

Evaluation of Geomorphological Quality Control of Geo-electrical Data at Gidan Kwano Campus, Federal University of Technology, Minna, Central Nigeria

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Abstract

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. The three spatial co-ordinate values (x,y,z) that specified full-body georeferencing scheme were collected for 861 principal stations for an 8km² grid corresponding to station-spacing of 100m. Processing the data set by means of the Surfer@10 route yielded the desired contour map and the corresponding landform profile. Juxtaposing the landform profile map with acquired geoelectrical field data shows correlation that ensures that the field data can indeed be relied upon.

Keywords: Topographic; geomorphological; landform; quality-control; georeferencing

Introduction

Accurate mapping and archival of subsurface information must necessarily follow a full suite of methods designed to reduce errors in interpretation of field data, as well as providing the ability to correctly pinpoint likely prospects in the study area. Before this ability should be honed and errors should be reduced, it is absolutely imperative to device a means by which “raw” data collected in the field would be subjected to a process of quality control (QC). Moreover, independent verification of the field data must be assured. Accurate geoelectrical surveys for subsurface information should be conducted with proper tie-ins to related surveying, geological, and data management controls. These controls form a suite of protocols the absence of which would surely increase the error margins in the final interpretation of the data collected in the course of the field survey. These protocols are those related to accurate traverse fixing, georeferencing of survey stations, the creation of site-specific geomorphological and petrographic maps, and the creation of site-specific Geographic Information System (GIS). In fact, Jonah and Duromola (2014A), Jonah and Ayofe (2014B), Jonah and Bawa (2014C), Jonah and Baba (2014D), Jonah *et al.* (2014E; 2014F; 2014G; 2014H; 2014I), 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. This study, which is concerned with the creation of site-specific geomorphological map as the means by which QC of “raw” data would be carried out, is the first in a suite of papers that discuss these protocols.

The Phase II Development/Location of Study: There is no doubt that the proposed Gidan Kwano Campus (GKC) Development Phase II would be subsumed in the gridded areal extent shown in relation to the tadpole-shaped feature that is Phase I in Fig.1.

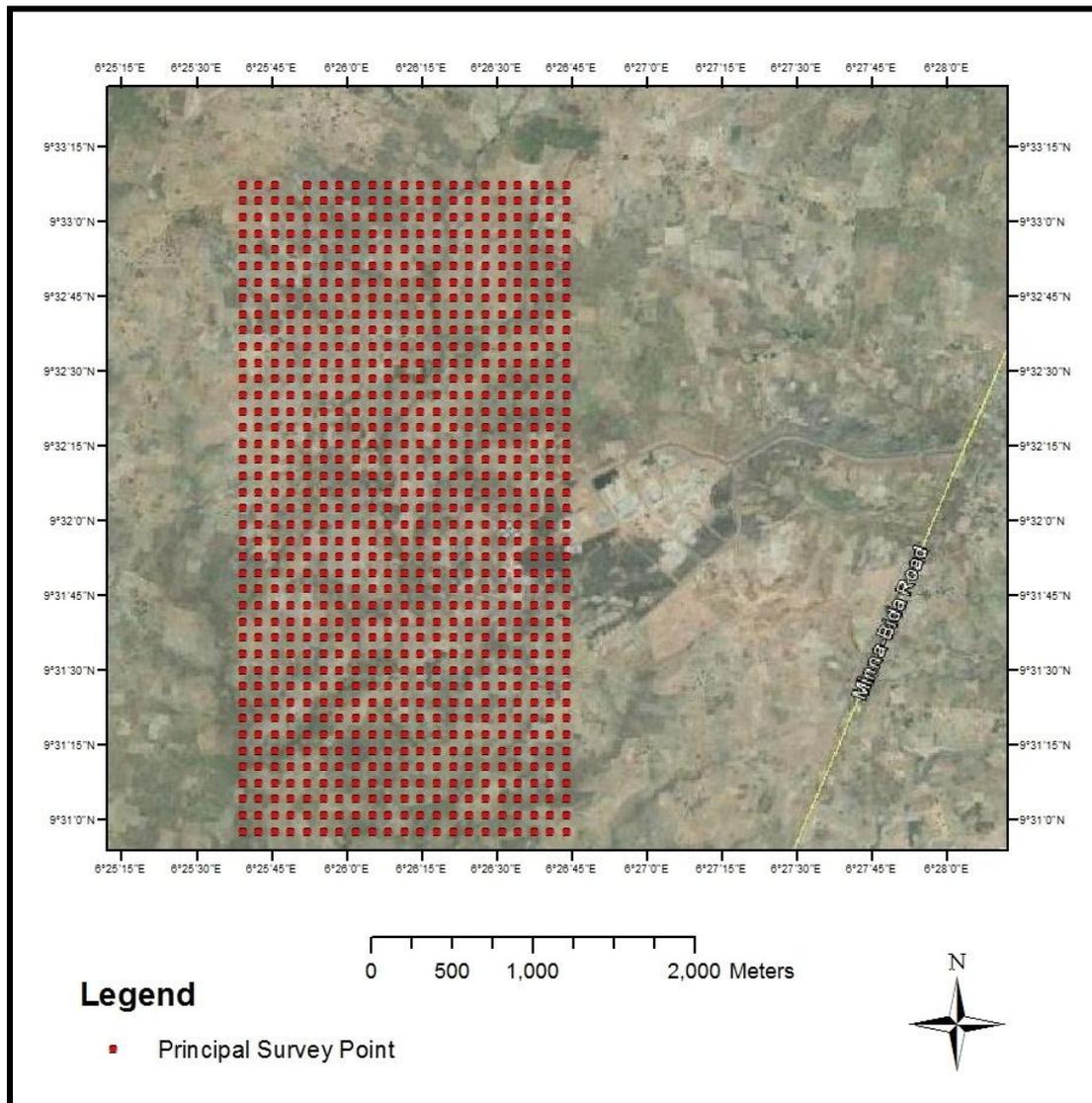


Fig.1. Locations of the principal stations against the backdrop of a satellite imagery map showing the tad-pole shaped feature of Phase I (i.e. the existing developed portion). (The Minna-Kateregi-Bida Road is seen as the linear slope in the bottom right of this figure.)

The extent (the gridded area of Fig.1) of the area of study is 8km², understood to be a perfect rectangular grid A, B, C, D identified by the following georeferenced values: 09°30'57.8"N, 006°25'39.0"E; 09°30'57.8"N, 006°26'43.8"E; 09°33'07.4"N, 006°26'43.8"E; 09°33'07.4"N, 006°25'39.0"E.

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 quartzo-feldspar pegmatite dykes. Outcrops are found along the river valleys as flat-lying bodies. 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.

Brief Review of Literature: ABEM (1999) and the published literature (Jonah and Jimoh, 2013A) have argued for the need to create purpose-specific topographic map for a defined area of study. Jonah and Jimoh (2013D) reported on a study centred on the production of a *topographic map* and the creation of a six-layer *Geographic Information System (GIS)* for a fifteen square-kilometre (15 km²) areal extent of the Gidan Kwano Campus of the Federal University of Technology, Minna, Niger State. The authors argued that geological or geophysical surveys must be tied-in to an existing Geographic Information System (GIS) platform and georeferencing of survey stations should be the acceptable norm. The authors pointed out that the objectives of their study were the creation of a detailed topographic map for the area of study so as to reduce ambiguities in future geoscientific studies, the implementation of georeferencing protocol at the area of study, the creation of a Geographic Information System (GIS) database for the area of study, and the creation of specific GIS layers for the area of study. It is understood that these GIS layers define the outcrop, arboreal, economic resource, land use, as well as squatters' settlements profile of the area of study. The area selected for this study is located at the following co-ordinate grids: N09°30'25.20'', E006°26'11.34''; N09°33'07.20'', E006°26'11.34'' and N09°30'25.20'', E006°24'34.14''; N09°33'07.20'', E006°24'34.14''; this area covers the portion of the Gidan Kwano Campus (GKC) where near-term, mid-term, and long-term facility expansion works are expected to be sited. Latitude, longitude, elevation (i.e. x, y, z) information using the Etrex hand-held Global Positioning System (GPS) units were collected every 100m along every N-S and E-W axes at the area of study, thus forming a grid of 1581 georeferenced stations of interest for the topographic

map generation. X, y, z information-gathering sequence for the GIS layers was a non-gridded, spatial-oriented exercise. The site-specific topographic map for this project work was generated using the Golden Surfer 8 software. In addition, the ArcView GIS was used to create a six-layer Geographic Information System (GIS) for the area of study. The authors concluded that the topographic map and GIS database could be considered as a suite of very important reference materials that can be assessed by researchers engaged in future surface and subsurface formation studies in the area of study.

Graph drawing and cartography interact when graphs that already have an embedding (i.e. geometric networks) have to be visualized. Examples of such networks are street, subway, river, or cable networks. Often it helps to visualize the underlying network for analyzing the quantity under consideration. For example, traffic on a road network can be visualized by drawing each road as a rectangle whose width is proportional to the amount of traffic in that road (Wolff, 2004). One of the main problems in map production is a process called *generalization*. Given cartographic data that has been collected at large scale, this data must be simplified in order to produce maps at small scale. In order to obtain readable maps, detail must be reduced and spacing must be enlarged. Traditionally this has been done manually by cartographers, but increasingly semi-automated and even automated methods are in use, particularly in conjunction with Geographic Information Systems, GIS. The esthetic constraints that govern the process of drawing geometric networks can be seen as an example of generalization: usually vertices must keep a certain minimum distance and edges are restricted to polygonal lines that use few directions and have few bends. Note that general graph-drawing algorithms cannot be used ad hoc for drawing geometric networks since they do not respect the given embedding. A good drawing of a geometric network must reflect geometry in a certain way since a user typically has some intuitive notion of the underlying geometry, a *mental map* in other words. For example, the user of a metro system expects stations in the north to appear on the top of maps that depict the metro system. Thus the aim of drawing geometric networks is to find a good compromise between distorting geometry and maximizing aesthetics (Eades *et al.*, 1991).

The term “topographic surveying” encompasses a broad range of surveying and mapping products, ranging from aerial mapping to ground and underground surveys (www.140.194.76.129.org). “Control surveying” is a survey which provides horizontal or vertical position data for the support

or control of subordinate surveys or for mapping (www.140.194.76.129.org). Topographic surveys have been defined as follows: “A topographic map shows, through the use of suitable symbols, (1) the spatial characteristics of the earth’s surface, with such features as hills and valleys, vegetation and rivers, and (2) constructed features such as buildings, roads, canals, and cultivation. The distinguishing characteristic of a topographic map, as compared with other maps, is the representation of the terrain relief.”

According to Wikipedia (2011), a contour line (also *isoline* or *isarithm*) of a function of two variables is a curve along which the function has a constant value (also Courant et al., 1996). In cartography, a contour line (often just called a "contour") joins points of equal elevation (height) above a given level, such as mean sea level. A contour map is a map illustrated with contour lines, for example a topographic map, which thus shows valleys and hills, and the steepness of slopes. The contour interval of a contour map is the difference in elevation between successive contour lines (Tracy, 1907). More generally, a contour line for a function of two variables is a curve connecting points where the function has the same particular value. The gradient of the function is always perpendicular to the contour lines. When the lines are close together the magnitude of the gradient is large: the variation is steep. A level set is a generalization of a contour line for functions of any number of variables. Contour lines are curved or straight lines on a map describing the intersection of a real or hypothetical surface with one or more horizontal planes. The configuration of these contours allows map readers to infer relative gradient of a parameter and estimate that parameter at specific places. Contour lines may be either traced on a visible three-dimensional model of the surface, as when a photogrammetrist viewing a stereo-model plots elevation contours, or interpolated from estimated surface elevations, as when a computer program threads contours through a network of observation points of area centroids. In the latter case, the method of interpolation affects the reliability of individual isolines and their portrayal of slope, pits and peaks (Davis, 1986).

According to Wikipedia (2010), Geographic Information System (GIS) represents a new paradigm for the organization of information and design information system, the essential aspect of which is use of the concept of location as the basis for the structuring of information system. The main advantage of using GIS is its ability to access and analyze spatially distributed data with respect to its actual spatial location overlaid on a base map of the area of coverage that allows analysis not

possible with the other data base management systems. The main benefit of using the GIS is not merely the user friendly visual access and display, but also the spatial analysis capability and the applicability to apply standard GIS functionalities such as simultaneous access to several layers of data and the overlay of some, as well as the ability to interface with external programs and software for decision support data management, and user specific functions. A Geographic Information System (GIS) or geospatial information system is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographically referenced data. In the simplest terms, GIS is the merging of cartography, statistical analysis, and database technology. A GIS can be thought of as a system — it digitally creates and "manipulates" spatial areas that may be jurisdictional, purpose or application-oriented for which a specific GIS is developed. Hence, a GIS developed for an application, jurisdiction, enterprise or purpose may not be necessarily interoperable or compatible with a GIS that has been developed for some other application, jurisdiction, enterprise, or purpose. What goes beyond a GIS is a spatial data infrastructure (SDI), a concept that has no such restrictive boundaries.

The Method Employed

Traverse Fixing, Co-ordinate Identification, and Elevation Measurements: Accurate traverse fixing is desirable to build a grid for the 8km² area of study and georeferencing of survey stations is desirable to independently verify the results of this study. Having selected the site for this study, these protocols were duly implemented. At 100m separation, a total of 21 profile lines were identified in the longitudinal traverse sense and a total of 41 profile lines were identified in the transverse traverse sense. This traverse fixing scheme results in $21 \times 41 = 861$ principal survey stations grid. Each of these principal survey stations was visited whence its latitude, longitude, and elevation information (x, y, z) were measured and duly recorded. Directional straight-line traverses were usually approximately fixed by the use of the compass clinometer. The hand-held Garmin GPSmap76® global positioning system unit was employed as the perfect QC tool to ensure movement along a true straight line either in the north-south or east-west directions.

The Topographic Map and the Geomorphic Feature of the Area of Study

The acquired data field was processed by means of the Surfer®10 software to produce the topographic map of Fig.2 and the geomorphic feature map of Fig.3.

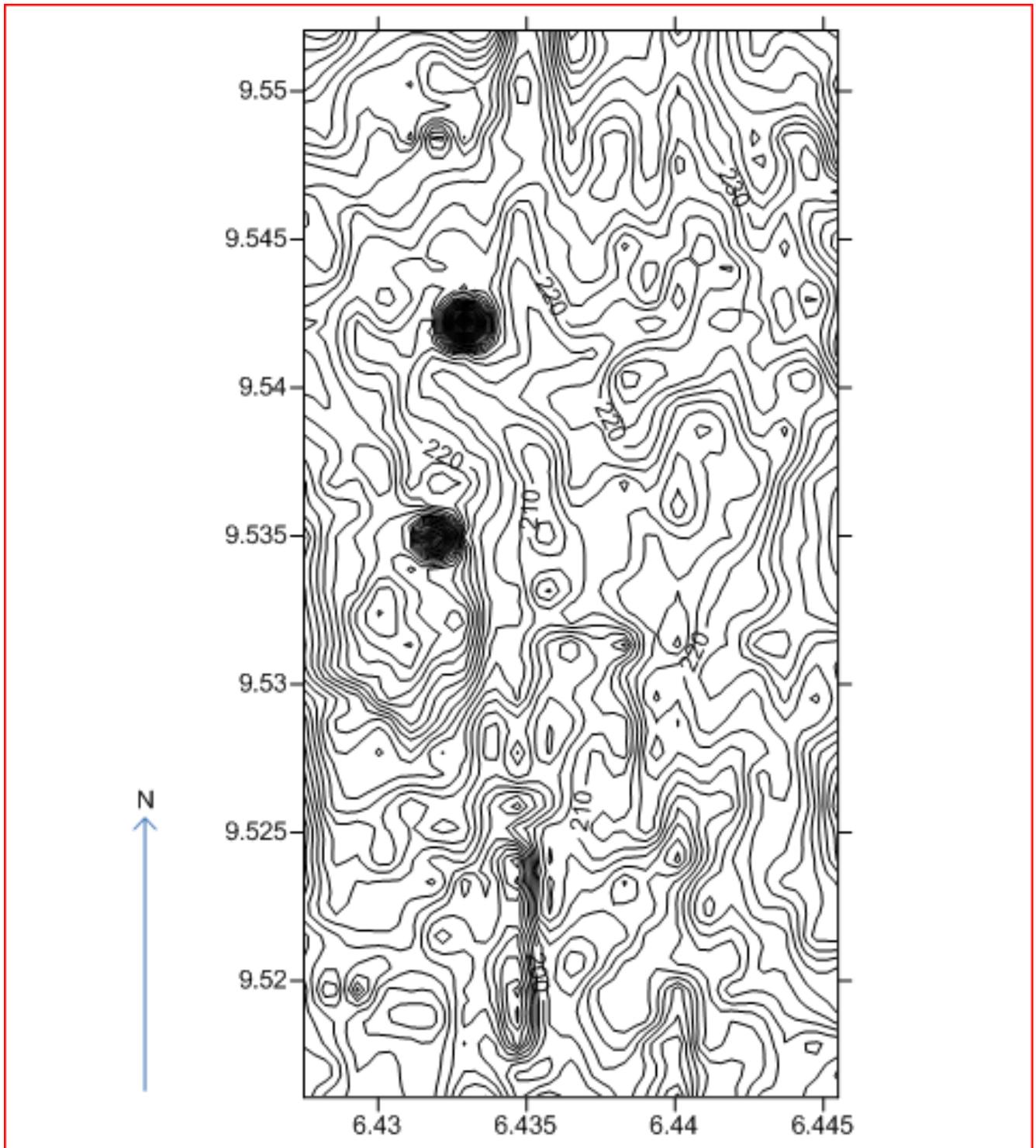


Fig.2. Topographic map of the area of study. (Contour interval: 2m.)

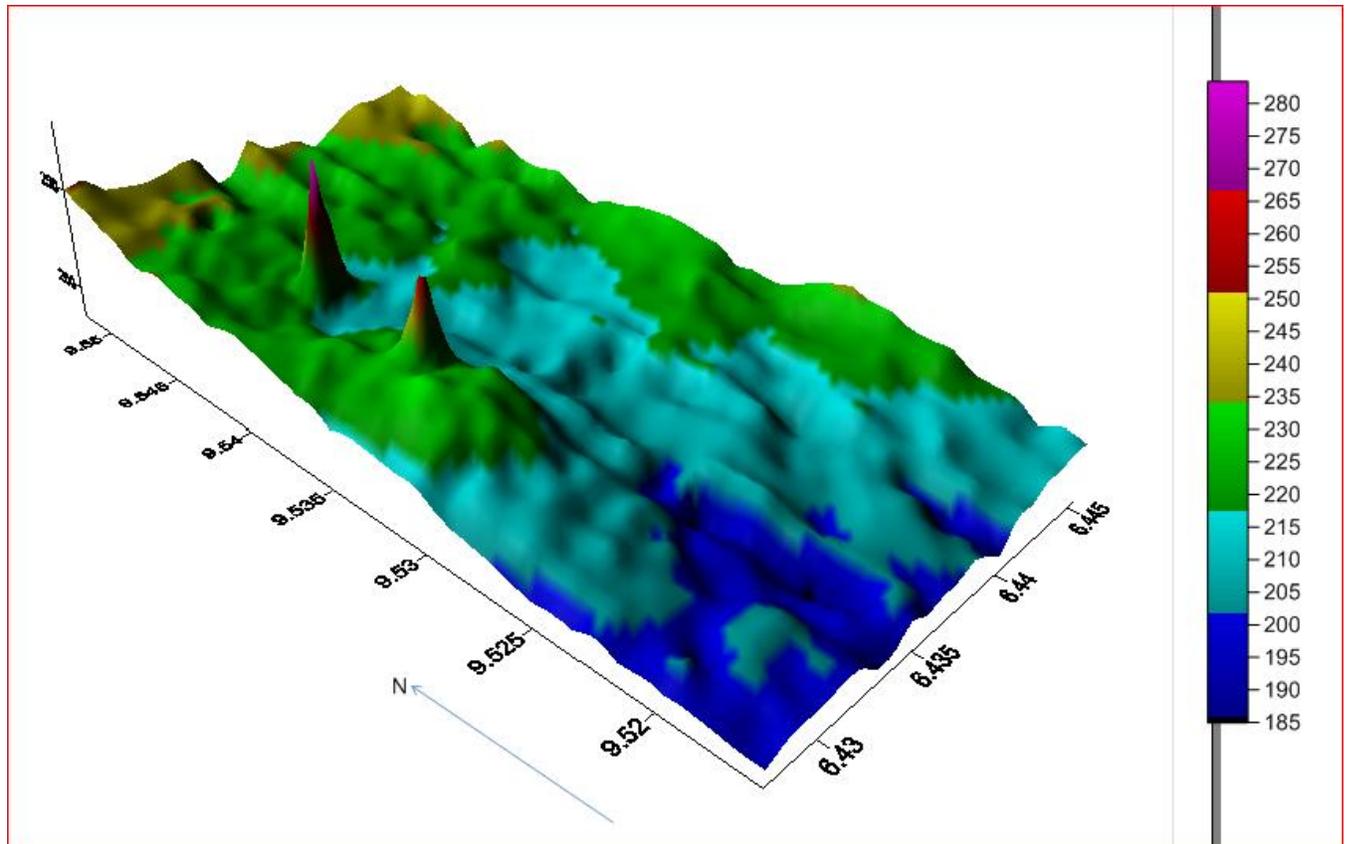


Fig.3. The geomorphic feature map of the area of study

Discussion

The topographic map of Fig.2, produced at an interval of 2m, shows a smoothly-varying contour regime from north to south of the area of study; the high 230s metres predominate in the north of the area of study whilst the low 200s metres predominate in the south of the area of study. The corresponding geomorphic map of Fig.2, shown as Fig.3, interprets the dual bunched bobs seen in Fig.2 between latitude 9.535^0 and 9.545^0 as points of anomalous significant elevation in relation to the surrounding area, whilst the elongated bunch seen at longitude 6.435^0 and with its manifestation occurring at the edge of the study area just beyond longitude 6.430^0 to the west is interpreted as a region of anomalous depression in relation to the surrounding area. Otherwise, the predominant elevation values at the area of study are between 205m and 235m.

Jonah et al. (2014I) have produced a purpose-specific depth map at a 2km² areal extent of the study area that encompassed one-quarter the east-west length of the present area of study (Fig. 4). This study concluded that the region of longitude 6.434⁰ has the highest sediment accumulation or overburden thickness over the bedrock at the area surveyed. The thick sediment signature can be traced through longitude 6.430⁰ to the west of Fig.4.

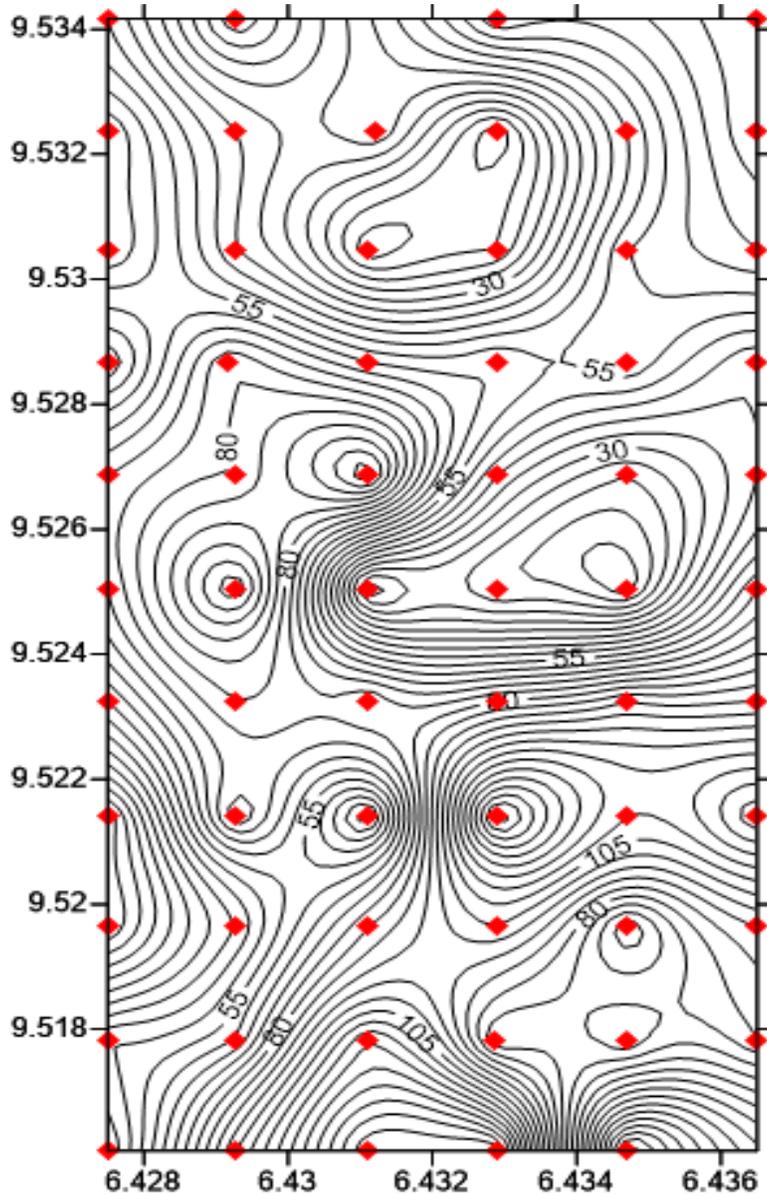


Fig.4. Purpose-specific depth map for a portion of the area of study encompassing one-quarter the east-west length of the present area of study. (Contour interval: 5m.)

What this means is that, having identified the region between longitudes 6.430^0 and 6.435^0 as thickly-sedimented, depression-like (i.e. comparatively low elevation regime), it would be instructive to compare the trend of geoelectrical data acquired at these locations with those from a particular “highland” region of the area of study.

The Geomorphic Feature Map Now as a Tool of Quality Control of Acquired Transverse Traverse Geoelectrical Data at the Area of Study: The ongoing geoelectrical survey mentioned at the outset designates the most southerly 2km west-east (the sense of numerical designation for this ongoing study) direction of constant latitude $09^030'57.80''$ as transverse traverse one (TT1), although the principal profile lines are in a south-north direction (also the sense of numerical designation for principal survey stations for this ongoing study). Thus, the most southerly survey stations, at 100m separation, are P1-1, P2-1, P3-1, P4-1, P5-1, P6-1, P7-1, P8-1, P9-1, P10-1, P11-1, P12-1, P13-1, P14-1, P15-1, P16-1, P17-1, P18-1, P19-1, P20-1, and P21-1. At the georeferenced co-ordinates of $09^030'57.80''$ and $006^026'01.68''$ Station P8-1 corresponds to the longitude point of 6.434^0 as can be made out in Fig.4. In Fig.4, the red dots bordering the longitude point of 6.434^0 are Stations P7-1 and P9-1. Now, let us examine their resistivity characters to a surveyed depth of 100m (see Tables 1 to 3).

Table 1: Resistivity character for Station P7-1 (N09⁰30'57.80"; E006⁰25'58.44")

AB/2	MN/2	GEOM. FACTOR, K	RESISTANCE	STANDARD DEVIATION	CURRENT (I)	STACKS	RESISTIVITY (Ω m)
1	.50	2.36	14.978 Ω	0.02	100mA	4	35.348
2	.50	11.8	3.2670 Ω	0.01	100mA	2	38.550
3	.50	27.8	1.4451 Ω	0.17	100mA	4	40.171
5	.50	77.8	547.91m Ω	0.42	100mA	4	42.627
6	.50	112	403.73 m Ω	0.27	100mA	4	45.218
6	1.00	55	825.10 m Ω	0.32	100mA	4	45.381
8	1.00	99	527.25 m Ω	0.43	100mA	4	52.198
10	1.00	156	404.11 m Ω	0.22	100mA	4	63.041
10	2.50	58.9	350.69 m Ω	0.39	100mA	4	20.655
15	2.50	137	201.65 m Ω	0.01	100mA	4	27.626
20	2.50	245	134.9 m Ω	0.16	100mA	4	33.051
30	2.50	562	108.51 m Ω	1.10	100mA	4	60.983
40	2.50	1001	88.298 m Ω	2.90	100mA	4	88.386
40	7.50	323	204.33 m Ω	0.87	100mA	4	65.999
50	7.50	512	143.70 m Ω	0.57	100mA	4	73.574
60	7.50	742	108.71 m Ω	0.46	100mA	4	80.662
70	7.50	1014	92.881 m Ω	1.70	100mA	4	94.180
80	7.50	1329	61.578 m Ω	0.43	100mA	4	81.826
80	15.00	647	410.05 m Ω	0.42	100mA	4	265.30
90	15.00	825	348.92 m Ω	0.14	100mA	4	287.859
100	15.00	1024	312.99 m Ω	0.39	100mA	4	320.501

Table 2: Resistivity character for Station P8-1 (N09⁰30'57.80"; E 006⁰26'01.68")

AB/2	MN/2	GEOM. FACTOR, K	RESISTANCE	STANDARD DEVIATION	CURRENT (I)	STACKS	RESISTIVITY (Ω m)
1	.50	2.36	3.359 Ω	0.83	50mA	4	7.927
2	.50	11.8	517.63 m Ω	0.41	100mA	4	6.108
3	.50	27.8	236.79 m Ω	1.00	100mA	4	6.583
5	.50	77.8	-53.378m Ω	-21.2	100mA	4	4.153
6	.50	112	74.420 m Ω	1.80	100mA	4	8.335
6	1.00	55	162.05 m Ω	0.83	100mA	4	8.912
8	1.00	99	106.61 m Ω	2.70	100mA	4	10.554
10	1.00	156	73.130 m Ω	3.00	100mA	4	11.408
10	2.50	58.9	248.79 m Ω	0.66	100mA	4	14.654
15	2.50	137	265.05 m Ω	3.30	100mA	4	36.312
20	2.50	245	138.16 m Ω	2.40	100mA	4	33.849
30	2.50	562	94.236 m Ω	12.0	100mA	4	52.961
40	2.50	1001	48.350 m Ω	40.0	100mA	4	48.398
40	7.50	323	149.67 m Ω	2.20	100mA	4	48.343
50	7.50	512	87.979 m Ω	2.30	100mA	4	45.041
60	7.50	742	83.296 m Ω	2.80	100mA	4	61.806
70	7.50	1014	64.133 m Ω	2.80	100mA	4	65.031
80	7.50	1329	31.432 m Ω	5.80	100mA	4	41.773
80	15.00	647	109.56 m Ω	1.50	100mA	4	70.885
90	15.00	825	88.544 m Ω	0.90	100mA	4	73.049
100	15.00	1024	46.523 m Ω	6.10	100mA	4	47.639

Table 3: Resistivity character for Station P9-1 (N09⁰30'57.80"; E006⁰26'04.92")

AB/2	MN/2	GEOM. FACTOR, K	RESISTANCE	STANDARD DEVIATION	CURRENT (I)	STACKS	RESISTIVITY (Ω m)
1	.50	2.36	62.726 Ω	0.29	100mA	4	148.033
2	.50	11.8	30.11 Ω	0.00	100mA	2	355.298
3	.50	27.8	20.268 Ω	0.01	100mA	2	563.450
5	.50	77.8	9.26 Ω	0.00	100mA	2	720.428
6	.50	112	2.647 Ω	0.07	100mA	4	296.464
6	1.00	55	3.926 Ω	0.04	100mA	4	215.93
8	1.00	99	2.775 Ω	0.07	100mA	4	274.725
10	1.00	156	2.344 Ω	0.05	100mA	4	365.664
10	2.50	58.9	5.266 Ω	0.03	100mA	4	310.167
15	2.50	137	2.506 Ω	0.08	100mA	4	343.322
20	2.50	245	1.079 Ω	0.07	100mA	4	264.355
30	2.50	562	364.44 m Ω	0.67	100mA	4	204.815
40	2.50	1001	160.64 m Ω	1.50	100mA	4	160.801
40	7.50	323	473.97 m Ω	0.24	100mA	4	153.092
50	7.50	512	271.73 m Ω	0.15	100mA	4	139.126
60	7.50	742	182.48 m Ω	3.20	100mA	4	135.400
70	7.50	1014	159.83 m Ω	2.50	100mA	4	162.068
80	7.50	1329	110.14 m Ω	0.95	100mA	4	146.376
80	15.00	647	223.90 m Ω	0.51	100mA	4	144.863
90	15.00	825	249.84 m Ω	3.70	100mA	4	206.118
100	15.00	1024	235.60 m Ω	8.00	100mA	4	241.254

It is so obvious that the lowest resistivity regime predominates in Table 2, corresponding to Station P8-1, corresponding to the location identified with the thickest sediment cover (i.e. point of longitude 6.435⁰). At this point, the following prompt is invoked: does this low resistivity regime translates to any meaningful thing in the physical sense? 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 (2013B) and the “Olasehinde Protocol,” enunciated in Jonah et al (2014F). 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 instructive to point out here that even though the resistivities of rocks do not depend on water content only, these informal laws are enunciated “rules-of-thumb” that serve as effective guides to groundwater prospectors out in the field. The bases of these protocols have been found to be effective over a two-decade period now for delineating approximate locations of groundwater yield (Olasehinde, 1989; 1999; Muftau Jimoh, personal communication). Based on these dual empirical rules, at least on a qualitative basis, Station P7-1 can only be good for groundwater prospect down to a depth of 80m, Station P8-1 can be good well beyond the 100m depth-mark, and Station P9-1 is restricted to the 90m depth-mark. The relative high resistance showings of Station P9-1 at shallow depths may be explained away by the observation that this location is situated on the bank of a stream with exposed and scattered bodies of outcrops.

Now, consider a point in the “highland” segment of the area of study, say, Station 10-3. This can be approximately located at the intersection of the 9.518⁰ line of latitude and the 6.436⁰ line of longitude in Fig.8. The resistivity profile of Station 10-3 is shown in Table 4. It is observed that, based on these dual empirical rules, Station P10-3 can only be good for groundwater prospect down to a depth of only 40m, implying a comparatively low yield with respect to the prospects of P7-1, P9-1, and especially P8-1.

Table 4: Resistivity character for Station P10-3 (N09⁰31'04.28"; E006⁰26'08.16")

AB/2 (m)	MN/2 (m)	GEOM. FACTOR, K	RESISTANCE	STANDARD DEVIATION	CURRENT (I)	STACKS	RESISTIVITY (Ω m)
1	.50	2.36	39.174 Ω	0.06	50mA	4	92.451
2	.50	11.8	2.4431 Ω	0.05	50mA	4	28.829
3	.50	27.8	558.61m Ω	0.20	100mA	4	15.529
5	.50	77.8	391.84 m Ω	0.30	100mA	4	30.485
6	.50	112	313.56 m Ω	0.38	100mA	4	35.119
6	1.00	55	488.97 m Ω	1.00	100mA	4	26.893
8	1.00	99	360.35 m Ω	0.31	100mA	4	35.675
10	1.00	156	270.21 m Ω	0.26	100mA	4	42.153
10	2.50	58.9	864.50 m Ω	0.05	100mA	4	50.919
15	2.50	137	508.02 m Ω	0.00	100mA	4	69.598
20	2.50	245	354.03 m Ω	0.40	100mA	4	86.737
30	2.50	562	212.17 m Ω	0.24	100mA	4	119.23
40	2.50	1001	160.83 m Ω	0.45	100mA	4	160.99
40	7.50	323	630.81 m Ω	0.34	100mA	4	203.75
50	7.50	512	515.19 m Ω	0.33	100mA	4	263.77
60	7.50	742	379.87 m Ω	0.01	100mA	4	281.86
70	7.50	1014	272.96 m Ω	0.54	100mA	4	276.78
80	7.50	1329	225.94 m Ω	0.15	100mA	4	300.27
80	15.00	647	496.59 m Ω	0.93	100mA	2	321.29
90	15.00	825	416.95 m Ω	1.50	100mA	4	343.98
100	15.00	1024	345.67 m Ω	2.50	50mA	4	353.97

Conclusion

Strictly from a qualitative perspective, the topographic map of Fig.2, when employed in tandem with its equivalent three-dimensional (3-D) geomorphic profile map of Fig.3, form a veritable tool of quality control of “raw” data that aids visual inspection of the fidelity of these data collected out there in the field.

Recommendation

Recall that the topographic map of this study was produced for principal stations at 100m station-separation. Surely, more detailed geomorphological features would be shown if elevation values are collected at intervening or intercalated stations referenced to the principal stations.

References

- ABEM (1999). *Instruction Manual: Terrameter SAS 4000/SAS 1000*, ABEM Instrument AB, Sundbyberg (Sweden).
- Courant, R., Robbins, H., and Stewart, I. (1996). *What Is Mathematics? An Elementary Approach to Ideas and Methods*, Oxford University Press, New York.
- Davis, J. C. (1986). *Statistics and Data Analysis in Geology*, Wiley.
- Eades, P., Lai, W., Misue, K., Sugiyama, K. (1991). Preserving the mental map of a diagram. In *Proc. Compugraphics '91*, Sesimbra, Portugal, Vol.1, pp 34 – 43.
- Jonah, S.A., Akpan, E. U., Bakara, I. U., Tanimowo, B., Abdullahi, B., Nwachukwu, E. I., Maishanu, I. H., Dania, R., Ezemonye, C.V., Fanisi, O., Ejiga, U., Benu, I.S., Banjo, G. Pius, A., Okunola, I.A., Jimoh, M.O., Amadi, A.N. and Ejepu, J.S. (2013C). Geospatial analysis and Geographic Information System (GIS) mapping of a greenhouse gas at Minna, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*, **9(3)**, 69 - 81.
- Jonah, S.A. and Ayofe, L.F. (2014B). Creation of a Geographic Information System for Minna, Niger State, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*, **1(1)**, 237 – 254.
- Jonah, S.A. and 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)*: **Accepted for publication.**

- Jonah, S.A. and Bawa, S.C. (2014C). Measurements of the levels of environmental noise at major stalling traffic points in Minna, Niger State, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*, **1(1)**, 255 – 268.
- Jonah, S.A. and Duromola, S.A. (2014A). Determination of concentration of sulphur dioxide at major stalling traffic points in Minna, Niger State, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*, **1(1)**, 224 – 236.
- Jonah, S.A. and Jimoh, M.O. (2013A). Production of a topographic map and the creation of a six-layer Geographic Information System (GIS) for a fifteen square-kilometre (15 km²) areal extent of the Gidan Kwano Campus of the Federal University of Technology, Minna, Niger State, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*, **9(2)**, 75 - 89.
- Jonah, S.A., Baba-Kutigi A.N., Uno, U.E., Danganana, M.L., Kolo, M.T., Ofor, N.P., Unuevho, C.I., Onoduku, U.S., Abba, F. M., Alhassan, D.U., Amadi, A.N., Umar, M.O., and Kimpa, M.I. (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., and 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., and 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., Dania, R., Ezemonye, C.V., Fanisi, O., Ejiga, U., Benu, I.S., Banjo, G. Pius, A., Akpan, E. U., Bakara, I. U., Tanimowo, B., Abdullahi, B., Nwachukwu, E. I., Maishanu, I. H., James, G.O., Okunola, I.A., Jimoh, M.O., Amadi, A.N. and Ejepu, J.S. (2013D). Mapping concentrations of carbon dioxide over Central Kubwa, Abuja, using Geographic Information System. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*, **10(1)**, 40 - 55.
- Jonah, S.A., James, G.O., Adeku, D.E., Ahmed, F., Alhassan, A., Hamza, S., Igbideba, O. I., Kwaghua, 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. (2013B). 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., Kwaghua, 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. (2014F). Pre-Drilling Geoelectrical Survey at a Built-up Compound at Barkin-Sale Ward, Minna, Niger State, Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*, **1(2)**, 86 – 97.

Jonah, S.A., James, G.O., Adeku, D.E., Ahmed, F., Alhassan, A., Hamza, S., Igbideba, O. I., Kwaghua, 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. (2014I). Geoelectrical investigation for aquifer and geotechnical properties at the planned Gidan Kwano Campus Development Phase II, Minna, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*: **Undergoing review**.

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

Jonah, S.A., Umoh, S.E., James, G.O., Adeku, D.E., Ahmed, F., Alhassan, A., Hamza, S., Igbideba, O. I., Kwaghua, 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. 2014G. A blind geoelectrical survey commissioned to affirm or deny the presence of aquifer at a compound at Minna, Central Nigeria. *Journal of Information, Education, Science, and Technology (JIEST)*, **1(2)**, 20 – 38.

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

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.

Tracy, J. C. (1907). *Plane Surveying; A Text-Book and Pocket Manual*, J. Wiley & Sons, New York.

Wikipedia, (2010). <http://www.wikipedia.org>.

Wikipedia, (2011). Contour line. http://www.en.wikipedia.org/wiki/contour_line, retrieved on 17th October 2011.

Wolff, A. (2004). <http://www.nwcg.gov/pms>. Retrieved 9th September 2011.

www.140.194.76.129.org. Retrieved on 12th September 2011.