GEOELECTRICAL INVESTIGATION FOR AQUIFER AND GEOTECHNICAL PROPERTIES AT THE PLANNED GIDAN KWANO CAMPUS DEVELOPMENT PHASE II, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA

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Abstract
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. with respect 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 objective of this study is the creation of a database for aquifer and geotechnical information. Station-separation for the 2km^2 areal extent of the study area was fixed at 200m; thus there are sixty-six principal stations slated for this survey. 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) are coincident with the top of large outcrops. 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. 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 are flagged as "strongly aquiferous." The region of all TT9s, TT10s, and TT11s, incidentally closest to the existing Phase I development, especially TT9-3, TT9-4, TT10-3 are most suited for locations that would not prove logistical challenges for site selection for buildings and other structural development. It is 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.

Keywords: Geoelectrical; aquifer; geotechnical; georeferencing; VES; transverse traverse; iso-resistivity

Introduction
The news that the management of the Federal University of Technology (F.U.T.), Minna, in late 2012, signed a memorandum of understanding (MOU) with a private developer to expand the students' hostel complexes, and the news that the Federal Government of Nigeria would inject sum two hundred and twenty (220) billion naira annually into the Nigeria's university system for wide-ranging infrastructural development as a result of the amicable resolution of the Federal Government (FG) versus Academic Staff Union of Universities (ASUU), FG-ASUU, impasse was a

most welcome development indeed. The study group members immediately recognized challenges in these proposed schemes, and in line with the founding principles of the F.U.T. Minna, a combination groundwater prospect and geotechnical information survey was planned to cover the areal extent of $9^0$30′57.8′′N, $6^0$26′11.4′′E; $9^0$32′02.6′′N, $6^0$26′11.4′′E; $9^0$32′02.6′′N, $6^0$25′39.0′′E; $9^0$30′57.8′′N, $6^0$25′39.0′′E where preliminary civil works suggest that this is the preferred location for the proposed expanded infrastructural development, i.e. Phase II. A successful aquifer-cum-geotechnical survey at this designated area of study would provide a database of groundwater prospects and geotechnical information that the F.U.T. Minna could consult and incorporate into the wider Physical Planning and Development (PPD) scheme. 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 *et al.* (2014A; 2014B; 2014C; 2014D; 2014E; 2013A; 2013B; 2013C; 2013D; 2013E; 2013F; 2011A; 2011B; 2011C; 2011D) have always argued in favour of georeferencing field dataset and their concomitant tie-in to their specific GIS database.

Surface electrical resistivity surveying is based on the principle that the distribution of electrical potential in the ground around a current-carrying electrode depends on the electrical resistivities and distribution of the surrounding soils and rocks. The usual practice in the field is to apply an electrical direct current (DC) between two electrodes implanted in the ground and to measure the difference of potential between two additional electrodes that do not carry current. Usually, the potential electrodes are in line between the current electrodes, but in principle, they can be located anywhere. The current used is either direct current, commutated direct current (i.e., a square-wave alternating current), or AC of low frequency (typically about 20 Hz). All analyses and interpretation are done on the basis of direct currents. The non-uniqueness or ambiguity of the resistivity method is scarcely less than with the other geophysical methods. For these reasons, it is always advisable to use several complementary geophysical methods in an integrated exploration program rather than relying on a single exploration method (www.epa.gov; Kearey and Brooks, 1988; Parasnis, 1986; Ako and Olorunfemi, 1982; Bonde, 1997; Dangana, 2002; Gana, 1995; Okwueze and Ezeanyi, 1985; Okwueze *et al*., 1981; Olorunfemi & Fasuyi, 1993; Olorunfemi & Okhue, 1992).

On Aquifer: An aquifer is underground water bearing permeable rock. They acts as reservoirs for groundwater, and sometimes flows out in springs. Aquifers can dry up when people drain them faster than nature can refill them. Sedimentary rock such as sandstone, sand and gravel are examples of water bearing rock. The top of the water level in an aquifer is called the water table. An aquifer fills with water from rain that drains into the ground. In some areas, the water passes through the soil on top of the aquifer; in some others it enter through joints and cracks in rocks. The water moves downward until it meets less permeable rock (www.uwsp.edu).

On the Geotechnical Concept: Geotechnical investigation is usually carried out by professionals that provide information on the physical properties of soil, rocks and rocks types, topography of the selected area as well as using it as a measure of thermal resistivity of soil which is very vital for underground water survey. Geotechnical investigation include surface exploration and sub-surface exploration of the selected site as it provides information regarding elevation, vertical ground movement, map citations, acquisition of geoelectrical data sets through vertical electric sounding process thereby providing a guide for adequate explanation on the nature of investigation of underground water, problem statement, recommendation as well as references (www. wikipedia.org).

It was observed that, at the moment, there exist no aquifer and geotechnical information in the Federal University of Technology Minna's database for the proposed Phase II of the Gidan Kwano Campus. It is imperative that such subsurface information be available before undertaking any structural development and expansion scheme. In recognition of this stated problem this study was designed with the following critical objectives:

(i) Creation of a database for a $2km^2$ area at Phase II for aquifer and geotechnical I nformation;

(ii) Adaptation of the techniques of the fieldwork undertaken here to surveying for possible aquifer prospects at locations that are basically built-up and constricted; this ensures that a particular skill is honed for self-reliance, thus fulfilling the key aspect of the "Student Entrepreneurship Curriculum."

Meeting the stated objectives above would ensure that: Massive cost-saving by the Management of the Federal University of Technology, Minna, with respect to acquiring information for aquifer and geotechnical information at the defined $2km^2$ areal extent of Phase II.

The Area of Study

The location most suited for 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 ABCD 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. At a $2km^2$ areal extent, the present area of study identified by the following georeferenced co-ordinates: $09^{0}30'57.8''$N, $006^{0}25'39.0''$E; $09^{0}30'57.8''$N, $006^{0}26'11.4''$E; $09^{0}32'02.6''$N, $006^{0}26'11.4''$E; $09^{0}32'02.6''$N, $006^{0}25'39.0''$E is subsumed in the wider Phase II. This is seen in the ArcMap platform of Fig.2. In relation to Phase I (i.e. the existing developed portion of the Gidan Kwano Campus), the satellite imagery overlay map showing the extent of this study is shown in Fig.3; on this figure, the tadpole-shaped feature is Phase I, seen to the east of the VES green-dotted grid of the area of study.

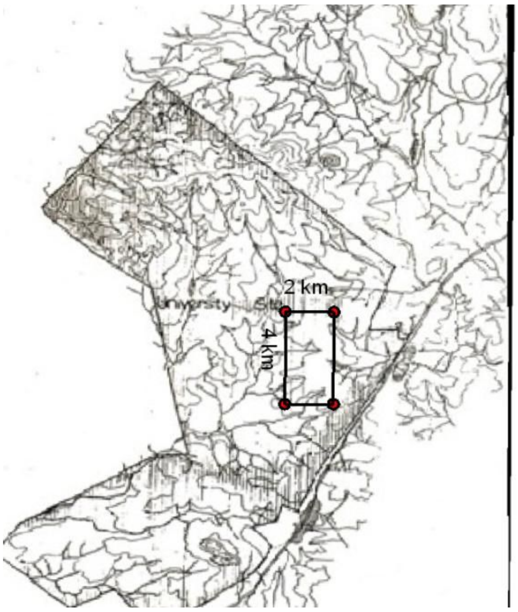

Fig.1. Location most suited for Phase II development at the Gidan Kwano Campus

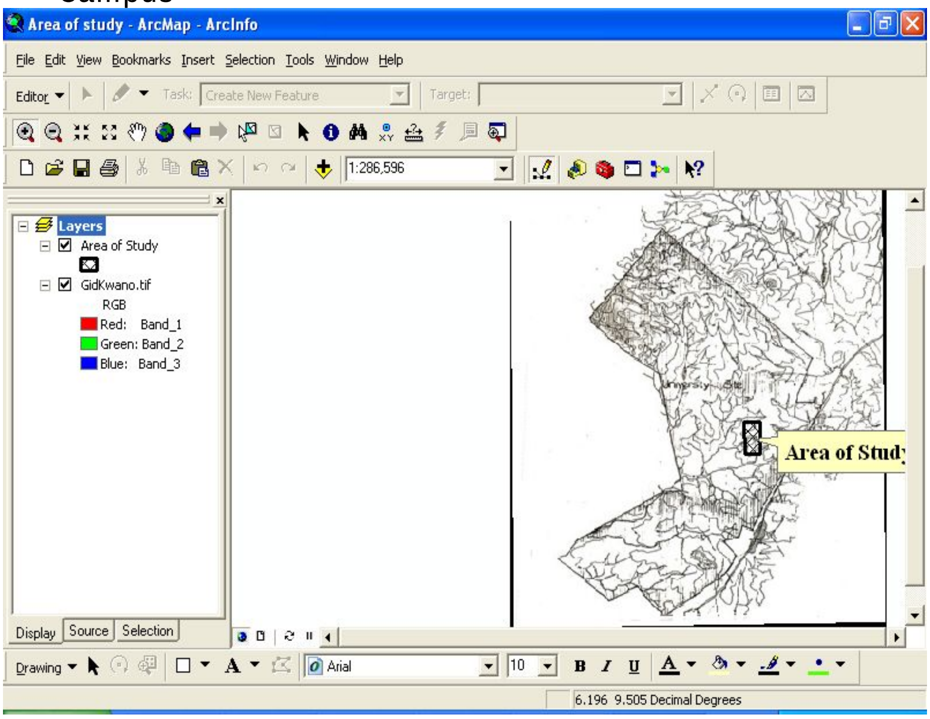

Fig.2: Extent of the 2km^2 area of study on the georeferenced map of the Gidan Kwano Campus presented on the ArcMap platform. (The extent of the GKC is 100km^2.)

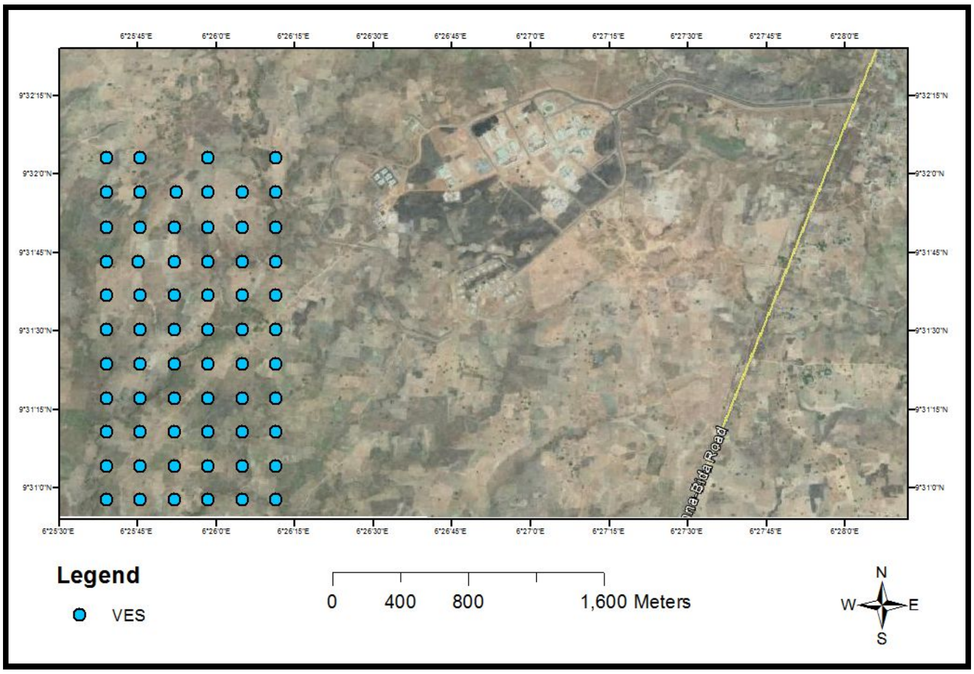

Fig.3: Satellite imagery overlay map showing the extent of project work in relation to Phase I. (The tadpole-shaped feature is Phase I, seen to the east of the VES green-dotted grid of the area of study.)

Brief Geology of the Gidan Kwano Campus

The area is underlain by Basement Complex rocks consisting of medium-grained biotite granite interbanded with coarse-grained leucocratic granite and intruded in places by quatzo-feldspar pegmatite dykes. The dykes strike parallel to the strike of the foliation, and they range from 0.5m to 3.5m in diameter. Outcrops are found along the river valleys as flat-lying bodies. They range in sizes from 3x5m to about 8x15m. Pinkish feldspar (i.e. potassium feldspar) is the dominant mineral in the granite gneiss and the pegmatite. This implies that its weathered product will be rich in clay. The rock types found here are believed to be part of older granite suite and are mostly exposed along the river channels where they appear in most cases weathered. Based on the relative grain size, the major rock types are (i) porphyritic coarse-grained granite, and (ii) medium to fine-grained granites. The former are mostly flat-lying with sizes ranging from few metres to about thirty metres. They are believed to continuously underlay the region that is covered by the thick overburden and are found outcropping along the river channels. Owing to biological weathering, the outcrops are broken into boulders. The latter are also flat-lying along the river channels and relatively high rising elongated outcrops on the surface, and unlike the pophyritic granite they are less weathered. The rocks are found in East-West (E-W) treading veins and joints which are sometimes filled by aplitic or quartz; this is in contrast to the porphyritic granite that are found in the North-South (N-S) trending quarts and aplitic veins ranging in length from 2m to about 15m. The medium to fine-grained granitic rocks are broken up into boulders in some places and they show the effect of weathering in the form of colour change, and loose rock fragments (Adesoye, 1986).

Co-ordinate Identification

Station-separation for the 2km^2 areal extent study area was fixed at 200m. 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 200m station-separation, there are 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 is 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 designation for these sixty-six principal stations and their respective latitude and longitude co-ordinates are given in Table 1.

Table 1. The sixty-six principal stations and their respective co-ordinates

TT	N	E
TT1-1	09°30′ 57.8″	006°26′11.4″
TT1-2	09°30′ 57.8″	006°26′4.9″
TT1-3	09°30′ 57.8″	006°25′58.4″
TT1-4	09°30′ 57.8″	006°25′52.0″
TT1-5	09°30′ 57.8″	006°25′45.5″
TT1-6	09°30′ 57.8″	006°25′39.0″
TT2-1	09°31′4.2″	006°25′39.0″
TT2-2	09°31′4.2″	006°25′45.5″
TT2-3	09°31′4.2″	006°25′52.0″
TT2-4	09°31′4.2″	006°25′58.4″
TT2-5	09°31′4.2″	006°26′4.9″
TT2-6	09°31′4.2″	006°26′11.4″
TT3-1	09°31′10.7″	006°26′11.4″
TT3-2	09°31′10.7″	006°26′4.9″
TT3-3	09°31′10.7″	006°25′58.4″
TT3-4	09°31′10.7″	006°25′52.0″
TT3-5	09°31′10.7″	006°25′45.5″
TT3-6	09°31′10.7″	006°25′39.0″
TT4-1	09°31′17.2″	006°25′39.0″
TT4-2	09°31′17.2″	006°25′45.5″
TT4-3	09°31′17.2″	006°25′52.0″
TT4-4	09°31′17.2″	006°25′58.4″
TT4-5	09°31′17.2″	006°26′4.9″
TT4-6	09°31′17.2″	006°26′11.4″
TT5-1	09°31′23.6″	006°26′11.4″
TT5-2	09°31′23.6″	006° 26’4.9”
TT5-3	09°31′23.6″	006°25′58.4″
TT5-4	09°31′23.6″	006°25′52.0″
TT5-5	09°31′23.6″	006°25′45.5″
TT5-6	09°31′23.6″	006°25′39.0″
TT6-1	09°31′ 30.1″	006°25′39.0″
TT6-2	09°31′ 30.1″	006°25′45.5″
TT6-3	09°31′ 30.1″	006°25′52.0″
TT6-4	09°31′ 30.1″	006°25′58.4″

TT6-5	09°31′ 30.1″	006°26′4.9″
TT6-6	09°31′ 30.1″	006°26′11.4″
TT7-1	09°31′ 36.6″	006°26′11.4″
TT7-2	09°31′ 36.6″	006°26′4.9″
TT7-3	09°31′ 36.6″	006°25′58.4″
TT7-4	09°31′ 36.6″	006°25′52.0″
TT7-5	09°31′ 36.6″	006°25′45.5″
TT7-6	09°31′ 36.6″	006°25′39.0″
TT8-1	09°31′ 43.0″	006°25′39.0″
TT8-2	09°31′ 43.0″	006°25′45.5″
TT8-3	09°31′ 43.0″	006°25′52.0″
TT8-4	09°31′ 43.0″	006°25′58.4″
TT8-5	09°31′ 43.0″	006°26′4.9″
TT8-6	09°31′ 43.0″	006°26′11.4″
TT9-1	09°31′49.5″	006°26′11.4″
TT9-2	09°31′49.5″	006° 26’4.9”
TT9-3	09°31′49.5″	006°25′58.4″
TT9-4	09°31′49.5″	006°25′52.0″
TT9-5	09°31′49.5″	006°25′45.5″
TT9-6	09°31′49.5″	006°25′39.0″
TT10-1	09°31′56.0″	006°25′39.0″
TT10-2	09°31′56.0″	006°25′45.5″
TT10-3	09°31′56.0″	006°25′52.0″
TT10-4	09°31′56.0″	006°25′58.4″
TT10-5	09°31′56.0″	006°26′4.9″
TT10-6	09°31′56.0″	006°26′11.4″
TT11-1	09°32′02.6″	006°26′11.4″
TT11-2	09°32′02.6″	006° 26’4.9”
TT11-3	09°32′02.6″	006°25′58.4″
TT11-4	09°32′02.6″	006°25′52.0″
TT11-5	09°32′02.6″	006°25′45.5″
TT11-6	09°32′02.6″	006°25′39.0″

Data Collection Procedure

The Schlumberger array of the Vertical Electrical Sounding (VES) mode of the resistivity survey, which involved the artificial introduction of the default equipment factory-set value of current of 10mA (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 project work. 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 trend of the VES survey for this project work was in a transverse traverse (TT) sense, from TT1-1 to TT1-6, TT2-1 to TT2-6, and so on up to TT11-1 to TT11-6. 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; this omission may be inferred from Fig.3.

Data Processing

Conversion of Field Resistance Values to Resistivity Values: The initial processing step involved in the treatment of the dataset 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.

Production of Resistivity Curves by WinResist®

Introduction: 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 recognized 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.

The WinResist® Approach: For this 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. Of the 63 resulting graphs, only 10 are presented here; these are shown as Figs 4 to 13. It must be pointed here that equipment glitch precluded the production of a field curve for TT1-1 because not enough sequence of dataset was collected at this location.

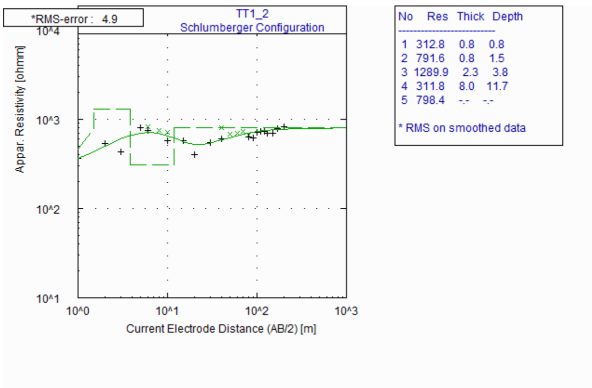

Fig. 4: WinResist® plot for TT1-2

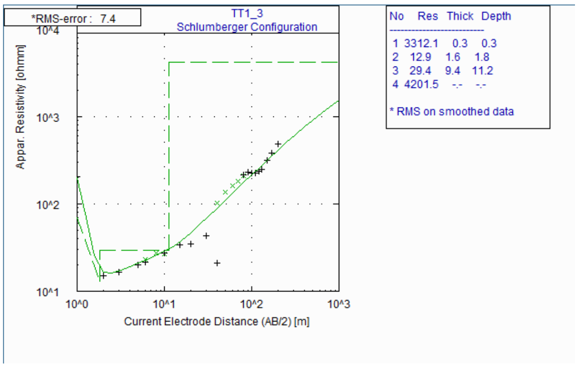

Fig. 5: WinResist® plot for TT1-3

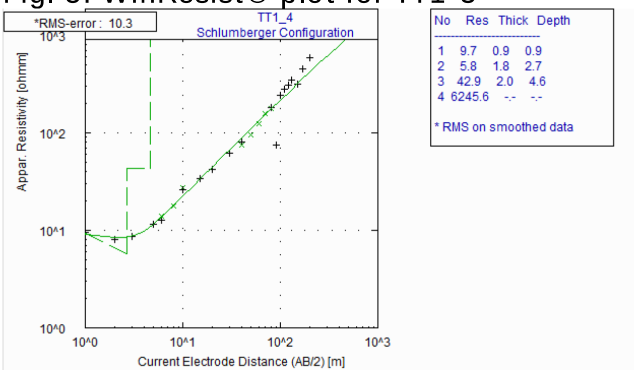

Fig. 6: WinResist® plot for TT1-4

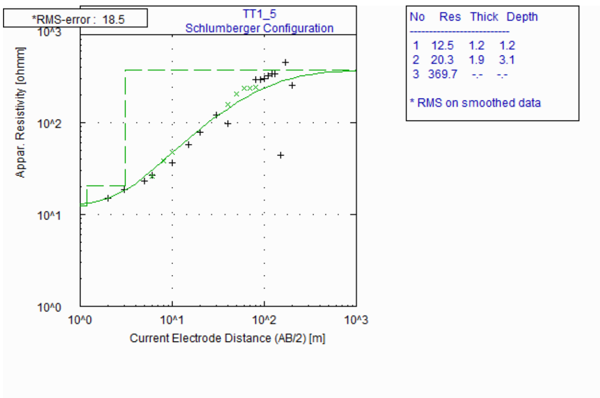

Fig. 7: WinResist® plot for TT1-5

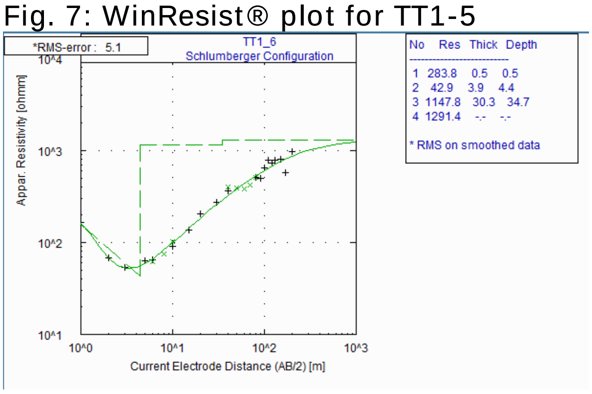

Fig. 8: WinResist® plot for TT1-6

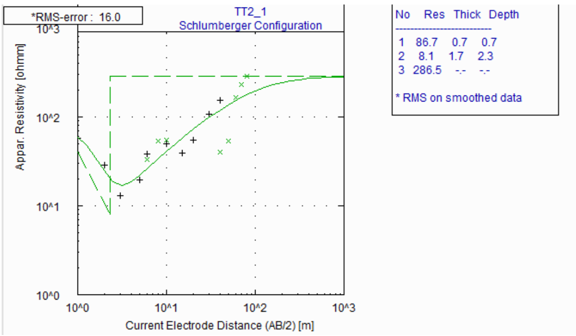

Fig. 9: WinResist® plot for TT2-1

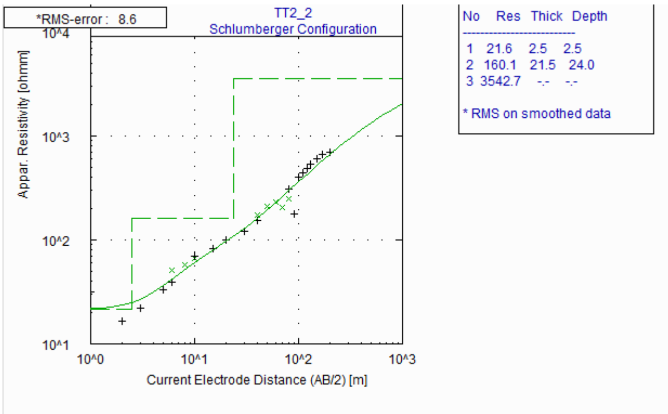

Fig.10: WinResist® plot for TT2-2

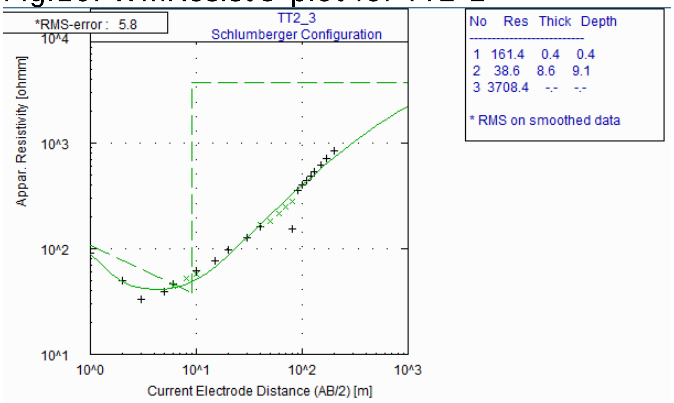

Fig.11: WinResist® plot for TT2-3

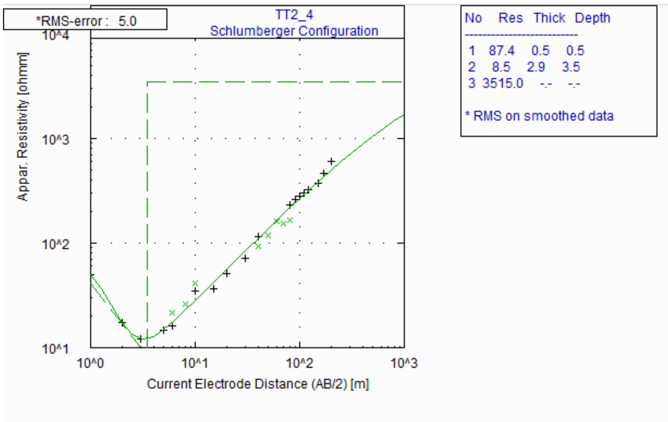

Fig.12: WinResist® plot for TT2-4

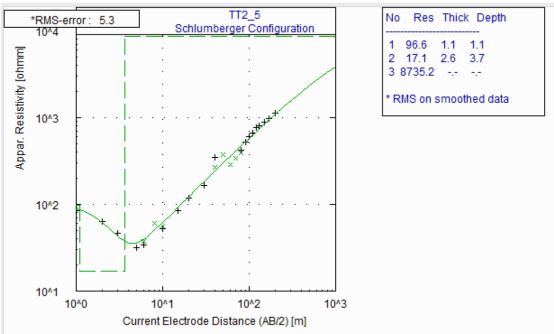

Fig.13: WinResist® plot for TT2-5

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 vital 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 20m, 30m, 40m, 50m. 60m, 70m. 80m. 90m, and 100m, see Figs 14 to 22. The Surfer® 10 package transforms the XYZ dataset (longitude, latitude, and resistivity values) to create contour maps and other useful graphic maps. Longitude and Latitude values in degree decimals for each of the sixty-four VES were chosen as X and Y respectively; X and Y values were varied with Z, and thence the values of resistivity at chosen depths.

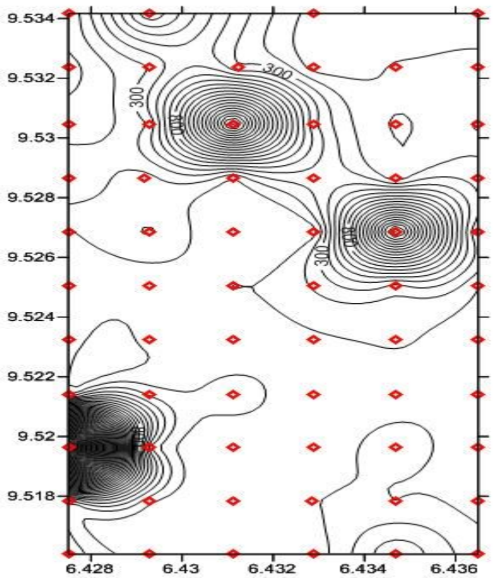

Fig.14: Iso-resistivity map at **20m (Contour interval: 100Ωm**)

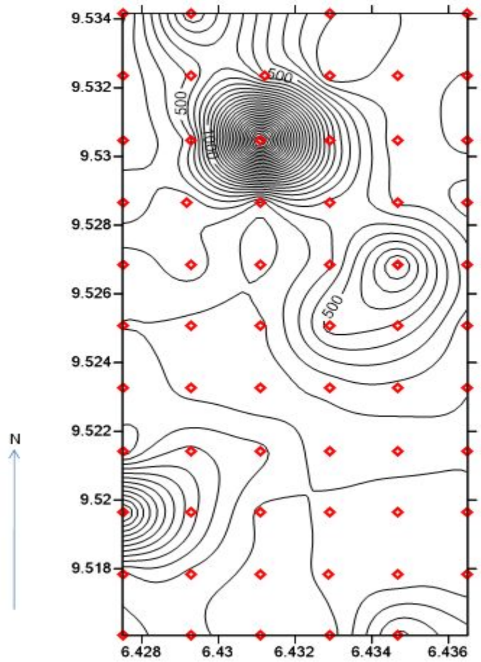

Fig.15: Iso-**resistivity map at 30m (Contour interval: 100Ωm**)

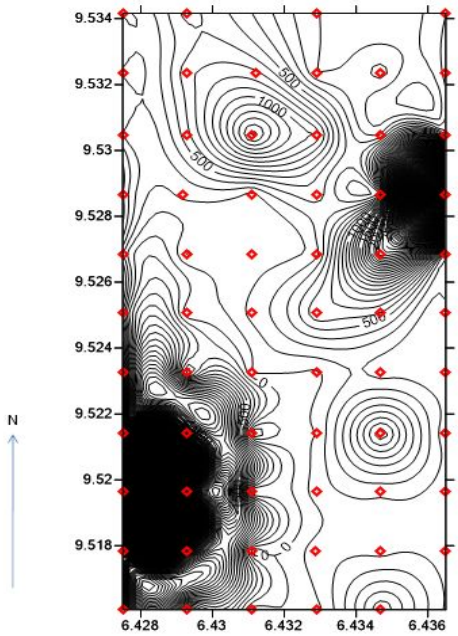

Fig.16: Iso-resistivity map a**t 40m (Contour interval: 100Ωm**)

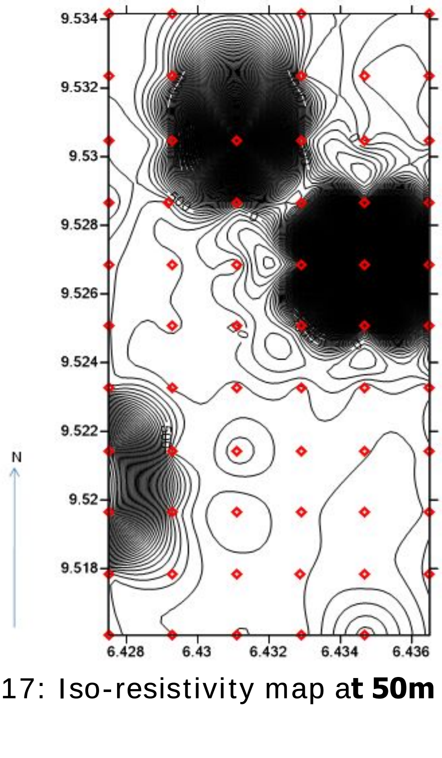

Fig.17: Iso-resistivity map a**t 50m (Contour interval: 100Ωm**)

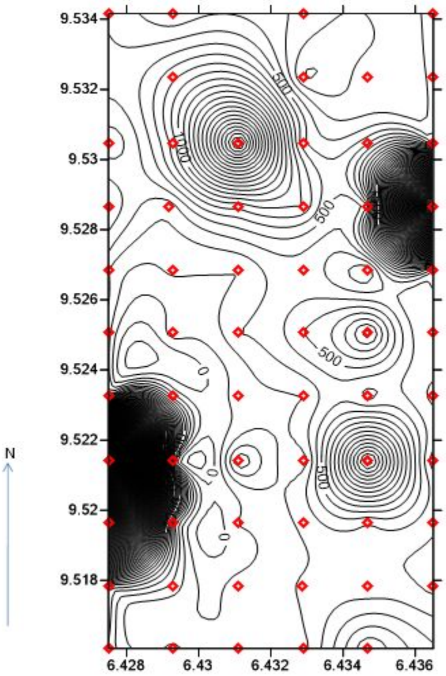

Fig.18: Iso-resistivity map at 6**0m (Contour interval: 100Ωm**)

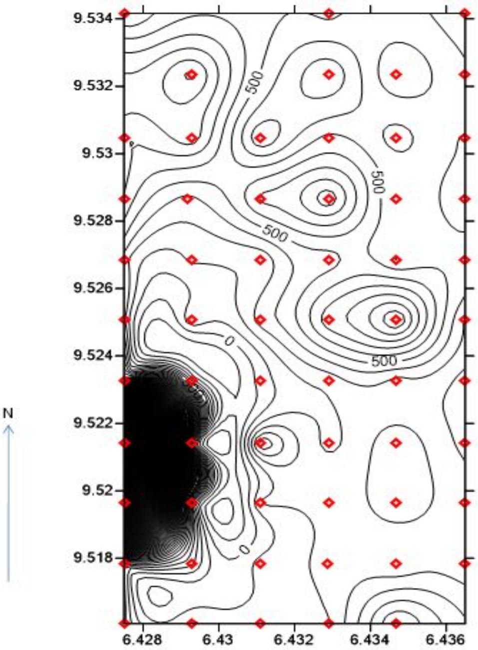

Fig.19: Iso-**resistivity map at 70m (Contour interval: 100Ωm**)

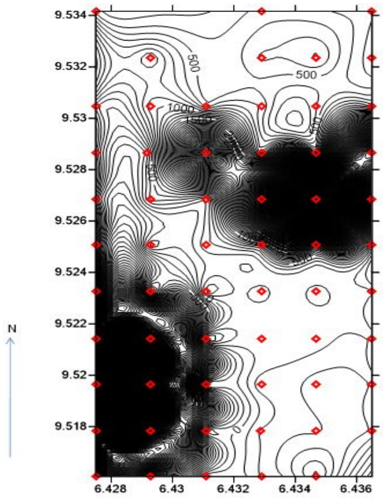

Fig.20: Iso-resistivity map a**t 80m (Contour interval: 100Ωm**)

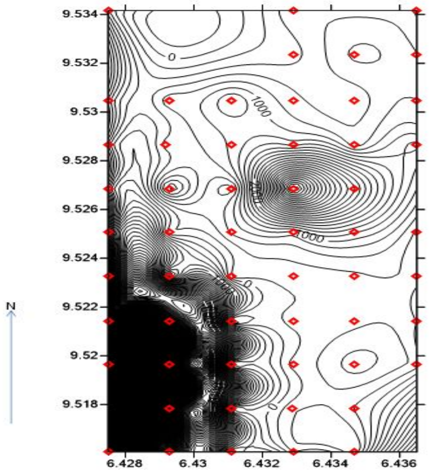

Fig.21: Iso-**resistivity map at 90m (Contour interval: 100Ωm**)

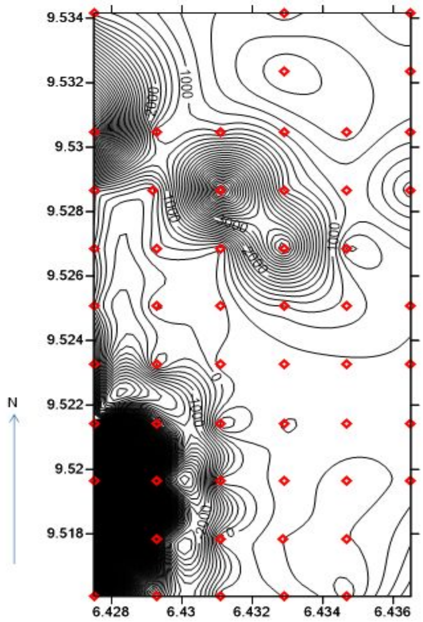

Fig.22: Iso-resistivity map at 1**00m (Contour interval: 100Ωm**)

Production of Depth Map for Geotechnical Information at the Study Area: The Surfer® 10 software was also employed to produce a depth map for geotechnical information at the study area, see Fig.23.

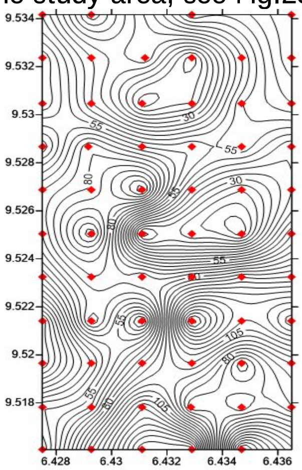

Fig. 23: Depth map for geotechnical information

Discussion of Result

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 Standardization for Minna Area," enunciated in Jonah *et al.* (2013F) and the "Olasehinde Protocol," enunciated in Jonah *et al.* (2014A). For this 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 0.3Ω at the 20m depth or greater (or, in resistivity terms, between 200Ωm and 300Ωm at the 20m depth and less than 200Ωm at depths greater than 20m) is indicative of possible groundwater prospect. The "Olasehinde Protocol" states that resistivity values between 180Ωm and 250Ωm at the 20m to 25m depth mark are indicative of possible groundwater prospect. It is important to point out here that even though the resistivities of rocks do not depend on water content only, these informal laws are enunciated "rules-of-thumb" that serve as effective guides to groundwater prospectors out in the field. The bases of these protocols have been found to be effective over a two-decade period now for delineating approximate locations of groundwater yield (Olasehinde, 1989; 1999; Muftau Jimoh, personal communication).

The WinResist® Plots: Figs 9, 10, 11, 12, and are observed to be three-layered; Figs 5, 6, and 8 are observed to be four-layered; Fig. 4 is observed to be five-layered.

The Iso-Resistivity Maps at Depths: As a result of invoking the "Geoexplore Empirical Standardization for Minna Area" and the "Olasehinde Protocol" to determine aquifer prospect for this study, areas of contour closures corresponding to resistivity values well above 1000Ωm are necessarily ignored in our "geological prognosis."

The 20m-Depth Map:- At this depth, contour closures corresponding to resistivity values well above 1000Ωm are noticed at TT2-5 to TT2-6, TT3-5 to TT3-6, TT4-5 to TT4-6, TT7-1 to TT7-3, and TT9-3 to TT9-5.

The 30m-Depth Map:- It can be seen at this depth that dense cluster of contours of resistive value above 500Ωm occurs at TT3-5, TT3-6, TT6-1 to TT6-3, TT7-1 to TT7-3. Also resistivity value above 1000Ωm occurred at TT8-4, TT9-3, TT9-5, and TT10-3 to TT10-5.
The 40m-Depth Map:- At 40m depth, the contours are sparsely distributed and occur densely at TT2-5, TT2-6, TT3-5, TT3-6, TT4-5, TT4-6.

The 50m-Depth Map:- At this depth higher resistivity value above 50000Ωm can be seen at TT6-1 to TT6-3, TT7-1 to TT7-3, TT8-1 to TT8-2.

The 60m-Depth Map:- Corresponding resistivity values above 1000Ωm is observed at TT2-6, TT3-6, TT4-5, TT4-6, and TT5-6. Also at TT7-1,TT8-2,TT9-1,TT9-4 and TT9-5.

The 70m-Depth Map:- Very dense clusters are observed at TT2-6, TT3-5, TT3-6, TT4-5, TT4-6, TT5-5 and TT5-6. The contour closures correspond to a very high resistivity values.

The 80m-Depth Map:- Extremely high resistivity values are seen as thick contours closures at TT1-4 to TT1-6, TT2-4 to TT2-6, TT3-4 to TT3-6, TT4-4 to TT4-6, TT5-4 to TT5-6, also at TT6-1 to TT6-3, TT7-1 to TT7-3, TT8-1 to TT8-4.

The 90m-Depth Map:- At 90m sparsely distributed contours are seen except at TT2-5, TT2-6, TT3-5 and TT3-6.

The 100m-Depth Map:- Similarly to the 90m-depth, at 100m, contours closures are seen around TT2-5 and TT2-6, TT3-5 and TT3-6.

The Depth Map: The depth map, showing the variation of depth-to-top-of-bedrock across the area of study, shows a preponderance of contour closures in the southern half of the study area; this can only mean the northern half is characterized by comparatively contour scatters. This preponderance of contour closures can only mean, too, that the southern half of the study area is characterized by thick overburden materials which, strictly speaking, are good for aquifer regime.

Conclusion

Extraction of Aquifer Information: As a result of invoking the "Geoexplore Empirical Standardization for Minna Area" and the "Olasehinde Protocol," the following VES stations are considered good prospects for aquifer: 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. These VES stations are spread throughout the study from the TT1s in the extreme south of the study area to the TT9s near extreme north of the study area. Now, imposing a tough groundwater prospect identification using the constraints of the "Geoexplore Empirical Standardization for Minna Area," the "Olasehinde Protocol," and the depth map of Fig.76 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.

Extraction of Geotechnical Information: Fig. 23 provides a good guide for extracting geotechnical information for the area of study. The pattern of display of the contour lines of Fig.23 indicates that the regions where there are considerable contour closures correspond to areas of thin overburden! Since the northern half is characterized by comparatively contour scatters, this can only mean that the overburden thickness is comparatively thin here. Therefore the bedrock is not so deeply-seated as to prove a logistical challenge for site selection for buildings and other structural development. This is the situation observed at TT9-3, TT9-4, TT10-3 in particular, and other neighbouring TTs encompassing TT11-2 and TT11-4. Incidentally the region of all TT9s, TT10s, and TT11s are closest to the existing Phase I development.

Recommendation

It is 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.

References

Adesoye, S. A. (1986). *Master plan of the Federal University of Technology's permanent site, Minna*. Adesoye and Partners, Kaduna, Nigeria.

Ako, B. J. & Olorunfemi, M. O. (1982). Geoelectric survey for groundwater in the New Basalt of Vom, Plateau State. *Journal of Mining and Geology*, 8(2), 273-280.

Bonde, D. S. (1997). *Geoelectrical survey for groundwater resources in Egba, Shiroro Local Government Area, Niger State*, M.Tech. Dissertation, Federal University of Technology, Minna.

Dangana, L. M. (2002). *Electrical resistivity survey of Tunga Kawo Dam, Wushishi, Niger State, Nigeria*, M.Tech. Dissertation, Federal University of Technology, Minna.

Gana, J. S. (1995). *Geophysical exploration for groundwater in Yakila, Niger State*, M.Tech. Dissertation, Federal University of Technology, Minna.

http://www.uwsp.edu/water/portage/umdrstmd/aquifer..html

http://www.wikipedia.org/

http://www.epa.gov/esd/cmb/Geophysics website/index.html

Jonah, S. A., Akpan, E. U., Bakara, I. U., Tanimowo, B., Abdullahi, B., Nwachukwu, E. I., Maishanu, I. H., Dania, R., Ezemonye, C. V., Fanisi, O., Ejiga, U., Benu, I. S., Banjo, G. Pius, A., Okunola, I. A., Jimoh, M. O., Amadi, A. N. & Ejepu, J. S. (2013A). 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. & Ayofe, L. F. (2013B). Creation of a geographic information system for Minna, Niger State, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*. Accepted for publication.

Jonah, S. A., & Baba, E. A. (2014D). 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). Undergoing review.*

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

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

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

Jonah, S. A., Okoro, N. N., Umar, M., Bakara, I. U. & Umoh, S. E. (2014E). 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., Baba-Kutigi A. N., Uno, U. E., Dangana, M. L., Kolo, M. T., Ofor, N. P., Unuevho, C. I., Onoduku, U. S., Abba, F. M., Alhassan, D. U., Amadi, A. N., Umar, M. O. & Kimpa, M. I. (2011A). Spatial analysis and geographic information system (GIS) mapping of noise pollution in Bosso Local Government Council, Niger State, Nigeria. *Environmental Technology and Science Journal (ETSJ).* 4 (1), 4 – 19.

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

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

Jonah, S. A., James, G. O., Adeku, D. E., Ahmed, F., Alhassan, A., Hamza, S., Igbideba, O. I., Kwaghhua, F. I., Kyari, M., Macaulay, V. F., Olarewaju, S. I., Onyeodili, G., Popoola, G. B., Sofeso, O. A., Switzer, F. K. & Umoh, U. E. (2013F). A survey for groundwater at a lot at the Dan Zaria Academic Estate, Federal University of Technology, Minna, Central Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*, 9(3), 26 – 38.

Jonah, S. A., James, G. O., Adeku, D. E., Ahmed, F., Alhassan, A., Hamza, S., Igbideba, O. I., Kwaghhua, F. I., Kyari, M., Macaulay, V. F., Olarewaju, S. I., Onyeodili, G., Popoola, G. B., Sofeso, O. A., Switzer, F. K. & Umoh, U. E. (2014A). 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)*, Accepted for publication.

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. & Umoh, U. E. (2014B). A blind geoelectrical survey commissioned to affirm or deny the presence of aquifer at a compound at Minna, Central Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*, Undergoing Review.

Jonah, S. A., 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. & Umoh, U. E. (2014C). A wetland lot geoelectrical investigation for groundwater development at Bosso Estate, Minna, Central Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*, Undergoing Review.

Jonah, S. A., Okunlola, I. A., Amadi, A. N., Baba-Kutigi A. N. & Umar, M. O. (2011D). Investigation of nitrogen dioxide indices and the creation of a unique geographic information system (GIS) layer map for nitrogen dioxide pollution in Minna, Niger State. *Environmental Technology and Science Journal (ETSJ),* 4 (1), 74 – 82.

Kearey, P. & Brooks, M. (1988). *Fundamentals of geophysics*. Cambribge: Cambridge University Press.

Okwueze, E. E. & Ezeanyi, V. (1985). The vertical electrical sounding (VES) method in laterite region and iron-rich area. *Journal of Mining and Geology,* 22 (1 & 2), 173-280.

Okwueze, E. E., Ebeniro, J. O., & Mbogning, M. (1981). The geoelectric structure of Late Nyos Dam, Cameroon, and its geoelectric implication. *Journal of Mining and Geology*, 8(2), 273-280.

Olasehinde, P. I. (1989). Elucidating fracture patterns of the Nigerian Basement Complex using electrical resistivity methods. *Z. Agnew Geowiss Heft*, 8, 109 – 120.

Olasehinde, P. I. (1999). An integrated geologic and geophysical exploration technique for groundwater in the basement complex of west-central part of Nigeria. *Water Resources*, 10, 46-49.

Olorunfemi, M. O. & Fasuyi, S. A. (1993). Aquifer types and the geoelectric/ hydrogeological characteristics of part of the Central Basement Terrain of Nigeria (Niger State). *Journal of African Earth Sciences,* 16(3), 309-317.

Parasnis, D. S. (1988). *Principles of applied geophysics (4ed.)*. London: Chapman and Hall

Zohdy, A. A. R. (1989). A new method for the automatic interpretation of Schlumberger and Wenner sounding curves. *Geophysics*, 54(2), 245-253.

Appendix: Universities under survey

S/N	Universities	Year of Est.	Professionals	Para-Professionals	Total
1	University of Ilorin, Ilorin	1975	13	10	23
2	University of Jos, Jos	1975	22	20	42
3	Federal Univ. of Technology, Minna	1982	24	18	42
4	University of Abuja	1988	15	08	23
5	University of Agriculture, Makurdi	1988	13	45	58
6	Benue State University, Makurdi	1992	08	08	16
7	Kogi State University, Ayingba	1999	14	09	23
8	Nassarawa State University, Keffi	2002	05	05	10
9	National Open University of Nigeria, Abuja (Study Centre)	2003	04	01	05
10	Ibrahim Badamasi Babangida University, Lapai	2005	14	05	19
11	Al-Hikmah University, Ilorin	2005	06	01	07
12	Bingham University, New Karu	2005	06	-	06
13	University of Mkar, Mkar	2005	04	06	10
14	Salem University, Lokoja	2007	02	02	04
15	African University of Science and Technology, Abuja	2007	02	-	02
16	Kwara State University, Malete-Ilorin	2009	06	03	09
17	Nigerian Turkish Nile University, Abuja	2009	02	-	02
	Total		160	141	301

Source: NUC and Field Survey (2012)