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

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Abstract

The earlier study at the planned Gidan Kwano Campus was a sole vertical electrical sounding (VES) survey concerned with identifying aquifer prospects, as well as providing geotechnical information for a 2km^2 areal extent subsumed in the greater Phase II Development. The aim of the present study is to plug the knowledge gaps of geological information for the intervening 200m-spread station spacing of the earlier survey; the objectives herein are to validate the conclusions drawn with respect to aquifer prospects from the earlier survey using the earlier method and an IP discriminator and define a framework by which studies of this format (i.e. georeferenced) could easily be replicated. Because of the dual vertical electrical sounding-induced polarisation (IP) nature of this survey, the areal extent of this project work was limited to 1km^2 and survey proceeded in the transverse traverse (i.e. TT) sense for individual stations and a south-north profile. Initially, each of the thirty-six intercalated survey stations, six on a TT, were georeferenced in terms of their x, y, z variables (i.e. latitude, longitude, elevation) using the hand-held Garmin72 Global Positioning System (GPS) unit. The Schlumberger array of the VES mode was employed for both the resistivity and the induced polarisation surveys. The results obtained indicated that the following VES locations are considered good prospects for groundwater: TT1-2, TT1-3, TT1-4, TT1-6, TT2-1, TT2-2, TT2-3, TT2-4, TT3-1, TT3-2, TT3-3, TT3-4, TT3-5, TT4-1, TT4-2, TT4-3, TT4-4, TT4-5, TT5-1 TT5-2, TT5-4, TT5-5, TT6-5, and TT6-6. The IP data set was used in a qualitative sense for this survey to constrain the conclusion drawn regarding the most promising VES locations of TT5-4, TT1-2, TT1-3, and TT2-2.

Keywords: Intercalation; Resistivity; Chargeability; Groundwater; Aquifer

Introduction

The earlier study at the planned Gidan Kwano Campus was a vertical electrical sounding (VES) survey concerned with identifying aquifer prospects, as well as providing geotechnical information for a 2km^2 areal extent of survey subsumed in the greater Phase II Development (Jonah *et al.*, 2014I). It was pointed out also that the extent of this greater Phase II Development was an 8km^2 area forming a contiguous landmass with the existing Phase I. The initial plan for this project was to occupy coincident points of the earlier study and do sole induced polarization (IP) survey to serve as a validation tool of the earlier survey, especially with the conclusions drawn regarding aquifer prospects. Survey-station identification for the earlier study was aided by the hand-held Garmin GPSmap76 unit, while the hand-held Garmin72 was the unit available for this present study. Alas, it was observed in the field that the ground locations of the same latitude and longitude numerical specifications were not coincident for the Garmin GPSmap76 and the Garmin72 units. Actually, the ground location of Garmin GPSmap76 was exactly 100m to the east of that of Garmin 72 along a constant line of latitude. Thus, since a strictly validation exercise could not be carried out because of unavailability of Garmin GPSmap76, it was decided to do a dual VES-IP along constant lines of latitude for survey stations that are necessarily intercalated with those of the earlier study. No doubt, the final result of this study would enhance the aquifer prospect database generated by the earlier study. Nowadays, because of the need to ensure independent verification of the results being presented, it is instructive to adopt the practice of georeferencing survey and prospect stations. This practice, in effect, also eliminates the awkward requirement of using wooden pegs to identify survey and prospect locations. In fact, Jonah and Duromola (2014A), Jonah and Ayofe (2014B), Jonah and Bawa (2014C), Jonah *et al.* (2014D; 2014E; 2014F; 2014G; 2014H; 2014I; 2014J), Jonah and Jimoh (2013A), Jonah *et al.* (2013B; 2013C; 2013D), and Jonah *et al.* (2011A; 2011B; 2011C; 2011D) have always argued in favour of georeferencing field data and their concomitant tie-in to their specific GIS database.

Whilst the earlier survey was a sole VES exercise at 200m station-spacing over the 2km^2 areal extent, this present intercalated survey was limited to 1km^2 because of the its dual VES-IP nature. What is understood here is that the ground location of a specific station designation of the present survey is exactly 100m to the west of that same specific station designation of that of the earlier survey. In this case, TT1-1 of the present survey is intercalated between TT1-1 and TT1-2 of the earlier survey: TT1-1 of the present survey is exactly mid-point of TT1-1 and TT1-2 of the earlier survey; TT1-1 of the present survey is 100m west of TT1-1 of the earlier survey and 100m east of TT1-2 of the earlier survey.

The Area of Study

The 1km^2 areal extent of this survey is subsumed in the greater Phase II Development. Its georeferenced co-ordinates are the following: 09^{0}30′57.8′′N, 006^{0}25′39.0′′E; 09^{0}30′57.8′′N, 006^{0}26′11.4′′E; 09^{0}31′30.2′′N, 006^{0}26′11.4′′E; 09^{0}31′30.2′′N, 006^{0}25′39.0′′E.

The Phase II Development at the Gidan Kwano Campus: The location most suited for the Phase II Development at the Gidan Kwano Campus is the 8km^2 areal extent shown in Fig.1, defined to be a perfect rectangle on the ground with its ends corresponding to the following georeferenced co-ordinates: 09^{0}30′57.8′′N, 006^{0}25′39.0′′E; 09^{0}30′57.8′′N, 006^{0}26′43.8′′E; 09^{0}33′07.4′′N, 006^{0}26′43.8′′E; 09^{0}33′07.4′′N, 006^{0}25′39.0′′E (Jonah *et al.*, 2014I).

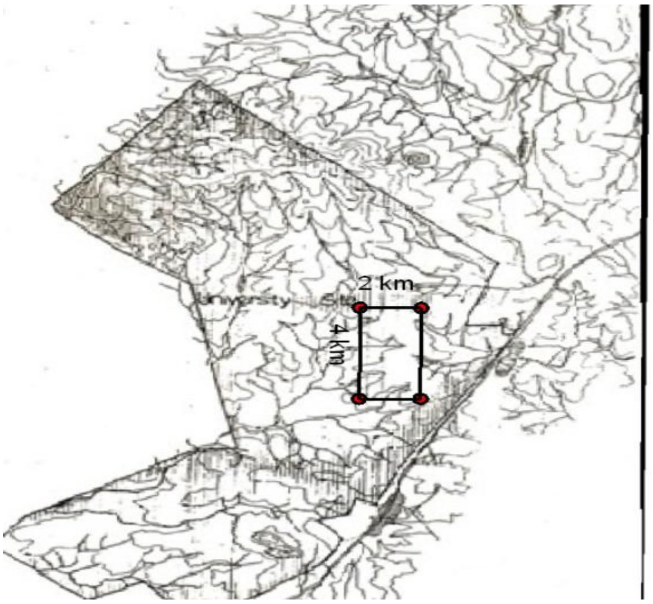

Fig.1. Location most suited for Phase II development at the Gidan Kwano Campus

Literature Review

With respect to studies that have been done at the Gidan Kwano Campus Phase II Development, Jonah *et al*. (2014I; 2014J) may be readily cited. Jonah *et al*. (2014I) reported that the desire of the management of the Federal University of Technology (F.U.T.), Minna, to inaugurate the structural development of Phase II of the Gidan Kwano Campus presented a challenge for the F.U.T. as to the creation of a database that the F.U.T. could consult and incorporate into the wider Physical Planning and Development (PPD) scheme. The authors pointed out that the objective of this study was the creation of a database for aquifer and geotechnical information. Station-separation for this 2km^2 areal extent of the study area was fixed at 200m; thus there were sixty-six principal stations slated for this survey. Further, the authors remarked that, because of the need to ensure independent verification of the results being presented, georeferencing of all survey stations for the vertical electrical sounding (VES) investigation was carried out too. However, only sixty-four principal stations were occupied for this exercise because locations of transverse traverse 11-2 and 11-4 (TT11-2 and TT11-4) were coincident with the top of large outcrops. The authors reported that the data collected was processed by means of the windows-compatible WinResist tool to determine the number of layers at each VES station and the Surfer 10 tool to produce the iso-resistivity maps at depths and the map of the thickness regime that is always desired for geotechnical interpretation. The authors clarified that, as a result of invoking the “Geoexplore Empirical Standardization for Minna Area,” the “Olasehinde Protocol,” and using the depth map as a strict control the VES locations identified as TT1-3, TT1-4, TT2-4, TT4-1, and TT4-3 were flagged as “strongly aquiferous.” It was understood that the region of all TT9s, TT10s, and TT11s, incidentally closest to the existing Phase I development, especially TT9-3, TT9-4, TT10-3 were most suited for locations that would not prove logistical challenges for site selection for buildings and other structural development. The authors recommended that the result of this study be adopted wholeheartedly by the Management of the Federal University of Technology, Minna, as a complementary document for the development of Phase II of the Gidan Kwano Campus.

Jonah *et al*. (2014J) concerns the evaluation of geomorphological quality control of geoelectrical data at the Gidan Kwano Campus Development Phase II. The authors pointed out that as part of a suite of protocols needed as controls for geoelectrical data collected out in the field, a purpose-specific topographic map was created to serve as a veritable tool of quality control (QC) for an ongoing fieldwork. It is understood that the three spatial co-ordinate values (x,y,z) that specified full-body georeferencing scheme were collected for 861 principal stations for an $8km^2$ grid corresponding to station-spacing of 100m. The authors reported that processing the data set by means of the Surfer®10 route yielded the desired contour map and the corresponding landform profile. As a fine-tuning technique, the authors juxtaposed the landform profile map with acquired geoelectrical field data and they observed correlation that ensures that the field data can indeed be relied upon.

Dataset of Study

Only once was a wet stream barrier that precluded data collection encountered at TT5-3. Otherwise, there were 35 separate VES and IP readings to a depth of 200m except where the natural barriers of stream, thicket, or outcrop were impediments.

Results and Discussion

Initially, the VES field resistance values in ohms were converted to corresponding resistivity values by multiplying each of the resistance values by its corresponding geometrical factor. The IP values, in chargeability of milliseconds, need no such processing involving the geometrical factors.

Interpretation of Present Intercalated Vertical Electrical Sounding (VES) Data: The field resistivity values were initially subjected to the log-log plot routine of the Windows-compatible WinResist® software whence corresponding field curves for all the stations occupied were produced. Each of the WinResist® log-log plot provides information on the numbers of layers, the average resistivity values of these layers, and their approximate thicknesses.

Production of Iso-Resistivity Maps at Depths: In order to show the variation of resistivity on a constant plane across the area of study, it is necessary to produce resistivity maps at constant depths (i.e. the iso-resistivity maps). For this study, the Surfer® 10 software was used to generate the iso-resistivity maps at 10m, 20m, 30m, 40m, 50m, 60m, 70m, 80m, 90m, and 100m, see Figs 2 to 11.

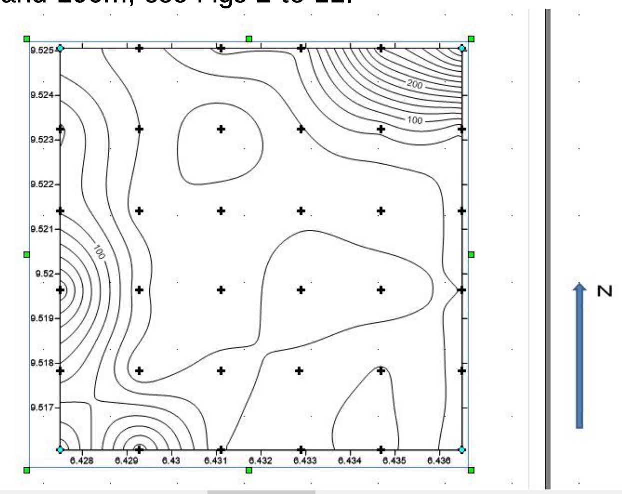

Fig.2: Iso-resistivity map **at 10m (Contour interval: 20Ωm**)

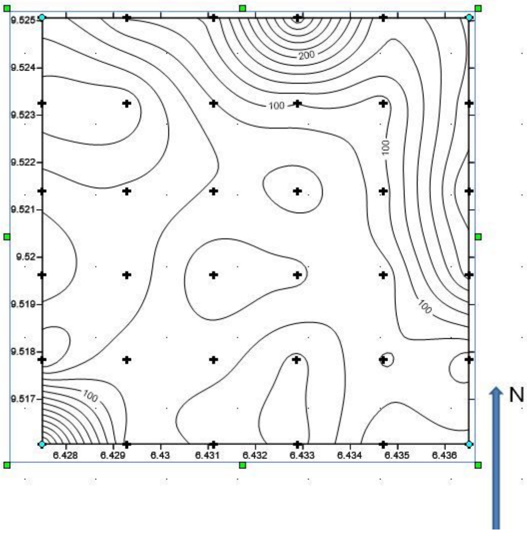

Fig.3: Iso-resistivity map **at 20m (Contour interval: 20Ωm**)

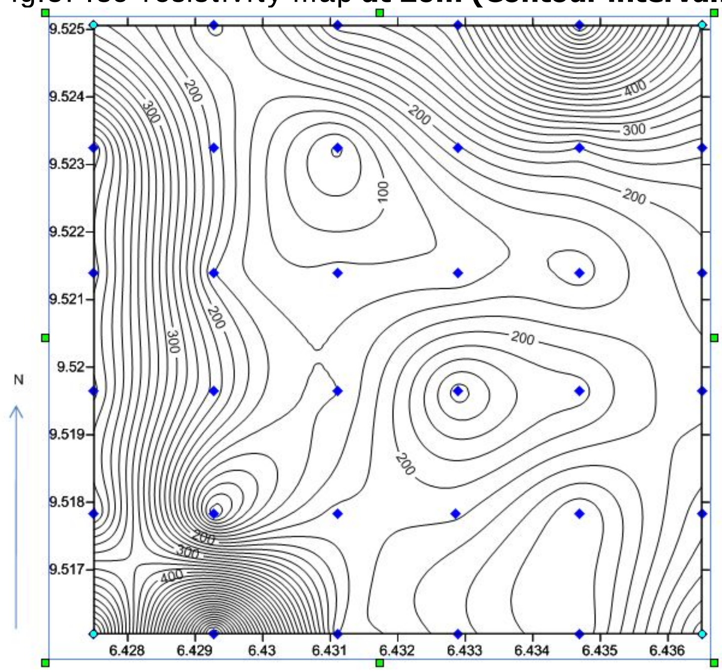

Fig.4: Iso-**resistivity map at 30m (Contour interval: 20Ωm**)

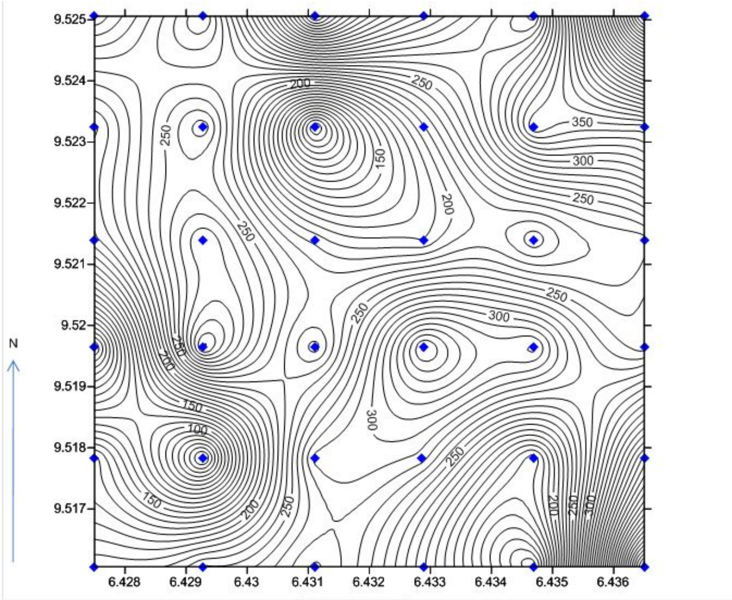

Fig.5: Iso-resistivity map **at 40m (Contour interval: 20Ωm**)

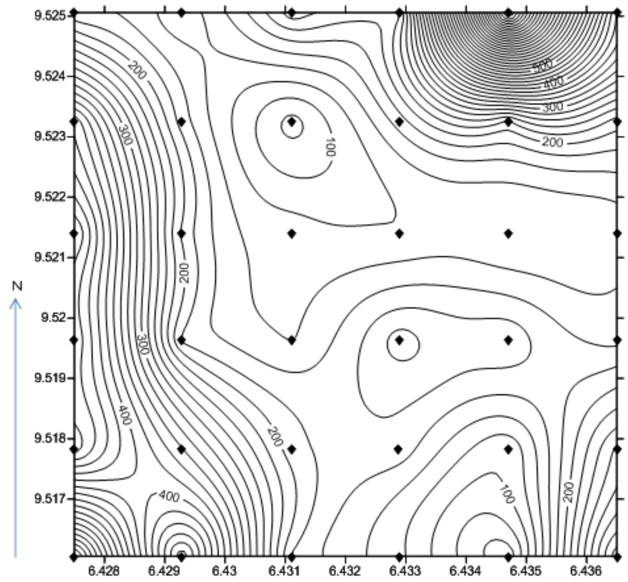

Fig.6: Iso-resistivity map **at 50m (Contour interval: 20Ωm**)

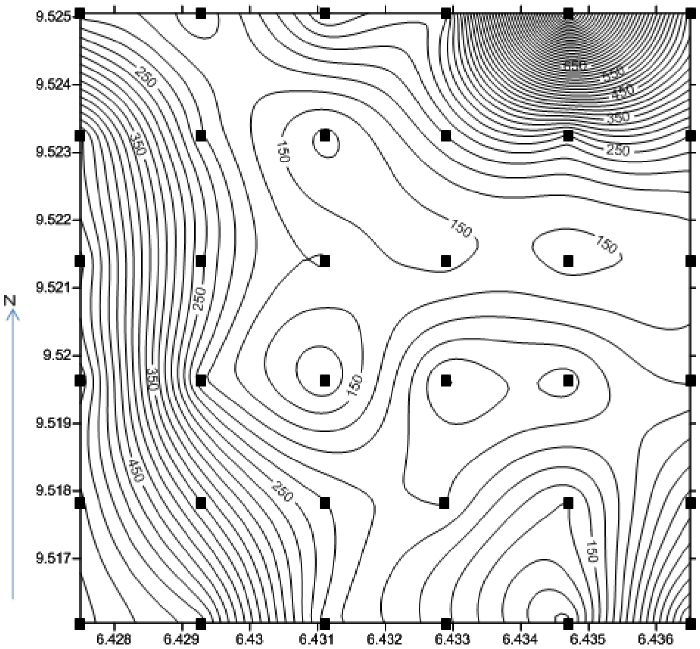

Fig.7: Iso-resistivity map **at 60m (Contour interval: 20Ωm**)

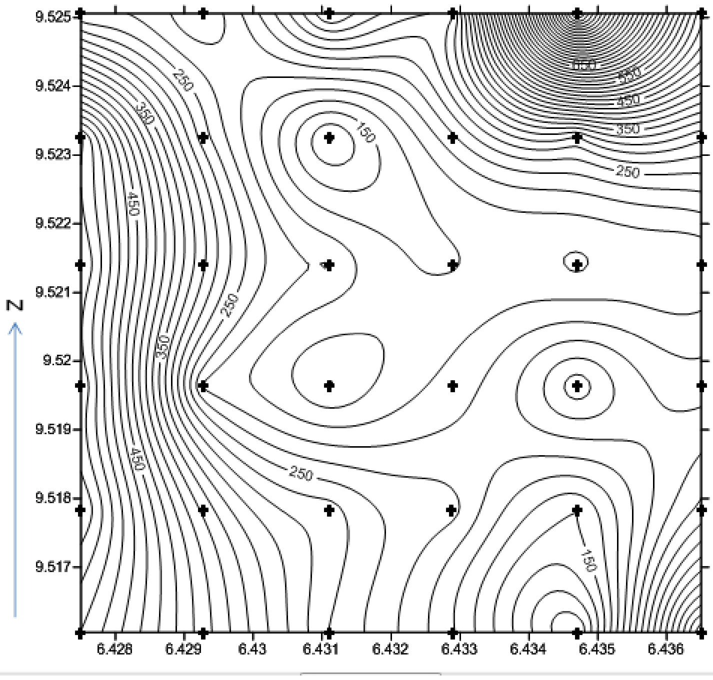

Fig.8: Iso-resistivity map at 70m (**Contour interval: 20Ωm**)

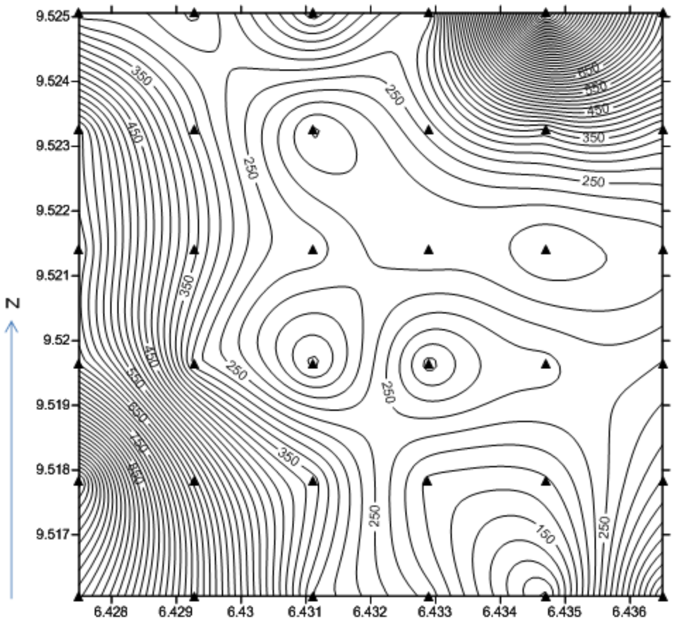

Fig.9: Iso-resistivity map **at 80m (Contour interval: 20Ωm**)

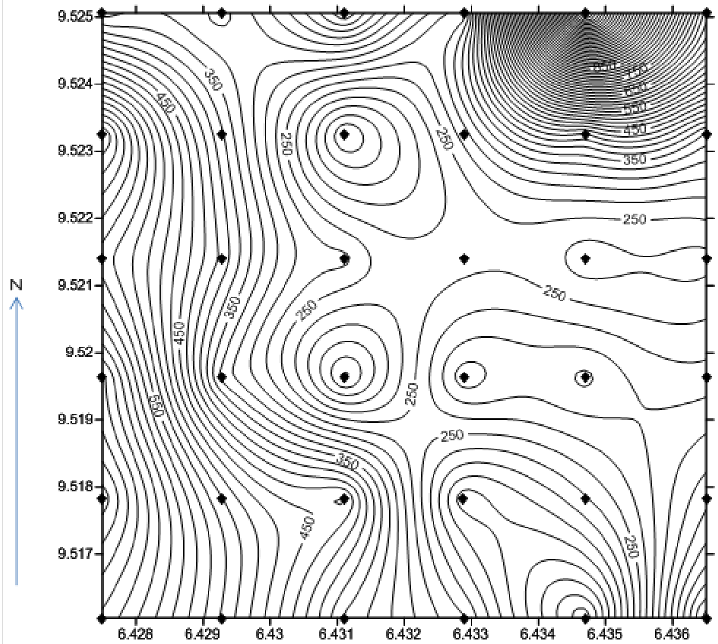

Fig.10: Iso-resistivity map **at 90m (Contour interval: 20Ωm**)

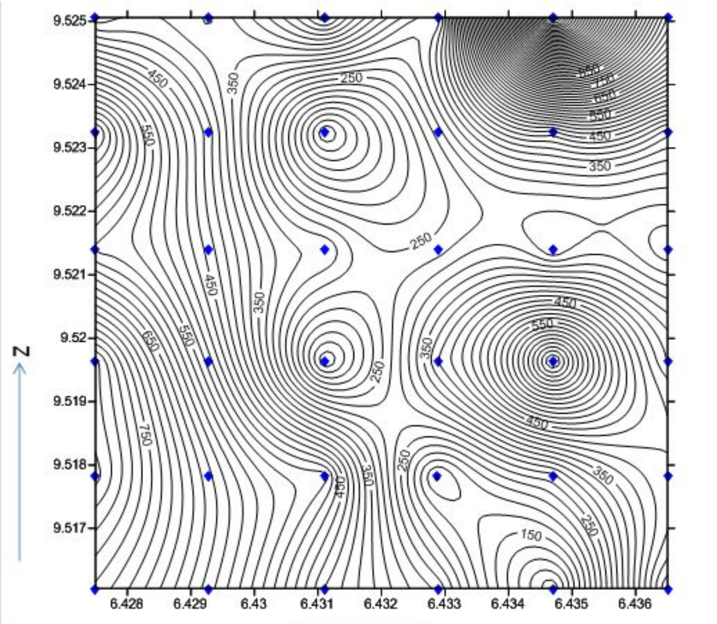

Fig.11: Iso-**resistivity map at 100m (Contour interval: 20Ωm**)

The Surfer® 10 software was also employed to produce a depth map at the area of study, see Fig.12.

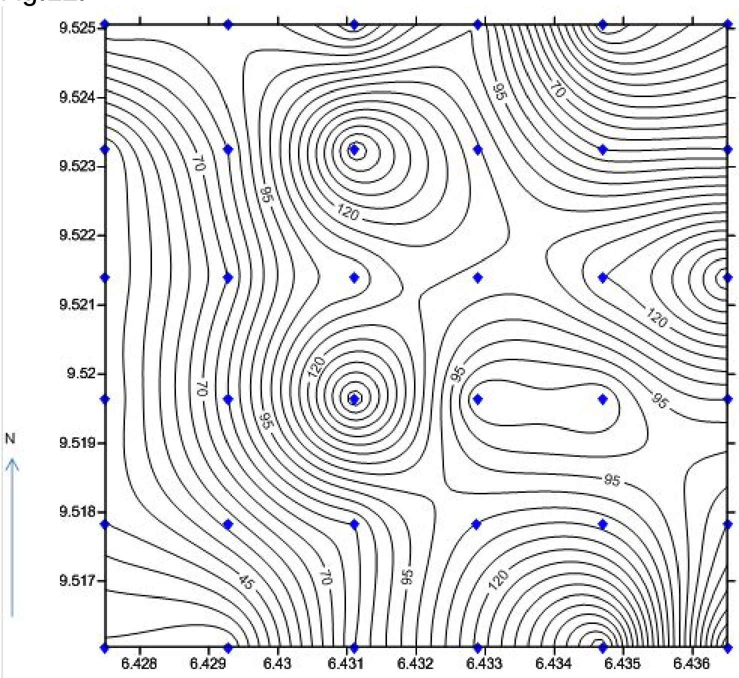

Fig.12: Depth map at the area of study

Discussion of Result

Qualitative Discussion of the Function of the Induced Polarisation Data for the Present Intercalated Survey: The intercalated nature of this present survey implies corroboration, too, of the earlier survey. The results of the earlier survey pinpointed some groundwater prospects (Jonah *et al.*, 2014I). Whilst the result of this present intercalated survey would be subjected to the same basic interpretation techniques like those of the earlier survey, a refinement of sorts herein would be provided by making recourse to the results of the tandem induced polarisation survey on a qualitative basis only. In this case, 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 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.

Juxtaposition of the Discussion of Results of the Earlier Survey and the Present Intercalated Survey:

Discussion of Result of the Earlier Survey:- This is as enunciated in (Jonah *et al.*, 2014I).
Discussion of Result of the Present Intercalated Survey:-The “Geoexplore Empirical Standardization for Minna Area” and the “Olasehinde Protocol.” It was pointed out earlier that “the result of this present intercalated survey would be subjected to the same basic interpretation techniques like those of the earlier survey.” A key reference tool that was germane to the interpretation of the earlier survey was the dual “Geoexplore Empirical Standardization for Minna Area” and the “Olasehinde Protocol.” 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, 1989; 1999; Muftau Jimoh, personal communication). On the bases of these dual protocols, therefore, TT1-1 is not considered an aquifer prospect; TT1-2 is a good showing up to the 150-m depth, TT1-3 is a good showing up to the 70-m depth, TT1-4 is a good showing up to the 50-m depth, TT1-5 is not considered an aquifer prospect, TT1-6 is a good showing up to the depth of the barrier encountered, TT2-1 is a good showing up to the 40-m depth, TT2-2 is a good showing up to the 80-m depth, TT2-3 is a good showing up to the 50-m depth, TT2-4 is a good showing up to the 50-m depth, TT2-5 has incomplete information, TT2-6 is not a prospect. TT3-1 is a good showing up to the 60-m depth; TT3-2 is a good showing up to the 50-m depth, TT3-3 is a good showing up to the 40-m depth, TT3-4 is a good showing up to the 110-m depth, TT3-5 is a good showing up to the 60-m depth, TT3-6 is not a good showing, TT4-1 is a good showing to the 80-m depth, TT4-2 is a good showing to the 80-m depth, TT4-3 is a good showing to the 80-m depth, TT4-4 is a good showing to the 60-m depth, TT4-5 is a good showing to the 50-m depth, TT4-6 is not a good showing. TT5-1 is a good showing to the 40-m depth; TT5-2 is a good showing to the 40-m depth, TT5-3 coincided with a wet stream barrier, TT5-4 is a good showing to the 120-m depth, TT5-5 is a good showing to the 50-m depth, TT5-6 is not a good showing, TT6-1 is not a good showing, TT6-2 is not a good showing, TT6-3 is not a good showing, TT6-4 would not be a

good showing down to the 30m, TT6-5 is a good showing to the 70-m depth, and TT6-6 is a good showing to the 50-m depth.

The WinResist® Plots: The WinResist® plots were vital guides to determining the numbers of layers at each survey location and, most important of all for this survey, for extracting information on the depth to basement used in the production of the isopach map of Fig.12.

The Iso-Resistivity Maps at Depths: On the maps of Fig.2 to Fig.11, the transverse traverse (TT) designations are in increasing order from south to north (i.e. TT1 to TT6); each profile unit designation is from east to west (as in TT1-1 to TT1-6). The crosses of these figures form a 6 x 6 matrix. Thus the lowest resistivity value of 20Ωm can easily be made out on the 10m-depth map of Fig.12 at TT5-4. In Fig.13, on the 20m-depth map, TT5-2 to TT5-5 form a linear spread of progressively decreasing resistivity from 100Ωm to 20Ωm. TT4-2 to TT4-5, TT3-2 to TT3-5, and TT2-2 to TT2-5 also mirror this pattern. On the 30m-depth map of Fig.14, TT5-4 stands out as the lowest-resistivity region at 60Ωm in a "sea" of ohmic spikes. On the 40m-depth map of Fig.15, TT5-4, TT2-5, and TT1-2 stand out as the lowest-resistivity regions. TT5-4 and TT1-2 are made out still as the lowest resistivity regions on the 50m-depth map of Fig.16; the resistivity value at TT2-5 increases over this 10m-window enormously. TT4-1 to TT4-4 and TT3-1 to TT3-4 form a region of "associate low-resistivity" at this depth, too. The trend of Fig.16 is continued in Fig.17 for the 60m-depth map; the new "entrant" here is TT1-3 and TT2-2. For the 70m-depth map of Fig.18, the resistivity trend of Fig.17 is exactly imaged here. For the 80m-depth map of Fig.19, for the 90m-depth map of Fig.20, and for the 100m-depth map of Fig.21, the resistivity trend of Fig.17 is exactly imaged here, too.

The Isopach Map: The regions of low resistivity values at depths correlate strongly with the regions of contour closures observed on the isopach map of Fig.12.

Conclusion

It was pointed out that the ground location of a specific station designation of the present survey is exactly 100m to the west of that same specific station designation of that of the earlier survey. In this case, TT1-1 of the present survey is intercalated between TT1-1 and TT1-2 of the earlier survey: TT1-1 of the present survey is exactly mid-point of TT1-1 and TT1-2 of the earlier survey; TT1-1 of the present survey is 100m west of TT1-1 of the earlier survey and 100m east of TT1-2 of the earlier survey.

Along the first TT profile (i.e. TT1), the earlier survey identified the following prospects and their corresponding drill window based on the suite of protocols under consideration:
TT1-3: 30m to 150m aquifer drill window
TT1-4: 30m to 150m aquifer drill window

TT1-3 of the present survey is intercalated between *TT1-3* and *TT1-4* of the earlier survey. The interpretation route adopted for this survey indicated that, for the present survey, TT1-3 is a good showing up to the 70-m depth. Thus, for the 200m-spread of *TT1-3* to *TT1-4*, three VES stations on an east-west line at 100m separation could be drilled for groundwater to the varying total depths (TDs) of *150m*-70m-*150m*. In essence, the stated aim of "plugging the knowledge gap of geological information for intervening 200m-spread station spacing of the earlier survey" has largely been achieved over this 200m-spread. Even though for the present survey, TT1-4 is a good showing up to the 50-m depth, it does not *positively intercalate TT1-4* to *TT1-5* of the earlier survey because the earlier survey does not identify *TT1-5* as a prospect location based on the dual protocols under consideration. Interestingly, the present survey indicates that TT1-5 is not considered an aquifer prospect! Thus, the 100m-spread between *TT1-5* and TT1-5 and the 100m-spread between TT1-5 and *TT1-6* should not be considered for drilling for groundwater exploitation at all.

Along the second TT profile (i.e. TT2), the earlier survey identified the following prospects and their corresponding drill window based on the suite of protocols under consideration:
TT2-1: 30m to 80m aquifer drill window
TT2-2: 10m to 80m aquifer drill window
TT2-3: 15m to 90m aquifer drill window
TT2-4: 30m to 120m aquifer drill window
TT2-5: 15m to 60m aquifer drill window
TT2-6: 8m to 50m aquifer drill window

For the present survey, TT2-1 is a good showing up to the 40-m depth, TT2-2 is a good showing up to the 80-m depth, TT2-3 is a good showing up to the 50-m depth, TT2-4 is a good showing up to the 50-m depth, TT2-5 has incomplete information, and TT2-6 is not a prospect. Thus, there is *positive intercalation* at 100m-spread from *TT2-1*, through *TT2-2*, *TT2-3*, and *TT2-4*.

Along the third TT profile (i.e. TT3), the earlier survey identified the following prospects and their corresponding drill window based on the suite of protocols under consideration:
TT3-1: 20m to 90m aquifer drill window
TT3-2: 8m to 60m aquifer drill window
TT3-3: 20m to 100m aquifer drill window
TT3-4: 30mm to 80m aquifer drill window

For the present survey, TT3-1 is a good showing up to the 60-m depth; TT3-2 is a good showing up to the 50-m depth, TT3-3 is a good showing up to the 40-m depth, TT3-4 is a good showing up to the 110-m depth, TT3-5 is a good showing up to the 60-m depth, TT3-6 is not a good showing. Thus, there is *positive intercalation* at 100m-spread from *TT3-1*, through *TT3-2*, *TT3-3*, and *TT3-4*; this trend is extended to about 100m beyond *TT3-4* along the linear profile.
Along the fourth TT profile (i.e. TT4), the earlier survey identified the following prospects and their corresponding drill window based on the suite of protocols under consideration:
TT4-1: 20m to 130m aquifer drill window
TT4-2: 20m to 110m aquifer drill window
TT4-3: 40m to 150m aquifer drill window
TT4-5: 20m to 80m aquifer drill window

For the present survey, TT4-1 is a good showing to the 80-m depth, TT4-2 is a good showing to the 80-m depth, TT4-3 is a good showing to the 80-m depth, TT4-4 is a good showing to the 60-m depth, TT4-5 is a good showing to the 50-m depth, and TT4-6 is not a good showing. Thus, there is *positive intercalation* at 100m-spread from *TT4-1*, through *TT4-2*, *TT4-3*, *TT4*-4, and *TT4-5*; this trend is extended to about 100m beyond *TT4-5* along the linear profile.

Along the fifth TT profile (i.e. TT5), the earlier survey identified the following prospects and their corresponding drill window based on the suite of protocols under consideration:

TT5-1: 30m to 90m aquifer drill window
TT5-2: 20m to 90m aquifer drill window
TT5-3: 20m to 80m aquifer drill window
TT5-4: 40m to 80m aquifer drill window
TT5-5: 30m to 80m aquifer drill window
TT5-6: 20m to 50m aquifer drill window

For the present survey, TT5-1 is a good showing to the 40-m depth; TT5-2 is a good showing to the 40-m depth, TT5-3 coincided with a wet stream barrier, TT5-4 is a good showing to the 120-m depth, TT5-5 is a good showing to the 50-m depth, TT5-6 is not a good showing. Thus, there is *positive intercalation* at 100m-spread from *TT5-1*, through *TT5-2*, *TT5-3*, *TT5*-4, and *TT5-5*; this trend is extended to about 100m at *TT5-6* along the linear profile.

Along the sixth TT profile (i.e. TT6), the earlier survey identified the following prospects and their corresponding drill window based on the suite of protocols under consideration:
TT6-1: 5m to 70m aquifer drill window
TT6-5: 30m to 110m aquifer drill window
TT6-6: 30m to 70m aquifer drill window

For the present survey, TT6-1 is not a good showing, TT6-2 is not a good showing, TT6-3 is not a good showing, TT6-4 would not be a good showing down to the 30m, TT6-5 is a good showing to the 70-m depth, and TT6-6 is a good showing to the 50-m depth. The prospect locations of *TT6-1*, *TT6-5*, and *TT6-6* implies a correlation of no-prospects over the 200m-spread between *TT6-1* and *TT6-2*, the 200m-spread between *TT6-2* and *TT6-3*, the 200m-spread between *TT6-3* and *TT6-4*, and the 200m-spread between *TT6-4* and *TT6-5*. Thus, there is *positive intercalation* for no-prospects at 100m-spread from *TT6-1*, through *TT6-2*, *TT6-3*, and *TT6*-4; this trend is extended to about 100m at TT6-4 along the linear profile. *Positive intercalation* for prospects can be made out at 100m-spread between *TT6-5 and TT6-6*.

For the present survey, it can be inferred from the foregoing that based on the dual empirical protocol scheme, the following VES locations are considered good prospects for groundwater: TT1-2, TT1-3, TT1-4, TT1-6, TT2-1, TT2-2, TT2-3, TT2-4, TT3-1, TT3-2, TT3-3, TT3-4, TT3-5, TT4-1, TT4-2, TT4-3, TT4-4, TT4-5, TT5-1 TT5-2, TT5-4, TT5-5, TT6-5, and TT6-6. However, if prevailing economic circumstances dictates that only a very limited number of VES locations could be drilled for boreholes at the area of the present survey, then imposing a constraint involving analysis of the iso-resistivity contour maps of Fig.12 to Fig.21, then the highly prospective VES locations would be TT5-4, TT1-2, TT1-3, and TT2-2.

Now, for the recognised highly prospective VES locations of TT5-4, TT1-2, TT1-3, and TT2-2, how would it be certain that it was freshwater and not clay that is responsible for the observed low resistivity regime at depth? Recourse is made here to the section on the qualitative discussion of the function of the induced polarisation data. Herein, examination of the individual IP tables of values would be undertaken for TT5-4, TT1-2, TT1-3, and TT2-2. This qualitative 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).

Qualitative Examination of IP Table for TT5-4 (see Table 1): It is observed that a negative chargeability value of -55.4ms exist for TT5-4 at the 40m-depth mark: 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. Interestingly, above this 40m-depth mark layer (i.e. at the 30m-depth mark) for TT5-4, the absolute IP value of 178ms is much greater than the absolute value of 55.4ms at the 40m-depth. 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." 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. This being the case, the absolute IP value of 178ms at the 30m-depth mark is "high" compared to the absolute value of 55.4ms at the 40m-depth mark (i.e. "low IP"). Based on this reckoning, TT5-4 is a very strong candidate for groundwater prospect at the 40m-depth mark, and the iso-resistivity maps have also indicated a continuation of low-resistivity trend at depths beyond this 40m-depth mark.

Qualitative Examination of IP Table for TT1-2 (see Table 2): At the 40m-depth mark, a chargeability of -9.19ms is observed in contrast to an absolute "high" IP value of 106ms at the 5m-depth mark. The deduction that the clay bed lies atop the water-bearing strata in this situation is not misplaced. Based on this reckoning, TT1-2 is a very strong candidate for groundwater prospect at the 40m-depth mark, and the iso-resistivity maps have also indicated a continuation of low-resistivity trend at depths beyond this 40m-depth mark.

Qualitative Examination of IP Table for TT1-3 (see Table 3): The corresponding observation for the TT1-2 VES table of the TT1-3 location can be made out at the 5m-depth mark and at the 6m-depth mark. The iso-resistivity maps have indicated a continuation of low-resistivity trend at depths beyond the 40m-depth mark for this VES location.

Qualitative Examination of IP Table for TT2-2 (see Table 4): The corresponding observation for the TT1-2 VES table of the TT2-2 location can be made out at the 6m-depth mark and at the 8m-depth mark. The iso-resistivity maps have indicated a continuation of low-resistivity trend at depths beyond the 40m-depth mark for this VES location.

Table 1: Geoelectrical data record sheet for TT5-4

AB/2 (CURRENT)	MN/2 (POTENTIAL)	CHARGEABILITY (mS)	RESISTANCE	CURRENT (I)	STANDARD DEVIATION	STACKS	RESISTIVITY (**Ωm**)
1	.50	-0.047	17.739Ω	100mA	0.26	4	41.864
2	.50	-12.2	235.02mΩ	100mA	0.33	4	2.7730
3	.50	-23.9	64.468 mΩ	100mA	0.82	4	1.7922
5	.50	-26.7	38.619 mΩ	100mA	1.20	4	3.0045
6	.50	-39.9	25.032 mΩ	100mA	5.00	4	2.8035
6	1.00	-26.9	47.019 mΩ	100mA	4.30	4	2.5860
8	1.00	-20.4	32.349 mΩ	100mA	0.73	4	3.2026
10	1.00	-29.4	25.790 mΩ	100mA	0.57	4	4.0233
10	2.50	-16.0	58.415 mΩ	100mA	0.02	4	3.4406
15	2.50	-22.4	38.522 mΩ	100mA	1.30	4	5.2770
20	2.50	-35.0	29.240 mΩ	100mA	1.80	4	7.1631
30	2.50	-178	55.315 mΩ	100mA	5.50	4	31.087
40	2.50	-55.4	15.823 mΩ	100mA	11.0	4	15.015

40	7.50	10.8	76.541 mΩ	100mA	1.90	4	24.722
50	7.50	2.22	140.49 mΩ	100mA	2.80	4	71.915
60	7.50	-3.32	165.57 mΩ	100mA	5.30	4	122.85
70	7.50	0.19	105.01 mΩ	100mA	4.50	4	106.48
80	7.50	11.3	149.67 mΩ	100mA	3.20	4	198.91
80	15.00	11.3	204.50 mΩ	100mA	1.30	4	132.31
90	15.00	-0.89	152.77 mΩ	100mA	1.40	4	126.04
100	15.00	37.7	65.918 mΩ	100mA	3.50	4	67.499
110	15.00	-5.88	95.272 mΩ	100mA	0.03	4	119.08
120	15.00	-21.3	117.22 mΩ	100mA	1.10	4	173.95
130	15.00	-3.97	123.25 mΩ	100mA	0.55	4	215.30
150	15.00	-23.3	146.10 mΩ	100mA	0.05	4	340.93
170	15.00	25.4	56.223 mΩ	100mA	7.20	4	168.88
200	15.00	8.53	30.094 mΩ	100mA	0.85	4	125.38

Table 2: Geoelectrical data record sheet for TT1-2

GEOELECTRICAL DATA RECORD SHEET

TYPE OF SURVEY:..Induced Polarisation/Resistivity..**MODE:**..Time domain/VES.. **ARRAY:** ..Schlumberger……

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

LOCATION: (i) **N:** 09°30'57.8'' ....(ii) **E:** 006°26'04.92''...........**ELEVATION:** 202m……………….

OPERATOR:……………**RECORDER:**……… ……**DATE:** 12/05/2014……………..….**TIME:** 02:18 PM………………

TRANSVERSE TRAVERSE DESIGNATION: TT1-2…… **GPS UNIT:**… Garmin GPSmap72……….

AB/2 (CURRENT)	MN/2 (POTENTIAL)	GEOM. FACTOR, K	CHARGEABILITY (mS)	RESISTANCE	STANDARD DEVIATION	CURRENT (I)	STACKS	RESISTIVITY (Ωm)
1	.50	2.36	-1.12	3.434 mΩ	0.64	50mA	4	0.008
2	.50	11.8	-2.38	519.78 mΩ	0.44	100mA	4	6.133
3	.50	27.8	-0.26	237.32 mΩ	0.12	100mA	4	6.597
5	.50	77.8	-108.0	-63.81 mΩ	-12.53	100mA	4	4.964
6	.50	112	3.65	74.537 mΩ	1.70	100mA	4	8.348
6	1.00	55	0.91	160.41 mΩ	1.00	100mA	4	8.823
8	1.00	99	1.93	102.59 mΩ	1.50	100mA	4	10.156
10	1.00	156	8.26	73.066 mΩ	2.60	100mA	4	11.398
10	2.50	58.9	1.10	242.96 mΩ	0.79	100mA	4	14.310
15	2.50	137	-19.60	257.16 mΩ	2.40	100mA	4	35.230
20	2.50	245	-5.61	134.20 mΩ	1.90	100mA	4	32.879
30	2.50	562	-14.30	100.77 mΩ	2.60	100mA	4	56.632
40	2.50	1001	-20.40	48.35 mΩ	7.20	100mA	4	48.398
40	7.50	323	-9.19	151.42 mΩ	0.31	100mA	4	48.908
50	7.50	512	0.88	89.63 mΩ	2.90	100mA	4	44.355
60	7.50	742	-5.97	82.29 mΩ	20.00	100mA	4	61.059
70	7.50	1014	-2.60	64.99 mΩ	3.10	100mA	4	65.899
80	7.50	1329	25.20	35.89 mΩ	5.70	100mA	4	47.698
80	15.00	647	8.35	120.99 mΩ	0.92	100mA	4	78.281
90	15.00	825	2.20	88.81 mΩ	2.20	100mA	4	73.268
100	15.00	1024	209.00	49.50 mΩ	5.70	100mA	4	50.688
110	15.00	1244	25.40	13.63 mΩ	20.00	100mA	4	16.955
120	15.00	1484	22.80	36.02 mΩ	14.00	100mA	4	53.454
130	15.00	1746.90	-26.60	31.125 mΩ	6.90	100mA	4	54.372
150	15.00	2333.57	-35.00	85.33 mΩ	3.80	100mA	4	199.124
170	15.00	3004.09	-15.6	100.21 mΩ	9.20	100mA	4	301.040
200	15.00	4166.91	43.60	37.79 mΩ	6.80	100mA	4	157.468

Table 3: Geoelectrical data record sheet for TT1-3

AB/2 (CURRENT)	MN/2 (POTENTIAL)	CHARGEABILITY (mS)	RESISTANCE	CURRENT (I)	STANDARD DEVIATION	STACKS	RESISTIVITY (Ωm)
1	.50	0.67	13.614Ω	100mA	0.02	4	32.129
2	.50	0.52	2.0487Ω	100mA	2.70	4	24.166
3	.50	0.52	716.24mΩ	100mA	0.06	4	19.911
5	.50	1.15	157.27 mΩ	100mA	1.20	4	12.236
6	.50	-0.012	163.65 mΩ	100mA	0.12	4	18.329
6	1.00	-1.27	294.90 mΩ	100mA	1.10	4	16.219
8	1.00	1.28	197.39 mΩ	100mA	0.38	4	19.542
10	1.00	1.38	153.06 mΩ	100mA	0.07	4	23.877
10	2.50	1.78	497.12 mΩ	100mA	0.13	4	29.280
15	2.50	1.81	296.90 mΩ	100mA	0.24	4	40.675
20	2.50	2.01	215.58 mΩ	100mA	0.16	4	52.817
30	2.50	10.7	147.54 mΩ	100mA	0.23	4	82.917
40	2.50	1.72	119.24 mΩ	100mA	0.25	4	119.35
40	7.50	2.44	303.95 mΩ	100mA	0.30	4	98.175
50	7.50	2.55	243.92 mΩ	100mA	0.37	4	124.88
60	7.50	1.38	208.99 mΩ	100mA	0.29	4	155.07
70	7.50	0.38	189.67 mΩ	100mA	0.21	4	192.32
80	7.50	0.86	173.65 mΩ	100mA	0.80	4	230.78
80	15.00	0.23	333.05 mΩ	100mA	0.01	4	215.48
90	15.00	2.01	305.60 mΩ	100mA	0.25	4	252.12
100	15.00	1.58	278.61 mΩ	100mA	0.66	4	285.29
110	15.00	NATURAL	CONSTRAINT	AT	DISTANCE	NATURAL	CONSTRAINT
120	15.00	NATURAL	CONSTRAINT	AT	DISTANCE	NATURAL	CONSTRAINT
130	15.00	NATURAL	CONSTRAINT	AT	DISTANCE	NATURAL	CONSTRAINT
150	15.00	NATURAL	CONSTRAINT	AT	DISTANCE	NATURAL	CONSTRAINT
170	15.00	NATURAL	CONSTRAINT	AT	DISTANCE	NATURAL	CONSTRAINT
200	15.00	NATURAL	CONSTRAINT	AT	DISTANCE	NATURAL	CONSTRAINT

Table 4: Geoelectrical data record sheet for TT2-2

AB/2 (CURRENT)	MN/2 (POTENTIAL)	CHARGEABILITY (mS)	RESISTANCE	CURRENT (I)	STANDARD DEVIATION	STACKS	RESISTIVITY (Ωm)
1	.50	0.25	10.792Ω	100mA	0.01	4	25.469
2	.50	0.42	730.95mΩ	100mA	0.15	4	8.6250
3	.50	0.024	370.35 mΩ	100mA	0.11	4	10.295
5	.50	-3.44	161.01 mΩ	50mA	0.69	4	12.527
6	.50	-2.51	876.45 mΩ	50mA	2.70	4	98.162
6	1.00	2.17	249.36 mΩ	50mA	0.74	4	13.714
8	1.00	-0.99	181.56 mΩ	50mA	0.36	4	17.974
10	1.00	1.30	108.20 mΩ	100mA	0.31	4	16.879
10	2.50	-0.52	320.69 mΩ	100mA	1.10	4	18.889
15	2.50	-2.96	188.95 mΩ	50mA	0.63	4	25.886
20	2.50	1.37	143.46 mΩ	50mA	0.78	4	35.147
30	2.50	31.2	99.466 mΩ	50mA	1.20	4	55.899
40	2.50	27.6	75.905 mΩ	100mA	2.20	4	75.976
40	7.50	1.84	249.76 mΩ	100mA	0.37	4	80.672
50	7.50	-31.1	200.72 mΩ	100mA	3.20	4	102.77
60	7.50	-8.11	172.83 mΩ	100mA	0.26	4	128.24
70	7.50	-7.90	147.94 mΩ	100mA	1.30	4	150.01

80	7.50	2.79	132.88 mΩ	100mA	1.80	4	176.59
80	15.00	0.39	301.87 mΩ	100mA	0.45	4	195.31
90	15.00	2.16	276.60 mΩ	100mA	0.12	4	228.20
100	15.00	14.0	256.76 mΩ	100mA	0.34	4	262.92
110	15.00	NATURAL	CONSTRAINT	AT	DISTANCE	NATURAL	CONSTRAINT
120	15.00	NATURAL	CONSTRAINT	AT	DISTANCE	NATURAL	CONSTRAINT
130	15.00	NATURAL	CONSTRAINT	AT	DISTANCE	NATURAL	CONSTRAINT
150	15.00	NATURAL	CONSTRAINT	AT	DISTANCE	NATURAL	CONSTRAINT
170	15.00	NATURAL	CONSTRAINT	AT	DISTANCE	NATURAL	CONSTRAINT
200	15.00	NATURAL	CONSTRAINT	AT	DISTANCE	NATURAL	CONSTRAINT

Recommendation

Now that attention is being focused on the exploitation of groundwater resource at the Phase II Development of the Gidan Kwano Campus as an interim measure, it is recommended that for the 200m-spread of *TT1-3* to *TT1-4*, three VES stations on an east-west line at 100m separation could be drilled for groundwater to the varying total depths (TDs) of *150m*-70m-*150m*. Also, the VES locations *TT2-1*, *TT2-2*, *TT2-3*, and *TT2-4* could be drilled for groundwater at 100m linear spread. Drilling for groundwater is also recommended for the VES locations *TT3-1*, *TT3-2*, *TT3-3*, *TT3-4*, and 100m beyond *TT3-4* along the linear profile for the 100m-spread.

Along TT4, drilling for groundwater is recommended for the 100m-spread from *TT4-1*, through *TT4-2*, *TT4-3*, *TT4*-4, and *TT4-5*; this could be extended to about 100m beyond *TT4-5* along the linear profile. For TT5, drilling for groundwater is recommended for the 100m-spread from *TT5-1*, through *TT5-2*, *TT5-3*, *TT5*-4, and *TT5-5*; this could be extended to about 100m at *TT5-6* along the linear profile.

Transverse traverse number six (TT6), the northernmost traverse line of this survey, does not present such straightforward drill prospects. Drilling for groundwater prospect should not be carried out for the 100m-spread over the linear distance from *TT6-1*, through *TT6-2*, *TT6-3*, and *TT6*-4; this recommendation for drilling restriction extends to 100m linear spread to the west of *TT6*-4 (this is the equivalent of TT6-4 of the present survey). If drilling must be done at all along TT6, then it should be between *TT6-5 and TT6-6* at 100m-spread encompassing the mid-point location of TT6-5 of the present survey, as well as 100m beyond *TT6-6* to correspond to the location of the present TT6-6.

If prevailing economic circumstances precludes the drilling of a large number of boreholes at the area of the present survey, then it is recommended that only the VES locations of TT5-4, TT1-2, TT1-3, and TT2-2 be drilled for groundwater exploitation.

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