Iraqi Bulletin of Geology and Mining *Vol.12, No.2, 2016* *p 39 – 46*

EVALUATION OF FIVE ELECTRODE ARRAYS IN IMAGING SUBSURFACE SHALLOW TARGETS; A CASE STUDY

Ahmed S. Al-Zubedi[1]

Received: 03/ 05/ 2015, Accepted: 16/ 02/ 2016
Key words: Electrode arrays, Synthetic model, Dpole-dipole array, Wenner, Schlumberger, Electric imaging

ABSTRACT

In this study, five electrode arrays in 2D imaging surveys were tested through synthetic model to determine the most successful array in imaging the subsurface shallow targets. These arrays are Pole-pole, Pole-dipole, dipole-dipole, Wenner and Wenner-Schlumberger. The numerical modeling was made through two shallow walls buried in clayey deposits. The results showed that the dipole-dipole is the most suitable electrode array when both vertical and horizontal changes are present in the subsurface. This study indicates that the Wenner-Schlumberger array might be a good compromise between the Wenner and the Schlumberger and not with the dipole-dipole arrays in areas where both types of geological structures are expected, due to the increase of depth function of Schlumberger array with depth, while it decreases rapidly with depth with the dipole-dipole array. Therefore, it is recommended to use the dipole-dipole array for shallow investigations and to use Wenner-Schlumberger array in greater depths.

تقييم خمسة ترتيبات كهربائية في تصوير الاهداف الضحلة تحت السطح دراسة حالة

احمد سرداح الزبيدي

المستخلص

في هذه الدراسة، خمسة ترتيبات تستخدم في المسح الكهربائي ثنائي البعد اختبرت من خلال موديل صناعي، للتحديد الترتيب الأفضل في تصوير المصادر تحت السطح، هذة الترتيبات هي قطب- قطب، قطب- ثنائي القطب، ثنائي القطبين، فنر وترتيب فنر- شلمبرجر. صمم الموديل العددي من خلال تواجد جدارين مدفونيين تحت ترسبات طينية. أظهرت النتائج بأن ترتيب ثنائي القطبين هو اكثر الترتيبات ملائمة في حالة وجود التغيرات العمودية والأفقية تحت السطح، حيث كان الأكثر نجاحا في تصوير تلك الجدران من الترتيبات الأخرى. هذه الدراسة أيضا أظهرت بأن ترتيب فنر- شلمبرجر يجمع بين خصائص ترتيبي فنر وشلمبرجر في المناطق التي يتواجد فيها كلا النوعين من التراكيب الجيولوجية (العمودية والأفقية) تحت السطح، وليس بين خصائص ترتيبي ثنائي القطبين وفنر كما ذكرت الدراسات السابقة، وذلك لأن دالة العمق لترتيب شلمبرجر تزداد مع العمق بينما تقل لترتيب ثنائي القطبين. لذالك فإن الدراسة الحالية توصي باستخدام ترتيب ثنائي القطبين في التحري عن المصادر القريبة من السطح، واستخدام ترتيب فنر- شلمبرجر في حالة التحري عن المصادر الأكثر عمقا لأنها تعطي الصوره الأفضل عن هذه المصادر.

[1] General Commission for Groundwater, Baghdad, Iraq, e-mail: Ahmed.Srdah@yahoo.com

INTRODUCTION

The use of geophysical survey techniques can supply an excavation with a “road map” to subsurface features without disturbing the site. Among all the geophysical methods currently utilized for shallow investigations such as archeological purposes, resistivity method is the first to gain popularity. It has been in use for decades in hydrogeoloical, mining, geotechnical, environmental and engineering investigations. It has also been used for archaeological investigations since the 1940s and 1950s, (Bevan, 1998).

As a result, advances in field equipment, design capability and computer algorithms led to the appearance of 2D and 3D resistivity techniques in the 1990s. The 2D resistivity technique has become one of the most significant procedure for investigating underground structures including archeological remains (Kemna *et al*., 2002; Zhou *et al*., 2004; Ford and Williams, 2007; Loke *et al*., 2013; Al-Zubedi and Thabit, 2014, and Negri and Leucci, 2006). There are 92 electrode arrays used in the electrical resistivity method (Szalai and Szarka, 2008), but the types of these arrays, that are most commonly used in 2D imaging surveys, do not exceed ten arrays. These arrays are Wenner-Schlumberger, Wenner, dipole-dipole, Pole-dipole, Pole-Pole, and Multiple gradient arrays (Loke, 2012).

The choice of best array for a 2D imaging surveys depends on different factors, such as the investigation depth, sensitivity function that is connected with type of structure to be mapped, vertical and horizontal data coverage and the resolution of the array, in addition to, the sensitivity of the resistivity meter and background noise level (Loke, 2012). Depending on these factors, there are many studies carried out to determine which of these arrays respond best in imaging shallow targets in different situations such as the studies of Zhou *et al*., 2002; Seaton and Burbey, 2002, and Dahlin and Zhou, 2004, compared 2D resistivity imaging with 10 electrode arrays depending on different situations of synthetic models. The results of this comparison indicated a higher resolution and high sensitivity to geologic detail for shallow investigation offered by the dipole-dipole, Pole-pole and Pole-dipole than Wenner array.

In the present study, we will evaluate these arrays in addition to the Wenner-Schlumberger arrays made over a synthetic model, then compare the obtained results with field results derived from several authors to determine the most successful array in defining shallow targets by 2D imaging surveys.

SYNTHETIC MODEL DESCRIPTION

In order to investigate the capabilities of different electrode arrays in 2D imaging surveys, one synthetic model representing two walls of buried small room was designed. Forward modeling was done using the 2D forward modeling software RES2DMOD, made by Loke (2002).

The forward model is designed with survey line (12 m) long and with the unit electrode spacing of (0.5 m). The numerical modeling was made through two walls of buried small room located under electrodes 4 and 8 respectively at a depth of (1.4 m), and extending to a depth of (3.5 m) with (1 m) width for each one.

The resistivity of the walls is made (5 Ωm) buried by clay deposits of resistivity (1 Ωm). The distance between these walls is made (3 m), Fig. (1). However, the top soil that covers the target is a thin layer (0.3 m) thick with resistivity of (15 Ωm).

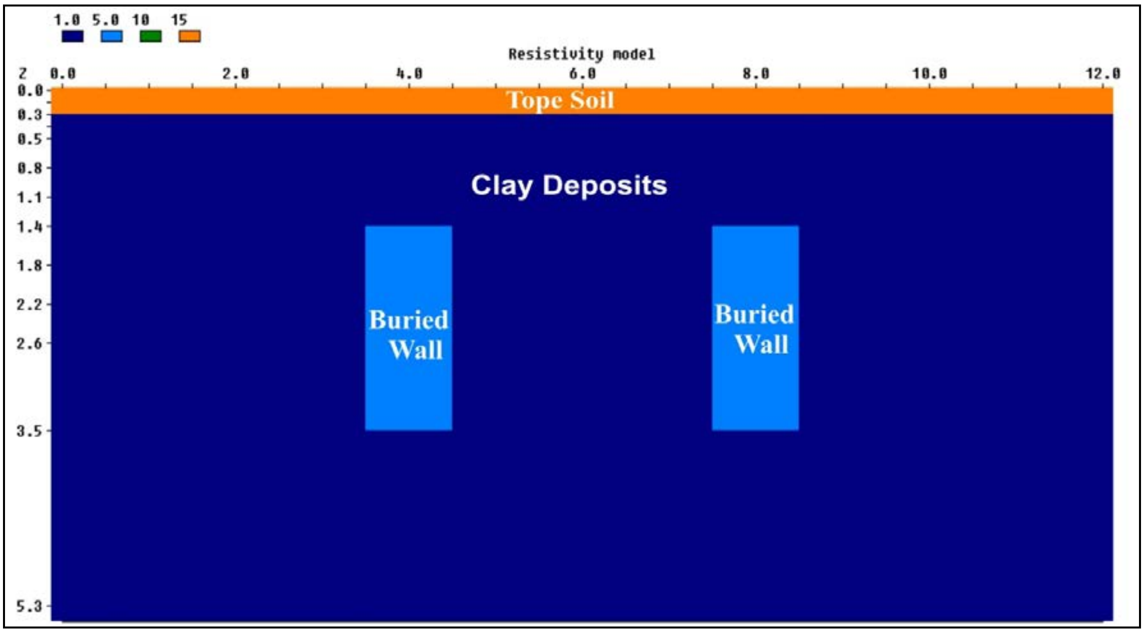

Fig.1: A synthetic model of two shallow targets

RUSTLES AND DISCUSSION

Five forward models of the dipole-dipole, Pole-pole, Pole-dipole, Wenner and Wenner-Schlumberger arrays are created from the synthetic model. The Wenner and Pole-pole surveys were performed using (8a) and (23a) respectively, while the dipole-dipole, Pole-dipole and Wenner-Schlumberger surveys were performed with increasing values from (1) to (5n), and from (1) to (4a) (Fig.2), to provide a higher resolution and maximize the depth of investigation. Random noise of (2%) was added to the apparent resistivity values of the dipole-dipole, Pole-pole and Pole-dipole arrays as they have weaker signal strength than that of Wenner and Wenner-Schlumberger arrays (Dahlin and Zhou, 2004; Loke, 2004 and Chitea and Georgescu, 2009).

The inverse models were carried out using the RES2DINV ver. 3.59 Software, by smoothness-constraint inversion and robust inversion options. The smoothness-constraint is well adapted for areas where the resistivity varies in a gradual manner. This method normally gives reasonable results if the data contains random or “Gaussian” noise, (deGroot-Hedlin and Constable, 1990). The robust inversion option (blocky optimization) is used when sharp boundaries are present. It attempts to find a model that minimizes the absolute values of the data misfit. In other words, it attempts to minimize the square of the difference between the observed and the calculated apparent resistivity values of a model, (Claerbout and Muir, 1973; Olayinka and Yaramanci, 2000 and Loke *et al*., 2013).

The robust inversion gave the best boundary resolution results than the others as the buried walls have sharp geologic boundaries. So it is used to interpret all resistivity data except the data obtained by Wenner array, where its inverse model carried out by robust inversion option doesn’t show any trace of the buried walls, Fig. (3).

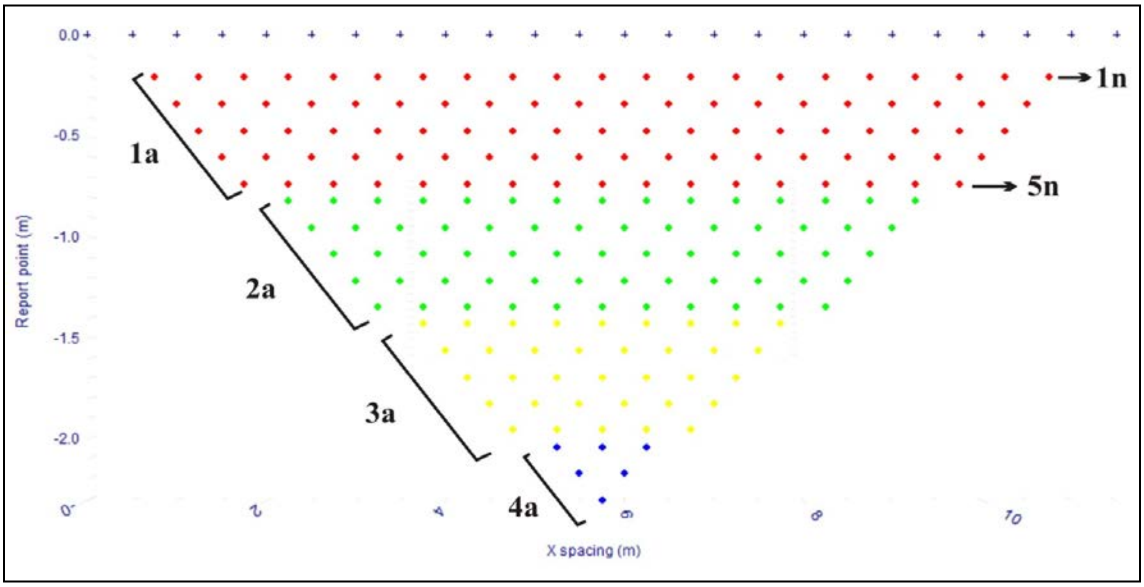

Fig.2: Shows pattern of levels of (n) value from 1n to 5n, and a-spacing from 1a to 4a for dipole-dipole, Pole-dipole and Wenner-Schlumberger arrays.

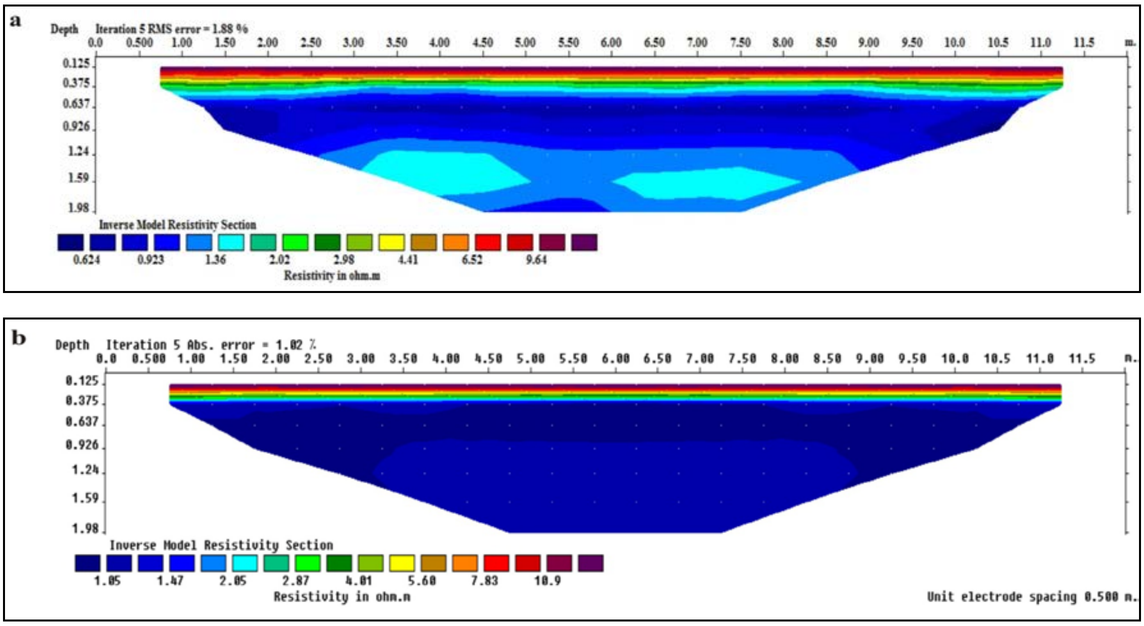

Fig.3: Inverse models of Wenner array data, **a)** smoothness-constraint, **b)** Robust inversion

The inverse model of the dipole-dipole array after five iterations with RMS errors (0.61%) was very successful in imaging the buried walls, but it is less accurate in imaging the location of right-hand buried wall that is located between electrodes location (7 – 9) (Fig.4a). This model reveals and confirms that the dipole-dipole array is more sensitive when the lateral resistivity variation is encountered, and it is therefore the best choice when mapping vertical structures, but relatively poor in mapping horizontal structures (Dahlin and Zhou, 2004; Chitea and Georgescu, 2009 and Loke, 2012). However, this array gave low depth of investigation of (2.69 m).

Tamssar (2013) evaluated the suitability of different electrode arrays (Wenner, Schlumberger, Pole-Pole and dipole-dipole) during ERT surveys in Karoo rocks, South Africa, to image dykes, sills, fault and fractures at different depths (40 – 95 m). The results indicated that the dipole-dipole array is not recommended for such structures due to its lower sensitivity to vertical changes in resistivity. On the other hand, a practical comparison that has been carried out by Abrahem (2013) using the three arrays, of Wenner-Schlumberger, Wenner, and dipole-dipole, has shown that the dipole-dipole is the best for shallow investigations. This means that the resolution of this array will decrease rapidly with depth. Therefore it is the best for shallow investigation.

After eight iterations with RMS errors (5.4%) (Fig.4b) the inverse model of the Pole-pole array seems insufficient in imaging the buried walls because it gives a distorted image of locations, extension and width of these structures. But it is very successful in imaging the depth of these walls. These results confirm that this array has a high sensitivity function near earth surface, and it is more sensitive to vertical structures and less sensitive to horizontal structures (buried walls), because it shows the two walls linked together. However, this array gave the greatest depth of investigation (up to 10.1 m) than other arrays.

An RMS error equal to (0.82%) is obtained after eight iterations. The inverse model of the Pole-dipole array was insufficient in imaging the buried walls as it gives distorted image of locations, width, extension and depth of these walls (Fig.4c). This means that the Pole-dipole array is poor in mapping vertical and horizontal structures such as two buried walls. However, this array has a good depth of investigation that reaches 4.30 m.

After five iterations with RMS errors of 1.88% (Fig.4d), the inverse model of the Wenner array is so insufficient to image the buried walls that it gaves distorted image about locations, width, extension and depth of these walls. This array may have difficulties in simultaneously imaging both horizontal and vertical structures. These results confirm the theoretical results of Dahlin and Zhou, 2004 and Loke, 2012. Those authors indicated that the Wenner array is relatively sensitive to vertical changes in the subsurface resistivity. Furthermore, these results don't agree with the practical results of Mihai (2013).

With an RMS error of (0.35%) obtained after seven iterations (Fig.4f), the inverse model of the Wenner-Schlumberger array is successful in imaging the buried walls, especially with increasing depth. This means that the sensitivity function of this array increases with depth and decreases near earth surface, as it starts by Wenner and ends with Schlumberger array. Therefore, the apparent resistivity measurements will be more representative to depth function when the (MN) spacing is decreased, (Al-Ane, 1998). These results do not agree with Loke’s results (Loke, 2012). This array might be a good compromise between the Wenner and the dipole-dipole arrays in areas where both types of geological structures are expected. However, the Wenner-Schlumberger and Wenner arrays gave the same depth of investigation of (1.98 m).

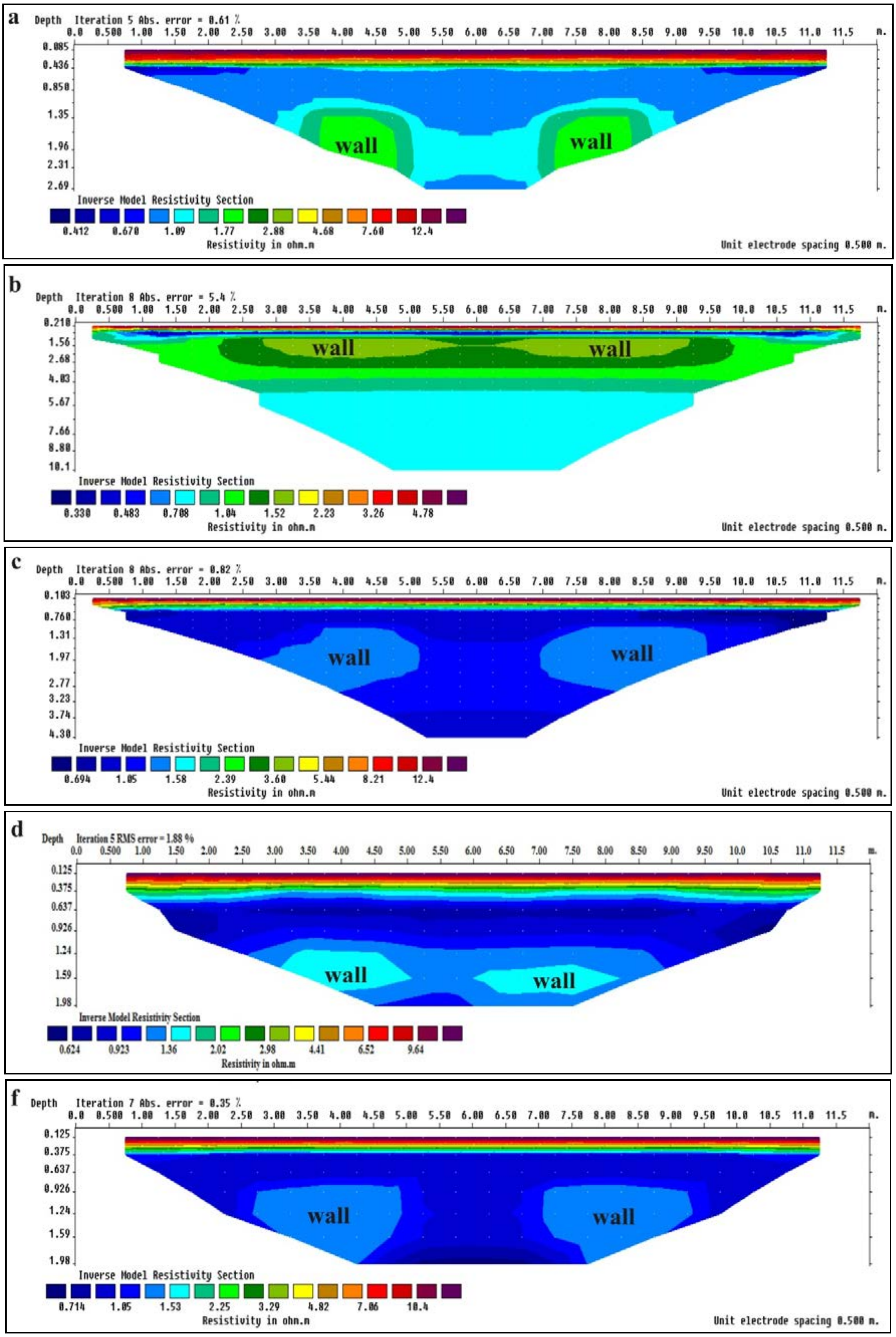

Fig.4: Inverse synthetic model for **a)** dipole-dipole, **b)** Pole-pole, **c)** Pole-dipole, **d)** Wenner, and **f)** Wenner-Schlumberger arrays

CONCLUSIONS

This comparison showed some important results, which are given as follows:

- The robust inversion did not give the best boundary resolution in all cases of the geological sharp boundaries.
- The dipole-dipole array shows better vertical and horizontal results and therefore it is better than other arrays in imaging the buried walls.
- The Wenner-Schlumberger array is successful in imaging the buried walls, especially with increasing depth, than the dipole, Pole-pole, Pole-dipole and Wenner arrays.
- The Wenner-Schlumberger array might be a good compromise between the Wenner and the Schlumberger and not with the dipole-dipole arrays in areas where same types of geological structures are expected, due to the fact that depth function of Schlumberger array increases with depth, while it decreases rapidly with depth in dipole-dipole array.
- The actual depth of buried walls is given by the Pole-pole array, without giving the actual extension of these walls with depth.
- The Pole-pole array gives the greatest depth of investigation than other arrays that reaches (10.1 m).
- The Wenner-Schlumberger and Wenner arrays gave the lowest depth of investigation of (1.98 m).
- This study recommends the use of the dipole-dipole array for shallow targets such as archeological objects and the use of Wenner-Schlumberger array for more depths because they give the best images of targets.

REFERENCES

Abrahem, S.N., 2013. Comparison Between The Ground Penetration Radar (GPR) and 2D Imaging in Delineation and Identification Subsurface Archaeological Structures in Uruk Site, Al-Muthanna Governorate, Ph.D. Thesis, (Unpublished), University of Baghdad, college of Science. 131pp.

Al-Ane, J.M., 1998. Theoretical and Application Consideration for the effect of the geometry on Schlumberger and dipole configuration. Unpublished, Ph.D. Thesis, University of Baghdad, college of Science, 144pp.

Al-Zubedi, A.S. and Thabit, J.M., 2014. Comparison between 2D imaging and vertical electrical sounding in aquifer delineation: a case study of south and south west of Samawa City (IRAQ). Arabian Journal of Geosciences, Vol.7, Issue 1, p. 173 – 180.

Bevan, B.W., 1998. Geophysical Exploration for Archaeology: An Introduction to Geophysical Exploration. Midwest Archeological Center. Copies available from Special Report No.1.

Chitea F. and Georgescu, P., 2009. Sensitivity function for various geoelectric arrays. Geophysical Research Abstracts. University of Bucharest, Faculty of Geology and Geophysics.

Claerbout, J.F. and Muir, F., 1973. Robust modeling with erratic data. Journal of Geophysics, Vol.38, p. 826 – 844.

Dahlin, T. and Zhou, B., 2004. A numerical comparison of 2D resistivity imaging with 10 electrode arrays. Geophysical Prospecting, Vol.52, p. 379 – 398.

deGroot-Hedlin, C. and Constable, S., 1990. Occam's inversion to generate smooth, two dimensional models from magnetotelluric data. Journal of Geophysics, Vol.55, No.12, p. 1613 – 1624.

Ford, D.C. and Williams, P.W., 2007. Karst Hydrogeology and Geomorphology. Chichester, 562pp.

Kemna, A., Kulessa, B. and Vereecken, H., 2002. Imaging and characterization of subsurface solute transport using electrical resistivity tomography (ERT) and equivalent transport models. Journal of Hydrology, Vol. 3 – 4, p. 125 – 146.

Loke, M.H., 2002. RES2DMOD version 3.01. Rapid 2D resistivity forward modelling using the finite-difference and finite-element methods. Penang, Malaysia.

Loke, M.H., 2004. Tutorial: 2-D and 3D Electrical Imaging Surveys, 135pp.

Loke, M.H., 2012. Tutorial: 2-D and 3D Electrical Imaging Surveys, 165pp.

Loke, M.H., Chambers J.E., Rucker D.F., Kuras O. and Wilkinson, P.P., 2013. Recent developments in the direct-current geoelectrical imaging method. Journal of Applied Geophysics, Vol.95, p. 135 – 156.

Negri, S., Leucci, G., 2006. Geophysical investigation of the Temple of Apollo (Hierapolis, Turkey). Journal of Archaeological Science, Vol.33, No.11, p. 1505 – 1513.

Mihai, A.E., Opris, A., Gerea, A.G. and Ivan-Enescu, D.A., 2013. Using Wenner resistivity mapping in archaeological sites Case study in three different sites. 4th International Geosciences Student Conference, 25 – 28 April 2013, Berlin.

Olayinka, A.I. and Yaramanci, U., 2000. Assessment of the reliability of 2D inversion of apparent resistivity data. Journal of Geophysical Prospecting, Vol.48, p. 293 – 316.

Seaton, W.J. and Burbey, T.J., 2002. Evaluation of two-dimensional resistivity methods in a fractured crystalline-rock terrain. Journal of Applied Geophysics, Vol.51, p. 21 – 41.

Szalai, S., Szarka, L., 2008. On the classification of surface geoelectric arrays. Geophysical Prospecting, Vol.56, No.2, p. 159 – 175.

Tamssar, A., 2013. An evaluation of the suitability of different electrode arrays for geohydrological studies in karoo rocks using electrical resistivity tomography. Ph.D. Thesis. Faculty of natural and agricultural science, University of Free State, South Africa, 183pp.

Zhou, QY., Matsui, H. and Shimada, J., 2004. Characterization of the unsaturated zone around a cavity in fractured rocks using electrical resistivity tomography. J. Hydraulic Res. Vol.42, p. 25 – 31.

Zhou, B., Beck, B.F. and Adams, A.L., 2002. Effective electrode array in mapping karst hazards in electrical tomography. Environmental geology, Vol.42, p. 922 – 928.

About the Author

Ahmed Srdah Kadhem Al-Zubedi, BSc. in Geology from Baghdad University. M.Sc. and Ph.D. in geophysics from Baghdad University. He is an author of a book entitled: Principles of Electrical Resistivity Techniques published by Lambert Academic Publishing and a number of scientific papers dealing with geophysical subjects. Currently he is working as Chief Geologist in General Commission for Groundwater, Ministry of Water Resources, Iraq.

e-mail: Ahmed.Srdah@yahoo.com