International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

2D Electrical Resistivity Tomography for the Investigation of the Subsurface Structures at the Shaqlawa Proposed Dam Site at Erbil Governorate, NE Iraq

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Abstract: ***Two dimensional Electrical Resistivity Tomography (ERT) method was used to investigate a Dam site in Shaqlawa-Erbil Governorate, NE Iraq, to delineate the nature of the subsurface structures to assess its suitability for the construction of dam. The main objectives are to investigate the depth to the bedrock, possible geologic structures, such as possible presence of faults, fractures, voids and clay in the dam axis and abutments. The selected method has the possibility to give an image of the subsurface and map lateral and vertical variations in the subsurface geology of the site. For this purpose, the (SYSCAL Switch and SYSCAL Pro Switch units) equipment was used with Wenner array (48 electrodes). Three 2D electrical resistivity tomography profiles were conducted, the space between electrodes is 5m and the length of the profiles are 235 m. The depth of the investigation is assumed to be 40 m. The acquired data were inverted to tomogram sections using tomographic inversion by using TomoLAB commercial software. The Tomography sections show that the subsurface is classified into three distinct geo-electric layers, with different resistivity values; starting with high to moderate resistivity value represents unconsolidated coarse materials such as boulder and gravel, while in some location fine soft materials such as silty clay has been appeared that is underlain by a second layer of high resistivity has been detected within upper Fars (Injana) Formation; it is mainly composed of sandstone saturated and/or compacted. The third layer has low resistivity which represents the fine materials deposition of the Upper Fars Formation. These results are confirmed and verified by using several boreholes data were drilled on the recommendation of the surveys. The results showed that the site is suitable for the construction of the proposed dam.***

Keywords: 2D Electrical Resistivity Tomography, Inversion, Proposed Dam Site, Geological structure, geotechnical investigation.

1. Introduction

Kurdistan is rich with surface and underground water and has a lot of rivers and springs. There are a number of large rivers in Kurdistan, which after passing through various areas of the Region, continue to other provinces in Iraq. However, just a few hundred meters from these rivers, draught is threatening the farmlands and farmers, livelihoods. The droughts that Kurdistan Region faced in the past few years were very severe, affecting a population that was already suffering from the impacts of previous drought spells, with a wider geographical reach and a disastrous impact on the lives of the population. Drought seems to have had a disastrous impact on the lives of the population [1]. Hence, saving water of rainfall and groundwater has therefore become one of the prime objectives of the area. For that reason, dams are usually built in areas; also dams have one of the most important roles in utilizing water resources.

More specifically, geophysical prospecting was applied to clarify the near surface geological setting in the area where a dam is to be constructed. An adequate assessment of geologic and geotechnical conditions of the proposed site is imperative for a safe dam design and construction. Originally, the location of the dam is indicated by General Directorate of Dam.

Geophysical investigation of the earth's subsurface at sites designated for civil engineering works should be of paramount interest because, near-surface structures, cavities, sink holes, voids, fractures, faults among others and/ or inhomogeneities in the foundation geo-materials are major origins of hazards in civil engineering structures [2].

The 2D Electrical Resistivity Tomography (ERT) method has been a powerful technique to investigate shallow subsurface electrical structures in various environments. (ERT) method is the most effective and environmentally friendly approaches to evaluate engineering sites generally and particularly for evaluating dam sites. The design of dam structures must be adapted to the existing site conditions [3] to minimize the losses. Failure to do any of these may invariably result in unplanned seepage and/or total collapse of the structure [4, 5].

The 2D electrical resistivity tomography method, because of its high resolution, is commonly used in measuring the electrical structure of shallow subsurface within several tens to hundred meters deep. A 2D electrical resistivity tomography survey is produced by injecting current into the ground through two current electrodes and measuring the resulting voltage difference at two potential electrodes. This process is repeated for many current/potential electrode configurations to produce a pseudo section of apparent resistivity. The resultant data are then processed using a 2D

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inversion. Variations in the underlying sediment or rock units indicated by different electrical resistivities can then be observed as strong gradients in resistivity. Although the subsurface resistivity distribution could then be interpreted and mapped by eye, we will show that this subjective method should be done with caution because of the diffusive nature of the electrical field.

The ERT method aimed to delineate the geophysical/ geologic features such as overburden thickness, bed rocks morphology, fractures in the subsurface thus, enabling the evaluation of the feasibility of the area for dam construction suitability. This paper aimed to delineate subsurface geoelectrical sequence/ materials and establish the existence of potentially hazardous geologic structure(s). The sharp contrast in geoelectrical characteristics of subsurface geologic materials displayed by the 2-D Tomography models makes it an ideal tool for near-surface geophysical investigations, thus necessitating its use in this study.

2. Materials and methods

2.1 Area of investigation

The proposed dam site is located within the Erbil Governorate which far about 58 km northeast of Erbil City, 8km to the southeast of Shaqlawa district, and about 3km northeast of Lassa village, it is referring to the valley named Rusark within the following coordinate: UTM time zone: X=446165 and Y=4026368 (figure 1). The geomorphology of the studied area reflects the dominant geological structures, lithological characteristics of geologic formations, climate factor and degree of erosion. The drainage patterns in studied area are also attributed to structural features such as sets and variations in rock competency.

2.2 Geological/structural setting of the proposed dam site

Tectonically, the studied area located in the High Folded Zone of the Unstable Shelf tectonic zone of the Arabian Platform [7,8] (figure 2). It is characterized by intense folding and orogenic uplift, with closely packed narrow anticlines and synclines. This zone was the site of deposition of Palaeogene molasses sediments [9].

The study area is located in the Mirawa syncline between Safeen anticline in the southwest and Shakrok anticline in the northeast (figure 2). Safeen anticline is one of the major anticlines in the high folded zone, which is an asymmetrical anticline, on-plane, and axial surface is directed (NW), gently double plunging fold with south-westward, trending NW-SE parallel to the Zagros Mountain Belt. Safeen Anticline is in the High Folded Zone, located about 45 km north east of Erbil city. Several different rock formations are exposed within the Shaqlawa dam area. The exposed Formations range in age from Cretaceous to Tertiary. The most important are Quaternary (Recent) deposits and Upper Fars (Injana) U-Miocene sediments. The proposed dam site is exactly located on those formations, while other Formations are of lesser interests because most of them are exposing as small patches at the margins of the catchment area.

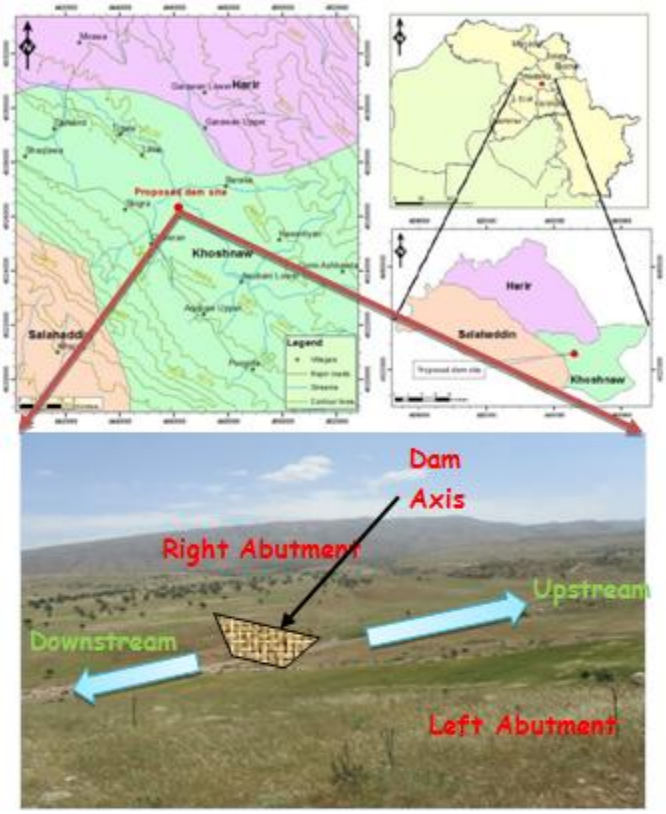

Figure 1: Location map of the proposed dam site

2.2.1 Recent deposits (Quaternary)

These deposits exposed in all parts of the proposed dam area. It is mainly consists of clayey and silty types, with dominant reddish brown colour, which are derived from older formations (figure 3), Locally, pebbles and some rock fragments occur within the soil generally limestone pebbles, up to 25 cm in diameter derived from the Pila Spi Formation, occur within these deposits [10] .

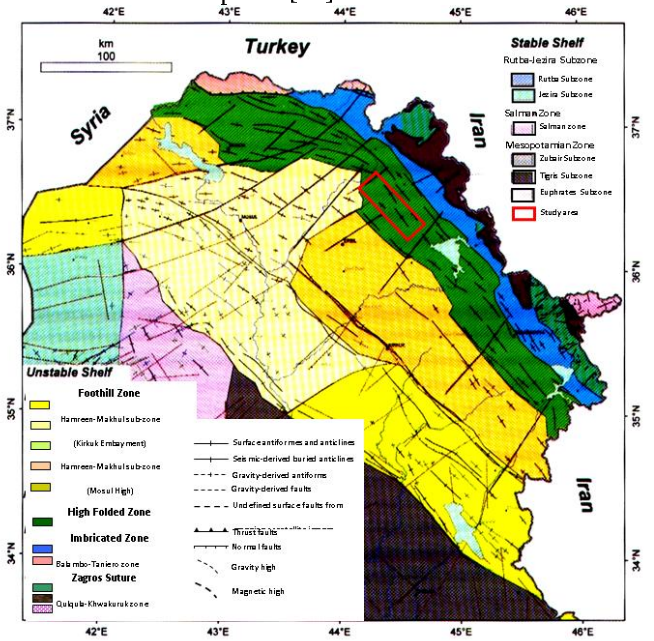

Figure 2: Tectonic zones and structural elements of the Unstable Shelf units [10].

Figure 3: Quaternary deposits of the proposed dam site.

2.2.2 Upper Fars formation (Injana) U- Miocene

The upper Fars formation was originally described in the Fars province of Iran but without a type locality in Iraq. According to [8] proposed the name Injana formation to replace the upper Fars in Iraq and defined a subsidiary type section near Injana Village. The age of the formation is Late Miocene according to [11]. This formation exposed in the core of synclines within the study region. This formation mainly consists of marl, siltstone, mudstone and sandstone whose size vary from medium to coarse and claystone whereas limestone and shale exist in lower part of the formation [9].

The formation forms hilly areas with continuous strike ridges and valleys due to alternation of hard and soft rocks. The studied area is covered by this formation shown in (figure 4). The formation consists of cyclic deposits of clastics, which in general coarsen upwards. The dominant color of the clastics is red color. Each depositional cycle consists of mudstone and sandstone. The mudstone is occasionally silty with some thin horizons of inter-bedded siltstone, which are reddish brown, and brown in color and are 0.1-0.5m thick (figure 5A). The claystone is reddish brown, grayish brown, and rarely green and violet in color, soft to fairly hard, weathered in some places usually covered by soil, which is silty and sandy. The sandstone is the second main constituent of the formation; the main color is reddish brown to brown, bedded, and the thickness of the individual beds ranges from 0.1 m up to 10m (figure 5B). Fracturing and Jointing are well developed in the sandstone. The sandstones are rich in sedimentary structures among them, mud balls; cross bedding, ripple marks; and borrowings are common. The thickness of the formation is variable; it ranges between 150-450m [6]. The lower contact of the Injana formation with the Fat'ha formation is conformable it is recognized in the field by the uppermost limestone horizon of the Fatah Formation which is always overlain by a thick red claystone bed.

2.2.3 Lower Fars formation (Fat'ha) M- Miocene

This formation mainly consists of alternation of evaporates (gypsum and anhydrite), marl (calcareous shale) limestone, siltstone and red claystone [10, 11]. The siltstone and red claystone beds are exposed only in the periphery of the basin while evaporates, carbonate and marl occur mainly in the center of the basin. The upper contact is gradational with Injana (previous Upper Fars) Formation and most probably (somewhat) diachronous [11].

3. 2-D Electrical Resistivity Tomography (ERT) Method

Traditionally, the direct-current (DC) electrical survey is used to determine the subsurface resistivity distribution by measuring the electrical potential difference between a pair of potential electrodes (P_1 and P_2 in figure 6) on the ground surface with a current applied through a pair of current electrodes (C_1 and C_2 in Figure 6) [13,14] . The apparent resistivity ρ_a in Ohm.m (Ω–m) is then computed from Ohm's law [15]:

$$\rho_a = k(\Delta v / I) - - - - - - - - (1)$$

Where k is a geometric constant that depends only on the reciprocal positions of the current and potential electrodes; Δv is the measured potential difference in mV; and I is the applied electric current in mA.

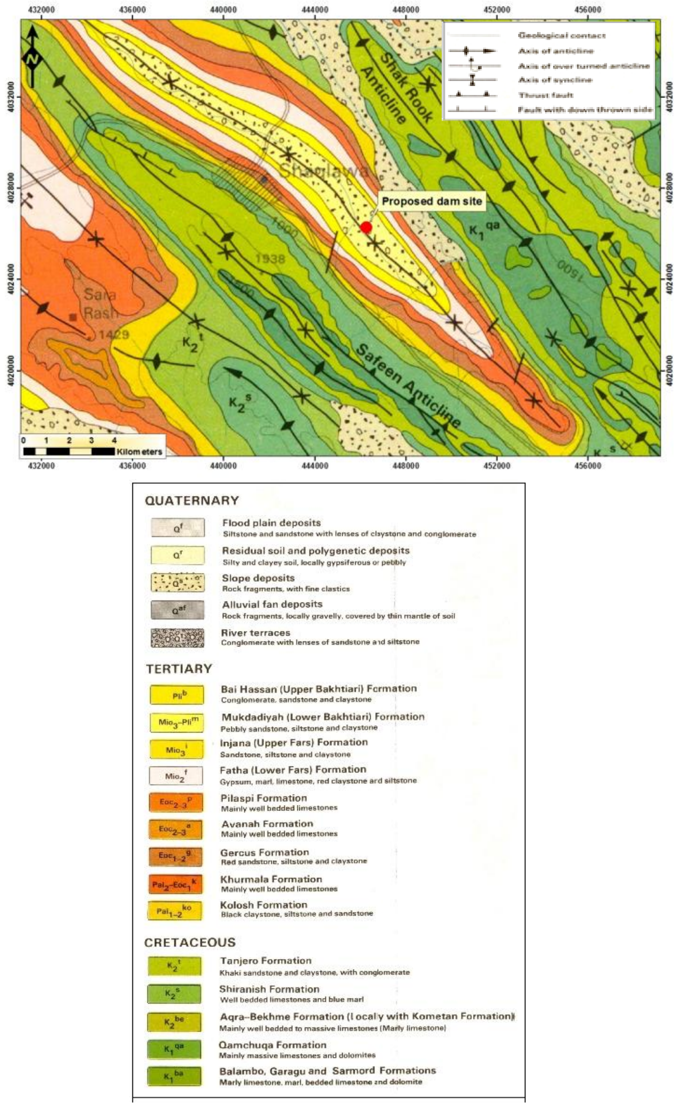

Figure 4: Geological map of the studied area [12].

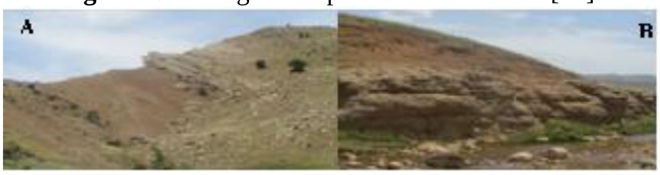

Figure 5: a- Alternation between claysilt and sandstone beds at the left abutment.

b- Sandstone beds at the right abutment of the proposed dam site.

Recent developments in DC technology allow automatic measurements, by switching the current and potential electrodes between a series of equally spaced electrodes laid out along a profile (figure 7). This allows a dense sampling of subsurface resistivity variation at shallow depth within a short amount of time. 2-D Electrical Resistivity Tomography have repeatedly fulfilled the expectations for obtaining rapid and cost-effective subsurface information and are thus indispensable supplements to borings in exploratory surveys for civil engineering purposes [17,18]. Ideally, the resulting geophysical model should be combined with the results from borings and/or other direct methods of geotechnical and geological exploration in order to improving the interpretation of the geophysical measurements, which in some cases have limited success under specific soil conditions. A more accurate model of the subsurface is a two-dimensional model where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line. In this case, it is assumed that resistivity does not change in the direction that is perpendicular to the survey line. In many situations, particularly for surveys over elongated geological bodies, this is a reasonable assumption [19].

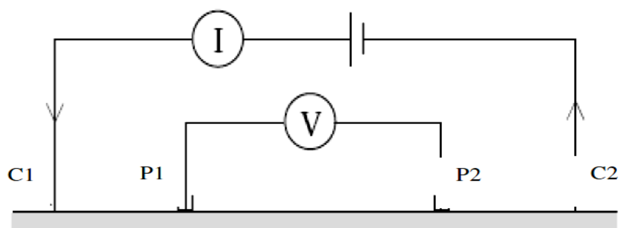

Figure 6: General four electrode configuration for resistivity measurement [16].

The electrical resistivity prospecting method consists of determining the distribution of a physical parameter that is characteristics of the subsoil (the resistivity) on the basis of a very large number of measurements of apparent resistivity made from the ground surface [14].

Two-dimensional electrical imaging/tomography surveys are usually carried out using a large number of electrodes, 25 or more, connected to a multi-core cable [20]. A resistivity meter system with an internal microprocessor controlled circuitry together with an electronic switching unit is commonly used to automatically select the relevant four electrodes for each measurement. A range of fast automated multi-electrode and multi-channel data acquisition systems now exist that allows flexibility in the acquisition of geo-electrical resistivity data [21, 22, 23]. The use of multi-electrode/multi-channel systems for data acquisition in geo-electrical resistivity surveys has led to a dramatic increase in field productivity as well as increased quality and reliability of subsurface resistivity information obtained [21].

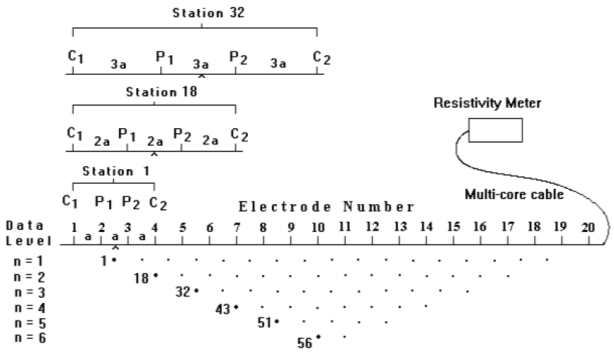

Figure 7: A typical field arrangement for 2D ERT Surveys (Wenner array) [19].

Multi-electrode resistivity survey is a combinational technique of profiling and sounding involving a number of electrodes with a fixed inter-electrode spacing. With the multi-electrode survey one can get lateral as well as the vertical information of the shallow subsurface.

The measured apparent resistivity is converted into true resistivity using inversion software in order to produce the 2-D resistivity cross-section image (Tomogram). The Multi-Electrode Resistivity Imaging system used for data acquisition was a modified version of ABEM Lund Imaging system known as IRIS SYSCAL Switch Resistivity meter. The output from the inversion software displays the inverse model resistivity section. To convert the resistivity picture into a geological picture, some knowledge of typical resistivity values for different types of subsurface materials and the geology of the area surveyed, is important. The resistivity of rocks and soils in a survey area can vary by several orders of magnitude. In comparison, density values used by gravity surveys usually change by less than a factor of 2, and seismic velocities usually do not change by more than a factor of 10. This makes the resistivity and other electrical or electromagnetic based methods very versatile geophysical techniques [19].

The most commonly used arrays in the 2D electrical imaging surveys are conventional arrays such as the Wenner, Schlumberger or Dipole-Dipole arrays. These arrays are often well understood in terms of their depths of investigations, lateral and vertical resolution, and signal–to-noise ratios. Generally, the Wenner and Schlumberger arrays provide good vertical resolution for horizontal structures and high signal-to-noise data [24].

4. 2-D ERT Measurements

One of the new developments in recent years is the use of 2-D electrical Tomography surveys to map areas with moderately complex geology [20]. Such surveys are usually carried out using a large number of electrodes, in this surveys 48 electrodes were used, connected to a multi-core cable. A laptop microcomputer together with an electronic switching unit is used to automatically select the relevant four electrodes for each measurement. Normally a constant spacing between adjacent electrodes is used. The multi-core cable is attached to an electronic switching unit which is connected to a laptop computer. The fieldwork was related to surveying the profiles and borehole locations (table 1) are plotted on the general plan (figure 8). The combination of borehole and geoelectrical survey provides some good correlation in subsurface profile assessment required in designing of any important civil engineering structures. The ERT measurements were carried out along three profiles in May 2013 at Shaqlawa proposed dam site (Figure 8), with standard Wenner array (48electrodes); the space between electrodes is 5m and the length of each profile is 235 m, and the depth of the investigation is assumed to be 40 m. The equipment (SYSCAL Switch and SYSCAL Pro Switch units) was used which includes a large number of electrodes located along a line at the same time, and which carries out an automatic switching of these electrodes for acquiring profiling data. The effect of the topography must be taken into account when carrying out an inversion of the data set. For that reason during the survey at the field the elevations of the electrodes were measured along the profile where the elevation changed by twelve channels global positioning system (GPS) set- the "GARMIN GPS 12".

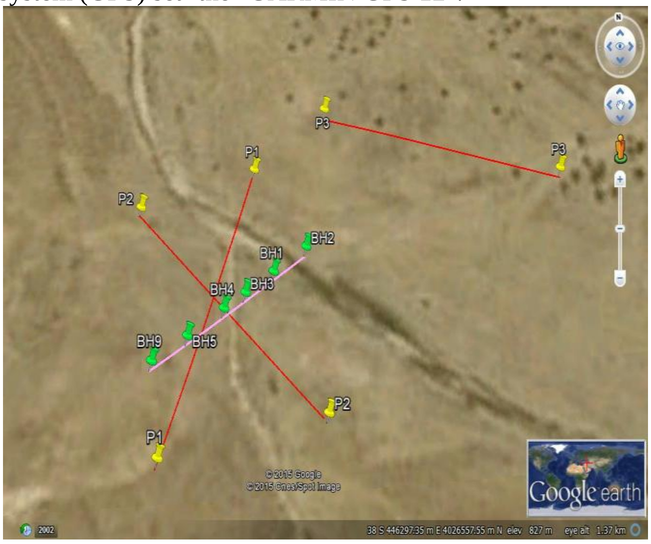

Figure 8: Image shows the field survey layout and location of boreholes at Shaqlawa proposed dam site.

5. 2-D ERT Data processing and results

To convert the resistivity picture into a geological picture, some knowledge of typical resistivity values for different types of subsurface materials and the geology of the area surveyed, is important. The resulting measurements were combined with the available geological and geotechnical reports of the study area and were used to assess the structure of the near-surface geology. After the acquisition of the geophysical data, Interpretation of the resistivity results was carried out using commercial software TomoLAB® which belongs to (Geoastier Italian Company). The ERT data after collected by using a previous produces a subsurface map of the “apparent” resistivity distribution. The apparent resistivity distribution of the subsurface structure is then inverted using the commercial TomoLab® software to estimate the true resistivity structure. The inversion is stopped once the difference of the root mean square (RMS) error between the current and previous iterations is <0.1%. The inverted data produce the 2D resistivity distribution map, which can then be used for extracting information about the contact between sediments and bedrock. The inversion problem is to find resistivity values of the cells that have best fitness between the easured and calculated apparent resistivity values [26].

Table 1: Location of the boreholes and depth at Shaqlawa dam site [27]

BH. No.	*Latitude*	*Longitude*	*Elevation (m) a.s.l.*	*Depth(m)*
1	446276	4026552	827.5	25
2	446308	4026570	827	25
3	446250	4026537	828	25
4	446229	4026526	829	25
5	446195	4026547	831	25
9	446166	4026490	840	25

6. Geoelectrical sections

6.1 Profile 1 (parallel to the dam axis)

It is parallel to the proposed dam axis and running normal to the strike of the outcrops (SW - NE). The first electrode is assumed to be on the left abutment, at the coordination (X = 446262 and 446172; Y = 4026637 and 4026423 UTM) (figure 8). The outcrops of Injana (upper Fars) Formation occur in the area and its surrounding area. A layer of recent sediments and alluvium deposit as well as weathered product of Upper Fars formation is covering surface of the area, it has resistivity ranging from 35 to 95 Ω.m, and it is composed of boulders, gravels, sand and silt. The layer has thickness ranging from 8 to 10 m (figure 9). The second layer is representing the sandstone bed of Injana (upper Fars) Formation in the left abutment, it shows resistivity about 30 Ω.m. This layer has thickness ranging from 10 to 12 m and extends to the center of the dam axis because it has dip direction toward NE.

A low resistive layer is detected at depths ranging from 8 to 10 m; it is composed of claystone, siltclay and siltstone. It has resistivity ranging from 15 to 20 Ω.m this layer is extend to the lower part of the resistivity section. This layer represents the fine materials of Injana (upper Fars) Formation. A correlation of the lithological section penetrated at position of BH1, BH2, BH3 and BH4 (figure 10) suggests that the depth to bedrock vary between 3 m to 7 m with an increase in depth at the two extreme boreholes (BH1 and BH4) along the dam axis.

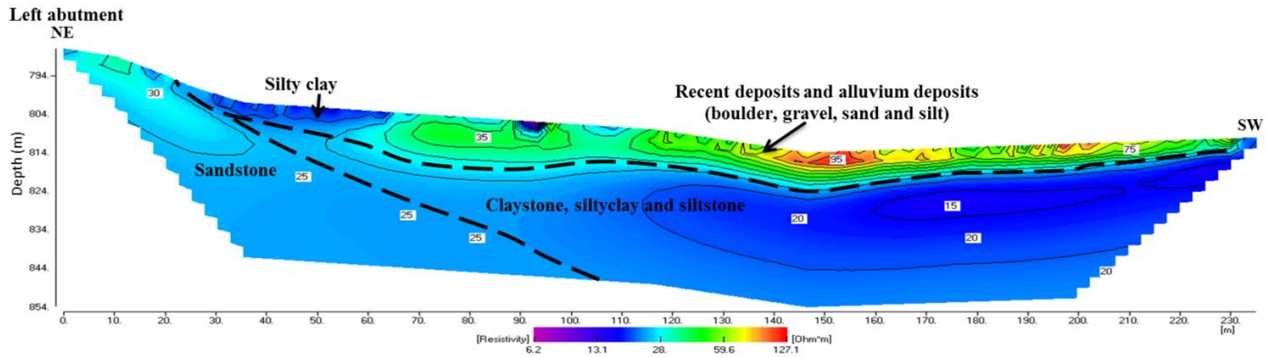

Figure 9: Inverse resistivity model along profile 1 which is parallel to the proposed dam axis

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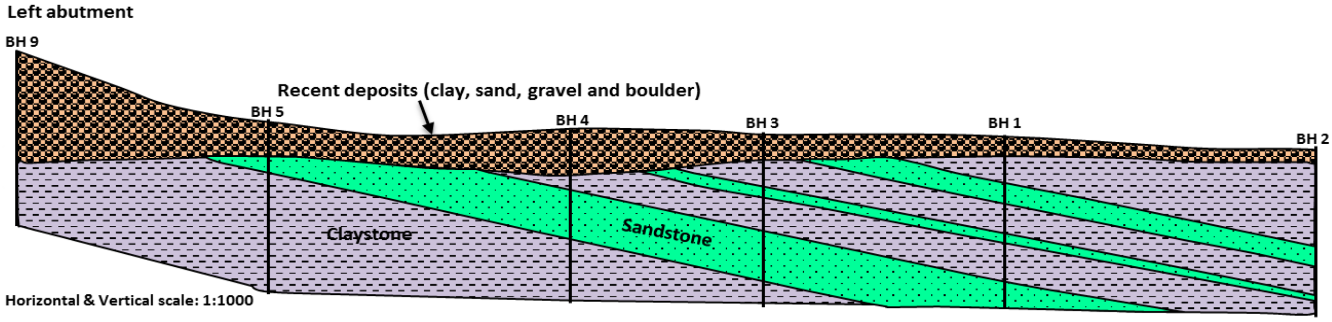

Figure 10: Boreholes lithological correlation along the dam axis [27].

6.2 Profile 2 (perpendicular to the dam axis)

It is located in the central of the valley, the first electrode is assumed to be at the upstream, at the coordination (X= 446318 and 446153; Y= 4026445 and 4026610 UTM). The profile it is normal to proposed dam axis and running parallel to the strike of the outcrops (SE-NW). The outcrops of Upper Fars Formation occur in the area and its surrounding area. In this profile three layers were recognized, the first continuous surface layer represents by top soil with resistivity ranging from 45 to 170 Ω.m (figure 11). These variations in resistivity occur due to variety types of recent sediments. It is composed of boulder, gravel, sand, silt and clay with thickness ranging from 8 to 10m. The second layer represents the first constituent of upper Fars formation which is composed of claystone and siltstone with resistivity ranging from 7 to 15 Ω.m and with thickness ranging from 6 to 10m.

The third layer is composed of Sandstone bed rock of Upper Fars formation with resistivity ranging from 25 to 40 Ω.m and the sandstone bed contain water.

6.3 Profile 3 (Right Abutment)

It is located in the right abutment which is parallel to the strike. The first electrode is located in the left side of the profile at the coordination (X= 446335 and 446555; Y= 4026682 and 4026610 UTM). The first electrode is assumed to be on the upstream (figures 1 & 8). In this profile three layers were recognized. The first one is representing recent sediments with resistivity ranging from 25 to 360 Ω.m in the center of the profile; it is composed of coarse sediments: boulder, gravel, pebble, sand and silt. It has thickness ranging from about 8 to 10m (figure 12). And laterally in the right directions changes to top soil composed of sand which is located at the left side of profile. The second layer is composed of dry siltstone and silt clay with resistivity ranging from 20 to 40 Ω.m. The resistivity of this layer decrease towards the left to 20 Ω.m with thickness ranging from about 3 to 5m. This decreasing in the resistivity value is due to increasing fine sediments in the upper Fars constituents. The third layer is composed of compact sandstone bed rock of Upper Fars formation with resistivity ranging from 85 to 130 Ω.m and in small part the lithology changes in to fracture sandstone with resistivity about 50 Ω.m.

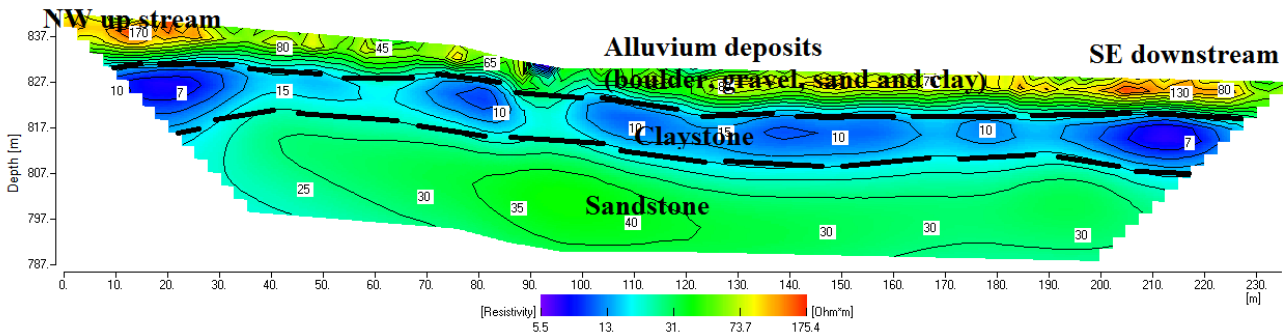

Figure 11: Inverse resistivity model along profile 2 which is perpendicular to the proposed dam axis.

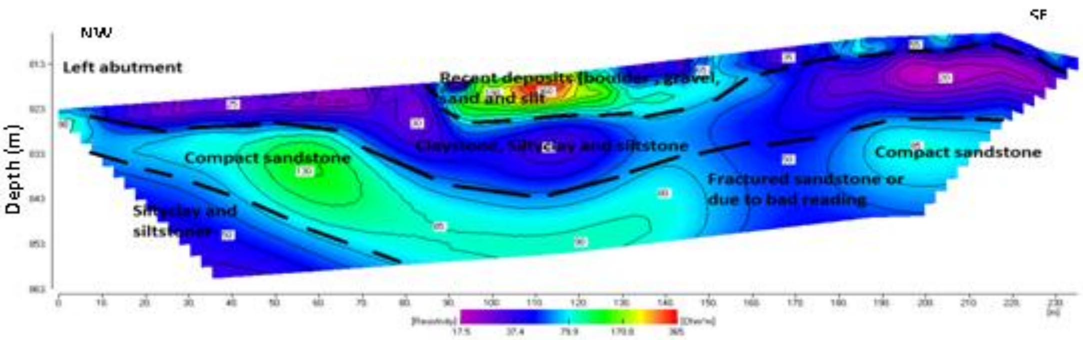

Figure 12: Inverse resistivity model along profile 3 which is on the right abutment of the proposed dam.

7. ERT Results Correlated With Borehole Drilling

The stability of any engineering structure is primarily dependent on their supporting foundation which is largely a function of the nature and condition of the underlying soil materials [26]. Six borings were drilled at dam axis during the period at July and September of 2013 [27]. The purpose of this geotechnical investigation was to determine the subsurface features such as depth and lithology of the bed rocks. A correlation of the lithological section penetrated at position of BH1, BH2, BH3 BH4, BH5 and BH9 (figures 9, 10) suggests that the depth to bedrock vary between 3 m to 7 m with an increase in depth at the two extreme boreholes BH9 along the dam axis. The borehole No.5 is the nearest one from the inverse section along profile 1 which far away for about 11.0m horizontally to the west of the profile 1. The depths to the surface of the Injana Formation are nearly coinciding with the depths obtained from interpretation of 2D resistivity tomography. While borehole No.4 is the nearest borehole from the profile 2 which is far away for about 6.5m to the southwest of the profile 2. In the profile 1 three horizons were recognized (figure 9) at the same time in the borehole three horizons were recognized too (figure 10), in both sections the sandstone bed appear from the left abutment side with some differences that's may due to the difference in time for taking measurements of both data, especially the resistivity method is very impressible for any change in the subsurface materials.

There are no near boreholes at the third profile to comparing with it. Generally the borehole lithological correlation along the dam axis (figure 10) is approximately coinciding with the interpretation of 2D Electrical Resistivity Tomography along profile 1 (figure 9) which is nearly parallel to the dam axis with taking in mind for elevation and distance (figure 8).

8. Conclusions

2-D Electrical Resistivity Tomography were carried out at the Shaqlawa Proposed Dam Site at Erbil Governorate, NE-Iraq and the data were analyzed by using TomoLab Inversion software. The results of the 2D (ERT) method and boreholes data are combination together to proving geoelectrical section.

The ERT investigations were conducted successfully for determine any subsurface geological deficiency that may pose a problem for the building and finally to investigate the suitability of the proposed dam site. Based on the interpretation of the 2D (ERT) and geotechnical data the following results obtained; The top surface layer shows moderate to high resistivity ranging from 25 to more than 360 Ohm.m, it is composed mainly of coarse materials such as boulder and gravel, while in some location fine soft materials such as siltyclay has been appeared. The thickness of the recent sediments is ranging from 8 to 10 m. A layer of high resistivity about 25 to 130 Ohm.m, has been detected within upper Fars Formation (Injana); it is mainly composed of sandstone. A layer of low resistivity has been identified which represents the fine materials deposition of the Upper Fars Formation, the resistivity is ranging from 7 to 40 Ohm.m. The correlation between 2D Inverse resistivity models with borehole data show good agreement. In structural point of view there is no faults have been detected in this location as well as there is no evidence of the existence of cavities and there are no any risky sources.

9. Acknowledgement

The authors would like to thank Mr. Akram A. Rasul; General Director at the General Directorate of Dams and Reservoirs-Erbil for provided the needed support for this paper especially using the (SYSCAL Switch and SYSCAL Pro Switch units) equipment and providing geotechnical data. And we are also grateful to Dr. Mariwan A. Chnarayee, lecturer at Geological department, Sciences College, University of Salahaddin for his cooperation and support during Geophysical work of this paper.

References

[1] United Nations Development Programme,Iraq, "Drought Impact Assessment, Recovery and Mitigation Framework and Regional Project Design in Kurdistan Region (KR)", pp. 79, 2011.

[2] K.O. Ozegin, A.O. Oseghale, A.L. Audu, and E.J. Ofotokun, "An application of the 2–D D.C. Resistivity method in Building Site Investigation – a case study: South Nigeria", Journal of Environment and Earth Science, 3 (2), pp.108-112, 2013.

[3] O. Ajayi, M.O. Olorunfemi , J. S. Ojo, C.W. Adegoke-Anthony, K.K. Chikwendu, M. I. Oladapo, A.I. Idornigie, and F. Akinluyi., "Integrated geophysical and

geotechnical investigation of a dam site on River Mayo Ini, Adamawa State, Northern Nigeria ", Afr. Geosci. Rev., 12 (3), pp. 179-188, 2005.
[4] O.M. Olorunfemi, J.S. Ojo, F. Sonuga, O. Ajayi and M.I. Oladapo, "Geoelectrical and Electromagnetic Investigation of the Failed Koza and Nasarawa Earth Dams Around Katsina, Northern Nigeria", J. Mining Geol., 36 (1), pp. 51 – 65, 2000a.
[5] M.O. Olorunfemi, J.S. Ojo, F. Sonuga, O. Ajayi and M.I. Oladapo, "Geophysical Investigation of Karkarku dam embankment", Global J. Pure Appl. Sci., 6 (1), pp. 117- 124, 2000b.
[6] R. Youkhanna, and V. Sissakian., "Stratigraphy of Shaqlawa - Quwaosnjag area", Journ. Geol. Soc. Iraq, 19 (3), pp. 137-154, 1986.
[7] T. Buday, and S.Z. Jassim, The regional geology of Iraq (Tectonism, Magmatism and Metamorphism). Vol.2, Geological Survey and Mineral Investigation, Baghdad, Iraq,352p., 1987.
[8] T. Buday and S.Z. Jassim, "Final report and the regional geological survey of Iraq"; Unpubl., Report, S. O. M. Library, Vol. 2, Tectonic, Framework, 1984.
[9] T. Buday, The regional geology of Iraq. Stratigraphy and Paleogeography. Dar Al-Kutib Publishing house, University of Mosul, Mosul, Iraq, 445p., 1980.
[10] S.Z. Jassim and J.C. Goff, Geology of Iraq (First edition). Published by Dolin, Prague and Moravian Museum, Brno, Czech Republic, 341p., 2006.
[11] R.G. Bellen, R.G., H.V. Dunnington, R. Wetzel, and D.M. Morton, Lexique stratigraphique International, Vol.III, Asie. In: Dubertret, L., (director), fasc. 10c. Iraq, Cenre Nat. Reaserche Scientifique, (Paris), 333p., 1959.
[12] V. K. Sissakian, "Geological Map of Shaqlawa area northeast Iraq", GEOSURV, Baghdad, Iraq, 1997.
[13] G.V. Keller, and F.C. Frischknecht, Electrical Methods in Geophysical Prospecting. Pergamon Press Inc., New York, USA, 1966.
[14] W.M. Telford, L.P. Geldart and R.E. Sheriff, Applied geophysics, 2ed, Cambridge Univ. Press, 744p., 1990.
[15] D.S. Parasnis, Principles of Applied Geophysics, fifth ed., Chapman and Hall, London, 1997.
[16] H. Abdelwahab, "Comparison of 2D and 3D resistivity imaging methods in the study of shallow subsurface structures", Greener J. Phys. Sci., 3(4), pp. 149-158, 2013.
[17] P.V. Sharma, Environmental and Engineering Geophysics, Cambridge University Press, 475 p., 1997
[18] ASCE , "Case histories of geophysics applied to civil engineering and public policy Proc. Sessions sponsored by the Geophysical Engineering Committee of the ASCE Geotechnical Engineering Division in conjunction with the ASCE National Convention" (Washington, DC, 10–14 November 1996) (Geotechnical Special Publication No. 62) P. Michaels and R. Woods (Reston, VA: American Society of Civil Engineers).
[19] M. H. Loke, "Tutorial: 2-D and 3-D electrical imaging surveys".128p. 2004.
[20] D.H. Griffiths and R.D. Barker, "Two dimensional resistivity imaging and modeling in areas of complex geology", J. Appl. Geophysics., 29, pp. 211-226, 1993.
[21] R.D. Barker, "The offset system of electrical resistivity sounding and its use with multicore cable", Geophy. Prosp., 29, pp. 128-143, 1981.
[22] P. Stummer and H.R. Maurer, "Real-time experimental design applied to high-resolution direct-current resistivity surveys", International Symposium on Optical Science and Technology, Expanded Abstracts, pp.143-150, 2001.
[23] E. Auken, L.Pellerin, N.B. Christensen and K. Sorensen., "A survey of current trends in near-surface electrical and electromagnetic methods", Geophys., 71(5), pp. 249-260, 2006.
[24] T. Dahlin and B. Zhou, "A numerical comparison of 2D resistivity imaging with ten electrode arrays", Geophysical prospecting, 52, pp. 379-398, 2004.
[25] F. A. Alfouzan," Optimization Strategies of Electrode Arrays Used in Numerical and Field 2D Resistivity Imaging Surveys", Ph.D. thesis. University of Sains Malaysia. 2008.
[26] E.T. Faleye and G.O. Omosuyi, "Geophysical and Geotechnical characterization of foundation beds at Kuchiyaku, Kuje area, Abuja, Nigeria", Journal of emerging trends in Engineering and Applied Sciences, 2 (5), pp. 864–870, 2011.
[27] General Directorate of Dams and Reservoirs, Kurdistan Region-Iraq, Ministry of Agriculture and Water Recourses, Shaqlawa Dam Geological and Geotechnical Internal Reports, 2014.

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