عن تحديد الخزان الجوفي في منطقة الدراسة، ودراسة مدى تأثرها بالمياه المالحة المتأتية سواءاً من البحر أو من طبقات أعمق حاملة مياه جوفية مالحة. وزعت نقاط المسح على خمس مسارات طول كل منها 3 كم، وان المسافة الفاصلة بين نقطة وأخرى 500 مترا وبين مسار وآخر 2 كم. رسمت المنحنيات الكهربائية الحقلية بالاعتماد على بيانات المقاومة النوعية الكهربائية الظاهرية لجميع نقاط القيـاس، وفسرت نوعيا من خلال دراسة طبيعة هذه

المنحنيات، إذ تم تصنيفها إلى خمسة أنواع هي (HKQQ, KQQ, KQQQ, QQ, and QQQ)، كما تم رسم خمسة مقاطع بينية على طول المسارات المختارة للحصول على صورة أولية للتغاير العمودي والأفقي للرواسب تحت السطحية، بعد ذلك تم رسم خمس مقاطع جيوكهربائية حيث تم تحديد عدد الطبقات تحت السطحية وأعماقها وسماكاتها فضلا عن تحديد عمق المياه الجوفية في كل نقطة قياس وعلى طول المسارات قيد الدراسة. لوحظ من خلال تفسير المقاطع المرسومة أعلاه فضلا عن المقاطع البينية التغاير في قيم المقاومة النوعية الظاهرية وخاصة عند مسافات النشر الاولى عندما تكون المسافة بين أقطاب التيار (2/AB) صغيرة والمتمثلة بالطبقة السطحية دلالة على التغير الحاصل في المحتوى الرسوبي حيث تتواجد ترسبات جافة من الرمل والحصى وقليل من ترسبات الجبس بالاتجاه الأفقي، فضلا عن نقصان قيم المقاومة النوعية مع العمق خاصة عند الفترات العمقية المحتملة لتواجد المياه الجوفية والذي يشير إلى حصول زيادة في ملوحة هذه المياه عند هذا العمق خاصة عند المنطقة الواقعة في منتصف المسارات تقريبا والناتج من اختلاط المياه المالحة للجزء السفلي من مكمن الدبدبة المائي مع المياه الجوفية المويلحة للجزء العلوي منه نتيجة عمليات السحب غير المبرمجة، كما لوحظ حصول انخفاض كبير في قيم المقاومة النوعية شرق منطقة الدراسة بالقرب من حدود خور الزبير لتدل بذلك على زيادة قيم التوصيلية الكهربائية وبالتالي زيادة ملوحة المياه المتأتية من احتمالية اقتحام المياه البحرية المالحة القادمة من البحر والتي تم ملاحظتها بصورة واضحة من خارطة تساوي المقاومة النوعية المرسومة للجزء الأعلى من الخزان وأيضا من مقارنة نتائج التحاليل الهيدروكيميائية لعشرة آبار مع النتائج أعلاه.