Application of 2D Electrical Resistivity Method for Detections of Subsurface Karst Hazards Within the State Company for Glass and Refractories in Ar-Ramadi City, Iraq

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Abstract
The electrical resistivity method has been applied to detect the subsurface karst hazards using Dipole-dipole and Wenner – Schlumberger arrays with a spacing equal to 1m and n-factor 6 at three selected stations within the State Company for Glass and Refractories in Al-Ramadi City, Iraq. The results indicate that the area formed a weakness zone as two separated zones, the first at a depth in the range of 2.5–5 m within the quaternary deposits and the second weakness zone within the Injana Formation deposits at an approximate depth range of 7 – >12 m. The investigation advises conducting physical, chemical, and engineering site investigations to decide the suitable treatment techniques to solve these problems.

Keywords: Electrical Resistivity method; Dipole – dipole array; Wenner – Schlumberger array; Cavity detection; Karst hazards

1. Introduction

Major challenges with gypsiferous soils are prevalent in a variety of human activities. It has a significant impact on construction and infrastructure. Gypsiferous soils are made up of a secondary gypsum-rich within the soil that forms as a result of increased evaporation of salty and sulphate-rich groundwater in dry and warm environments. The majority of the original soil components (clay, silt, and sand) remain present in gypsiferous soils, but they are filled with varying levels of gypsum. Gypsum is more abundant in fine-grained soils than in coarse-grained soils. Almost all gypsum collects above the capillary water zone; in arid places where the water table is approximately 3 m below the ground surface, almost all gypsum accumulates above the capillary water zone (Mou'taz et al. 2010). The electrical resistivity method is one of the popular geophysical methods that are used for shallow subsurface and investigating several types of environmental problems and engineering applications due to its simple physical principle were provides high resistivity contrast that exists for delineating and evaluating the subsurface layers, effectual data acquisition and provides valuable subsurface images (Chitea and Georgescu, 2009; Dahlin and Zhou, 2004; Salman et al., 2020). The electrical resistivity method aims to describe and designate the variations of the physical parameters (ground resistance versus depth) of underground formations (Al-Gabery, 1997; Ballard et al., 1982). It is measuring a set of data in which numerous parameters such as apparent resistivity, conductivity, depth, etc. using an artificial source of current through point electrodes. Each of these parameters is correlated to one or more physical properties of the subsurface (Mahato, 2018; Telford et al., 1990).

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The electrical resistivity method is based on injecting the electrical current from an electrical resistivity instrument into the ground using two electrodes (A, B) that are made up of stainless steel and measuring the potential using two electrodes (M, N) (Ernstson and Kirsch, 2006; Loke, 2018). The arrays of the electrical resistivity method have distinct advantages and disadvantages in terms of depth of investigation, the spatial sensitivity to the horizontal and/or vertical variations, in addition to the signal strength of the selecting array. Regardless of the effects of noise (i.e., the effects of near-surface local variations in resistivity measurements which may place a limit on the detectability and resolution of karst structures), the application of an inappropriate array type will affect their recognition and discrimination in the pseudo sections (Salman et al., 2020; Zhou et al., 2002).

The aims of study are detecting, evaluating 2D mapping karst hazards using the electrical resistivity method through used two commonly arrays which are dipole-dipole and Wenner-Schlumberger.

2. Materials and Methods

2.1. Location and Geological Setting of the Study Area

The State Company for Glass and Refractories site in Al-Ramadi city, Al-Anbar (33° 25' 57.792" N, 43° 15' 34.8084" E), 5 Kilometers west of Al-Ramadi city lines up with Al-Warar stream branching of the Euphrates River (Fig. 1).

Fig. 1. A satellite image shows 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 rather small. The structure fractures of the Precambrian eon towards in the direction of (N–S) and (NW–SE) (Jassim and Goff, 2006). Structurally, the zone is restricted by Amij Samarra – Halabcha Transvers Fault crosses the upmost part that is one of the main subsurface structural lineaments. One more significant structural feature is the Abu – Jir Fault Region, which is also subsurface fault and running in the direction of (NW – SE) (Jassim and Goff, 2006). The stratigraphic sequence of the area composed from Quaternary deposits, Injana Formation, Fatha Formation. These deposits are consisting of marl, siltstone, claystone, and fine sandstone with secondary gypsum along with gypsiferous soil and gypcrete and sabkha deposits (Jassim and Goff, 2006; Salman et al., 2020).
2.2. Data Acquisition and Processing

Syscal Pro has been implemented as a resistivity meter, the Syscal Pro is an all-in-one multimode resistivity, induces polarization sounding and profiling techniques for environmental and engineering geophysical observations. The 2D electrical profiles were performed using Dipole–dipole and Wenner–Schlumberger arrays with a-spacing of 1m for each array at three selected stations within the study area (Fig. 2) (Table 1). The Dipole-dipole array is consisting of four linear electrodes with fixed a-spacing between the current (A, B) and potential (M, N) electrodes (Fig. 3A). The Dipole-dipole array is highly sensitive to horizontal variations, but insensitive to vertical variations in resistivity. Thus, it is respectable in mapping vertical subsurface structural bodies, such as dykes and cavities, but relatively poor in mapping horizontal structural bodies such as sills or sedimentary layers (Al-Ane, 1998; Loke, 2022). The Wenner–Schlumberger array is a combination of Wenner and Schlumberger arrays where the electrode position is as same as Wenner Alpha array, but the spacing between the current electrodes and potential electrodes is “n” times the spacing of the two potential electrodes (Fig. 3B). Wenner–Schlumberger is sensed and distinguishes of high resistivity below the current electrodes. That implies, Wenner – Schlumberger array sensitive to changes in resistivity horizontally and vertically as well as has a depth investigation 10% deeper than the Wenner array with the same spacing of current electrodes. Also, the signal strength is higher than Wenner array (Hermawan and Putra, 2016; Loke, 2018). Wenner-Schlumberger array can cover Wenner array weaknesses such as insufficient horizontal coverage, although it is not more useful than the Dipole–dipole array (Hermawan and Putra, 2016).

Fig. 2. Location of the selected stations of the 2D electrical profiles

Table 1. Field parameters of each 2D survey line

<table>
<thead>
<tr>
<th>Array type</th>
<th>NO. of electrodes</th>
<th>Profile Length (m)</th>
<th>a – Spacing (m)</th>
<th>Level</th>
<th>Max. depth of investigation (m)</th>
<th>NO. of readings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wenner-Schlumberger</td>
<td>120</td>
<td>120</td>
<td>1</td>
<td>54</td>
<td>22.3</td>
<td>3240</td>
</tr>
<tr>
<td>Dipole – dipole</td>
<td>120</td>
<td>120</td>
<td>1</td>
<td>54</td>
<td>15.6</td>
<td>4455</td>
</tr>
</tbody>
</table>
Fig. 3. The electrical electrode arrays; (A) The dipole-dipole array; (B) Wenner – Schlumberger array.

Firstly, the data processing has been performed using ProSysll were using to view, edit, remove the bad data points, and sort the readings before carrying out the 2D inverse, where the readings exported from the resistivity meter device as a binary data file and then converted to a data file with the extension (.dat) to reads within the RES2DIN program after the first data processing stage. Secondly, using RES2DINV software which is a computer program developed by Loke, to Geotomo Software used for processing the resistivity readings and calculating the inverse profile of the selected data to a resistivity model section used for geological interpretation, the processing parameters applied on the data were listed in Table 2.

Table 2. The processing parameters that applied on the data.

<table>
<thead>
<tr>
<th>Damping Factor</th>
<th>Automatic Damping Factor with Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Damping Factor</td>
<td>0.2100</td>
</tr>
<tr>
<td>Minimum Damping Factor</td>
<td>0.0500</td>
</tr>
<tr>
<td>Vertical to Horizontal Flatness Filter Ratio (Weight)</td>
<td>2</td>
</tr>
<tr>
<td>Number of Iterations</td>
<td>5-7</td>
</tr>
<tr>
<td>Contour Interval</td>
<td>Logarithmic Contour Interval</td>
</tr>
</tbody>
</table>

3. Results and Discussion

3.1. 2D Inverse Model of Wenner-Schlumberger Array

The 2D inverse model has been split into three resistivity values which are low, intermediate, and high resistivity values that comprise the inverse model for each array acquisition. The inverse model section of the Wenner-Schlumberger array at station-1 indicates and appears to have high resistivity values, especially down the electrode number 101 to 108 at the right of the inverse model section which refers to an expected cavity at approximate depth (3.19 - 7.5) m. Where the low subsurface section appeared as a single layer with lower resistivity values (Fig. 4).

Fig. 4. The 2D inverse model of Wenner-Schlumberger array at station-1.

The inverse model section of the Wenner-Schlumberger array at station-2 appeared the section as three zones extending horizontally, where the first zone at an approximate depth of (3m) and represented by high resistivity values, especially between the electrodes (35 – 62). The second zone is characterized
as a single layer that have low resistivity values and interbedded with high resistivity values form the third zone down the electrodes (61-67) which consists of high resistivity values, where the third zone at an approximate depth (14) m that gradually increases the resistivity values as going down the section. This ambiguity can be interpreted as an expected cavity filled with sediments. This area is called the weakness zone which characterizes as an unstable area that can be caused threaten the buildings and can cause cracks and subsidence in the soil. This area lies within the Injana Formation, composed of claystone interbedded with secondary gypsum and sandy loam. Gypsiferous soils occur in places where gypsum is deposited and when there is not sufficient soil depth or drainage for the calcium and sulfate to leach. Instead, they accumulate in the subsoil profile or form interbedded layers (Fig.5).

![Fig. 5. The 2D inverse model of Wenner-Schlumberger array at station-2.](image)

The inverse model section of the Wenner – Schlumberger array at station-3 which is clearly indicates the subsurface layers is totally influenced, these anomalies clearly confirm the subsurface layer are completely influenced by the groundwater seepage as a result of the sediments that interbedded with secondary gypsum and several gaps, voids and an expected cavity have been marked in the inverse model at depth approximately (2-6.5) m. The inverse section appeared at depth approximately 13.5 m rich in secondary gypsum deposits (Fig.6).

![Fig. 6. The 2D inverse model of Wenner-Schlumberger array at station-3.](image)

3.2. 2D Inverse Model of Dipole – dipole Array

The 2D inverse model of the Dipole – dipole array of station-1 indicates the resistivity anomalies at approximate depth (2-9) m that formed the karst area within the weakness zone that contains an expected cavity, voids, and lens, where formed within Injana Formation at right part of the section. In comparison, the Dipole – dipole array produced a section with finer subsurface detailing of the layers. This distinction has occurred due to the spatial accurateness and the strength of the array in determining
the resistivity anomalies with which the Dipole – dipole overpowered the Wenner – Schlumberger array, as well as its ability that distinguished it in the vertical coverage (Fig. 7).

![Fig. 7. The 2D inverse model of Dipole – dipole array at station-1.](image)

The 2D inverse model of the Dipole-dipole array of station-2 indicates the resistivity anomalies with high contrast where appeared many voids along the inverse profile formed due to the subsurface layers’ rich in gypcrete and secondary gypsum interbedded with the sediments. At an approximate depth of 9.12 m, a sharp expected cavity presence extends horizontally from electrodes 32-55. The large cavity could be filled or partially filled with sediments (Fig. 8).

![Fig. 8. The 2D inverse model of Dipole – dipole array at station-2.](image)

The 2D inverse model of the Dipole – dipole array of station-3 clearly indicates the resistivity contrast between the anomalous part of the weakness zone and background resistivity distribution, where the weakness zone lies at approximate depth (2 – 6.75) m that showed separated voids along the profile and extended along the profile. As well as an expected cavity at an approximate depth (12) m. These voids and cavities can be developed to connect with each other due to groundwater seepage and the subsurface layers rich in gypcrete deposits. This problem indicates that the area is entirely affected by the interaction of groundwater with the gypsum present in the Formation deposits, which leads to the dissolving of the gypsum. So, these voids generate cavitations that may be filled with sediments or partially filled. The result is soil subsidence, which leads to cracks in facilities and buildings (Fig. 9).

![Fig. 9. The 2D inverse model of Dipole – dipole array at station-3.](image)
5. Conclusions

The electrical resistivity method has been implemented as an investigation tool to recognize and analyses subsurface engineering problems. It is found that the study is totally damaged and formed a weakness zone as two separated zones at an approximate depth (2.5 – 5) m within the quaternary deposits and the second weakness zone within the Injana Formation deposits at an approximate depth (7 – >12) m. The main differences between the Wenner-Schlumberger and Dipole-dipole arrays offer a good indication for choosing the best array for detecting karats areas. In particular, the Dipole-dipole array had surpassed the Wenner-Schlumberger arrays in detecting more details and provides the perfect and accurate image of the subsurface layers because of the signal to noise ratio and array coverage, particularly in detecting the weakness zones with more elements. The entire karst zone was captured by the Wenner-Schlumberger array.

The lithological characterizations of the Al-Ramadi area are covered mainly with layers rich in gypsiferous. One of the primary deposits that currently causes issues with the stability of infrastructure and engineering problems is gypsiferous soil. Gypsum dissolves in water and causes cavities, fractures, and voids that cause structures and roadways to settle differentially, rupture, and collapse. In many areas, especially during the recharge season, groundwater levels within Al-Ramadi range from shallow to deep, leads to creating several issues. The study recommends conducting physical, chemical, and engineering site investigations to decide the appropriate treatment techniques to solve these problems.

References

