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A blind geoelectrical survey commissioned to affirm or deny the presence of aquifer at a compound at Minna, Central Nigeria

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Abstract

When the owner of a property, located on a knoll, tasked the survey crew to prospect for aquifer at his lot, no clue was provided as to what the result of an earlier survey by an independent crew was: thus, members of the present crew were required to independently plan and execute a geoelectrical survey at this same location, the result of which is expected to corroborate or weaken the conclusions reached in the earlier survey. At the outset, the client's property was visually reconnoitered; the extent and preferred traverse directions were noted. The survey crew proposed a north-south (i.e. longitudinal traverse, LT) profiling scheme at 10m-separation between survey stations and 10m-separation between profile lines for the reconnaissance phase to a depth of 15m. Thence, detailed Vertical Electrical Sounding (VES) surveys were conducted for locations of "low-ohmic interest" to a depth of 100m. The result of the reconnaissance phase indicated the lowest resistance value of 1.6348Ω at "LT4-1." Upon final VES surveys, and based on an empirical protocol for the likely presence of groundwater in the basement complex geological province, it was concluded that the prospect for aquifers of good yield at the area of study was very poor indeed: this conclusion actually corroborated the one drawn from the initial survey.

Keywords: Reconnaissance; knoll; geoelectrical; traverse; low-ohmic; aquifer; empirical; protocol

1.0 Introduction

Presently, at Minna, Niger State, Nigeria, householders put a lot of stock in the results of geoelectrical surveys carried out at their lots to locate the presence of groundwater sources because of the need to maximize returns on investment committed to borehole development. Nearly everyone will agree that mankind, at this point in time more than ever before, is saddled with the critical responsibility of sustainably managing the earth's resources that are beginning to show signs of decline. Water is one such very important resource, and thus the search for underground water sources as supplements to the surface water sources to meet the demand of a burgeoning population is central to individual endeavours and government policies. In science, this search is encompassed in the earth sciences' disciplines of geology and applied geophysics. Pre-drilling reconnaissance ("recce") geophysical surveys for groundwater development are usually carried out by means of the Constant Separation Traversing (CST) mode of the resistivity method, and this study proposed to do the reconnaissance component of the survey to an initial “probe” depth of 15m. The area of survey is a rocky knoll with interspersed verdant depressions that gently slopes on its southern and northeastern flanks. Even on this knoll, patches of outcrops can be observed, too. The outcrops that cluster in the northeastern sector of the client’s property are principally granitic in nature. A shallow, collapsed hand-dug well was observed on the low slope of the northeastern sector as an anthropogenic geological relic. The objective of this study was the adoption of an independent approach to plan and execute a geoelectrical survey in order to validate or invalidate the result of an earlier study carried out to identify the possible location of aquifer at the area of study. The map of Minna is shown in Fig.1. In Fig.2, indicating the satellite imagery overlay map of the study area at the Ahmadu Bahago Secundary School neighbourhood, all the CST locations are shown as blue dots and all the VES locations are shown as red dots. On this map, the major arterial Bosso Road can be made out, as well as its branched-off segment to Angwan Biri and its further right-turn to Tayi Village located to the rear of the Ahmadu Bahago Secundary School compound, seen in this image at the southeast. It is noteworthy to point out that this study is a component of a suite of skills acquisition scheme for final-year students of the Department of Physics, Federal University of Technology, Minna.

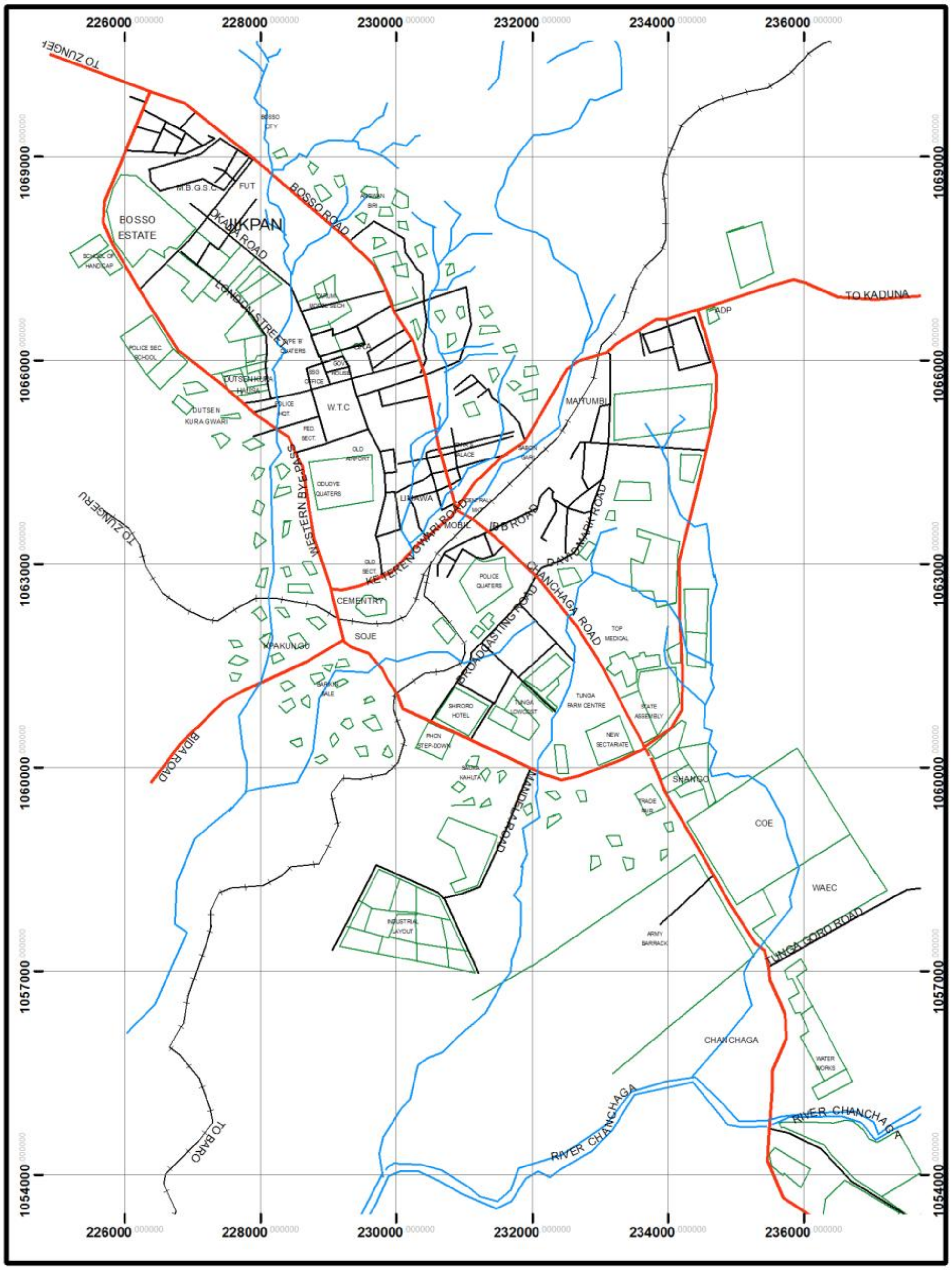


Fig.1. Map of Minna

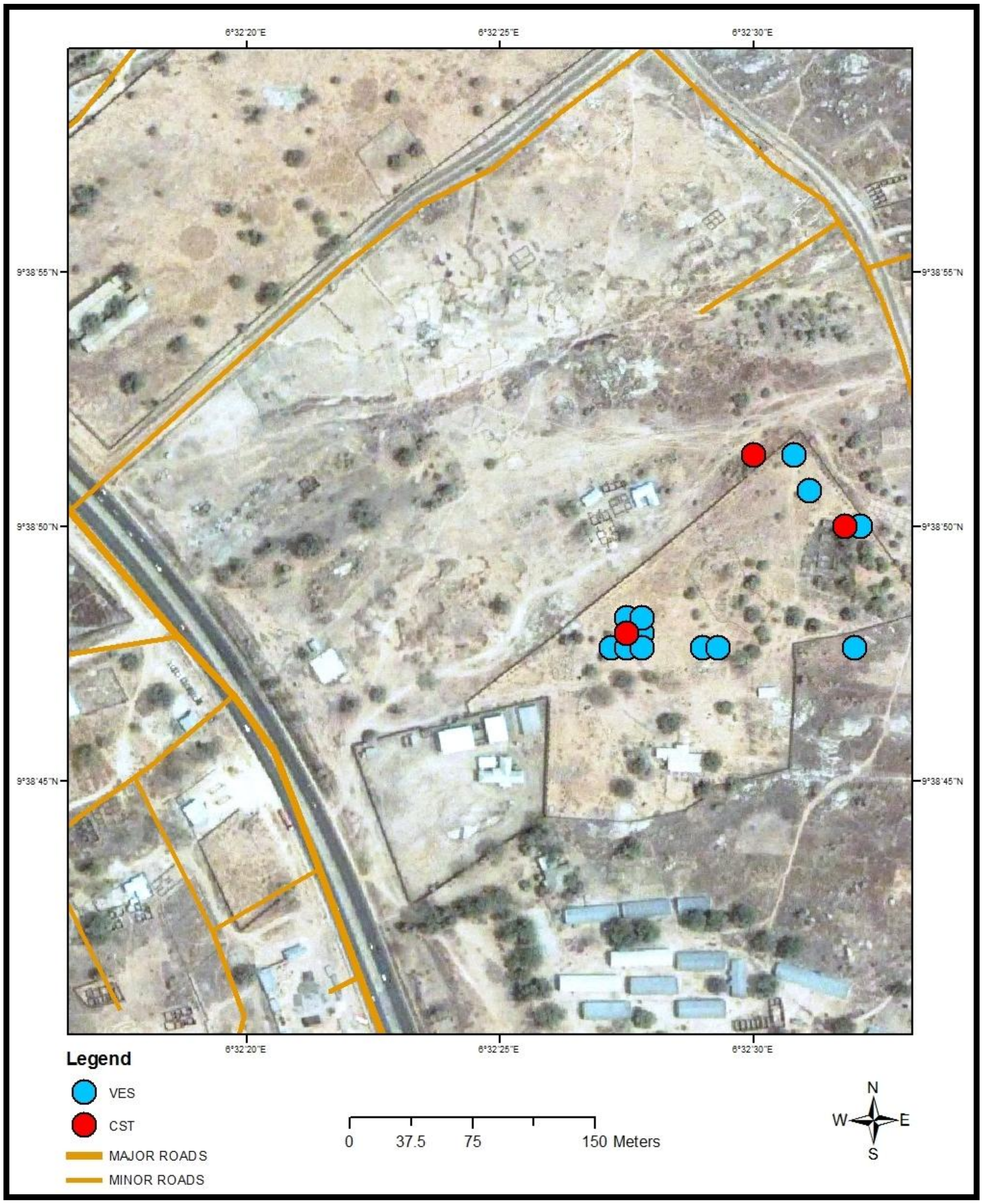


Fig.2. Specific study area at the Ahmadu Bahago Secundary School neighbourhood, (All CST locations are shown as blue dots and all VES locations are shown as red dots.)

2.0 The Geoelectric Survey

2.1 The Method Employed: The geophysical work carried out here is based on electrical resistivity survey using the Constant Separation Traversing (CST) and the Vertical Electrical Sounding (VES) techniques (Kearey and Brooks, 1988; Parasnis, 1986). Generally, an electrical resistivity method involves the artificial introduction of current into the ground through point electrodes. Potentials are subsequently measured at other electrodes in the vicinity of the current flow. By this means, it is then possible to measure or determine an effective or apparent resistivity of the subsurface. Low resistivity in a given area is a likely indicator of the presence of groundwater (Ako and Olorunfemi, 1982; Bonde, 1997; Dangana, 2002; Gana, 1995; Okwueze and Ezeanyi, 1985; Okwueze et al, 1981; Olorunfemi and Fasuyi, 1993; Olorunfemi and Okhue, 1992). A slightly different approach to complete a study of the kind described here was adopted by Jonah et al (2013) in their work at the Dan Zaria Academic Estate, opposite the Gidan Kwano Campus, Federal University of Technology, Minna. The resistivity type geoelectric survey in the VES mode of the Schlumberger array was employed for the reconnaissance and final stages of this investigation. This "unconventional" approach was the acquisition of VES data at shallow depths (i.e. progressively down to 10m) over the area of study in order to determine the point of lowest resistivity instead of the approach to determine the lateral variation of resistivity at these shallow depths using the Constant Separation Traversing (CST) method. The point of lowest resistivity thus identified was surveyed to a final depth of 100m. There is some advantage to this "unconventional" approach, nonetheless: by doing pre-drilling reconnaissance geophysical surveys for groundwater development by means of the VES mode of the resistivity method instead of the CST mode of the resistivity method to an initial "probe" depth of 10m, a greater data field would be created but at attendant high costs. It is expected that the greater data field thus created would help minimize errors in pinpointing the possible location of aquifer within the surveyed lot. This comparatively greater data field would offset the apparent disadvantage of surveying a very limited land area.

2.2 Data Collection Procedure: Since the walled compound surveyed was not exactly in the shape of a regular geometrical form (as a perfect rectangle, for instance) that may easily be defined by a smooth georeferenced signature of its A, B, C, D points; also, within the compound proper, built-up areas and exposed sheer rock faces imposed further constraints. Because of this fact, the survey crew designated eight longitudinal traverses (LTs), following a north-south (N-S) profile trend, at 10-m separation, that ranged between LT1-1 (i.e. the first survey station of the first longitudinal traverse) at 09^{0}38'47.6", 006^{0}32'27.2" and LT8-1 (i.e. the first survey station of the eight longitudinal traverse) at 09^{0}38'47.6", 006^{0}32'29.3": these two points implied southern extremities of the geoelectrical survey; the extent of the northern extremities was determined on location by the perimeter fencing. Upon completion of the LT survey phase, the survey crew commenced the transverse traverse (TT) phase; each TT aspect was based on a principal LT. The ABEM Terrameter SAS 4000 was employed for this survey. The non-geometrical form of the area of study can be made out in Fig.2, as well as the defined straight-line LTs imposed by physical constraints on the properties which are defined by the blue dots: the TTs can also be made out in their straight-line format; the VES locations are not linearised herein, naturally.

3.0 Data Presentation

3.1 Introduction: The CST LT values at the 15m-depth that correspond to a Wenner array separation of 10m for eighteen CST stations are shown in Tables 1-18.

3.2 Tables of Result for all CST LTs

Table 1. LT1-1 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Warm
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** 09^{0}38'47.6" **E:** 006^{0}32'27.2"	309m	James	James
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15th March 2013	9:01a.m	LT1-1	Garmin GPSmap76	**31.198Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	5.47%	5mA	4	=======

Table 2. LT2-2 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$38’47.9” **E:** $006^0$32’27.5”	319m	Adeku	Adeku
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15th March 2013	==========	LT2-2	Garmin GPSmap76	**4.3329Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	0.71%	5mA	4	=======

Table 3. LT2-3 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$38’48.2” **E:** $006^0$32’27.5”	310m	Ahmed	Ahmed
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15th March 2013	1:20p.m	LT2-3	Garmin GPSmap76	**15.128Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	0.566%	1mA	2	=======

Table 4. LT3-2 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$38'47.9" **E:** $006^0$32'27.8"	=========	Alhassan	Alhassan
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15th March 2013	=========	LT3-2	Garmin GPSmap76	**22.314Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	0.352%	2mA	2	=======

Table 5. LT3-3 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$38'48.2" **E:** $006^0$32'27.8"	=========	JAMES	JAMES
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15th March 2013	=========	LT3-3	Garmin GPSmap76	**36.235Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	50.00%	1mA	4	=======

Table 6. LT4-1 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** 09^{0}38’51.4” **E:** 006^{0}32’30.8”	328m	Hamza	Hamza
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15th March 2013	===========	LT4-1	Garmin GPSmap76	**1.6348Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	11.1%	1mA	4	=======

Table 7. LT5-1 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** 09^{0}38’50.7” **E:** 006^{0}32’31.1”	310m	Igbideba	Igbideba
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15th March 2013	==========	LT5-1	Garmin GPSmap76	**13.288Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	0.133%	10mA	5	=======

Table 8. LT6-1 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** 09^{0}38’47.6” **E:** 006^{0}32’32.0”	294m	Kwaghhua	Kwaghhua
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15^{th} March 2013	===========	LT6-1	Garmin GPSmap76	**11.142Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	0.124%	10mA	2	=======

Table 9. LT7-1 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** 09^{0}38’47.6” **E:** 006^{0}32’29.0”	330m	Kyari	Kyari
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15^{th} March 2013	==========		Garmin GPSmap76	**13.988Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	6.60%	2mA	4	=======

Table 10. LT8-1 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** 09^{0}38’47.6” **E:** 006^{0}32’29.3”	319m	Macaulay	Macaulay
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15th March 2013	==========		Garmin GPSmap76	**24.282Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	0.013%	2mA	2	=======

3.3 Tables of Result for all CST TTs

Table 11. TT1-1 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** 09^{0}38’47.6” **E:** 006^{0}32’27.2”	309m	Olarewaju	Olarewaju
DATE	**TIME**	**TRANSVERSE TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15th March 2013	===========	TT1-1	Garmin GPSmap76	**37.437Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	2.10%	5mA	4	=======

Table 12. TT1-2 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$38’47.6” **E:** $006^0$32’27.5”	309m	Onyeodili	Onyeodili
DATE	**TIME**	**TRANSVERSE TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15^{th} March 2013	12:50PM	TT1-2	Garmin GPSmap76	**10.196Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	7.87%	1mA	4	=======

Table 13. TT1-3 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$38’47.6” **E:** $006^0$32’27.8”	307m	Onyeodili	Onyeodili
DATE	**TIME**	**TRANSVERSE TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15^{th} March 2013	12:50PM	TT1-3	Garmin GPSmap76	**4.9735Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	5.39%	2mA	4	=======

Table 14. TT2-1 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Warm
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$38’47.6” **E:** $006^0$32’27.5”	309m	Sofeso	Sofeso
DATE	**TIME**	**TRANSVERSE TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15^{th} March 2013	==========	TT2-1	Garmin GPSmap76	**11.945Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	0.048%	5mA	2	=======

Table 15. TT2-2 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Warm
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000			Switzer	Switzer
DATE	**TIME**	**TRANSVERSE TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15^{th} March 2013	==========	TT2-2	Garmin GPSmap76	**9.2745Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	8.41%	2mA	4	=======

Table 16. TT3-1 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$38’47.6” **E:** $006^0$32’27.8”	307m	Umoh	Umoh
DATE	**TIME**	**TRANSVERSE TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15^{th} March 2013	==========	T3-1	Garmin GPSmap76	**13.627Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	0.866%	5mA	2	=======

Table 17. TT4-4 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$38’50.0” **E:** $006^0$32’31.8”	314m	James	James
DATE	**TIME**	**TRANSVERSE TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15^{th} March 2013	==========	T4-4	Garmin GPSmap76	**7.3685Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	0.983%	5mA	2	=======

Table 18. TT4-5 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Sunny
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** 09^{0}38’50.0” **E:** 006^{0}32’32.1”	291m	Adeku	Adeku
DATE	**TIME**	**TRANSVERSE TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
15th March 2013	==========	T4-5	Garmin GPSmap76	**21.586Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	1.52%	10mA	2	=======

4.0 Data Analysis

4.1 Reconnaissance CST Survey: The objective of this initial phase was to identify the CST points or stations, in LT or TT format, having the lowest resistivity values at the 15m-depth that correspond to a Wenner array separation of 10m from amongst the eighteen CST stations of Tables 1-17. On-the-field inspection of the CST dataset revealed that the lowest resistance value of 1.6348Ω was obtained at “LT4-1” corresponding to the following geographic co-ordinate: 09^{0}38’51.4”, 006^{0}32’30.8”. In order to ensure full spread of the VES data field, and upon carrying out on-the-spot visual analysis of the CST dataset, three other “low-ohmic” points of less than 8Ω were also flagged for detailed survey to the 100m depth point, viz: “LT2-2” at 09^{0}38’47.9”, 006^{0}32’27.5”, and “TT4-4” at 09^{0}38’50.0”, 006^{0}32’31.5”. Thus, a convenient regime of “low-ohmic” resistivity values of less than 8Ω was selected.

4.2 Final Survey in VES Mode: Thus, “LT4-1,” “LT2-2,” and “TT4-4” were selected for the “deep-probe” stage down to a depth of 100m; the results of this final “deep-probe” VES survey are shown in Tables 19-21.

Table 19. Deep-Probe Geoelectrical Data Record Sheet for LT4-1. (During data processing, "LT4-1" was named merely "TT3" not in accord with any rule.)

TYPE OF SURVEY: Resistivity **MODE:** Vertical Electrical Sounding **ARRAY:** Schlumberger

PLACE: Minna **WEATHER:** Sunny **EQUIPMENT:** ABEM Terrameter SAS 4000

LOCATION: (i) **N:**09^{0}38'51.4" (ii) **E:**006^{0}32'30.8" **ELEVATION:** 328m **DATE:** 16th March 2013

AB/ 2	MN/ 2	GEOM. FACTOR, K	RESISTANCE	STANDARD DEVIATION	CURRENT (I)	STACKS	RESISTIVITY
1	.50	2.36	169.69Ω	**REDUNDANT**	**INFO**	**COLUMN**	400.468Ωm
2	.50	11.8	16.858Ω	**FOR**	**ABEM**	**TERRAMETER**	198.924Ωm
3	.50	27.8	6.5577Ω	**INFO**	**NOT**	**RECORDED**	182.304Ωm
5	.50	77.8	2.9354Ω	**REDUNDANT**	**INFO**	**COLUMN**	228.374Ωm
6	.50	112	2.3842Ω	**FOR**	**ABEM**	**TERRAMETER**	267.030Ωm
6	1.00	55	4.9200Ω	**INFO**	**NOT**	**RECORDED**	270.600Ωm
8	1.00	99	3.4387Ω	**REDUNDANT**	**INFO**	**COLUMN**	340.431Ωm
10	1.00	156	2.7252Ω	**FOR**	**ABEM**	**TERRAMETER**	425.131Ωm
10	2.50	58.9	9.2730Ω	**INFO**	**NOT**	**RECORDED**	546.180Ωm
15	2.50	137	10.195Ω	**REDUNDANT**	**INFO**	**COLUMN**	1396.715Ωm
20	2.50	245	8.6351Ω	**FOR**	**ABEM**	**TERRAMETER**	2115.600Ωm
30	2.50	562	10.228Ω	**INFO**	**NOT**	**RECORDED**	5748.136Ωm
40	2.50	1001	7.0026Ω	**REDUNDANT**	**INFO**	**COLUMN**	7009.603Ωm
40	7.50	323	6.0496Ω	**FOR**	**ABEM**	**TERRAMETER**	1954.021Ωm
50	7.50	512	2.8427Ω	**INFO**	**NOT**	**RECORDED**	1455.462Ωm
60	7.50	742	1.1022Ω	**REDUNDANT**	**INFO**	**COLUMN**	817.832Ωm
70	7.50	1014	2.2042Ω	**FOR**	**ABEM**	**TERRAMETER**	2235.059Ωm
80	7.50	1329	1.1593Ω	**INFO**	**NOT**	**RECORDED**	1540.710Ωm
80	15.00	647	6.2966Ω	**REDUNDANT**	**INFO**	**COLUMN**	4073.900Ωm
90	15.00	825	2.0641Ω	**FOR**	**ABEM**	**TERRAMETER**	1702.883Ωm
100	15.00	1024	1.9934Ω	**INFO**	**NOT**	**RECORDED**	2041.242Ωm

Table 20. Deep-Probe Geoelectrical Data Record Sheet for LT2-2. (During data processing, "LT2-2" was named merely "TT2" not in accord with any rule.)

TYPE OF SURVEY: Resistivity **MODE:** Vertical Electrical Sounding **ARRAY:** Schlumberger

PLACE: Minna **WEATHER:** Sunny **EQUIPMENT:** ABEM Terrameter SAS 4000

LOCATION: (i) **N:**09^{0}38'47.9" (ii) **E:**006^{0}32'27.5" **ELEVATION:** 319m **DATE:** 16th March 2013

AB/2	MN/2	GEOM. FACTOR, K	RESISTANCE	STANDARD DEVIATION	CURRENT (I)	STACKS	RESISTIVITY
1	.50	2.36	99.091Ω	**REDUNDANT**	**INFO**	**COLUMN**	233.855Ωm
2	.50	11.8	19.848Ω	**FOR**	**ABEM**	**TERRAMETER**	234.206Ωm
3	.50	27.8	10.462Ω	**INFO**	**NOT**	**RECORDED**	290.844Ωm
5	.50	77.8	5.4199Ω	**REDUNDANT**	**INFO**	**COLUMN**	421.668Ωm
6	.50	112	4.0705Ω	**FOR**	**ABEM**	**TERRAMETER**	455.896Ωm
6	1.00	55	9.4889Ω	**INFO**	**NOT**	**RECORDED**	521.890Ωm
8	1.00	99	5.6549Ω	**REDUNDANT**	**INFO**	**COLUMN**	559,835Ωm
10	1.00	156	4.2818Ω	**FOR**	**ABEM**	**TERRAMETER**	667.961Ωm
10	2.50	58.9	11.715Ω	**INFO**	**NOT**	**RECORDED**	690.014Ωm
15	2.50	137	6.2375Ω	**REDUNDANT**	**INFO**	**COLUMN**	854.538Ωm
20	2.50	245	4.2575Ω	**FOR**	**ABEM**	**TERRAMETER**	1043.088Ωm
30	2.50	562	3.5515Ω	**INFO**	**NOT**	**RECORDED**	1995.943Ωm
40	2.50	1001	1.6804Ω	**REDUNDANT**	**INFO**	**COLUMN**	1682.080Ωm
40	7.50	323	6.9650Ω	**FOR**	**ABEM**	**TERRAMETER**	2249.695Ωm
50	7.50	512	5.9228Ω	**INFO**	**NOT**	**RECORDED**	3032.474Ωm
60	7.50	742	4.9228Ω	**REDUNDANT**	**INFO**	**COLUMN**	3652.718Ωm
70	7.50	1014	2.9202Ω	**FOR**	**ABEM**	**TERRAMETER**	2961.083Ωm
80	7.50	1329	3.7002Ω	**INFO**	**NOT**	**RECORDED**	4917.566Ωm
80	15.00	647	6.1219Ω	**REDUNDANT**	**INFO**	**COLUMN**	3960.869Ωm
90	15.00	825	5.4606Ω	**FOR**	**ABEM**	**TERRAMETER**	4504.995Ωm
100	15.00	1024	3.1967Ω	**INFO**	**NOT**	**RECORDED**	3273.421Ωm

Table 21. Deep-Probe Geoelectrical Data Record Sheet for TT4-4. (During data processing, “TT4-4” was named merely “LT3” not in accord with any rule.)

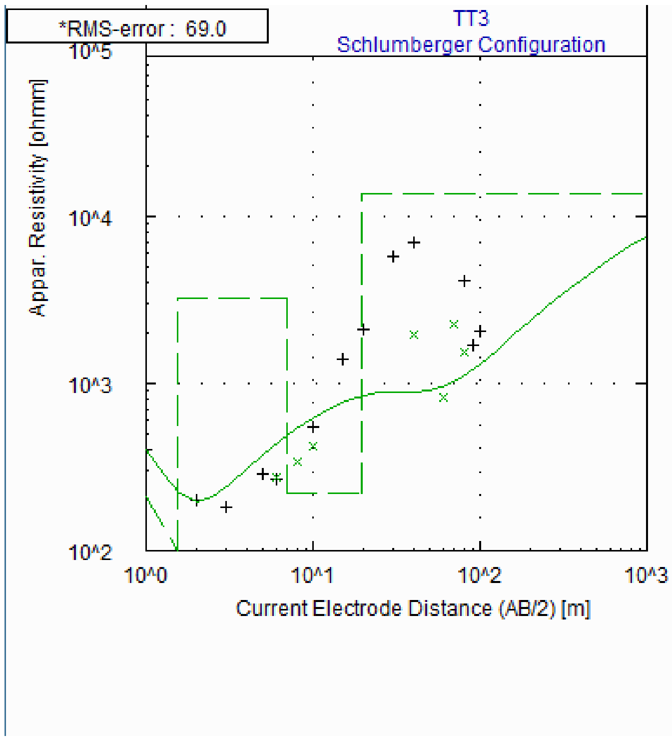
TYPE OF SURVEY: Resistivity **MODE:** Vertical Electrical Sounding **ARRAY:** Schlumberger

PLACE: Minna **WEATHER:** Sunny **EQUIPMENT:** ABEM Terrameter SAS 4000

LOCATION: (i) **N:**09^{0}38’50.0” (ii) **E:**006^{0}32’31.8” **ELEVATION:** 314m **DATE:** 16th March 2013

AB/ 2	MN/ 2	GEOM. FACTOR, K	RESISTANCE	STANDARD DEVIATION	CURRENT (I)	STACKS	RESISTIVITY
1	.50	2.36	259.12Ω	0.009%	10mA	2	611.523Ωm
2	.50	11.8	27.533Ω	0.166%	10mA	2	324.889Ωm
3	.50	27.8	11.387Ω	0.037%	10mA	2	316.559Ωm
5	.50	77.8	3.4951Ω	0.127%	10mA	2	271.919Ωm
6	.50	112	2.3436Ω	0.149%	10mA	2	262.483Ωm
6	1.00	55	4.7907Ω	0.851%	10mA	2	263.489Ωm
8	1.00	99	2.8659Ω	0.088%	10mA	2	283.724Ωm
10	1.00	156	2.0409Ω	0.282%	10mA	2	318.38Ωm
10	2.50	58.9	6.4007Ω	0.163%	10mA	2	377.001Ωm
15	2.50	137	3.7405Ω	0.406%	10mA	2	512.449Ωm
20	2.50	245	2.6944Ω	0.111%	10mA	2	660.128Ωm
30	2.50	562	1.8348Ω	0.255%	10mA	2	1031.158Ωm
40	2.50	1001	1.4961Ω	0.649%	5mA	2	1497.596Ωm
40	7.50	323	5.6418Ω	0.253%	5mA	2	1822.301Ωm
50	7.50	512	4.6111Ω	0.804%	10mA	2	2360.883Ωm
60	7.50	742	4.1481Ω	0.034%	10mA	2	3077.890Ωm
70	7.50	1014	FENCEWORK	BARRIER	FENCEWORK	BARRIER	FENCEWORK
80	7.50	1329	FENCEWORK	BARRIER	FENCEWORK	BARRIER	FENCEWORK
80	15.00	647	FENCEWORK	BARRIER	FENCEWORK	BARRIER	FENCEWORK
90	15.00	825	FENCEWORK	BARRIER	FENCEWORK	BARRIER	FENCEWORK
100	15.00	1024	FENCEWORK	BARRIER	FENCEWORK	BARRIER	FENCEWORK

The field curves for Tables 19 - 21 were obtained by plotting the apparent resistivity against half-current electrode spacing by means of the WinResist® plot, see Figs 3 - 5; the initial outputs were the "default" graphs. These were further smoothed by iterations which were done in layers, thus resulting in final "modelled" outputs. The smoothed graphs are those that have connections to all the plotted points on the graph.



No	Res	Thick	Depth
1	931.7	0.4	0.4
2	99.4	1.1	1.5
3	3218.1	5.4	6.9
4	219.5	12.6	19.6
5	13796.7	-.-	-.-

* RMS on smoothed data

Fig.3. WinResist® plot for Table 19

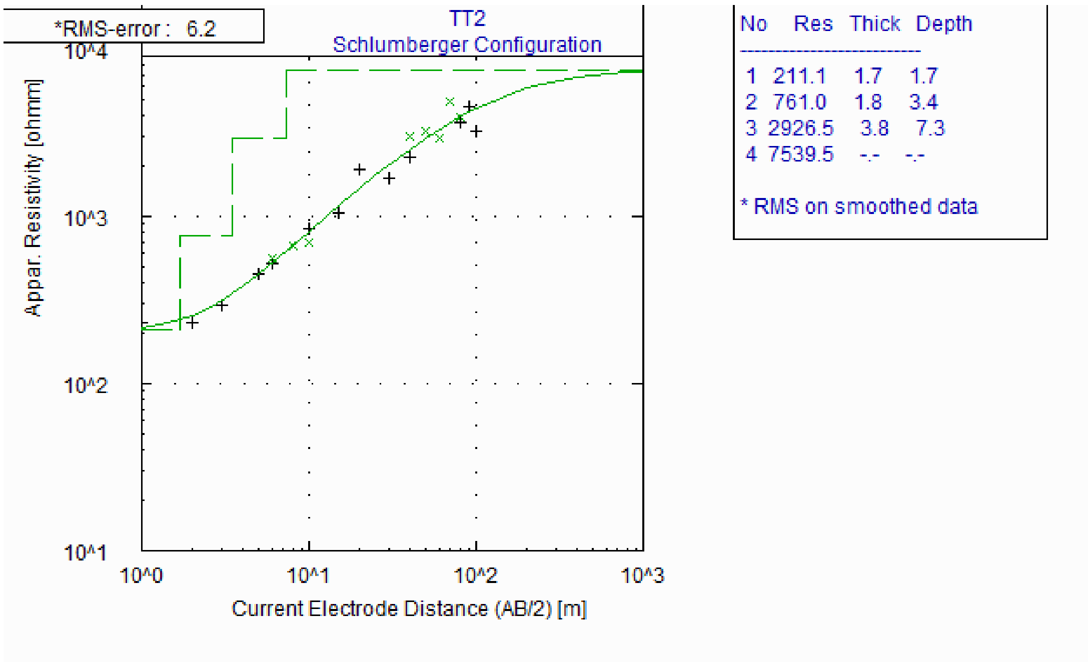


Fig.4. WinResist® plot for Table 20

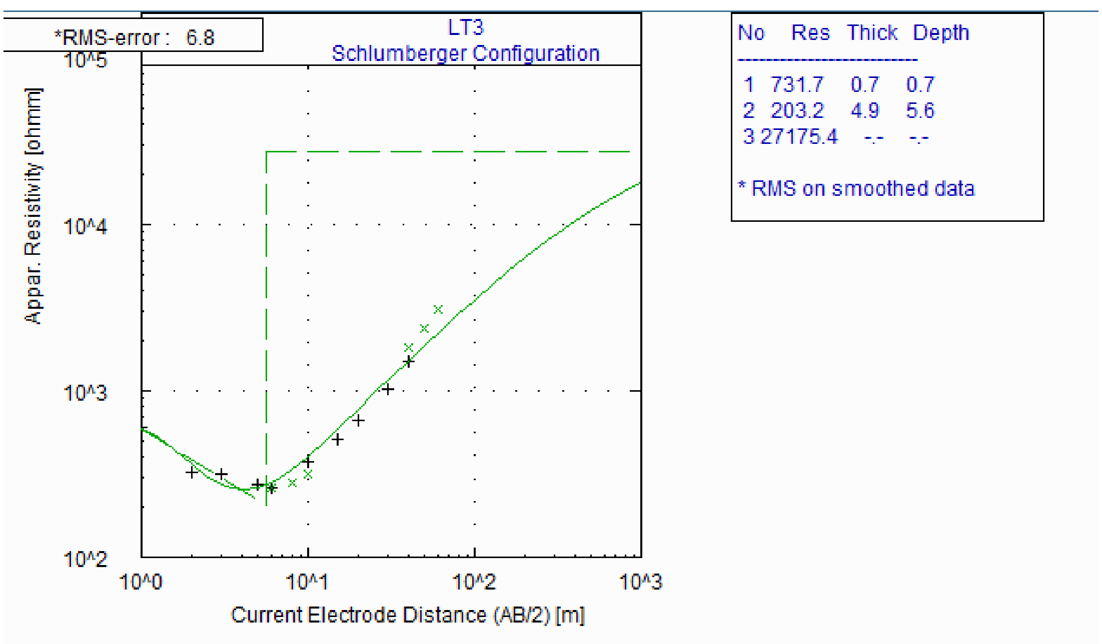


Fig.5. WinResist® plot for Table 21

5.0 Discussion and Conclusion

5.1 The Continuous Variation of Resistivity with Depth: A continuous variation of resistivity with depth curve is easily derived from multilayer step-function curve by drawing a curve that passes through the logarithmic midpoint of each vertical and horizontal line on the multilayer step function model. In view of the fact that the layer depths are logarithmically closely-shaped, the derived continuous variation of resistivity with depth model is equivalent to the original model (Zohdy, 1989); for the present context, see Figs 3 - 5.

5.2 Vertical Electrical Depth Sounding Result: The derived continuous variation of resistivity with depth model indicates that a five-layer sequence was identified for VES LT4-1 (Fig.3), a four-layer sequence for LT2-2 (Fig.4), and a three-layer sequence for TT4-4 (Fig.5). The authors have based their interpretation for aquifer prospect at the three VES locations on an informal and fairly successful empirical rule to determine the likely presence of groundwater in the Minna basement complex geological province; the authors have taken much liberty here to call this empirical rule "Olasehinde Protocol." Based on this standardization, which states that resistivity values between 180Ωm and 250Ωm at the 20m to 25m depth mark is indicative of possible groundwater prospect, the survey crew observed from the three log-log plots presented that high resistivities predominate in the desired "aquiferous" zones at each of the VES points. It is instructive to point out here that even though the resistivities of rocks do not depend on water content only, this informal law is an enunciated "rule-of-thumb" that serves as an effective guide to groundwater prospectors out in the field (Olasehinde, personal communication). Thus, the survey crew posits that the prospect for groundwater yield at the points surveyed is very poor indeed; therefore, the crew would not recommend that a borehole be sunk at the property surveyed based on this study.

References

Ako, B.J. and Olorunfemi, M.O. (1982). Geoelectric survey for groundwater in the New Basalt of Vom, Plateau State. *Journal of Mining and Geology*, 8(2), 273-280.

Bonde, D.S. (1997). *Geoelectrical survey for groundwater resources in Egba, Shiroro Local Government Area, Niger State*, M.Tech. dissertation, Federal University of Technology, Minna.

Dangana, L.M. 2002. *Electrical resistivity survey of Tunga Kawo Dam, Wushishi,* *Niger State, Nigeria*, M.Tech. dissertation, Federal University of Technology, Minna.

Gana, J.S. 1995. *Geophysical exploration for groundwater in Yakila, Niger State*, M.Tech. dissertation, Federal University of Technology, Minna.

Jonah, S.A., James, G.O., Adeku, D.E., Ahmed, F., Alhassan, A., Hamza, S., Igbideba, O. I., Kwaghhua, F.I., Kyari, M., Macaulay, V. F., Olarewaju, S.I., Onyeodili, G., Popoola, G.B., Sofeso, O.A., Switzer, F. K., and Umoh, U. E. (2013). A survey for groundwater at a lot at the Dan Zaria Academic Estate, Federal University of Technology, Minna, Central Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*, **9**(**3**), 26 - 38.

Kearey, P. and and Brooks, M. 1988. *Fundamentals of Geophysics*, Cambribge University Press, Cambridge.

Okwueze, E.E. and Ezeanyi, V. 1985. The vertical electrical sounding (VES) method in laterite region and iron-rich area. Journal of Mining and Geology, 22 (1 and 2), 173-280.

Okwueze, E.E., Ebeniro, J.O., and Mbogning, M. 1981. The geoelectric structure of Late Nyos Dam, Cameroon, and its geoelectric implication. *Journal of Mining and Geology*, 8(2), 273-280.

Olorunfemi, M.O. and Fasuyi, S. A. 1993. Aquifer types and the geoelectric/hydrogeological characteristics of part of the Central Basement Terrain of Nigeria (Niger State). Journal of African Earth Sciences, 16(3), 309-317.

Olorunfemi, M.O. and Okhue, E.T. 1992. Hydrogeological and geological significance of geoelectric survey at Ile-Ife. *Nigerian Journal of Mining and Geology*, 28(2), 221-228.

Parasnis, D.S. 1988. *Principles of Applied Geophysics (4ed.)*, Chapman and Hall, London.

Zohdy, A.A.R. (1989). A new method for the automatic interpretation of Schlumberger and Wenner sounding curves. *Geophysics*, 54(2), 245-253.