Analyses of Pseudosection Specific Routes of Different Orientations of Fault-Traces to Determine Groundwater Flow Pattern at a 4 km² Tranche of New Development, Gidan Kwano Campus Phase II, Federal University of Technology, Minna, Nigeria

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Abstract
Having drawn general conclusions with respect to groundwater prospects from the results of a vertical electrical sounding survey of a 4km² tranche of New Development at the Gidan Kwano Campus Phase II, it is necessary to examine further the groundwater recharge prognoses of the NE-SW trending subsurface fault-traces that have been pinpointed. Thus, this study was concerned with the analyses of pseudosection specific routes of the different orientations of fault-traces culminating at locations P2-1 (Station1, Profile2), P3-1 (Station1, Profile3), P4-1 (Station1, Profile4), P8-1 (Station1, Profile8), P9-1 (Station1, Profile9), and P6-2 (Station2, Profile6). The pseudosections along the NE-SW diagonal fault-traces of these locations confirm that the fault-traces culminating at these points are continuous subsurface fracture routes for groundwater flow; furthermore, the observed flow pattern has been classified in this study as either "normal" or "reverse." Thus, it is recommended that based on the current survey regime, an appropriate "water farm" scheme should be centred on these locations. Such a water farm scheme would involve the drilling of boreholes down to the total depth (TD) surveyed for the individual points of interest and feeding their output to a storage facility for onward processing and distribution through an appropriate purpose-specific waterworks for the Gidan Kwano Campus Phases I and II.

Keywords: *Fault-Trace; pseudosection; groundwater; prognosis; recharge*

Introduction
The work completed at the 4 km² tranche of New Development of the Gidan Kwano Campus (GKC) of the Federal University of Technology (F.U.T.), Minna, was a 2km x 2km dual vertical electrical sounding (VES)-induced polarisation (IP) survey represented in the grid formats of Figs 1 and 2. The Schlumberger array of the VES mode, at 100m station-spacing, was employed for the survey. The survey trend was an east-west (or transverse traverse, TT) sense for individual stations and a south-north profile, thus defining a two-dimensional configuration. The station-designation format for this study also follows a two-dimensional spatial awareness: principal profile lines are in the north-south direction, with the first profile line being the westernmost line of longitude; numerical station-designation is from west to east. The actual field survey proceeded from south to north because it was most convenient for the survey crew as the southwestern portion of the area of study was considered the most distant from the staging point and thus the most "difficult" to tackle; this "difficulty" had to be tackled first. Thus, the first assigned station of survey based on this format is the most extreme southwestern point in the 2 km by 2 km grid appropriately called P1-1; that is, Station 1 of Profile 1. Station 2 of Profile 1 (P1-2) is exactly 100m to the north of Station 1; Station 3 of Profile 1 (P1-3) is exactly 100m to the north of Station 2 and exactly 200m north of Station 1, and so on. P2-1 means Station 1 of Profile 2; this is exactly 100m to the east of P1-1; P3-1 is exactly 100m to the east of P2-1 and exactly 200m to the east of P1-1. With respect to geoelectrical studies that have been carried out at the local Basement Complex of which the location of this study is a part, the following works are cited: Abdulrashid (2005); Salako *et al.* (2010); Jonah *et al.* (2013); Jonah *et al.* (2014A); Jonah *et al.* (2014B); Jonah *et al.* (2014C); Jonah *et al.* (2015A); Jonah *et al.* (2015B); Jonah *et al.* (2015C); Jonah *et al.* (2015D); Jonah *et al.* (2015E); Jonah *et al.* (2015F); Jonah and Olasehinde (2016).

The result of the fault-trace of water-bearing fracture signatures inferred from a combination of the geoelectric cross-sections and the induced polarisation tables is shown as Fig.3 whilst that of the trace of low-resistivity signature trend inferred from the pseudosection plots is shown as Fig.4.

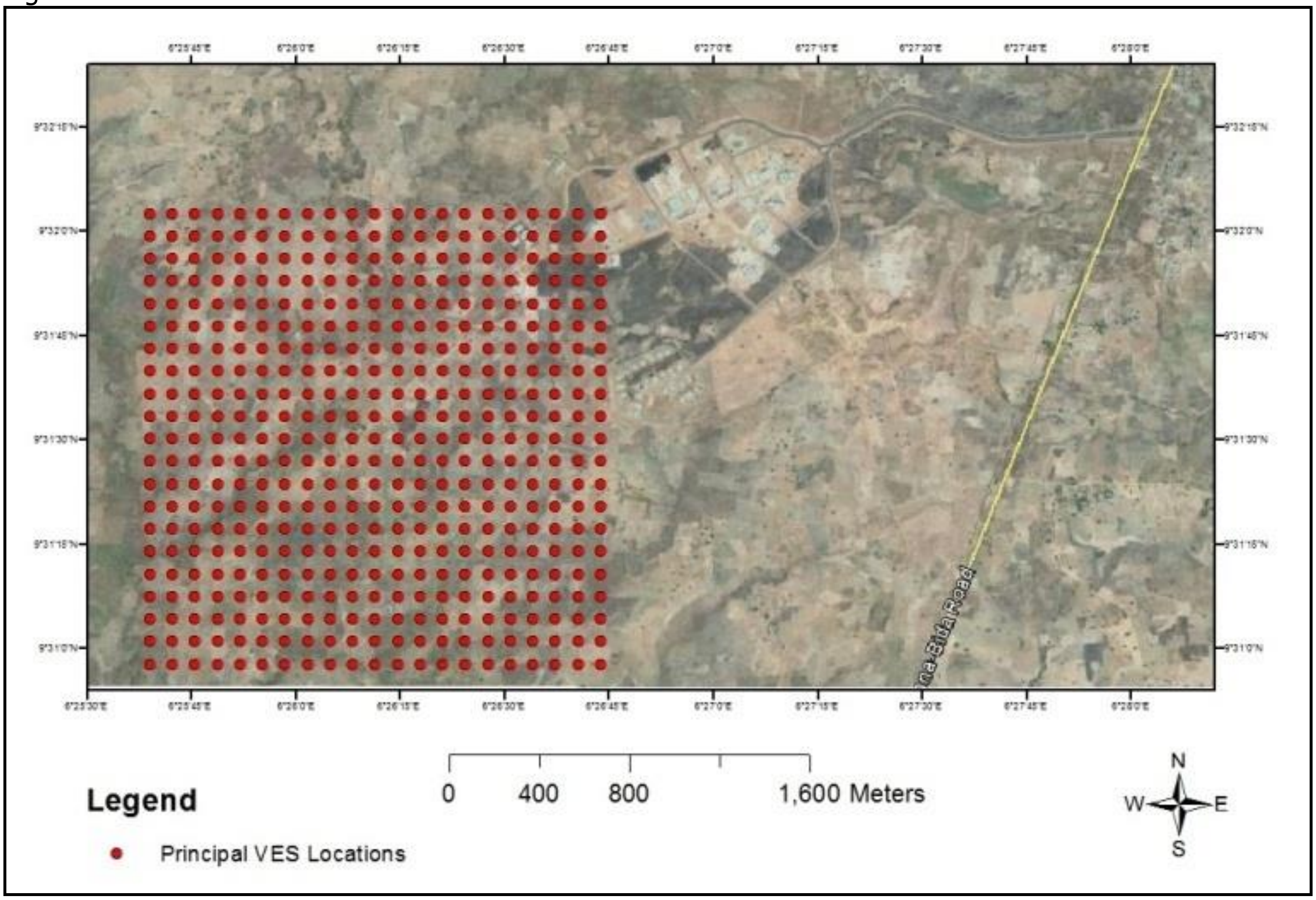

Fig.1. Grid of the 4km^2 tranche of New Development at the GKC. (The tadpole-shaped feature is Phase I, the present developed portion of the GKC, seen to the northeast of the red-dotted grid of the 4km^2 areal extent; the Minna-Kateregi-Bida Road is seen as the linear slope to the far east of the grid.)

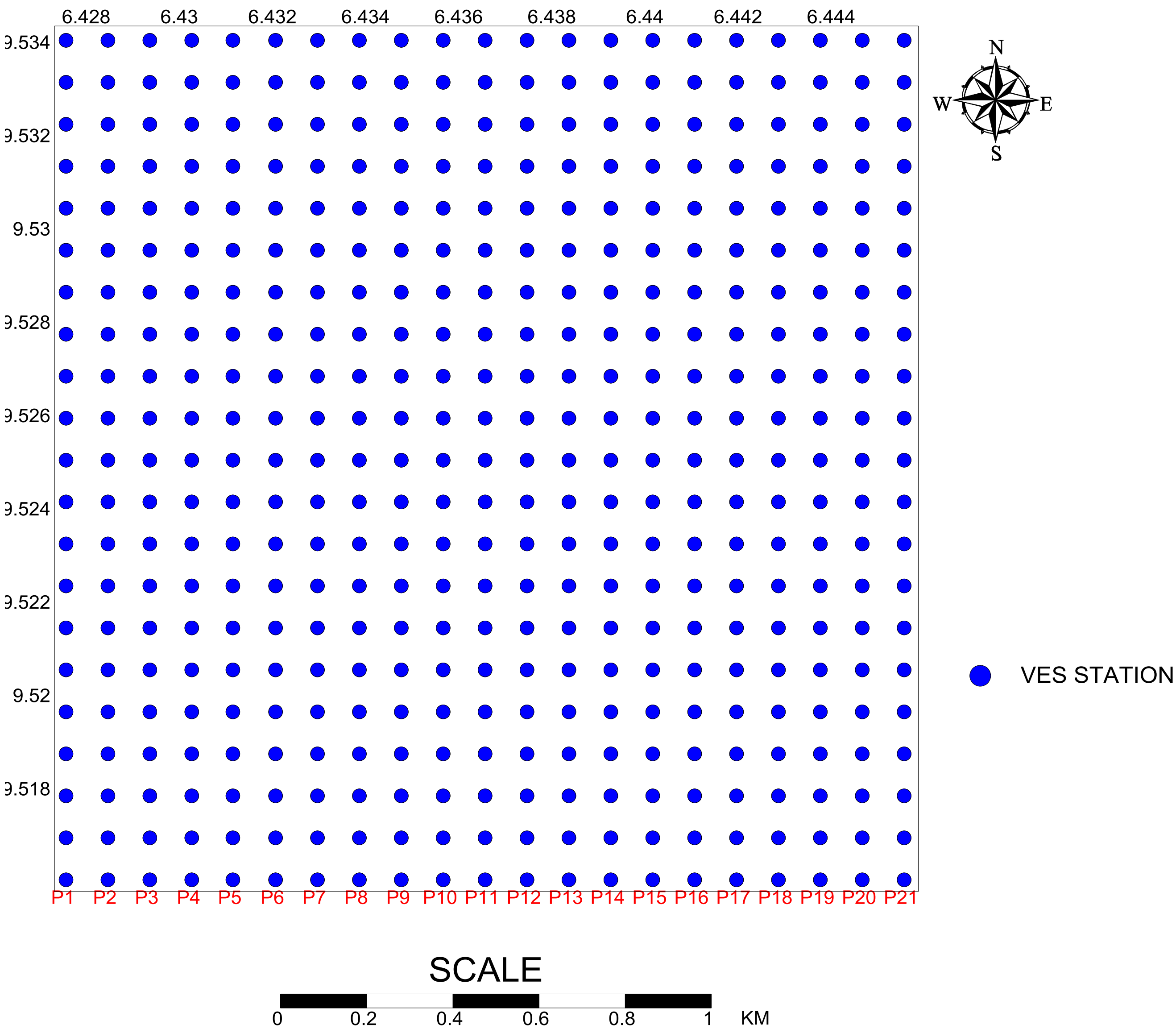

Fig.2. Conventional grid matrix format of the layout of Fig.1

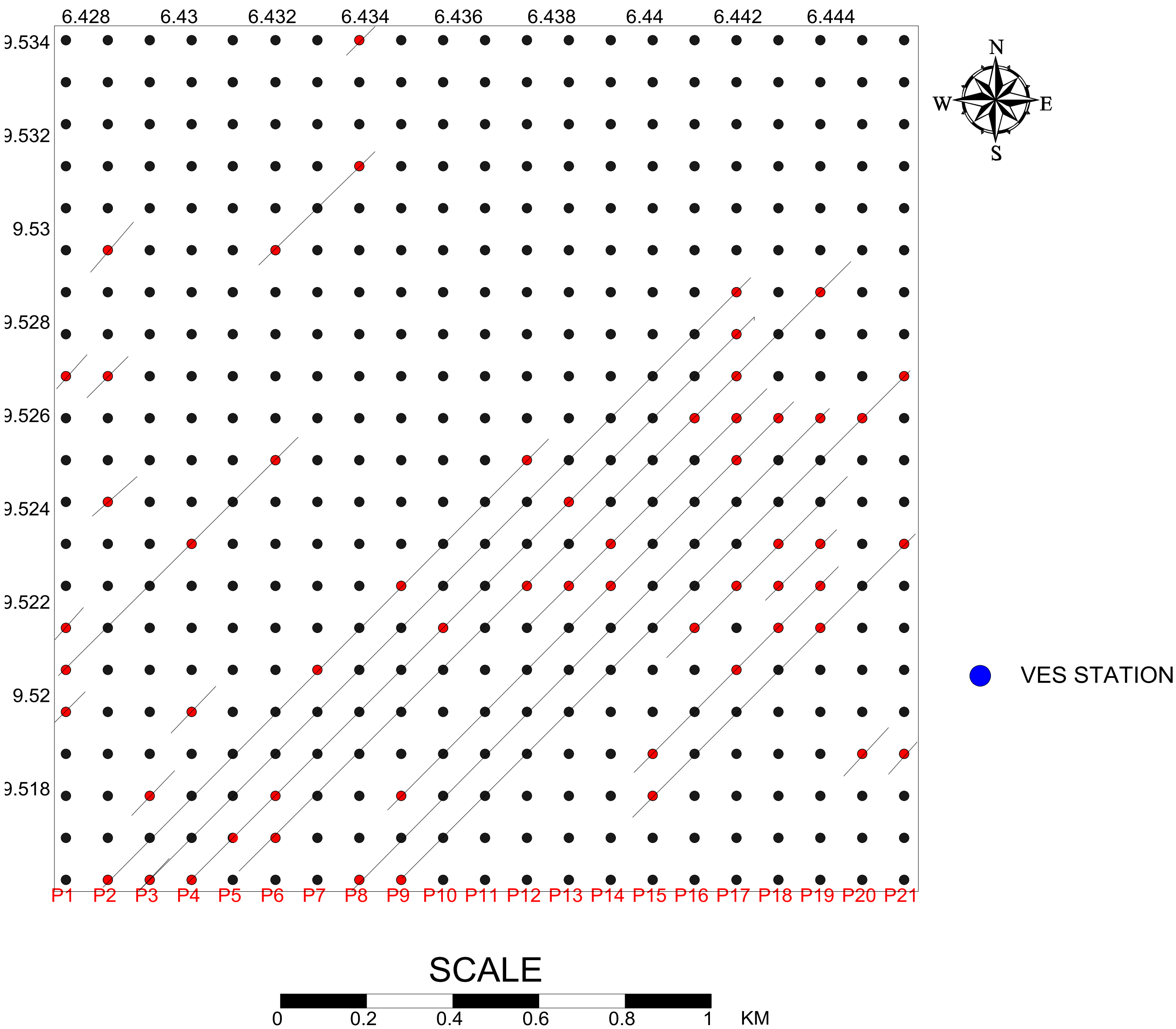

Fig.3. Fault-trace of fracture signatures inferred from a combination of the geoelectric cross-sections and the induced polarisation tables on the conventional grid matrix of the layout of survey stations

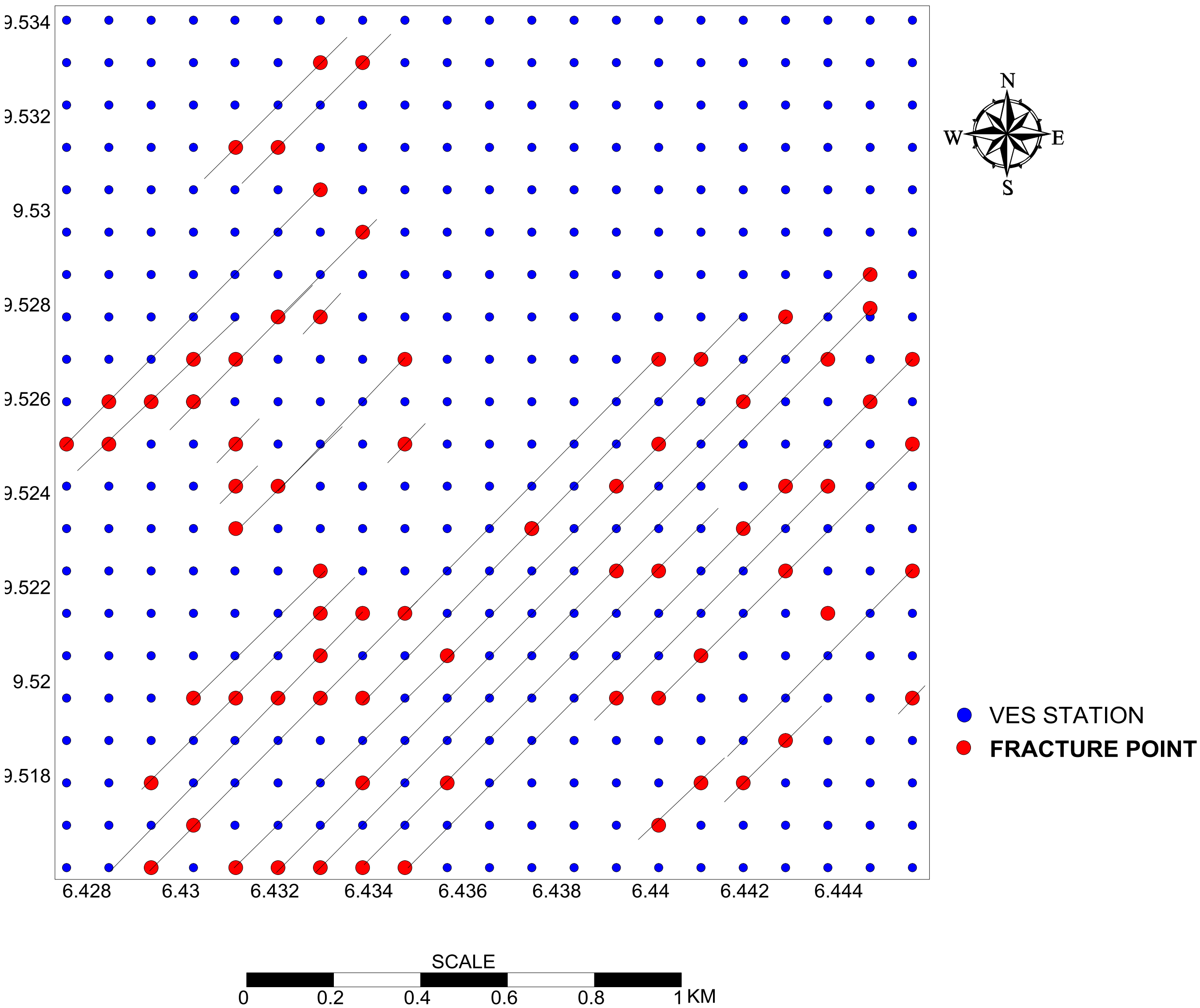

Fig.4. Trace of low-resistivity signature trend inferred from the pseudosection plots on the conventional grid matrix of the layout of survey stations

The slope of the landform of which this $4km^2$ is a tranche indicates a resultant north-south east-west tilt (see Fig.5) which would suggest groundwater prospects at the southwestern portion; observations of Figs 3 and 4 strongly corroborate this fact. Thus, conclusion drawn from the interpretation route for groundwater potentials at the $4km^2$ area of study indicates that there is discerned a sense of "geological fault-sources" at the right of the central mid-plane much close to the southeast and also a sense of "geological fault-sinks" at some points on the first transverse traverse line much close to the southwest. These "geological fault-sinks" located on the slope of the landform of the area of study are the most important aquifer locations because they are situated on the low-slopes of subsurface fault lines; the generally shallow nature of the water-bearing fractures concentrated on the high-slope at the right of the central mid-plane much close to the southeast is the perfect "aquifer source" for the generally deeply-incised nature of the water-bearing fractures concentrated on the low-slope at the southwest. Examination of Figs 3 and 4 shows that only for P3-1, P8-1, and P9-1 do the traces for coincide at the "sink." Information gleaned from Fig.3 (the "most reliable" trace) is now used to analyse the different "primary geological fault-sinks" and the sole "secondary geological fault-sink" due to water-bearing fractures only; the "primary geological fault-sinks" are those located on the first east-west TT line at P2-1, P3-1, P4-1, P8-1, and P9-1 while the "secondary geological fault-sink" is that located on the second east-west TT line at P6-2. These "sources" and "sinks" basically defines a northeast (NE)-southwest (SW) fault trend.

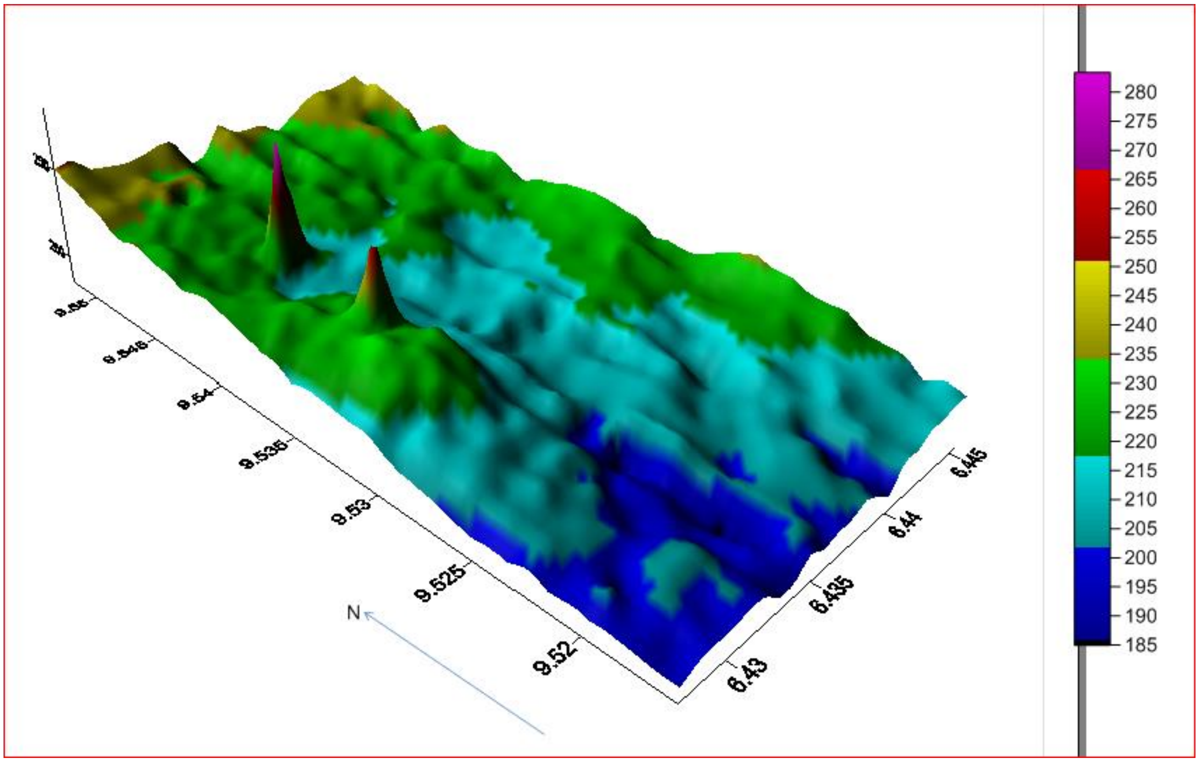

Fig.5. Site-specific geomorphic feature map of the wider 8km^2 Phase II Development

Analyses of Pseudosection Specific Routes of Different Orientations of Fault-Traces

"Geological fault-sink" at P2-1. The fault-line culminating at P2-1 extends over a diagonal length of 1287.5m (~1.3km). The result of the pseudosection along the fault-line culminating at P2-1 would determine if the groundwater recharge prognosis for P2-1 is very good.

Pseudosection along Fault-Trace Culminating at P2-1:- The fault-trace of interest here connects P2-1, P9-8, and P12-11, and the cross-section along this fault-trace is shown as Fig.6.

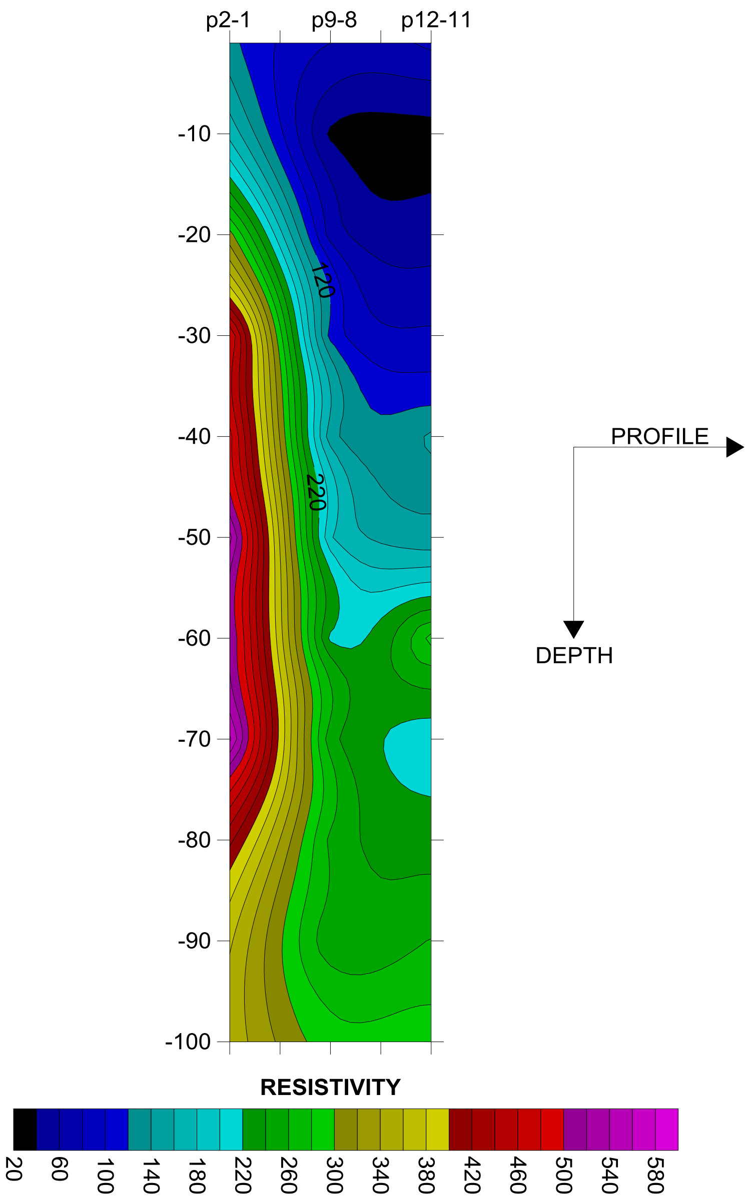

Fig.6. Pseudosection along fault-trace connecting P2-1, P9-8, and P12-11

It seen in Fig.6 that, along the diagonal connecting P2-1, P9-8, and P12-11, the information gleaned from the pseudosection plot indicates a groundwater recharge in the direction of P12-11 as deduced from the resistivity trend. There is a "low-resistivity plunge" in the high-slope direction. Since groundwater recharge exists along that diagonal, it should be designated "reverse recharge trend."

"Geological fault-sink" at P3-1. The fault-line culminating at P3-1 extends over a diagonal length of 1800m (1.8km). The result of the pseudosection along the fault-line culminating at P3-1 would determine if the groundwater recharge prognosis for P3-1 is very good.

Pseudosection along Fault-Trace Culminating at P3-1:- The fault-trace of interest here connects P3-1 and P17-15; the cross-section along this fault-trace is shown as Fig.7.

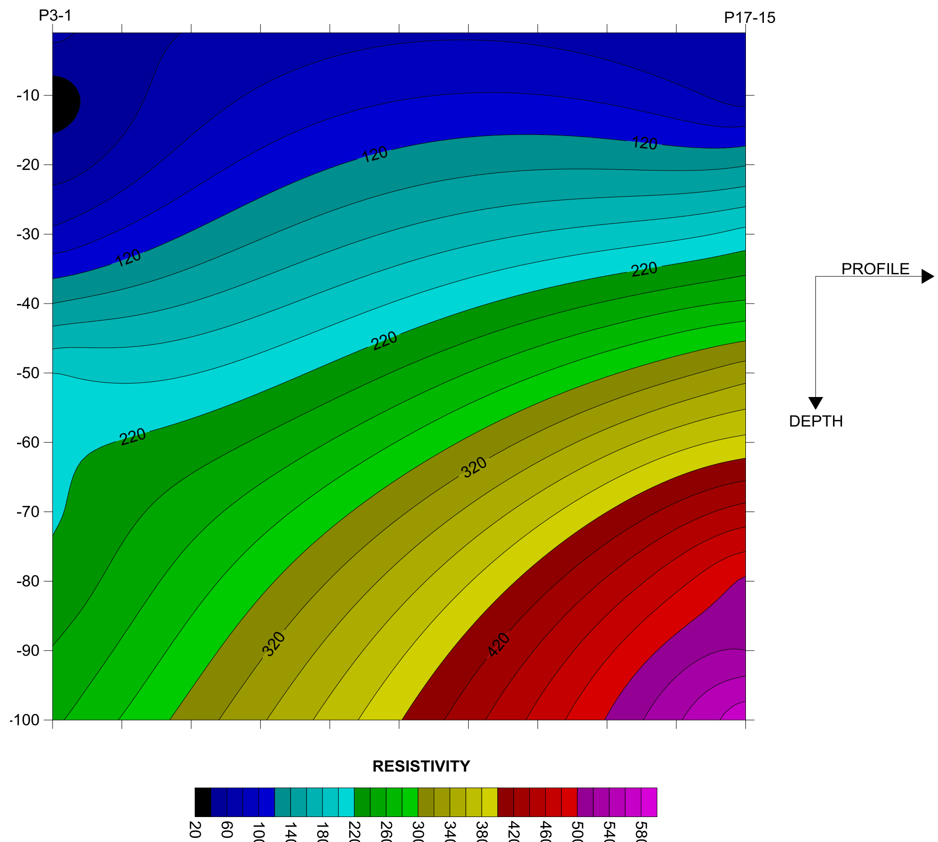

Fig.7. Pseudosection along fault-trace connecting P3-1 and P17-15

It seen in Fig.7 that, along the diagonal connecting P3-1 and P17-15, the information gleaned from the pseudosection plot indicates a groundwater recharge in the direction of P3-1 as deduced from the resistivity trend. In this case, there is a "low-resistivity plunge" in the low-slope direction. Since groundwater recharge exists along that diagonal, it should be designated "normal recharge trend."

"Geological fault-sink" at P4-1. The fault-line culminating at P4-1 extends over a diagonal length of 1675m (~1.7km). The result of the pseudosection along the fault-line culminating at P4-1 would determine if the groundwater recharge prognosis for P4-1 is very good.

Pseudosection along Fault-Trace Culminating at P4-1:- The fault-trace of interest here connects P4-1, P5-2, P6-3, P10-7, P13-10 and P17-14; the cross-section along this fault-trace is shown as Fig.8.

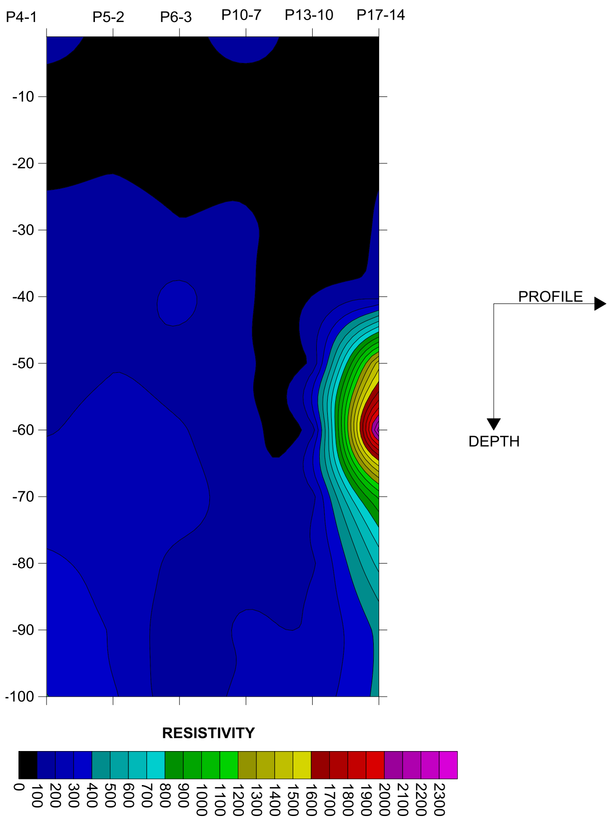

Fig.8. Pseudosection along fault-trace connecting P4-1, P5-2, P6-3, P10-7, P13-10, P17-14

It is observed in Fig.8 that, along the diagonal connecting P4-1, P5-2, P6-3, P10-7, P13-10 and P17-14, the information gleaned from the pseudosection plot indicates a groundwater recharge in the direction of P4-1, as best as could be made out, and as deduced from the resistivity trend. In this case, there is a "low-resistivity plunge," as it were, in the low-slope direction. Since groundwater recharge exists along that diagonal, it should be designated "normal recharge trend."

"Geological fault-sink" at P8-1. The fault-line culminating at P8-1 extends over a diagonal length of 1400m (1.4km). The result of the pseudosection along the fault-line culminating at P8-1 would determine if the groundwater recharge prognosis for P8-1 is very good.

Pseudosection along Fault-Trace Culminating at P8-1:- The fault-trace of interest here connects P8-1 and P19-12; the cross-section along this fault-trace is shown as Fig.9.

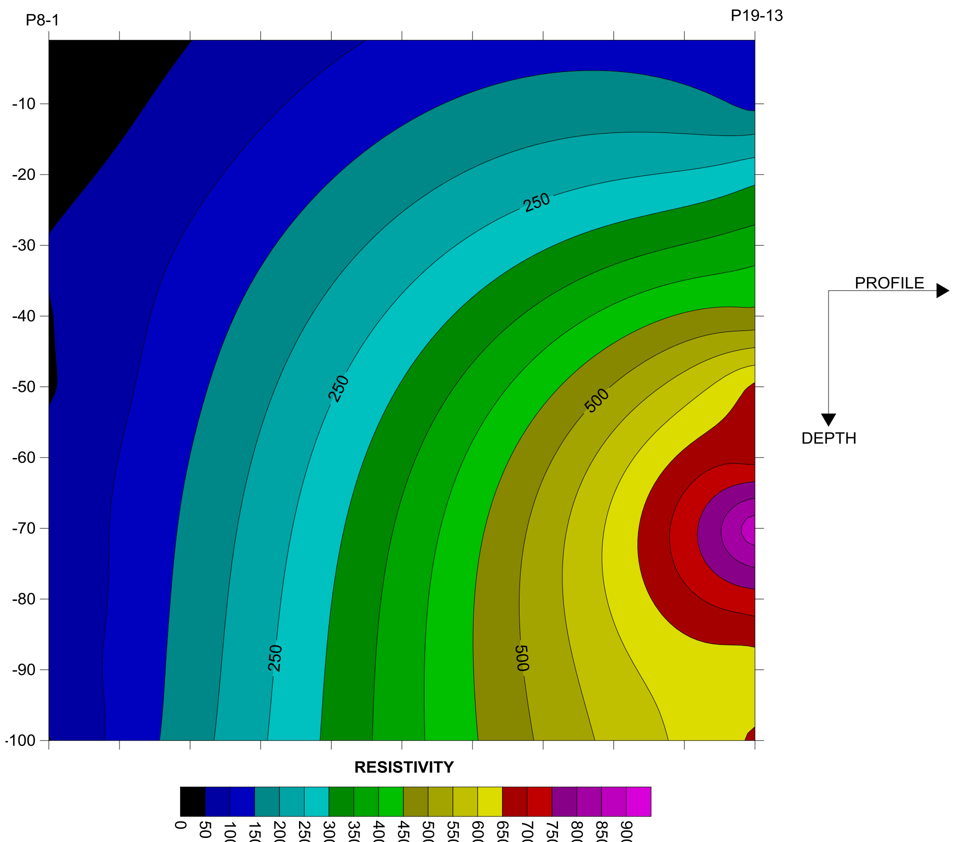

Fig.9. Pseudosection along fault-trace connecting P8-1 and P19-12

It seen in Fig.9 that, along the diagonal connecting P8-1 and P19-12, the information gleaned from the pseudosection plot indicates a groundwater recharge in the direction of P8-1 as deduced from the resistivity trend. In this case, there is a "low-resistivity plunge" in the low-slope direction. Since groundwater recharge exists along that diagonal, it should be designated "normal recharge trend."

"Geological fault-sink" at P9-1. The fault-line culminating at P9-1 extends over a diagonal length of 1537.5m (~1.5km). The result of the pseudosection along the fault-line culminating at P9-1 would determine if the groundwater recharge prognosis for P9-1 is very good.

Pseudosection along Fault-Trace Culminating at P9-1:- The fault-trace of interest here connects P9-1, P20-12, and P21-13; the cross-section along this fault-trace is shown as Fig.10.

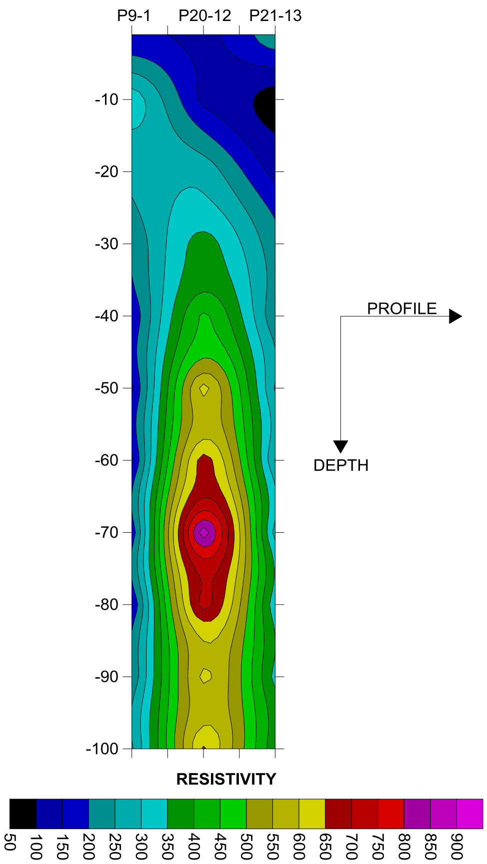

Fig.10. Pseudosection along fault-trace connecting P9-1, P20-12, and P21-13

It seen in Fig.10 that, along the diagonal connecting P9-1, P20-12, and P21-13, the information gleaned from the pseudosection plot would, at first glance, indicate a groundwater recharge in the direction of P21-13 as deduced from the resistivity trend, and there is a well-discerned "low-resistivity plunge" in the high-slope direction. Since groundwater recharge exists along that diagonal, it should be designated "reverse recharge trend." However, upon closer inspection of Fig.10, it is observed that in spite of the "reverse recharge trend" designation for P9-1, there are pockets of low-resistivity bodies at depths here which imply that P9-1 could be exploited on a "standalone" basis.

"Geological fault-sink" at P6-2. The fault-line culminating at P6-2 extends over a diagonal length of 1687.5m (~1.7km). The result of the pseudosection along the fault-line culminating at P6-2 would determine if the groundwater recharge prognosis for P6-2 is very good.

Pseudosection along Fault-Trace Culminating at P6-2:- The fault-trace of interest here connects P6-2, P12-8, P16-12, P17-13, and P19-15; the cross-section along this fault-trace is shown as Fig.11.

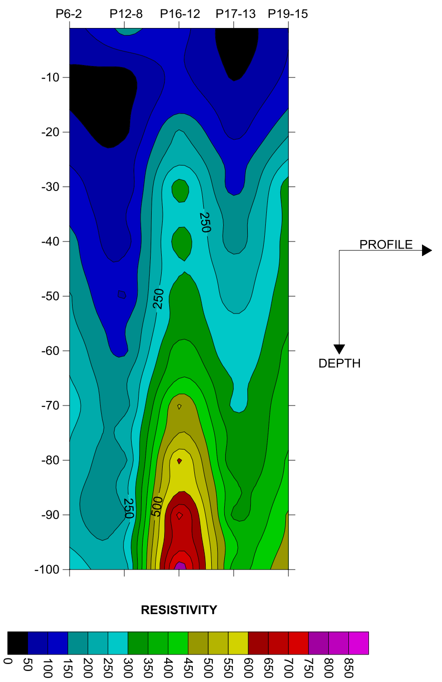

Fig.11. Pseudosection along fault-trace connecting P6-2, P12-8, P16-12, P17-13, and P19-15

It seen in Fig.11 that, along the diagonal connecting P6-2, P12-8, P16-12, P17-13, and P19-15, the information gleaned from the pseudosection plot indicates a groundwater recharge in the resultant direction of P12-8 as deduced from the resistivity trend. In this case, there is a resultanat "low-resistivity plunge" in the low-slope direction. Since groundwater recharge exists along that diagonal, it should be designated "normal recharge trend."

On the "Ideal Groundwater Recharge Curve." In conformance with the slope of the landform and the fact that P8-1 is on the low-slope of the diagonal connecting it to P19-12 and the conclusions drawn from independent studies that P8-1 is a good prospect, the shape of the resistivity profile curve of the pseudosection plot of Fig.9 should be considered the "ideal groundwater recharge curve." Having established the fact of this situation, it then means that P8-1 is a perfect groundwater "sink" considering that the resistivity profile progressively "plunges" to P8-1. The ideal shape would be a "dome" of decreasing high-resistivity signatures having its core at the high-slope such that its low-resistivity end "plunges" to the low-slope.

Conclusion

The pseudosections along the NE-SW diagonal fault-traces of P2-1, P3-1, P4-1, P8-1, P9-1, and P6-2 confirm that the fault-traces culminating at these points, as observed in Figs 3 and 4, are continuous subsurface fracture routes for groundwater flow. The observed flow pattern has been classified in this study as either "normal" or "reverse."

Groundwater Recharge Prognosis for P2-1 Based on Pseudosection Analysis of the Fault-Trace Culminating at P2-1. Prognosis is good and the recharge trend is "reverse."
Groundwater Recharge Prognosis for P3-1 Based on Pseudosection Analysis of the Fault-Trace Culminating at P3-1. Prognosis is good and the recharge trend is "normal."
Groundwater Recharge Prognosis for P4-1 Based on Pseudosection Analysis of the Fault-Trace Culminating at P4-1. Prognosis is good and the recharge trend is "normal."
Groundwater Recharge Prognosis for P8-1 Based on Pseudosection Analysis of the Fault-Trace Culminating at P8-1. Prognosis is good and the recharge trend is "normal."

Groundwater Recharge Prognosis for P9-1 Based on Pseudosection Analysis of the Fault-Trace Culminating at P9-1. Prognosis is good and the recharge trend is "reverse."
Groundwater Recharge Prognosis for P6-2 Based on Pseudosection Analysis of the Fault-Trace Culminating at P6-2. Prognosis is good and the recharge trend is "normal."
Location of Best Curve-Fit for the Defined Ideal "Groundwater Recharge Curve." P8-1

Recommendation
Based on the current survey regime, an appropriate "water farm" scheme should be centred on the locations of P2-1, P3-1, P4-1, P8-1, P9-1, and P6-2. Such a water farm scheme would involve the drilling of boreholes down to the total depth (TD) surveyed for the individual points of interest and feeding their output to a storage facility for onward processing and distribution through an appropriate purpose-specific waterworks for the GKC Phases I and II.

References
Abdulrashid, U. A. (2005). *Seismic Refraction Investigation of the Western Part of the Federal University of Technology, Gidan Kwano Campus, Minna, Nigeria*, MTech. dissertation, Federal University of Technology, Minna.

Jonah, S.A., Akpomie, D.P., Ezekwebekwe, L. O., Isah, E.A., Muhammed, A.N., Momoh, A.A., Okoye, C.K., Okpara, K. K., Oni, N.O., Alade, R. O., Yahaya, G. A., Zubair, R.O., Onoja, E.U., & Daramola, O. (2015F). A dual topographic-petrographic control for a 1km^2 VES-IP study completed at the Gidan Kwano Campus Phase II Development, Minna, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED),* 11(3), 65 - 76.

Jonah, S.A. & Olasehinde, P.I. (2015E). Qualitative induced polarisation validation of the results of a 2km^2 VES Study completed at the Gidan Kwano Campus Phase II Development, Federal University of Technology, Minna, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED),* 11(3), 34-46.

Jonah, S.A. & Olasehinde, P.I. (2016). Correlation of dry season and wet season geoelectrical values for the ABEM Terrameter SAS 4000 at coincident points at the Planned Phase II Development, Gidan Kwano Campus, Federal University of Technology, Minna, Nigeria. *Unpublished*.

Jonah, S.A., James, G.O., Adeku, D.E., Ahmed, F., Alhassan, A., Hamza, S., Igbideba, O. I., Kyari, M., Kwaghhua, F.I., Macaulay, V. F., Olarewaju, S.I., , Onyeodili, G., Popoola, G.B., Sofeso, O.A., Switzer, F. K., & Umoh, U. E. (2013). 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., Kyari, M., Kwaghhua, F.I., 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)*, 1(2), 86-97.

Jonah, S.A., James, G.O., Adeku, D.E., Ahmed, F., Alhassan, A., Hamza, S., Igbideba, O. I., Kyari, M., Kwaghhua, F.I., Macaulay, V. F., Olarewaju, S.I., , Onyeodili, G., Popoola, G.B., Sofeso, O.A., Switzer, F. K., & Umoh, U. E. (2015A). 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., Jimoh, M.O., & Umar, M. (2015C). A wet-season geoelectrical investigation for groundwater development at a built-up property at the Western Bye-Pass, Minna, Nigeria. *Journal of Science, Technology, Mathematics, and Education (JOSTMED)*, 11(1), 109 - 117.

Jonah, S.A., Umoh, S.E., James, G.O., Adeku, D.E., Ahmed, F., Alhassan, A., Hamza, S., Igbideba, O. I., Kyari, M., Kwaghhua, F.I., 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)*, 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., Kyari, M., Kwaghhua, F.I., 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)*, 1(2), 158 – 171.

Jonah, S.A., Olasehinde, P.I., & Umar, M. (2015B). 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., & Yunana, T. (2015D). 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 Science, Technology, Mathematics, and Education (JOSTMED),* 11(2), 32-50.

Salako, K. A., Abdulrashid, U. A., Adetona, A.A., Rafiu, A.A., Ofor, N.P., Alhassan, D.U., & Jonah, S.A. (2010). Geophysical investigation of western part of Federal University of Technology, Gidan Kwano Campus, Minna, Niger State, using electrical and seismic refraction methods. *Natatural and Applied Science Journal*, 11(2), 249-264.