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A wetland lot geoelectrical investigation for groundwater development at Bosso Estate, Minna, Central Nigeria

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Abstract

In order to carry out a geoelectrical investigation for groundwater development at a wetland lot at the Bosso Estate, Minna, Central Nigeria, the target objective (i.e. client's property) was visually reconnoitered; the extent, local geology, and preferred traverse directions of the area of survey were noted. The survey crew proposed a southwest-southeast profile to be the longitudinal traverse (LT) at 10m-separation between survey stations and 10m-separation between profile lines for the initial low-resistance reconnaissance scheme to a depth of 15m. Thence, detailed Vertical Electrical Sounding (VES) survey would be conducted for locations of "low-ohmic interest" to a depth of 70m. In essence, this exercise was treated as a blind geoelectrical prospecting by the team members because the client had exclusive possession of the result of an earlier, independent survey conducted for aquifer prospect at this lot. On-the-field inspection of the CST dataset revealed that the lowest resistance value of 2.1919Ω was obtained at "LT3-5" corresponding to the following geographic co-ordinate: $09^0$39'15.8", $006^0$30'46.6"; an arbitrary field benchmark of <3Ω was selected for this fieldwork. The survey crew based their interpretation for aquifer prospect at the VES locations on an informal and fairly successful empirical rule to determine the likely presence of groundwater in the basement complex geological province, called the "Olasehinde Protocol." Based on this standardization, the survey crew observed the prospect for groundwater yield is encouraging at location "LT3-5." This location is actually circa 5-6m displaced from the position of the initial survey carried out two years before as verified by the client. The survey party recommends that a borehole be sunk at this location, down to an effective depth of 50m. Really, beyond the 20m depth mark, the resistivity varies smoothly down to the total depth (TD) surveyed.

Keywords: Traverse; groundwater; geoelectrical; resistivity

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 wetland patch at the Bosso Estate, Minna, measuring 40m by 20m, devoted to wet-season paddy rice cultivation; no prominent outcrop can be seen on the surface. Interestingly, as was the case with Jonah et al (2014A), 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 wetland lot just past the first professors' quarter, Ar-Rayan School Road, Bosso Estate, Minna, Niger State, Central Nigeria, all the CST locations are shown as blue dots and all the VES locations are shown as red dots. On this map, the Ar-Rayan School Road can be made out as well as the second professors' quarter seen as the built-up most northwesterly segment of the map in alignment with the Ar-Rayan School Road. On this map, also, the linear CST1s and CST3s can be made out easily, seen located on a small drainage plain. The first professors' quarter is 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.

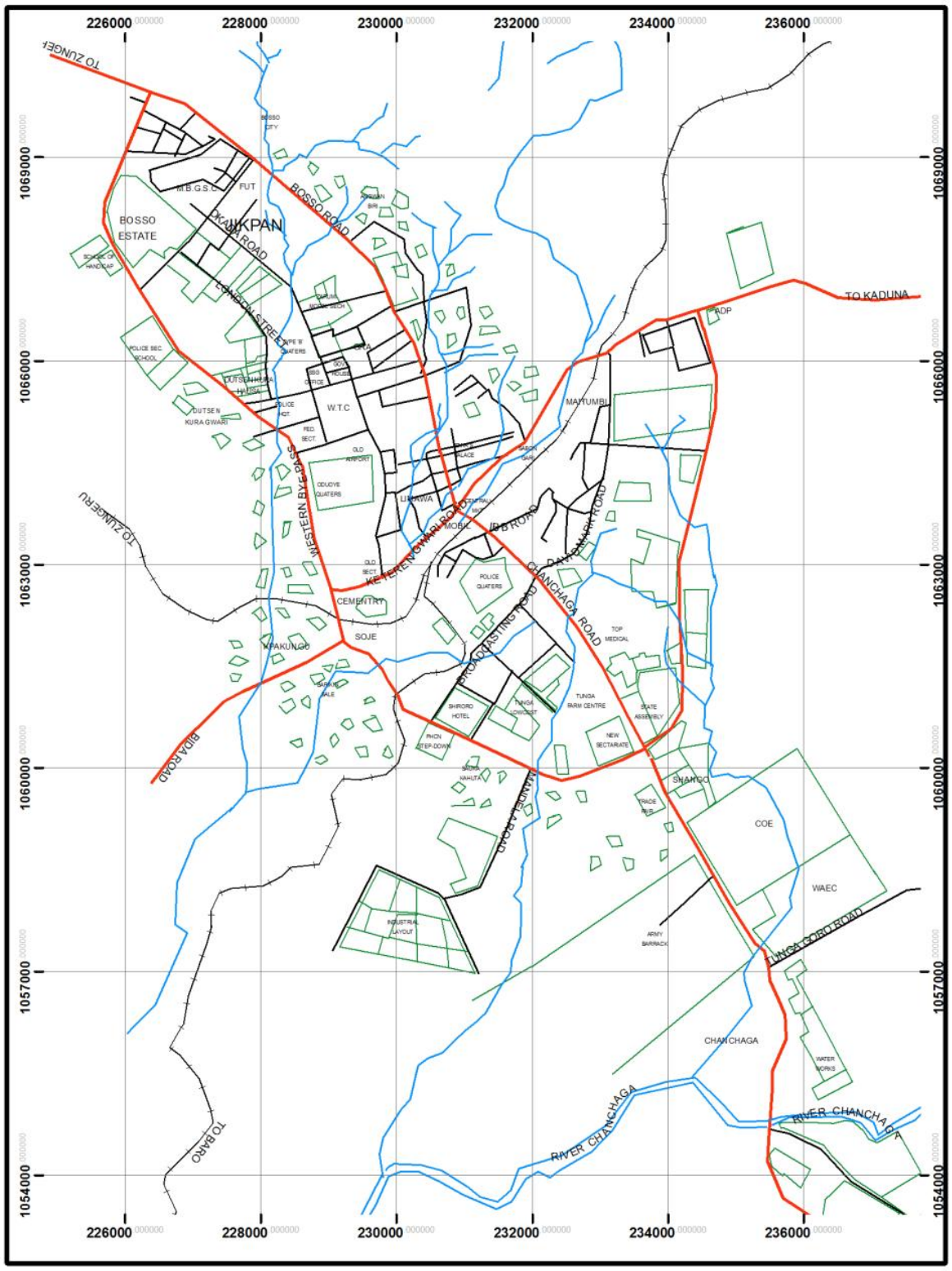

Fig.1. Map of Minna

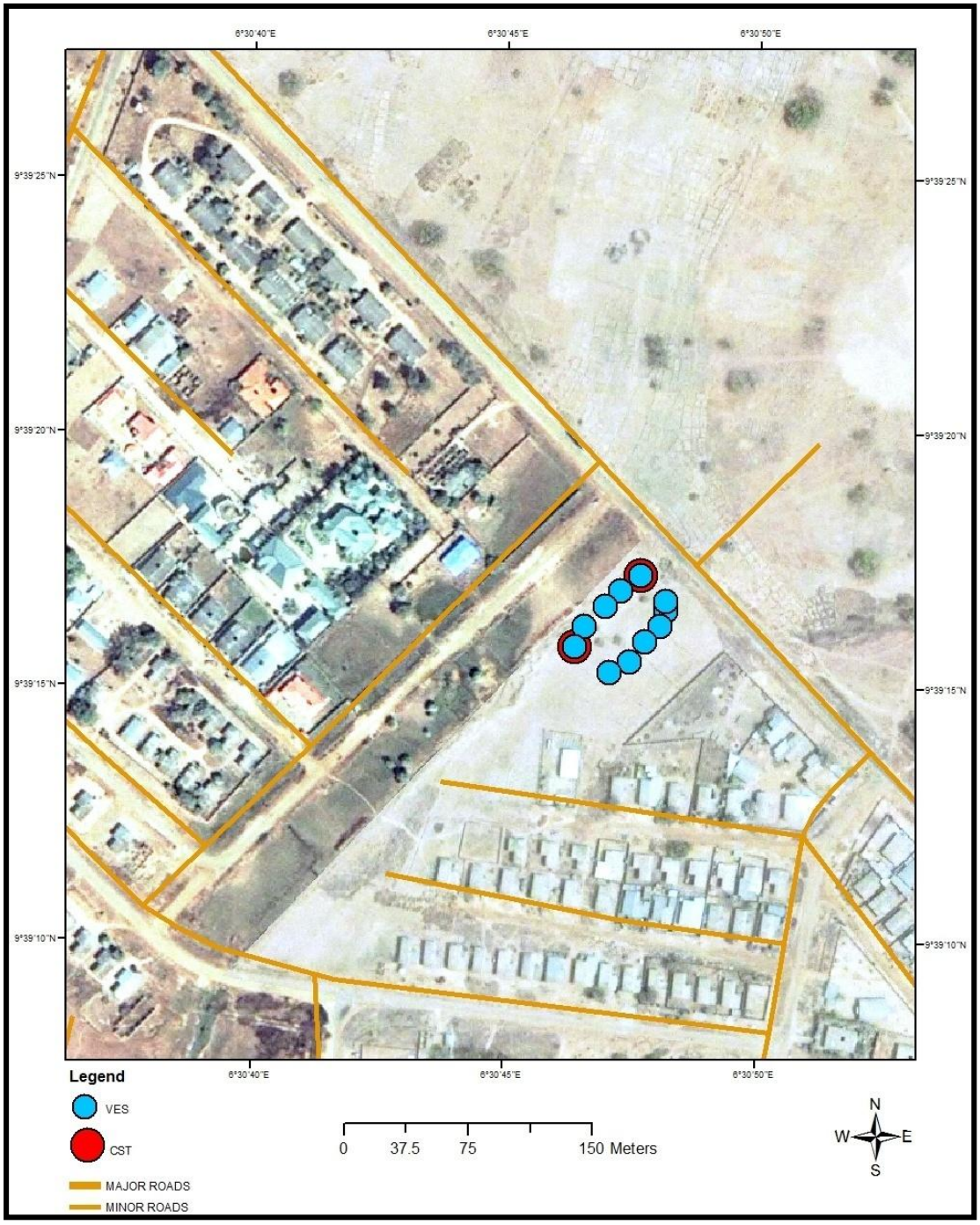

Fig.2. Specific study area at the Ahmadu Bahago Secundary School neighbourhood, (All CST locations are shown as blue dots and the two VES locations are shown as red dots, coincident with two CST positions.)

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, though: 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.

In fidelity to the "conventional" approach, Jonah et al (2014A) prospected for aquifer at a lot located on a granitic knoll in Minna. 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 Constant Separation Traversing (CST) 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.

A third approach in the series of surveys undertaken by Jonah et al (2014B) was the "No CST" format, informally described as "not carrying out any reconnaissance survey in order to determine the lateral variation of resistivity." For this field technique, the VES survey to the 100m-depth is carried out for each of the selected locations. The survey crew adopted this method to prospect for the suitable location for a desired borehole at a built-up compound of an enclosed bungalow with a self-contained sewage system; only the three corners of the brick fence away from the corner where the cesspool was situated defined in one north-south (longitudinal traverse, LT) and two east-west (transverse traverse, TT) modes were suitable for this survey. Since the client desired that a borehole must be drilled at her property, the survey crew considered it inexpedient to do a CST survey, hence the "No CST" format. The derived continuous variation of resistivity with depth model indicated that a four-layer sequence was identified for VES TT1, a four-layer sequence for VES LT1, and a three-layer sequence for VES TT2. The authors based their interpretation for aquifer prospect at the three VES locations on a combination of informal and fairly successful dual empirical rules to determine the likely presence of groundwater in the basement complex geological province. Based on these rules, TT1 indicates the best prospect for groundwater yield in the area of survey with good showings from the 30m-depth mark down to the 50m-depth; LT1 could be discounted in water yield terms with respect to TT1, and TT2 satisfies the criteria at the 20m-depth mark and discontinuously still, at the 50m-depth mark before a spike in "ohmic" values. Also, it was observed that the 50m-depth mark for TT1 and TT2 correlate very well as a prospective aquifer zone. If drilling must be done at all, then it was recommended that point TT1 be considered a good prospect for groundwater yield over the 20-m "yield window." Because of the smoothly-changing continuum of resistivity values down to the 100m-depth mark, it was recommended that drilling should be terminated at this maximum or total depth (TD) of survey in order to tap into the fractured basement at this TD. Incidentally, TT1 was upslope of the sewer pit, which was a plus for this VES station over the possible prospect of TT2.

2.2 Data Collection Procedure: Even though the configuration of the wetland lot is rectangular, the lot's length does not trend in a north-south line (i.e. the longitudinal traverse) and, of course, the lot's breadth does not trend in an east-west line (i.e. the transverse traverse). Thus, the survey crew proposed a southwest-southeast profile to be the longitudinal traverse (LT) at 10m-separation between survey stations and 10m-separation between profile lines for the initial low-resistance reconnaissance scheme to a depth of 15m, see Fig.2. The horizontal profiling depth of 15m depth was fixed because it was observed that, on the property, a couple of hand-dug wells of less than this 15m-depth mark were still recharging to ensure that they were sources of low-quality water for the Bosso Estate community water vendors; the thinking was that if these wells were recharging at less than 15m-depth, then determining the lateral variation of resistivity at this depth would guide the team members in choosing the locations of the VES points. CST measurements were recorded for LT1-2 to LT1-5; a paved road barrier excluded measurement at LT1-1. Only CST LT2-1 was recorded because of the client's desire to avoid potential borehole development at the dead-centre of his lot; LT2-1 was at the frontage sector of the client's lot. Thus CST LT3-1 to LT3-5 was duly completed; this explains the CST format seen in Fig.2. The ABEM Terrameter SAS 4000 was employed for this survey.

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 eleven CST stations are shown in Tables 1-11.

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	Cool and dusty
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$39′16.5″ **E:** $006^0$30′48.4″	289m	James	James
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
13th February 2014	=======	LT1-1	Garmin *etrex*	**Not measured because of paved road barrier**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	=======	=======	=======	=======

Table 2. LT1-2 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Cool and dusty
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$39’16.2″ **E:** $006^0$30’48.3″	280m	Adeku	Adeku
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
13th February 2014	5:02p.m	LT1-2	Garmin *etrex*	**3.5970 Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	=======	10mA	=======	=======

Table 3. LT1-3 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Cool and dusty
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$39'15.9″ **E:** $006^0$30'48.0″	278m	Kwaghhua	Kwaghhua
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
13th February 2014	5:12p.m	LT1-3	Garmin *etrex*	**5.856 Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	=======	10mA	=======	=======

Table 4. LT1-4 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Cool and dusty
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$39'15.5″ **E:** $006^0$30'47.7″	278m	Sofeso	Sofeso
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
13th February 2014	5:25p.m	LT1-4	Garmin *etrex*	**2.4600 Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	=======	10mA	=======	=======

Table 5. LT1-5 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Cool and dusty
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$39'15.3″ **E:** $006^0$30'47.3″	278m	James	James
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
13th February 2014	5:35p.m	LT1-5	Garmin *etrex*	**5.2103 Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	=======	10mA	=======	=======

Table 6. LT2-1 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Cool and dusty
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$39'16.7″ **E:** $006^0$30'48.4″	278m	Adeku	Adeku
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
13th February 2014	5:46p.m	LT2-1	Garmin *etrex*	**6.8116 Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	=======	10mA	=======	=======

Table 7. LT3-1 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Cool and dusty
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$39'17.2″ **E:** $006^0$30'47.9″	279m	Kwaghhua	Kwaghhua
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
13th February 2014	5:58p.m	LT3-1	Garmin *etrex*	**5.6846 Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	=======	10mA	=======	=======

Table 8. LT3-2 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Cool and dusty
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$39'16.9″ **E:** $006^0$30'47.5″	279m	Sofeso	Sofeso
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
13th February 2014	6:19p.m	LT3-2	Garmin *etrex*	**3.9414 Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	=======	10mA	=======	=======

Table 9. LT3-3 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Cool and dusty
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$39'16.6″ **E:** $006^0$30'47.2″	278m	James	James
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
13th February 2014	6:32p.m	LT3-3	Garmin *etrex*	**3.6020Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	=======	10mA	=======	=======

Table 10. LT3-4 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Cool and dusty
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$39'16.2″ **E:** $006^0$30'46.8″	277m	Adeku	Adeku
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
13th February 2014	6:44p.m	LT3-4	Garmin *etrex*	**3.3863Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	=======	2mA	=======	=======

Table 11. LT3-5 CST at 15m

AB/2 = 15m ELECTRODE SEPARATION = 10m

TYPE OF SURVEY	**MODE**	**ARRAY**	**PLACE**	**WEATHER**
Resistivity	Constant Separation Traversing	Wenner	Minna	Cool
EQUIPMENT	**LOCATION**	**ELEVATION**	**OPERATOR**	**RECORDER**
ABEM Terrameter SAS 4000	**N:** $09^0$39'15.8″ **E:** $006^0$30'46.6″	279m	Kwaghhua	Kwaghhua
DATE	**TIME**	**LONGITUDINAL TRAVERSE DESIGNATION**	**GPS UNIT**	**RESISTANCE**
13th February 2014	6:57p.m	LT3-5	Garmin *etrex*	**2.1919Ω**
GEOMETRICAL FACTOR, K (2πa)	**STANDARD DEVIATION**	**CURRENT**	**STACKS**	=======
62.84	=======	5mA	=======	=======

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 eleven CST stations of Tables 1-11. On-the-field inspection of the CST dataset revealed that the lowest resistance value of 2.1919Ω was obtained at "LT3-5" (Table 11) corresponding to the following geographic co-ordinate: $09^0$39′15.8″, $006^0$30′46.6″; the next low–resistance point (an arbitrary field benchmark of <3Ω was selected) of 2.4600Ω was observed at the geographic co-ordinate of $09^0$39′15.3′, $006^0$30′47.7′, i.e. "LT1-4," see Table 4. Because of the presence of a hand-dug well just adjacent to LT3-1, this location was also earmarked for "deep-probe" VES investigation even though the CST ohmic value was 5.6846Ω, Table 7.

4.2 Final Survey in VES Mode: The VES survey was carried out for stations "LT3-1" and "LT3-5." Equipment glitch precluded a full survey at "LT1-4;" incidentally, this location would present logistical challenge with respect to eventual borehole development because it is just on the fringe of a perimeter fence built by the client's neighbour. The result of the VES survey for "LT3-1" and "LT3-5" is presented in Tables 12 and 13, and their corresponding log-log plots are shown in Figs 3 and 4.

Table 12. Deep-Probe Geoelectrical Data Record Sheet for LT3-1

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

PLACE: Minna **WEATHER:** Cool and dusty **EQUIPMENT:** ABEM Terrameter SAS 4000

LOCATION: (i) **N:** $09^0 39' 17.2''$ (ii) **E:** $006^0 30' 47.9''$ **ELEVATION:** 279m **DATE:** 14th Feb. 2014

AB/2	MN/2	GEOM. FACTOR, K	RESISTANCE	STANDARD DEVIATION	CURRENT (I)	STACKS	RESISTIVITY
1	.50	2.36	97.378Ω	========	10mA	=======	229.8121Ωm
2	.50	11.8	27.973Ω	========	10mA	=======	330.0814Ωm
3	.50	27.8	8.7385Ω	========	10mA	=======	242.9303Ωm
5	.50	77.8	2.2036Ω	========	10mA	=======	171.4401Ωm
6	.50	112	1.6321Ω	========	10mA	=======	182.7952Ωm
6	1.00	55	3.4642Ω	========	10mA	=======	190.531Ωm
8	1.00	99	2.4301Ω	========	10mA	=======	240.5799Ωm
10	1.00	156	1.9085Ω	========	10mA	=======	297.726Ωm
10	2.50	58.9	4.7682Ω	========	10mA	=======	280.8470Ωm
15	2.50	137	2.7179Ω	========	10mA	=======	372.3523Ωm
20	2.50	245	1.6243Ω	========	10mA	=======	397.9535Ωm
30	2.50	562	1.0762Ω	========	10mA	=======	604.8244Ωm
40	2.50	1001	780.43mΩ	========	10mA	=======	781.2104Ωm
40	7.50	323	2.1690Ω	========	10mA	=======	700.587Ωm
50	7.50	512	1.6869Ω	========	10mA	=======	863.6928Ωm
60	7.50	742	1.3091Ω	========	10mA	=======	971.3522Ωm
70	7.50	1014	1.1196Ω	========	10mA	=======	1135.2744Ωm
80	7.50	1329	========	========	========	=======	========
80	15.00	647	========	========	========	=======	========
90	15.00	825	========	========	========	=======	========
100	15.00	1024	========	========	========	=======	========

Table 13. Deep-Probe Geoelectrical Data Record Sheet for LT3-5

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

PLACE: Minna **WEATHER:** Cool and dusty **EQUIPMENT:** ABEM Terrameter SAS 4000

LOCATION: (i) **N:** $09^0 39' 15.8''$ (ii) **E:** $006^0 30' 46.6''$ **ELEVATION:** 279m **DATE:** 14th Feb. 2014

AB/ 2	MN/ 2	GEOM. FACTOR, K	RESISTANCE	STANDARD DEVIATION	CURRENT (I)	STACKS	RESISTIVITY
1	.50	2.36	501.78Ω	=======	5mA	=======	1184.2008Ωm
2	.50	11.8	47.678Ω	=======	5mA	=======	562.6004Ωm
3	.50	27.8	9.9289Ω	=======	5mA	=======	276.0234Ωm
5	.50	77.8	1.3367Ω	=======	10mA	=======	103.9965Ωm
6	.50	112	864.13mΩ	=======	10mA	=======	96.7826Ωm
6	1.00	55	1.9570Ω	=======	10mA	=======	107.635Ωm
8	1.00	99	1.3304Ω	=======	10mA	=======	131.7096Ωm
10	1.00	156	1.0612Ω	=======	10mA	=======	165.5472Ωm
10	2.50	58.9	2.4253Ω	=======	10mA	=======	142.8502Ωm
15	2.50	137	1.3280Ω	=======	10mA	=======	181.936Ωm
20	2.50	245	855.85mΩ	=======	10mA	=======	209.6833Ωm
30	2.50	562	684.8mΩ	=======	10mA	=======	384.858Ωm
40	2.50	1001	588.72mΩ	=======	10mA	=======	589.3087Ωm
40	7.50	323	1.6587Ω	=======	10mA	=======	535.7601Ωm
50	7.50	512	1.3169Ω	=======	10mA	=======	674.2528Ωm
60	7.50	742	965.88mΩ	=======	10mA	=======	716.6830Ωm
70	7.50	1014	1.0221Ω	=======	10mA	=======	1034.4094Ωm
80	7.50	1329	=======	=======	=======	=======	=======
80	15.00	647	=======	=======	=======	=======	=======
90	15.00	825	=======	=======	=======	=======	=======
100	15.00	1024	=======	=======	=======	=======	=======

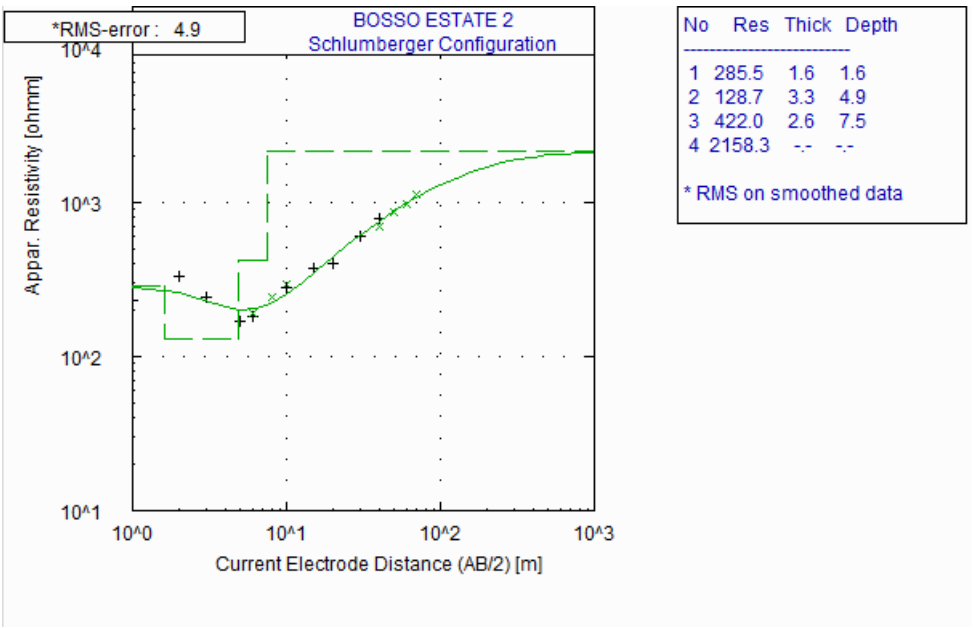

Fig. 3. WinResist® plot of Table 12 for "LT3-1."

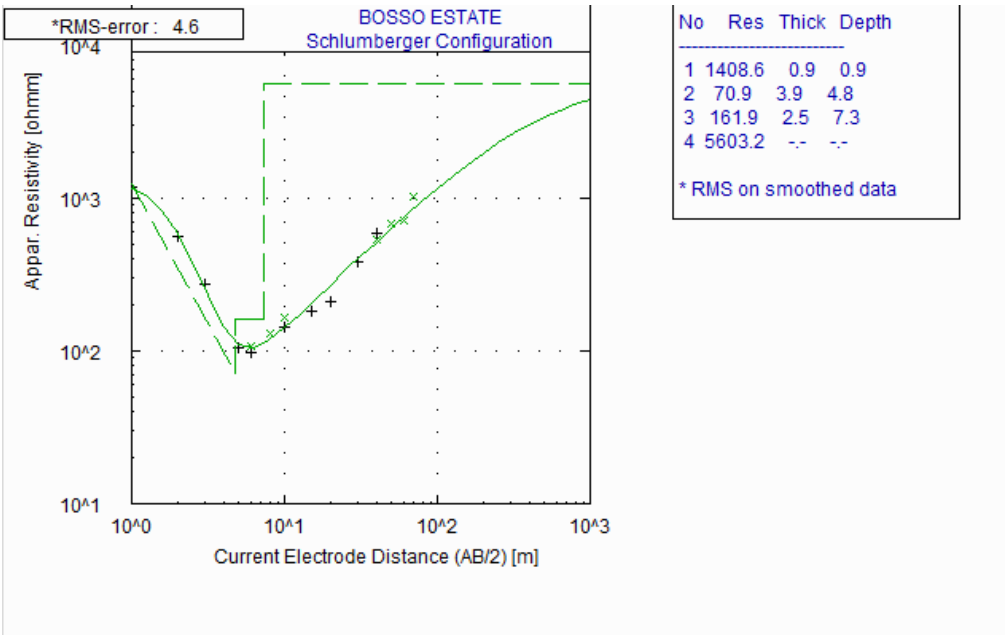

Fig. 4. WinResist® plot of Table 13 for "LT3-5."

5.0 Discussion, Conclusion, and Recommendation

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 and 4.

5.2 Vertical Electrical Depth Sounding Result: Each of the plots of Figs 3 and 4 indicates a four-layer sequence. The survey crew based their interpretation for aquifer prospect at the two VES locations on an informal and fairly successful empirical rule to determine the likely presence of groundwater in the basement complex geological province (Olasehinde, 1989; 1999). The survey crew has 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 that only location "LT3-5" meets this standard.

5.3 Conclusion: The prospect for groundwater yield is encouraging at location "LT3-5." This location is actually circa 5-6m displaced from the position of the initial survey carried out two years before as verified by the client (Prof. A. S. Ma'aji, personal communication). With the informal rule-of thumb of drill radius of 3m from a location's dead centre, this survey effectively corroborates the earlier one.

5.4 Recommendation: The survey party recommends that a borehole be sunk at location "LT3-5," down to an effective depth of 50m. Really, beyond the 20m depth mark, the resistivity varies smoothly down to the total depth (TD) surveyed.

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