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# Geoelectrical Investigations at Three Bridge Sites, North Nyala, Southern Darfour State, West-Sudan

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**Abstract** Resistivity measurements were carried out to delineate the depth of the basement rocks (bedrock) and the lithology of the overlying sediments for the purpose of bridges construction route. The survey was conducted at three sites: Andro, Duma and Manwashi, north Nyala, Southern Darfur State, Western Sudan. These sites (Andro, Duma and Manwashi ) are located along Nyala _ El-Fashir road at a distance approximately of 15km, 42km and 75km from Nyala (respectively). The surface geology of the area is dominated by the basement complex rocks which are overlain by thin layer of superficial deposits.The modeling of the VES data was done using IX1D software. The final results of the modeled and interpreted resistivity data are presented in the form of geoelectrical sections. These sections have shown a close agreement with the geological and hydrogeological conditions of the area. Three zones were identified in these sections, they are the top dry zone (<1 m to >3 m) representing the superficial deposits, the middle zone (Saturated zone) represents the groundwater aquifer. It varies in lithology from weathered and cracked basement rocks to the Alluvial deposits with a significant heterogeneous nature which varies from clayey, silty, sandy, pebbly and boulders layers. The bottom zone (Fresh basement rocks) represents the bedrock. It indicate an increase of hardness and compaction from Andro , Duma and Manshawi sites respectively. These findings can be used successfully for constructions the bridges of the three sites.
**Keywords** resistivity, VES, bridge, site investigation, Darfur

## Introduction

In this study, vertical electrical sounding using Schlumberger array were carried out to investigate the selected routes of three bridge sites, North Nyala, Southern Darfour State, West-Sudan. These sites (Andro, Duma and Manwashi ) are located along Nyala _ El-Fashir road at a distance approximately of 15 km, 42 km and 75 km from Nyala (respectively), as shown in fig.1.

The climate of the area is hot and dry during most of the year; the rainy season lasts for three months, from June to September. The mean annual precipitation rates is 450 mm. Runoff concentration is closely linked to the underlying geology and to surface relief. Fig.2 shows the drainage system in the basement complex and the volcanic. There are no drainage lineaments in the sand dunes (Qoz) area which overlying the Nubian sandstone Formation. Recharge of the aquifer in Darfur occurs mainly through runoff concentration in the basement complex area and subsequent infiltration in the wadi channels. Recharge to the wadi aquifers is dependent on the state of depletion and the particular geological setting ( Thorweihe,. et al.. 1990).

The first persons to describe the geology of the area were Delany (1952), Whiteman (1971), Sonntag, et al. (1982), and Thorweihe (1990), Several groundwater development project were carried out in Darfour (BRGM 1983; HUMPHERYS and Partner 1983; and HUNTING 1976). Geophysics plays an important role in geotechnical investigations, for a wide range of projects related to bridge and Dams site location, roadworks. Resistivity are capable of mapping a variety of geological structures, such as soil overburden, aquifers, contamination plumes, sea water intrusion, faults and fractures (Kunetz 1966; Griffith and Barker 1993;

Barker 1996, Flathe 1955, Morries et al. 1996, Dobecki and Romig 1985, Elzein 1998, Ward 1990, Yang et al. 1994).

The main objective of this study is to delineate the depth of the basement rocks (bedrock) and the lithology of the overlying sediments for the purpose of the Bridges route into the three sites: Andro, Duma and Manwashi.

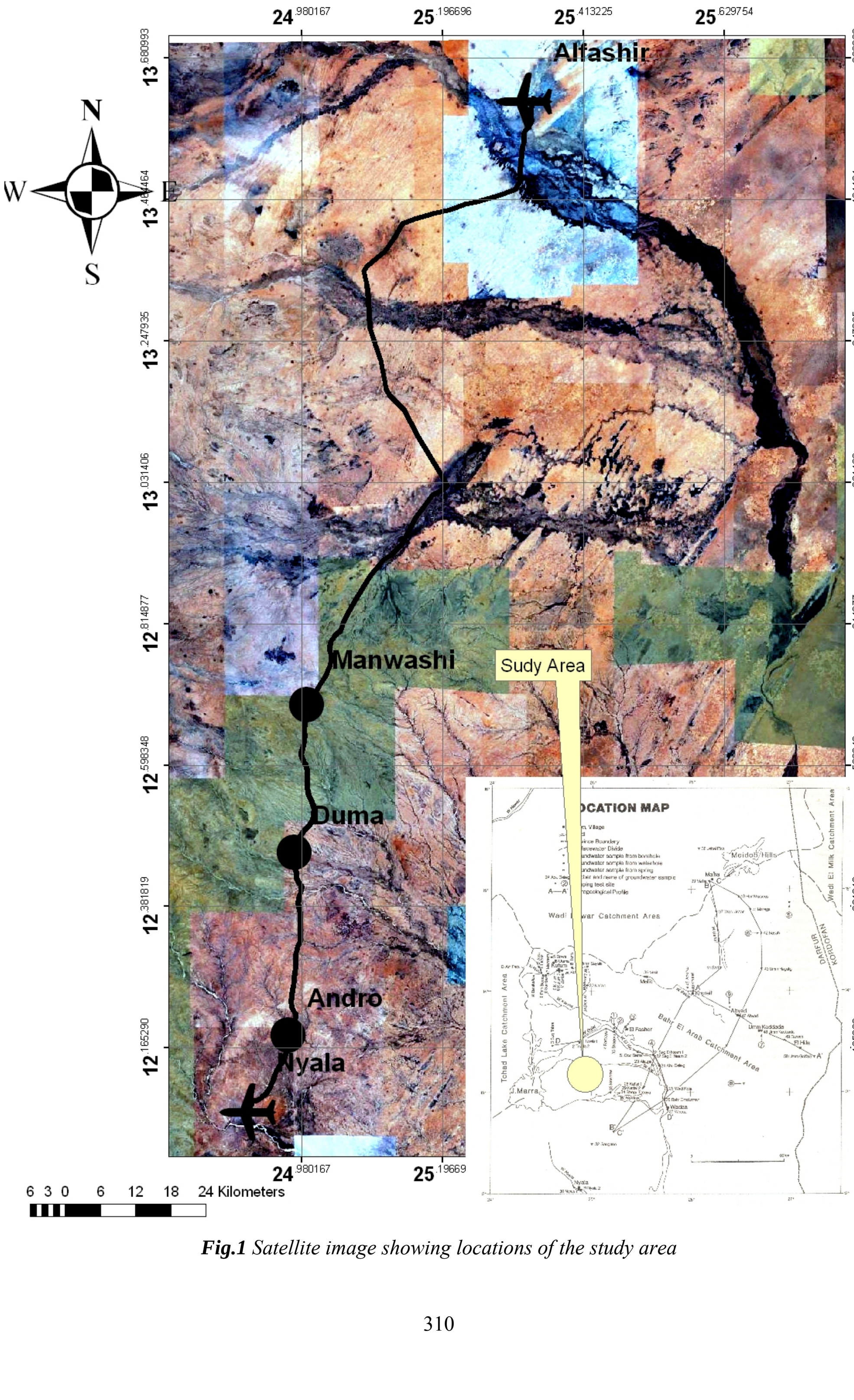


*Fig.1* *Satellite image showing locations of the study area*


***Fig.2*** *Drainage systems in Darfur (after ONC, 1979 and Hunting, 1970)*

## The geology and hydrogeology of the investigated sites

The Geology of Darfur area (fig.3) can be summarized into a few simple rock units (Thorweihe et al. 1990), which are from the bottom to the top:

(e) Superficial Deposits

(d) Volcanic Rocks

(c) Nubian Sandstone Formation

(b) Metasediments

(a) Basement Complex

The investigated area is situated on the basement complex which consist mainly of pre-Cambrian metamorphic rocks intruded by igneous rocks. The basement is overlain by Alluvial deposits of shallow thickness (<1m to >20m). The Alluvial is heterogeneous and is composed of clay beds, silts and sand. Gravels and boulders are found interspread within the sediments. The basement rocks are composed mainly of Gneisses and Schists. Quartz veins occur in the whole area. The fresh basement is generally covered by a zone of altered basement rocks of highly variable thickness. The thickness is associated with the distribution of the drainage system and reaches up to 100m underneath the major wadies.

Metasediments are generally covered by the Qoz, occurred south and east of Sag El Naam Basin. The Nubian formation covers most of the landscape in the area. It is composed of medium to coarse –grained, cross-bedded sandstone, massive to conglomeritic sandstone.

Volcanic rocks of middle to upper Tertiary age, and probably Miocene, range from basalts to trachyte. crop out in the Meidob Hills in the north, in the Tagabo hills between Mellit and Malha and in the Jebel Marra complex with it's eastward directed lava outflows to the Shagera Basin (PUDLO et al in press).

The superficial deposits in the area exist as Alluvial and Qoz. The Alluvial are in the head water sections of wadis are mainly composed of sand with some clay lenses. The thickness of Alluvial ranges from <10 m up to 60 m.

The groundwater aquifers in the area are the weathered basement and the Alluvial deposits of the wadis. The alluvial aquifer is mainly composed of medium to coarse sand. The water table is near the surface (<1 m to >3 m), this level may increase during the dry season and in the years with low rain fall.

## Electrical resistivity survey

In order to delineate variations of the alluvial deposits thickness at the wadis sites, the best geophysical techniques to be employed are the electrical or electromagnetic methods because of the electrical contrasts between conductive over-bank deposits and the resistive coarse-grained sediments in the inner wadis, as well the contrast between the higher resistive basement rocks and the overlying saturated zone of weathered basement and the alluvial deposits which are overlain by more resistive dry superficial deposits. The electrical resistivity method was selected because the Resistivitymeter is available, being less costly, more portable and the shallow nature of the basement rocks and the water table.

In resistivity measurements a direct current is injected into the ground using two electrodes and the voltage difference is measured between another two electrodes. The ratio of the voltage output to the current input is referred to as the impedance of the earth (Dobrin, 1976). The Schlumberger array is widely used in the resistivity surveys because it is an efficient means of collecting a large number of data points and these observations are sensitive to the lateral position and depth characteristics of the resistivity distribution. In this array the spacing between the current electrodes (*AB*) are much larger than the potential electrodes (*MN*), *MN*=*AB*/5. In vertical electrical sounding the spacing between the current electrodes is usually increased while the spacing between the potential electrodes remains fixed for several readings.

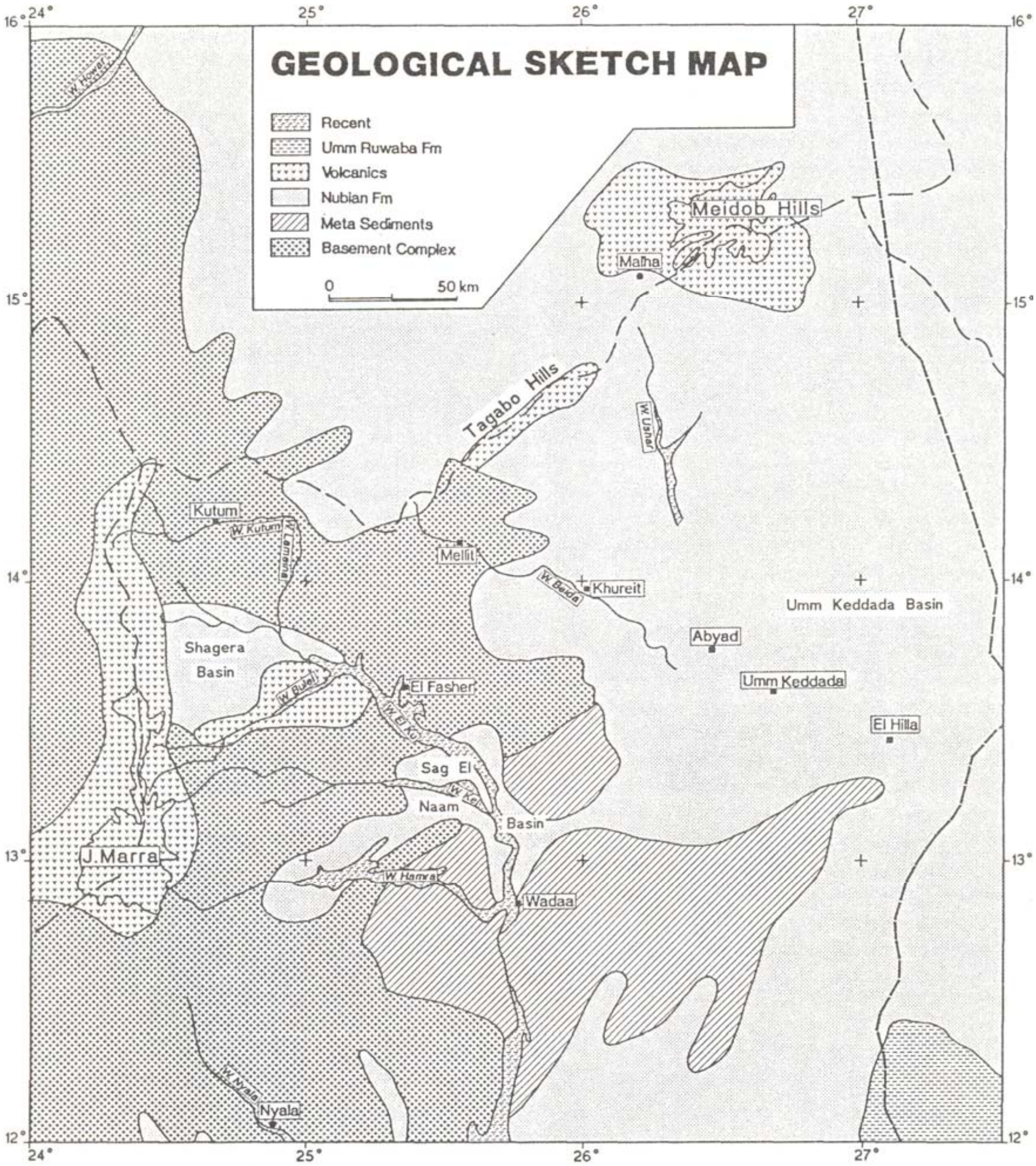


***Fig. 3*** *Geological map of Darfur area (after BRGM 1981)*

The apparent resistivity, $\rho_a$ can be calculated by using the following equation:

$$\rho_a = kR \tag{1}$$

where $k$ is the geometrical factor and $R$ is the resistance of the ground. The geometry scheme for this array is shown in Fig. 4.

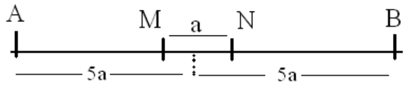


***Fig. 4*** *Sketch diagram of the Schlumberger array.*
*(a: distance between the potential electrodes)*

Data were collected during the field trip (17 – 22, Nov. 2011) by using ABEM (SAS4000) TERRAMETER. A total of 13 vertical electrical soundings were performed, using the Schlumberger electrode configuration, covering the whole of the three sites. To ensure a penetration of up to 50 m, a maximum current electrode separation of 300 m was selected. The resistivity soundings were carried out simultaneously with the drilling program. The boreholes or trial pits are conveniently sited at regular intervals along the bridge routes. Most of the sounding points were conducted nearby boreholes and dug wells for correlation purposes. The location of the resistivity lines are shown in Fig. 5.

## Results and interpretation of the resistivity data

Qualitative interpretation of resistivity sounding data, involves the study of the types of sounding curves obtained. Such curves are known as K, H, A and Q type curves (Keller and Frischknecht, 1966). Typical examples of these curves types are shown in fig 6. The interpretation of the curves constitutes the basis of the quantitative interpretation of the electrical sounding data. The main purposes of quantitative interpretation of VES are to determine the thickness of the different formations having different resistivities.

The inversion and modeling of the resistivity sounding data is carried out by using inversion software (IX1D). The program calculates the apparent resistivity, thickness and the number of layers. The interpretation was checked by calibration of sounding data with the nearby boreholes data. Correlation with the known geology, trial pits and boreholes gives a realistic interpretation. The optimum depth of exploration would be of the order of 20 to 30 m although it is possible to produce interpretations up to a depth of 50 m.

Geoelectrical cross sections were obtained by combining one dimension resistivity models and boreholes information. The results of the three sites are discussed through their geoelectrical cross-sections, extending north-south parallel to the suggested bridge routes. The three sites are located in the wadis plain. The geology consists of alluvial sediments, which are wadis deposits with medium- grained sands, gravels and boulders in the filled channels separated by fine-grained sediments (over-banks deposits) of clays and silts.

## Andro site

Andro site is located north Nyala at a distance of about 15km from the town, latitude 12.184° and longitude 24.9632° (fig. 5). The resistivity survey line has a length of 60m, with 4 VES points and one borehole. The distance between the VES points is 20m, two points are situated at the over-bank (VES. No. 1&4) and the other two (VES. No. 2&3) are situated at the inner part of the Wadi. Fig. 7 shows the geoelectrical cross-section of Andro site.

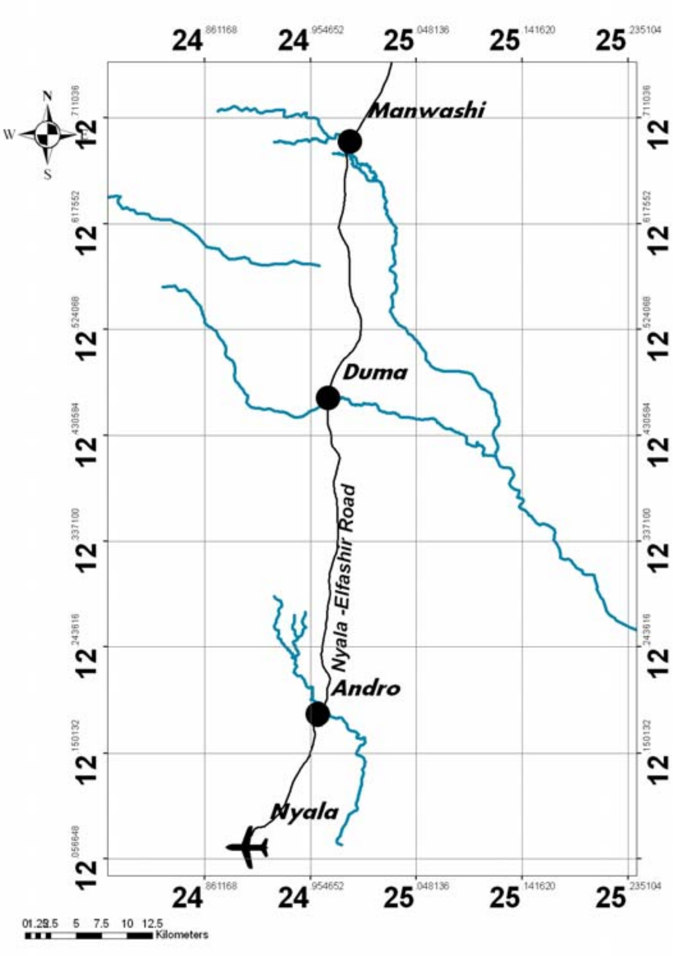


***Fig.5*** *The location of the Resistivity survey Sites*

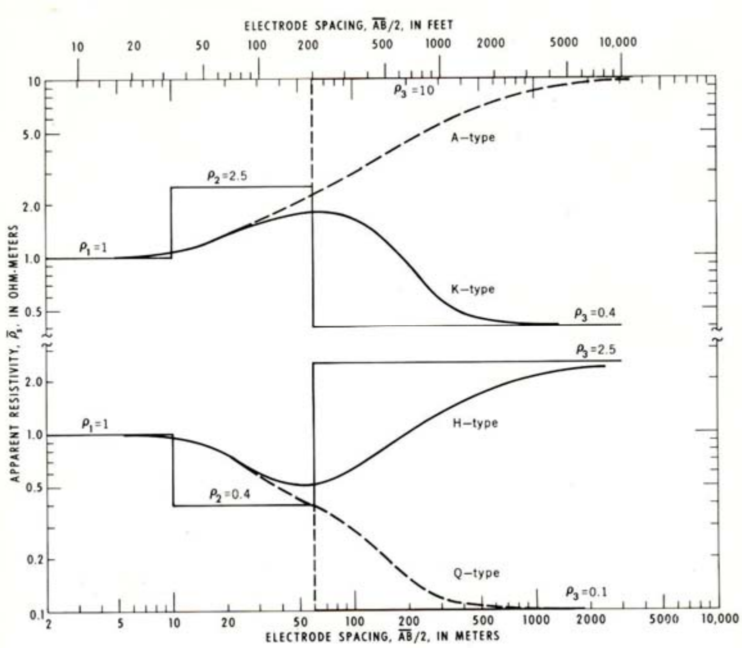


***Fig.6*** *Examples of four types of the three layer Schlumberger sounding curves (Zohdy, 1974)*

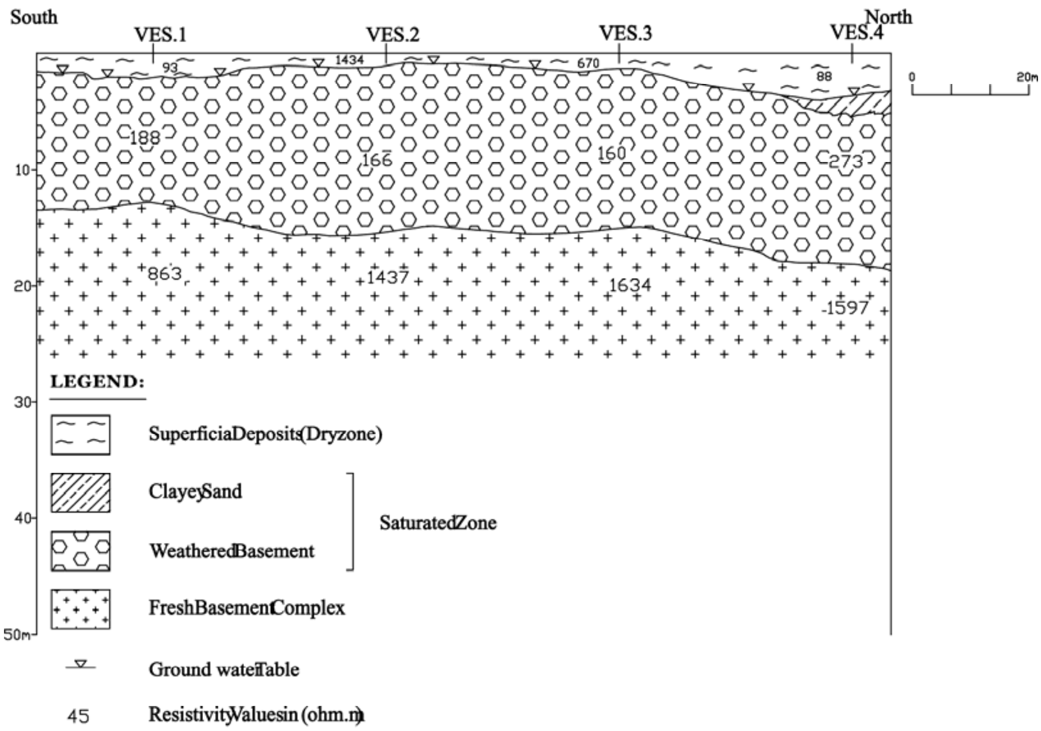


***Fig.7*** *Geoelectrical Section for Adnro Site*

The results of the interpreted curves along this line (appendix) are corresponding to three and four layers case. The curve types in the central part of the line (inner part of the wadi) are H types (VES.3& 4). The high resistivity of the bottom layer (>1000 Ω·m) represents the fresh basement rocks. The middle layer has low resistivity (160 – 166 Ω·m) which are due to the presence of the saturated zone (groundwater aquifer), which is probably composed of weathered or cracked basement rocks and or alluvial deposits boulder intercalated with sandy or silty clay. The top layer is of high resistivity layer (670 – 1434 Ω·m) representing the dry zone of sandy superficial deposits.

The curve types in the over-bank of the wadi are A and HA type curves (VES.1 & 4) where the resistivity of the middle layer varies from 188 to 273 Ohm-m. It represents the saturated zone (this layer is of relatively higher resistivity compared with the same layer in VES 2&3. This reinforce the idea that the basement in the over-bank is not highly weathered compared with inner part of the Wadis). The layer is intercalated with sandy or silty clay lense in the northern part under VES.4 (HA type). The bottom layer has higher resistivity values (863 - 1597 Ω·m) due to presence of fresh basement rock. While the top layer has resistivity values which varies from 88 to 93 Ohm.m representing the dry clayey sand of superficial deposits Quantitatively, this section has three main layers , these are :

1) The top dry superficial deposits which has a thickness varying from <1 m in the inner part of the wadi to >3 m in the over-bank , this depth represents the groundwater level in this site.

2) The middle layer represents the saturated zone (groundwater aquifer) which is interpreted as moderately weathered or cracked basement rocks or as alluvial deposits of boulder intercalated with sandy and silty clay.

3) The bottom layer represents the fresh basement rock and has a depth which varies from 12 to 17 m.

***Table1*** *Results of the quantitative interpretation of the resistivity data, Andro site*

| Resistivity Values Ohm (m) | Interpreted layer | Thickness (m) | Depth (m) |
|---|---|---|---|
| 90 -1400 | Dry top layer (Superficial deposits) | < 1 m to > 3 m | |
| 160 -270 | Saturated zone | 10 - 13 | |
| >1000 | Fresh basement rocks | | 13 - 15 |

## Duma site

This site is located north Nyala at a distance of about 42km from the town, latitude 12.4572° and longitude 24.9725° (fig. 5). The resistivity survey line has a length of 400m, with 5 VES points and 12 boreholes. The distance between the VES points is 100m, two points are situated at the over-bank (VES. No. 1&5) and three points (VES. No. 2&3) are located at the inner part of the Wadi. Fig. 8. is the geoelectrical cross-section of Duma site.

The results of the interpreted curves along this line are corresponding to three and four layers case. The curve types in the southern and central part of the line are KH types (VES.1, 2& 3) while the curves in the northern part of the line (VES. 4 &5) are H type curves. This indicates a top dry layer of lateral facies changes varying from clayey in the southern part to sandy in the northern part of the line. The resistivity along this layer varies from 122 to 528 Ohm.m. The top layer is underlain by a zone of low resistivity values, which varies from 32 to 73 Ohm.m. It represents the saturated zone (groundwater aquifer). The aquifer is composed of highly weathered basement rocks or alluvial deposits of pebbly sandy and silty clays .The low resistivity value (7 Ω·m) in the southern part of this zone may represent clayey or silty clayey lenses. The saturated zone is underlain by a high resistivity zone (>10000 Ω·m) which indicates the presence of fresh basement rocks.

Quantitatively, this section has three main layers , and can be described as follows:
(1) The top dry superficial deposits which has a thickness varying from <.5 m in the northern part of the line to about 2 m in the southern part of the line. This depth (<.5 m – 2 m) may represents the groundwater level in this site.
(2) The middle layer represents the saturated zone (groundwater aquifer) which is interpreted as highly weathered basement rocks or as alluvial deposits of pebbly sandy and silty clays.
(3) The bottom layer represents the fresh basement rocks, and it has a depth which varies from 4 m to 21 m. The topography of the basement rocks (Bedrock) along this line is highly undulating with a lower depth of 4 m under (VES.1).

***Table2*** *Results of the quantitative interpretation of the resistivity data, Duma site*

| Resistivity values Ω·m | Interpreted layers | Thickness (m) | Depth (m) |
|---|---|---|---|
| 120 - 520 | Top dry layer (superficial deposits) | < 0.5 m to 2 m | |
| 50 - 60 | Saturated zone | 3 - 20 | |
| 400 - 4000 | Fresh basement rocks | | 4 - 22 |

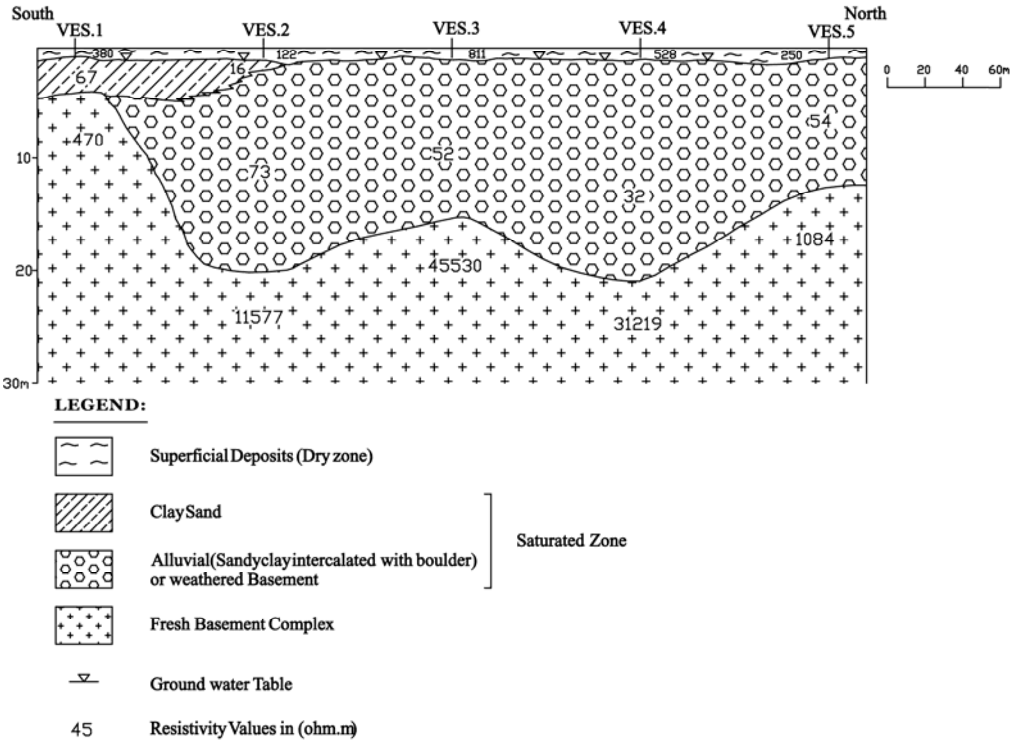


***Fig.8*** *Geoelectrical Section for Duma Site*

## Manwashi site

This site is located north Nyala at a distance of about 75km from the town, at latitude 12.6901° and longitude 24.9933° (fig. 5).. The resistivity survey line has a length of 110m, with 4 VES points and 6 boreholes. The distance between the VES points is 36m, two points are located at the over-bank (VES. No. 1&4) and the other two (VES. No. 2&3) are situated at the inner part of the Wadi. Fig.9. is the geoelectrical cross-section of Manshawi site.

The results of the interpreted curves along this line are corresponding to three layers case (H type curve). The top layer has a resistivity which varies from high values (>578 Ohm.m) in the inner part of the Wadi to relatively lower values (132 to 291 Ohm.m) in the over-bank of the Wadi. This indicates the presence of a dry top layer of lateral facies changes from sand in the inner part of the Wadi to silty clay in the over-bank of the Wadi.

The top layer is underlain by a zone of low resistivity values, which varies from 13 to 48 Ohm.m, it represents the saturated zone (groundwater aquifer) which is probably composed of highly weathered basement rocks or alluvial deposits of sandy and silty clay .The low resistivity value (13 Ω·m) in the northern part of this zone (over-bank) may represent a clayey or silty clayey lenses. The high resistivity of the bottom layer (>27000 Ω·m) is due to the presence of fresh basement rocks.

Quantitatively, this section has three main layers, and can be described as follows:

1)The top dry superficial deposits which has a thickness varying from 0.5m in the inner part of the wadi to about 2m in the over-bank. This depth represents the groundwater level in this site.

2) The middle layer represents the saturated zone (groundwater aquifer) which is interpreted as highly weathered basement rocks or as alluvial deposits of sandy and silty clay.

3) The bottom layer represents the fresh basement rocks. It has a depth which varies from 11 to 22m. The topography of the basement rocks (Bedrock) along this line is highly undulating (fig. 9).

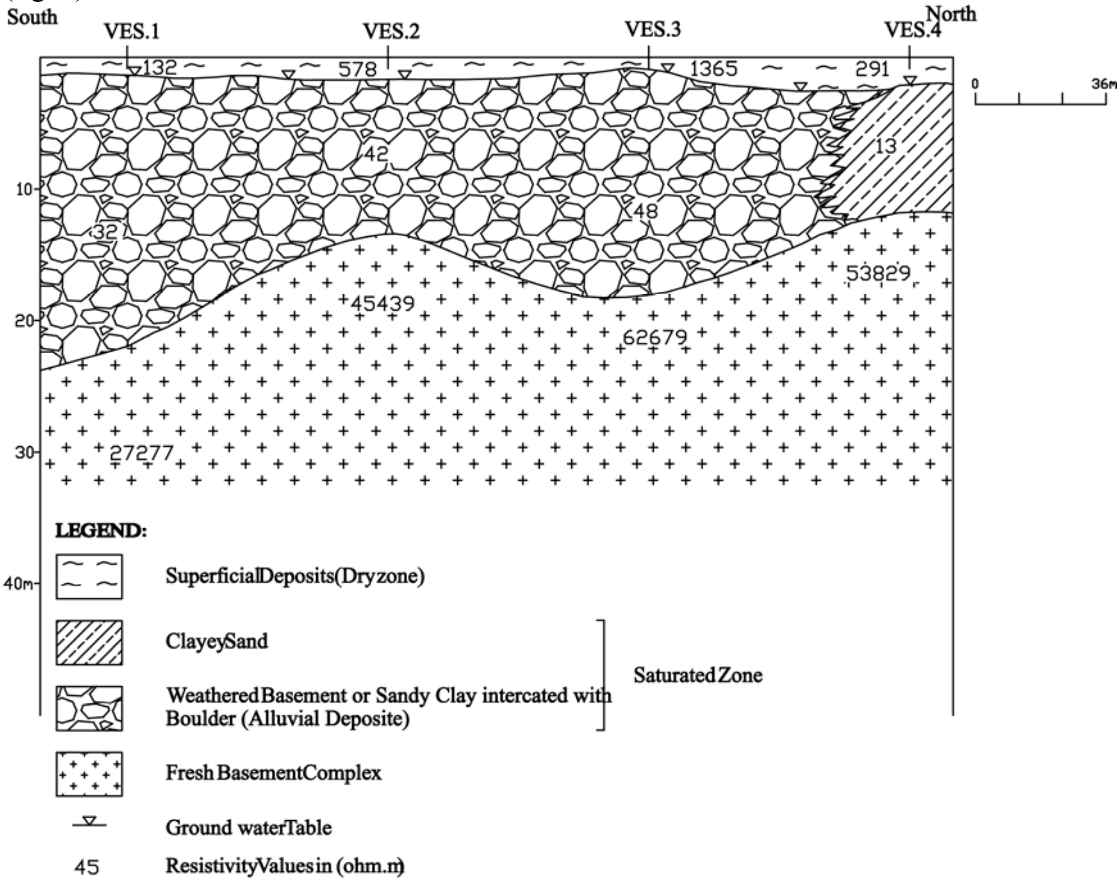


***Fig.9*** *Geoelectrical Section for Manwashi Site*

***Table3*** *Results of the quantitative interpretation of the resistivity data, Manwashi site*

| Resistivity values Ω·m | Interpreted layers | Thickness (m) | Depth (m) |
|---|---|---|---|
| 130 - 1300 | Dry top layer (Superficial deposits) | 0.5 - 2 | |
| 30 - 50 | Saturated zone | 10 - 20 | |
| 27000 - 60000 | Fresh basement rocks | | 11 - 22 |

## Conclusions and Recommendations

Geoelectrical measurements were successfully used for site investigations, in order to map the topography of the subsurface bedrock, and the lithology of the overlying sediments as well as to delineate the groundwater levels. The most significant conclusions of the current study are as follows:
(1) The topography of the basement is undulating, varying in depth from < 4 m to >20 m.
(2) There is a similarity in the lithology of the saturated zone of Duma and Manshawi Sites.

(3) The groundwater level varies from <1 m in the inner part of the Wadis to >3m in the over-bank deposits. This level may increase during the dry season and in the years with low rainfall.
(4) The geological sections of the three sites can generally be divided into three zones as follows:
(a) The top dry zone (<1 m to >3 m) representing the superficial deposits
(b) The middle zone (Saturated zone) represents the groundwater aquifer. Its lithology varies from weathered and cracked basement rocks to the Alluvial deposits with their heterogeneity nature which varies from clayey, silty, sandy, pebbly and boulders layers.
(c) The bottom zone (Fresh basement rocks) represents the bedrock. It shows the increase of hardness and compaction from Andro, Duma and Manshawi sites respectively.
(5) There are several clay layers which are intercalated with sand as proved by drilling.
(6) The thickness of the weathered basement rock in the inner parts of the wadis is more than in the over-bank.
(7) The saturated zone in Duma and Manwashi sites must be excavated up to the fresh basement rocks.
(8) The upper-part of the saturated zone in Andro site must be excavated while the cracks and joints in the lower part of this zone can be filled in by cement grouting.
(9) The interpreted resistivity results agree with the general geology and drilling in formations as well as the engineering work in the area

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