*International Journal of Industrial Technology, Engineering, Science, and Education (IJITESED), 2018, Vol.1 No.1, 73 - 80*

# Basement aquifer identification from combined topographic, petrological, and resistivity data acquired within FUT's Gidan Kwano Campus, Minna, Northccentral Nigeria

Jonah, S.A. and *Saidu, S.

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

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

## Abstract

It is usually not the norm, so far as studies carried out in the local basement complex geology of the Minna Area is concerned, to constrain the accuracy of the interpretation of VES data-set with a correspondingly-produced purpose-specific topographic and petrographic maps of the key area of study. Such approach would serve as a veritable tool of quality control (QC) of the interpretation of the acquired VES data-set. The aim of this study is to implement a valid quality control scheme for an earlier single-mode VES study. The topographic survey proceeded along transverse traverses in a west-east, east-west zig-zag format until transverse traverse (TT) 101 was completed. The petrographic survey phase of this study was concerned with the study of the aspects of the different outcrops seen at the area of study in terms of their strike, dip, and other structural orientation. Over the 2 $km^2$ area of study of interest here, it is observed that terrain or ground elevation progressively increases from south to north, from circa 208m in the southern reaches to circa 224m in the northern reaches with the lowest median of 204m occurring toward the mid-plane of the area of study. An important observation herein, too, is that elevation increases from west to east. It is understood from the petrographic map that the area of study is underlain by a continuous body of granite associated with discontinuous bodies of schist and pegmatite. Examination of the landform map of the area of study positively correlates the conclusion of aquifer prospects drawn from the earlier survey and it is strongly recommended to drill these locations for groundwater exploitation.

**Keywords: Topographic; petrographic; quality-control; groundwater**

## Introduction

For the 100 $km^2$ areal extent of the Gidan Kwano Campus (GKC), information on spatial topography is as gleaned from Adesoye (1986). Jonah and Jimoh (2013) discussed the production of a topographic map for a 15 $km^2$ extent of the GKC, which at 100 m station-spacing of the data collection process, was considered to be a refinement to that of Adesoye (1986) for that corresponding slice of ground. Actually, for the Adesoye (1986) map, information on landform attribute could not be easily gleaned whereas this is not the case for the contour map of Jonah and Jimoh (2013) because the contour patterns and values are discernible on account of taking

elevation information at 100 m comparatively closer intervals. For the 8 $km^2$ areal extent that is being touted as the ideal location for the Gidan Kwano Campus Phase II Development (Jonah *et al.* 2014A; 2014B; 2015A), Jonah *et al.* (2014B) have produced a site-specific topographic map, with its corresponding site-specific geomorphic map, still at 100 m station-spacing of the data collection process, that give more information about landform regimes compared to what could be gleaned from Adesoye (1996). The 2 $km^2$ areal extent area-of-study of this present study is subsumed in the 8 $km^2$ areal extent that is being touted as the ideal location for the Gidan Kwano Campus Phase II Development. Over this 2 $km^2$ areal extent, Jonah *et al.* (2014A) have completed a vertical electrical sounding (VES) survey to locate aquifer prospects; whilst the rule adopted for the interpretation of the result of their survey followed standardized technical nuances, there was no surface geomorphological control to aid their interpretation. This study is principally concerned with creating a topographic map, at 20 m station-spacing of the data collection process to serve as a further aid in the interpretation of the VES results of Jonah *et al.* (2014A). Petrographic mapping, of the type that is being proposed for this study, whence subsurface aquifer information is tied directly to surface systematic description of the texture of rocks in order to constrain interpretation even further, is an entirely novel concept for the 100 $km^2$ areal extent of the GKC. Suffice to point out, also, that there was no surface petrographic control to aid the interpretation of Jonah *et al.* (2014A). Thus, too, this study is principally concerned with creating a petrographic map to serve as a further aid in the interpretation of the VES results of Jonah *et al.* (2014A). The 2 $km^2$ of interest here, subsumed in the Gidan Kwano Campus Phase II Development, is identified by the following georeferenced co-ordinates, viz: $09^0 30' 57.8'' N$, $006^0 25' 39.0'' E$ (most extreme southwest); $09^0 30' 57.8'' N$, $006^0 26' 11.5'' E$ (most extreme southeast); $09^0 32' 02.8'' N$, $006^0 26' 11.5'' E$ (most extreme northeast); $09^0 32' 02.8'' N$, $006^0 25' 39.0'' E$ (most extreme northwest). It is known that the area of study under consideration herein is part of the Nigerian Basement Complex (NBC). It is usually not the norm, so far as studies carried out in the local basement complex geology of the Minna Area is concerned, to constrain the accuracy of the interpretation of VES data-set with a correspondingly-produced purpose-specific topographic and petrographic maps of the key area of study. Such approach would serve as a veritable tool of quality control (QC) of the interpretation of the acquired VES data-set. Jonah *et al.* (2014B) used the result of a topographic as a tool of QC for geoelectric data over an 8 $km^2$ areal extent of the proposed Phase II Development of the Gidan Kwano Campus. As at the present, there is no evidence that a dual topographic-petrographic

validation of the result of a VES survey in the Minna Area has been undertaken. The aim of this study is to implement a valid quality control scheme for an earlier single-mode VES study completed at a 2 $km^2$ tranche of the Gidan Kwano Campus Phase II Development, Federal University of Technology, Minna. The objectives of this study are the following: (i) The use of a purpose-specific topographic map to validate the result of a single-mode VES study completed at a 2 $km^2$ tranche of the Gidan Kwano Campus Phase II Development; herein, elevation values (that is, the "z" parameter) at designated principal stations of 20m over the 2 $km^2$ areal extent under consideration would be collected. The full gamut of this "z" values would be contoured in order to create a site-specific topographic map; at 20 m station-spacing, it is expected that the topographic map data field should produce a very detailed geomorphological profile of the area of study. (ii) The use of a purpose-specific petrographic map to validate the result of a single-mode VES study completed at a 2 $km^2$ tranche of the Gidan Kwano Campus Phase II Development; herein, a systematic description of the major outcrops occurring at the area of study would be implemented by means of specifying the nature and structural aspects of the outcrops in terms of their strike, dip, joint character, fracture character, fault character (where applicable), and so on. The result of Jonah *et al.* (2014A), to determine groundwater prospects over a 2 $km^2$ slice of the Gidan Kwano Campus Phase II Development, was based on the conventional "first-stage" VES interpretation schedule. The conclusions drawn regarding groundwater prospects over this 2 $km^2$ slice would be further strengthened when the result of this "first-stage" interpretation is tied to the result of the topographic map (resulting in a "second-stage" interpretation); tying this outcome further to the petrographic map would result in a "third-stage" interpretation scheme in order that the conclusions drawn may be truly relied on. There are 101 transverse traverses of the 2 $km^2$ areal extent of the area of study at 20 m station-spacing for the topographic map data-collection phase. Each transverse traverse (TT) is 1km (1000 m) long. At 20 m station-spacing there are 51 measurement stations on each TT, thus the total number of measurement stations is 51 x 101 = 5151. Elevation information was collected from these 5151 stations in order to create the topographic map of this study. The petrographic phase of this study was determined by the number of major outcrops that occur over the area of study. According to Jonah *et al.* (2014A; 2014B; 2015A; 2015B; 2015C), the location most suited for the Phase II Development at the Gidan Kwano Campus is the 8 $km^2$ 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 (most extreme southwest); $09^0$30′57.8″N, $006^0$26′43.8″E (most extreme southeast); $09^0$33′07.4″N, $006^0$26′43.8″E (most extreme northeast); $09^0$33′07.4″N, $006^0$25′39.0″E (most extreme northwest). According to Obaje (2009), the Nigerian Basement Complex (NBC) is one of the three major litho-petrological components that make up the geology of Nigeria. The NBC forms a part of the Pan-African mobile belt and lies between the West African and Congo Cratons and south of the Tuareg Shield (Black, 1980). It is intruded by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau and is unconformably overlain by Cretaceous and younger sediments. The Nigerian basement was affected by the 600 Ma Pan-African orogeny and it occupies the reactivated region which resulted from plate collision between the passive continental margin of the West African craton and the active Pharusian continental margin (Burke and Dewey, 1972; Dada, 2006). The basement rocks are believed to be the results of at least four major orogenic cycles of deformation, metamorphism, and remobilization corresponding to the Liberian (2,700 Ma), the Eburnean (2,000 Ma), the Kibaran (1,100 Ma), and the Pan-African cycles (600 Ma). The first three cycles were characterized by intense deformation and isoclinal folding accompanied by regional metamorphism, which was further followed by extensive migmatization. The Pan-African deformation was accompanied by a regional metamorphism, migmatization and extensive granitization and gneissification which produced syntectonic granites and homogeneous gneisses (Abaa, 1983). Late tectonic emplacement of granites and granodiorites and associated contact metamorphism accompanied the end stages of this last deformation. The end of the orogeny was marked by faulting and fracturing (Gandu *et al.*, 1986; Olayinka, 1992). Within the basement complex of Nigeria four major petro-lithological units are distinguishable, namely: (i) The Migmatite-Gneiss Complex (MGC), (ii) The Schist Belt (Metasedimentary and Metavolcanic rocks), (iii) The Older Granites (Pan African granitoids), and (iv) Undeformed Acid and Basic Dykes.

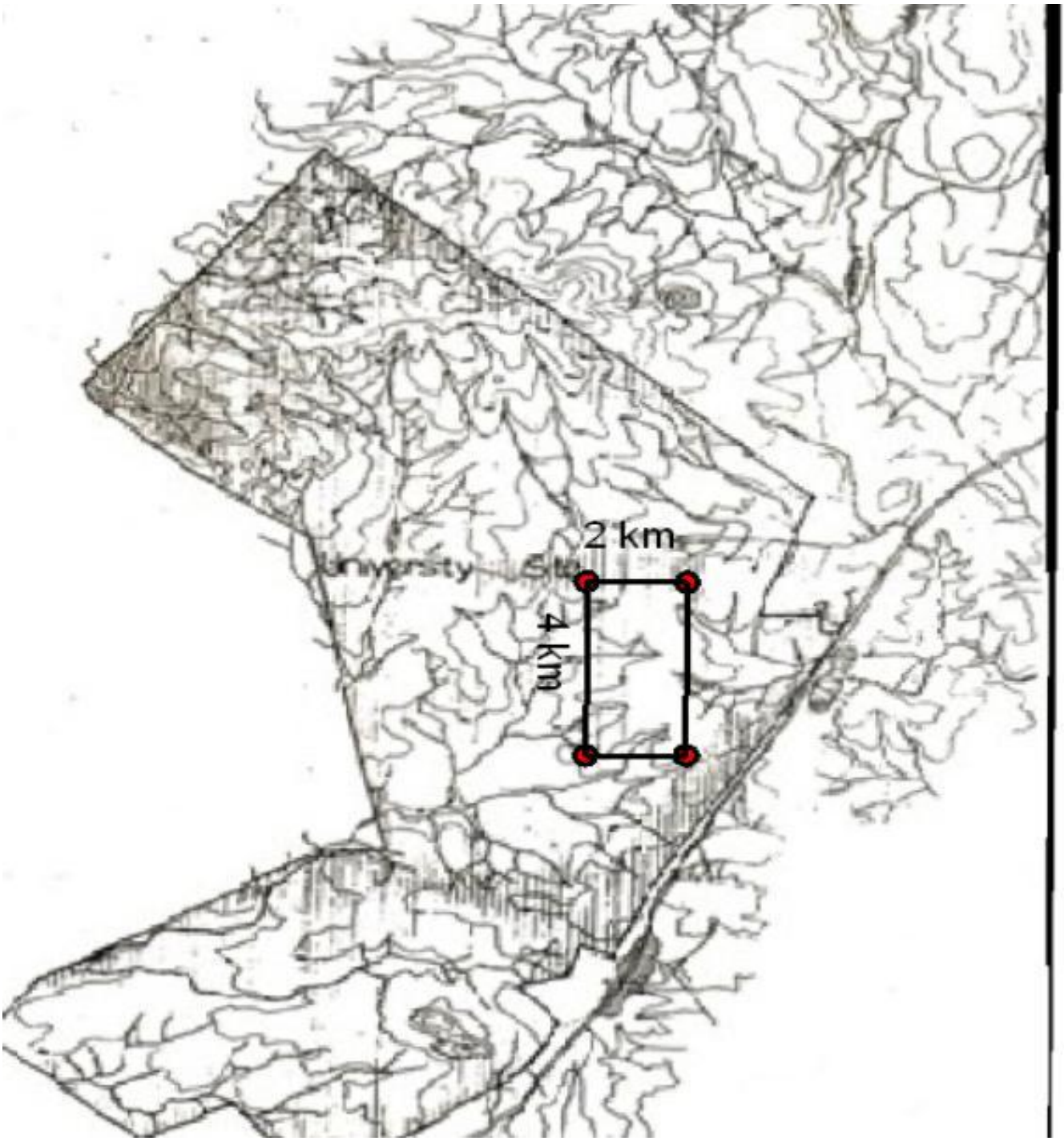


Fig.1. Location most suited for Phase II development at the Gidan Kwano Campus. (The GKC is the horse-shoe shape feature of Fig.1.)

**Survey Methods**

**The Topographic Survey:-** The essential idea herein is the collection of elevation values at 20 m station spacing over the 2 $km^2$ areal extent of the study area of interest. The survey proceeded along transverse traverses in a west-east, east-west zig-zag format until TT 101 was completed. Since each TT length was 1km long, upon completion of the $101^{st}$ traverse the survey crew has in reality trekked a distance equal to the length of the roadway linking Minna to Suleja; all the while the survey crew had to pause to take elevation readings at 20 m intervals. It is expected that the 20m station spacing adopted for this study would yield a large data field with a concomitant high resolution of the ground being survey. The layout of this topographic survey is as shown in Fig.2. Note that the designation for traverses along a north-south (N-S) direction is longitudinal traverses (LT) and the designation for traverses along an east-west (E-W) is transverse traverse (TT).

**The Petrographic Survey:-** The petrographic survey phase of this study was concerned with the study of the aspects of the different outcrops seen at the area of study in terms of their strike, dip, and other structural orientation. Each of the outcrops encountered was designated by a sample number, a designation of its rock type, its ground location, its georeferenced location, its camera image code, as well as its strike, dip, and other structural aspects. For this study, the overriding interest regarding the petrographic survey, is simply to restrict the scope to macroscopic petrography only.

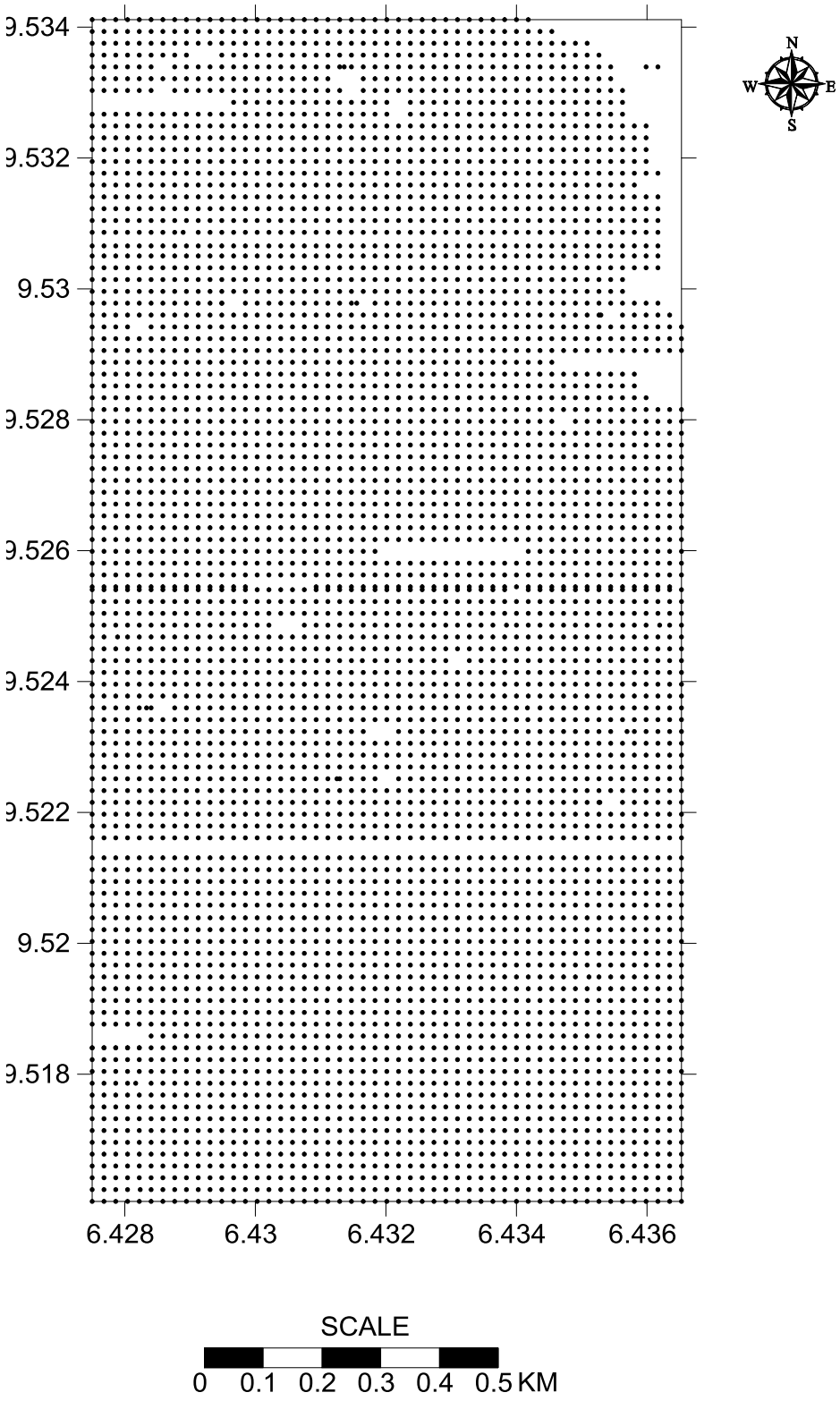


Fig.2. Layout of topographic survey

## Results and Discussion

### Examination of the Results of the 2 km$^2$ Single-Mode VES Survey:-

Station-separation for the 2 km$^2$ VES areal extent study-area was fixed at 200 m. What this means is that, along the north-south direction (longitudinal traverse or LT) there were six profiles and along the east-west direction (transverse traverse or TT) there were eleven profiles. At 200 m station-separation, there were sixty-six principal stations slated for this survey. Suffice to recall that, because of the need to ensure independent verification of the results being presented, it was instructive to adopt the practice of georeferencing survey and eventual prospect stations. This georeferencing of survey stations requirement was achieved by visiting each of the principal stations and recording their respective latitude and longitude co-ordinates by means of the Garmin GPSmap76 hand-held global positioning system unit. The Schlumberger array of the vertical electrical sounding mode of the resistivity survey, which involved the artificial introduction of the default equipment factory-set value of current of 10 mA (except where local geology does not permit this) into the ground through point electrodes, was employed throughout for the principal data collection phase of this study. The resulting potential was compared with the particular default current value by the terrameter, thereby displaying the resistance value. Resistance values at sixty-four of the sixty-six principal stations that were identified for this survey were recorded; resistance values could not be measured for two VES stations because these locations correspond to the top of massive outcrops. There were twenty-seven sequences of measurements for each VES location, except where equipment glitch (usually battery-related problems do not permit this). The transverse traverse designations are in increasing order from south to north (i.e. TT1 to TT11); each profile unit designation is from east to west (as in TT1-1 to TT1-6). This VES survey also proceeded along transverse traverses in a west-east, east-west zig-zag format until TT 11 was completed. Only stations TT11-2 and TT11-4 could not be surveyed in the course of this project exercise because their positions on the ground are exactly on top of bodies of outcrops. The initial processing step involved in the treatment of the data-set was the conversion of field resistance values to their corresponding resistivity values, usually taken to be the apparent resistivity values, which are the resistivity values of inhomogeneous earth. This was done by multiplying each of the field resistance values by their corresponding geometric factor (Kearey and Brooks, 1984; Parasnis, 1986; ABEM, 1999). Usually, after determining the resistivity values from the field

resistance values, it is desirable to generate curves, commonly log-log plots, showing the variation of resistivity values with the effective depth surveyed at that particular sequence for each VES station. It is recognised that the effective depth of penetration is equal to half the current electrodes spacing (if the current electrodes are separated by distance AB, then this AB/2). According to Zohdy (1989), 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. This approach makes it easy to construct maps of contoured resistivity values at different depths and to construct contoured geoelectric sections. For this 2 $km^2$ study, the field curves were obtained by plotting the apparent resistivity against half-current electrode spacing by the aid of the Windows-compatible WinResist® software. 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.

**Discussion of Result of the 2$km^2$ Single-Mode VES Survey:-**

**On the "Geoexplore Empirical Standardization for Minna Area" and the "Olasehinde Protocol."** Presently, there exist dual empirical rules to determine the likely presence of groundwater in the basement complex geological province. These rules are the "Geoexplore Empirical Standardisation for Minna Area" and the "Olasehinde Protocol." For the 2 $km^2$ study, the interpretation for aquifer prospects at the sixty-four VES locations was based on these rules. The "Geoexplore Empirical Standardization for Minna Area" states that ohmic resistance values of less than or equal to 0.3 Ω at the 20 m depth or greater (or, in resistivity terms, between 200 Ωm and 300 Ωm at the 20 m depth and less than 200 Ωm at depths greater than 20 m) is indicative of possible groundwater prospect. The "Olasehinde Protocol" states that resistivity values between 180 Ωm and 250 Ωm at the 20 m to 25 m depth mark are 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.

**Extraction of Aquifer Information for the 2 km$^2$ Single-Mode VES Survey:-** As a result of invoking the "Geoexplore Empirical Standardisation for Minna Area" and the "Olasehinde Protocol," the following VES stations are considered good prospects for aquifer (indicated here also are their corresponding drill window):

TT1-3: 30m to 150m aquifer drill window

TT1-4: 30m to 150m aquifer drill window

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

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

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

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

TT6-1: 5m to 70m aquifer drill window

TT6-5: 30m to 110m aquifer drill window

TT6-6: 30m to 70m aquifer drill window

TT7-1: 10m to 40m aquifer drill window

TT9-1: 10m to 40m aquifer drill window

TT9-2: 10m to 50m aquifer drill window

TT9-6: 10m to 60m aquifer drill window

The VES stations listed above are spread throughout the study from the TT1s in the extreme south of the study area to the TT11s in the extreme north of the study area. Now, imposing a tough groundwater prospect identification using the constraints of the "Geoexplore Empirical Standardisation for Minna Area," the "Olasehinde Protocol," and the depth map viewed for its overburden thickness character, the following VES locations are now flagged as "strongly aquiferous:" TT1-3, TT1-4, TT2-4, TT4-1, and TT4-3. The co-ordinates of these aquifer prospect locations are the following:

TT1-3: 09°30′ 57.8″; 006°25′58.4″ ≡ $9.516^0$; $6.433^0$

TT1-4: 09°30′ 57.8″; 006°25′52.0″ ≡ $9.516^0$; $6.431^0$

TT2-4: 09°31′4.2″; 006°25′58.4″ ≡ $9.518^0$; $6.433^0$

TT4-1: 09°31′17.2″; 006°25′39.0″ ≡ $9.521^0$; $6.428^0$

TT4-3: 09°31′17.2″; 006°25′52.0″ ≡ $9.521^0$; $6.431^0$

**Examination of the Results of the Present Survey**

**The Topographic Map:-** The topographic map for this study was produced by the aid of the Surfer-11® and Rockworks2006® applications. The "raw" elevation data in Microsoft Word® was converted into Microsoft Excel® by the Rockworks2006® application by which route the co-ordinates in degrees, minutes, and seconds were converted into degree-decimals values for ready input into the Surfer-11® application. In the Surfer-11® environment, the degree-decimals values data-field was saved initially, then the saved data was gridded, and subsequently the gridded data was used to create the required two-dimensional and three-dimensional maps. The result of this exercise showing the two-dimensional map is presented as Fig.3.

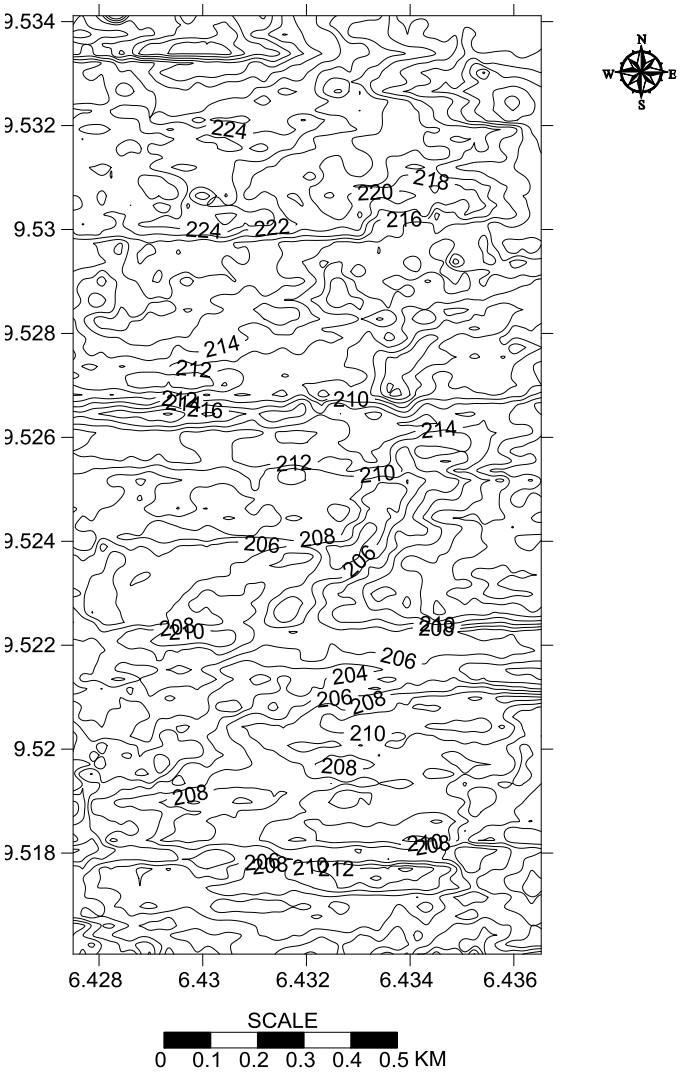


Fig.3. Topographic map of the area of study. Contour interval: 2m.

The corresponding digital elevation model map is shown as Fig.4.

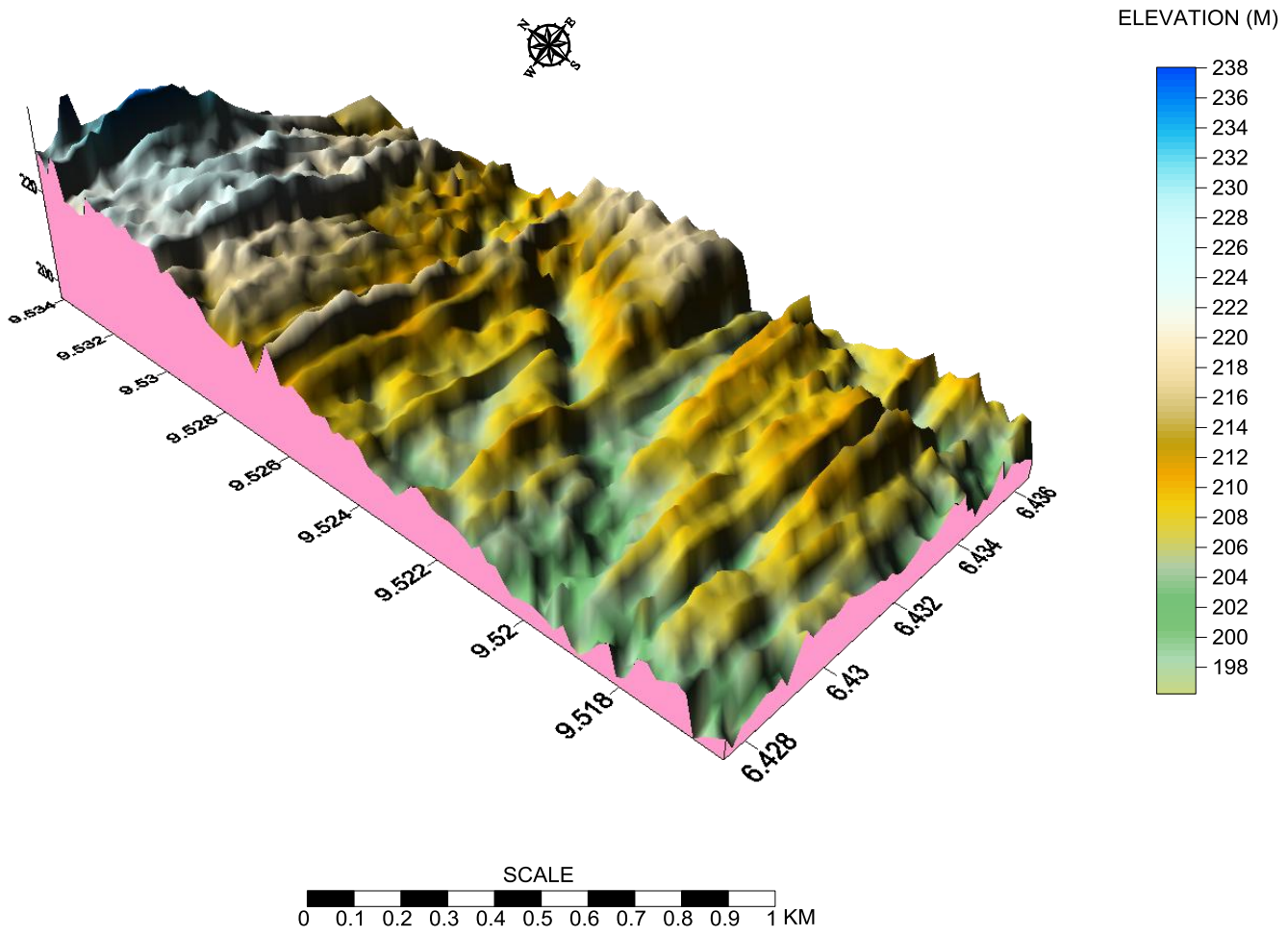


Fig.4. Digital elevation model map of the area of study

**The Petrographic Map:-** Production of the petrographic map was rather straightforward; information obtained from the recorded sample data set (rock type, plate location, GPS location, strike, description, etc.) was embedded into Microsoft Word® and transferred to the Surfer-11® to produce the petrographic map. On this map, there is a key representing different rock types. The result of this exercise is presented as Fig.5.

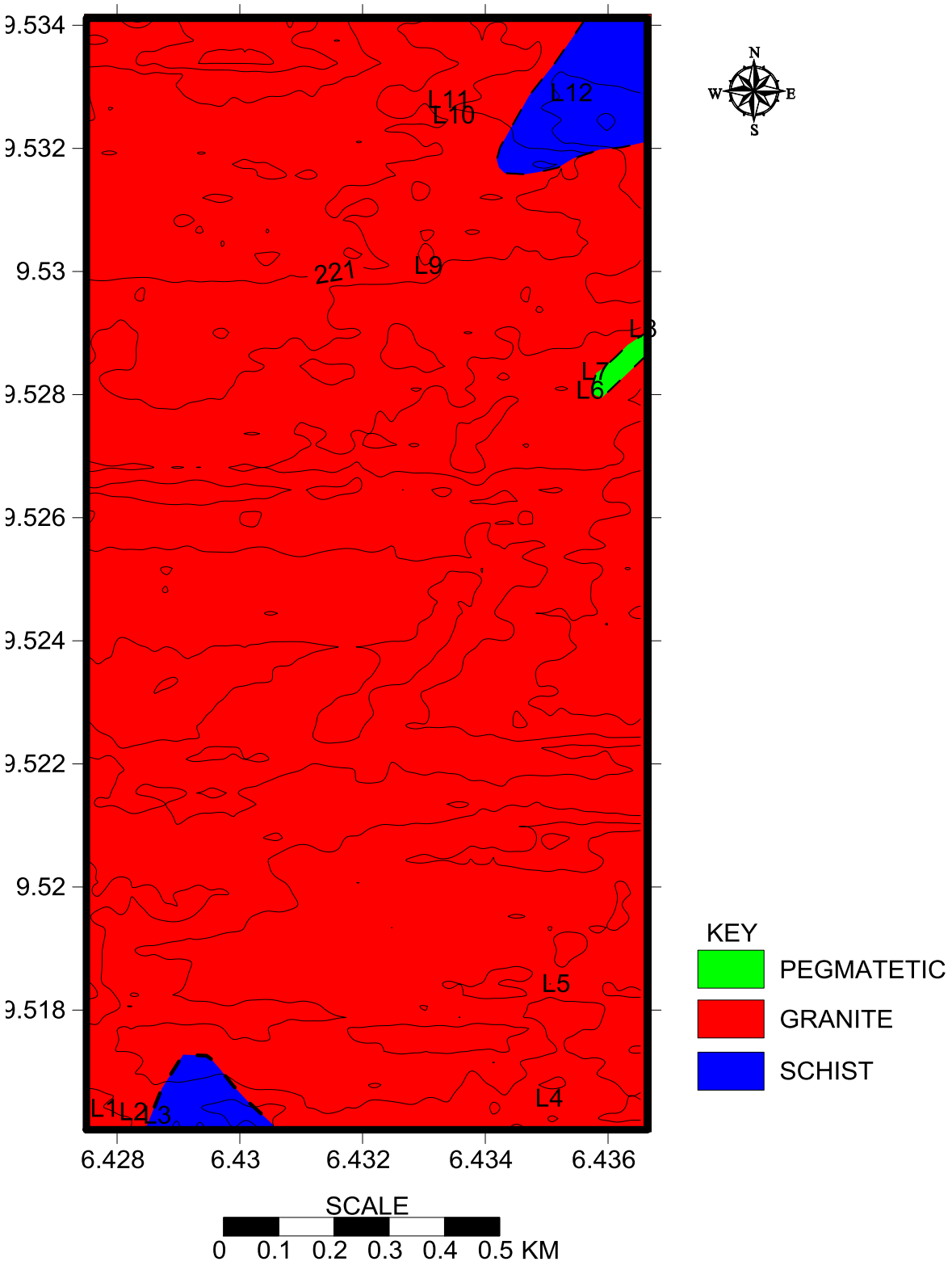


Fig.5. Petrographic map of the area of study

**Discussion of Result of the Present Survey**

**The Topographic Map:-** Over the 2km$^2$ area of study of interest here, it is observed that terrain or ground elevation progressively increases from south to north, from circa 208 m in the southern reaches to circa 224 m in the northern reaches: however, the lowest point of 204 m occur toward the southern mid-plane of the area of study; this can be made out in Fig.3. An important observation herein, too, is that elevation increases from west to east. On the three-dimensional (3-D) digital elevation model (DEM) map of Fig.4, the elevation information of Fig.3 translates to an understanding that the landform of the 2 km$^2$ area of study gently slopes from north to south and from east to west.

**The Petrographic Map:-** It is understood from the petrographic map of Fig.5 that the area of study is underlain by a continuous body of granite with small schist and pegmatite bodies adjoining this granite. Really, over the area of study the mapped bodies of schist and pegmatite are insignificant in comparative extent with the granitic substrate.

**Conclusion and Recommendation**

**Conclusions Drawn from Topographic Map:-** The gentle slopes of the landform, north-to-south and east-to-west, observed in Figs 3 and 4 can only mean that there is a residual southwest slope of the area of study; the implication of this fact for groundwater prospects, by intuitive deduction, is that if conclusions concerning locations of aquifers that are drawn from a geophysical survey identifies prospects at the southwest corner of the area of study, then these conclusions must not be ignored. Intuitive deduction aside, what is most important out in the field is the conclusion drawn based on the results that are got from a proper field survey. Recall that it was observed that the previous 2 km$^2$ single-mode VES survey identified aquifer prospects at the following locations:

TT1-3: 09°30′ 57.8″; 006°25′58.4″ ≡ $9.516^0$; $6.433^0$

TT1-4: 09°30′ 57.8″; 006°25′52.0″ ≡ $9.516^0$; $6.431^0$

TT2-4: 09°31′4.2″; 006°25′58.4″ ≡ $9.518^0$; $6.433^0$

TT4-1: 09°31′17.2″; 006°25′39.0″ ≡ $9.521^0$; $6.428^0$

TT4-3: 09°31′17.2″; 006°25′52.0″ ≡ $9.521^0$; $6.431^0$

Fig.4 is a veritable platform by which validation of the conclusion drawn from the $2km^2$ single-mode VES survey can be made. Consider, first, TT1-3 at $9.516^0$; $6.433^0$: where is this point located on Fig.4? The point $9.516^0$; $6.433^0$ can be located on the map to be in a depression along the east-west slope of the first profile line, although not necessary at the exact southwest as intuition would have determined; on ground, the point $9.516^0$; $6.433^0$ is actually located on a fertile depression far away from any observable outcrop, more like a sediment-filled ancient valley. As a result of this fact, it is concluded that TT1-3: 09°30′ 57.8″; 006°25′58.4″ ≡ $9.516^0$; $6.433^0$ remains a strong candidate for drilling for groundwater prospect.

Now, consider TT1-4 at $9.516^0$; $6.431^0$: where is this point located on Fig.4? This point is actually 200m to the west of TT1-3 at $9.516^0$; $6.433^0$ along the same profile line of equal latitude. Yet, again, on Fig.4 this point is located in a local depression along the east-west slope of the first profile line nearer the exact southwest corner than TT1-3. As a result of this fact, it is concluded that TT1-4: 09°30′ 57.8″; 006°25′52.0″ ≡ $9.516^0$; $6.431^0$ remains a strong candidate for drilling for groundwater prospect.

Consider TT2-4 at $9.518^0$; $6.433^0$: the second profile line at latitude $9.518^0$, as seen in Fig.4, slices through the landform of the area of study as a continuous local depression. TT2-4 is located slightly to the eastern flank than the exact southwest, but instrumental control and the fact that TT2-4 lies in a local depression (the local "highlands" may well be the tops of scattered outcrops) enables the conclusion that TT2-4: 09°31′4.2″; 006°25′58.4″ ≡ $9.518^0$;$6.433^0$ remains a strong candidate for drilling for groundwater prospect.

Consider TT4-1 at $9.521^0$; $6.428^0$: The "almost exact southwest and depression" descriptor exactly fits the location of TT4-1, as seen in Fig.4. Basically, TT4-1 sits in a local elevation low. It is concluded that TT4-1: 09°31′17.2″; 006°25′39.0″ ≡ $9.521^0$; $6.428^0$ remains a strong candidate for drilling for groundwater prospect.

Consider TT4-3 at $9.521^0$; $6.431^0$: although the point TT4-3 is not located at the southwest corner of the area of study, it sits at a local depression close to the mid-plane of the area of study. Since the basic idea of this "sit-in-a-depression" concept could well mean locations in the local valley morphology where local rock emplacements may have been significantly eroded and sand cover has accumulated over time and the prospect location not coinciding with the top of any

outcrop, it is concluded that TT4-3: 09°31′17.2″; 006°25′52.0″ ≡ $9.521^0$; $6.431^0$ remains a strong candidate for drilling for groundwater prospect.

**Conclusions Drawn from Petrographic Map:-** The pegmatite body and the schist body intrusions into the granitic substrate of the area of study do not coincide with any prospect locations identified from the earlier $2km^2$ single-mode VES survey. What this means is that, barring significant sand thicknesses as the constituent bodies of aquifers at the locations identified herein, it follows that the sources of groundwater at the points identified would be fracturing of the mass of the granitic rock at depths.

**Recommendation:-** It is strongly recommended that all of the aquifer prospects identified from the previous $2km^2$ single-mode VES survey be drilled for groundwater exploitation at the planned Gidan Kwano Campus Phase II Development.

## References

Abaa, S.I. (1983). The structure and petrography of alkaline rocks of the Mada Younger Granite Complex, Nigeria. *J Afr Earth Sci*, 3, 107–113.

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

Adesoye, S.A. (1986). *Master Plan of the Federal University of Technology's Permanent Site, Minna*. Adesoye and Partners, Kaduna, Nigeria.

Black, R. (1980). Precambrian of West Africa. *Episodes* 4:3–8.

Burke, K.C. and Dewey, J.F. (1972). Orogeny in Africa. In: Dessauvagie, T.F.J., Whiteman, A.J. (eds), *Africa Geology*, University of Ibadan Press, Ibadan, pp 583–608.

Dada, S.S. (2006). Proterozoic evolution of Nigeria. In: Oshi, O. (ed), *The Basement Complex of Nigeria and its Mineral Resources (A Tribute to Prof. M. A. O. Rahaman)*, Akin Jinad & Co., Ibadan, pp 29–44.

Gandu, A.H., Ojo, S.B., Ajakaiye, D.E. (1986). A gravity study of the Precambrian rocks in the Malumfashi area of Kaduna State, Nigeria. *Tectonophysics*, 126, 181–194.

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. and Jimoh, M.O. (2013). 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., 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. (2014A). Geoelectrical investigation for aquifer and geotechnical properties at the planned Gidan Kwano Campus Development Phase II, Federal University of Technology Minna, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED),* **11**(**2**), 81 - 100.

Jonah, S.A., Olasehinde, P.I., and Umar, M. (2014B). 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),* **2** (**1**), 122 –134.

Jonah, S.A., Olasehinde, P.I., Jimoh, M.O., Umar, M., and Yunana, T. (2015A). 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),* **11**(**2**), 32 - 50.

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

Scientific Publications, Oxford.

Obaje, N.G. (2009). *Geology and Mineral Resources of Nigeria*. In: Lecture Notes in Earth

Sciences, Springer-Verlag, Berlin.

Olayinka, A.I. (1992). Geophysical siting of boreholes in crystalline basement areas of Africa. *J*

*Afr Earth Sci*, 14,197–207.

Parasnis, D.S. (1986). *Principles of Applied Geophysics (4 ed.),* 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.