International Journal of Geophysics and Geochemistry
2015; 2(4): 92-97
Published online July 20, 2015 (http://www.aascit.org/journal/ijgg)

AASCIT American Association for Science and Technology

Keywords
Abuja,
Basement Groundwater,
Vertical Electrical Sounding (VES),
Geophysical Survey

Received: June 28, 2015
Revised: July 8, 2015
Accepted: July 9, 2015

Geophysical Analysis of Basement Terrain Groundwater Using Vertical Electrical Sounding: A Case Study of Parts of Abuja North Central Nigeria

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Citation

Omeje Maxwell, Ebele James Ejike, Paulinus Ekene Ugwuoke. Geophysical Analysis of Basement Terrain Groundwater Using Vertical Electrical Sounding: A Case Study of Parts of Abuja North Central Nigeria. *International Journal of Geophysics and Geochemistry.* Vol. 2, No. 4, 2015, pp. 92-97.

Abstract

The successful exploitation of groundwater requires a proper understanding of the hydrogeological characteristics of the sub-surface aquifers found within the basement complex. This can be carried out using various geophysical survey methods. Groundwater occurs in the joints, fissures, fractures, shear zones and weathered overburden of un-weathered rocks. Therefore effective groundwater development requires careful geophysical analysis and interpretation of data. The use of vertical electrical sounding (VES) for groundwater (hydrogeological) exploration is popular in the basement complex rocks and sedimentary basins. This study was aimed at analysing the hydro geological characteristics such as bedrock depth, lithological units and degree of fracturing and drilling location of groundwater in the basement complex / terrain of Garki, Kurudu, Dei-Dei and Kubwa areas of Abuja, North central Nigeria using Resistivity Method. Finally, the results indicate that the choice of geophysical survey method determined by physical properties of the area; influence groundwater availability, susceptibility and supply.

1. Introduction

The successful exploitation of groundwater basement terrain requires a proper understanding of the hydrogeological characteristics of the aquifer units. This is due to the discontinuous and localized nature of the aquifers in the basement. The characteristics of ground water aquifers can be determined using geophysical survey methods. Examples of these techniques include magnetometry, electrical resistance, ground-penetrating radar and electromagnetic survey which are based on different physical properties *see table 1*. The primary objective of geophysical survey methods is to locate boundaries where contrasts in physical properties exist. Consequently, these variations in physical properties usually give rise to geophysical anomalies in relation to background value. Examples of detectable underground anomalies include wells, pits, gullies, ditches, walls, floors, hearths, kilns and roads. In addition, geophysical survey methods are used to locate intrusive tests on the basis of geographical data so as to correlate the geophysical results with physical interpretations [1, 2].

Therefore the choice of geophysical methods is largely based on the different physical properties of the area under investigation as presented in *table 1*. For example gravity methods are influenced by density variations within the subsurface geology; making it ideal for exploring major sedimentary basins. However this method is unsuitable for localized near surface ground water exploration due the inexistence of density variations between the saturated and unsaturated rocks [1]. In contrast, the resistivity method is based in the difference electrical resistivity between terminals driven into the ground at intervals such as pits, ditches and gullies. The varying resistances can then be plotted as a series of contours or simply anomalies of features [2-4].

For the hydrogeological applications, the use of vertical electrical sounding (VES) also known as Resistivity Sounding (RES) for groundwater exploration is popular for basement complex rocks. This method has been used extensively by many researchers for groundwater investigation in the basement complex terrains and the sedimentary basins in Nigeria [5-7].

The study area is located in Abuja and serves as the city's principal business district and the location of strategic government offices, [8].

Consequently, this study is aimed at analyzing the groundwater in the basement terrain Area of Abuja, Nigeria using Vertical Electrical Sounding. The study was conducted by JIMKELLY GEOPHYSICAL SERVICES NIG. LTD for providing Campus Ohmega tetrameter used for resistivity data to locate a viable point to drill a productive water borehole. The survey was also aimed at:

- Determining the depth to bedrock
- Delineating the lithological units that constitute the overburden (regolith)
- Determining the degree of fracturing of the basement
- Select the suitable point for the construction of the borehole.

The area of investigation falls within the basement complex rocks of Northern Nigeria. The assemblage of rocks consists of gniesses, granite-gneiss, migmatite, schist bed and their modification. In the study area which forms the Basement Complex of north central Nigeria; with lithologic units falling under three main categories, which include (1) Undifferentiated. migmatite complex of Proterozoic to Archean origin, (2) Metavolcano-Sedimentary rocks of late Proterozoic age and (3) older granite complex of late Precambrian - Lower Paleozoic age, also known as Pan-African granites[8]. All these rocks have been affected and deformed by the Pan-African thermo tectonic event. Detailed reports of the lithological description, history, structure and geochemistry of the basement complex of Nigeria are given in Oyawoye [9]. Figure 1 shows the geology of the study area.

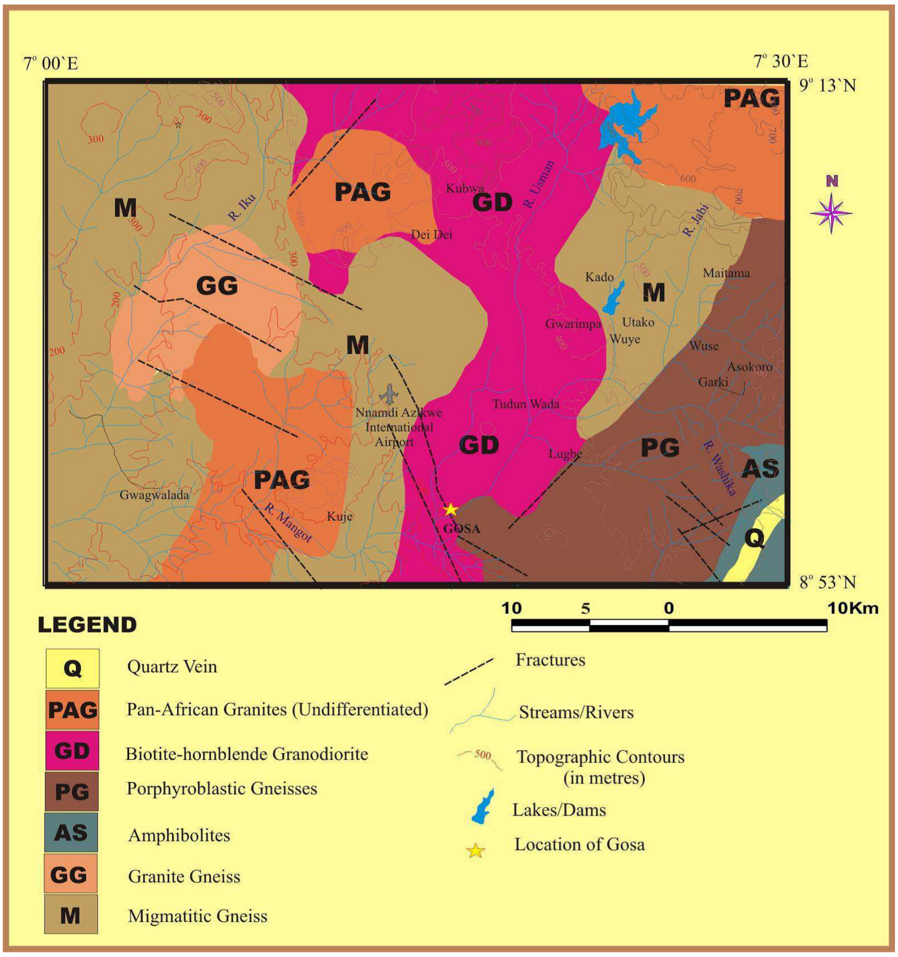

Fig. 1. *Geologic Map of the Study Area (After Omeje et al., 2013).*

Table 1. *Examples of Geophysical Methods.*

Geophysical Method	Dependent Physical Property	Major Applications
Gravity	Density	Oil and gas exploration, Geological studies
Magnetic	Susceptibility	Site Investigation, Archaeology Oil and gas exploration, Geological studies
Seismic Refraction	Elastic Moduli; Density	Geological studies, Oil and gas exploration
Seismic Reflection	Elastic Moduli; Density	Geological studies, Oil and gas exploration.
Resistivity	Resistivity	Environmental Site Investigation, Hydrogeological investigation, Detection of subsurface cavities.
Magnetic-telluric	Resistivity	Oil and gas exploration, Geological studies.
Electro-Magnetic (EM)	Conductance; inductance	Oil and gas exploration, Geological studies, Environmental Site Investigation, Hydrogeological investigation, Detection of subsurface cavities.
Magnetic Resonance Sounding (MRS)	Magnetic Moment	Hydrogeological investigation.
Radiometrics	γ-radioactivity	Exploration and Mineral deposits development.

2. Materials & Methods

2.1. Procedure

The investigation of the target area was carried out using Vertical Electrical Sounding (VES) of electrical Resistivity Method. The method was designed to detect the physical and structural characteristics of the basement rocks such as variation in conductivity. The varying conductivities or resistances are consequently plotted as a series of contours or anomalies can consequently be used to determine the occurrence and depth of productive aquifers. The survey involved the selection of two-stations and probing points. FULL SCHLUMBERGER array with maximum electrode separation of AB/2= 50 meters was acquired using Allied Ohmega C2 Resistivity Meter by JIMKELLY GEOPHYSICAL SERVICES NIG. LTD. The field data obtained was presented as curve of apparent resistivity values (ohm-meter) against half of the current electrode separation (AB/2) in meters on a log-log scale. A 3-mode filter was employed to jettison associated noise due mostly to electrical signals interference from adjacent power transmission lines.

2.2. Data Interpretation

The Vertical Electrical Sounding (VES 1) displayed simple QH-type curve. Therefore quantitative partial curve matching method was adopted. This technique involves two main steps. A sort segment of the curve was cross matched with a 2-layer master curve. From the most appropriate matching, the value ρ1 (apparent resistivity of the first layer, the depth to the top of the second layer *h*1 and ρ2, the apparent resistivity of the second layer were obtained. VES 2 displayed simple KH- type curve. Therefore quantitative partial curve matching method was adopted. This technique involves two main steps. A sort segment of the curve was cross matched with a 2-layer master curve. From the most appropriate matching, the value ρ1 (apparent resistivity of the first layer, the depth to the top of the second layer h1 and ρ2, the apparent resistivity of the second layer were obtained. VES 3 displayed simple H- type curve. Therefore quantitative partial curve matching method was adopted. This technique involves two main steps. A sort segment of the curve was cross matched with a 2-layer master curve. From the most appropriate matching, the value ρ1 (apparent resistivity of the first layer, the depth to the top of the second layer h1 and ρ2, the apparent resistivity of the second layer were obtained. VES 4 displayed simple KH-type curve respectively. Therefore quantitative partial curve matching method was adopted. This technique involves two main steps. A sort segment of the curve was cross matched with a 2-layer master curve. From the most appropriate matching, the value ρ1 (apparent resistivity of the first layer, the depth to the top of the second layer h1 and ρ2, the apparent resistivity of the second layer were obtained. Computer software WINRESIST 2004 Version was used to improve the quality of the interpretation.

3. Results & Discussion

In general, the main source of water in a basement complex is the weathered zone and or in the joints and fractured system in un-weathered rocks. Preliminary investigation of the location revealed it is underlain by crystalline basement complex rocks. Consequently, the occurrence of groundwater at these locations may be primarily due to the development of secondary porosity. Furthermore, this can be attributed to weathering and/or fracturing of the basement rocks which aids permeability. The aforementioned parameters were thus used to determine a suitable location for drilling the borehole.

The results of the Vertical Electrical Sounding (VES 1, VES2, VES 3 and VES 4) measurement and data set analysis are presented in table 2. The profile plots of the VES data are shown in Figures 2,3,4 and 5 respectively. It revealed 3 distinct layers exist before the basement for VES 1. Furthermore, it was observed that the lithology at VES 1 consists of sandy clay top soil, sandy clay, which is underlain by micaceous sandy clay weathered basement followed by a well-defined fractured basement rock. The estimated overburden thickness at VES 1 is between 10-15 m. The positive inference observed at VES 1 showed well-defined fractured basement and hydrogeological properties characteristic of regions with abundant groundwater supplies. Therefore VES 1 was marked as a viable drill point and drilling was carried out at a depth of 70 meters. Subsequently, grouting was carried out at a depth of about 10 meters to avoid pollution from surface sources. The data set analysis revealed distinct 4-layers before basement for VES 2. The lithology at VES 2 is composed of top soil, underlain by laterite, which is been underlain by hardpan. Immediately underlying this layer is sandy clay weathered basement which is been underlain by well-defined fractured basement rock. Estimated overburden thickness at VES 2 is between 25-30 meters.

Table 2. *Drilling Guide.*

VES 1 (Garki)	Resistivity (ohmm)	Depth (m)	Lithology
L1	154	1.0	Sandy clay top soil
L2	112	4.0	Sandy clay
L3	30	10.3	Micaceous sandy
L4	730	10.5	Fractured basement
VES 2 (Kurudu)			
L 1	633	1.0	Top soil
L2	719	3.6	Laterite
L 3	8913	5.0	hardpan
L 4	233	23.4	sandy clay weathered basement
L5	1283	23.4-∞	Fractured basement
VES 3 (Dei-Dei)			
L 1	320	1.1	Sandy clay top soil
L2	100	10.8	sandy clay weathered basement
L3	493	10.8-∞	Fractured basement
VES 4 (Kubwa)			
L 1	257	0.8	Sandy clay top soil
L 2	1219	1.7	Laterite
L3	530	15.6	Weathered basement
L 4	100000	15.6-∞	Fresh basement

VES 2 has positive inference in terms of thick overburden and a well-defined fractured basement and as such, it possesses requisite hydro-geological characteristics that could supply underground water in fair quantity to well when drilled. VES 2 is therefore a viable drill point. From the above analysis, VES 2 is hereby recommended for drilling. Recommended drill depth is 40 metres. The hole should be grouted to a depth of about 3 metres to avoid pollution from surface sources. The data set analysis revealed distinct 2-layers before basement for VES 3. The lithology at VES 3 is composed of sandy clay top soil, underlain by sandy clay weathered basement which is underlain by well-defined fractured basement rock. Estimated overburden thickness at VES 3 is between 9-12 metres. VES 3 has positive inference in terms of a well-defined fractured basement and as such, it possesses requisite hydro-geological characteristics that could supply underground water in fair quantity to well when drilled. VES 3 is therefore a viable drill point. From the above analysis, VES 3 is hereby recommended for drilling. Recommended drill depth is 35-40 metres. The hole should be grouted to a depth of about 3 metres to avoid pollution from surface sources. The data set analysis revealed distinct 3-layers before basement for VES 4.The lithology at VES 4 is composed of sandy clay top soil, underlain by laterite which is been underlain by weathered basement. Immediately underlying this layer is fresh basement rock. Estimated overburden thickness at VES 4 is between 14-16 meters. VES 4 does not have positive inference in terms of a well-defined fractured basement and as such, it does not possess requisite hydro-geological characteristics that could supply underground water in fair quantity to well when drilled. VES 4 is therefore not a viable drilling point.

Consequently, the computer software WINRESIST ™ 2004 Version was used to improve the quality of the interpretation [10]. The interpretations are as presented in figures 1, 2,3 and 4 respectively.

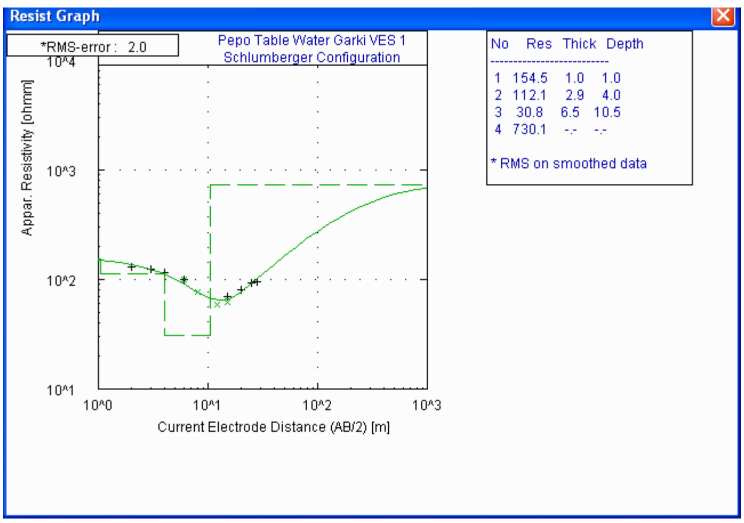

Fig. 2. *VES of Garki Area .*

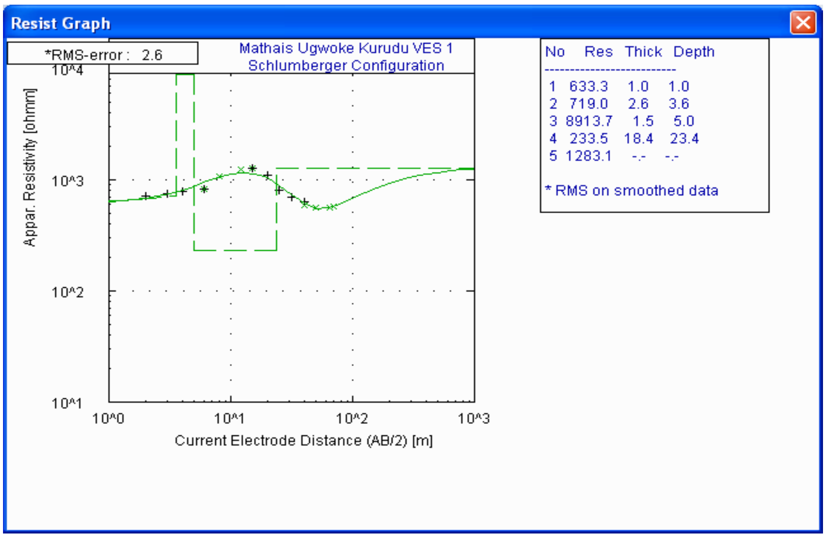

Fig. 3. *VES of Kurudu Area.*

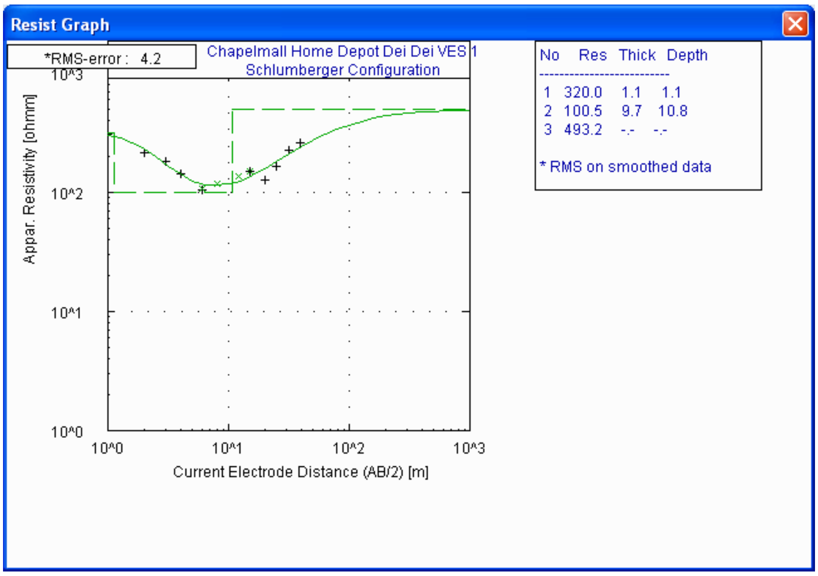

Fig. 4. *VES of Dei-Dei Area .*

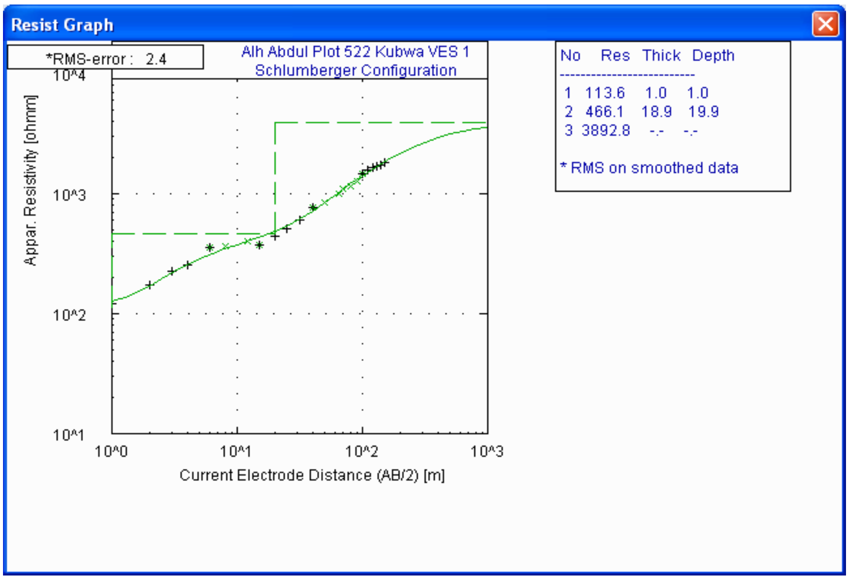

Fig. 5. *VES of Kubwa Area .*

4. Conclusion

The study was aimed at analysing the hydrogeological characteristics of basement terrain groundwater in Abuja, Northcentral Nigeria using the Resistivity Method. The results were used to determine the bedrock depth, lithological units, and degree of fracturing of the basement complex. Furthermore, a suitable point for the construction of the boreholes in the target area was determined. Finally, the study showed the choice of geophysical survey method determined by physical properties of the area; which in turn influences groundwater availability, susceptibility and supply. This also plays a vital role quality and quantity of water available for human consumption.

Acknowledgement

The authors would like to acknowledge Maxico Hydrosolution consult for the scientific idea of geophysical prospecting in this study. The authors will gratefully acknowledge JIMKELLY GEOPHYSICAL SERVICES NIG. LTD for providing Campus Ohmega terameter used for resistivity data acquisition.

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