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Application of the Electrical Resistivity Method to Investigate Groundwater in Ramadi, Western Iraq

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ABSTRACT

The vertical electrical sounding (VES) survey was carried out using a Schlumberger array. The purpose of this study is to investigate groundwater in the West of Ramadi City. Fieldwork for 20 VES points was carried out. The results of VES are presented through geo-electrical sections which indicate the presence of an aquifer in the studied area. Display the resistivity variation between the irregular portions of the water table and the host sediment. The vertical extension of the wet zone is between 1.5 m to 9.5 m. Where groundwater level in the three wells located in the University of Anbar, a 7-kilometer area and 18-kilometer area, was identical to its level in the three imaging reversed models.

Introduction

The resistivity method is considered one of the best geophysical methods for groundwater investigation. The estimate operations are fundamental to detecting the possessions of primary particles that form materials. The motion of an electrified midst or an electrode creates an electrical current [11].

The Vertical Electrical Sounding (VES) approach was utilized without drilling to assess influence of soil crevices of a centmetric range on the resistivity of sand. Data were obtained on a laboratory scale utilizing an ABEM SAS 4000 Terrameter device implemented with a Winner array [8].

Vertical electrical sounding technique was applied using schlumberger array in (43) points which were distributed in Ramadi city . Electrical measurements were carried out to coincide with the sediments of the study area which have a low resistivity values . Several resistivity maps were plotted to study horizontal variation in resistivity values of electrical zones. The depth to the bottom of the first zone was found to be ranging from (0.7-2.8) meter [5].

A numeral of researchers utilized the resistivity technique for different applications to delineate covered bodies such as voids and fractures and the presence of groundwater. [13] discovered karst features using same method. [10] exercised the ERI tomography for underground cave disclosure in the east of SA. [1]; [15]; [14] correlate the 2D resistivity imaging survey and Bristow's mode in detecting the caves which are found at Haditha-Hit region, west of Iraq. The results are fitting with error percentage of 2%. Four traverses of 2D imaging resistivity were done in the Het region. The results explain that the cave extends of distance equal to 58.6 m, West-East, the errors of 3%, and 2% in depth and height respectively. [14] behavior a 2D resistivity imaging survey across the K-3 cave get it in the Hadiitha area- In the west of Iraq. 2D readings were picked along two intercrossing lines over the cave, everyone a 105 m extend. The Dipole-dipole array was carried out with a (n) factor of 6 and a spacing of 5 m. Dipole-dipole ground electrode imaging was performed. Cave K-3 is well exposed, with the cave found at a depth of 35. 5 m and an extension of more than 50 m. [3] used a Dipole-dipole array to image the gypsum soil layer in a selected area at the University of Anbar. This survey was conducted along seven convergent 2D lines in the E-W direction, and the data of all 2D lines were then combined to produce 3D impedance imaging models. The 2D and 3D imaging models show the thickness of the gypsum soil layer at this selected site to be 2.53 m, characterized by considerable differences in resistivity

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values in the range from 50 to more than 400 Ωm. [4] revealed that the Umm El-Adham cavity is one of the known cavities within the gypsum rocks in the north of the city of Heet. This cave was used as a special case to evaluate the 3D resistivity imaging technique to draw this type of cavity in the complex gypsum rock. The 3D rendering was achieved by assembling four 2D resistivity imaging lines. Both options were able to identify the cave, but the second option was more accurate, as the dimensions of the cave in the inverse model were closer to the actual dimensions. [2] used 2D and 3D resistivity imaging techniques to identify shallow subterranean caverns in the Haditha region, western Iraq. The horizontal slices of the 3D models in these caverns exhibit anomalously high resistivity at 0–0.80 m, 0.80–1.72 m, 1.72–2.78m, and 2.78–3.99 m. In this study, the 2D electrical resistivity technique was applied to discover groundwater zones and evaluate the subsurface natural structures shaped in the study area.

Materials and Methods

The study area was chosen on western side, west Ramadi city, between 33°25'7.12"N and 43°14'38.21"E, (Fig. 1). Subsurface geology, represented by Quaternary sediments and the Ingana Formation which includes gypsum soil, light brown mudstone, light pink mudstone, silt sediment and medium to coarse sandstone in graded nature

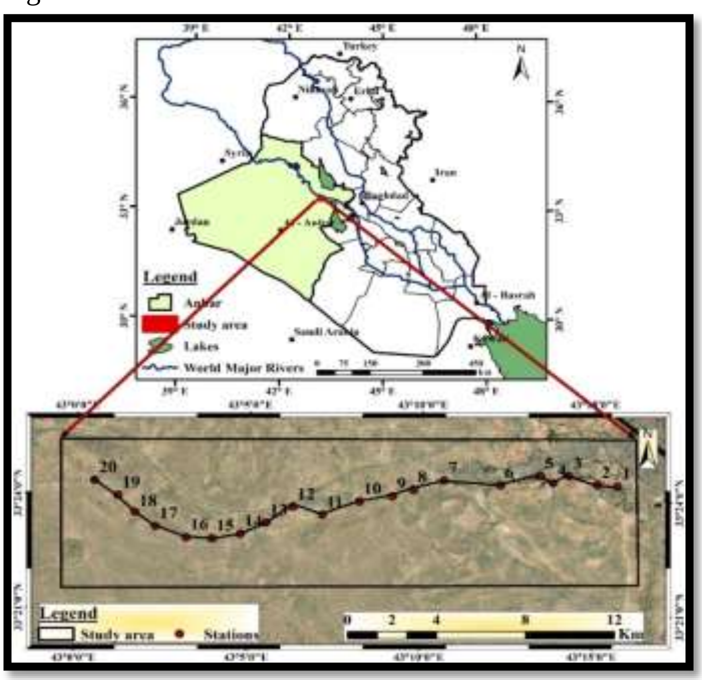


Figure 1. Location map of Study area

Sediments of medium to coarse silt and sandstone form the primary structure in the sediment gradient. The formation thickness is up to 18 m, and the lower seam surface of the Ingana Formation is the hole formation [12]

The interpretation of vertical electrical sounding (VES) is carried out automatically by using the (IPI2Win) program. IPI2Win program is designed for vertical electrical sounding and/or induced polarization data curves interpreting along a single profile [7]. It is presumed that a user is an experienced interpreter willing to solve the geological problem posed as well as to fit the sounding curves. Targeting the geological result is the specific feature distinguishing IPI2Win from another popular program of automatic inversion.

The forward problem is solved using linear filtering. The thoroughly tested filter and filtering algorithm implementation provides fast and accurate direct problem solutions for a wide range of models, covering all reasonable geological situations.

The program is also designed for present results of VES interpretation in the form of a pseudo cross section by drawing VES points along the horizontal axis and values of apparent resistivity (ρa) for each (AB/2) along the vertical axis.

Processing and interpreting of VES data

The purpose of this step is to get quantitative result about the qualitative results obtained from the first work step. All the points' curves are smoothed by using the IPI2Win program [7].

The smoothing process applied in this program is good and distinct in that it makes the curve resulting from the field measurements a resistivity continuous curve with the agreement of its parts. The vertical probe curve (VES-4) is a good example of this process. Figure (2) shows the type of curve for VES-4. It consists of five parts, each part represents a distance of MN which is constant for several measurements (Fig. 3).

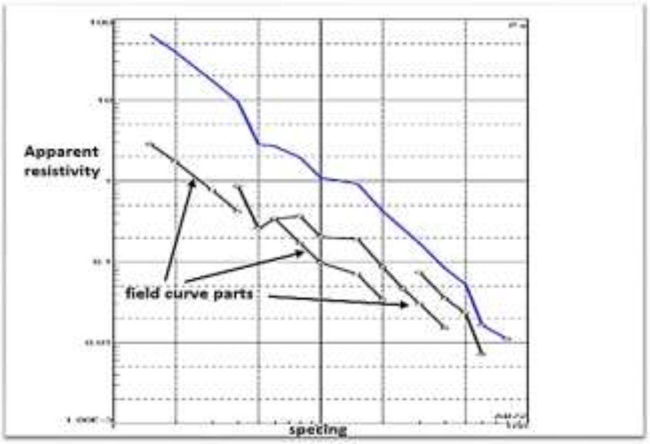


Figure 2. Field curve of VES -4

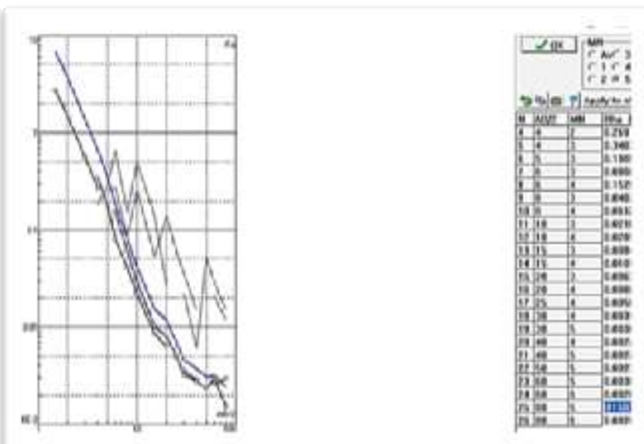


Figure 3. Smoothing of VES - 4 curve using IPI2Win program according to average before smoothing

Results and Discussion:

Interpretation of VES data in calculating the values of thickness and apparent resistivity of different sedimentation zones by studying the type of curve of variation of the resistivity values of the vertical electrical sounding (VES). sounding values used to get a complete idea of the area surveyed [6]. The qualitative and quantitative interpretation is the next process after completing the field curve smoothing process.

The qualitative interpretation must precede the quantitative interpretation to determine the type of curve that represents the distribution of the resistivity values of the successive rock layers. The resistance curves of the study area were studied as following

QHK curve type: For point VES-4 representing the covariance of apparent resistivity values with depth covariance, it is subdivided into five electrical horizons, the relationship between the perpendicular probe resistivity values of this point ($\rho 1 > \rho 2 > \rho 3 < \rho 4 > 5$) (Fig. 4). These values were validated with the tomography section of the drilled well (BH-CDS-1) [9] .(Fig. 5). These values show that the resistance values of the first layer are the largest in comparison to the second layer. The rise in these values is due to the presence of gypseous soil and gypcrete. Also the desiccation of the exposed sediments on the surface due to direct exposure to the sun's heat. The lower resistivity of the second layer is also due to the groundwater saturation of the existing claystone. The current groundwater level is the cause of this decrease in values, in addition to the disappearance of the secondary gypsum with a mud layer. Due to the presence of the silt layer, the resistivity value of the fourth layer is higher than that of the third layer. The last layer shows a decrease in the resistivity value caused by the presence of the clay layer.

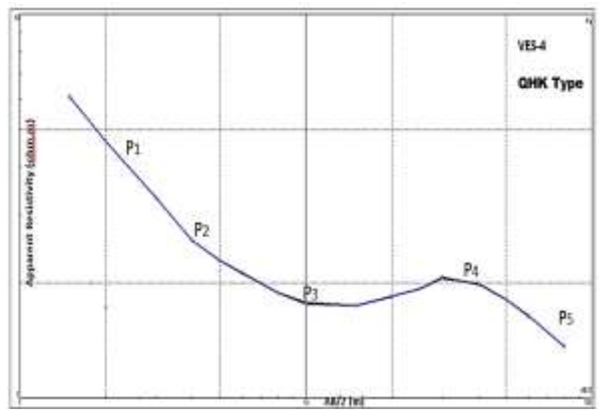
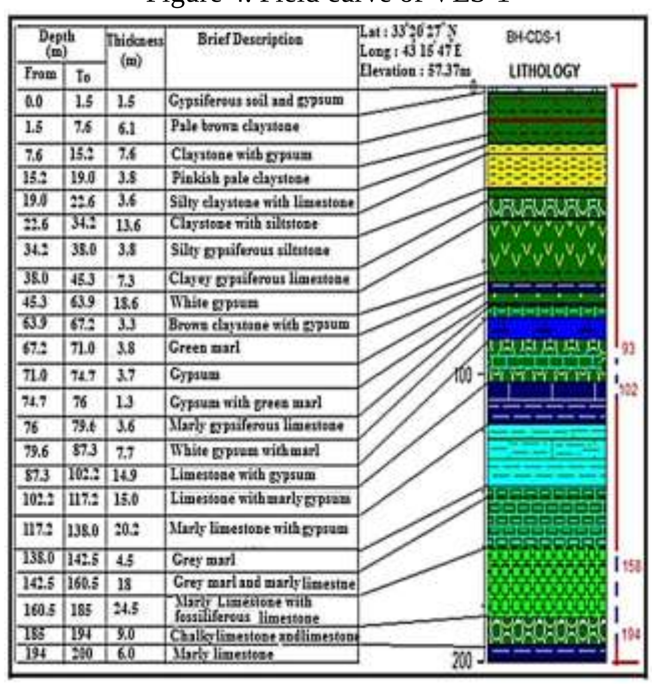


Figure 4. Field curve of VES-1



Depth (m) From	Depth (m) To	Thickness (m)	Brief Description
0.0	1.5	1.5	Gypsiferous soil and gypsum
1.5	7.6	6.1	Pale brown claystone
7.6	15.2	7.6	Claystone with gypsum
15.2	19.0	3.8	Pinkish pale claystone
19.0	22.6	3.6	Silty claystone with limestone
22.6	34.2	13.6	Claystone with siltstone
34.2	38.0	3.8	Silty gypsiferous siltstone
38.0	45.3	7.3	Clayey gypsiferous limestone
45.3	63.9	18.6	White gypsum
63.9	67.2	3.3	Brown claystone with gypsum
67.2	71.0	3.8	Green marl
71.0	74.7	3.7	Gypsum
74.7	76	1.3	Gypsum with green marl
76	79.6	3.6	Marly gypsiferous limestone
79.6	87.3	7.7	White gypsum withmarl
87.3	102.2	14.9	Limestone with gypsum
102.2	117.2	15.0	Limestone withmarlygypsum
117.2	138.0	20.2	Marly limestone withgypsum
138.0	142.5	4.5	Grey marl
142.5	160.5	18	Grey marl and marlylimestne
160.5	185	24.5	Marly Limestone with fossiliferous limestone
185	194	9.0	Chalkylimestone andlimestone
194	200	6.0	Marly limestone

Figure 5. Stratified section of the well(BH-CDS-1) drilled inside the University of Anbar [9]

HKH curve type: Comprises of VES-10, which represent five electrical horizons, the order of which is (ρ1>ρ2<ρ3>ρ4<ρ5) (Fig. 6).

The upper horizon has a higher resistivity value relative to the next horizon. As it represents the dry surface of the upper soil. The low resistivity that characterizes the second horizon is caused by the presence of clay lenses saturated with groundwater. The third horizon increases the resistivity value due to the absence of the clay layer. Fourth Horizon the resistivity values become lower due to the increase in salinity in the groundwater due to the sediment dissolution processes. The presence of the silt layer in the fifth horizon leads to an increase in the resistivity values

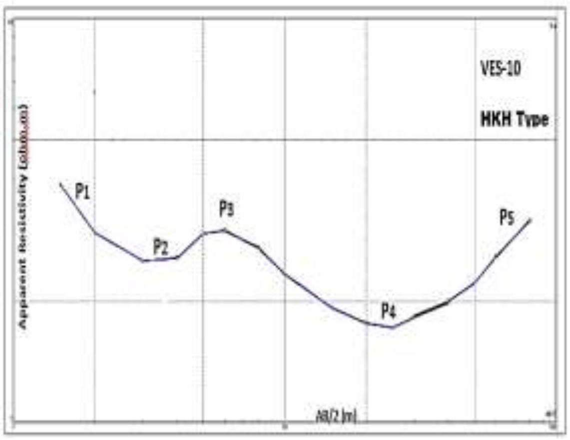


Figure 6. Field curve of VES-10

KHK curve type: VES-15, consist of five horizons, the order of which is (ρ1<ρ2>ρ3 <ρ4>ρ5) Figure (7).

The first horizon shows low resistivity value, it represent lay the topsoil of surface with gypsums soil In contrast, The sandy layer is located above the water level, which is characterized by dryness when compared to the lower horizon. A decrease in resistivity values is observed in the third horizon due to the rise in the level of groundwater through it, and this is confirmed by the stratigraphic sequence of the water well BH-CDS-1. The fourth horizon is characterized by high resistivity, while in the last horizon, there is a rapid decrease in the resistivity value due to the presence of clay layers or silty clay layers.

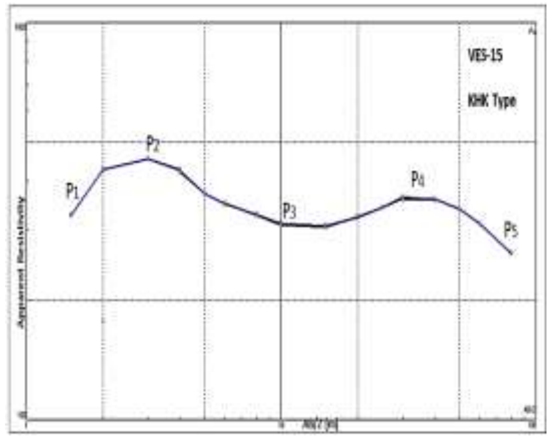


Figure 7. Field curve of VES-15

QH curve type: Includes VES-20. This region, which is considered the extreme point in the southern part of the study area, is characterized by four electrical horizons in which the resistance values are from top to bottom: ρ1 > ρ2 > 3 < 4 Figure (8). This arrangement came due to the presence of the current groundwater level in addition to the absence of the secondary gypsum layer within the clay layer.

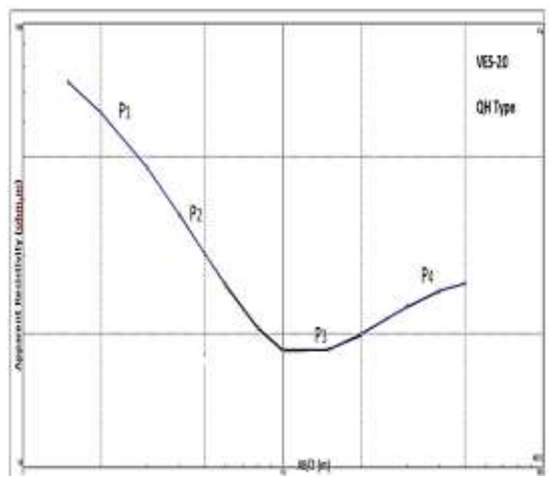


Figure 8. Field curve of VES-15

Comparison between the lithology sequence of the well and the VES curve shows the change in lithology. The first layer is high apparent resistivity, representing the dry topsoil. The other layers in which the resistivity values vary according to the type of rock and sediment or the water content. The last layer has a low apparent resistivity, but some VES points have increased apparent resistivity values because they contain dry sand deposits associated with silt deposits.

In IPI2Win programs, the model parameters of VES points are represented by a blue line of the pseudo-log plot. It includes resistivity, thickness, and the upper boundary depth and altitude. The model parameters show in the separate window titled with the fitting error values (known model window). The field curve appears in red color. All calculations were characterized by low-fitting errors for the forward calculation by the software. However, good smoothing work on the apparent resistance curve helped a lot in obtaining distinct interpretation results.

(Figure 9) shows the automated interpretation of the VES-1 curve. Five horizons were obtained through interpretation using the program, which was characterized by an RMS error rate of 1.9%, which is an excellent percentage. Resistivity values for the first, second, third, fourth, and fifth horizons were obtained as 2.44 Ω.m at a depth of 1.11 m, 0.988 Ω.m at a depth of 3.54 m, 0.33 Ω.m at a depth of 7.24 m, 4.34 Ω.m at a depth of 15.66 m and 0.014 Ω.m at a depth of 27.57 m which represent the soil. The surface is pale brown siltstone, pale brown siltstone with secondary gypsum, siltstone, and siltstone with limestone respectively. This arrangement came in comparison with the stratigraphic sequence of the BH-CDS-1 well

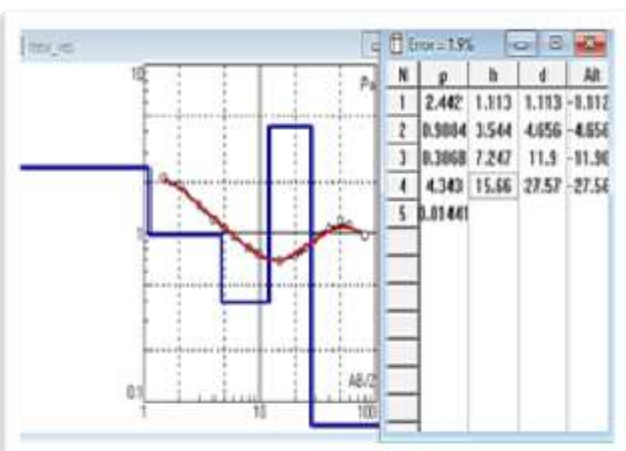


Figure 9. Shows the model of VES -1

Figure (10) shows the automated interpretation of the VES-10 curve. Four horizons were obtained through the interpretation of this point, and the RMS error rate was equal to 4.34%. The resistivity values of the first, second, third, and fourth horizons is 21.6 Ωm. m at a depth of 0.15 meters, 2.76 Ωm. m at a depth of 7.31 meters, and 0.839 Ωm. m at a depth of 15.6 meters. The topsoil is considered. As for the second horizon, its resistance value is 2.76 Ωm. m at a depth of 7.31 meters and 3.39 Ωm. m at a depth of 65.1 meters. It consists of topsoil, pale brown siltstone, and pale brown siltstone with secondary gypsum and siltstone respectively. The fourth horizon is characterized by a layer of mudstone with a large thickness of 49.5 m. The resistivity of the last horizons decreases with the depth

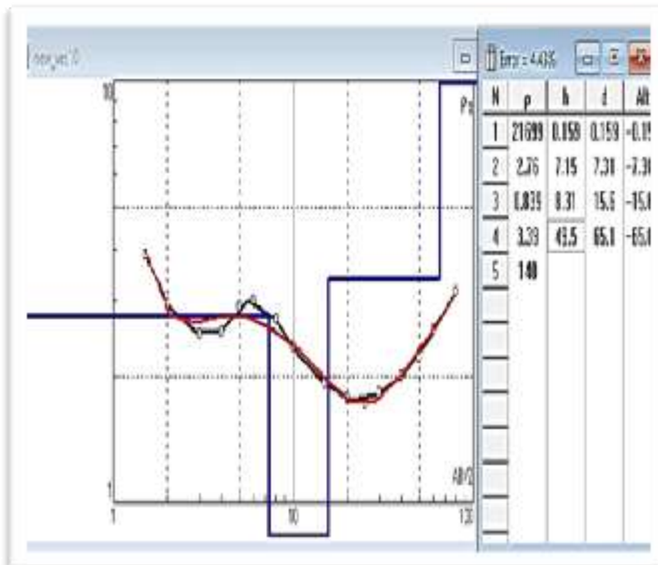


Figure 10. Shows the model of VES-10

Figure 11 shows an explanation of the variance of resistivity values at point VES-20, which was characterized by an excellent RMS error of 0.761%. The variation in these values characterizes four horizons of resistivity values arranged from top to bottom: 85.3 Ωm. m at a depth of 1.16 m, 28.7 Ωm. m at a depth of 3.8 m, and a thickness of 2.64 m, 9.4 Ωm. m at a depth of 7.85 m and a thickness of 4.04 m, and 31.9 Ωm. m at a depth of 78.65 m and a thickness of up to 70.7 m respectively. The first layer was characterized by a high resistivity value, as it consists of dry surface soil deposits

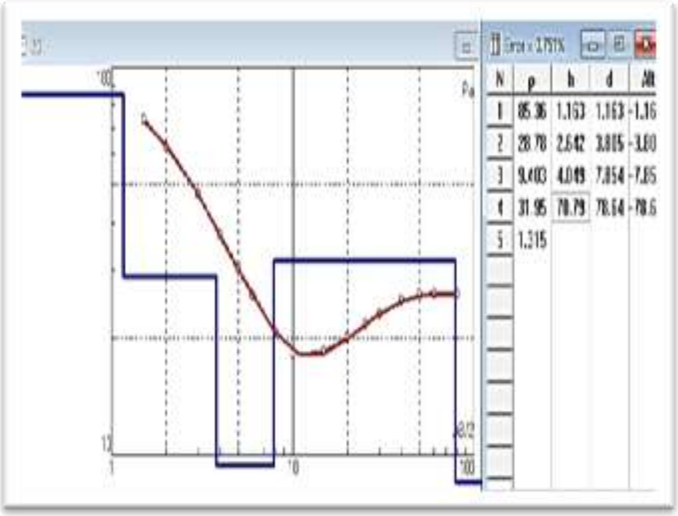


Figure 11. Shows the model of VES-20

Table 1: Shows the Quantitative results of all the VES points in the study area

VES	ρ1	ρ2	ρ3	ρ4	ρ5	h 1	h 2	h 3	h 4	Type
1	2.44	0.988	0.386	4.34	0.014	1.113	3.54	7.27	15.66	QHK
2	0.208	10.2	2.07	10.5	0.035	0.01	2.03	33.8	44.2	KH
3	6.54	1.42	29.6	2.37	273	1.91	6.09	15.2	40.8	HKH
4	0.95	0.25	2.48	0.135	273	1.91	6.09	15.2	40.8	HK
5	5.69	2.26	10.45	0.86	2.98	1.66	2.81`	8.24	6.67	HKA
6	0.085	1.26	0.038	0.5	1.11	0.58	1.6	2.29	24	KH
7	0.75	0.3	1.45	0.01	273	1.53	8.44	18.7	39.5	HK
8	1.21	0.257	2.68	0.1	273	1.43	9.16	13	44.5	QHK
9	0.28	0.04	0.712	0.045	273	1.37	2.07	7.14	43.7	HK
10	216	2.76	0.83	3.39	140	0.15	7.15	8.31	49.5	HKH
11	2.89	15.3	4.21	4.21	866	1.02	1.67	16.67	25.01	KH
12	6.61	2.18	5.77	0.025	867	1.17	8.24	24.9	15.6	QHK
13	9.53	3.23	7.42	0.025	866	0.73	9.91	27.9	11.29	HK
14	1.16	11.8	0.45	2.86	867	0.519	1.25	1.23	52.9	KH
15	177	1115	122	495	146	0.5	1.05	2.73	22.7	KHK
16	30.8	475	5.63	143	13	0.5	0.88	3.14	61.1	KH
17	17.3	2.32	53.4	3.35	1.22	0.91	2.29	3.96	49.9	HK
18	35.7	5.94	137	23.1	1.28	2.59	2.7	7.54	48	KHK
19	4.19	0.34	7.51	0.34	6.77	2.22	1.03	15	47.8	QHK
20	85.3	28.7	9.4	31.9	1.31	1.16	2.8	4.04	70.79	QHK

Geo electrical Section

The geo electrical section expresses the lateral and vertical variation of the resistance values, which resulted from matching them in 20 VES points. Use a surfer program to draw it (Fig. 12).

This section distinguishes five zones with different characteristics in terms of resistivity values and thicknesses as following:

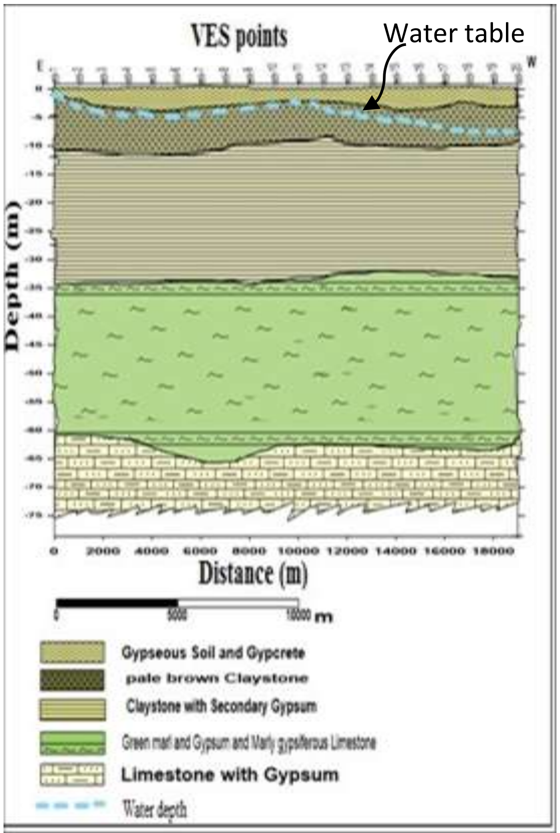


Figure 12. The geo electrical section along profile VES 1-20 points

1- The resistivity values range between 0.085 Ω.m in VES-6 and 35.7 Ω.m in VES-15. The topsoil layer represents the surface layer that usually has a high resistivity value because it is characterized by drying out due to exposure to sunlight. However, this range was characterized by a resistivity of a small value at the VES point due to the high groundwater level near the surface.
2- The second horizon has the lowest resistivity value of 0.04 Ω.m at VES-9 and the highest value of 15.3 Ω.m at VES-11, and its average thickness is 11 meters. It consists of clay stone. resistivity values are the lowest of the first zone.
3- The third horizon has the highest resistivity value of 137Ω.m at VES-18 and the lowest resistivity value of 0.038 Ω.m. in the VES-6. At point VES-1 the groundwater level is at a depth of 3 meters in well BH-CDS1, at point VES-8 the depth of groundwater is 2 meters in well 2. This change in the water table causes a sudden drop in resistivity values. The constituent deposits of this range are shale with secondary gypsum according to well BH-CDS1.
4- The fourth horizon has the lowest resistivity value at the VES-7 point, which is 0.01 Ω.m, and the highest value at the VES-15 point, which is 495Ω.m. The deposits of this range consist of siltstones with limestone.
5- In the fifth horizon, the lowest values of resistivity are 0.014 Ω.m at the VES-1 point, and the highest value is 8.67 Ω.m at the VES-12 point. The reason for the decrease in resistivity values is the presence of clay layers in addition to the high salinity of groundwater as a result of the dissolution process of rocks during their transition to this range.

Conclusion

We can conclude that.

1. High apparent resistivity value of the top layer reflects the variable of lithology, while decreases with the depth.

2. The resistivity contrasts of the anomalous zone of the wetlands and the surrounding sediment is very clear in the inverse resistivity model. This indicates the efficiency of the Schlumberger array arrangement in detecting the groundwater at shallow sediments.

3. Resistivity, which is represented in this paper by sediments saturated with groundwater, with a depth of 1.5 meters and a thickness ranging from 9.5 meters to 11.5 meters. Where the groundwater level in the three wells located in the University of Anbar, a 7-kilometer area and 18-kilometer area, was identical to its level in the three imaging reversed models. Therefore, the results of this study can be considered good and reliable.

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تطبيقات المقاومة النوعية الكهربائية في التحري عن المياه الجوفية في الرمادي غرب العراق

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الخلاصة:

تم إجراء مسح الجس الكهربائي الرأسي (VES) باستخدام مصفوفة شلمبرجير. الغرض من هذه الدراسة هو التحري عن المياه الجوفية في غرب مدينة الرمادي. تم تنفيذ العمل الميداني لـ 20 نقطة .VESيتم عرض نتائج VES من خلال المقاطع الجيوكهربائية التي تشير إلى وجود طبقة المياه الجوفية في منطقة الدراسة. تم عرض تباين المقاومة بين الأجزاء غير المنتظمة من منسوب المياه الجوفية والرواسب المضيفة. الامتداد الرأسي للمنطقة الرطبة يتراوح بين 1.5 متر و9.5 متر. حيث كان منسوب المياه الجوفية في الآبار الثلاثة الموجودة في جامعة الأنبار، بمنطقة 7 كيلومترات ومنطقة 18 كيلومترًا، مطابقًا لمستواه في النماذج التصويرية الثلاثة المعكوسة.

الكلمات المفتاحية: ترتيب شلمبرجر، التحريات الجيوفيزيائية، الرمادي، غرب العراق.