Detection of Buried Utilities Using Electrical Resistivity Imaging (ERI) Technique

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Abstract

The main objective of this paper is to show the ability of resistivity technique for investigating the buried utilities (their location and depth) for characterizing the surrounding subsurface soils. This study deals with implementation of 2-D electrical resistivity imaging (ERI) to detect the location of buried utilities existing in the Al-Dhubat Interchange in Kut city, Wassit Governorate south of Baghdad. Interpretation results of the subsurface investigation of this site have been compared with those obtained from conventional methods. Generally, the site is characterized by its gradual decreases in resistivity with depth with range of resistivity values (<1-140 ohm.m) which is mostly consists of silty clay to clayey silt with lenses or pockets of medium, stiff and very stiff silty clay with sand or gravel.

Several utility pipes with different diameters of φ1200, φ1100, φ600 and φ 400 mm with low resistivity values (<1 ohm.m) have been identified in the 2-D resistivity sections. The results of 1-D VES are in agreement with that of 2-D ERI as their resistivity values decrease with depth. Besides, IP values for this site are in agreement with the resistivity data as it is an indicator of clay content and their uniform sections reflecting the high moisture content and the effect of salts in the subsurface soil and water.

Keywords: 2-D Electrical Resistivity Imaging (ERI); 1-DVES; Induced Polarization (IP); Buried Utilities

الكشف عن الخدمات المدفونة باستخدام تقنية المقاومة النوعية التصويرية (ERI)

الخلاصة

ان الهدف الأساسي لهذا البحث هو إظهار قدرة تقنية المقاومة النوعية الكهربائية للتحري عن الخدمات المدفونة (موقعها وعمقها) و توصيف التربة تحت السطحية المحيطة بها. تتعامل هذه الدراسة مع تطبيق طريقة المقاومة

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النوعية الكهربائية التصويرية ثنائية البعد (2-D ERI) لكشف وتحديد موقع وعمق الخدمات المدفونة والموجودة في تقاطع الضباط في مدينة الكوت بمحافظة واسط جنوب بغداد. تمت مقارنة نتائج تفسير التحري تحت السطحي لهذا الموقع مع تلك التي تم الحصول عليها من الطرق التقليدية. عموما، يتميز الموقع بالتناقص التدريجي لقيم المقاومة النوعية مع العمق بمدى قيم تتراوح ما بين (أقل من 1- 140 أوم.م) مكونة معظمها من الطين الغريني إلى الغرين الطيني مع عدسات أو جيوب من الطين الغريني والرمل والحصى بقوام متوسط، وقاسي الى قاسي جدا. تم تحديد عدة أنابيب خدمة بأقطار مختلفة هي φ1200 و φ1100 و φ600 و 400 φ ملم مع قيم مقاومة نوعية منخفضة (أقل من 1 أوم.م) في مقاطع المقاومة النوعية ثنائية البعد. كانت نتائج الجس الكهربائي العمودي (1-D VES) في اتفاق مع تلك الخاصة بثنائية البعد (2-D ERI) طالما تقل قيمها مع العمق. علاوة على ذلك، كانت قيم IP لهذا الموقع في اتفاق مع بيانات المقاومة النوعية طالما تعد كمؤشر للمحتوى الطيني وعكست مقاطعها المتجانسة المحتوى العالي للرطوبة وتأثير الأملاح في التربة والمياه تحت السطحية.

INTRODUCTION

An adequate ground investigation is an essential preliminary to the execution of a civil engineering project. Sufficient information must be obtained to enable a safe and economic design to be made and to avoid any difficulties during construction. The principal objects of the site investigation are to: (1) determine the sequence, thicknesses and lateral extent of the soil strata and bedrock; (2) obtain representative samples of the soils (and rocks) for identification and classification in laboratory tests to determine relevant soil parameters; (3) identify the groundwater conditions [1].

Geophysical surveying provides a relatively rapid and cost-effective means of deriving really distributed information on subsurface geology. In the exploration for subsurface resources, the geophysical methods are capable of detecting and delineating local features of potential interest that could not be discovered by any realistic drilling program. Geophysical surveying does not dispense with the need for drilling, when properly applied; it can optimize exploration programs by maximizing the rate of ground coverage and minimizing the drilling requirement. An alternative method of investigating subsurface geology is, of course, by drilling boreholes, but these are expensive and provide information only at discrete locations [2].

The choice of a geophysical method appropriate for site investigation will depend on a wide range of factors including: site ground conditions; special situations (e.g. the need to drilling); specific technical requirements (e.g. the needs for groundwater monitoring and soil sampling); site specific operational issues (e.g. accessibility, proximity to non-involved persons etc.); presence of subsurface features (e.g. tanks, voids and archaeological features); time available; and cost [3].

The resistivity surveys method is one of the oldest geophysical techniques which has been used for many decades in geological, hydrogeological, mining, geotechnical, environmental, archeological and even hydrocarbon exploration [4, 5]. Many works have been done to establish a relationship between soil engineering test and Electrical Resistivity Imaging (ERI) data to produce continuous information of the subsurface and to probe into several meters below the surface [6]. Survey design and layout strategies that produce optimum information using different ERI configurations and set up in different geological settings have been the topic of several studies (such as Stummer et al., 2004[7]; Ayolabi et al., 2009 [8]; Karim et al., 2013[9]). From site measurements, the true resistivity of the subsurface soil layers and utilities can be estimated. The resistivity

of a type of soil or rock may vary widely due to various geological parameters (such as mineral and fluid content, porosity and degree of water saturation in the soil/rock) [10].
The main objective of this paper is to show the ability of resistivity technique to investigate the buried utilities as a fast method for detecting the location and depth of buried pipes and cables and giving the subsurface characterization of the surrounding soils.

ELECTRICAL RESISTIVITY METHOD

Basic Principles of ERI

The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. The basic principles of Resistivity Imaging (RI) depend on the linear relationship between electric current (I) and potential difference (V) which is given by the following equation [11, 12]:

$$V = IR \qquad \dots(1)$$

where R is the resistance.
For a given material (conductor), the resistance is proportional to its length (L) and inversely proportional to its cross-sectional area (A). This relationship is expressed in the following equation:

$$R = \frac{\rho L}{A} \qquad \dots(2)$$

The proportionality constant (ρ) is the resistivity of the conductor. It is a physical property of the conductor which expresses its ability to resist the flow of electric current.
For a homogeneous ground with single electrode, the potential will separate radially outward the current source, where area (A) will be a half sphere ($2\pi r^2$) with radius (r). Thus, Eq. 1 is rewritten as:

$$\rho = RK \qquad \dots(3)$$

where K=2πr for the half sphere. Equation 3 consists of two parts: the first is the resistance (R) and the second is called the geometric factor (K) which describes the geometry of the electrode configuration [12, 13].

For a homogeneous ground with four electrodes, the geometric factor in Eq. 3 will be varied according to the type of electrodes configuration shown in Figure 1. The most common electrode arrays used in Electrical Resistivity Imaging (ERI) are Wenner, dipole-dipole and Wenner-Schlumberger arrays [14].

In fact, the geological structures of the ground are inhomogeneous and the measured resistivity does not represent the true resistivity, but an apparent resistivity [11, 14]. Therefore, in an inhomogeneous ground, the resistivity (ρ) in Eq. 3 will be replaced by an apparent resistivity (ρ_a):

$$\rho_a = RK \qquad \dots(4)$$

The apparent resistivity value depends on the geometry of electrode (geometric factor, K). The relationship between the "apparent" resistivity and the "true" resistivity is a complex relationship. To determine the true subsurface resistivity from the apparent resistivity values is carried out by the "inversion" problem.

Induced Polarization

In certain conventional resistivity surveys, it can be noted that the potential difference measured between the potential electrodes do not drop instantaneously to zero when the current is turned off. Instead, the potential difference drops sharply at first, then gradually decays to zero after a given interval of time. This means that certain bodies in the ground can become electrically polarized. Upon turning off the polarizing current, the ground gradually discharges and returns to equilibrium. This phenomenon is the foundation of a geophysical survey technique called Induced Polarization (IP) [15].

STUDY AREA

This study was carried out in the Al-Dhubat Interchange site in Kut city, Wassit Governorate, about 172 km to the south of Baghdad (Fig. 2). The main reason for selecting the study area is represented by the proposal which is introduced to construct a bridges interchange within Kut city, so it is required to detect all the existing utilities. Moreover, the study area has been covered with soil site investigation in addition to the availability of three boreholes were drilled in this site (B.H. 2 and B.H. 3 within the site) in addition to third one (B.H. 1) outside the site at 160 m east B.H. 2 [16]. In general, the soil stratification logs for these boreholes are almost similar with few differences as indicated by the soil section for the three boreholes (Fig. 3). As a whole, this information allows the correlation of ERI measurements with boreholes log, field and experimental tests. Besides, all the existing utilities have been assigned by Siraj Offshore for Consulting Engineer (SOCE, 2014) [17] (Plate 1).

METHODOLOGY

1-D and 2-D Surveys

The main features for 1-D include a 4 electrodes, battery operated unit with a robust waterproof design for reliable operation in harsh environment with others features (Plate 2a), while for 2-D the 64 electrodes unrestricted switching in a compact (Plate 2b). The greatest limitation of the resistivity sounding method is that it does not take into account lateral changes in layer's resistivity. Such changes are probably the rule rather than the exception. The failure to include the effect of such lateral changes can results in errors in the interpreted layer's resistivity and/or thickness [18]. For 1-D surveying, the sounding cable set is intended to facilitate Schlumberger soundings. The cables incorporate heavy gauge conductors with excellent insulation to ensure good survey results. Moreover, there are convenient, short hook-up cables that reduce setup times and permit to position the cable drums as desired.

For 2-D surveying, the equipment is switched on after all the necessary arrangement of electrodes, cables set, selector unit and battery. External batteries are recommended for measurements during ABEM Lund Imaging survey to ensure sustainable energy during data acquisition.

For both 1-D and 2-D configurations, some field mistakes may be faced which may increase the value of error such as: bad connection between the electrode and the ground; bad connection between the electrode and the cable (or clips cord); cutting in the metal wire inside the cable; feet steps near the electrodes during the measuring operation; and raining or high moisture content.

Survey Design

For 2-D imaging, eight spreads with total length of 700 m and different electrode spacing have been surveyed as follows: 4 (120 m long- 3 m spacing), 3 (60 m long- 1.5 m spacing), and 1 (40 m long- 1 m spacing) by using Wenner-Schlumberger array for all spreads. The 2-D inversion resistivity sections for Lines-R1 to R6 are trending from SE to NW direction except Lines-R7 and R8 (Fig. 4). ABEM Terrameter SAS 4000 was used for data collection of ERI. The maximum depth of investigation of the surveyed site was about 26 m.

Resistivity Data Processing

The apparent resistivity measurements were collected using the conventional Wenner-Schlumberger array, it was possible to transform the field dataset into a format that can be readable by the software RES2DINV for data processing and modeling. RES2DINV is a program that automatically generates a 2-D resistivity model for subsurface from field data measurements. The inversion routine used by the program is based on the smoothness-constrained least-squares method [19].

The 2-D model used by this program divides the subsurface into a number of rectangular blocks. By default, the program uses a heuristic algorithm partly based on the position of the data points to generate the size and position of the model blocks. The depth to the deepest layer in the model is set to be about the same as the largest depth of investigation of the datum points, and the number of model blocks does not exceed the number of datum points (i.e no. of model blocks equals no. of datum points) [18].

The purpose of this program is to determine the resistivities of the rectangular blocks that will produce an apparent resistivity pseudosection which agrees with the actual measurements. The optimization method basically tries to reduce the differences between the calculated and measured apparent resistivity values by adjusting the resistivity of the model blocks. A measure of such differences is given by the Root-Mean-Squared (RMS) error. However, the model with the lowest possible RMS error can sometimes show large and unrealistic variations in the model resistivity values and might not always be the "best" model from a geological perspective. In general, the most prudent approach is to choose the model at the iteration after which the RMS error does not significantly change. This usually occurs between the 3^{rd} and 5th iterations [20].

RESULTS AND DISCUSSION

Resistivity data collected along 8 lines (Lines R1 to R8) have been analyzed with the assistance of computer softwares, RES2DINV for 2-D and IPI2WIN for 1-D. Generally for 2-D survey, the resistivity are ranging between (<1-140 ohm.m) for Wenner-Schlumberger arrays with maximum depth of investigation is around 26 m. The overburden soils exhibit pronounced thickness variation along these sections. The whole sections reflect approximately three resistivity layers with relatively low values along depth. By correlating ERI values with boring logs and available data from site investigation, the resistivity values (<10 ohm.m) are interpreted as silty clay to clayey silt with conductive response of the moistures content due to the presence of salts such as sulphate SO_4 and chloride Cl^- that leading to brackish water quality of the moisture content (Table 1). Some areas of high resistivity values around (105-140 ohm.m), specially for the first layers, are due to the filling materials and lenses or pocket of medium, stiff-very stiff silty clay with sand or gravel.

In addition, several utility pipes with different diameters have been identified (such as φ1200, φ1100, φ 600 and φ 400 mm) at different depths which are characterized by their very low resistivity areas (<0.5 ohm.m). Besides, some other low resistivity areas are recognized and explained as soft clay soil. Low Resistivity values (as an average <5 ohm.m) are interpreted as silty clay to clayey silt. Some areas of relatively high resistivity values (around 20-30 ohm.m) assigned to anomalous areas at or near surface layer which are explained as soil with appreciable amount of filling materials (fill material mixed with sand, clay, coarse rubble and the ruins of the building materials). High resistivity value (>36 ohm.m) at depth more than 23 m are explained as sandy silt to silty sand especially after 30 m. It is worth to mention that the decreasing resistivity with depth is affected by the conductive response of the moisture content due to the presence of salts. Regarding the existing utilities, the pipe diameters of φ1200 mm at depth around 6-8 m and φ1100 mm at depth around 8 m are recognized within the sections of Lines- R1 and R2 (Figs. 5 and 6).

As well as, sections of Lines- R3, R4, R5 and R6 (Figs. 7 to 10) assigned probably to the position of the pipe diameter φ1100 mm at the center of these sections at depth approximately 4-5 m. The pipe diameter of φ400 mm at depth a round 6-7 m is clearly identified at the center Line-R7section (Fig.11). At depth approximately 5-6 m, the pipe diameter φ 600 mm is indicated in the Line-R8 section (Fig.12). It is worthy to mention that some drift in pipe locations is observed in comparison to that assigned by Siraj Offshore for Consulting Engineer (2014) [16].

The IP values for the site are ranging between (0.5-73 mV/V) with good agreement with resistivity data, where high chargeability are associated with low resistivity. In general, most of the IP images showed homogenous sections indicating to the high conductive response due to the high effect of salts in water of the site. Figure 13 shows the inverted chargeability section for Line-R7 as a representative section.

For 1-D survey, data were collected from 4 VES points along Lines-R3, R4, R5 and R7. In quantitative interpretation, the method of partial curve matching was used. The resistivity curves are classified into four categories (HK, QQ, K and Q types). Figures 14 and 15 illustrate the interpretation results of VES points along Lines-R5 (QQ type) and R7 (HK type) respectively as representative curves. The results are in good agreement with that of 2-D ERI

Table 2 presents an abbreviation for utility lines detected in the site study with an approximate position and depth using resistivity technique compared with that obtained by Siraj Offshore for Consulting Engineer (2014) [16].

CONCLUSIONS

The main conclusions which can be drawn from this study are summarized as follows:

1. Electrical Resistivity Imaging (ERI) gives good presentation for wide subsurface area alongside with drilling to make integration and to cover the gaps between boreholes.
2. This study reveals that there are several pipes present which have been correlated with the presence of underground utilities assigned by Siraj Offshore for Consulting Engineer.
3. In general, electrical resistivity in this site decreases with depth as the study area mostly consists of silty clay to clayey silt soil and due to groundwater effect. The deposits of the studied site are characterized by their inhomogeneity which are assigned by their wide range of resistivity values ranging from <1 to 140 ohm.m specially for the first layers owing to the filling materials, lenses (or pockets) of medium, stiff and very stiff silty clay with sand or gravel.
4. Comparing interpretation results of 2D and 1-D VES, it is found that 2-D imaging is better than VES technique in detecting the variety of layers at the surveyed area. So VES results can be calibrated on the light of 2-D imaging technique results.
5. The IP values for this site are ranging from 0.315 to 73 mV/V showing a good agreement with the resistivity data. IP measurements are good complement to resolve ambiguities in the interpretation, as it is an indicator of clay content where high chargeability (low resistivity) refers to soft clay, while low chargeability corresponds to high values in the resistivity sections for the same site. Also, most IP sections appeared homogenous that may reflect the high moisture content and the effect of salts in water.
6. Several types of utilities and anomalous areas have been identified on ERI sections such as pipes with different diameters φ (400, 600, 1100, and 1200) mm. While, other types of utilities such as electrical utilities are not appeared due to the low resistivity of such utilities and high salt content in the subsurface soils and water.

Table (1) Results of Chemical Analysis [17].

B.H No.	Depth (m)		Soil				Water			
	From	To	O.C.%	Cl^-(mg/l)	TSS%	SO_3%	pH	Cl (mg/l)	SO_4(mg/l)	TDS (mg/l)
1	1.5	2.0	0.5	2250	3.8	1.26	7.6	1150	1900	3100
	6.0	6.5	0.3	600	1.9	0.80				
	7.5	8.0	0.4	900	2.7	1.14				
	10.5	11.0	0.3	1650	2.6	1.30				
	13.5	14.0	0.1	2400	3.0	1.60				
	23.0	23.5	0.2	1650	3.9	1.47				
	34.0	35.0	0.3	2850	3.8	1.26				
2	2.0	2.5	0.4	3900	3.8	1.49	7.5	600	1580	2200
	7.0	7.5	0.1	900	2.7	1.14				
	12.5	13.0	0.2	750	2.1	1.03				
	15.5	16.0	0.3	1050	1.3	0.91				
	20.0	20.5	0.3	900	1.8	1.72				
	28.0	28.5	0.5	1950	3.7	1.03				
	37.5	39.5	0.2	2550	2.6	0.57				
3	1.5	2.0	0.4	3900	3.5	1.50	7.7	500	1250	1880
	3.5	4.5	0.5	1350	1.5	1.03				
	9.0	9.5	0.2	600	2.8	0.80				
	14.5	15.5	0.3	750	2.9	1.26				
	21.5	22.0	0.3	1050	1.6	1.26				
	29.5	30.5	0.2	1950	3.0	1.72				

Table (2) Approximate position and depth of utilities existing in the site study by resistivity technique.

Utility type	Position with respect to Siraj O.C.E, 2014	Position with respect to this study	Percentage of errors %	Average depth from the present study
Sewerage pipe φ1100 mm (from pipe to the Al-Muʾatasim storm water pump station)	50 m	45 m	11	4 m
Sewerage pipe φ1200 mm (from pipe to the street back Al-Muʾatasim storm water pump station)	34 m	37 m (Line-R1)	8	7 m
Sewerage pipe φ400 mm (from pipe to the street of Al-Dhubat)	58 m	62 m (Line-R7)	6	6 m
Sewerage pipe φ600 mm (from pipe to the street of Al-Dhubat)	70 m	76 m (Line-R8)	7	5 m

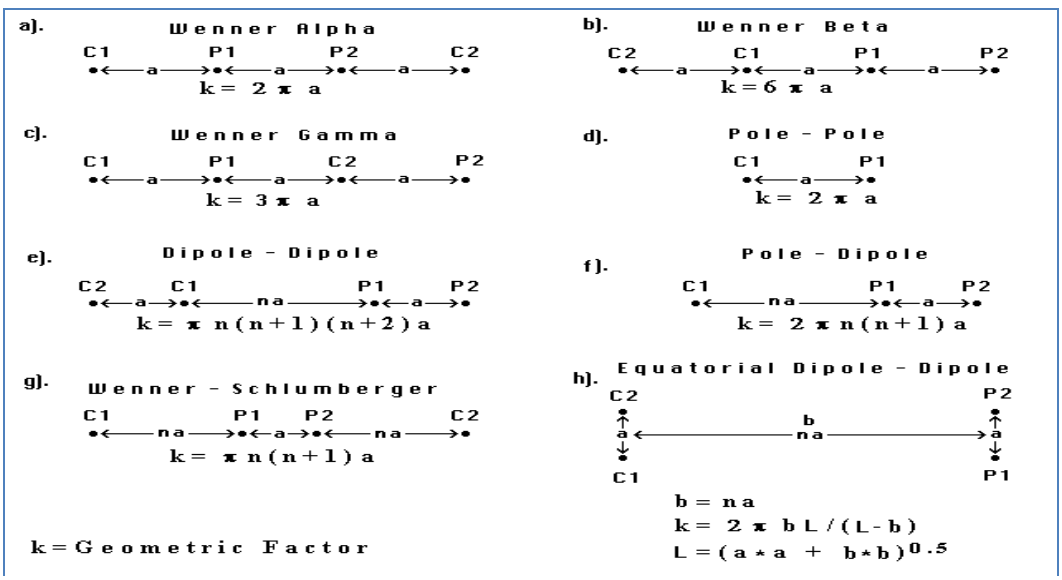
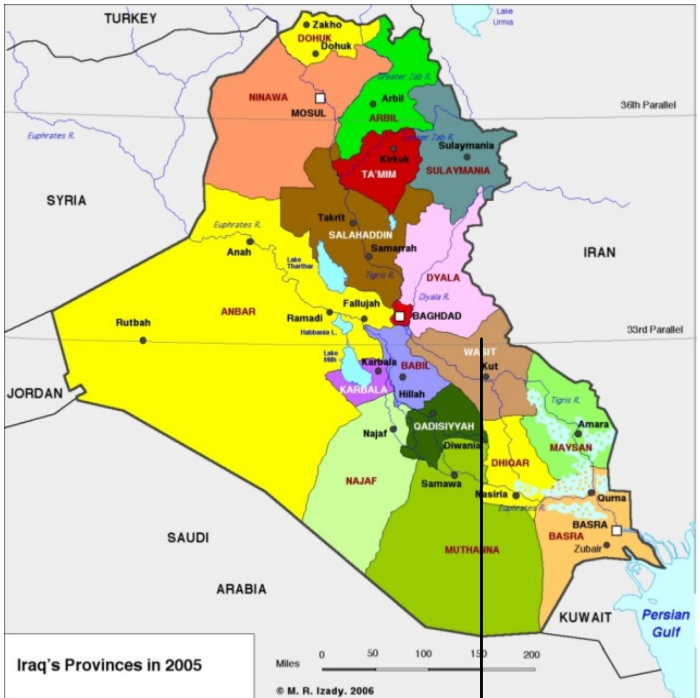


Figure (1) Common arrays used in resistivity surveys and their geometric factors [12].



(a)

(b)

Figure (2) (a) Location of site study in Kut city, Wassit Governorate; (b) Satlllite image for the site and surroundings.

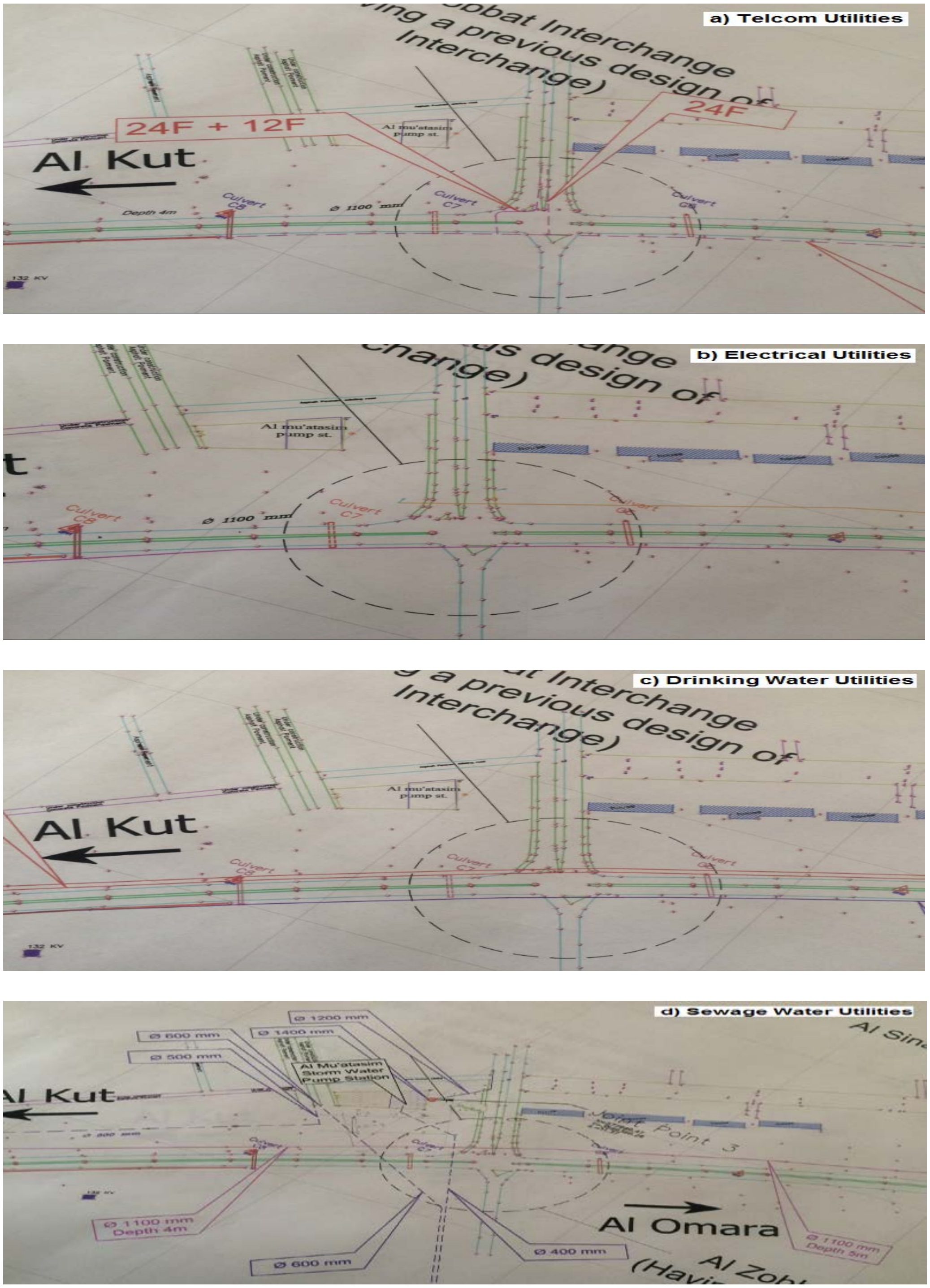


Plate (1) (a) Telcom Utilities; (b) Electrical Utilities; (c) Sewage water Utilities; (d) Drinking water Utilities [17].

(a) **(b)**

Plate(2) ABEM Terrameter SAS 4000 with accessories for: (a) 1D and (b) 2D configurations.

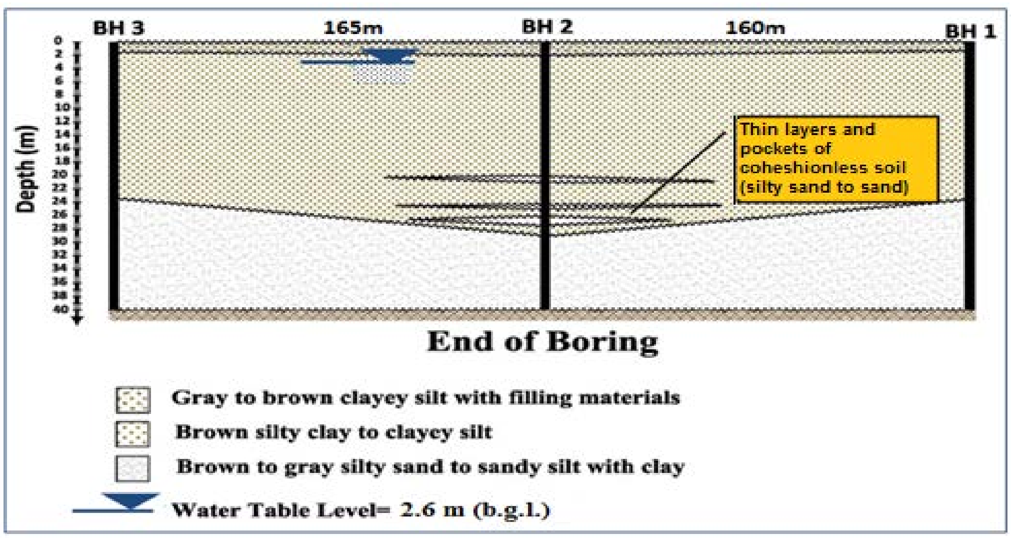


Figure (3) Soil section for the three boreholes [16].

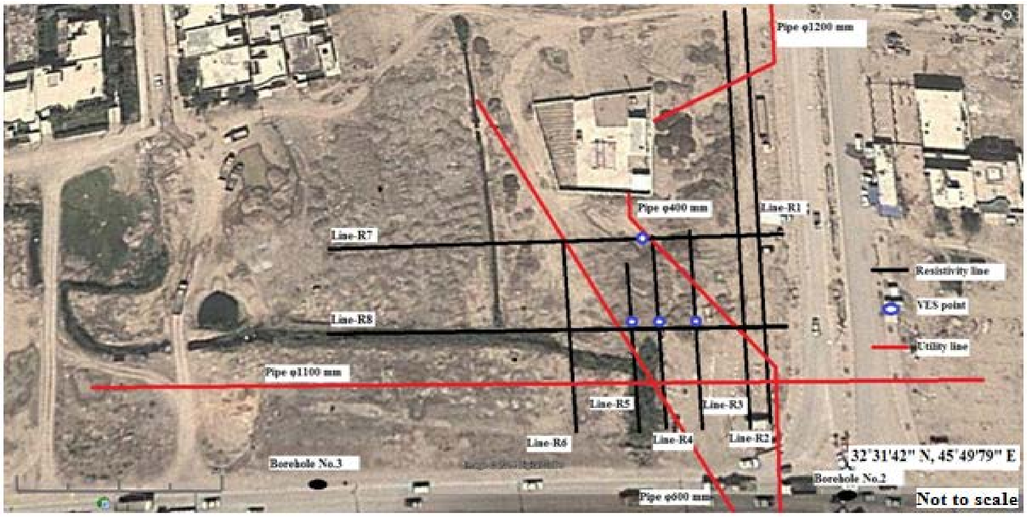


Figure (4) Acquisition geometry for 2D resistivity in site.

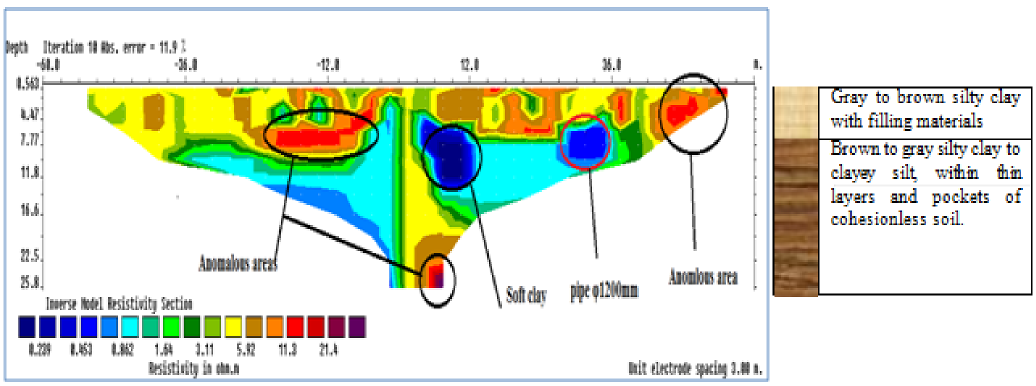


Figure (5) Inverted resistivity section for Line-R1.

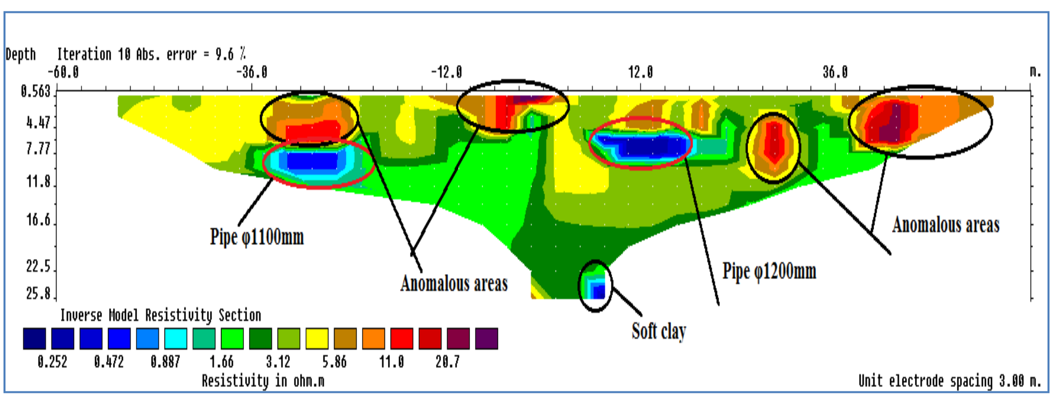


Figure (6) Inverted resistivity section for Line-R2.

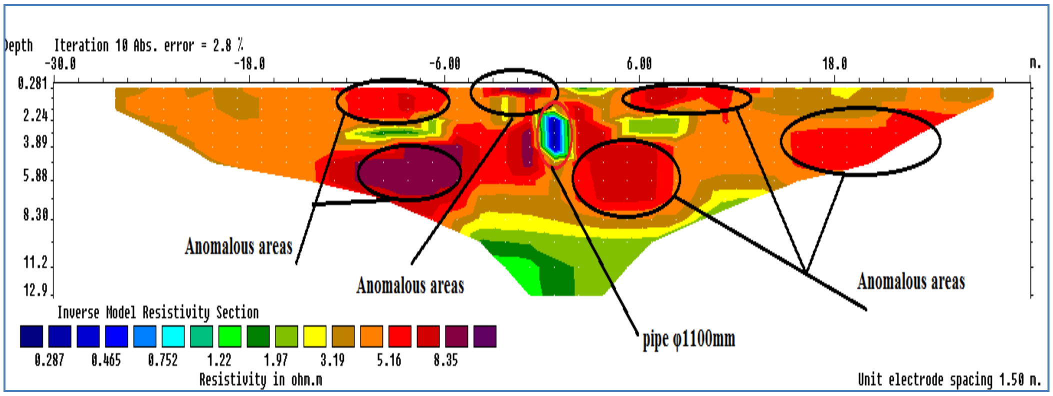


Figure (7) Inverted resistivity section for Line-R3.

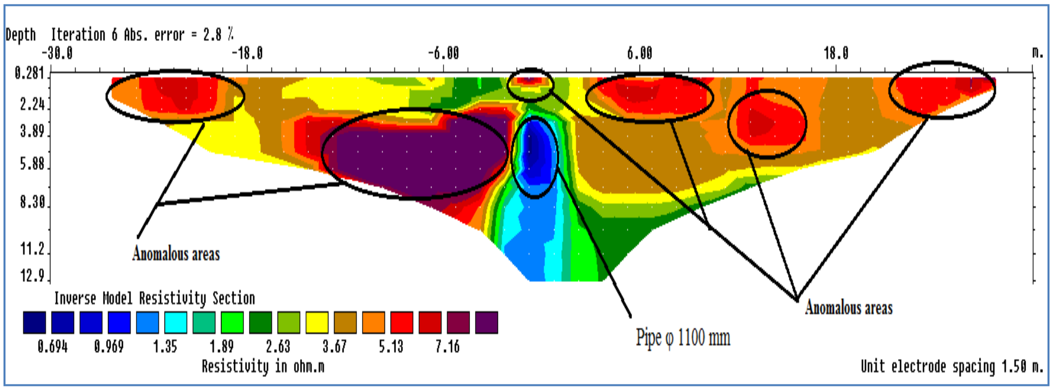


Figure (8) Inverted resistivity section for Line-R4.

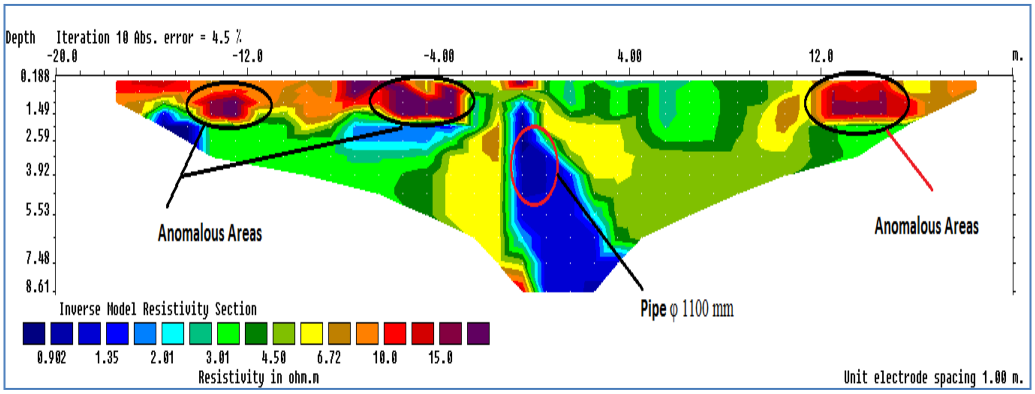


Figure (9) Inverted resistivity section for Line-R5.

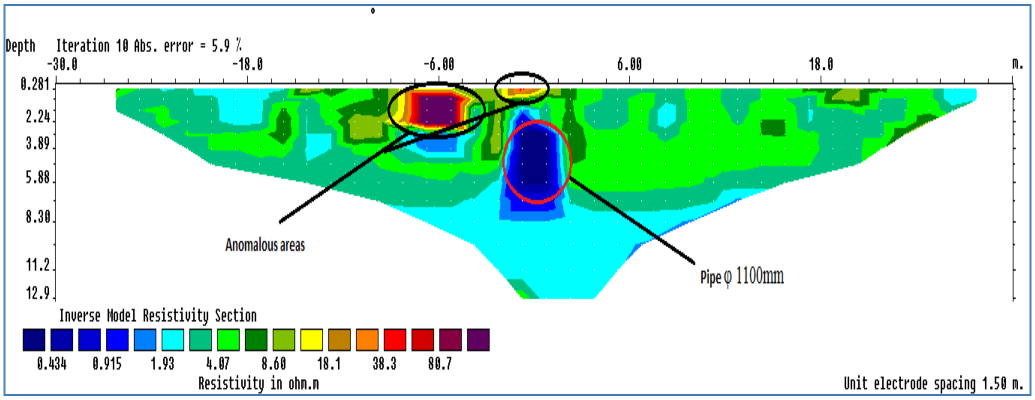


Figure (10) Inverted resistivity section for Line-R6.

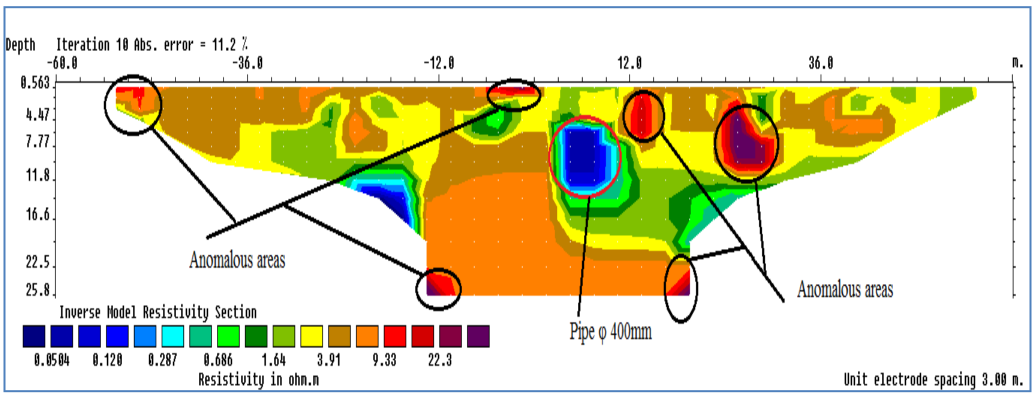


Figure (11) Inverted resistivity section for Line-R7.

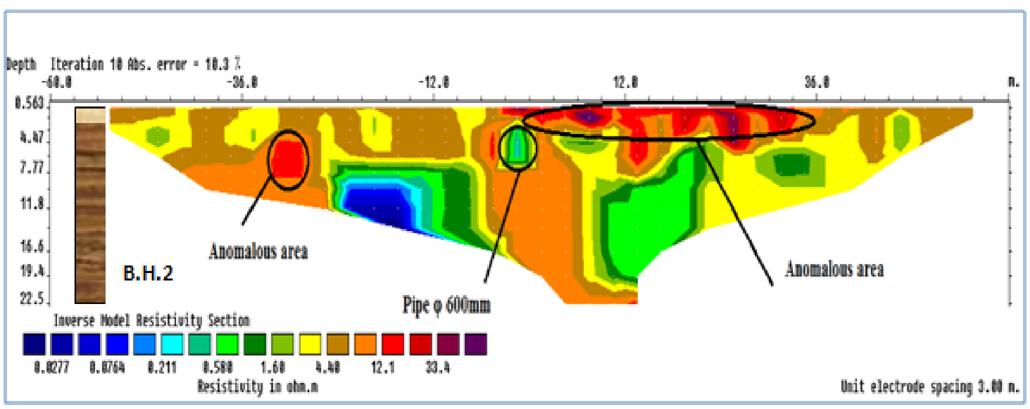


Figure (12) Inverted resistivity section for Line-R8.

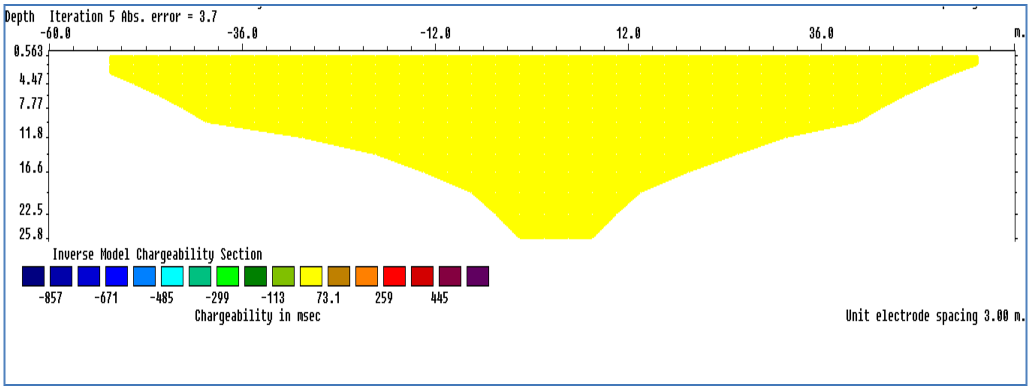


Figure (13) Inverted chargeability section for Line-R7.

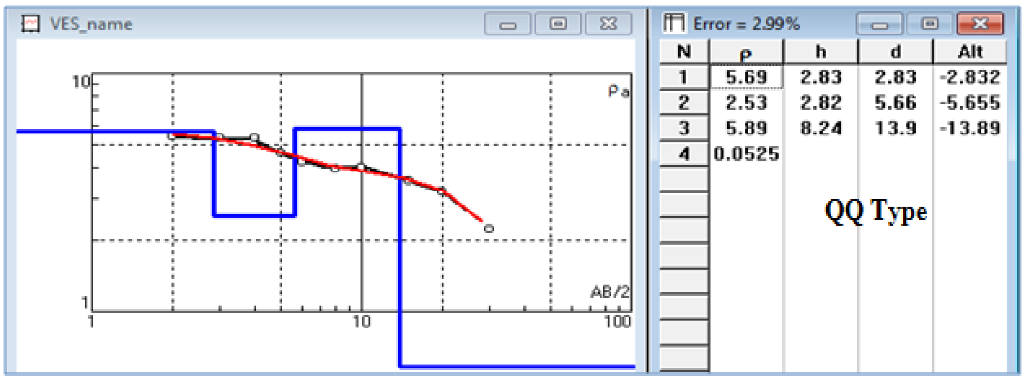


Figure (14) 1D-VES point along Line-R5.

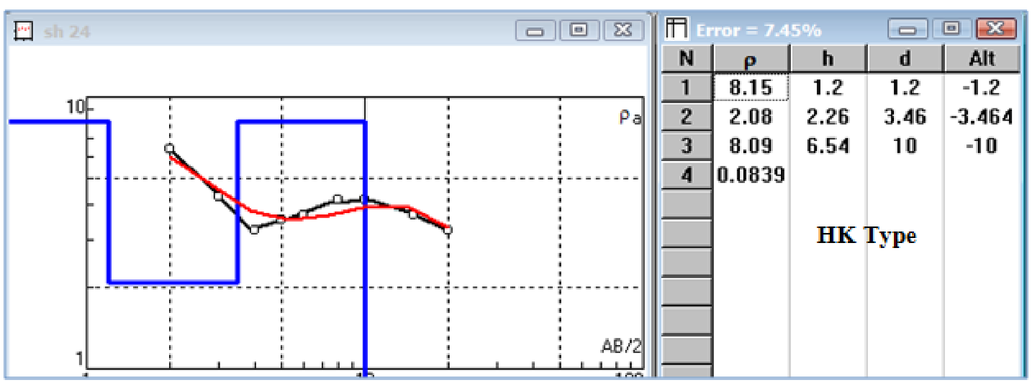


Figure (15) 1D-VES point along Line-R7.

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