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Interpretation of Geoelectric Pseudo-Section of a Profile Across a Functional Borehole Located in-between Two Non-Functional Dug-Wells

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Abstract
Electrical resistivity imaging survey was carried at Agban, Kaura Area of Kaduna State Nigeria. A profile of 500m length was deliberately selected to cut across a functional borehole located averagely 100m in-between two non-functional dug-wells. Ten (10) VES Points were sounded along the profile in the N-S direction. Terrameter SAS300 was the instrument used. The tomogram of the profile shows that the area is underlain by four layers; the first layer is sandy clay with resistivity range of 200-500Ωm. This is taken as the Overburden. The second layer is the weathered basement which constitutes of Sandy soil and water. This is taken to be the aquifer which varies along the profile. The third layer comprise of coarse grain sand which is the fractured basement of resistivity range of 1000-2000Ωm. The fourth layer of resistivity greater than 2000Ωm is the fresh basement. The image also shows a U-shaped fracture zone within the subsurface, the borehole was drilled through this fracture which contains water. This fracture causes water to migrate from the locations of the wells and accumulate at the borehole site. This research has gone a long way to establish the facts that since the dug wells are shallow; they failed at the end of the dry season when groundwater levels fall. It is a common knowledge that little specialist equipment is used for the construction of a well even though it is difficult to construct hand dug wells in hard rock. On the basis of the results of this study, we therefore recommend that thorough geophysical survey should always be carried out in the basement complex before constructing dug wells for them to be sustainable.
Keywords: Resistivity1, Kaura2, Well

1. INTRODUCTION
Groundwater is one of the most important natural resources. Its availability in Basement Complex rocks is commonly due to the development of secondary porosity and permeability resulting from weathering and fracturing. Aquifers are known to occur within the highly weathered overburden and the fractured zones of the basement rock (Afuwai et al., 2013). The discontinuous nature of the basement aquifer system makes detailed knowledge of the geology, hydrogeological and geophysical investigations inevitable. Electrical resistivity method is one of the most relevant geophysical methods applied in groundwater investigation in the basement terrains. The vertical electrical sounding (VES) technique using Schlumberger configuration has proved useful especially for the delineation of weathered and fractured zones in the basement rocks.

Kaura area lies within the crystalline hydrogeological province of northern Nigeria belonging to the Younger Granite and Basement Complex suites. These rocks lack primary porosity where groundwater could accumulate for exploitation. For these rocks to store water there must exist in them secondary porosity, which invariably results from weathering and fracturing. However, the spatial distribution and depth of this kind of porosity vary from one location to another, hence the occurrence of groundwater in these rocks is sporadic and borehole siting for its abstraction in this geological terrain is often difficult.

Although the storage of weathered basement aquifers is low relative to many other aquifer types due to limited vertical and lateral extent, typical long-term average volumes of water available at the end of the wet season (100 mm) are vastly greater than the 1-3 mm/a which it is estimated would be required to bring the population of Africa up to the World Health Organisation recommended water supply of 25 litres/head/day (Chilton et al., 1995). However, problems of groundwater availability and access in the shorter term complicate the picture. These problems arise due to two major constraint: the extended periods of below average rainfall that occur in arid and semi-arid regions which reduce the recharge necessary to replenish the limited aquifer storage; and the low permeability of basement aquifers which can cause significant dewatering of aquifers in the vicinity of pumping wells and boreholes (Eduvie et al., 2004).

Although, with the aid of hydrogeological expertise, boreholes may be drilled that allow abstraction of upwards of 150 m^3/day from basement aquifers, the productivity of these aquifers is generally poor due to low permeability and saturated thickness of weathered material .In extreme cases these may be so low that the yield from wells may not even be sustainable over the period of one dry season (Afuwai, 2014). However, even relatively productive wells may suffer during periods of drought as seasonal replenishment of these low storage aquifers is essential. During these periods, problems of reduced storage are exacerbated by increased groundwater abstraction as alternative water sources disappear. In regions affected by such conditions the siting and design of groundwater sources is crucial.

Deeper fractures within the basement rocks are also an important source of groundwater, particularly where the weathered zone is thin or absent. These deep fractures are tectonically controlled and can sometimes provide supplies of up to one or even five litre/s (Akintorinwa et al., 2009). Sands and gravels eroded from basement rocks and deposited in valleys can also be important sources of groundwater. The groundwater resources within the regolith and deeper fracture zones depend on the thickness of the water-bearing zone and the relative depth of the water table (Alan et al., 2000). The deeper the weathering, the more sustainable the groundwater. However, due to the complex interactions of the various factors affecting weathering, water-bearing horizons may not be present at all at some locations.

Different methods have been used to abstract groundwater from basement aquifers. The most common are boreholes and dug wells. Collector wells have also been used with much success, although their distribution is at present fairly limited (Barker, 2001). Each of these abstraction methods has their own advantages and limitations. Boreholes are quick to drill, can penetrate hard rock easily and can be drilled to depths of 100 m. However, drilling is expensive and can limit the participation of communities. Boreholes are necessary in basement areas for abstracting water from deep fracture zones. Dug wells are best used to exploit aquifers within thick, near surface zones of weathering. The main advantage of dug wells is that they can store a large amount of readily accessible water. Wells also have a large internal surface area, which maximises seepage from the aquifer

Around August 2013, when the raining season was at its peak, the average water table of the area was taken to be 12m, this was done by sampling sixty one (61) dug wells randomly. It was observed that most functional boreholes have wells around them with relatively low water table (averagely 7m); and for the non-functional boreholes the wells around them have relatively high water table (averagely 34m). Around three non-functional boreholes at Zankan, Kukum-Daji and Bondong all within Kaura it was observed that the wells very close to them have failed. And surprisingly, at Agban, an Area within Kaura, a functional borehole has two wells averagely 100m away from it that are dry. To find out why these dug-wells have failed; is the primary objective of this research.

2. SURVEY AREA

Kaura area lies between latitudes $9^0 30'$ N and $9^0 45'$N and longitudes $8^0 20'$E and $8^0 35'$E. The area has an approximately landmass of 770 km^2 within the crystalline hydrogeological province of northern Nigeria (Figure1) belonging to the Younger Granite and Basement Complex suites. These rocks lack primary porosity where groundwater could accumulate for exploitation. For these rocks to store water there must exist in them secondary porosity, which invariably results from weathering and fracturing. However, the spatial distribution and depth of this kind of porosity vary from one location to another, hence the occurrence of groundwater in these rocks is sporadic and borehole siting for its abstraction in this geological terrain is often difficult, this is why for this study, to achieve high resolution images of the subsurface the resistivity tomography technique is employed.

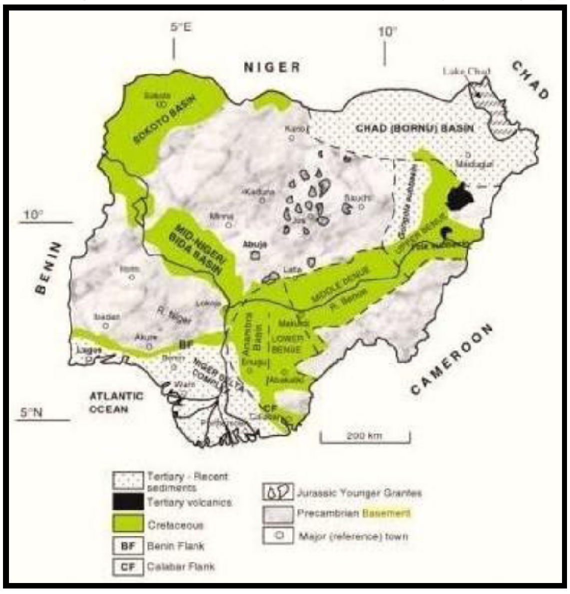

Figure1. Geological Map of Nigeria (from: Geological Survey of Nigeria, 1974).

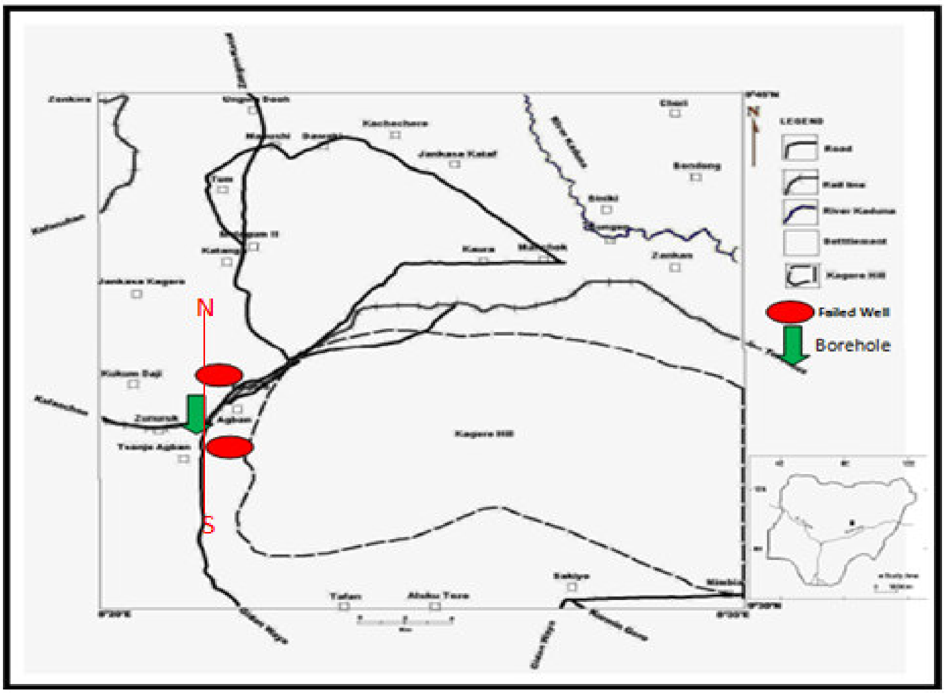

Figure2. Map of Kaura showing the failed dug well (coloured red) and functional boreholes (coloured red).

3. LOCATION, EXTENT AND ACCESSIBILITY

The area under study is located in Kaduna State within the Basement Complex rocks of north-Central Nigeria. It lies between latitudes 9030' N and 9045'N and longitudes 8020'E and 8035'E. The area has an approximately landmass of 770 km2 (Yanet, 1996). The area is traversed by good roads network which are the Jos –Kagoro Kaduna road that runs East-West. Others are the Kagoro-Kafanchan road, Kagoro –Manchok Jos road and Kagoro-Mabushi road Manchok-Jankasa Mabushi roads. In the central part of the study area, Rail line traverses from Kafanchan-Kagoro to Jos Terminus in Plateau State.

4. RELIEF AND DRAINAGE

The relief is undulating highlands to average height of about 1,800 m above sea level in the study area. There are two major rivers in the area; these are River Kaduna at the NE of study area and River Assob at the SE. Most of the streams are seasonal. The course of these rivers seems to suggest features of structural significance, aided by fractures normal to direction of regional strike and drains to River Kaduna with its tributary at the north-eastern part of the study area.

5. GEOLOGY OF THE AREA

The study area is made up of the rocks of the Migmatite-Gneiss Complex, Gneiss, Younger Metasediments, Older Granites, Younger Granites and Newer Basalts. The distribution of the various rock types is as shown on the geological map of the area (Figure 3). Basement rocks that occur in the study area could be classified into:

1. Migmatites-Gneiss Complex
2. Schists
3. Older Granites
4. Younger Granites
5. Newer Basalts.

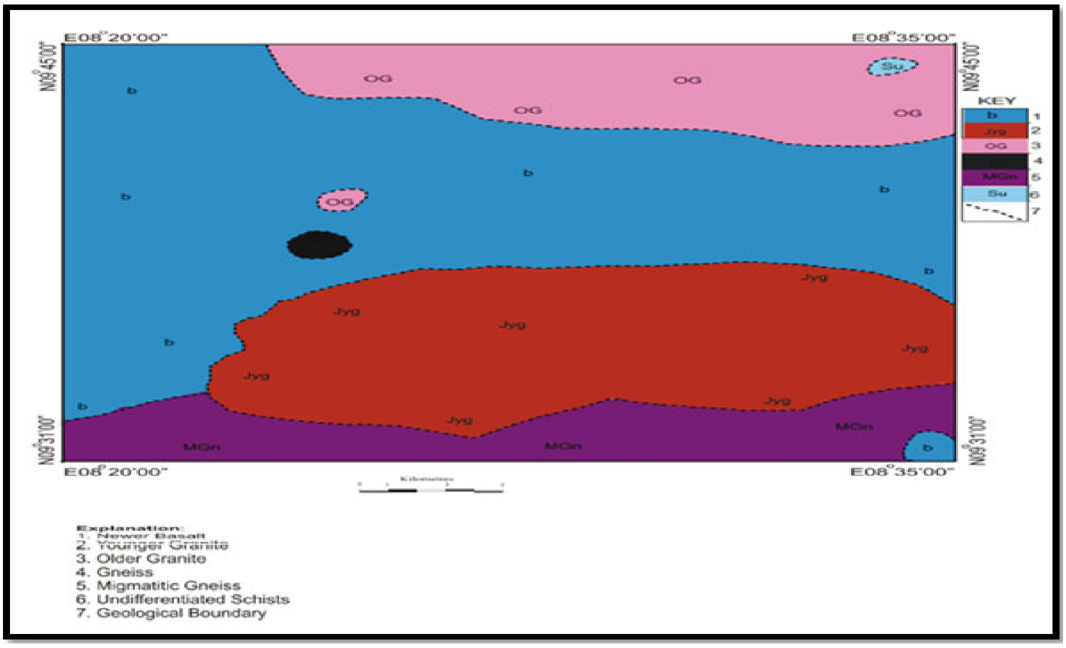

Figure3. Geological map of the Kaura. (Yanet, 1996).

6. MATERIALS AND METHOD

The method of study includes geophysical investigation using resistivity method and analysis of records on boreholes located within the area. In the DC resistivity surveying, using the Schlumberger array (figure4), an electric current is passed into the ground through two outer electrodes (current electrodes), and the resultant potential difference is measured across two inner electrodes (potential electrodes) that are arranged in a straight line, symmetrically about a centre point. The ratio of the potential difference to the current is displayed by the Terrameter as resistance. A geometric factor (G) in metres is calculated as a function of the electrode spacing. The resistance reading obtained by the Terrameter is multiplied by this factor to give an apparent resistivity value. The electrode spacing is progressively increased, keeping the centre point of the electrode array fixed. Schlumberger arrays are relatively sensitive to vertical variations in the subsurface resistivity below the centre of the array but less sensitive to horizontal variations in the subsurface resistivity. The arrays have moderate depths of investigation and generally strong signal strength which is inversely proportional to the geometric factor used in calculating the apparent resistivity values (Christopher, 2011). The major limitation of these arrays is the relatively poor horizontal coverage with increased electrode spacing.

Vertical Electrical Soundings (VES) using Schlumberger array were carried out at different points along five (5) profiles. Each profile has its azimuth N-S, E-W, NW-SE or NE-SW (guided by the emplaced structures). The largest Current electrode spacing AB used was 200m, that is, $\frac{AB}{2}$=100m. The principal instrument used for this survey is the ABEM Signal Averaging System, **(**SAS 300) Terrameter. The resistance readings at every VES point were automatically displayed on the digital readout screen and then written down on paper. The geometric factor, K, was first calculated for all the electrode spacings using the formula; $K = \pi\ (L^2/2l - b/2)$, for Schlumberger array with MN=2l and $\frac{AB}{2}$=L. The values obtained, were then multiplied with the resistance values to obtain the apparent resistivity, ρ_a, values. Then the apparent resistivity, ρ_a, values were plotted against the electrode spacings ($\frac{AB}{2}$) on a log-log scale to obtain the VES sounding curves using a computer software *IPI2win+IP*.

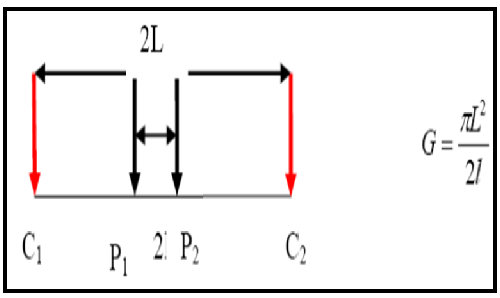

Figure4. The Full-Schlumberger Array

7. RESULTS AND DISCUSSIONS

The data analysis was performed using IPI2Win+IP method for the automatic interpretation of schlumberger vertical electrical sounding. This method was used to obtain the model for the apparent resistivity of each sounding point. The true resistivity models at every sounding point along the profile were used to produce the geoelectric Pseudo section.

Three resistivity sounding curve types were obtained from the studied area and these are the H ($\rho 1>\rho 2<\rho 3$), A ($\rho 1< \rho 2<\rho 3$) and KH ($\rho 1>\rho 2< \rho 3>\rho 4$) type curves. The VES profile was correlated and merged with respect to the direction of the profile line and the closeness of the individual VES stations. On the pseudo section, the top horizontal scale represents the names of the sounding points, while the bottom horizontal ruler represents the coordinates of the sounding points. Vertical lines mark the sounding point given as *AO (m)* being equivalent to half the current electrode spacing, *AB/2*. The interpretation made for the tomogram is placed by its side. The log of the borehole and the geology of Kaura Area aided the interpretation.

Ten (10) VES Points were sounded along a profile of 500m length in the N-S direction. The profile was deliberately taken such that it cut-across non-functional dug-wells and a functional borehole. The first non-functional well is located very close to VESwel1. The functional borehole is located at VESwel5 about 180m away from the second well which is located in-between VESwel9 and VESwel10. The two wells were dug to a depth of about 18m averagely. The borehole is located at latitude $09^{0}35^{I}29.68^{II}$N and longitude $08^{0}22^{I}28.55^{II}$E. This borehole is hand pumped. It has been functional ever since it was drilled in 1988. The borehole was constructed by Kaduna State Water Board. It was drilled to a depth of 55m, the initial recorded yield was 15litre/min and the static water level was 10m. The tomogram (figure5) shows that the area is underlain by four layers; the first layer is sandy clay with resistivity range of 200-500Ωm. This is taken as the Overburden. The second layer is the weathered basement which constitutes of Sandy soil and water. This is taken to be the aquifer which varies along the profile. The third layer comprise of coarse grain sand which is the fractured basement of resistivity range of 1000-2000Ωm. The fourth layer of resistivity greater than 2000Ωm is the fresh basement. The image also shows a U-shaped fracture zone within the subsurface, the borehole was drilled through this fracture which contains water. This fracture may be responsible for water to migrate from the locations of the wells and accumulate at the borehole site.

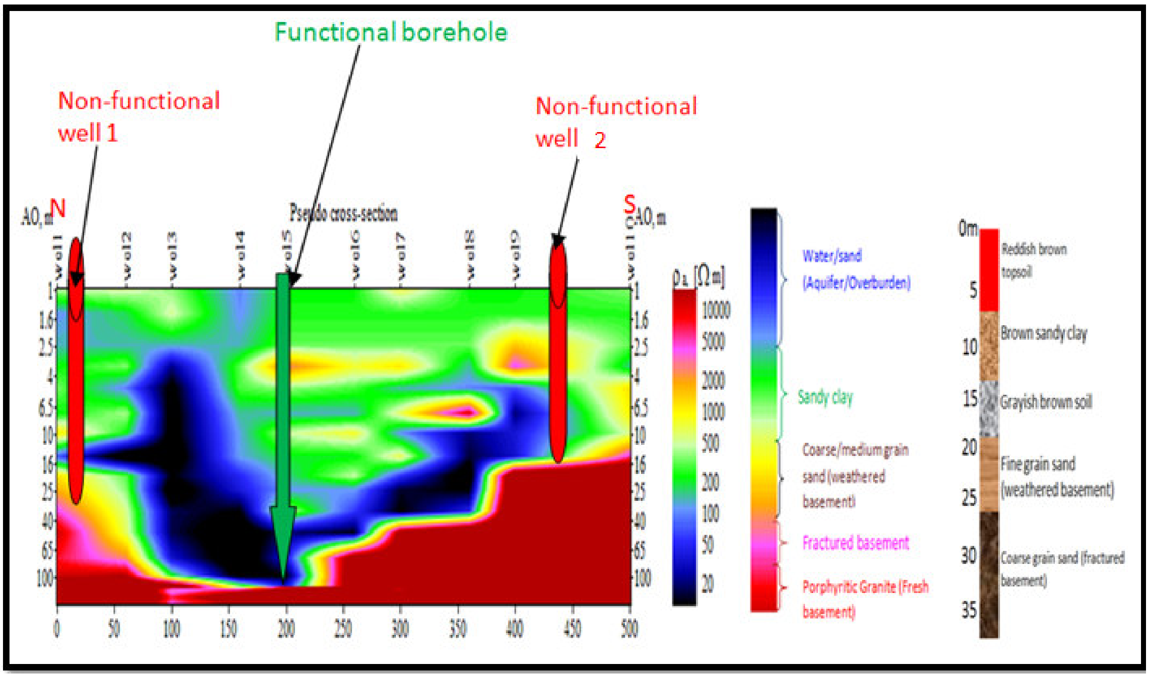

Figure5. Resistivity tomography section for Agban Profile.

8. CONCLUSION

This research has gone a long way to establish the fact that the two (2) non-functional dug-wells within the survey area failed as a result of a fracture through which water migrate from the locations of the wells and accumulate at the borehole site. Since the dug wells are usually shallow, they can sometimes fail at the end of the dry season when groundwater levels fall.

It is a common knowledge that little specialist equipment is used for the construction of a well even though it is difficult to construct hand dug wells in hard rock. On the basis of the results of this study, we therefore recommend that thorough geophysical survey should always be carried out in the basement terrain before constructing dug wells for them to be sustainable.

9. REFERENCES

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