The Efficiency of 2D Electrical Resistivity Arrays in Shallow Subsurface Investigations: A Comparative Study between Three Conventional Arrays

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Abstract

Two-dimensional (2D) field data was used to evaluate the performance of three electrical resistivity arrays for shallow subsurface investigations. The three arrays analyzed include Wenner-α, Dipole-dipole and Wenner-Schlumberger. The study was conducted at the University of Technology Baghdad /Iraq to evaluate the performance of these arrays in subsurface soil investigations. The three profiles were surveyed with total length of 60 m for each line, and the depth of penetration reach to 12m. Results showed two geoelectrical layers: the upper layer with high resistivity represents the topsoil layer (loamy soil) and the second layer with low resistivity represents the clayey layer. Among the three arrays tested, Wenner-Schlumberger array was the best for the study area as it was suitable for field conditions, more informative, provides high signal strength and deeper depth of penetration in the soil.

Key Words: Electrical Resistivity Arrays, ERI, Depth of Penetration and Soil Investigations.

كفاية مصفوفات المقاومة النوعية الكهربائية ثنائية البعدين في التحريات التحت السطحية القريبة: مقارنة بين ثلاثة مصفوفات تقليدية

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الخلاصة

استعملت بيانات حقلية ثنائية البعدين لتقييم أداء ثلاثة مصفوفات للمقاومة الكهربائية للتحريات تحت السطحية القريبة. هذه المصفوفات تتضمن، ترتيب فنر الفا وثنائي القطبين فنر–شلمبرجر. أجريت الدراسة في الجامعة التكنولوجية – بغداد/ العراق لتقييم أداء هذه الترتيبات في تحريات التربة تحت سطح الأرض. مسحت المسارات الثلاثة بطول 60 م، وعمق اختراق 12 م. أظهرت النتائج طبقتين جيوكهربائيتين: الطبقة العليا ذات المقاومة العالية تمثل طبقة التربة العليا (التربة المزيجية) والطبقة الثانية ذات المقاومة المنخفضة تمثل الطبقة الطينية. ومن بين الترتيبات الثلاثة التي تم اختبارها، كانت مجموعة فنر–شلمبرجير هي الأفضل لمنطقة الدراسة لأنها مناسبة للظروف الميدانية، وأكثر إفادة، وتوفر قوة إشارة عالية واعمق اختراقاً في التربة.

الكلمات المفتاحية: مصفوفات المقاومة الكهربائية، تصوير المقاومة النوعية، عمق الاختراق وتحريات التربة.

Introduction

The electrical resistivity of soil or any material is defined as a quantifier of how strongly that material resists the flow of the electric current which passes through it. The electrical resistivity of earth materials usually depends on several factors, like mineralogy, porosity, water content, fissures and fractures (Keller and Frischknecht, 1966). The chemical content of the water that fills the pores and fissures exerts more influence on the electrical resistivity of the mineral grains that comprise the materials itself (Dobrin and Savit, 1988). In dry conditions, most of the earth's materials become non-conducting, in other words, have extremely high electrical resistivity which will decrease largely when fluid is present (Cozzolino, *et al.,* 2018). In general, the soil has wide ranges of electrical resistivity (Laloy, *et al.*, 2011; Abdulrazzaq, 2011), typically ranging from 10 to 1000 ohm.m, while exceptional values range from 1 to 10000 ohm.m (Aziz, *et al.,* 2015).

The geophysical methods are used widely at this time especially, after the life improvement in the different fields. They give a true picture of the subsurface structures with rapidity and low cost if it was compared with other methods, liked the drilling wells (Karim *et al.,* 2014; Abdulrazzaq, *et al.,* 2015). Direct current resistivity (DCR) is considered as important geophysical methods that are used widely in groundwater investigation and interpreted many problems in the subsurface layers (Karim, *et al.,* 2014). Vertical Electrical Sounding (VES) is the earliest technique was used until lately when VES technique changed to a new techniques, which is 2D and 3D electrical resistivity imaging (ERI) (Abdulrazzaq, *et al.,* 2019). Recent scientific advances allow the enhancement of subsurface characteristics and the understanding of geological conditions at the time of the survey. Further applications of electrical resistivity methods were developing as knowledge increases and challenges in many aspects such as such as civil engineering, archaeological exploration, site and soil investigations, etc. (Sudha, *et al.*, 2009; Aziz, 2012). ERI is one of the newest approaches to these investigations (Griffiths and Barker, 1993; Loke, 2012).

Different array types can be used in the electrical resistivity techniques depending on the electrode spacing and mutual position of current and potential electrodes. Many issues should be considered in choosing the appropriate array type such as signal strength, the investigation depth, structure type, it is sensitivity to the horizontal and vertical targets, and the sensitivity of the device and the background noise level (Roy and Apparao, 1971; Loke, 2012).

The study aims are to evaluate three conventional array types to find the more suitable one in soil investigation.

Materials and Methods

Electrical Resistivity-basic Theory

The Electrical Resistivity Imaging (ERI) concept is based on the relation that normally gives a resistance value. The basic governing equation is Ohm's law:

$$\Delta V = R \times I \ldots (1)$$

where I is the electrical current, V is the voltage and R is the resistance. Resistance is calculated from a known current generated by the equipment and voltage measured at the surface. Generally, the further the current travels, the greater the resistance. Also, the less cross-sectional area the current has to travel through, the greater the resistance. These two properties of current flow, in conjunction with the intrinsic resistivity of the material that the current is travelling through, that determines the resistance. The following equation defines the resistance (R) as a function of the geometry of a resistor and the resistivity of the cylindrical body:

$$\mathbf{R} = \frac{\boldsymbol{\rho} \times \mathbf{L}}{\mathbf{A}} \; \ldots \; (2)$$

Where L is the distance travelled by the current, A is the cross-sectional area of the current path, and (ρ) is the resistivity and by rearranging Equation (2), the resistivity can be expressed as:

$$\boldsymbol{\rho} = \frac{\mathbf{R} \times \mathbf{A}}{\mathbf{L}} \; \ldots \; (3)$$

In this case, the apparent resistivity ρ_a value can be calculated by:

$$\boldsymbol{\rho_a = kR} \; \ldots \; (4)$$

Where ρ_a is the bulk resistivity of all subsurface layers influencing the flow of current (U.S. Army Corps of Engineers, 1995; Milsom, 2003). From I and V, the value ρ_a will calculated from dividing the measured potential difference by the applied current times the geometric factor (k).

$$\boldsymbol{\rho_a = k(\frac{V}{I})} \; \ldots \; (5)$$

Where k is knowen as the geometric factor that depends on the arrangement of the four electrodes. Thus, a factor which defines the ease for I to flow through the earth is known as ρ.

Conventional Array Types

There are many electrode arrays used in the electrical surveys. The choice of the best array for a field survey depends on different elements, such as the investigation depth, background noise level and sensitivity of resistivity device (Roy and Apparao 1971; Loke, 2012). However, the types of electrical arrays used in this study are Wenner, Dipole-dipole, and Wenner-Schlumberger.

2.2.1 Wenner Arrays

Wenner array has been used since 1916 in the geophysical prospecting. The array depends on four electrodes (C1, P1, P2, and C2), where C1 and C2 are often considered the current electrodes, while P1 and P2 are the potential electrodes (Fig 1). The distance between electrodes P1 P2 equals to 1/3 C1 C2 or C1 P1 = P1 P2 = P2 C2 = a. The spacing between the four electrodes is considered as a depth function for measurements. **Dipole-dipole Array**

There are multiple types of Dipole-dipole arrays such as Equatorial, Azimuthal, Parallel, Perpendicular, Radial, and Polar or Axial array (Keller and Frischknecht, 1966).

The Polar Dipole–dipole array is the most widely used in pseudo-section plotting because of the easy fieldwork, accordingly, it is useful for measuring lateral resistivity changes, so it is used in geotechnical and environmental applications. The position of the apparent resistivity is placed extending downward at 45o from the midpoints of the C1-C2 and P1-P2 electrode pairs.

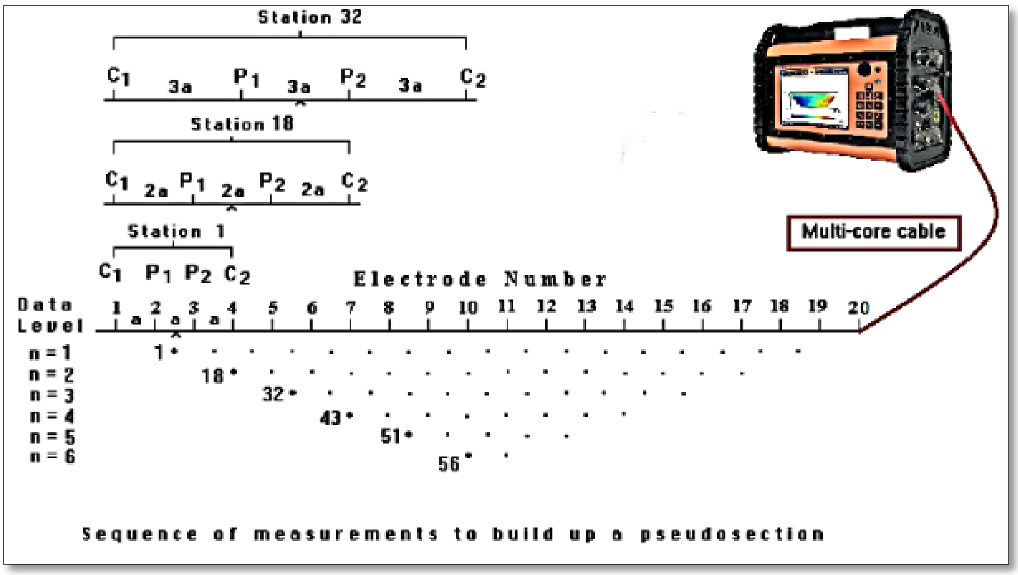

Fig. (1) The Sequence Measurement of Wenner Array (Loke, 2012).

The placement of the apparent resistivity values is only a place holder and is not representative of the true location of that value, but rather the zone of influence for those electrode pairs.

Wenner-schlumberger Array

Wenner-schlumberger array is considered a hybrid array which combination of the Wenner and Schlumberger arrays and become one of the imperative array utilized in the electrical resistivity method (Fig.3). This array has a median depth of investigation and moderately sensitive to both horizontal and vertical targets, and has a slightly better coverage compared with the Wenner array (Al fouzan, 2008).

Data Acquisition

The ABEM Terrameter SAS 4000 (Signal Averaging System 4000) was the resistivity device used to measure all 2D resistivity data in the University of Technology, Baghdad (Fig. 4), consecutive readings were taken automatically, and the results were averaged continuously. The main features include a 64-electrode unrestricted switching in a compact.

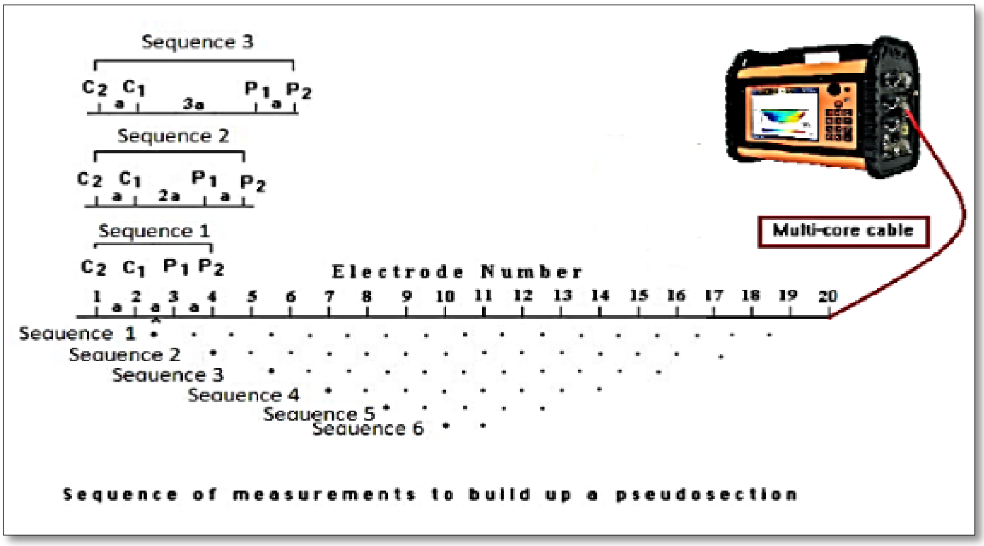

Fig. (2) The Sequence Measurement of Dipole-dipole Array (Loke, 2012).

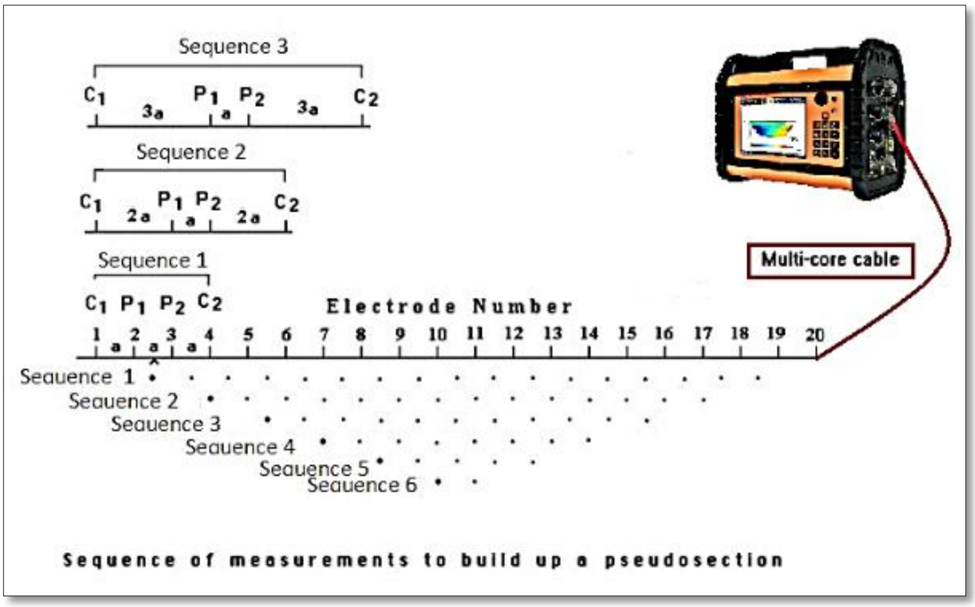

Fig. (3) The Sequence Measurement of Wenner-schlumberger Array (Loke, 2012).

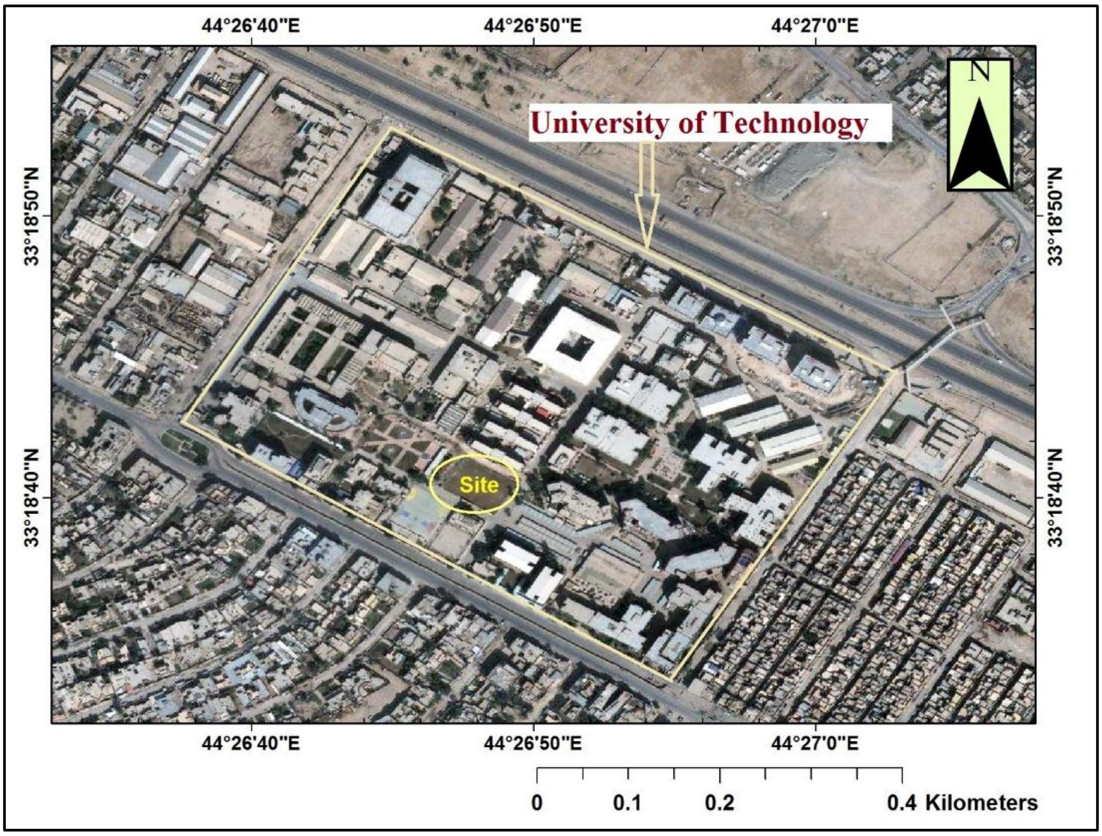

Fig. (4) Location of the Study Area (University of Technology).

Survey Design

Three profiles were collected, namely, Line W, Line WSC and Line DD. The research project involved a 41 electrode SAS 4000 multi-electrode resistivity system to collect the apparent resistivity data. The 41 electrodes are on two interconnect electrode cables with 20 electrodes each. The resistivity imaging survey trends from south to north was conducted with 1.5 m electrode spacing. The total length of the survey line was 60 m. A general 2D profile acquisition of the resistivity data is fairly straightforward. The data was processed and inverted using RES2DINV software.

Results and Discussion

5.1 2D ERI Survey

Line W

The 2D inversion resistivity pseudo-section of Line W (Fig. 5) trends from S to N direction with a total length of 60 m, and the maximum depth of investigation is 10 m using Wenner array. The resistivity values vary between 4.45 and 13.8 ohm.m with RMS of 11.73 % after 3 iterations.

The image reveals two different layers. The first layer shows high resistivity value ranging from 9 to 14 ohm.m, the depth of this layer is around 1.3m, accordingly, and this layer may be represented as loamy soil. The second layer exhibits lower resistivity values ranging from 4 to 7ohm.m, which could be interpreted as a clayey layer.

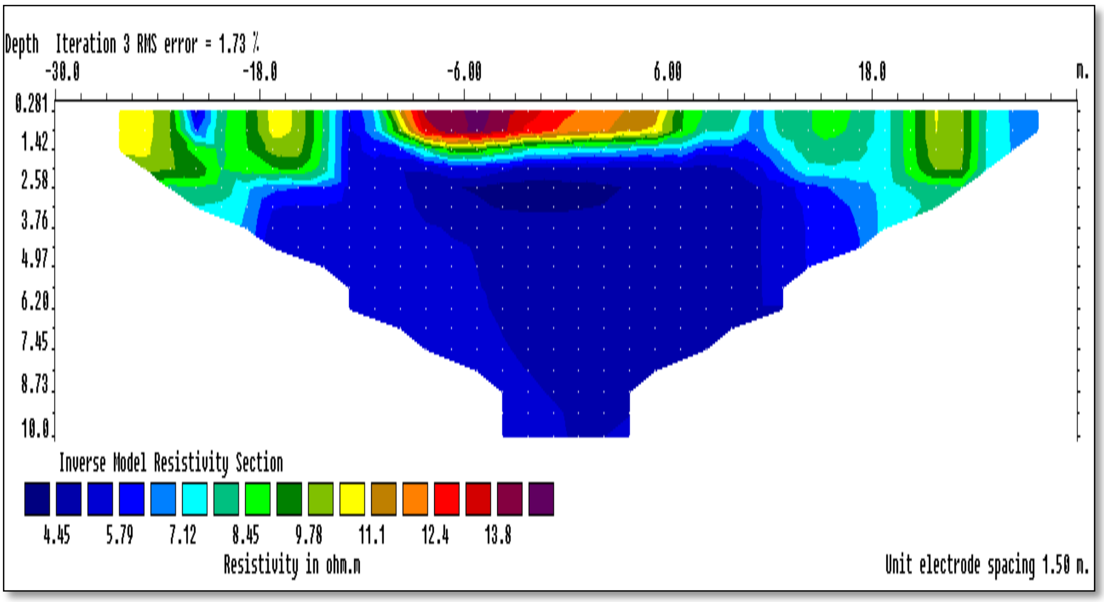

Fig. (5) Inverted Resistivity Section for Line W.

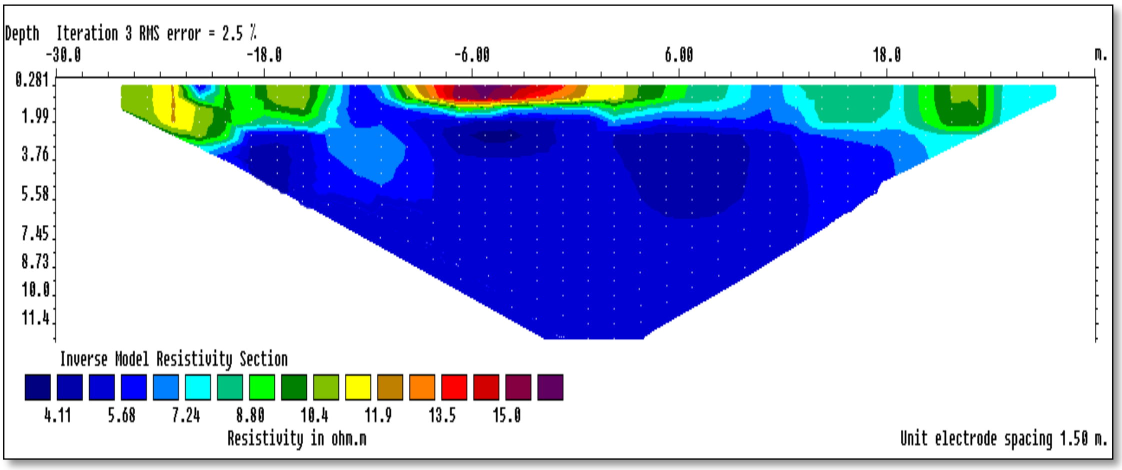

Fig. (6) Inverted Resistivity Section for Line WSC.

Line WSC

The 2D inversion resistivity pseudo-section of Line WS trends from S to N direction using Wenner-Schlumberger array with a total length of 60 m, and the maximum depth of investigation is 11.4 m (Fig. 6). The resistivity values vary between 4.11 and 15 ohm.m. The root means square (RMS) is 2.5 % after 3 iterations. The inversion resistivity image shows two main electric layers: the upper layer with a resistivity value ranging between 11 to 15 ohm.m which could be represented by the uppermost loamy soil (fill material mix of sand and clay), the depth of this layer ranged from N.G.L to about 1.5 m. While the second layer depicts a low resistivity value ranging from 4 to 7 ohm.m, and it may be interpreted as a clayey layer.

Line DD

The horizontal section of this line is shown in Figure 7. The resistivity values ranged between 1 and 29 ohm.m. The RMS is 8.9 % after 3 iterations. The length of this spread line is 60 m with a maximum depth of investigation is 8.7 m using Dipole-Dipole array. The surface uppermost layer showed relatively high resistivity values ranging from 13 to 17 ohm.m which may refer to loamy soil, with an inhomogeneous resistivity distribution which could be explained by the variable water content levels within the same layer. To the lower, a low resistivity area (with blue

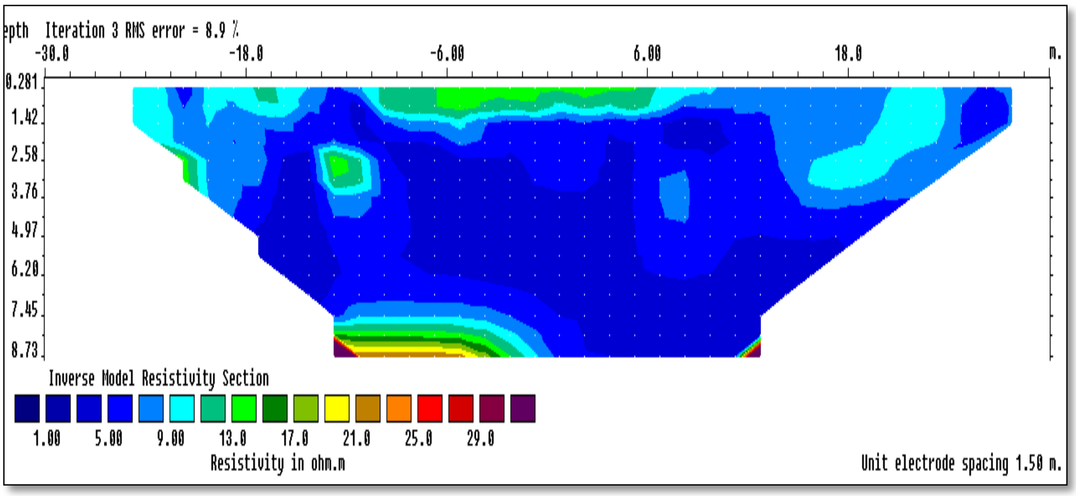

Fig. (7) Inverted Resistivity Section for Line DD.

color) with values between 1 to 5 ohm.m may be interpreted as the clayey layer.

This profile presents mainly distinguishable zone with high resistivity values occurs at the left side of the spread at a depth 7.4 m down to 8.7 m with a maximum value around 29 ohm.m. These anomalies could be interpreted as a pocket of wet sand or clayey sand to sandy clay.

Conclusions

- The maximum depth of investigation is ranging between 8.7 to 11.4 m, and resistivity value ranges from 1 to 29 ohm.m.
- Two layers are recognized, the upper with high resistivity (9-17) ohm.m represents the topsoil layer, the loamy soil, with showing inhomogeneous resistivity distribution reflecting the inhomogeneity in deposits with varied water content. The second layer with low resistivity (1-7 ohm.m) represents the clayey layer.
- It is found that Wenner-schlumberger array is a suitable one to be considered and used for such investigation as it is suitable for field conditions; provides high signal strength and provides adequate penetration depth.
- The field results showed that Wenner-schlumberger array is better than the other two arrays regarding horizontal resolution, in addition to showing the least root mean square.

References

Abdulrazzaq, Z.T. (2011) Application of Vertical Electrical Sounding to Delineate and Evaluate of Aquifers Characteristics in Baiji-tikrit Basin. M.Sc. Thesis, University of Tikrit.

Abdulrazzaq, Z.T.; Al-heety, A.J. and Shanshal, Z.M. (2019) Integration of 1D and 2D Electrical Resistivity Techniques to Determine the Thickness and Extension of the Main Aquifer in Al-rehaemia Area, Al-najaf Governorate, Central Iraq. Iraqi Bulletin of Geology and Mining 15, 1-13.

Abdulrazzaq, Z.T.; Aziz, N.A. and Alwan, H.A. (2015) Study of Groundwater Level in Samarra City by Using 2D Resistivity Imaging Technique. Iraqi Journal of Science and Technology, 6, 11-26.

Al fouzan, F.A. (2008) Optimization Strategies of Electrode Arrays Used in Numerical and Field 2D Resistivity Imaging Surveys. PhD. Thesis, University Sains Malaysia.

Aziz, N.A. (2012) Three Dimension Electeical Resistivity and IP Imaging for Soil Layers Invistgation at UOT-Baghdad. M.Sc. Thesis, University of Technology.

Aziz, N.A.; Abdulrazzaq, Z.T. and Alwan, H.A. (2015) The Efficiency of 2D Electrical Resistivity Arrays in

Shallow Subsurface Investigations: A Comparative Study between Three Conventional Arrays. Iraqi Journal of Science and Technology, 6, 83-88.

Cozzolino, M.; Di. Giovanni, E.; Mauriello, P.; Piro, S. and Zamuner, D (2018) Geophysical Methods for Cultural Heritage. In: Geophysical Methods for Cultural Heritage Management. Springer Geophysics. Springer, Cham, 9-66.

Dobrin, M.B. and Savit, C.H. (1988) Introduction to Geophysical Prospecting. McGraw-hill, New York.

Griffiths, D. and Barker, R. (1993) Two-dimensional Resistivity Imaging and Modelling in Areas of Complex Geology. Journal of Applied Geophysics, 29, 211-226.

Karim, H.; AL-Qaissy, M. and Aziz, N.A. (2014) 2D and 3D Resistivity Imaging for Soil Site Investigation. Engineering and Technology Journal, 32, 249-272.

Keller, G. and Frischknecht, F. (1966) Electrical Methods in Geophysical Prospecting. Pergamon Press, New York.

Laloy, E.; Javaux, M.; Vanclooster, M.; Roisin, C. and Bielders, C.L. (2011) Electrical Resistivity in a Loamy Soil: Identification of the Appropriate Pedo-electrical Model. Vadose Zone Journal, 10, 1023-1033.

Loke, M.H. (2012) Tutorial: 2D and 3D Electrical Imaging. http://www.geore_

Milsom, J. (2003) Field Geophysics, 3rd Edition, John Wiley and Sons Ltd.

ntals.co.uk/Lokenote.pdf.

Roy, A. and Apparao, A. (1971) Depth of Investigation in Direct Current Methods. Geophysics, 36, 943-959.

Sudha, K.; Israil, M.; Mittal, S. and Rai, J. (2009) Soil Characterization Using Electrical Resistivity Tomography and Geotechnical Investigations. Journal of Applied Geophysics, 67, 74-79.

U.S. Army Corps of Engineers, (1995) Engineer Manual 1110-1-1802, CECW-EG, Department of the Army, Washington, DC 20314-1000.