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Pre-Drilling Geoelectrical Survey at a Built-up Compound at Barkin-Sale Ward, Minna, Niger State, Nigeria

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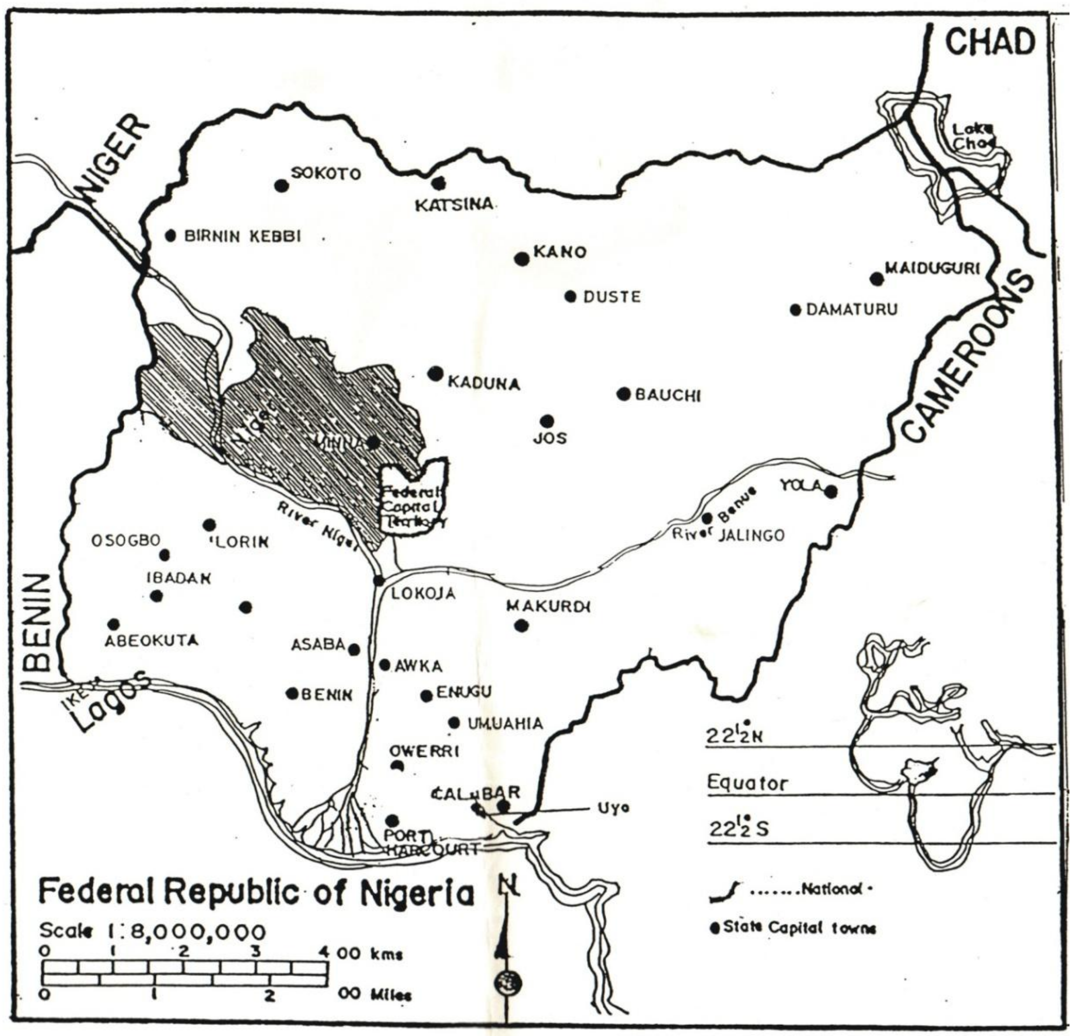
Abstract

The three corners of a brick fence enclosing a bungalow away from the corner where a cesspool was situated, defined in one north-south (longitudinal traverse, LT) and two east-west (transverse traverse, TT) modes, was selected for this survey. 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. Also, it is 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 is 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, 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 is upslope of the sewer pit, which is a plus for this VES station over the possible prospect of TT2.

Keywords: Pre-drilling, geoelectrical, built-up, aquifer, VES

Introduction

The built-up compound is an enclosed bungalow with a self-contained sewage system, measuring 22m by 12m. A very important consideration, at the outset, was the selection of locations far from the sewer pit for Vertical Electrical Sounding (VES) measurements: these locations were, appropriately, the three corners of the brick fence away from the corner where the cesspool was situated; the two south-facing frontage fence corners and a north rear fence corner. The three selected fence corners are identified by the geographic co-ordinates $9^0$35’20.8’’N; $6^0$31’30.5”E (hereby called transverse traverse number 1 or TT1), $9^0$35’20.8’’N; $6^0$31’30,1”E (hereby called longitudinal traverse number 1 or LT1), and $9^0$35’21.5’’N; $6^0$3130.1’”E (hereby called transverse traverse number 2 or TT2). Note that the longitudinal traverse designation is north-south trending VES survey and the transverse traverse designation is east-west trending VES survey. 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. The area of survey is situated on a slight hillock that gently slopes toward a stream bank about 150m away to the north. Observed on the surface are granitic outcrops with pegmatite intrusions. Hand-dug wells in the vicinity of the area of survey indicate the presence of weathered basement rocks at comparatively shallow depths (i.e. less than 20m). The Barkin-Sale Ward is an outlying (away from the city centre proper) administrative unit of Minna town, the capital of the state of Niger in central Nigeria. The map of Nigeria showing the position of Niger State is shown in Fig.1.



Niger State in the Context of the Federal Republic of Nigeria
(Source: AAP, Kaduna)

Fig.1. Map of Nigeria with Niger State shown shaded. (Source: Adesoye and Partners.)

On the map of Niger state, Fig.2, Minna is seen at the intersection of the $09^{0}37'$ latitude and the $006^{0}33'$ longitude lines, corresponding to the city centre proper. At the georeferenced locations of $9^{0}35'20.8''$N; $6^{0}31'30.5''$E, $9^{0}35'20.8''$N; $6^{0}31'30,1''$E, and $9^{0}35'21.5''$N; $6^{0}31'30.1'''$E for the three VES stations, the Barkin-Sale Ward is really to the southwest of the Minna city centre.

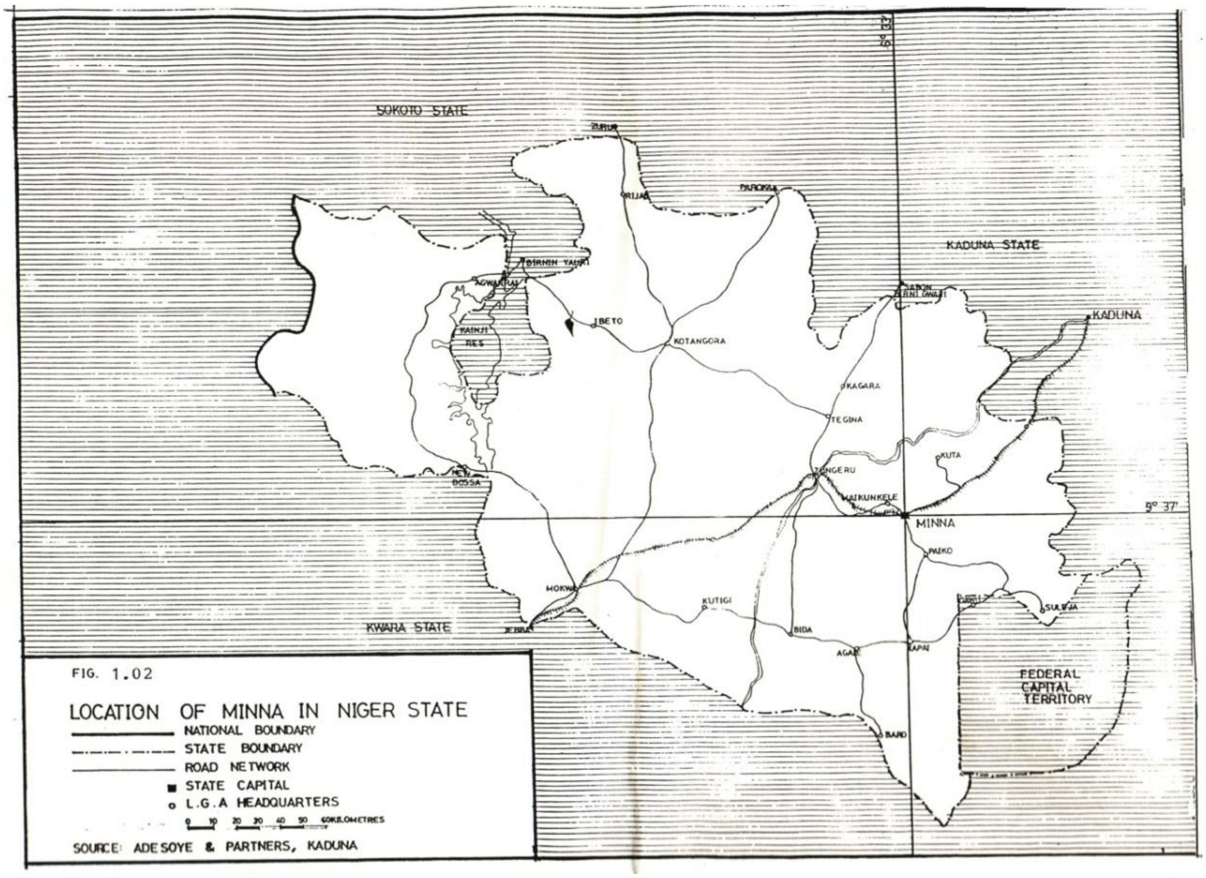


Fig.2. Map of Niger State showing the location of Minna

The aforementioned three VES stations, represented by three red dots, can be viewed on the satellite overlay map of Miina shown as Fig.3. Like was pointed out earlier, the built-up compound is an enclosed bungalow measuring 22m by 12m, as can be observed in Fig.3. Like was pointed out, too, the area of survey is situated on a slight hillock that gently slopes toward a stream bank about 150m away to the north: this fact can also be observed in Fig.3; the stream is the dark wiggle that snakes through Fig.3. On Fig.3 can also be seen, as a main red line, the roadway at Kpakungu (opposite the Justice Fati Lami Abubakar College of Arts and Islamic Legal Studies compound) that leads to the Gidan Kwano neighbourhood.

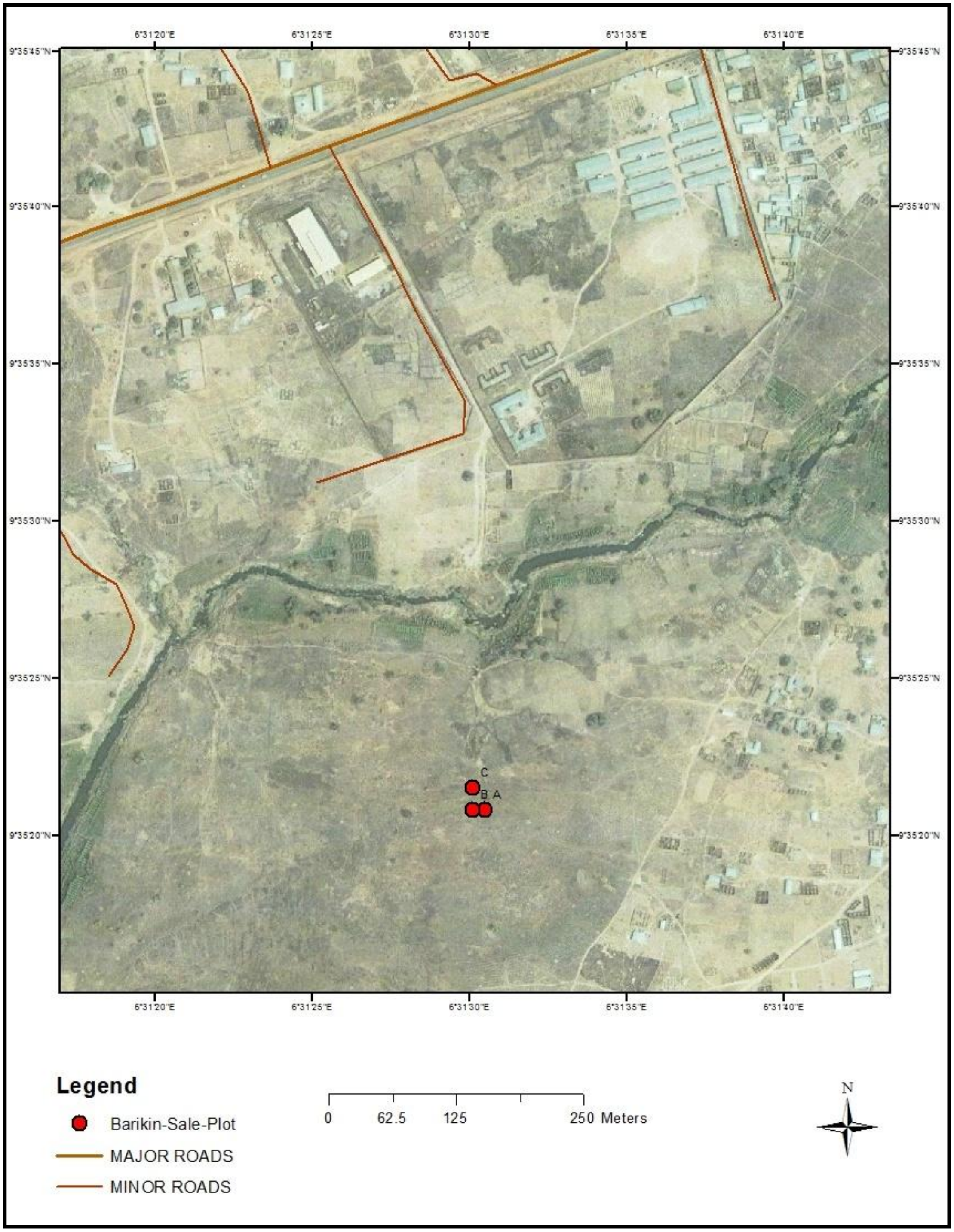


Fig.3. Satellite overlay map of Miina. (The red dots represent locations where VES survey was undertaken.)

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. Particular emphasis was placed on the accurate value of georeferencing of survey stations because, only then, could independent verification of the field data be assured. Jonah et al (2013A; 2013B; 2013C; 2013D; 2013E; 2011A; 2011B; 2011C; 2011D) have all argued in favour of georeferencing field dataset and their concomitant tie-in to their specific GIS database.

The Geoelectric Survey

The Method Employed: The geophysical work carried out here is based on electrical resistivity survey using 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 (2013F) 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.

In fidelity to the “conventional” approach, Jonah *et al.* (2013G) 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.

Data Collection

Data collection within the walled compound [exactly in the shape of a rectangle that may easily be defined by a smooth georeferenced signature of its A, B, C, D points (facing south, in the direction of the frontage of the building), viz: 9^{0}35’20.8’’N; 6^{0}31’30.1”E, 9^{0}35’20.8’’N; 6^{0}31’30.5”E, 9^{0}35’21.5’’N: 6^{0}31’30.5”E, 9^{0}35’21.5’’N; 6^{0}31’30.1’”E] posed a particular logistic challenge because the two-bedroom bungalow and sewer tank occupied nearly all the available space. Thus, the survey crew designated the three corners of the brick fence away from the corner where the cesspool was located as desired stations for VES surveys, terminating at the 100m-depth mark in one LT and two TT modes. TT1 is at the extreme left-hand corner (i.e. east) of the frontage whilst LT1 is at the extreme right-hand corner (i.e. west) of the frontage; TT2 is the northernmost right-hand corner of the lot under investigation. The VES survey was initiated and completed on a sunny March day. The ABEM Terrameter SAS 4000 was employed for this survey.

Data Presentation

The VES LT and VES TT values at the 100m-depth (“deep-probe”) are shown in Tables 1-3. The tabular mode of presentation shown here is a highly simplified format that readily summarizes the gamut of information displayed by the ABEM Terrameter SAS 4000. Even though the field parameters for “standard deviation,” “current,” and “stacks” are effectively redundant (ABEM information desk, personal communication), their inclusion in the table and recording their values where possible are required for field visual quality control purposes only. Note here that the value of a particular resistivity is:

resistivity = resistance x geometric factor, K

The field curves for Tables 1 - 3 were obtained by plotting the apparent resistivity against half-current electrode spacing by means of the WinResist® plot; see Figs 4-6; 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.

Table 1. Deep-Probe Geoelectrical Data Record Sheet for TT1

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

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

LOCATION: (i) **N:** 09^{0}35'20.8'' (ii) **E:** 006^{0}31'30.5" **ELEVATION:** 211m **DATE:** 13th March 2013

AB/2	MN/2	GEOM. FACTOR, K	RESISTANCE	STANDARD DEVIATION	CURRENT (I)	STACKS	RESISTIVITY
1	.50	2.36	40.276Ω	**REDUNDANT**	**INFO**	**COLUMN**	95.0514Ωm
2	.50	11.8	17.406Ω	**FOR**	**ABEM**	**TERRAMETER**	205.3908Ωm
3	.50	27.8	846.51mΩ	**INFO**	**NOT**	**RECORDED**	23.5330Ωm
5	.50	77.8	1.0692Ω	**REDUNDANT**	**INFO**	**COLUMN**	83.1838Ωm
6	.50	112	3.4650Ω	**FOR**	**ABEM**	**TERRAMETER**	388.080Ωm
6	1.00	55	824.96mΩ	**INFO**	**NOT**	**RECORDED**	45.3728Ωm
8	1.00	99	394.08mΩ	**REDUNDANT**	**INFO**	**COLUMN**	39.0139Ωm
10	1.00	156	426.39mΩ	**FOR**	**ABEM**	**TERRAMETER**	66.5168Ωm
10	2.50	58.9	1.1429Ω	**INFO**	**NOT**	**RECORDED**	67.3168Ωm
15	2.50	137	615.50mΩ	**REDUNDANT**	**INFO**	**COLUMN**	84.3235Ωm
20	2.50	245	283.34mΩ	**FOR**	**ABEM**	**TERRAMETER**	69.4183Ωm
30	2.50	562	563.40mΩ	**INFO**	**NOT**	**RECORDED**	316.6308Ωm
40	2.50	1001	109.52mΩ	**REDUNDANT**	**INFO**	**COLUMN**	109.6295Ωm
40	7.50	323	729.18mΩ	**FOR**	**ABEM**	**TERRAMETER**	235.5251Ωm
50	7.50	512	403.42 mΩ	**INFO**	**NOT**	**RECORDED**	206.550Ωm
60	7.50	742	472.00 mΩ	**REDUNDANT**	**INFO**	**COLUMN**	350.224Ωm
70	7.50	1014	357.02 mΩ	**FOR**	**ABEM**	**TERRAMETER**	362.0132Ωm
80	7.50	1329	334.84mΩ	**INFO**	**NOT**	**RECORDED**	445.0023Ωm
80	15.00	647	754.86mΩ	**REDUNDANT**	**INFO**	**COLUMN**	488.0023Ωm
90	15.00	825	631.43mΩ	**FOR**	**ABEM**	**TERRAMETER**	520.9297Ωm
100	15.00	1024	603.71mΩ	**INFO**	**NOT**	**RECORDED**	618.1990Ωm

Table 2. Deep-Probe Geoelectrical Data Record Sheet for LT1

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

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

LOCATION: (i) **N:** 09^{0}35’20.8’’ (ii) **E:** 006^{0}31’30.1” **ELEVATION:** 225m **DATE:** 13th March 2013

AB/2	MN/2	GEOM. FACTOR, K	RESISTANCE	STANDARD DEVIATION	CURRENT (I)	STACKS	RESISTIVITY
1	.50	2.36	126.72Ω	**REDUNDANT**	**INFO**	**COLUMN**	299.0592Ωm
2	.50	11.8	10.660Ω	**FOR**	**ABEM**	**TERRAMETER**	125.7880Ωm
3	.50	27.8	647.45mΩ	**INFO**	**NOT**	**RECORDED**	19.9991Ωm
5	.50	77.8	1.1187Ω	**REDUNDANT**	**INFO**	**COLUMN**	87.0349Ωm
6	.50	112	769.37mΩ	**FOR**	**ABEM**	**TERRAMETER**	86.1694Ωm
6	1.00	55	1.4602Ω	**INFO**	**NOT**	**RECORDED**	80.3110Ωm
8	1.00	99	968.58mΩ	**REDUNDANT**	**INFO**	**COLUMN**	95.8894Ωm
10	1.00	156	680.02mΩ	**FOR**	**ABEM**	**TERRAMETER**	106.0831Ωm
10	2.50	58.9	1.6911Ω	**INFO**	**NOT**	**RECORDED**	99.6058Ωm
15	2.50	137	909.62mΩ	**REDUNDANT**	**INFO**	**COLUMN**	124.6179Ωm
20	2.50	245	612.67mΩ	**FOR**	**ABEM**	**TERRAMETER**	150.1042Ωm
30	2.50	562	457.13mΩ	**INFO**	**NOT**	**RECORDED**	256.9071Ωm
40	2.50	1001	300.93mΩ	**REDUNDANT**	**INFO**	**COLUMN**	301.2309Ωm
40	7.50	323	789.69mΩ	**FOR**	**ABEM**	**TERRAMETER**	255.0699Ωm
50	7.50	512	554.70mΩ	**INFO**	**NOT**	**RECORDED**	284.0064Ωm
60	7.50	742	479.06mΩ	**REDUNDANT**	**INFO**	**COLUMN**	355.4625Ωm
70	7.50	1014	446.78mΩ	**FOR**	**ABEM**	**TERRAMETER**	453.0349Ωm
80	7.50	1329	206.75mΩ	**INFO**	**NOT**	**RECORDED**	274.1505Ωm
80	15.00	647	670.93mΩ	**REDUNDANT**	**INFO**	**COLUMN**	434.0917Ωm
90	15.00	825	697.91mΩ	**FOR**	**ABEM**	**TERRAMETER**	575.7758Ωm
100	15.00	1024	423.59mΩ	**INFO**	**NOT**	**RECORDED**	433.7562Ωm

Table 3. Deep-Probe Geoelectrical Data Record Sheet for TT2

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

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

LOCATION: (i) **N:** 09^{0}35'21.5'' (ii) **E:** 006^{0}31'30.1" **ELEVATION:** 224m **DATE:** 13th March 2013

AB/ 2	MN/ 2	GEOM. FACTOR, K	RESISTANCE	STANDARD DEVIATION	CURRENT (I)	STACKS	RESISTIVITY
1	.50	2.36	57.227Ω	**REDUNDANT**	**INFO**	**COLUMN**	135.0557Ωm
2	.50	11.8	6.8557Ω	**FOR**	**ABEM**	**TERRAMETER**	80.6973Ωm
3	.50	27.8	501.81mΩ	**INFO**	**NOT**	**RECORDED**	13.0503Ωm
5	.50	77.8	559.86mΩ	**REDUNDANT**	**INFO**	**COLUMN**	43.5571Ωm
6	.50	112	126.76mΩ	**FOR**	**ABEM**	**TERRAMETER**	9.8619Ωm
6	1.00	55	1.4337Ω	**INFO**	**NOT**	**RECORDED**	78.8535Ωm
8	1.00	99	1.0024Ω	**REDUNDANT**	**INFO**	**COLUMN**	99.2376Ωm
10	1.00	156	615.24mΩ	**FOR**	**ABEM**	**TERRAMETER**	95.5774Ωm
10	2.50	58.9	1.8256Ω	**INFO**	**NOT**	**RECORDED**	107.5278Ωm
15	2.50	137	957.68mΩ	**REDUNDANT**	**INFO**	**COLUMN**	131.2022Ωm
20	2.50	245	859.64mΩ	**FOR**	**ABEM**	**TERRAMETER**	210.6118Ωm
30	2.50	562	512.11mΩ	**INFO**	**NOT**	**RECORDED**	287.6058Ωm
40	2.50	1001	554.31mΩ	**REDUNDANT**	**INFO**	**COLUMN**	534.6643Ωm
40	7.50	323	2.0181Ω	**FOR**	**ABEM**	**TERRAMETER**	651.8463Ωm
50	7.50	512	385.44mΩ	**INFO**	**NOT**	**RECORDED**	197.3453Ωm
60	7.50	742	494.72mΩ	**REDUNDANT**	**INFO**	**COLUMN**	367.0822Ωm
70	7.50	1014	1.1509Ω	**FOR**	**ABEM**	**TERRAMETER**	1167.0126Ωm
80	7.50	1329	380.42mΩ	**INFO**	**NOT**	**RECORDED**	505.5782Ωm
80	15.00	647	888.87mΩ	**REDUNDANT**	**INFO**	**COLUMN**	575.0989Ωm
90	15.00	825	2.0802Ω	**FOR**	**ABEM**	**TERRAMETER**	1716.1650Ωm
100	15.00	1024	BATTERY	DOWN	BATTERY	DOWN	BATTERY

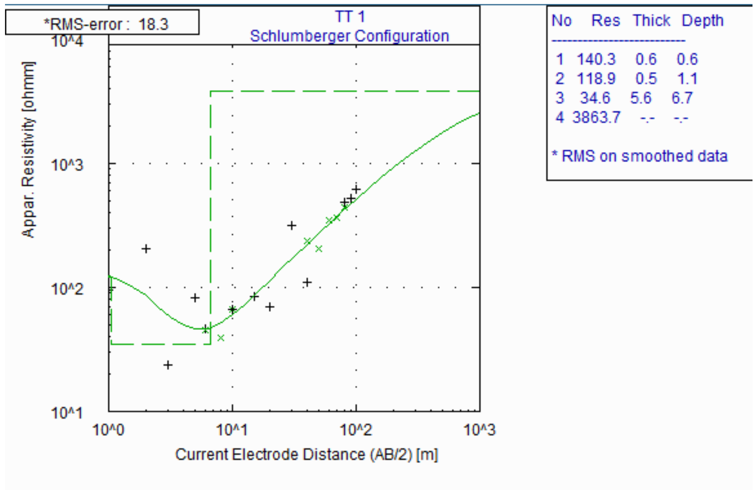


Fig.4. WinResist® plot for Table 1

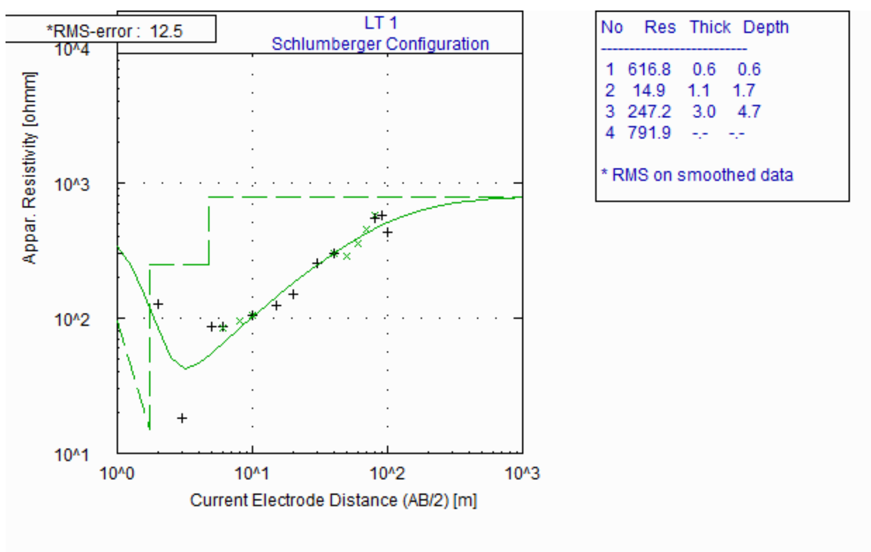


Fig.5. WinResist® plot for Table 2

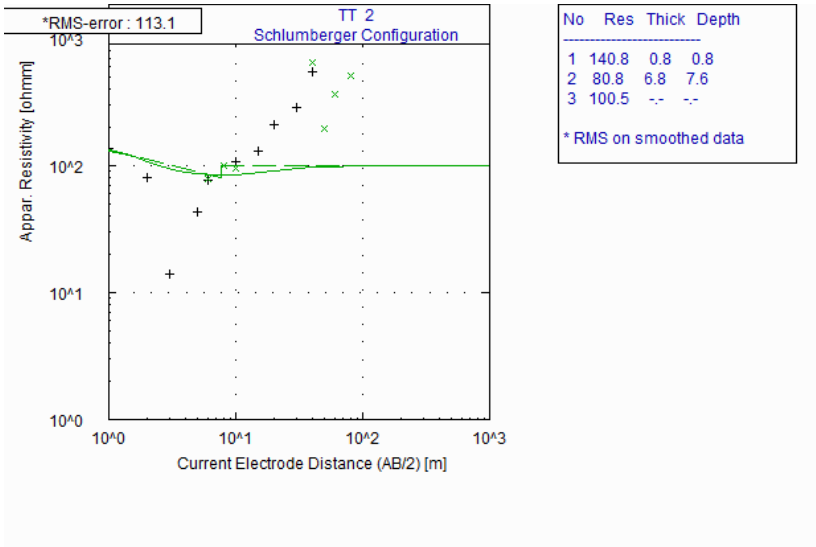


Fig.6. WinResist® plot for Table 3

Discussion, Conclusion, and Recommendation

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 4 - 6.

Vertical Electrical Depth Sounding Result: The derived continuous variation of resistivity with depth model indicates that a four-layer sequence was identified for VES TT1 (Fig.4), a four-layer sequence for VES LT1 (Fig.5), and a three-layer sequence for VES TT2 (Fig.6). The authors have 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 (Olasehinde, 1989; 1999). These rules are the “Geoexplore Empirical Standardization for Minna Area,” enunciated in Jonah et al (2003A) and the “Olasehinde Protocol,” enunciated in Jonah et al (2003B). The “Geoexplore Empirical Standardization for Minna Area” states that ohmic resistance values of less than or equal to 0.3Ω at the 20m depth or greater (or, in resistivity terms, between 200Ωm and 300Ωm at the 20m depth and less than 200Ωm at depths greater than 20m) is indicative of possible groundwater prospect. The "Olasehinde Protocol" states that resistivity values between 180Ωm and 250Ωm at the 20m to 25m depth mark is indicative of possible groundwater prospect. It is instructive to point out here that even though the resistivities of rocks do not depend on water content only, these informal laws are enunciated "rules-of-thumb" that serve as effective guides to groundwater prospectors out in the field. The bases of these protocols have been found to be effective over a two-decade period now for delineating approximate locations of groundwater yield (Olasehinde, personal communication; Muftau Jimoh, personal communication).

Based on the aforementioned protocols, 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 is observed that the 50m-depth mark for TT1 and TT2 correlate very well as a prospective aquifer zone.

Recommendation

If drilling must be done at all, then it is 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, 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 is upslope of the sewer pit, which is a plus for this VES station over the possible prospect of TT2.

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., Akpan, E. U., Bakara, I. U., Tanimowo, B., Abdullahi, B., Nwachukwu, E. I., Maishanu, I. H., Dania, R., Ezemonye, C.V., Fanisi, O., Ejiga, U., Benu, I.S., Banjo, G. Pius, A., Okunola, I.A., Jimoh, M.O., Amadi, A.N. and Ejepu, J.S. (2013D). Geospatial analysis and Geographic Information System (GIS) mapping of a greenhouse gas at Minna, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*, **9**(**3**), 69 – 81.

Jonah, S.A. and Ayofe, L.F. (2013B). Creation of a Geographic Information System for Minna, Niger State, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*: **Accepted for publication.**

Jonah, S.A. and Bawa, S.C. (2013C). Measurements of the levels of environmental noise at major stalling traffic points in Minna, Niger State, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*: **Accepted for publication.**

Jonah, S.A. and Duromola, S.A. (2013A). Determination of concentration of sulphur dioxide at major stalling traffic points in Minna, Niger State, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*: **Accepted for publication**.

Jonah, S.A. and Jimoh, M.O. (2013E). Production of a topographic map and the creation of a six-layer Geographic Information System (GIS) for a fifteen square-kilometre (15 km^2) areal extent of the Gidan Kwano Campus of the Federal University of Technology, Minna, Niger State, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*, **9**(**2**), 75 - 89.

Jonah, S.A., Baba-Kutigi A.N., Uno, U.E., Dangana, M.L., Kolo, M.T., Ofor, N.P., Unuevho, C.I., Onoduku, U.S., Abba, F. M., Alhassan, D.U., Amadi, A.N., Umar, M.O., and Kimpa, M.I. (2011C). Spatial analysis and Geographic Information System (GIS) mapping of noise pollution in Bosso Local Government Council, Niger State, Nigeria. *Environmental Technology and Science Journal (ETSJ).* **4** (**1**), 4 – 19.

Jonah, S.A., Baba-Kutigi, A.N., Uno, U.E., Kolo, M.T., Okunlola, I.A., Unuevho, C.I., Jimoh, M.O., Onoduku, U.S. Okoye, N.O., Alhassan, D.U., Eze, C.N., Abba, F.M., Kimpa, M.I., Aje, J.D., Amadi, A.N., Umar, M.O., Ejepu, J.S., and Taufiq, S. (2011A). Measurements of environmental noise levels and the creation of a unique Geographical Information System (GIS) layer map for environmental noise pollution in Chanchaga Local Government Council, Minna, Niger State. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*, **8**(**1**), 82 - 107.

Jonah, S.A., Baba-Kutigi, A.N., Uno, U.E., Kolo, M.T., Okunlola, I.A., Unuevho, C.I., Jimoh, M.O., Onoduku, U.S. Okoye, N.O., Alhassan, D.U., Eze, C.N., Abba, F.M., Kimpa, M.I., Aje, J.D., Amadi, A.N., Umar, M.O., Ejepu, J.S., and Taufiq, S. (2011B). Measurements of carbon monoxide concentrations and the creation of a unique Geographical Information System (GIS) layer map for carbon monoxide pollution in Minna, Niger State. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*, **7**(**3**), 57 – 76.

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. (2013F). 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.

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. (2013G). A blind geoelectrical survey commissioned to affirm or deny the presence of aquifer at a compound at Minna, Central Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*: Undergoing Review.

Jonah, S.A., Okunlola, I.A., Amadi, A.N., Baba-Kutigi A.N., and Umar, M.O.

(2011D). Investigation of nitrogen dioxide indices and the creation of a unique Geographic Information System (GIS) layer map for nitrogen dioxide pollution in Minna, Niger State. *Environmental Technology and Science Journal (ETSJ)*, **4** (**1**), 74 – 82.

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.

Olasehinde, P.I. 1989. Elucidating fracture patterns of the Nigerian Basement

Complex using electrical resistivity methods. *Z. Agnew Geowiss Heft*, **8**, 109 – 120.

Olasehinde, P.I. 1999. An integrated geologic and geophysical exploration technique

for groundwater in the basement complex of west-central part of Nigeria. *Water Resources*, **10**, 46-49.

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. (1986). *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.