ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management

SCHLUMBERGER RESISTIVITY SOUNDINGS FOR GROUNDWATER EXPLORATION: A CASE STUDY OF KAJURU AREA OF NORTHERN NIGERIAN BASEMENT COMPLEX

Elijah E. Nkitnam[*1], Ema M. Abraham[1], Ifeanyi Obihan[2], Joseph O. Osumeje[3], Bisan Yabuwat[4], Cyril G. Afuwai[5], Collins C. Chiemeke[6], Kolawole M. Lawal[3], and Chibuike N. Nnamani[7]
[*1]Department of Geophysics, Federal University, Ndufu Alike Ikwo, Nigeria.
[2]Department of Earth Science, Salem University, Lokoja, Nigeria
[3]Department of Physics, Ahmadu Bello University, Zaria, Nigeria
[4]National Oil Spill Detection and Response Agency, Kaduna, Nigeria
[5]Department of Physics, Federal University, Dutsen-Ma, Nigeria
[6]Department of Physics, Federal University, Otuoke, Nigeria
[7]Department of Mathematics, Ahmadu Bello University, Zaria, Nigeria

KEYWORDS: Kajuru, Basement Complex, Schlumberger Soundings, 1D Layer Model, Aquifer.

ABSTRACT
Geoelectric soundings using the symmetric Schlumberger configuration were carried out to investigate the groundwater potential in fifteen communities of Kajuru local government area within the Northern Nigerian Basement Complex. The project employed the acquired vertical electrical soundings (VES) data and hydrogeophysical expression of structural features and aquiferious zones to model groundwater prospects in the area. Model layers correspond to weathered, fractured and fresh basement zones of varied thickness and lithology. The VES curves obtained were predominantly KH and QH type curves. The topsoil, laterites and pebbles have thicknesses from 2-7m with a resistivity range of 2807m-3600 Ωm. Following this layer is a progression into mainly sandy clay units with a weathered denser sandier base. The thickness of the zone varies from 8-20m and resistivity range of 198-406 Ωm. The partially weathered and fractured portions of the basement have thickness ranges of 9-26m and resistivity of 106-357Ωm. The depth to fresh basement extent from 28m to 36m depending on the intensity of fracturing and weathering, it has resistivity greater than 650 Ωm. The permeable rock units are the fine-coarse sands of the weathered basement and crystalline fractures. The groundwater potentials of the sites investigated appears generally reasonable for borehole development.

INTRODUCTION
Kajuru Local Government Area is situated south of Kaduna city; it is one of the twenty-three (23) local government areas of Kaduna State of Nigeria. Kajuru local government area is located within latitude 9° 59'N and 10° 55'N and longitude 7° 34'E and 8° 13'E with an area of 2,464 km^2. The area is situated within the Guinea savannah belt of Nigeria; it has a mean annual rainfall of 1400mm while the day time temperature can be as high as 34°C. The area is largely a rural settlement tending toward semi urban; it has a population estimate of 110,868 with an annual growth rate of 2% [1]. The population is dominant by Adara ethnic group, whose occupation includes farming and trading. The settlements of Kajuru Local Government area are rapidly expanding due to increasing population density and urbanization. Hence pressure is continuously been put on existing water supply facilities including wells and streams. These pressure and seasonal variations in groundwater level, is usually climax in some parts by dry wells and streams during the peak of dry season. This has necessitated investigation for alternative and sustainable sources of water supply to meet the demand of the growing agrarian communities of Kajuru Local Government Area.

Borehole drilling and construction has become of recent a reliable source of water supply now patronized by government, individuals and organizations. To reduce the risk involve in drilling abortive borehole, Geophysical techniques are employed to assess geologic and hydro geologic conditions that control ground water flow such as fractures, buried channels or geologic traps.

In the area, different scales of geophysical investigations have been conducted to search for groundwater by government agencies, organizations and private individuals. However documented geological and geophysical investigations in the area include: Physico-mechanical evaluation of the geological characteristics of the rock units [2], radiometric studies [3], [4], and regional geologic mapping [5], [6]. In the adjoining areas, successful application of geoelectric techniques to prospect for groundwater has been reported [7], [8], [9].

Global Journal of Engineering Science and Research Management

This study is aimed at the application of resistivity sounding technique to delineate potential aquifer zones in the crystalline rocks and the regolith units of the Basement Complex in Kajuru Area; and hence identify suitable sites for the drilling and construction of productive water boreholes, in line with the global campaign for increasing access to clean and portable drinking water to inhabitants and the promotion of sanitation practice.

Geological and Hydrogeological Setting

Kajuru area lies within the northern section of the Nigerian geological provinces composed of Precambrian basement complex rocks (Figure 1).

Generally, the Nigeria Basement Complex is classified into three broad lithological groups: the migmatite-gneiss complex, which is widespread throughout the country; the metasedimentary and metavolcanics rocks which form schist belts and appear to be dominantly restricted to the western part of the half of the country; and the Older Granites which intrude both the migmatite-gneiss complex and the schist belts and consistently yielded Pan-African ages [10].

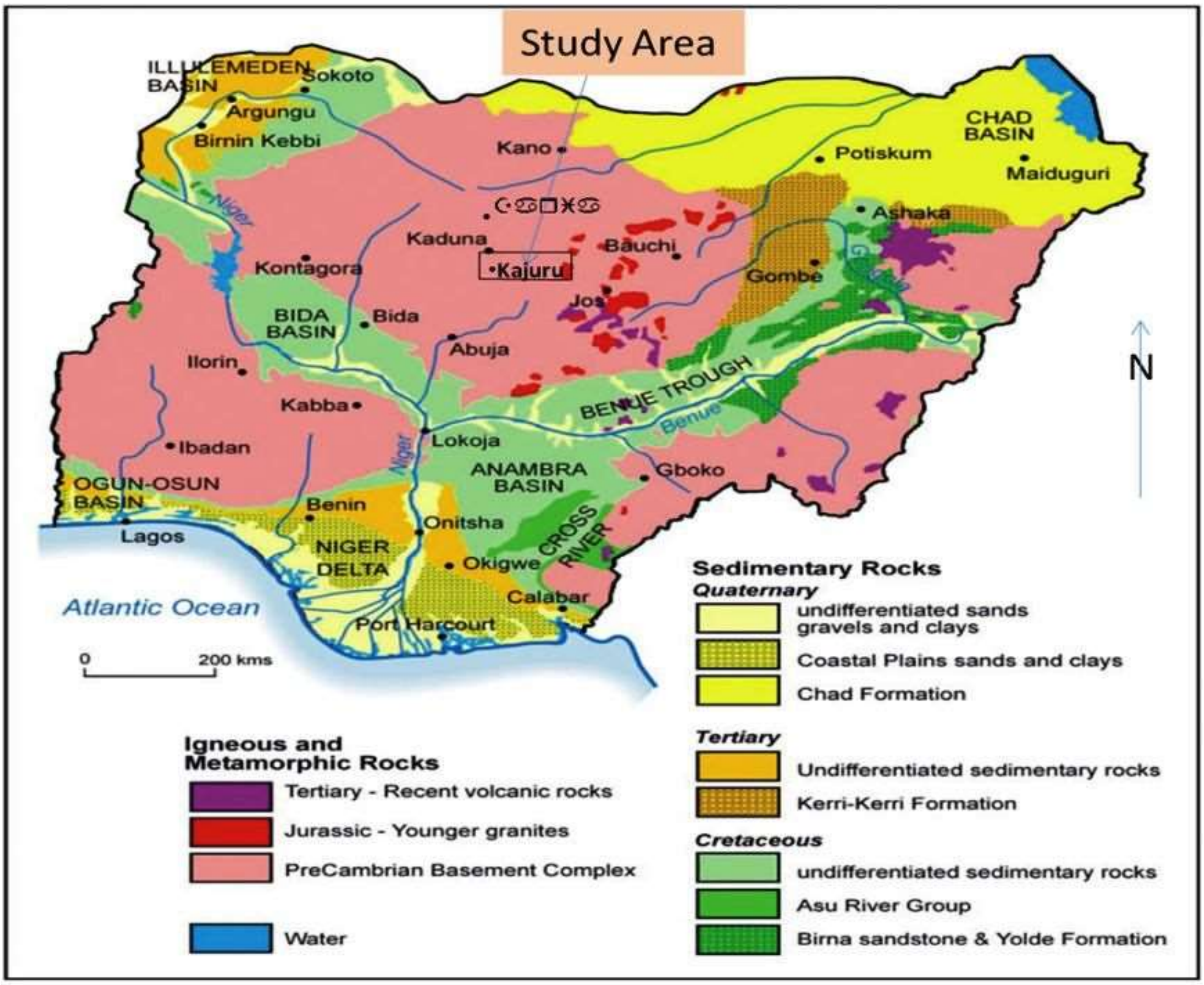

Figure 1: Generalized Geological Map of Nigeria Showing the Study Area (adopted from [21], [22])

The hydrogeology of Nigeria outlined by [11] is explained in detail in [12]. There are three main aquifer types in Nigeria: crystalline rocks, consolidated sedimentary rocks and unconsolidated sedimentary deposits (Figure 1). In crystalline basement areas, fractures, faults, joints, and shear zones are common but localized. The weathered mantle renders the normally impermeable crystalline rocks suitable for ingress and storage of water [13]. In prospecting for groundwater in these areas, it is important to determine the lateral and vertical limits of the faults, fractures, joints and also the extent and thickness of the weathered mantle. The major geological units are:

i) The Basement Complex which comprises over 50% of the country's area and are moderate to poor aquifers, contributing to the groundwater supply. It consists of low permeability rocks with groundwater occurring in weathered mantle and fractured zones. Yields frequently range between less than 1.0 l/s and 2.0l/s.
ii) The sedimentary Basin Formations such as the Tertiary deposits of the Chad and Sokoto Basins, the Cretaceous deposits of the Niger and Benue troughs, and the sedimentary formations of the Niger Delta, yield groundwater in varying quantities.
iii) The Tertiary Volcanics found in parts of Plateau, Cross River, Adamawa and Taraba states.

The rock units in Kajuru area have been mapped (Figure 2): [6] carried out regional mapping of the rocks in the area which include gnesis, granites and schist. [2] also documented the major rock units to include the gneisses (porphyroblastic, granitic and banded), and the biotite granites (porphyritic and medium to coarse grained varieties).

In the area, the Granitic outcrops form elevated inselbergs and pavements. Alluvium and laterites occur as superficial deposit. There are also expressions of structural features (fractures, voids and pore openings) that aid groundwater movement, accumulation and abstraction. The detection of these structures and permeable (weathered rock) units are the targets of the resistivity method in the basement terrain such Kajuru area.

MATERIALS AND METHODS

The investigations consisted mainly of geological reconnaissance, hydrogeological assessment and vertical electrical soundings (VES) at strategically located points and orientations.

Geophysical resistivity techniques are based on the response of the earth to the flow of electrical current. In this investigation, the vertical electrical sounding (VES) technique which is a 1-D resistivity approach was employed. It involves the use of a pair of current electrodes and a pair of potential electrodes to the measure the resultant potential difference within the subsurface (Figure 3). By increasing the spacing of the electrodes, the depth of the investigation below the centre point is increased. The full Schlumberger configuration was adopted with maximum half-current electrode spread (AB/2) between 1 and 80m while the half-potential electrode separation (MN/2) was maintained between 0.3 and 5m. Terameter SAS 300C was used to carry out the resistivity measurements in the field.

The VES was conducted at selected sites in 15 different locations (Figure 2); at each site two soundings were carried out at perpendicular distance of 80 to 120m. These locations were selected public places including primary schools at Akusha, Gurgu, Janwuriya, Kufana, Rimau and Makurdi Kasuwan Maganin.

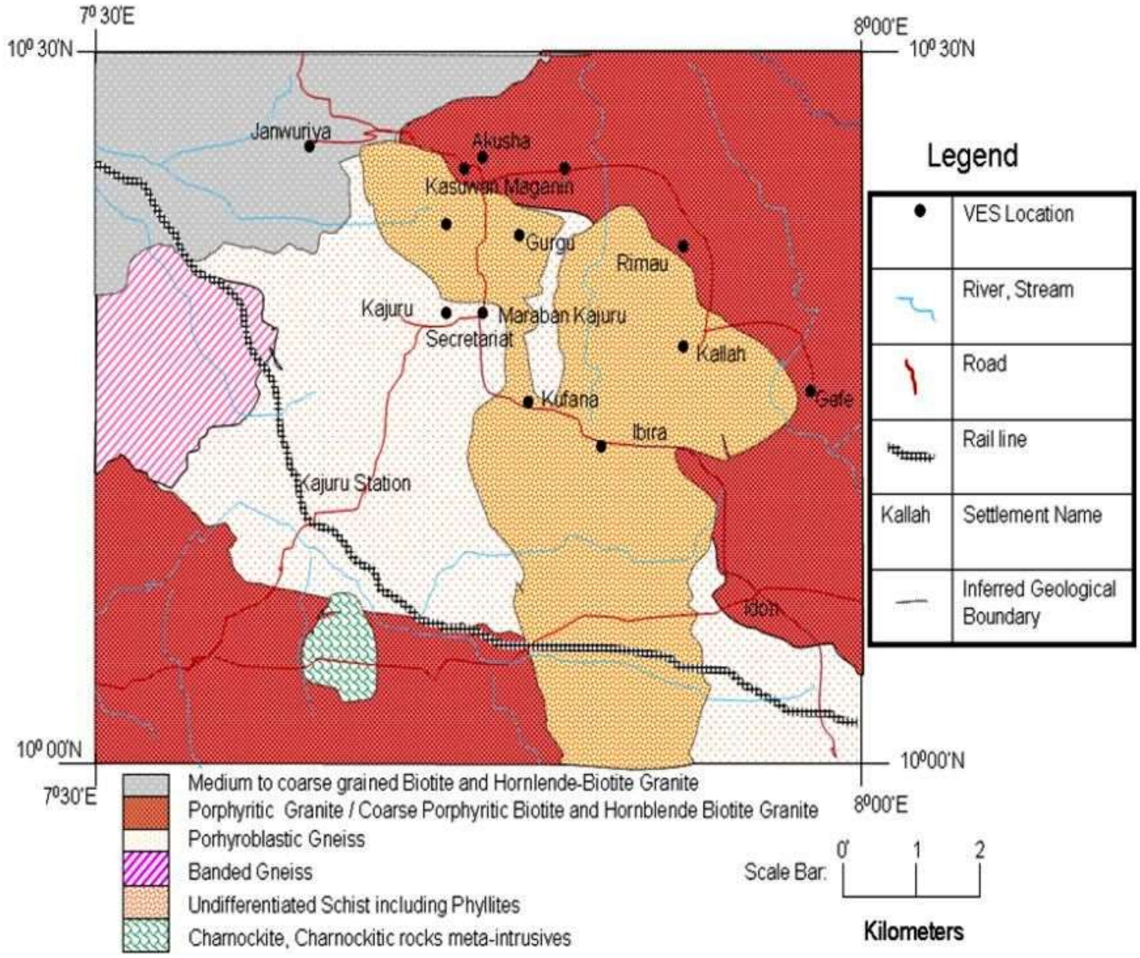

Figure 2: Geological Map of the Study Area (Modified from [2], [6])

Market squares and open fields at the Secretariat Complex, Ungwan Gefe, Ibirah, Sabon Garin Kallah, Kasuwan Magganin Motor Park/Market area, Kasuwan Maganin Court area, Maraban Kajuru, ECWA Kasuwan Maganin, and Rafin Roro were also investigated.

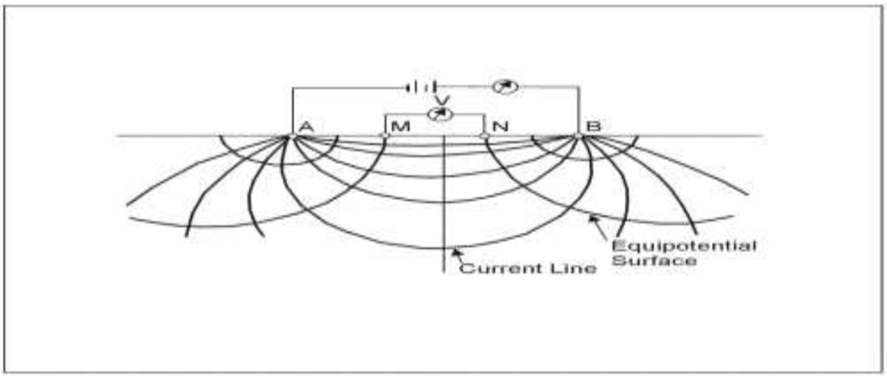

Figure 3: The Four Electrode Array for Resistivity Measurements [19]

ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management

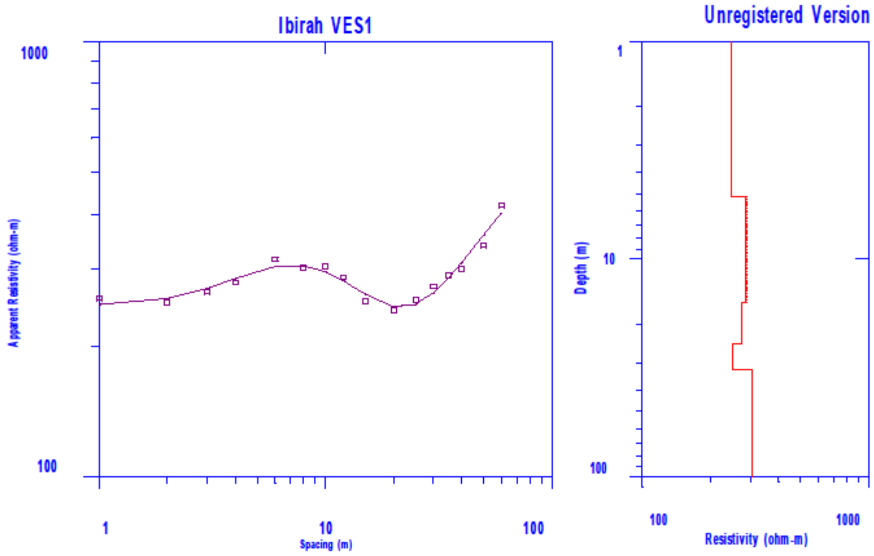

Figure 4: 1D Inversion of apparent resistivity data of the VES point (VES1) at Ibira in modelled curve and cross-section

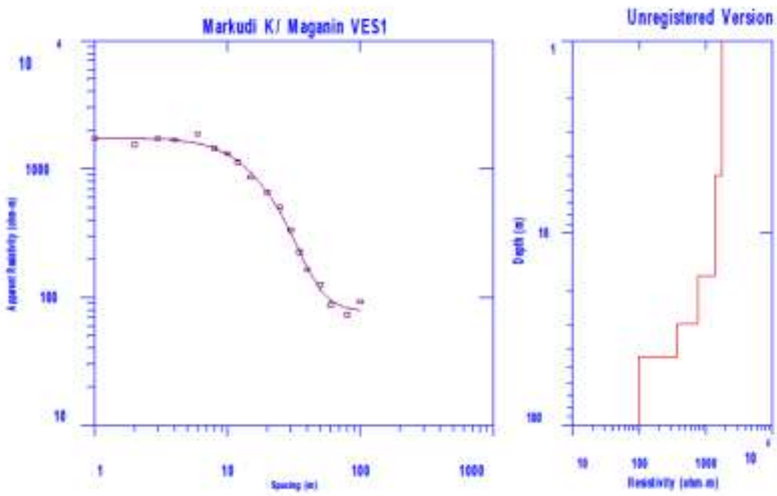

Figure 5: 1D Inversion of apparent resistivity data of the VES point (VES1) at Makurdi Kasuwan Maganin in modelled curve and cross-section

Global Journal of Engineering Science and Research Management

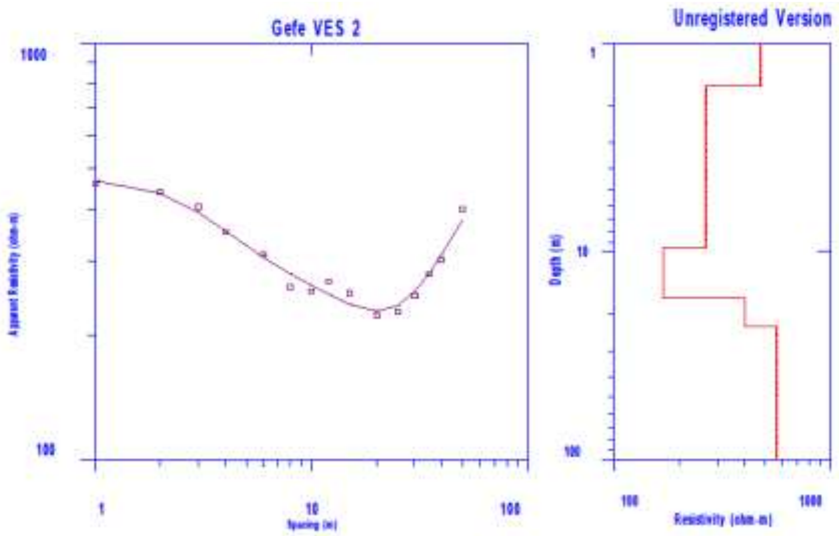

Figure 6: 1D Inversion of apparent resistivity data of the VES point (VES2) at Gefe in modelled curve and cross-section

RESULTS AND DISCUSSION

The measured VES data are the results of the variations with depth of the subsurface resistivity as a function of the surveyed geometry and the electrical impedance of the sub surface material. These resistivity measurements termed apparent resistivity data are plotted as 1-D sounding curves on a log-log scale and interpreted in terms of lithologic and or geohydrologic model of the subsurface.

The initial results of the VES survey were obtained by curve matching the plotted sounding curves with standard master curves and their auxiliary point charts following the procedure outlined by [14]. The field curves obtained at these locations is a four to model. The type of field curves and resistivity sequences of the layers are presented in Table 1.

Table 1: Type of field curves obtained at the specified locations

S/No.	Location Name	Layers	Types of Curves	Sequences of Layers	VES No.
1.	Akusha	4	KH	$\rho_1 < \rho_2 > \rho_3 < \rho_4$	VES 1
2.	Gefe	4	QH	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	VES 2
3.	Gurgu	4	QH	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	VES 2
4.	Ibira	4	KH	$\rho_1 < \rho_2 > \rho_3 < \rho_4$	VES 1
5.	Janwuriya	4	KH	$\rho_1 < \rho_2 > \rho_3 < \rho_4$	VES 1
6.	Makurdi Kasuwan Maganin	4	QQ	$\rho_1 > \rho_2 > \rho_3 > \rho_4$	VES 1
7.	Rafin Roro	4	QH	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	VES 2
8.	Rimau	4	QH	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	VES 2
9.	Sabon Garin Kallah	4	QH	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	VES 1
10.	Secretariat	4	QH	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	VES 1

The resistivity data were subsequently processed by Interpex IX1D program using one dimensional (1D) inversion to model the vertical variations of subsurface resistivity at depths [15], [16]. Forward modeling and the automated inversion processes were used interchangeably to produce best fit curves that agree with qualitative interpretation. The 1D interpretation (1D layered model) of all soundings was satisfactory with relatively good matches between the measured and calculated curves (Figure 4 to Figure 6).

The interpreted results are presented as one dimension earth layer models of the subsurface (Figure 7 to Figure 9). Hence saturated and unsaturated zones are mapped from the resistivity values and correlation with known information of the lithology; since the flow of electric current and water in a medium follows the path of low resistance [17] , [18].
The subsurface models reveal generally five-six layer units which do not necessarily correspond to distinct lithological layers. These have been inferred to reflect four lithological layers in light of the geological setting in

the area. The topsoil, laterites and pebbles has thicknesses varying from 2-7m with a resistivity range of 2807-3400 Ωm. Below is a gradation into mainly sandy clay layer with a weathered denser sandier base. Thickness of the zone varies from 8-20m and resistivity range of 198-406 Ωm. Following is the basement with partially weathered/fractured portions. This zone may be hard with boulders depending on the weathering history with individual thickness ranges of about 9-26m and resistivity of 106-357 Ωm, depending on the VES position. At the base of the investigated column is fresh basement of resistivity often greater than 650 Ωm.

The Measurement of resistivity (inverse of conductivity), is in general, a measure of water saturation and connectivity of pore spaces [18], [19], [20]. The Vertical Iso-ohms Sections of the geoelectric models enable the delineation of anomalous zones of very low to moderately low resistivity values as potential aquifer zones. Therefore the unsaturated zones can be distinguished from the saturated zones of the weathered sandy units and the water filled fractures. The mapped aquifer zones in each VES Location including their thickness and apparent resistivities are shown in Table 2.

Table 2: Resistivity and thickness of the aquifer zones delineated at Specified VES locations

S/No.	VES Location	Aquifer zones					
		Crystalline Fractures			Weathered Basement (Sandy)		
		Thickness (m)	Apparent Resistivity (Ωm)		Thickness (m)	Apparent Resistivity (Ωm)	
			Range	Average		Range	Average
1.	Akusha	8	234 - 251	243	17	204 - 238	222
2.	ECWA	11	395 - 499	447	24	417 - 530	474
3.	Gefe	17	194 - 547	371	11	98 - 107	103
4.	Gurgu	9	76 - 158	117	27	231 - 487	359
5.	Ibirah	12	216 - 231	224	14	213 - 245	229
6.	Janwuriya	10	424 - 554	489	6	558 - 759	659
7.	Kasuwan Maganin Court Area	8	132 - 147	140	16	213 - 245	229
8.	Kasuwan Maganin Motor Park	7	141 - 162	152	13	237 - 251	244
9.	Kufana	19	234 - 254	244	8	201 - 236	219
10.	Rafin Roro	13	167 - 195	181	14	132 -135	134
11.	Rimau	12	104 - 168	136	17	174 - 211	193
12.	Makurdi Kasuwan Maganin	8	88 - 125	107	21	265 - 506	386
13.	Maraban Kajuru	14	231 - 278	256	8	204 - 246	225
14.	Sabon Garin Kallah	20	152 - 277	215	14	220 - 258	239
15.	Secretariat	6	117 - 152	135	5	132 - 159	146

The relatively high to moderate resistivity values relate to thick columns of laterites and clayey units around Kasuwan Maganin and environ, which vary toward Gurgu, Rimau, Gefe and Rafin Roro can be attributed to the highly saprolitic basement in the area. Also, the increase in resistivity values at depth following the anomalous zones indicates the penetration of an impermeable, nonconductive layer inferred as the fresh basement.

Thus the model sections derived from the geoelectric parameters suggest that the groundwater potentials of the sites investigated will be generally comparatively adequate for borehole development. It is imperative that adequate depths be achieved to serve as storage sumps and the aquiferous zones fully penetrated so as to provide adequate yields. Hence minimum drill depths of between of 40 and 50m are recommended.

CONCLUSION

The one dimensional (1D) inversion model of the vertical variations of subsurface resistivity at depths was achieved. These subsurface models have been inferred to reflect four lithological layers in light of the geological setting in the area. The geologic sections derived from the geoelectric parameters suggest that the main aquifers (the permeable rock units) in the area are the sandy units of the weathered basement and crystalline fractures. The groundwater potentials of the sites investigated appears generally reasonable for borehole development. Therefore the drilling of productive boreholes is envisaged at depths of between of about 40 and 50m in the area.

ACKNOWLEDGEMENTS

Engr. Douglas K. Njimen, Mr. Danjuma Awhila, Mr. John Sarkin-Samari and Mr. David Magaji of Kaduna State Ministry of Water Resources are appreciated for their encouragement.

REFERENCES

1. National Population Commission (NPC), *Population and Housing census report*, Abuja, Nigeria, 2006.
2. Amuda, A.G., Adedokun, T.A., Uche, O.A.U., and Amuda, A.K. Engineering geological Characterization of Basement Rocks for Construction Aggregates: A Case Study of Kajuru Area Kaduna, Nigeria. *Civil and Environmental Research*, Vol**.** **6**, No.12, 2014: www.iiste.org
3. Arisekola, T. M. and Ajenipa, R.A. Progress report of Nigeria airborne Geophysical data results: Preliminary applications to uranium and thorium exploration. IAEA-CYTED-UNECE Workshop on UNFC-2009 at Santiago, Chile, 2013.
4. Afolalu, F.O., Lawal, K.M., and Ahmed A.L. Grouting trotting of an aeroradiometric anomaly in Kajuru Area, Northcentral Nigeria. *Journal of Mining and Geology*, Volume **45** Number 1 pp 21-26, 2009.
5. McCurry, P. The Geology of the Precambrian to Lower Palaeozoic Rocks of Northern Nigeria- A review. *In*: Kogbe, C.A. (Ed) *Geology of Nigeria*, Elizabethan Press, Lagos, pp. 15 -19, 1976.
6. Udo, A.N. 1973. Note on the geology of Sheet **45** (Kajuru), Nigerian Geological Survey Agency, Kaduna
7. Aboh, H.O. Detailed regional geophysical investigation of the subsurface structures in Kaduna Area, Nigeria: PhD Dissertation, Ahmadu Bello University, Zaria, 2001.
8. Aboh, H.O., and Osazuwa, I.B. Lithological deduction from a regional geoelectric investigation in Kaduna Area, Kaduna State, *Nigerian Journal of Physics*, Volume **12**, pp 1-2, 2000.
9. Dan-Hassan, M. A., and Olorunfemi, M. O. Hydro- geophysical investigation of a basement terrain in the North-central part of Kaduna State, Nigeria: *Journal of Mining and Geology*, Volume **35** Number 2, pp 189 – 206, 1999.
10. Ajibade, A.C. and Fitches, W.R. The Nigerian Precambrian and the Pan-African Orogeny. *In: Precambrian Geology of Nigeria*, A publication of the Nigerian Geological Survey Agency, Abuja, Nigeria. pp. 45-55, 1988.
11. Dan-Hassan, M. A. Managing Nigeria's Groundwater Resources for Safe Drinking Water: A paper presented at the Nigeria Water and Sanitation Association Workshop, June 16 – 18, 2014, Abuja, 2014.
12. Adelana, S. M. A., Olasehinde, P. I., Vrbka, P., Edet, A. G. and Goni, I. B. An overview of the Geology and Hydrogeology of Nigeria. In: S. M. .A. Adelana and A. M. Mc Donald (Eds.), *Applied groundwater studies in Africa*. IAH Selected papers in Hydrogeology, Vol. **13**. Leiden, Netherlands. CRC Press/Balkema, 2008.
13. Offodile, M.E. Hydrogeology: Groundwater study and development in Nigeria. Mecon Geology and Engineering Services Ltd., Jos, Nigeria, 3rd edition, 2014.
14. Orellana, E. and Mooney, H.M. *Master Tables and Curves for Vertical Electrical Sounding over Layered Structures*. Interciencia, Madrid, 1966.
15. Verave, R. T., Mosusu, N and Irarue, P. 1D Interpretation of Schlumberger DC Resistivity Data from the Talasea Geothermal Field, West New Britain Province, Papua New Guinea Proceedings World Geothermal Congress, Melbourne, Australia, 2015.
16. Bahoi, A. K. An Assessment of Electrical Resistivity Soundings Data by Different Interpretation Techniques. *International Journal of Biological, Ecological and Environmentl Science (IJBEES)* Vol**.** **1**, No. 3, ISSN 2277 – 4394, 2012.
17. Yadav, G. S. and Abolfazli, H. Geoelectrical soundings and their relationship to hydraulic Parameters in semiarid regions of Jalore, Northwestern India. *Journal of Applied Geophysics*, **39**, 35-51, 1998.
18. Cardimona, S. Lecture Notes: Electrical Resistivity Techniques for Subsurface Investigation, Department of Geology and Geophysics, University of Missouri-Rolla, MO. 2009.

ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management

19. Telford W. M, Geldart, L. P., and Sheriff, R. E. *Applied Geophysics,* Second edition, Cambridge University Press, 1990.
20. Keary, P., Brooks, M. and Hill, I. *An Introduction to Geophysical Exploration,* Blackwell Science Ltd. United Kingdom, 2002.
21. Mac Donald, A. M., Davies, J. and Carlow, R. C. African hydrogeology and rural water supply. In: S. M. A. Adelana & A. M. Mac Donald (Eds.). *Applied Groundwater Studies in Africa* (pp. 127 – 148), London, CRC Press, 2008.
22. Olasehinde, P.I. *The Groundwaters of Nigeria: A solution to sustainable national water needs*. Inaugural lecture, series **17,** Federal University of Technology, Minna, Nigeria, 2010.