Journal of Science, Technology, Mathematics, and Education (JOSTMED), 2015, Vol.11 No.3, 34 - 46

Qualitative Induced Polarisation Validation of the Results of a 2 km^2 VES Study Completed at the Gidan Kwano Campus Phase II Development, Federal University of Technology, Minna, Nigeria

Jonah, S.A. and Olasehinde, P.I.

Department of Physics, Federal University of Technology, Minna, Nigeria

* Department of Geology, Federal University of Technology, Minna, Nigeria

Abstract

The 2km^2 vertical electrical sounding (VES) study under consideration here is Jonah *et al.* (2014[i]) for which no tandem and coincident-point induced polarisation (IP) data set was collected in the course of that survey completed in 2013; this 2km^2 VES survey was conducted at 200m principal station-spacing and the areal extent is subsumed within the southern half of the 8km^2 total area Gidan Kwano Campus (GKC) Phase II Development. The aim of this study is to provide "a refinement of sorts" or "a further constraint" on the result of the interpretation of the VES survey at the 2km^2 slice of Phase II of the GKC by employing corresponding IP data set in quality control (QC) mode. All aspects of the tandem VES-IP survey in two-dimensional (2-D) mode was completed in the transverse traverse (TT) trend. For the qualitative discussion herein, examination of each of the separate IP tables of values was fixed for a benchmark depth of 40m because this 40m-window restriction is due to the fact that, in the larger basement complex region of which the present area of study is but a small constituent, the thicknesses of the different phases of overburden materials never exceed 35m. Based on the analysis of the corresponding IP tables, for which the IP method is the second-stage constraint to the earlier VES interpretation, the aquifer prospects that were tagged "strongly aquiferous" in Jonah *et al.* (2014[i]) are now even qualified as "very strongly aquiferous," meaning that the IP method is a great QC tool like was suggested by Parasnis (1986).

Keywords: quality-control; areal; transverse-traverse; subsume; triumvirate; aquiferous

Introduction

The 2km^2 vertical electrical sounding (VES) study under consideration here is Jonah *et al.* (2014[i]) for which no tandem and coincident-point induced polarisation (IP) data set was collected in the course of that survey completed in 2013; this 2km^2 VES survey was conducted at 200m principal station-spacing and the areal extent is subsumed within the southern half of the 8km^2 total area Gidan Kwano Campus (GKC) Phase II Development. A tandem, triumvirate schedule geoelectrical survey has been defined for the southern half 4km^2 of the Gidan Kwano Campus Phase II Development; this triumvirate schedule is the VES, IP, and self-potential (SP) surveys.

Only the tandem VES-IP survey in two-dimensional (2-D) mode has been completed to a reasonable degree at this $4km^2$ areal extent; the result of the interpretation of the VES component of the total data field is discussed in Jonah *et al.* (2015[c]); based on the recommendation of Jonah *et al.* (2015[c]), another vista was explored in Jonah *et al.* (2015[d]). The tandem VES-IP survey in 2-D mode was completed at 100m principal station-spacing, and thus there would be coincident points of survey for all the principal stations occupied in the course of the single-mode VES survey of the $2km^2$ areal extent; actually, this $4km^2$ areal extent 2-D survey, begun in 2011, was completed in 2014. It is the IP results at coincident locations of the $2km^2$ areal extent, still 2-D, survey that would be used in the validation discussion herein. Thus, the IP data field that is employed for the present study lags the VES data field by one year, essentially clarifying that both sets of data were not collected in *pari passu*. There is no problem about this time lapse because Jonah *et al.* (2015[e]) have demonstrated that the readings of the ABEM Terrameter SAS 4000 terrameter that was the "workhorse" of all of these surveys correlates fairly well over varying weather conditions.

The aim of this study is to provide "a refinement of sorts" or "a further constraint" on the result of the interpretation of a VES survey at a $2km^2$ slice of Phase II of the GKC by employing corresponding IP data set in quality control (QC) mode.

The nearest to the kind of endeavour being presented herein was discussed in Jonah *et al.* (2015[b]) where an intercalated VES-IP survey was carried out in *pari passu*, the VES in tandem with the IP, over a $1km^2$ areal extent subsumed in the $2km^2$ areal extent of the present study. Well, suffice to emphasize once more that the $2km^2$ areal extent of the present study is subsumed in the $4km^2$ areal extent of Jonah *et al.* (2015[c]) and this $4km^2$ is subsumed in the $8km^2$ total area of Phase II (discussed, amongst other related works in Jonah *et al.*, 2014[j]). Even though the area of study of Jonah *et al.* (2015[b]) is subsumed in the area of study of Jonah *et al.* (2014[i]), the IP data of Jonah *et al.* (2015[b]) could not be used for the present analysis because the principal stations of Jonah *et al.* (2015[b]) intercalates the principal stations of the present study by 100m and thus their survey stations are not coincident.

The extent of the $2km^2$ area of study is shown in Fig.1 in relation to Phase I (that is, the existing developed portion of the GKC). The missing green dots of Fig.1 are the two locations of the principal stations coincident with the tops of two unitary bodies of outcrops where VES measurements could not be taken in 2013 for the Jonah *et al.* (2014[i]) schedule.

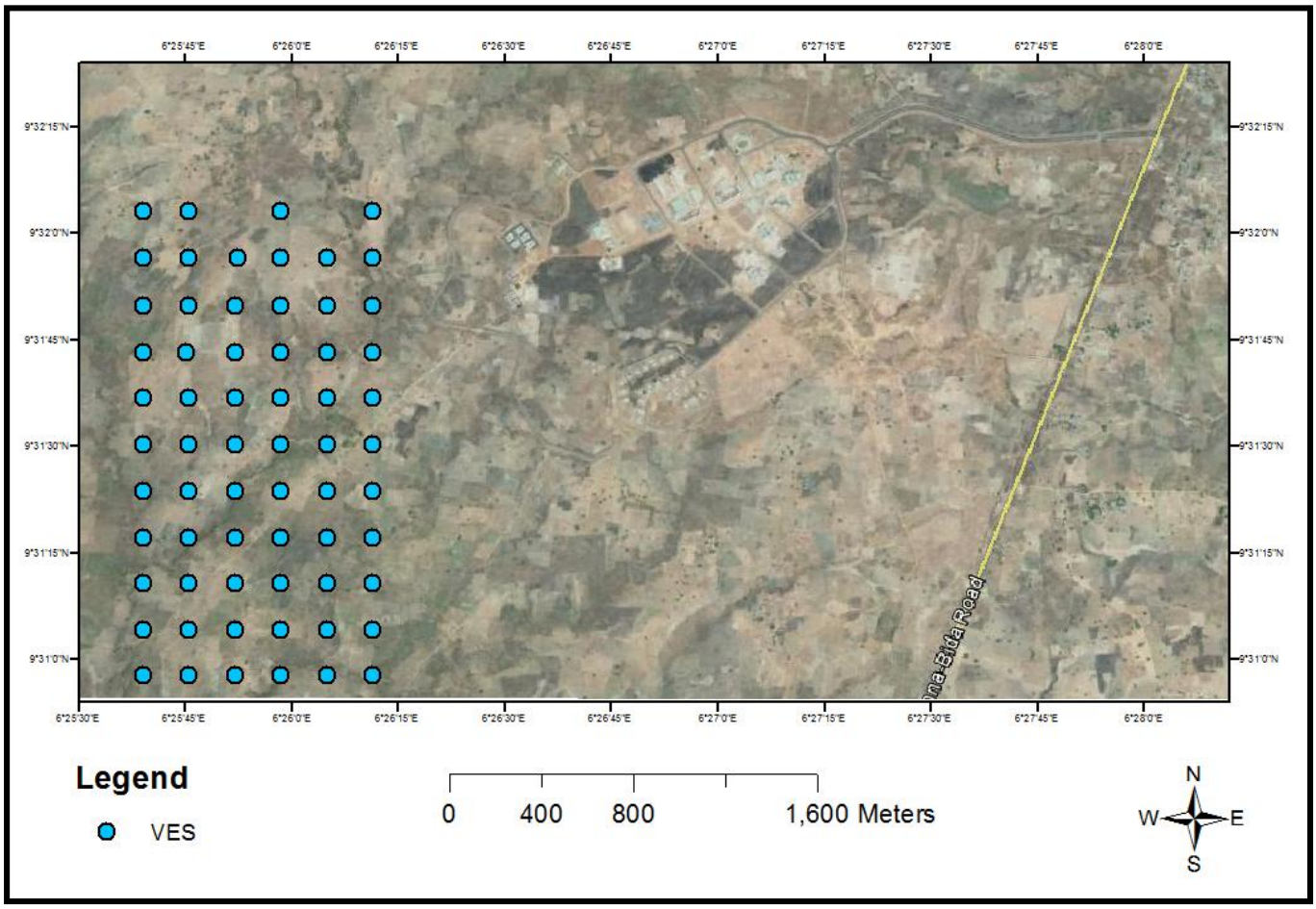

Fig.1. Satellite imagery overlay map showing the extent of project work in relation to Phase I. (The tadpole-shaped feature is Phase I, seen to the east of the VES green-dotted grid of the area of study and the Minna-Kateregi-Bida Road is seen as the linear slope in the bottom right of this figure.)

At 200m station-spacing, the schedule of the 2km^2 survey results in a 6x6 grid format (36 principal stations; see Fig.1) whilst at 100m station-spacing, the schedule of the 4 km^2 survey results in a 21x21 grid format (441 principal stations); this can be made out in Fig.2. Thus the idea of the 2km^2 areal extent being "subsumed" in the 4km^2 areal extent is easily understood.

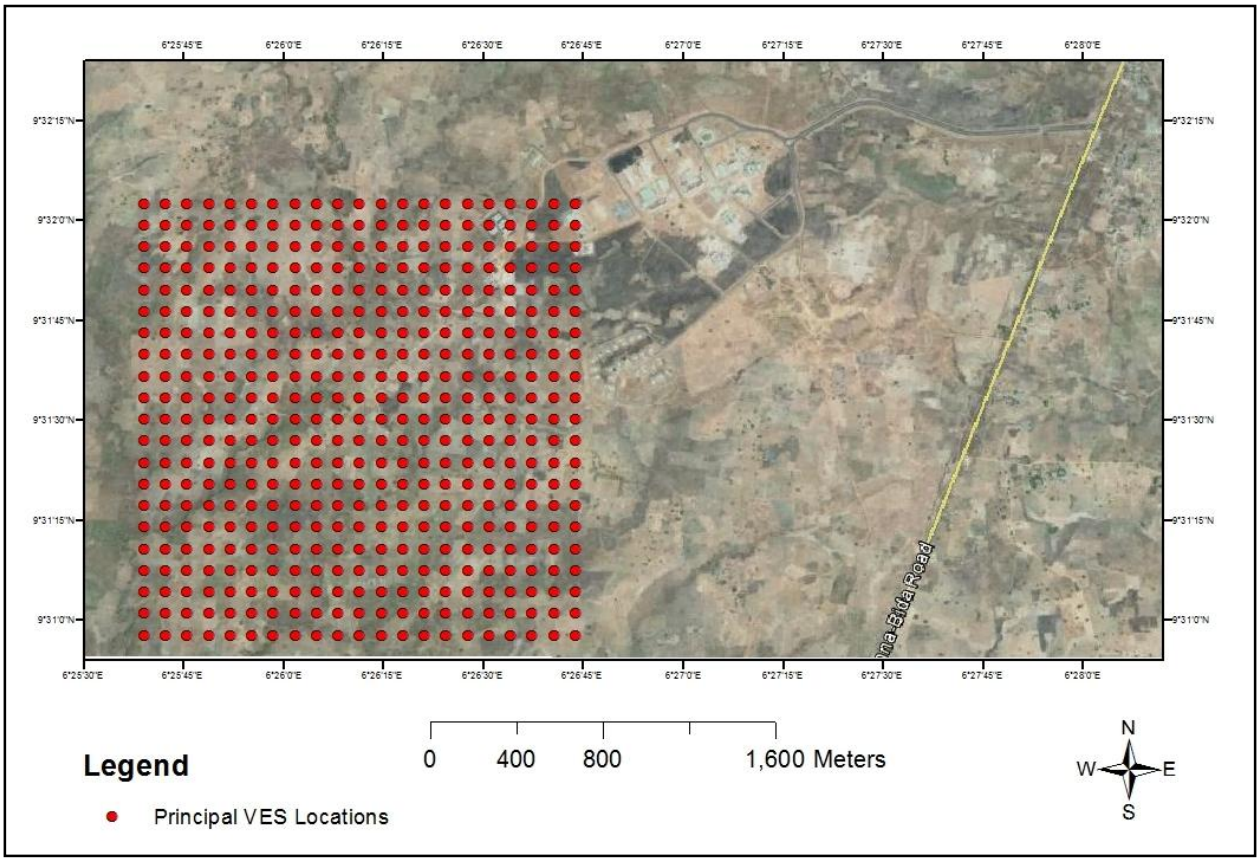

Fig.2. Locations of the principal stations of the 4km^2 areal extent

Well, it was mentioned that "only the tandem VES-IP survey in two-dimensional (2-D) mode has been completed to a reasonable degree at this 4km^2 areal extent." The meaning of this can be discerned in Fig.3, where only the principal survey stations for the 4km^2 areal extent that were occupied during the course of this survey have been colour-coded against the original red backdrop. Barriers due to wet-stream, outcrop, thicket, built-up area, instrumental error (that is, "Error 12" of the ABEM Terrameter 4000), and raw sewage precluded measurements at the red-coloured locations of Fig.3 except at the longitudinal traverse (LT) length of Number 11 where VES and IP data were collected in LT trend in 2011. Thus far, all aspects of surveys completed have been in the transverse traverse (TT) trend.

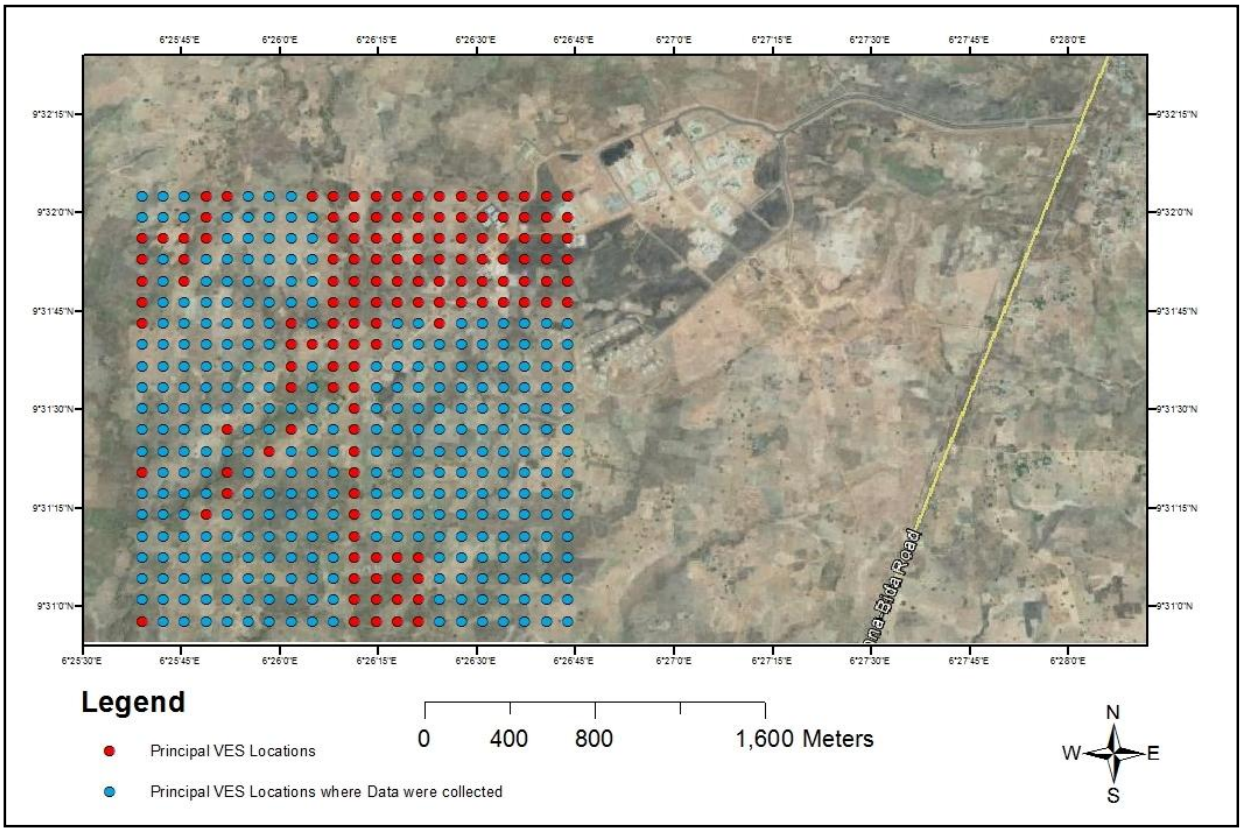

Fig.3. Locations of the principal stations of the 4km^2 areal extent colour-coded for locations where data was collected for this survey

Accurate mapping and archival of surface and subsurface information must necessarily follow a full suite of methods designed to reduce errors in interpretation of field data, as well as providing the ability to correctly pinpoint likely prospects in the study area. Moreover, independent verification of the field data must be assured. In fact, Jonah (2015[a]); Jonah, Olasehinde, Jimoh, Umar, and Yunana (2015[b]); Jonah, Olasehinde, Umar, and Yunana (2015[c]); Jonah, Olasehinde, Jimoh, Umar, and Yunana (2015[d]); Jonah, Olasehinde, and Umar (2015[e]); Jonah and Duromola (2014[a]), Jonah and Ayofe (2014[b]), Jonah and Bawa (2014[c]); Jonah, Baba, and Umoh (2014[d]); Jonah, Okoro, Umar, Bakara, and Umoh (2014[e]); Jonah *et al.* (2014[f]), Jonah *et al.* (2014[g]), Jonah *et al.* (2014[h]), Jonah *et al.* (2014[i]); Jonah, Olasehinde, and Umar (2014[j]); Jonah, Jimoh, and Umar (2014[k]); Jonah and Jimoh (2013[a]), Jonah *et al.* (2013[b]), Jonah *et al.* (2013[c]), Jonah *et al.* (2013[d]), Jonah *et al.* (2011[a]), Jonah *et al.* (2011[b]), Jonah *et al.* (2011[c]); Jonah, Okunlola, Amadi, Baba-

Kutigi, and Umar (2011[d]) have always argued in favour of georeferencing field data and their concomitant tie-in to their specific GIS database.

Discussion

The ideas germane to the discussion of this present study have been enunciated in Jonah *et al.* (2015[b]) whence the following critical remarks were noted, viz: "the interpretation would be guided by the statement-of-fact enunciated on p. 222 of Kearey and Brooks (1984) to wit: the sources of significant IP anomalies are water-filled shear zones; it is understood from ABEM (1999) that IP results can distinguish between groundwater and clay. This property is significant because it constrains the IP method to be an effective discriminator when making deduction as to the presence of groundwater. According to Parasnis (1986), p. 180, 'the advantage of IP soundings (as a complement to VES) is that they are able to distinguish between clay layers (high IP) and some other low-resistivity strata like salt-water beds (no IP).' Thus, where it is suspected that groundwater may be present, recourse to the corresponding IP value recorded in *pari passu* at that depth would help dispel whatever doubt there may be." If measurements in *pari passu* were not implemented, then measurements completed at the corresponding depths of survey at a time lag should be used.

For the 2km^2 VES study completed at the Gidan Kwano Campus Phase II (Jonah *et al.* 2014[i]), upon making recourse to a dual empirical rule that guide the identification of groundwater prospects in the basement complex geology alongside a consideration of the iso-resistivity contour maps at depths, the following locations were tagged as "aquiferous:" TT1-3, TT1-4, TT2-1, TT2-2, TT2-3, TT2-4, TT2-5, TT2-6, TT3-1, TT3-2, TT3-3, TT3-4, TT4-1, TT4-2, TT4-3, TT4-5, TT5-1, TT5-2, TT5-3, TT5-4, TT5-5, TT5-6, TT6-1, TT6-5, TT6-6, TT7-1, TT7-5, TT9-1, TT9-2, and TT9-6. Upon imposing a first-stage constraint to this conclusion that is based on a consideration of the overburden thickness map, the following locations were flagged as "strongly aquiferous:" TT1-3, TT1-4, TT2-4, TT4-1, and TT4-3. Basically, this present study examines a second-stage constraint based on a qualitative consideration of IP data collected at corresponding points of the VES locations.

A transverse traverse (TT) is an east-west profiling scheme; this scheme was adopted for the 2km^2 and the 4km^2 surveys represented in Figs 1 and 2. In reality, for the 2km^2 schedule of 2013, data

collection convention was from east to west: since the southernmost TT was occupied first, TT1-3 of Fig.1 is the third green dot to the left of the most extreme southeast dot; TT1-4 is one pace to the left of TT1-3. Based on this convention, it could easily be made out that TT11-2 and TT11-4 are the locations that are coincident with the top of unitary bodies of outcrops. It is known that TT1-1 is identified by the following georeferenced co-ordinates: $N09^{0}30'57.80''$; $E006^{0}26'11.40''$. Thus, at 400m to the west of TT1-1, TT1-3 is identified by the following georeferenced co-ordinates: $N09^{0}30'57.80''$; $E006^{0}25'58.44''$ and TT1-4 at 600m to the west of TT1-1 is identified by the following georeferenced co-ordinates: $N09^{0}30'57.80''$; $E006^{0}25''51.96''$. TT2-4 is the fourth station of the second TT (counting from east to west, of course); the second TT is the profile line exactly 200m to the north of TT1 in Fig.1; TT2-4 is identified by the following georeferenced co-ordinates: $N09^{0}31'04.28''$; $E006^{0}25'51.96''$. TT4-1 is identified by the following georeferenced co-ordinates: $N09^{0}31'17.24''$; $E006^{0}26'11.40''$ and TT4-3 is identified by the following georeferenced co-ordinates: $N09^{0}31'17.24''$; $006^{0}25'58.44''$.

However, for the $4km^2$ schedule of 2014, data collection convention was from west to east; remembering that the station-spacing is 100m, the equivalent of TT1-3 is the seventh red dot to the right of the most extreme southwest red dot of Fig.2 and the seventh green dot to the right of the most extreme southwest green dot of Fig.3. TT1-4 is the fifth red dot to the right of the most extreme southwest red dot of Fig.2 and the fifth green dot to the right of the most extreme southwest green dot of Fig.3. In Fig.2, TT2-4 would be located on the third profile line exactly 200m to the north of TT1; actually, the fifth red dot on the third profile line from the west as can be made out in Fig.2 and also the fifth green dot on the third profile line from the west as can be made out in Fig.3. Now, considering Figs 2 and 3 still further, it should be obvious that there would be no difficulty "reading off" the positions of TT4-1 and TT4-3.

Qualitative Discussion of the Function of the Induced Polarisation Data for the Present Intercalated Survey. The IP tables for TT1-3, TT1-4, TT2-4, TT4-1, and TT4-3 are hereby presented as Tables 1 to 5. For the qualitative discussion herein, examination of each of the separate IP tables of values would be done only to a TD of 40m. This 40m-window restriction is due to the fact that, in the larger basement complex region of which the present area of study is but a small constituent, the thicknesses of the different phases of overburden materials never exceed 35m (Jimoh, 1998).

Table 1. IP data record sheet for TT1-3

TYPE OF SURVEY:…Induced Polarisation…...**MODE:**….Time Domain… **ARRAY: ……**Schlumberger……

PLACE:…Gidan Kwano Campus….**WEATHER:**.. Partly Sunny... **EQUIPMENT:**.ABEM Terrameter SAS 4000

LOCATION: (i) **N:**.. $09^0 30' 57.80''$.....(ii) **E:**.... $006^0 25' 58.44''$.....**ELEVATION:**…… 192m …….

OPERATOR:…SJ……**RECORDER:**…SJ…… ……**DATE:**… 12/05/2014……. **TIME:**… 04:39 P.M.…

TRANSVERSE TRAVERSE DESIGNATION:… TT1-3…… **GPS UNIT:**… Garmin GPSmap76……..

AB/2 (CURRENT)	MN/2 (POTENTIAL)	GEOM. FACTOR, K	CHARGEABILITY	STANDARD DEVIATION	CURRENT (I)	STACKS
1	.50	2.36	1.08	0.02	100mA	4
2	.50	11.8	2.34	0.01	100mA	2
3	.50	27.8	2.81	0.17	100mA	4
5	.50	77.8	3.08	0.42	100mA	4
6	.50	112	2.97	0.27	100mA	4
6	1.00	55	3.05	0.32	100mA	4
8	1.00	99	2.99	0.43	100mA	4
10	1.00	156	2.79	0.22	100mA	4
10	2.50	58.9	-4.24	0.39	100mA	4
15	2.50	137	-2.23	0.01	100mA	4
20	2.50	245	-1.00	0.16	100mA	4
30	2.50	562	-38.20	1.10	100mA	4
40	2.50	1001	-49.70	2.90	100mA	4
40	7.50	323	-21.70	0.87	100mA	4
50	7.50	512	-8.86	0.57	100mA	4
60	7.50	742	-8.92	0.46	100mA	4
70	7.50	1014	-24.20	1.70	100mA	4
80	7.50	1329	-3.20	0.43	100mA	4
80	15.00	647	1.71	0.42	100mA	4
90	15.00	825	1.90	0.14	100mA	4
100	15.00	1024	2.45	0.39	100mA	4

Table 2. IP data record sheet for TT1-4

TYPE OF SURVEY:…Induced Polarisation…...**MODE:**….Time Domain… **ARRAY: ……**Schlumberger……

PLACE:…Gidan Kwano Campus…**WEATHER:**…Partly Sunny ... **EQUIPMENT:**.ABEM Terrameter SAS 4000

LOCATION: (i) **N:**.. $09^0 30' 57.80''$.....(ii) **E:**.. $006^0 25'' 51.96''$.....**ELEVATION:**…… 200m ……

OPERATOR:…SJ……**RECORDER:**…SJ…… **DATE:**… 14/05/2014……. **TIME:**… 11:04 A.M …

TRANSVERSE TRAVERSE DESIGNATION:… TT1-4…… **GPS UNIT:**… Garmin GPSmap76……..

AB/2 (CURRENT)	MN/2 (POTENTIAL)	GEOM. FACTOR, K	CHARGEABILITY	STANDARD DEVIATION	CURRENT (I)	STACKS
1	.50	2.36	1.55	0.00	100mA	2
2	.50	11.8	0.92	0.07	100mA	4
3	.50	27.8	-2.48	1.30	100mA	4
5	.50	77.8	0.92	0.07	100mA	4
6	.50	112	1.42	0.08	100mA	4
6	1.00	55	4.77	1.20	100mA	4
8	1.00	99	1.88	0.13	100mA	4
10	1.00	156	1.79	0.27	100mA	4
10	2.50	58.9	1.67	0.16	100mA	4
15	2.50	137	1.33	0.24	100mA	4
20	2.50	245	1.38	0.13	100mA	4
30	2.50	562	1.47	0.22	100mA	4
40	2.50	1001	1.77	0.38	100mA	4
40	7.50	323	3.40	1.30	100mA	4
50	7.50	512	2.37	0.40	100mA	4
60	7.50	742	2.29	0.49	100mA	4
70	7.50	1014	2.92	0.59	100mA	4
80	7.50	1329	2.54	0.41	100mA	4
80	15.00	647	2.38	0.36	100mA	4
90	15.00	825	2.17	1.10	100mA	4
100	15.00	1024	2.61	0.63	100mA	4

Table 3. IP data record sheet for TT2-4

TYPE OF SURVEY:…Induced Polarisation…...**MODE:**….Time Domain… **ARRAY: …...**Schlumberger……

PLACE:…Gidan Kwano Campus…. **WEATHER:**… Sunny ….. **EQUIPMENT:**.ABEM Terrameter SAS 4000

LOCATION: (i) **N:**.. $09^0 31' 04.28''$.....(ii) **E:**..... $006^0 25'' 51.96''$.....**ELEVATION:**……201m…….

OPERATOR:…SJ……**RECORDER:**…SJ…… ……**DATE:**… 17/05/2014……. **TIME:**…… 12:50 P.M …

TRANSVERSE TRAVERSE DESIGNATION:… TT2-4…… **GPS UNIT:**… Garmin GPSmap76……..

AB/2 (m) (CURRENT)	MN/2 (m) (POTENTIAL)	GEOM. FACTOR, K	CHARGEABILITY	STANDARD DEVIATION	CURRENT (I)	STACKS
1	.50	2.36	0.44	0.06	100mA	4
2	.50	11.8	0.19	0.42	100mA	4
3	.50	27.8	-0.24	0.28	100mA	4
5	.50	77.8	-0.44	0.83	100mA	4
6	.50	112	0.93	0.56	100mA	4
6	1.00	55	-5.25	4.20	100mA	4
8	1.00	99	-0.65	0.77	100mA	4
10	1.00	156	-35.4	14.0	50mA	4
10	2.50	58.9	-5.18	2.40	100mA	4
15	2.50	137	0.60	3.10	100mA	4
20	2.50	245	0.65	0.08	100mA	4
30	2.50	562	-0.07	0.28	100mA	4
40	2.50	1001	-3.40	0.62	100mA	4
40	7.50	323	2.84	0.20	100mA	4
50	7.50	512	10.5	0.35	100mA	4
60	7.50	742	2.77	0.00	100mA	4
70	7.50	1014	2.79	0.17	100mA	4
80	7.50	1329	-12.6	0.74	100mA	4
80	15.00	647	-5.82	0.42	100mA	4
90	15.00	825	-8.44	1.50	100mA	4
100	15.00	1024	-28.5	3.60	100mA	4

Table 4. IP data record sheet for TT4-1

TYPE OF SURVEY:…Induced Polarisation…...**MODE:**….Time Domain… **ARRAY: ……**Schlumberger……

PLACE:…Gidan Kwano Campus…. **WEATHER:**…….. **EQUIPMENT:**.ABEM Terrameter SAS 4000

LOCATION: (i) **N:**.... $09^0$31’17.2’’.....(ii) **E:**... $006^0$26’11.4’’.....**ELEVATION:**……202m…….…….

OPERATOR:…SJ……**RECORDER:**…SJ…… ……**DATE:**……..… **TIME:**……

TRANSVERSE TRAVERSE DESIGNATION:… TT4-1…… **GPS UNIT:**… Garmin GPSmap76…….

AB/2 (CURRENT)	MN/2 (POTENTIAL)	GEOM. FACTOR, K	CHARGEABILITY	STANDARD DEVIATION	CURRENT (I)	STACKS
1	.50	2.36	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
2	.50	11.8	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
3	.50	27.8	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
5	.50	77.8	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
6	.50	112	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
6	1.00	55	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
8	1.00	99	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
10	1.00	156	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
10	2.50	58.9	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
15	2.50	137	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
20	2.50	245	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
30	2.50	562	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
40	2.50	1001	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
40	7.50	323	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
50	7.50	512	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
60	7.50	742	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
70	7.50	1014	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
80	7.50	1329	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
80	15.00	647	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
90	15.00	825	1P DATA SET	AVAILABLE	ONLY IN	LT TREND
100	15.00	1024	1P DATA SET	AVAILABLE	ONLY IN	LT TREND

Table 5. IP data record sheet for TT4-3

TYPE OF SURVEY:…Induced Polarisation…...**MODE:**….Time Domain… **ARRAY: ……**Schlumberger……

PLACE:…Gidan Kwano Campus…. **WEATHER:**…Partly Sunny... **EQUIPMENT:**.ABEM Terrameter SAS 4000

LOCATION: (i) **N:**.. $09^0 31' 17.24''$.....(ii) **E:**..... $006^0 25' 58.44''$.....**ELEVATION:**……197m…….

OPERATOR:…SJ……**RECORDER:**…SJ…… ……**DATE:**…… 25/06/2014……. **TIME:**… 12:30 P.M.……

TRANSVERSE TRAVERSE DESIGNATION:… TT4-3…… **GPS UNIT:**… Garmin GPSmap76……..

AB/2 (m) (CURRENT)	MN/2 (m) (POTENTIAL)	GEOM. FACTOR, K	CHARGEABILITY	STANDARD DEVIATION	CURRENT (I)	STACKS
1	.50	2.36	0.67	0.06	100mA	4
2	.50	11.8	0.33	0.02	100mA	4
3	.50	27.8	0.070	0.03	100mA	4
5	.50	77.8	-2.02	2.20	100mA	4
6	.50	112	-0.69	0.29	100mA	4
6	1.00	55	1.27	0.29	100mA	4
8	1.00	99	-0.40	0.04	100mA	4
10	1.00	156	0.67	0.05	100mA	4
10	2.50	58.9	1.00	0.07	100mA	4
15	2.50	137	1.38	0.01	100mA	4
20	2.50	245	1.10	0.19	100mA	4
30	2.50	562	1.00	0.88	100mA	4
40	2.50	1001	1.29	0.27	100mA	4
40	7.50	323	-1.86	1.60	100mA	4
50	7.50	512	0.82	0.31	100mA	4
60	7.50	742	1.20	0.14	100mA	4
70	7.50	1014	0.96	0.13	100mA	4
80	7.50	1329	1.20	0.11	100mA	4
80	15.00	647	1.11	0.18	100mA	4
90	15.00	825	1.02	0.10	100mA	4
100	15.00	1024	1.45	0.15	100mA	4

Qualitative Examination of IP Table for TT1-3 (see Table 1). It is observed that a negative chargeability value of -49.70ms exists for TT1-3 at the 40m-depth mark of Table 1: according to ABEM (1999), negative IP values can only mean that the resistivity of the current layer is less than that of the layer just above it; this trend would be contrary to the theoretical expectation that resistivity should increase as the depth increases for any VES location. The chargeability is -38.20ms at the 30m-depth mark, -1.00 at the 20m-depth mark, -2.23 at the 15m-depth mark, -4.24 at the 10m-depth mark, and +2.99 at the 8m-depth mark. Parasnis (1986) pointed out that clay layers correspond to "high IPs" and salt-water beds correspond to "no IPs:" whilst an IP data set can distinguish between a clay bed and an aquifer, there is no indication of a prominent clay layer of "high absolute value of IP" in Table 1. Instead, what can be inferred in this table is a progressive decrease of resistivity values at depths through the benchmark depth of 40m down to the 80m-depth mark. In absolute value terms, the values of IP at the 30m-depth mark is very close to that at the 40m-depth mark; interesting to note that the value at the 30m-depth mark is negative still. Suffice to point out here that in the study of Jonah *et al.* (2015[b]), TT1-3 of Jonah *et al.* (2014[i]), corresponding to the present TT1-3 under consideration, was flagged to have an aquifer drill window of 30m to 150m. Suffice, once more, to note that the station-spacing (corresponding to the maximum survey-able depth) of Jonah *et al.* (2014[i]) was 200m (>150m) and that for Jonah *et al.* (2015[c]) for which the IP values of Table 1 was extracted was 100m.

Qualitative Examination of IP Table for TT1-4 (see Table 2). Considering the 40m-depth benchmark, the convenience of IP "negatives" pattern does not present itself in Table 2. Nonetheless, at the 3m-depth mark a chargeability value of -2.48ms exists; otherwise there is observed a stream of low-magnitude IP values throughout. In Jonah *et al.* (2015[b]), TT1-4 of Jonah *et al.* (2014[i]), corresponding to the present TT1-4 under consideration, was flagged to also have an aquifer drill window of 30m to 150m. The 30m to 100m interval of Table 2 are "low-IPs," basically. The point that is being made here is a referral from Jonah *et al.* (2015[b]), viz: "Since Parasnis (1986) pointed out that clay layers correspond to 'high IPs', and salt-water beds correspond to 'no IPs', *it can be inferred that freshwater beds correspond to 'low IPs*.'" Further, in Jonah *et al.* (2015[b]), "however, according to Mr. Jonah (personal communication), in his work since 2011 at the greater area of the Phase II Development, what is 'high' or 'low' IP is a subjective matter depending on the prevailing values of the current survey under analysis."

Qualitative Examination of IP Table for TT2-4 (see Table 3). Considering the 40m-depth benchmark, a chargeability value of -3.40ms exists at this depth in Table 3. At the 30m-depth is an extremely low chargeability value of -0.07ms. In Table 3, the plethora of IP "negatives" pattern is spread through the shallow 3m-depth mark to the 100m-depth mark. In Jonah *et al.* (2015[b]), TT2-4 of Jonah *et al.* (2014[i]), corresponding to the present TT2-4 under consideration, was flagged to also have an aquifer drill window of 30m to 120m. Based on the point of argument being considered here, the 30m to the 40m interval and the 80m-depth mark downwards of Table 3 validates this position fairly well. Basically, what can be inferred in this table is a progressive decrease of resistivity values at depths through the benchmark depth of 40m down to the 100m-depth mark.

Qualitative Examination of IP Table for TT4-1 (see Table 4). The available IP data set for TT4-1 of the present study, corresponding to TT4-1 of Jonah *et al.* (2014[i]), was acquired in the LT format and thus in keeping with a strictly TT-based analysis the table could not be used for the present analysis. Nevertheless, Jonah *et al.* (2015[b]) flagged TT4-1 as having an aquifer drill window of 20m to 130m.

Qualitative Examination of IP Table for TT4-3 (see Table 5). Considering the 40m-depth benchmark, a chargeability value of -1.86 exists at this depth in Table 5. Above this benchmark to the 10m-depth mark is a stream of positives IP values. This situation perfectly suits the line of argument that is being presented herein, meaning basically that a low-resistivity bed is discernible at the 40m-depth benchmark. In Jonah *et al.* (2015[b]), TT4-3 of Jonah *et al.* (2014[i]), corresponding to the present TT4-3 under consideration, was flagged to also have an aquifer drill window of 40m to 150m. The coincidence of this 40m depth mark is very apt indeed!

Conclusion

On the TT1-3 Prospect. The dual empirical protocols alongside the iso-resistivity contour maps and still alongside the overburden thickness analysis routes that identified TT1-3 as "strongly aquiferous" have been corroborated by the IP data analysis route which is the central argument of this present study. Even though a depth benchmark was fixed for the IP data analysis of Jonah *et al.* (2015[b]) and the present study, both works are underscoring that the 30m-depth mark should not be ignored as a good groundwater window for TT1-3. The nearness of the IP absolute values at

the 30m-depth mark and at the 40m-depth mark of the present study surely mean that the same geological material is encountered at both these depths. Jonah *et al.* (2015[b]) "says" if drilling TT1-3, concentrate on the 30m to 150m interval for groundwater exploitation and the present study "says" if drilling TT1-3, do not ignore the 30m-40m interval and of course the 40m down to the 80m-depth mark interval for groundwater exploitation. Thus, TT1-3 is "very strongly aquiferous."

On the TT1-4 Prospect. A valid argument has been presented to indicate that TT1-4 is "very strongly aquiferous," too.

On the TT2-4 Prospect. A valid argument has been presented to indicate that TT2-4 is "very strongly aquiferous."

On the TT4-1 Prospect. Since the corresponding IP data set for TT4-1 is not available for the present analysis, it advised to stick to the "strongly aquiferous" label of TT4-1 as argued in Jonah *et al.* (2015[b]).

On the TT4-3 Prospect. A valid argument has been presented to indicate that TT4-3 is "very strongly aquiferous."

Recommendation

On the TT1-3 Prospect. It is recommended that TT1-3, located at Lat $09^0 30' 57.80''$ and Long $006^0 25' 58.44''$ based on the Garmin GPSmap76 Global Positioning System unit, should be drilled for groundwater exploitation purpose.

On the TT1-4 Prospect. It is recommended that TT1-4, located at Lat $09^0 30' 57.80''$ and Long $006^0 25'' 51.96''$ based on the Garmin GPSmap76 Global Positioning System unit, should be drilled for groundwater exploitation purpose.

On the TT2-4 Prospect. It is recommended that TT2-4, located at Lat $09^0 31' 04.28''$ and Long $006^0 25' 51.96''$ based on the Garmin GPSmap76 Global Positioning System unit, should be drilled for groundwater exploitation purpose.

On the TT4-1 Prospect. It is recommended that the planned corresponding IP data set survey in TT mode be completed as soon as possible so it could be employed in this analysis.

On the TT4-3 Prospect. It is recommended that TT4-3, located at Lat $09^0 31'17.24''$ and Long $006^0 25'58.44''$ based on the Garmin GPSmap76 Global Positioning System unit, should be drilled for groundwater exploitation purpose.

References

ABEM (1999). *Instruction Manual: Terrameter SAS 4000/SAS 1000*, ABEM Instrument AB, Sundbyberg (Sweden).

Jimoh, M.O. (1998). *Report on the Six Boreholes Drilled at the Main Campus of the Federal University of Technology, Minna, for the Petroleum (Special) Trust Fund.* Cemaco Ventures Ltd., Minna.

Jonah, S.A. (2015[a]). *Ozone (O_3) Level Study at Major Traffic Stalling Points in the Federal Capital City (FCC),* Unpublished Report, Federal University of Technology Minna Ventures Limited (FUTMIN Ventures), Minna (Nigeria).

Jonah, S.A., Akpan, E. U., Bakara, I. U., Tanimowo, B., Abdullahi, B., Nwachukwu, E. I., ……. and Ejepu, J.S. (2013[c]). 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. (2014[b]). Creation of a Geographic Information System for Minna, Niger State, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST),* 1(1), 237 – 254.

Jonah, S.A. and Bawa, S.C. (2014[c]). 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),* 1(1), 255 – 268.

Jonah, S.A. and Duromola, S.A. (2014[a]). Determination of concentration of sulphur dioxide at major stalling traffic points in Minna, Niger State, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST),* 1(1), 224 – 236.

Jonah, S.A. and Jimoh, M.O. (2013[a]). 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, E.A., and Umoh, S.E., (2014[d]). Measurement of the levels of carbon monoxide concentrations at major stalling traffic points in Minna, Niger State, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED):* 10(1), 15 - 29.

Jonah, S.A., Baba-Kutigi A.N., Uno, U.E., Dangana, M.L., Kolo, M.T., Ofor, N.P., …… and Kimpa, M.I. (2011[a]). 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., …… and Taufiq, S. (2011[b]). 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., …… and Taufiq, S. (2011[c]). 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., Dania, R., Ezemonye, C.V., Fanisi, O., Ejiga, U., Benu, I.S., Banjo, G. Pius, A., Akpan, E. U., Bakara, I. U., Tanimowo, B., Abdullahi, B., Nwachukwu, E. I., Maishanu, I. H., James, G.O., Okunola, I.A., Jimoh, M.O., Amadi, A.N. and Ejepu, J.S. (2013[d]). Mapping concentrations of carbon dioxide over Central Kubwa, Abuja, using Geographic Information System. *Journal of Science, Technology, Mathematics, and Education (JOSTMED),* 10(1), 40 - 55.

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[b]). 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. (2014[f]). Pre-drilling geoelectrical survey at a built-up compound at Barkin-Sale Ward, Minna, Niger State, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*, 1(2), 86 – 97.

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. (2014[i]). Geoelectrical investigation for aquifer and geotechnical properties at the planned Gidan Kwano Campus Development Phase II, Minna, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*: ***Accepted for Publication***.

Jonah, S.A., Jimoh, M. O., and Umar, M. (2014[k]). A wet-season geoelectrical investigation for groundwater development at a built-up property at the Western Bye-Pass, Minna, Nigeria. *Journal of Information, Education, Science, and Technology (JOSTMED): **Accepted for Publication***.

Jonah, S.A., Okoro, N.N., Umar, M., Bakara, I. U. and Umoh, S.E. (2014[e]). Geographic Information System mapping of raw sewage discharge points in Minna, Niger State, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED): **Accepted for publication***.

Jonah, S.A., Okunlola, I.A., Amadi, A.N., Baba-Kutigi A.N., and Umar, M.O. (2011[d]).

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.

Jonah, S.A., Olasehinde, P.I., and Umar, M. (2014[j]). Evaluation of geomorphological quality control of geo-electrical data at Gidan Kwano Campus, Federal University of Technology, Minna, Central Nigeria. *Journal of Information, Education, Science, and Technology (JIEST):* ***Accepted for publication***.

Jonah, S.A., Olasehinde, P.I., and Umar, M. (2015[c]). Interpretation of two-dimensional vertical electrical sounding data of a 4km^2 tranche of new development, Gidan Kwano Campus Phase II, Federal University of Technology, Minna, Nigeria. *Journal of Information, Education, Science, and Technology (JOSTMED):* ***Undergoing Review***.

Jonah, S.A., Olasehinde, P.I., and Umar, M. (2015[d]). On the consistently low-resistivity regimes of the central to the southwest portions of a 4km^2 tranche of New Development, Gidan Kwano Campus Phase II, Federal University of Technology, Minna, Nigeria. *Journal of Information, Education, Science, and Technology (JOSTMED):* ***Undergoing Review***.

Jonah, S.A., Olasehinde, P.I., and Umar, M. (2015[e]). Correlation of dry season and wet season geoelectrical values for the ABEM Terrameter SAS 4000 at coincident points at the Planned Phase II Development, Gidan Kwano Campus, Federal University of Technology, Minna, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST):* ***Undergoing Review***.

Jonah, S.A., Olasehinde, P.I., Jimoh, M.O., Umar, M., and Yunana, T. (2015[b]). An intercalated dual geoelectrical survey of an earlier study for groundwater at the planned Gidan Kwano Campus Development Phase II, Federal University of Technology, Minna, Nigeria. *Journal of Information, Education, Science, and Technology (JOSTMED):* ***Accepted for Publication***.

Jonah, S.A., Umoh, S.E., James, G.O., Adeku, D.E., Ahmed, F., Alhassan, A., …… and Umoh,

U.E. (2014[g]). 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),* 1(2), 20 – 38.

Jonah, S.A., Umoh, S.E., James, G.O., Adeku, D.E., Ahmed, F., Alhassan, A., …… and Umoh, U.E. (2014[h]). A wetland lot geoelectrical investigation for groundwater development at Bosso Estate, Minna, Central Nigeria. *Journal of Information, Education, Science, and Technology (JIEST),* 1(2), 158 –171.

Kearey, P. and Brooks, M. (1984). *An Introduction to Geophysical Exploration,* Blackwell Scientific Publications, Oxford.

Parasnis, D.S. (1986). *Principles of Applied Geophysics (4ed.),* Chapman and Hall, London.