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Geoeletrical Investigation for Groundwater Potential In Songhai Integrated Farms, Etigidi, Abi Local Government Area of Cross River State, Southeastern Nigeria

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Abstract: ***There is usually 95 to 100% uncertainty in drilling successful wildcat water wells, and therefore the need for good geoelectrical investigation for groundwater cannot be overemphasized. Twelve (12) Vertical Electrical Soundings (VES) employing the Schlumberger configuration were carried out to investigate the groundwater potentials of Songhai Integrated farms. The research was necessitated to investigate prolific aquiferous units for the drilling of water wells. The resistivity data from this investigation were plotted and interpreted both manually (using the classical curve matching technique) and with computer modeling (IP2win) resistivity inversion software. Though many points in the area revealed great potentials for groundwater, the aquifers were mostly near surface and maybe prone to contamination if drilled. However, two very prolific aquiferous units at great depths and with good thicknesses were delineated and recommended for the drilling of water wells (boreholes).***

Keywords: Aquifer, Borehole, IP2win, Resistivity, Schlumberger

1. Introduction

Songhai Integrated farms in Cross River State holds a wide range of livestock and crop plants, and was established in collaboration with the State Government to serve as a centre for Agricultural development, research and training. The need therefore for suitable water supply for plants, livestock and personnel cannot be overemphasized.

Considering the great difficulty in locating potential and prolific aquifers from mere geological recconnaissance survey alone, and also owing to the fact that it can never be adequate to evaluate and have better understanding of the hydrogeology of any area without other geological tools, a proper use of groundwater investigation techniques is required in order to locate these high yielding aquifers (Asare and Menyeh, 2013). Electrical resistivity method is one of the most useful techniques in groundwater geophysical exploration because the resistivity of rocks is very sensitive to its water content, and in turn the resistivity of water is very sensitive to its ionic content (Alile et al., 2011). Low resistivity values may be due to the presence of underground water in porous sedimentary rocks such as sands, sandstones (which may be fractured), siltstones and shales/clays etc and the presence of water in fractured basement or consolidated rocks. Muds- shale and clay present low resistivity values due to their electrical or ionic property, while sands and sandstone units will be more resistive in sedimentary environments, especially if they lack porosity and permeability and there is an absence of pore water. The more conductive (less resistive) a fractured basement rock, sand or sandstone unit is, the more permeable it is and in turn the higher the water content, although the presence of salt which offers very low resistivity values in sands and fractured sandstones may post a challenge in interpretation as the low values may be confused for shale/clay. It is fast becoming a norm with great importance to integrate both the knowledge of geology, geophysics, geochemistry and other investigation techniques to properly classify and describe an aquifer.

The geoelectrical resistivity method which still remains one of the best and most widely used technique for groundwater investigation and being a key to the objective of this work (which is to delineate potential aquiferous units in this locality and to determine which point(s) will be suitable for the drilling of prolific water wells (boreholes) was employed here.

2. Location and Geology of Study Area

The study area (Fig.1) is accessible through the Ugep-Abaomeghe road, approximately 10Km from Ugep town in Yakkur Local Government Area of Cross River State. It falls within the tropical rainforest belt of Nigeria characterized by heavy rainfall, low pressure and high precipitation, high evaporation and relatively high humidity. Annual rainfall is about 1550mm, and temperatures range from a maximum of about 32^0C in February to a minimum of about 21^0C in August. This climatic zone is characterized by two major seasons- the wet season with heavy rainfall, usually spanning from March to November and the dry season spanning from November to March. Within the rainy season, there is usually a shot break in rainfall in the month of August usually referred to as the August break. Geologically, the area forms part of the southwestern edge of the Ikom-Mamfe Embayment (a sub-basin of the Lower Benue basin), with sediments composed predominantly of alternating sequence of fissile shale and biotubated sandstone beds, belonging to the Amaseri Formation of late Turonian–Coniancian age in the Ikom-Mamfe basin of the lower Benue basin. The type section is clearly exposed along the old Ugep-Ediba road in Ediba clan of Abi L.G.A. The sediments here are highly indurated and lithified, and are intruded in some places by diabase (dolerite) and other igneous rocks, as found in parts of Ugep, Abi and Biase

Local Government Areas of Cross River State and in Afikpo area of Ebonyi State, which occur as pockets of dikes and sills intrusives in these sediments. Hydrogeologically, the Amaseri sandstone constitutes the Amaseri Hydrostratigraphic unit and covers about 24.6% of the Ikom-Mamfe basin (Edet and Okereke, 2014). Groundwater in this area is recharged primarily by rain and exists in areas where these rocks are fractured and in areas of weathered sandstones.

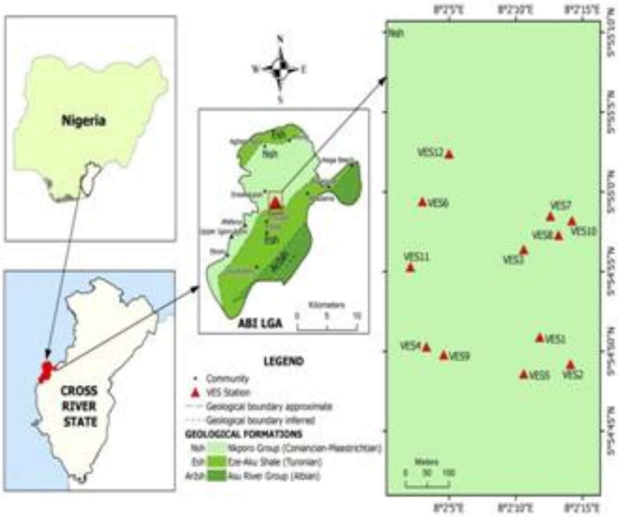

Figure1: Map of Abi Local Government Area and base map of study area showing Vertical Electrical Sounding (VES) stations

3. Methodology

The basic principle in geoelectrical resistivity survey involves passing electric current into the ground through current electrode(s) and measuring the ground impedance to current flow (resistivity) through potential electrode(s) by measuring the potential difference between them. Usually, the potential electrodes are in line with, and between the current electrodes as in the Schlumberger array, but in practice, and depending on the configuration or array type, they can be located anywhere. The type of current used maybe direct current (DC) or alternating current (AC) of low frequency (typically about 20Hz) in resistivity survey. Ground resistivity which is affected by a number of geological parameters such as the rock minerals, fluid type, porosity, permeability and degree of water saturation can be measured, with apparent resistivity values of subsurface recorded and true resistivity values of different rock layers estimated quantitatively and by computer iteration and inversion software. Where the earth is not homogeneous and isotropic, this estimate is called the apparent resistivity, which is an average of the true resistivity in the measured section of the earth (Mohammed et al., 2012). The apparent resistivity is calculated from the measured relationship between the applied current (***I***) and the potential difference (***V***) for a particular arrangement of, and spacing of electrodes to which the geometric factor (***K***) is dependent on.

In the four-point Schlumberger array method of survey which was employed here, 2 current electrodes and 2 potential electrodes (Fig. 2) were used.

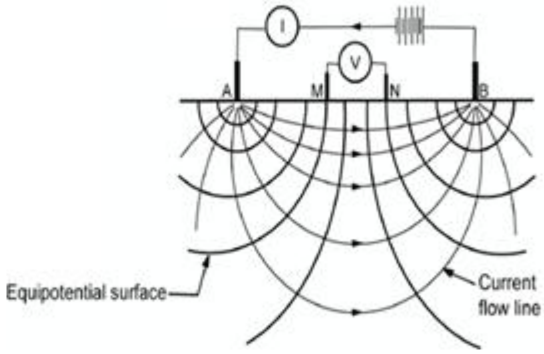

Figure 2: Illustration of surface resistivity method showing simplified current flow lines and equipotential surfaces arising from a set of current electrodes (**A/B** and **M/N** respectively)

A direct current (DC) of intensity, ***I*** is applied to the earth by means of 2 current electrodes on the surface with spacing **AB**, and potential difference (***V***) which is dependent on the conductivity conditions of the subsurface, is measured on the surface across 2 potential electrodes with spacing **MN** in the centre of the array. The apparent resistivity of each subsurface rock layer can be calculated from the relationship:

$$\rho_a = K.R \qquad \ldots\ldots(1)$$

Where **K** is the geometric factor and **R** is the resistance of the rock layer. From Ohm's law,

$$R = \frac{V}{I} \qquad \ldots\ldots (2)$$

Where ***V*** is the potential difference measured across the 2 potential electrodes and ***I*** is the current through the 2 current electrodes. If half current electrode spacing **AB/2** which is related to the depth of investigation is given as **l**, and half the potential electrode spacing **MN/2** is given as **a**, then for the Schlumberger array which was used in this investigation, the geometric factor, **K** can be calculated from the relationships:

$$K = \frac{\pi}{a}\left|\frac{(l)^2-(a)^2}{2}\right| \qquad \ldots\ldots (4)$$

and,

$$\rho_a = \frac{\pi}{a}\left|\frac{(l)^2-(a)^2}{2}\right| .R \qquad \ldots\ldots (5)$$

Data was collected using the GEOTRON (model: G41) resistivity meter- a high precision, highly efficient South African equipment (plates.2 and 3). This equipment converts subsurface material resistance values directly to apparent resistivity values (an advantage that saves time in the field). The Schlumberger configuration was adopted and current electrode spread covered up to 300m except for areas where obstacles will not permit a continuous traverse. The results for all resistivity data obtained from the field were plotted on log-log sheets and interpreted manually, using the curve matching technique with master curves and their auxiliaries, and this formed the basis for the use of computer inversion software (IP2WIN), to delineate potential water bearing zones.

Plate1. GEOTRON (model: G41) Resistivity-meter used in the survey

Plate2. GEOTRON (G41) in use in the field during the survey

4. Results

Below are results of interpreted resistivity data. Each of the interpreted resistivity curves is based on the data collected from a Vertical Electrical Sounding (VES) station. Here, they are designated SONGHAI VES1 to VES12 respectively, representing resistivity curves and interpreted data for 12 Vertical Electrical Sounding (VES) stations. A summary of the interpreted curves is shown in Table1-3.

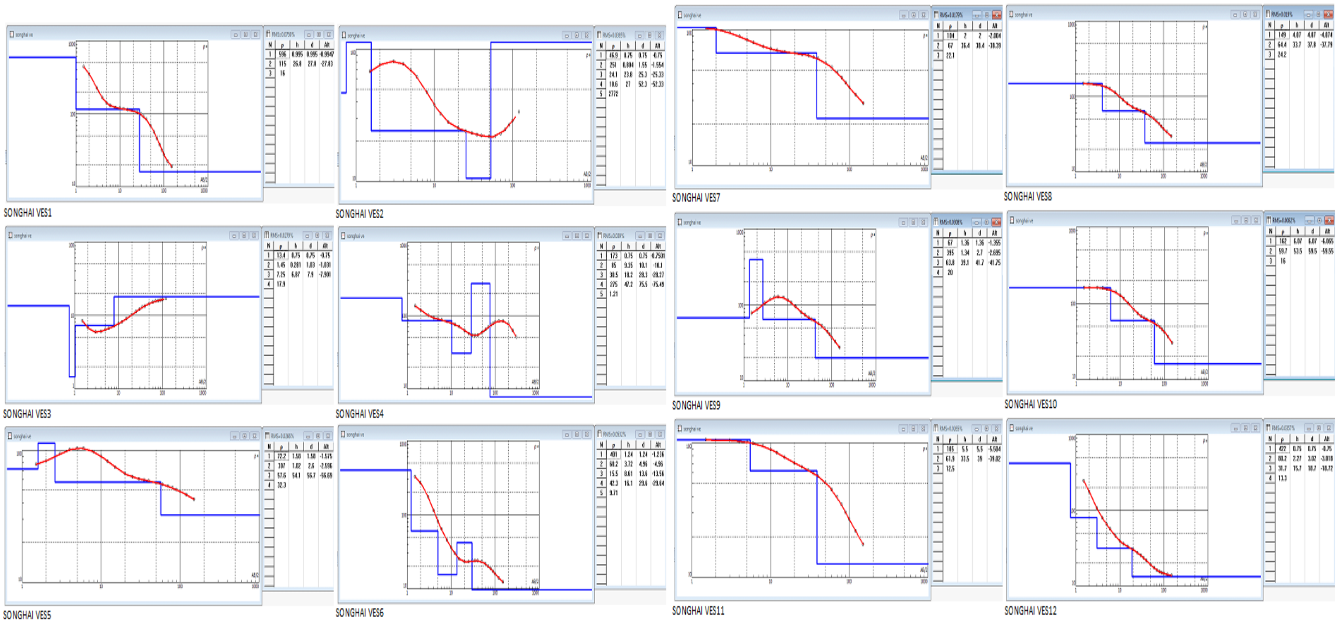

Figure 3: Modeled and interpreted resistivity data for 12 VES stations (designated SONGHAI VES 1-12)

Table1. Summary of interpretation (SONGHAI VES1-4)

Sounding Location	Curve type	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
SONGHAI VES1 N05°54'50.9" E008°02'11.8"	Q	1	596	0.995	0.995	Top soil composed of clayey-sands
		2	115	26.8	27.8	Saturated sandstone or fractured shale
		3	16	∞	∞	Highly fractured and saturated sandstone or shale
SONGHAI VES2 N05°54'49.2" E008°02'14.1"	KQH	1	46.9	0.75	0.75	Loose top soil composed of clayey-sands
		2	251	0.804	1.55	Top soil composed of clayey-sands
		3	24.1	23.8	25.3	Highly fractured and saturated shale or sandstone
		4	10.6	27	52.3	Highly fractured and saturated shale or sandstone
		5	2772	∞	∞	Consolidated sandstone with minor fractures and maybe partially wet.
SONGHAI VES3 N05°54'56.4" E008°02'10.6"	HA	1	13.4	0.75	0.75	Very loose top soil composed of partially wet sandy-clays
		2	1.45	0.281	1.03	Very loose top soil composed of partially wet clays
		3	7.25	6.87	7.9	Very loose top soil composed of partially wet clays
		4	17.9	∞	∞	Partially wet fractured shale
SONGHAI VES4 N05°54'50.3" E008°02'03.3"	QHK	1	173	0.75	0.75	Top soil composed of clayey-sands
		2	85	9.35	10.1	Clayey-sands
		3	30.5	18.2	28.3	Fractured shale, partially wet
		4	275	47.2	75.5	Fractured and saturated sandstone
		5	1.21	∞	∞	Highly fractured and saturated shale

Table2. Summary of interpretation (SONGHAI VES5-8)

Sounding Location	Curve type	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred lithology
SONGHAI VES5 N05°54'48.6" E008°02'10.6"	KQ	1	72.2	1.58	1.58	Top soil composed of clayey-sands
		2	307	1.02	2.6	Consolidated top soil
		3	57.6	54.1	56.7	Highly fractured and saturated sandstone or shale
		4	32.3	∞	∞	Highly fractured and saturated sandstone or shale
SONGHAI VES6 N05°54'59.4" E008°02'03.0"	QHK	1	401	1.24	1.24	Top soil composed of clayey-sands
		2	60.2	3.72	4.96	Top soil composed of clayey-sands
		3	15.5	8.61	13.6	Highly fractured and saturated shale or sandstone
		4	42.3	16.1	29.6	Highly fractured and saturated sandstone or shale
		5	9.71	∞	∞	Highly fractured and saturated shale
SONGHAI VES7 N05°54'58.5" E008°02'12.6"	Q	1	13.4	0.75	0.75	Very loose top soil composed of partially wet sandy-clays
		2	1.45	0.281	1.03	Very loose top soil composed of partially wet clays
		3	7.25	6.87	7.9	Very loose top soil composed of partially wet clays
		4	17.9	∞	∞	Partially wet fractured shale
SONGHAI VES8 N05°54'57.3" E008°02'13.2"	Q	1	149	4.07	4.07	Top soil composed of clayey-sands
		2	64.4	33.7	37.8	Fractured and saturated sandstone or shale
		3	24.2	∞	∞	Fractured and saturated sandstone or shale

Table3. Summary of interpretation (SONGHAI VES9-12)

Sounding Location	Curve type	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred lithology
SONGHAI VES9 N05°54'49.8" E008°02'04.6"	KQ	1	67	1.36	1.36	Top soil composed of clayey-sands
		2	395	1.34	2.7	Consolidated top soil
		3	63.8	39.1	41.7	Highly fractured and saturated sandstone or shale
		4	20	∞	∞	Highly fractured and saturated sandstone or shale
SONGHAI VES10 N05°54'58.2" E008°02'14.2"	Q	1	162	6.07	6.07	Top soil composed of clayey-sands
		2	59.7	53.5	59.5	Highly fractured and saturated sandstone or shale
		3	16	∞	∞	Highly fractured and saturated shale
SONGHAI VES11 N05°54'55.1" E008°02'02.1"	Q	1	105	5.5	5.5	Top soil composed of partially clayey-sands
		2	61.9	33.5	39	Fractured and saturated sandstone or shale
		3	12.5	∞	∞	Fractured and saturated shale
SONGHAI VES12 N05°55'02.4" E008°09'05.0"	Q	1	422	0.75	0.75	Top soil composed of clayey-sands
		2	80.2	2.27	3.02	Top soil composed of clayey-sands
		3	31.7	15.7	18.7	Partially wet fractured shale,
		4	13.3	∞	∞	Fractured and highly saturated shale

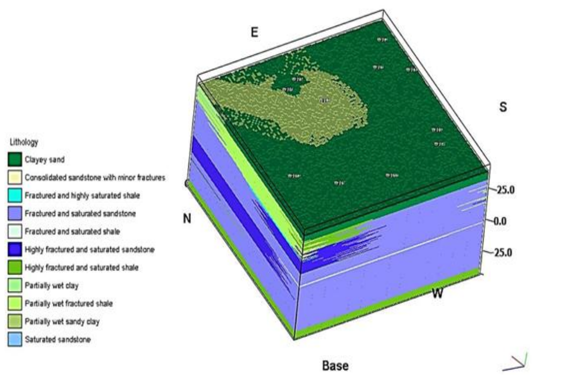

Figure 4: 3D model of the subsurface lithology of study area

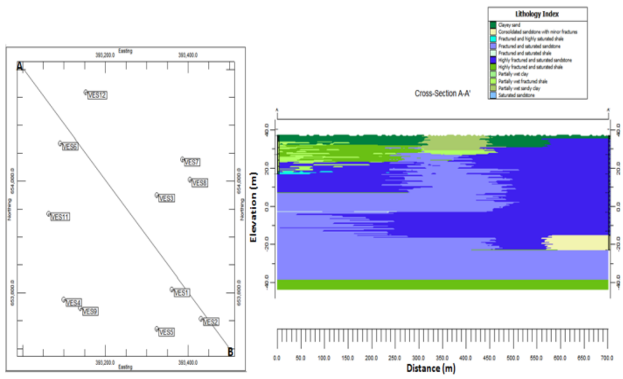

Figure 5: Cross section (AB) of study area showing subsurface lithology

Plate 3: Substantial amount of water during drilling of borehole at VES2 station which was one of the two points that were recommended for drilling

5. Discussion

From the modeled curves (Fig.3) as well as the summary of interpretations (tables 1-3), the VES stations models show typically Q, QHK, KQ, KQH, and HA type curves. Apparent resistivity values for subsurface layers fall within the range of values for silt, shale, sandstone and clay, and based on these values, the subsurface lithologies were inferred (tables 1-3, Fig.4 and 5). Low values at depths below stations could suggest either saturated fractured shale or saturated sandstone units. Sediments in this area may have been highly baked and fractured by the basement rocks that intruded them, and the fractures may also have been caused by tectonism, all contributing to creating conduits and increasing porosity and permeability in these rocks. The integration of the geology of the area and geophysics led to the interpretation of low resistivity zones as potential water bearing.

Delineating an aquiferous unit alone is not enough to recommend drilling. The thickness and depth of the aquifer must always be taken into consideration, as the thicker an aquifer is, the better the yield. Also shallow or near surface aquifers are more prone to contamination especially if they are unconfined compared to those at great depths. VES5, VES8, VES9, VES10 and VES11 aquifers with corresponding thicknesses of 54.1m, 33.7m, 39.1m, 53.5m and 33.5m show great thicknesses, but they are all near surface aquifers. On the other hand, aquifers of VES2 with apparent resistivity of 10.6Ωm, and thickness of 27m, and terminating at 52.3m; and VES4 with apparent resistivity of 273Ωm, thickness of 47.2m and terminating at a depth of 75.5m were considered to have good thicknesses and great depths for recommendation. These two VES points were considered the best for drilling of water boreholes and were recommended. Plate3 above shows substantial amount of water from the aquifer drilled through at VES2 station. The aquifer of fractured and saturated sandstone was encountered at a depth of 30m and extended up to about a depth of 65m as was seen by the analysis of drill cuttings during the drilling of the borehole. The second borehole at VES4 station encountered the aquifer at a depth of about 32m which extended over 40m and also yielding substantial amount of water.

6. Conclusion

Two successful boreholes were drilled in Songhai Integrated farms in Etigidi, Abi Local Government Area of Cross River State in Nigeria, based on results of geoelectrical resistivity survey for groundwater exploration. The area revealed potential aquiferous units from interpreted resistivity curves and models from 12 vertical electrical sounding (VES) stations. This investigation reveals that the drilling of any successful borehole strongly leans on good geoelectrical survey methods (especially resistivity) in the search for groundwater. Investigation has revealed that there is 95 to 100% uncertainty in drilling successful wildcat water wells which lack geophysical investigations and recommendations.

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