DOI: 10.24996/ijs.2023.64.9.16

ISSN: 0067-2904

Application of 2D Electrical Resistivity Method for Site Investigation in the State Company for Glass and Refractories in Ar-Ramadi City, Iraq

Amina M. Salman*, Ali M. Al-Rahim

Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq

Received: 24/6/2022 Accepted: 3/11/2022 Published: 30/9/2023

Abstract:

2D Electrical Resistivity has been applied at three selecting areas within the study area using Dipole-dipole and Wenner arrays with an a-spacing of 1 m, and the profile length was 120 m for both. The total data points were 4455 reads for Dipole-dipole, and the total data points for Wenner were 2340 reads, and the depth of each array was 15.4 m and 20.2 m, respectively. The 2D inverse results indicate the resistivity anomalies approximately at depth (2 - 7.8) m formed as a weakness zone lies within the quaternary and Injana Formation deposits and interbedded with secondary gypsum and gypcretes. Additionally, the inverse resistivity distribution model demonstrated that the area is impacted by groundwater that is interaction with sand, silt, and clay of the subsurface layers due to the gypsiferous and gypcrete deposits. They are distinguished by their ability to interact with water, whether it is surface or underground, and as a result, cause the emergence of a set of cavities and voids that may be filled with sediments that contain high levels of water and cause soil to wet. As well, the investigation gives the ideal array as Dipole-dipole rather than Wenner array due to its better in signal to noise ratio and provides the most suitable resolution for these applications, as well as the study, recommends conducting engineering and site investigations of the soil and determining the type of soil and the appropriate treatment methods that can overcome these problems.

Keywords: Voids, Site Investigation, Wenner array, Dipole – dipole array, Cavity, Gypsuferous Soils.

تطبيق الطريقة المقاومية الكهربائية ثنائية الابعاد للتحريات الموقعية في الشركة العامة للزجاج والحراريات في مدينة الرمادي، العراق

أمنه محمد سلمان*، علي مكي الرحيم

قسم علم الأرض، كلية العلوم، جامعة بغداد، بغداد، العراق

الخلاصه

تم اختيار ثلاث محطات داخل منطقة الدراسة وباستخدام ترتيب الأقطاب فنر وترتيب الأقطاب ثنائي القطب – ثنائي القطب بمسافة قطبية 1 متر وبامتداد افقي 120 مترًا لكليهما. وبلغت عدد القراءات الإجمالية 4455 قراءة لترتيب الأقطاب ثنائي القطب – ثنائي القطب وكانت نقاط البيانات الإجمالية لترتيب الأقطاب فنر 2340 قراءة، وبعمق تحري لكل ترتيب 15.4 متراً و20.2 متراً على التوالي. أشارت النتائج العكسية الثنائية

*Email: ammo45752@gmail.com

الأبعاد إلى شذوذ المقاومة الظاهرية عند العمق (2 – 7,8) متراً تقريباً والتي تكونت بشكل منطقة تمثل طبقة الضعف المتداخلة مع التجاويف والفراغات والتكهفات التي تقع ضمن رواسب فترة العصر الرباعي وتكوين إنجانة ومتداخلة مع الجبس الثانوي. كما أوضح نموذج توزيع المقاومة العكسي الثنائي البعد أن المنطقة تتأثر بالمياه الجوفية والتي تتفاعل بشكل مباشر مع الرمل والطين والغرين في الطبقات تحت السطحية نتيجة تداخل الرواسب الجبسية والتي تتميز بقدرتها على التفاعل مع المياه، وبالتالي تؤدي إلى حدوث مجموعة من التجاويف والفجوات تحت سطح الأرض والتي تسبب ضعف في الخصائص الهندسية للتربة نتيجة لعملية انتفاخ الترب الطينية وانهيار الترب الرملية. بالإضافة إلى ذلك، أعطى التحري بأن الترتيب المثالي هو ترتيب ثنائي القطب – ثنائي القطب بدلاً من ترتيب الأقطاب فنر نظرًا لأنه أفضل في نسبة الإشارة إلى الضوضاء وكذلك توفير الدقة الأكثر ملاءمة لهذه التطبيقات مع العمق، وكما أوصت هذه الدراسة بتطبيق الدراسات الهندسية الملائمة للتغلب على هذه المشكلة.

1- Introduction:

Geophysical methods have been implemented as a promising tool used for the detection of subsurface, especially the electrical resistivity techniques, because it is less complex and more economical for in-field investigations and provides valuable subsurface images used for detecting and evaluating the subsurface conditions such as corridors, crypts, cellars, caves, etc. These voids are empty, complete, or partially water-filled or filled with various types of deposits [1]. Different prospecting methods have been assigned to detect underground cavities. Success depends on their ability to achieve the target depth with a suitable resolution for each situation. The electrical resistivity method represents the ideal choice due to the high efficiency of the survey and the high resistivity contrast between the air-filled cavity and surrounding Formation [2, 3]. Ground resistivity is influenced by geological factors such as conductivity, mineral and fluid content, porosity, and the degree of water saturation in the rock [4, 5]. Typically, resistivity measurements are achieved by injecting current into the ground soil through the usage of two Current Electrodes ($C1\ and\ C2$) and determining the voltage difference at two Potential Electrodes ($P1\ and\ P2$) [6, 7].

Several authors have carried out 2D Electrical resistivity techniques for engineering site investigation to discriminate subsurface structures such as cavities and sinkholes such as; Cardimona [8] electrical resistivity techniques for subsurface investigation. Metwaly and Al-Fouzan [9] Application of 2D geoelectrical resistivity tomography for subsurface cavity detection in the eastern part of Saudi Arabia. Thabit and Abed [10] compare the two-dimension (2D) imaging resistivity survey and Bristow's method in detecting the accurate depth and shape of subsurface cavities which is located within the Haditha-Hit area in western Iraq. Salman et al., [11] used the application of the electrical resistivity method for site investigation at University of Anbar, Ramadi city, western Iraq. Jamaluddin and Umar [12] studied the identification of the subsurface layer with the Wenner-Schlumberger arrays configuration geoelectrical method. El-Qady et al., [13] Studied imaging subsurface cavities using geoelectric tomography and ground-penetrating radar. Satarugsa et al., [14] Applied Two-dimension Resistivity Imaging for Detection of Subsurface Cavities in Northeastern Thailand: A Case Study at Ban Non Sa Bang, Amphoe Ban Muang, Changwat Sakon Nakhon. Salman et al., [15] Comparison between Dipole-dipole and Pole-dipole arrays in delineating weak subsurface zones using 2D electrical imaging technique in Al-Anbar University, Western Iraq.

In the present study, the 2D electrical resistivity technique is applied to delineate the subsurface layers and evaluate the formed weakness zone structures. In addition, analyze the resolution of subsurface images under different subsurface conditions using dipole-dipole and Wenner arrays.

2- Materials and Methodology:

A. Location of the Study Area and Geological Settings:

The State Company for Glass and Refractories locates in Al-Anbar Provence (33º 25' 58" N,43º 15' 33" E), about 5 – 6 km west of Ramadi city lines up with Al-Warar stream branching from the Euphrates River (Figure1).

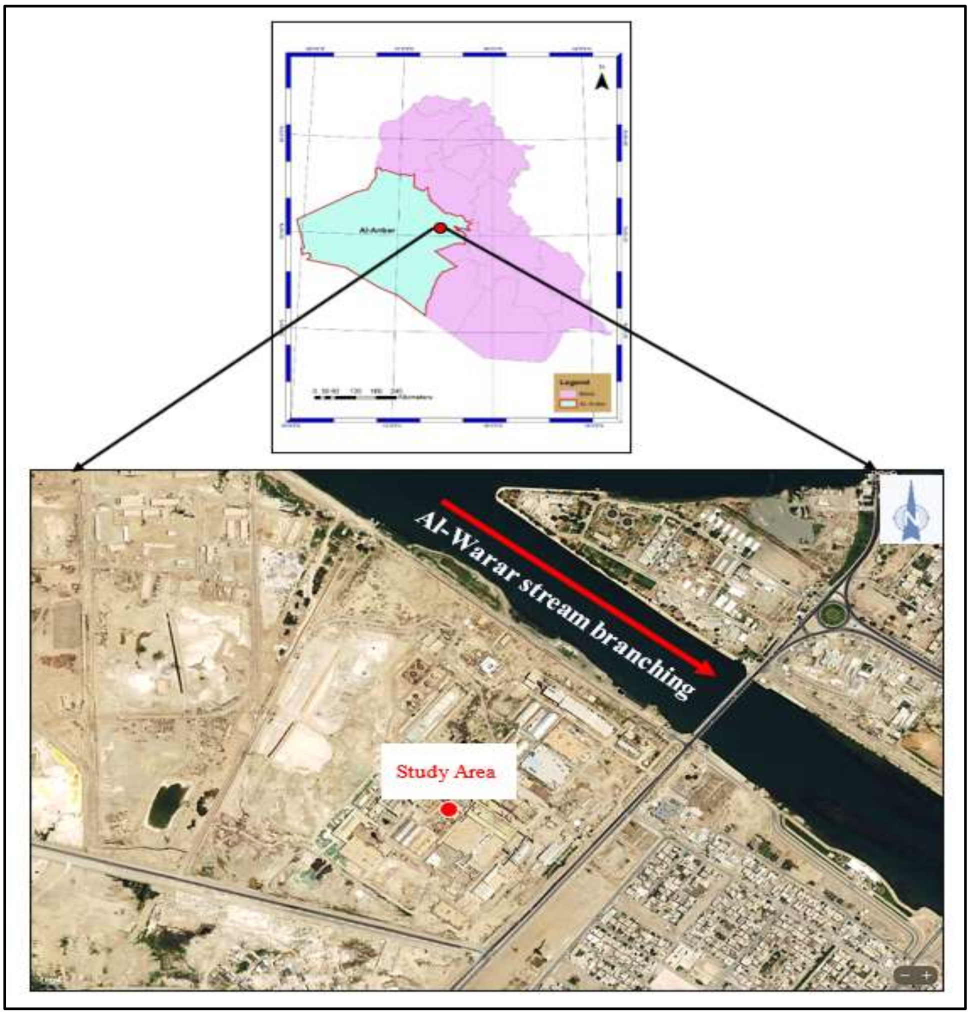

Figure 1: A satellite image shows the location of the study area.

Tectonically, the study area lies within the Salman Zone of the Stable Shelf of the Nubian – Arabian Platform from the west and Mesopotamian Zone (Euphrates Subzone) of the Unstable Shelf from the east; the thin layers of the Phanerozoic deposit were relatively small [16].

The structure fractures of the Precambrian towards the N-S and NW-SE directions [16]. Structurally, the zone is restricted by Amij Samarra – Halabcha Transverse Fault crosses the upmost part, one of the main subsurface structural lineaments. One more significant structural feature is the Abu – Jir Fault Region, which is also a subsurface fault running in the direction of ($NW - SE$) [15, 16]. The area's stratigraphic sequence is composed of Quaternary deposits, Injana Formation, and Fatha Formation. These deposits consist of marl, siltstone, claystone and fine sandstone with secondary gypsum along with gypsiferous soil and gypcrete and sabkha deposits [15, 17].

B. Data Acquisition and Processing:

The Wenner and Dipole – dipole arrays (Figure 2A &B) were used to gather a 2D electrical image. The Wenner electrode array is the simplest of arrays; that is consisting of four electrodes $(A, M, N, and\ B)$ placed in line and spaced equidistant from each other. The two outer electrodes, (A and B), are current electrodes, and the two inner electrodes, $(M\ and\ N)$, are potential electrodes [5]. The Wenner array has the strongest signal strength of any common array. This is especially important if the survey is conducted in areas with a lot of background noise and provides good resolution. One disadvantage of this array used for 2D surveys is the relatively poor horizontal coverage as electrode spacing increases [6]. Dipole-dipole array is made up of four electrodes $(A, M, N\ and\ B)$ in a straight line positioned on the ground. Dipole-dipole array demands high sensitivity instruments because the potential electrodes $(M\ and\ N)$ is outside the current electrodes $(A\ and\ B)$. In some cases, the current and potential electrodes may not equal the spacing between them because the n-factor controls the depth of penetration

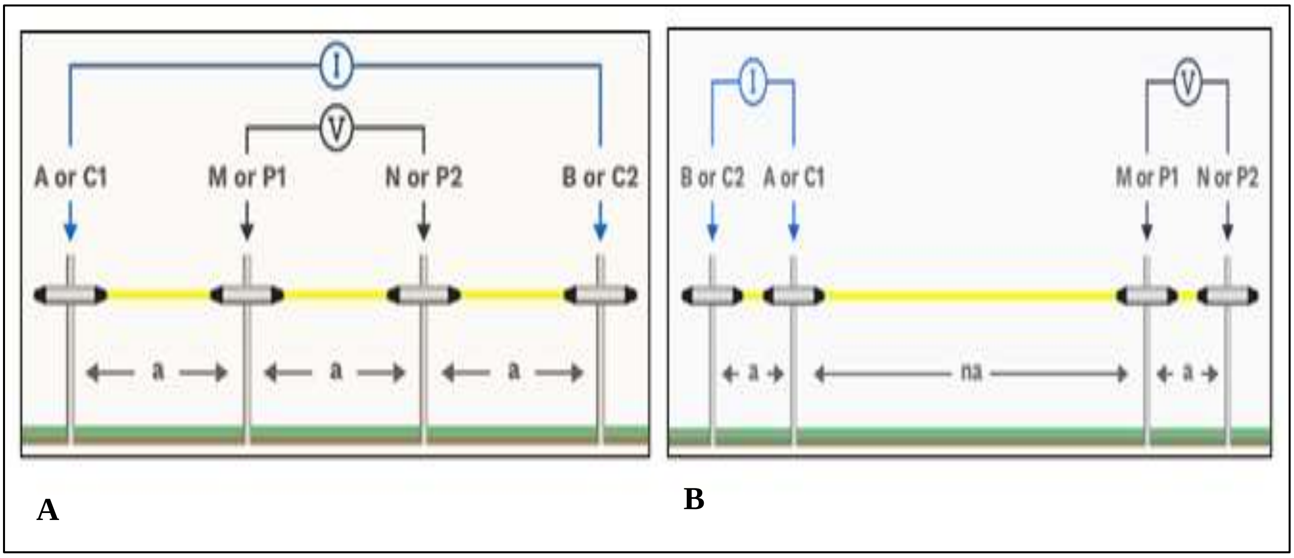

Figure 2: A sketch illustration, A) The Wenner array. B) Dipole – dipole array [14].

Syscal Pro instrument has been implemented in the field to calculate the apparent resistivity measurements using Wenner and Dipole-dipole arrays. Three selected stations have been used to discriminate, evaluate, and detect the subsurface layers (Figure 3). The field parameters used are illustrated in Table 1. Syscal Pro is an all-in-one multimode resistivity and induces polarization sounding and profiling techniques for environmental and engineering geophysical deconstructions.

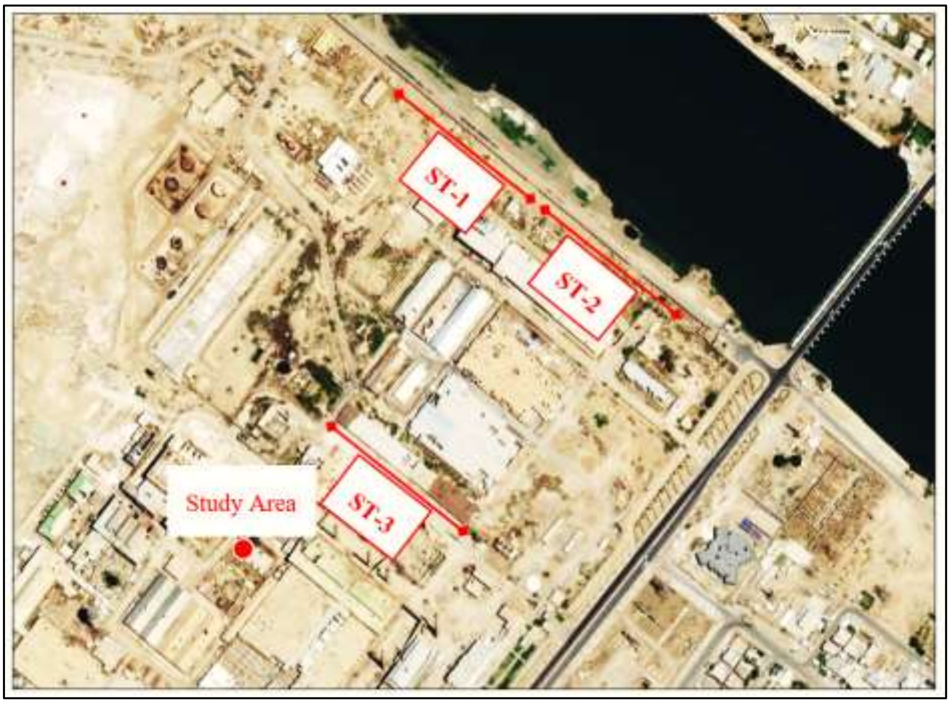

Figure 3: Location of selected stations.

Table 1: Field parameters of each 2D survey line.

Array type	NO. of electrodes	Profile Length (m)	a – Spacing (m)	Level	Max. depth of investigation (m)	NO. of readings
Wenner	120	120	1	39	20.2	2340
Dipole – dipole	120	120	1	54	15.4	4455

The data acquired from the field survey are transferred to PROSYS II, a software program used to manage, view and filter the field readings from the wrong data. The wrong data are defined as unwanted resistivity readings in the form of zero, negative or high resistivity values and are removed. The 2D resistivity model section has been performed using RES2DINV version (4.8.10), a computer software system that is used for converting the apparent resistivity values into a resistivity model section used for geological interpretation from the obtained data. The processing parameters that applied to the data are listed in Table 2.

Table 2: The processing parameters applied to the data.

Damping Factor	Automatic Damping Factor with Depth.
Initial Damping Factor	0.2100
Minimum Damping Factor	0.0500
Vertical to Horizontal Flatness Filter Ratio (Weight)	2
Number of Iterations	5-7
Contour Interval	Logarithmic Contour Interval

3-Results and Discussions:

A. 2D Inverse Model of Wenner Array:

The 2D inverse model represents the accurate image that is used for interpretation. The RMS error point to how to fit the calculated pseudo section is acceptable to the measured pseudo section, so it is better to decrease it as much as possible. The resistivity model section of the Wenner array at station-1 (Figure 4) points out a large variation in the resistivity values as shown in the profile as a single zone extends along with the inverse profile. These anomalies confirm that the groundwater seepage completely influences the subsurface layer due to the sediments interbedded with secondary gypsum at a depth of approximately (2.5 - 7.8) m. The water content and the degree of saturation make up the layer a weak zone that can form voids and cavities. The inverse model also indicates an expected cavity within the weakness zone at a depth of approximately (4.8 - 7.8) m.

The inverse model at station 2 (Figure 5) indicates the subsurface layers at approximate depths of 2.5 - 7.8 m. As in the inverse model, an expected cavity at an approximate depth of 4.8 m is filled with sediments, whereas the whole profile indicates fewer anomalies. This fact can be clarified that the groundwater does not influence the area, but some areas have been affected.

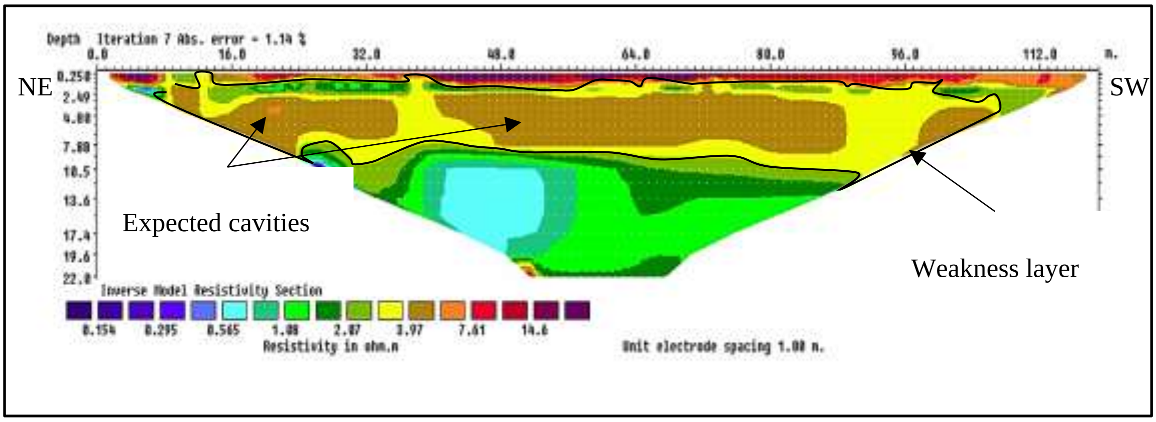

Figure 4: The 2D inverse model of Wenner array at station-1

The inverse model at station-3 (Figure 6) indicates the subsurface resistivity distribution was the weakness zone as a single layer at an approximate depth (1.5 – 7.88) m. As in ST-1 and ST-2, the resistivity anomaly variations refer to the acceptable interpretation for this case could be that the groundwater didn't affect the whole area. The weakness zone's maximum thickness seemed equal to 5.5 m within the Injana Formation, comprised of limestone, silty claystone interbedded with secondary gypsum, and sandy loam. Gypsiferous soils can make the subsurface layers unstable and results in the collapse of the layers to form sinkholes that work to threaten the infrastructure and the pattern of its engineering construction.

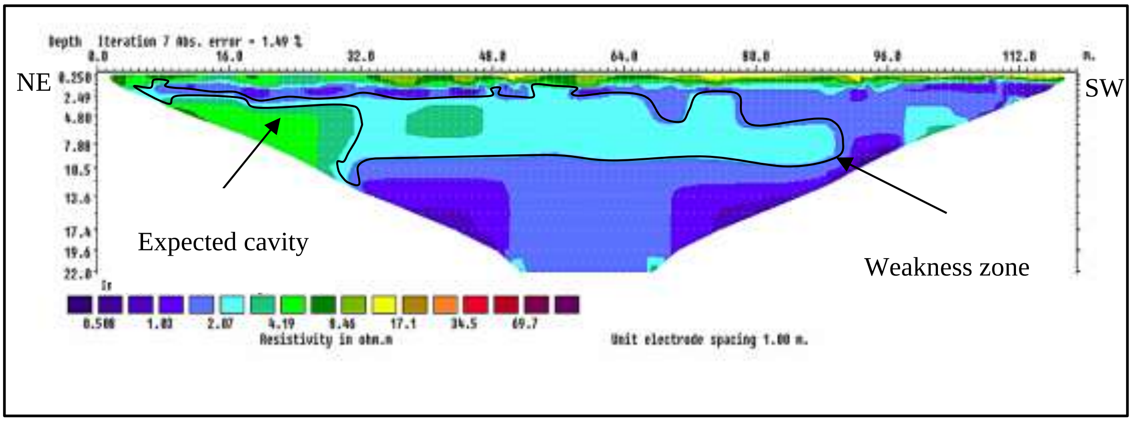

Figure 5: The 2D inverse model of Wenner array at station-2.

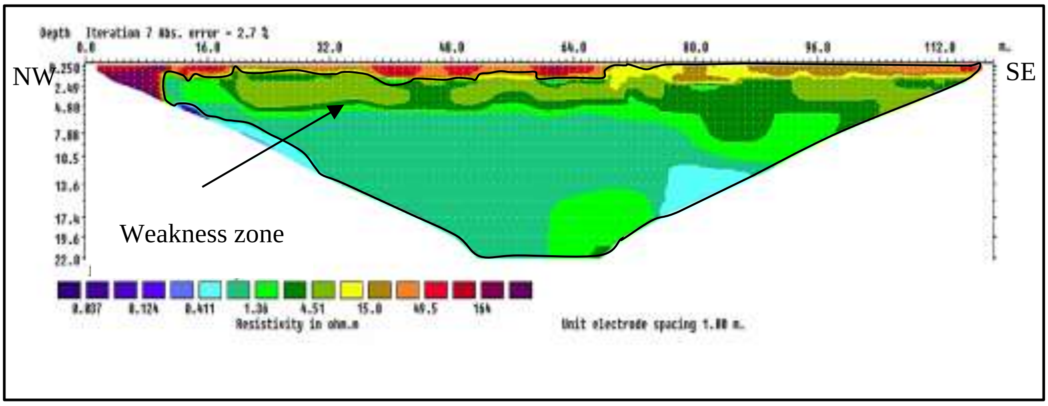

Figure 6: The 2D inverse model of Wenner array at station-3.

B. 2D Inverse Model of Dipole – dipole Array:

The Injana Formation deposits, which are primarily made up of silt, clay, sand, and sandy loam as well as interbedded with secondary gypsum and gypcretes, are composed primarily of silt, clay, sand, and sandy loam at approximate depth 2 to 7.8 m, according to the 2D inverse model of the station-1 Dipole-Dipole array (Figure 7). The dipole-dipole array has overpowered the Wenner array in determining the subsurface structures and has shown electrical inverse profile in determining the resistivity anomalies accurately. The inverse model showed the weakness zone accurately with more details.

Station 2 (Figure 8) indicates the area is influenced, especially at the same depth as ST-1 where the resistivity contrast indicates a significant anomaly at an approximate depth of 2 – 7 m. These anomalies could be an expected cavity filled with sediments.

Station 3 (Figure 9), the resistivity inverse model shows the top layer of the profile (first 1.5 m) is high resistivity values as a result of a dry layer near the surface, where the area is generally characterized by the presence of large proportions of voids were formed as a result of secondary gypsum extends with sediments at approximate depth (5 – 7.5) m. Which causes a serious threat to the area, and it becomes clear that the area of weakness forms a subsurface layer extending from an approximate depth of (2 to 7.8) meters for the entire study area.

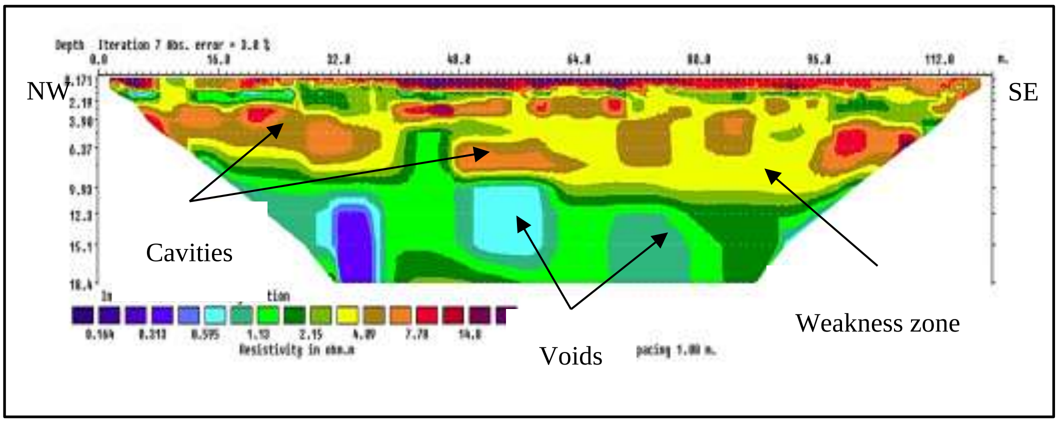

Figure 7: The 2D inverse model of Dipole – dipole array at station-1.

At the approximate depth (3.9) m to the left of the inverse, where cavity presence as three separated voids and the middle center of the inverse were indicated three cavities that be partially stuffed with sediments due to the interbedded of the gypcrete and secondary gypsum with the deposits of the Injana Formation. The area of these cavities ranges from 8 to 12 m**.**

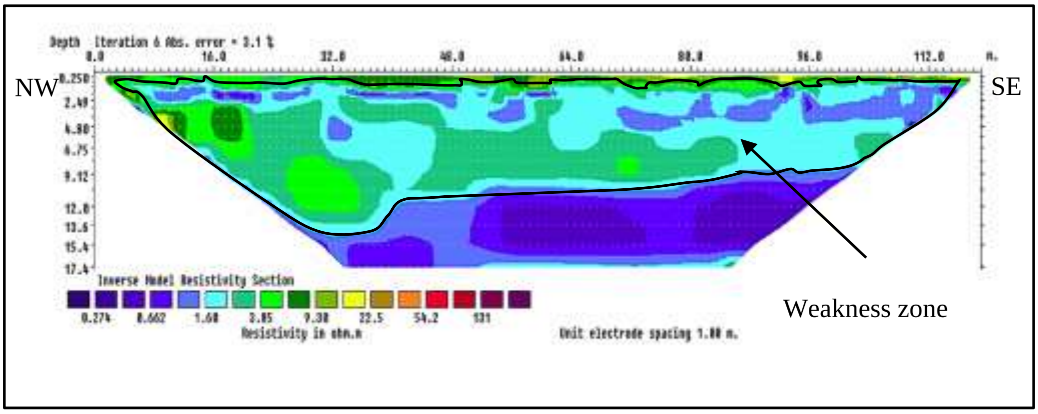

Figure 8: The 2D inverse model of Dipole – dipole array at station-2.

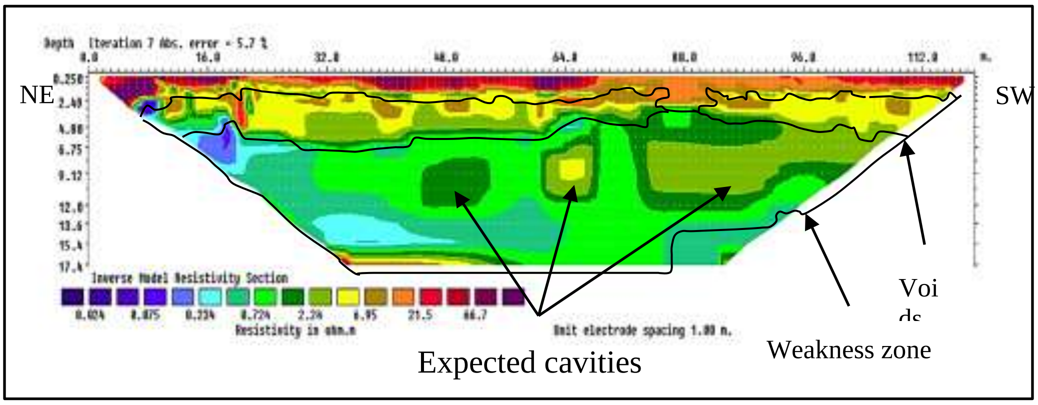

Figure 9: The 2D inverse model of Dipole-dipole array at station-3.

3- Conclusion:

The differences between the 2D Wenner and Dipole-dipole resistivity inverse are due to the features that distinguish each electrode array from others. Wenner array provides a higher resolution within the upper layers and is reduced with depth. On the other hand, the signal-to-noise ratio (S/N), geological nature, and water and mineral content also play an important role in the possibility of penetration and collecting the resistance between the potential electrodes. For example, station-1 (Fig. 4 and 7) indicates a perfect model with more details using the Dipole-dipole array, whereas the Wenner array indicates the subsurface weakness zone as a single layer. Resolution is important to determine the main features within the inverse resistivity distribution model.

The study area generally consists of the sediments of the Quaternary and Injana Formation, mainly sand, clay, marl and silt. Additionally, the subsoil has very high concentrations of secondary gypsum deposits, which are known for their propensity to interact with water, both above and below ground, resulting in cavities and voids. It breaks that may eventually be filled with water-rich sediments that weaken the soil, causing clay soils to swell and sandy soils to collapse.

Ar-Ramadi city is covered with shallow layers of gypsiferous soil, causing many environmental hazards, soil stability and engineering processes. Gypsiferous soil is one of the essential sediments that presently generate issues in the stability of infrastructures. This problem arises while dissolving gypsum in water, forming cavities, cracks, and voids, leading to differential settlement, rupture, and collapse of buildings and streets.

The groundwater levels in Ar-Ramadi city are shallow and deep into the surface in some areas, especially during the recharge season, causing multiple problems. Observing all the electrical inverse sections reveals that the area of weakness is concerted within the approximate depth of 2.5 – 7.8 m. It indicates that the weakness area is concentrated in this range and thus causes engineering problems.

The study recommends conducting engineering and site investigations of the soil and determining the type of soil and appropriate treatment methods to overcome these problems.

References:

[1] R. Putiška, M. Nikolaj, I. Dostál, and D. Kušnirák, "Determination of cavities using electrical resistivity tomography," *Contributions to Geophysics and Geodesy*, vol. 42, no. 2, pp. 201–211, Jan. 2012, doi: https://doi.org/10.2478/v10126-012-0018-3.

[2] P. P. Mahato, "Detection of Cavity Using Electrical Resistivity Tomography (ERT) at Patherdih, Jharia Coal Field, Dhanbad, India," *Universal Journal of Geoscience*, vol. 6, no. 4, pp. 114–117, Aug. 2018, doi: https://doi.org/10.13189/ujg.2018.060402.

[3] M. van Schoor, "Detection of sinkholes using 2D electrical resistivity imaging," *Journal of Applied Geophysics*, vol. 50, no. 4, pp. 393–399, Jul. 2002, doi: https://doi.org/10.1016/s0926-9851(02)00166-0.

[4] M. H. Loke, Tutorial: 2-D and 3-D electrical imaging surveys. 2018, pp. 1–243.

[5] R. F. Ballard, Y. Cuenod, and J. P. Jenni, "Detection of karst cavities by geophysical methods," vol. 26–27, no. 1, pp. 153–157, Dec. 1982, doi: https://doi.org/10.1007/bf02594210.

[6] A. S. M. Al-Gabery, "Geophysical Application for Engineering Purpose-Site Study," PDF, University of Baghdad, 1997. Unpublished Ph. D. Thesis, in Arabic.

[7] M. H. Loke, Tutorial: 2-D and 3-D electrical imaging surveys. 2016, pp. 1–243.

[8] S. Cardimona, "Electrical Resistivity Techniques For Subsurface Investigation," Feb. 2002.

[9] M. Metwaly and F. AlFouzan, "Application of 2-D geoelectrical resistivity tomography for subsurface cavity detection in the eastern part of Saudi Arabia," *Geoscience Frontiers*, vol. 4, no. 4, pp. 469–476, Jul. 2013, doi: https://doi.org/10.1016/j.gsf.2012.12.005.

[10] J. M. Thabit and A. M. Abed, "Detection of Subsurface Cavities by Using Pole- Dipole Array (Bristow's Method)/Hit Area-Western Iraq," *Iraqi Journal of Science*, vol. 55, no. 2A, pp. 444–453, 2014.

[11] A. M. Salman, A. M. Abed, and J. M. Thabit, "Comparison between Dipole-dipole and Pole-dipole Arrays in Delineation of Subsurface Weak Zones Using 2D Electrical Imaging Technique in Al-Anbar University, Western Iraq", *Iraqi Journal of Science*, vol. 61, no. 3, pp. 567–576, Mar. 2020.

[12] Jamaluddin and E. P. Umar, "Identification of subsurface layer with Wenner-Schlumberger arrays configuration geoelectrical method," *IOP Conference Series: Earth and Environmental Science*, vol. 118, p. 012006, Feb. 2018, doi: https://doi.org/10.1088/1755-1315/118/1/012006.

[13] El-Qady, Gad et al. "Imaging Subsurface Cavities Using Geoelectric Tomography and Ground-Penetrating Radar." *Journal of Cave and Karst Studies*, pp. 174-181, Mar. 2005.

[14] Satarugsa, Peangta et al. "Applied Two-dimension Resistivity Imaging for Detection of Subsurface Cavities in Northeastern Thailand: A Case Study at Ban Non Sa Bang, Amphoe Ban Muang, Changwat Sakon Nakhon.", pp. 26-27, 2004.

[15] A. M. Salman, J. M. Thabit, and A. M. Abed, "Application of the Electrical Resistivity Method for Site Investigation in University of Anbar, Ar-Ramadi City, Western Iraq", *Iraqi Journal of Science*, vol. 61, no. 6, pp. 1345–1352, Jun. 2020. DOI: https://doi.org/10.24996/ijs.2020.61.6.12.

[16] V. K. Sissakian and S. M. Muhammad, "The Geology of Ar-Ramadi Quadrangle," Unpublished, Iraq GEOSURV Library, 1994.

[17] S. Z. Jassim and J. C. Goff, "Geology of Iraq". Brno: Dolin, Prague and Moravian Museum, 2007.