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Geotechnical Investigation of Probable Aquifers Using Electrical Resistivity Method inSabonkauraBauchi(Northern Nigeria)

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--*ABSTRACT*---

Electrical Resistivity prospecting method was used in determining groundwater potential zone at SabonKaura village, Bauchi, Bauchi State using the vertical Electrical Sounding (VES) technique at points selected at convenience place away from contaminant sources), a total of eighteen (18) VES data using Schlumberger array with 300c model of ABEM Terrameter SAS was used in the survey. The VES data acquired were initially presented as field curves on a bi-log scale, and later refined by ID offix iterative inversion software program. The interpreted curves show H, and HA curves. The interpreted models indicate various layers that vary between three and four interpreted as topsoil, decomposed/weathered zone, slightly to a highly weathered basement and fresh basement. The first two lithologic units (topsoil and 1st aquifers) are overburden in origin and the 2nd aquifers are structurally controlled based on their resistivity value ranges and probable depth.

Keywords:*Resistivity, Aquifer, Shlumberger, Array, Groundwater*

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I. INTRODUCTION

Without water, life will be much difficult, and precious substance (mineral) to human life and ground water provides a reasonable constant supply which is not likely to be finished under natural conditions as groundwater resources are usually of high quality. Groundwater: Precambrian fresh underground rock covers more than half of the country. The main rock type in this geologic terrain includes igneous and metamorphic rocks such as migmatite and granite gneiss, (Carter et al 1963), generally, in their natural form are categorized as highly porous and permeable by induction through weathering while secondary permeability induced by tectonic activities serves as conduct movement. Hence, to get highly productive wells, the geophysical investigation becomes imperative as it helps to reveal groundwater bearing formation geological unit(s) in the subsurface.

1.1.Relief, Drainage, Location and Accessibility

The study area (sabonkaura) is generally characterized by low relief with some rock outcrops at the western part. SabonKaura is the study area which is located in Bauchi, Northern part of Nigeria which has dentritic drainage pattern. It lies between longitudes $9^{0}461$ and $9^{0}461$ east and latitudes $10^{0}161$and $10^{0}171$ north (Source: Geological survey of Nigeria survey sheet number 149). The area under survey lies to the west of Bauchi town and is accessed by a motorable road (the dual carriageway leading to Dass from Bauchi town. The SabonKaura village is also accessed by footpaths untarred road that leads to its settlements and environs.

1.2. Climate and Vegetation

The area under study is of tropical continental (Sudan) climate. This type of climate consists of two seasons: dry and rainy. The rain Period mostly starts in late April and ends in early October. Also, humidity is high and temperatures are high, about 32^{0}C (90^{0}f) (Bumette, 1965). The rain period usually Stops from November to April. Its time of dry weather with the temperature normally low at night and goes high at the day time high. Average temperature during the season is about 21^{0}c (about 70^{0}f) (Burnette, 1965).

Normally harmattan starts from December to February. This is the period when the North-East trade winds Start blowing southwards into the country from the Sahara belt. At this period it is generally cooler than normal and less humidity and visibility at certain times is restricted due to airborne dust. Vegetation of the study area is of the Savannah type with sporadic thorny bushes, scattered shrubs, and scattered trees.

1.3. Aim and Objectives

The aim and objectives of this work are to locate ground water zone such as faulted, weathered zones, since basement train are categorized with porous areas that can store water which can serve as the zones of interest. Resistivity methods of geophysical prospecting have proved a great success in search of pores spaces within rocks that can be highly productive.

Figure 1. Bauchi State Map

II. LITERATURE REVIEW

The Nigeria Geology is generally subdivided into three units; the basement complex environment, the volcanic rocks and the sedimentary basins. These units have, explained in detail by various workers (Buchanan et al, 1963; Oyawoye, 1970; Anner, 1980). Bauchi State is basically covered by crystal rocks of Nigerian basement complex mostly Precambrian to early Paleozoic (600-2000ma) in age. These consists of a mixture of some igneous rock such as pegmatite, bauchite, chanokite,and gneisses granites, gneisses, around the area.

The granites of the basement complex environment were first investigated by Falconer (1911), and were mapped and examined by Bain (1926) and Oyawoye (1958, 1961,1982). The gneisses occur as pendants or xenoliths in the granites and are generally a medium grained granoblastic aggregate of quartz, plagioclase and potassium feldspar (micro dine) Oyawoye (1958, 1961, 1962) and Makinjuola (1972). The granites are coarse grained and are composed essentially of quartzite, alkali feldspar, biotite and some muscovite with accessory hornblende and haematite, a period of formation of granites and magmatic activities are displayed and show diverse contact relationships with the metasediments (Oyawoye, 1962).

Pegmatite veins within the granites and gneisses comprised predominantly of potassium feldspar and very large crystal may form. A charnokitic rock occurs at the surrounding margin when where it forms a small outcrop. The older granite suites are predominantly of porphyritic biotite granite or biotite hornblende granite. They are usually foliated because of the mafic mineral present in them (Truswell and Cope, 1983).

2.1. Qurtzdiorite

Quartz occurs as veins and dikes within the migmatites and granites. The dikes vary in thickness from 10cm to as much as 100cm and also about 1km across. They generally cut across the Profile in the host rock having a sharp contact with them.

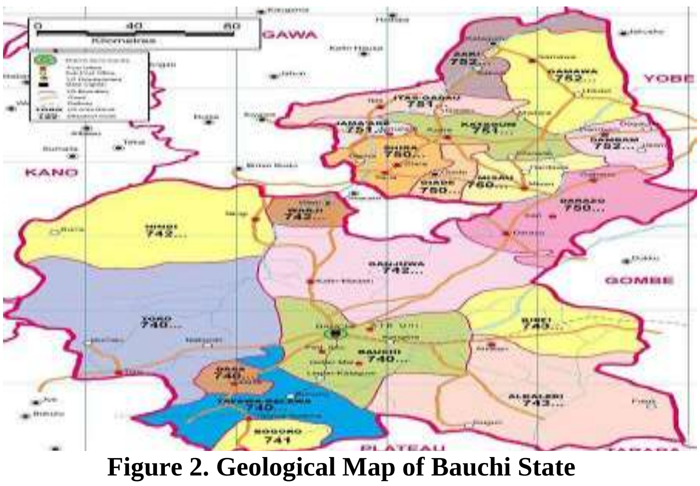

Figure 2. Geological Map of Bauchi State

2.1.1. Granite – Gneiss

Granite -gneiss are fine to medium grained, biotite rich granite rocks, found mostly in the southern part of Bauchi town. Normally comprised of white plagioclase and some microcline quartz and fairly abundant biotite-hornblende also confirm in varying amount (Oyawoye. 1958).

2.1.2. Fayalite Quartz Monzonite (Bauchite)

Fayalite quartz monzonite (Bauchite) and Quartz diorite, older granite complexes form in large amount within Bauchi area. The Bauchite are large bodies up to 10km across with gradational boundaries whereas the quartz diorites are small discrete intrusion up to about 1krn across or dikes close to or intruding into Bauchite. Bauchite described as coarse-grained augite syenite by Falconer (1911) and later by Bain (1926). The notable features of quartz diorite and Bauchite were first described by Oyawoye (1958,1961) who named the complex Bauchite.

The fresh sample of Bauchite looks green due to the green or brown color of quartz and feldspar Rahman, (1981). Bauchite is abundant as well as homogeneous un foliated with few joints. The mineral assemblage of Bauchite includes fayalite, ferrohedenbergite, orthoclase and little biotite, oligoclase. Accessory minerals include iron, titanium, apatite, zirconi and rare epidote (Rahman 1981).

2.1.3. Migmatites

Migmatite, the texture is not uniform it changes from coarse grained to medium grained. They represent a high grade metamorphosed series with excellent branding foliation migmatites are foliated with flakes of biotites defining the foliation. The migmatite is comprised of rock such as hornblende-bearing gneiss and granitic. The granite rock is usually biotite granite alternating with the comblende bearing gneiss. The hornblende is present in varying amount (Eborall, 1989).

2.2. Hydrogeology of the Area

The basement complex in the north-eastern part of Nigeria is divided into three principal groups (carter et, al 1970). the ancient metasedimentary, migmatide and gneises and older granide.The ancient metasediments comprise of rocks, which are now transformed to migmatide and gneises. The migmatidegneises largely comprises f migmatide and gneises, relict metasediments basic schist and gneises,calcareous quartzite and granitic rock (Rahman 1981).

The older granide represent a cycle of evolution in which anataxis and all stage of granitization and magmatic activities are displayed. The Precambrian to Paleozoic basement rock occur mainly around Bauchi town, Kafinmadaki, dass,, Toro, Tafawa Balewa, Ningi and some part of Darazo and Alkaleri.

The sedimentary portion of the state is dominated by kerri Kerri formation which comprises of medium to coarse grained sandstone, fine grained sand, (Dike, 1990), Falconer (1991) first name the formation and dated it Eocene. Most of the outcrop lie within the east-central area of Bauchi state (Dike 1993) and represent the record of early Tertiary sedimentary in the northern eastern Nigeria.

The maximum proven thickness of kerri Kerri formation varies from 300m to 320m (Dike 1993). The contact between kerrikerri formation and the basement complex composed mainly of conglomerate. The kerrikerri formation is seen to out crop in some part of Darazo, Alkaleri, and Dambam. Barber (1965) named the Quatemary thick sedimentary as the chad formation.it consist mainly of thick lacustrine and fluviatile deposit.

Basement complex have poor or no primary porosity and apart from fractured and joints, they are impermeable. Fracture and joints tend to store and transmit water fairly well near surface but become tighter with increase depth. Below the top soil, crystalline rock weathered, if the depth of water is sufficient (greater than 8m) the weathered mantle contained water in storage large enough to produce successful to borehole with an estimate yield of 75liter per minutes (Dike et, al 1993).

2.2.1. Basement Complex

The crystalline rocks in the environs are located of high relief with relatively surface run off and low infiltration rate Offodile (1983). The Precambrian basement complex comprising mainly the fayalite, quartz monzonite (Bauchite), granite, biotite-hornblende and the undifferentiated migmatite and gneiss units, overlain by a thin regolithLikkason and Shemang (1991). It noted that the fresh rock does not normally contain water; but when they are weathered, fractured, jointed and fissured they prove to be effective in terms of yielding minimum supply of water due to the cracks, joint and weathered within the rocks Dike, et al (1994). Considering the basement environment section of the state, the fractured zone of this complex forms aquifer with limited resources.

The weathered and cracks zones occurring within the fresh rock constitute the aquifer with water yield that tend to be constant depending on the rock type. The width of the cracks, joint and fractured layers forming the aquifer determined the yielding capacity of the area.

The maximum groundwater yielding in sabonkaura area (part of Bauchi) is found along the weathered and fissured zones which constitute the preferential flow paths for groundwater and it relies on the interconnection between the pores of the zones.

III. MATERIALS AND METHOD

This research work involves preliminary site investigation (reconnaissance survey) such as open well studies within the survey sites, descriptive surface lithologies, outcrop types and topographic controls structural lineaments and orientations and Electrical drilling method or V.E.S surveys for definition of aquifer depths, weak zone distribution and interval apparent resistively sections as contrasted to Geologic sections.

Geophysical surveys are basically the interpretation of variation in measured responses, either naturally or artificially generated within the earth crust. Such variation result from the difference in some notable properties like elasticity, magnetism, density, electrical resistivity etc below the area of interest. In this work observed data was interpreted by means of computer and manually and the final results were then used to locate a good area for portable water supply in the area.

3.2. Basic Principle for Resistivity Survey

To have a good perspective of the principles of geoelectric prospecting method, it will be very paramount to understand the behavior of electric current as it goes around a layered media, which is invariably the case rather than homogeneous earth, and how this affect the distribution of current through the ground. In most cases the translation of resistivity data the ground is considered as being made of approximately uniform resistivity layers bounded from others of different resistivity by the plane interface.

In general, thus corresponds to the area several geological compositions. In practice, current electricity is sent through the earth at one point C and leaves at another point C2. The resultant voltage is measured between two potential electrodes P1 and P2, where the potential difference DV is measured by the differences in the respective potential *V1* and *V2* at *PI* and *P2* as:

$$DV = VP_1 - VP_2 \qquad (1)$$

Where VP_1 and VP_2 are the potential differences generated at P_1 at P_2 due to currents source and sink at C and C' respectively.
Therefore equation (1) becomes;

$$AV = \frac{P1}{2\pi}\left[\left(\frac{1}{r1}-\frac{1}{r2}\right) - \left(\frac{1}{r3}-\frac{1}{r4}\right)\right] \qquad (2)$$

P = Rk where k is known as the geometric factor which relates to the spacing between electrodes and their arrangement and P is the resistively of a homogeneous earth as defined in figure 2.

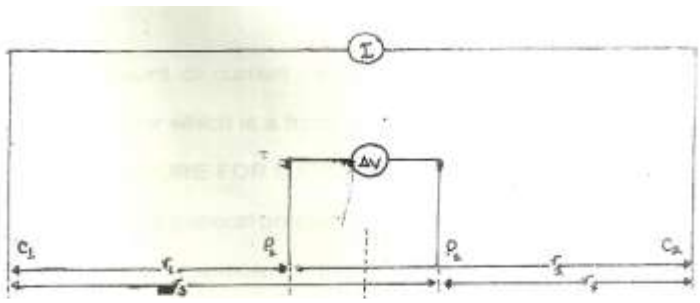

Figure 2 Shows the arrangement of Electrodes

3.3 Electrical drilling method or VES

The electrical drilling method was employed using 300c model of ABEM TERRAMETER SAS. This method relies on the potential difference created by the current and thereby establishing the electrical resistively of the material through which the current passed. Therefore, equation (3) becomes:

$$AV = \frac{P12\pi}{1}\left(\frac{1}{\left(\frac{1}{r1}\right)-\left(\frac{1}{r2}\right)-\left(\frac{1}{r3}\right)-\left(\frac{1}{r4}\right)}\right) \qquad (3)$$

Where *DV* is the resultant potential difference between the two potential electrodes. I is the quantity of electricity sent into the ground. And K is the geometric factor which is a function of electrode spacing.

3.4. Necessary steps to followed when taking the survey

These are the steps to be followed one after the order when taking the survey

i. A good location for the middle of electrode spread was found.
ii. The survey was oriented along the strike of the bedding plane and enough space of at least l00m on either side was ensured.
iii. 100m measuring tapes ran out on the opposite of the midpoint.
iv. Electrodes were hammered at required locations.
v. The resistivity meter, cables, and electrodes were connected,
vi. The result was obtained at various electrode locations.
vii. At least 4 readings for each spacing were taken (most meters can do this automatically).
viii. Small current (<5MA) was used at small electrode spacing.
ix. At larger electrode spacing, high currents (>5MA) was used since it becomes more difficult to accurately measure the resultant potential difference at the closely spaced inner electrodes.
x. The result was plotted alongside the survey to check the curve for the anomaly.
xi. When moving to larger potential electrode separation, minimum of two cross-over points were ensured for Schlumberger arrays.

IV. DISCUSSION OF RESULTS AND INTERPRETATION

The resistivity sounding measurements was conducted in early January 2017, at SabonKaura village using electrical drilling technique at points selected at convenience but away from contaminant source(s). The profiles are carefully chosen at moderate terrain (fig 1.1). Schlumberger array was employed in this research work because of its user-friendly when carrying out vertical electrical sounding that any local inhomogeneities near the fixed-potential electrodes, including those caused by hammering in the probes, are constant during measurements provided the potential electrodes are not moved during the measurements.

In-depth probing, the electrodes spacing's AB/2 are standardized. They are in order 1, 1.5, 2, 2.5, 3 and etc. It's important in order to obtain maximum penetration at greater depth with the expanding electrode spacing. As AB Increase MN also increases at a greater depth of AB so as to maintain a measurable potential. The data collected were processed with affix computer iterative software programmed, Corel draws 10 graphics.

Table 1 Summary of processed results of the geoelectric soundings

VES No.	Layer No.	APP. RES. (RM)	Thickness (M)	Approx, Depth (M)	Lithology	Remark
1	1	341	1.75	1.75	Topsoil	
	2	56	4.95	6.70	Weathered basement	Aquiferous
	3	285	3.59	10.30	Fractured basement	
	4	2690	-	-	Fresh basement	
2	1	561.2	0.374	0.374	Topsoil	
	2	163.7	6.03	6,41	Weathered layer	Aquiferous
	3	179.0	5,31	11.7	Fractured basement	
	4	1780.8	-	-	Fresh basement	
3	1	449.2	0.495	0.495	Topsoil	
	2	97.59	6.93	7.4	Weathered basement	Aquiferous
	3	572.4	-	-	Fresh basement	
4	1	321.3	1.62	1.62	Topsoil	Aquiferous
	2	51,1	6.45	8.1	Weathered	
	3	778.4	-	-	Fresh basement	
	1	533,6	1,96	1.96	Topsoil	Aquiferous
5	2	60.25	8.40	10.4	Weathered zone	
	3	314.9	3.32	13.7	Fractured zone	
	4	7327,5	-	-	Fresh basement	
6	1	568.7	1.82	1.82	Topsoil	Aquiferous
	2	54.24	10.14	12,0	Weathered tone	
	3	254.9	1.62	1 3.6	fractured basement	
	4	4063.6	-	-	Fresh basement	
7	1	687.8	1,58	1.58	Topsoil	Aquiferous
	2	47.82	14.16	15.7	Weathered	
	3	1331.2	-	-	Fresh basement	

8	1	365.2	1.12	1.12	Topsoil	Aquiferous
	2	58.11	11.67	12.8	Weathered zone	
	3	124.1	1.96	14.8	Fractured basement	
	4	8358.7	-	-	Fresh basement	
9	1	60.54	0.938	0.938	Topsoil	Aquiferous
	2	68.94	7.85	8.9	Weathered zone	
	3	686.7	-	-	Fractured basement	
10	1	255.1	1.18	1.18	Topsoil	Aquiferous
	2	74.45	6.49	7.7	Weathered	
	3	1513.2	-	-	Fresh basement	
11	1	377.0	1.15	1. 15	Topsoil	Aquiferous
	2	29.57	5.6	6.8	Weathered zone	
	3	1391.8	-	-	Fresh basement	
12	1	207,9	0.741	0. 741	Topsoil	Aquiferous
	2	86.25	13.3	14.0	Weathered zone	
	3	3571.8	-	-	Fresh basement	
13	1	897.0	1.46	1.46	Topsoil	Aquiferous
	2	65.32	12.52	14.0	Weathered zone	
	3	8526.7	-	-	Fresh basement	
14	1	547.0	0.983	0,983	Topsoil	1st aquifer
	2	59:66	8.83	9.8	Weathered zone	2nd aquifer
	3	122.5	1.62	11.4	Fractured zone	
	4	5310.1	-	-	Fresh basement	
15	1	266.0	1.51	1.51	Topsoil	Aquiferous
	2	57.42	12.86	14.4	Weathered zone	
	3	157.6	1.87	16.3	Fractured zone	
	4	6064.1	-	-	Fresh basement	
16	1	307.2	0.816	0. 816	Topsoil	
	2	96.59	22.78	23.60	Weathered zone	Aquiferous
	3	73.56	2.24	25.9	Fractured zone	
	4	2172.7	-	-	Fresh basement	
17	1	1.15	961.	1.15	Topsoil	
	2	19.23	178.	20.4	Weathered zone	Aquiferous
	3	2252.1	64 -	-	Fresh basement	
18.	1	1.75	598.0	1.75	Topsoil	
	2	11.8	50.24	13.6	Weathered zone	
	3	1092.9	-	-	Fresh basement	

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4.2 Basis for Interpretation of Geoelectric (Ves) Data

Models used in the translating of geoelectric surveys are exceedingly simple. Both methods were employed such as inverse and direct have been applied to interpret sounding data. Theoretically, both procedure shows that the underground comprised of structure and that the subsurface of discontinuities is plane and horizontal.

Fundamental of qualitative translation of apparent resistivity is its relation to the true resistivity distribution of the underground or a space function. Resistivity models are assumed to measure resistivity curves. The field curves are compared with such theoretical curves.

4.3 Interpretation of Geoelectric Data

This interpretation relies on a computer program for curve solutions. It is an inverse method and one derives the model from the field indirectly by numerical calculation on the computer. It is paramount to input an initial or guiding model (a tabulated structure with the plane and horizontal Interfaces). The computer, guided by this input model determines the model whose theoretical geoelectric curve best fits the field data by successive iterations.

At the end, the computer interprets not only the model it also shows the mathematical fit but also the degree of confidence/reliability (fitting error) in each result of the model (resistivity's and thicknesses of layers). However, the interpreted results permit the drawing of the geoelectric section.

4.4 Hydrogeological Units Based on Resistivity

Based on the result of the underground geological layers derived from the computer interpreted VES curves different profile procedure can be established. The study area shows four geo-electrical units comprising the top soil, deeply decomposed to the moderately weathered basement, fractured fresh basement rocks, and fresh impervious bedrock.

V. CONCLUSION

The geologic sections derived from the resistivity values shows that the decomposed rocks (weathered basements) and the solid rocks with possible fractures are the water-bearing zones around the area. (fig. 3) From the result of the survey, the most favorable spots for borehole location are VES 01, VES 02, VES 04, VES 05, VES 06, VES, 07, VES 08, VES 12, VES 13, VES 14, VES 15, VES, 16, VES 17, VES 18.

Most crystalline rocks are located in areas of high relief and the quantity of water available for exploitation relies on the drainage basin and slope showing groundwater flow direction, shape, and form of the catchments describing the morphology of the area McDonald et al (2009). The width of cracks or joined zones is also another factor controlling the quantity of water for exploration. Therefore, a liable spot must get the required thickness of aquifers zone giving reason to why VES 03, VES 09, VES 10 and VES 11 are not favorable drilling spots (table 1)

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