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SUBSURFACE CHARACTERIZATION TO DETERMINE A SUITABLE BOREHOLE LOCATION FOR IRRIGATION AT COLLEGE OF AGRICULTURE, MOKWA NUPE BASIN, NIGERIA

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ABSTRACT

A geo-electric survey involving 15 points Vertical Electrical Sounding and Induced Polarization was carried out to determine positions for the drilling of boreholes that will provide adequate water supply for extensive irrigation work at Niger State College of Agriculture Mokwa, Nigeria. The data were acquired with Schlumberger configuration at stations chosen across the study area. The acquired data were interpreted with IPI2WIN iterative computer software. The interpreted results suggest three geo-electric layers. Their equivalent geologic/lithological units suggest weathered and fractured basement as the aquiferous layers along the three profiles investigated within the study area. Suitable sites for construction of boreholes were outlined based on the aquifer thickness range of the aquiferous layers. The VES 4 & 5 along the first Profile was the most probable and viable site with the highest aquiferous thickness of 19.21 m, followed by the third profile with aquifer thickness of 11.88 and the least was profile 2 with aquifer thickness of 11.60 m. profile 1, VES point 4 or 5 was therefore recommended for top priority site when drilling the borehole.

Keywords: Aquifer, Borehole, Irrigation, Vertical Electrical Sounding (VES), Induced Polarization

INTRODUCTION

Groundwater is one of the important but necessary alternative to surface water sources in every community needs most especially for the agricultural purposes. The occurrence and distribution of groundwater greatly varies according to the local and regional geology, hydrogeological setting and the nature of the activities within the land. Groundwater is mostly hosted within zones of weathering and fracturing which often are not continuous in vertical and lateral extent (Hasan, *et al.* 2019). There is a growing increase in the demand for groundwater in Mokwa areas of Niger State. The area which is underlain by rocks of the Nupe Basement Complex and overlain by the sedimentary terrain consisting of essentially conglomerates, sandstones and claystones of Campanian to Maastrichtian age (Yusuf, *et al.* 2018), (Hasan, *et al.* 2019).

The main activities of the inhabitants of the study area (College Farm) is research, teaching and learning through farm practical, because of the lack of regular or sufficient water supply challenges, Research and farm practical activities are only restricted to the rainy season, leaving the Researchers and students as well as other famers idle for most part of the year (Arabi, Raimi, & Dewu, 2011) and (Akinlalu, & Afolabi, 2018). In an effort to improve the research, teaching and learning standard of the College and of course the living standard of the surrounding community (since most of the communities in this area are farmers), provision of sustainable water is an ultimate goal which must be achieved. Also there is every need to ensure qualitative and adequate water supply for irrigational purpose in order to guarantee all season farming (including dry season farming) in the study area. In a bid to address such challenges, Vertical Electrical Soundings were carried out, at the College form to determine suitable sites for drilling Borehole, which will serve as source for sustainable water supply for the College farm irrigation scheme.

Geophysical approach has been successfully used to provide aquifer properties that are important sources of groundwater for irrigation and other agricultural purposes (Olorunfemi, & Oni, 2019). The application of geophysical methods on the search for groundwater and its quality status is based on the principle that certain physical properties of rocks change considerably with water content in them (Muhammad, *et al.* 2019). The point of changes in the physical properties reveal a physical boundary characterized by variation in density, conductivity and elastic properties (Yusuf, *et al.* 2018). These variations make electrical resistivity (ER), gravimetric, Induced Polarization (IP) and seismic methods of geophysical prospecting a useful tool in groundwater exploration. Each of these methods has varying degree of success in furnishing useful information regarding groundwater exploration (Yusuf, 2016). Out of all these geophysical methods, ER and IP has an important attributes of responding to different materials than seismic and other methods, specifically to water content and salinity of subsurface units (Folorunso, 2017). All these put together, this research was designed to aim at assessing the subsurface environment to establish the viable point to locate borehole for irrigational purposes at the College of Agriculture Mokwa farm site. The set down objectives are to;

1. delineate the horizontal spatial patterns in soil properties, which strongly influence groundwater yields,
1. Detect the hydraulically active structures within the study areas,

2. delineate the areas within the farm site that has groundwater potential for domestic and irrigation purposes,
3. determine the most viable location for drilling borehole at the College farm.

MATERIAL AND METHODS

Study Area

The study area was geographically located between latitudes 9°17.217′ N and 9°17.286′ N and longitudes 5°04.173′ E and 5°04.139′ E at Mokwa Local Government Area of Niger State, Nigeria. The College farm site is located at mile 12, along Mokwa - New-Bussa road, beside ABU Zaria Farm site before Ndayako village.

Fig. 1: Study location on the Geographical map of Mokwa. (Google map 2020)

METHODOLOGY

The adopted geophysical method in this research involves measuring subsurface resistivity by simultaneously passing current into the ground via two current electrodes and measuring voltage created by the current flow in the vicinity of the electrodes using two neighboring potential electrodes. The normal earth usually has high resistance which is occasionally lowered by presence of conductive materials. Therefore, special metals with high impedance are used when adopting geophysical methods of ER and IP (Mohammed, Olorunfemi, & Idonigie, 2012). Such a voltmeter draws virtually no current, and the voltage drop through the electrodes is therefore negligible. The resistances of the current electrodes normally limit current flow but does not affect resistivity calculations (Olorunfemi, & Oni, 2019). A geometric factor is required to convert the field data obtained from these four-electrode arrays to resistivity. The result of any single measurement with any array could be interpreted as due to homogeneous ground with a constant resistivity. The geometric factors used to calculate this apparent resistivity, can be derived from the formula (Oritsejolonesan, & Saleh, 2012) and (Olatunji, Omonona, & Odediran, 2017).

$$V = \frac{\rho I}{2\pi a} \qquad (1)$$

For the electric potential **V** at a distance **a** from a point electrode at the surface of a uniform half-space (homogeneous ground) of resistivity **ρ** (referenced to a zero potential at infinity). The current **I** may be positive (if into the ground) or negative. For arrays, the potential at any voltage electrode is equal to the sum of the individual contributions from the current electrodes. In a four-electrode field survey over homogeneous ground the expression for the geometric factor (**K**) is as given by equation (2).

$$K = \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} - \frac{1}{BN}} \qquad (2)$$

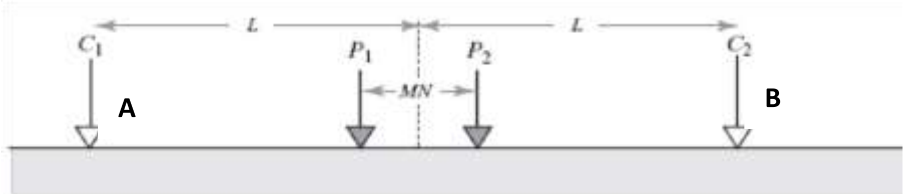


Fig. 2: Schlumberger array

Field Procedure

The farm site area was surveyed by firstly mapping out and wooden pegs driven into the ground at appropriate intervals. Steel electrodes connected to single core, multi-strand copper wires by crocodile clips were sent into the ground at the position of the wooden pegs (sounding points) and connected to the ABEM SAS 4000 Terrameter via connecting wires. The field procedure adopted was ER and IP surveys along the 3 profiles containing 15 VES points of 100 m inter profile spacing were occupied covering the study area (300) m^2. The adoption of the Schlumberger array for the data acquisition was most preferred because of its sensitivity to subsurface inhomogeneity (Yusuf, *et al.* 2018).

Coordinates of each profile were firstly recorded also readings for ER and IP were concurrently taken and recorded on the Datasheets. Adequate precautions were dully observed although there were some occasional challenges of error messages displayed by the Terrameter experienced mostly due to poor or no contact between the electrodes and the ground or the cables being disconnected. Such were resolved by re-hammering down the electrodes or in some cases wetting the surrounding ground with water and re-checking/reconnecting the wires. The co-ordinates of each of the profile were taken using Global Positioning System (GPS) and recorded along with the observed field data on the datasheet and thereafter further processed using computer, the output of which were the 2-D inverse models of the subsoil resistivity and chargeability. Adequate precautions were dully observed to minimize electrode positioning and contact errors during the measurements throughout the survey and thus to ensure quality and minimized errors in the data collected.

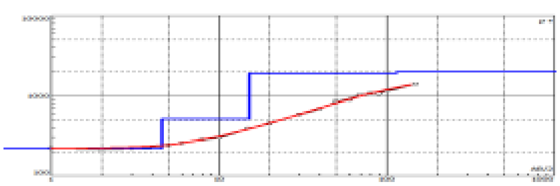
Interpretation Technique

The ER and IP surveying formed a powerful tool for sustainable and qualitative agricultural, environmental and engineering applications including hydro-geological mapping (Yusuf, 2018). The field data (pseudo-sections) were inverted to produce models representing subsurface ER and IP values. These were interpreted and presented in form of Iterative Curves, Log Tables a, 2-D Phase Pseudo-cross sections and Chargeability cross-sections with their possible geologic meanings and the ranges in chargeability values, layer thickness and depth as well. The interpreted ER and IP values were obtained by iterative computer modelling (IPI2WIN) of the apparent Resistivity and chargeability data (Nepal, Ananda, & Vijay, 2010). The data were plotted as phase pseudo and chargeability cross-sections in order to look at the groundwater potentials within the study area. The results were presented in terms of layer numbers (N), resistivity values (ρ), chargeability (η), thicknesses (h) and depths (d) of the geo-electric section for all the data points.

RESULTS AND DISCUSSION

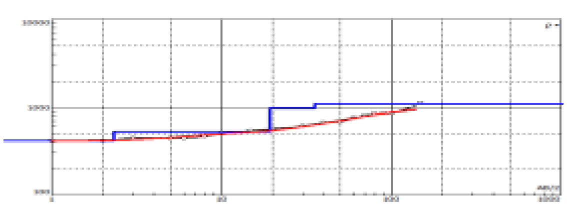
The acquired data were processed and interpreted with IPI2WIN iterative software that interprets ER and IP data and produce layered resistivity and chargeability models that reveals subsurface geology. Tables 1 – 3 are the iterated curves with layered log table from the data acquired along profile 1 at VES points 1 - 5 for the ER survey.

Table 1 (a): Iterated field curve and Log Table for VES1 of Profile 1 at the College Farm



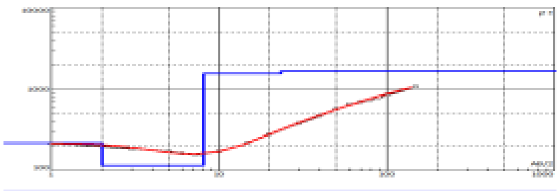
N	1	2	3	4								
ρ	219	515	1920	1922								
h	4.56	10.48	99.81									
d	4.56	15.04	114.85									
Alt	-4.5600	-15.0400	-114.8500									

(b): Iterated field curve and Log Table for VES2 of Profile 1 at the College Farm



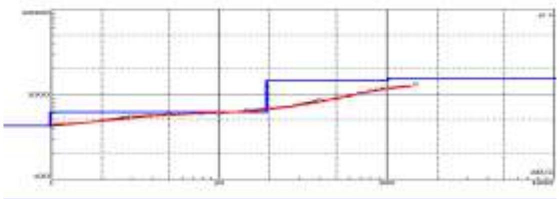
N	1	2	3	4								
ρ	412	527	963.17	974								
h	2.31	16.78	16.09									
d	2.31	19.09	35.18									
Alt	-2.3100	-19.0900	-35.1800									

(c): Iterated field curve and Log Table for VES3 of Profile 1 at the College Farm



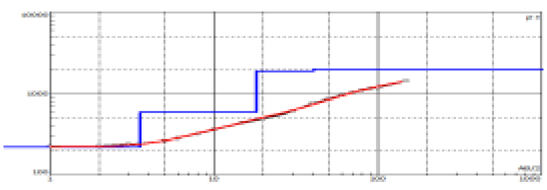
N	1	2	3	4
ρ	219	115.28	1541	1544
h	2	6.02	15.11	
d	2	8.02	23.13	
Alt	-2.0000	-8.0200	-23.1300	

(d): Iterated field curve and Log Table for VES4 of Profile 1 at the College Farm



N	1	2	3	4
ρ	427	613	1444	1452
h	0.99	18.01	81.3	
d	0.99	19	100.3	
Alt	-0.9900	-19.0000	-100.3000	

(e): Iterated field curve and Log Table for VES5 of Profile 1 at the College Farm



N	1	2	3	4
ρ	220	590	1871	1877
h	3.5	14.6	22.01	
d	3.5	18.1	40.11	
Alt	-3.5000	-18.1000	-40.1100	

Fig. 3 (a) and (b) showed Phase Pseudo cross-section and Chargeability Cross-section at VES points 1-5 with maximum electrode spacing of 1 – 200) m along profile 1 at the College farm site in Mokwa. The subsurface first layer resistivity varies between (219 to 427) Ωm with the thickness of between (2.00 to 4.91) m and depth ranged (2.00 – 4.91) m. While chargeability varied between (0.51 – 11.20) msec. with thickness ranged of up to 4.99 m, and depth ranged (0.01 – 1.03) m for the first layer. The second layer exhibited a resistivity variation of (115.28 to 613) Ωm with thickness range of up to 0.40 m and depth ranged (5.78 to 15.11) m were delineated. While that of the chargeability was between (0.01 – 75.10) msec. with thickness ranged of up to 19.21 m and depth ranged of up to11.99 m. For the third layer, the resistivity varied between (963.17 to 1871) Ωm, while thickness of (2.89 – 172.22) m and depth of (18.00 to 178) m for the third layer were delineated. The chargeability variation delineated was (23.30 – 79.00) msec. with thickness ranged of up to 0.60 m and depth ranged (23 to 100.03) m for the third layer. The lower resistivity zone (< 219 Ωm) observed along this profile (Fig. 3) in the second layer with a reasonable thickness of 19.21 m appears to be most probable viable borehole point Akinlalu & Afolabi (2018). This is represented by horizontal horizon made up of green, grey, yellow and pink colors delineated around VES points 3, 4 and 5 (Fig. 3). An IP anomaly indicated by a sharp drop of chargeability values from (75.10 down to 23.30) msec. between the second and third layers was observed between VES 1 to 3 which could imply fracture zone accounting for aquifer prospecting of this profile.

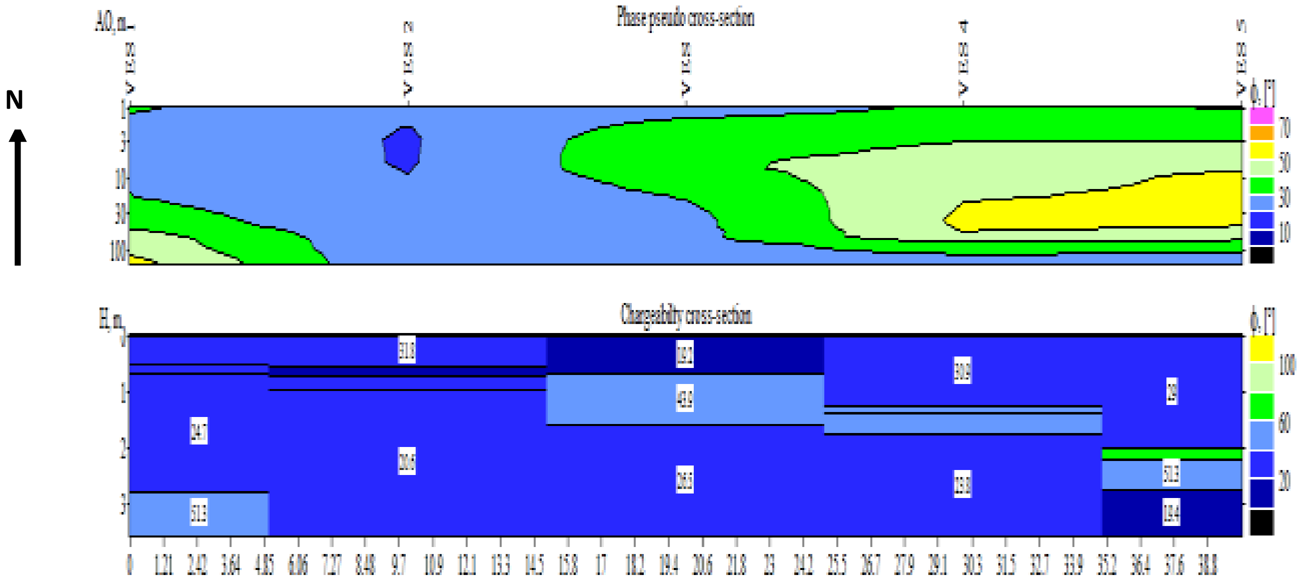
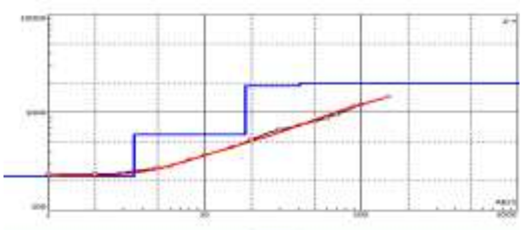


Fig.3: Phase Pseudo cross-section and Chargeability Cross-section at VES points 1-5 along profile 1 at the College far site in Mokwa.

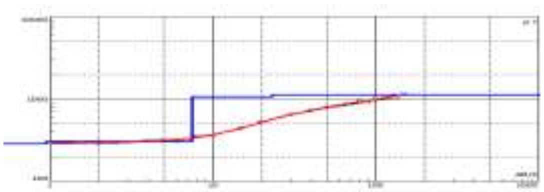
Tables 2(a – e) are the iterated curves with layered log tables for the data acquired along profile 2 for VES 1 – 5 points at the College farm site.

Table 2 (a): Iterated field curve and Log Table for VES1 of Profile 2 at the College Farm



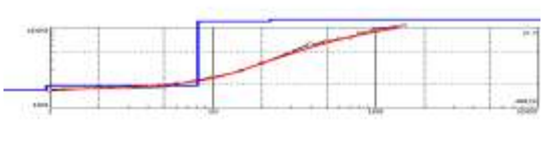
N	1	2	3	4								
ρ	220	590	1871	1877								
h	3.5	14.6	22.01									
d	3.5	18.1	40.11									
Alt	-3.5000	-18.1000	-40.1100									

(b): Iterated field curve and Log Table for VES2 of Profile 2 at the College Farm



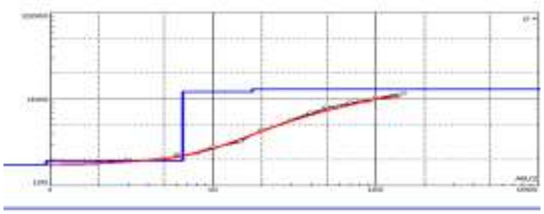
N	1	2	3	4								
ρ	284	304.9	1071	1077								
h	0.48	6.02	15.61									
d	0.48	6.5	22.11									
Alt	-0.4800	-6.5000	-22.1100									

(c): Iterated field curve and Log Table for VES3 of Profile 2 at the College Farm



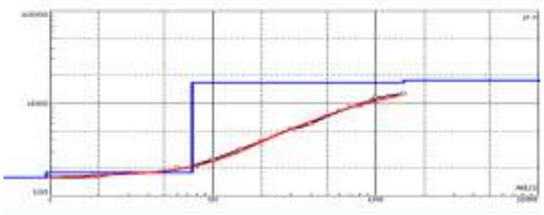
N	1	2	3	4								
ρ	169	189	1181	1192								
h	0.78	6.25	14.01									
d	0.78	7.03	21.04									
Alt	-0.7800	-7.0300	-21.0400									

(d): Iterated field curve and Log Table for VES4 of Profile 2 at the College Farm



N	1	2	3	4								
ρ	174	194.1	1217	1277								
h	0.68	5.95	11.2									
d	0.68	6.63	17.83									
Alt	-0.6800	-6.6300	-17.8300									

(e): Iterated field curve and Log Table for VES5 of Profile 2 at the College Farm



N	1	2	3	4								
ρ	157	177	1681	1689								
h	0.55	6.48	141									
d	0.55	7.03	148.03									
Alt	-0.5500	-7.0300	-148.0300									

Fig. 4. (a) and (b) showed Phase Pseudo cross-section and Chargeability Cross-section at VES points 1-5 along profile 2 at the College farm site in Mokwa. The subsurface first layer resistivity varies between (157 to 284) Ωm with the thickness variation of between (0.48 to 3.50) m and depth ranged (0.48 to 3.50) m. While chargeability varied between (19.20 to 32.50) msec. with thickness ranged (0.12 to 4.56) m and depth ranged (0.01 to 1.03) m for the first layer. The second layer exhibited a resistivity variation of (177 to 590) Ωm with thickness range of (6.50 to 18.10) m and depth ranged (5.78 to 15.11) m were delineated. While that of the chargeability was between (9.81 to 65.40) msec. with thickness ranged (0.75 to 19.96) m and depth ranged (8.02 to 20.01) m. For the third layer, the resistivity varied between (1071 to 1871) Ωm, while thickness variation was from (11.20 to 141) m and depth variation of (17.83 to 148.03) m for the third layer were delineated. The chargeability variation delineated was (21.00 to 86.90) msec. with thickness ranged (15.09 to 99.81) m and depth ranged (23 to 100.03) m. for the third layer. The lower resistivity zone (<178 Ωm) represented by green, grey, yellow and pink colors is indicative of water bearing zone which was delineated around VES points 3, 4 and 5 (Fig. 4). It has a reasonable aquifer thickness range of 11.60 m and depth ranged 9.33 m which is indicative of a viable borehole point Akinlalu & Afolabi (2018), Olorunfemi & Oni (2019). The evidence of its aquifer potential was exhibited by an IP anomaly of a sharp drop of chargeability values from (65.40 down to 21.00) msec. between the second and third layers was as equally correlated with that of ER which also dropped from (1071 to 590) Ωm.

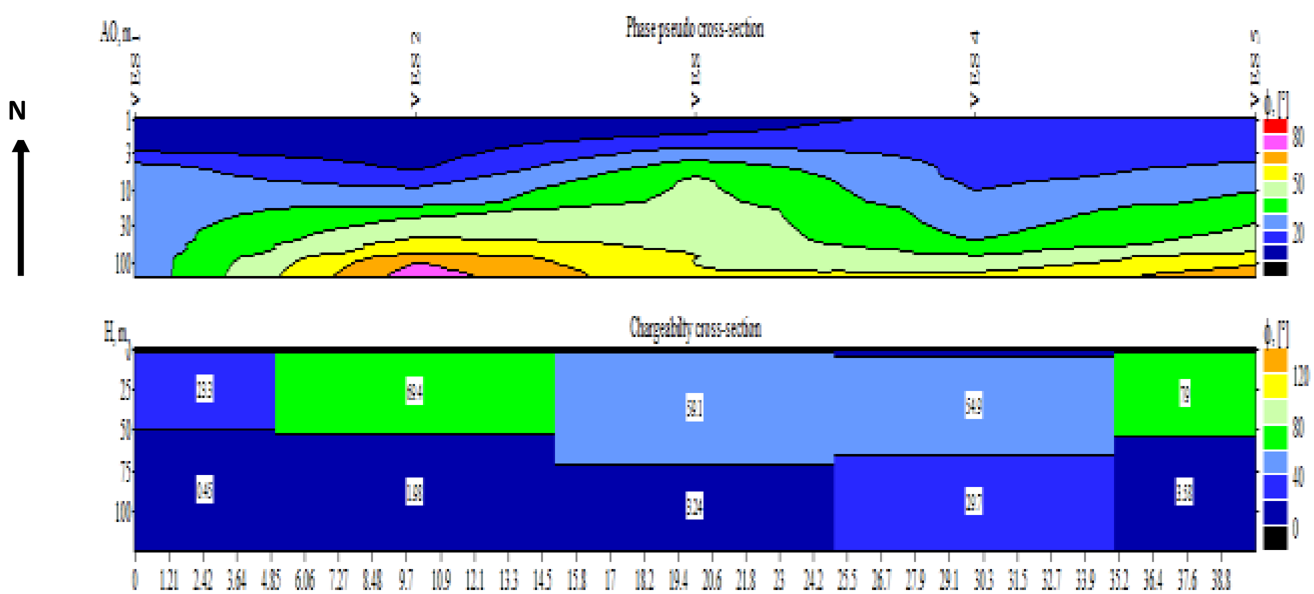
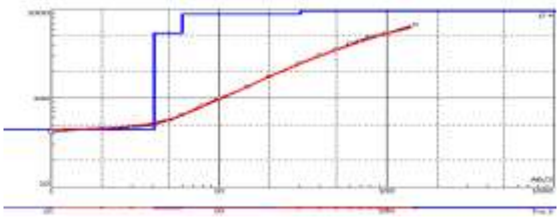


Fig. 4. Phase Pseudo cross-section and Chargeability Cross-section at VES points 1-5 along profile 1 at the College far site in Mokwa.

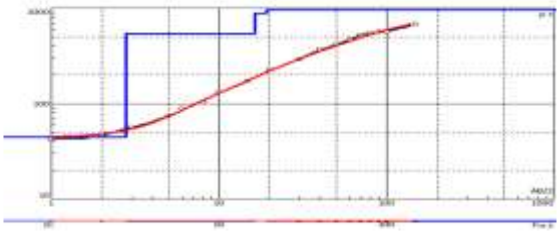
Tables 3(a – e) are the iterated curves with layered log tables for the data acquired along profile 3 for VES points 1 – 5 assessed within the College farm site.

Table 3 (a): Iterated field curve and Log Table for VES1 of Profile 3 at the College Farm



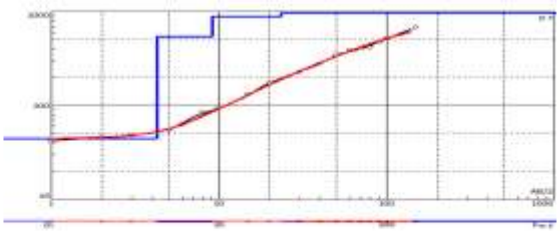
N	1	2	3	4								
ρ	44.36	434	1227	1361								
h	2	4.09	17.91									
d	2	6.09	24									
Alt	-2.012	-6.091	-24.021									

(b): Iterated field curve and Log Table for VES2 of Profile 3 at the College Farm



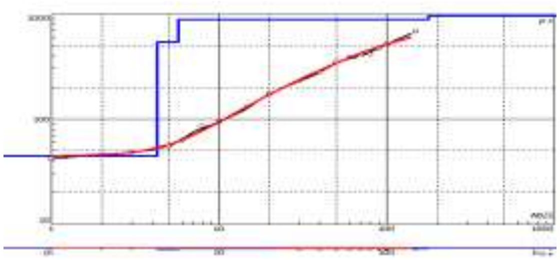
N	1	2	3	4								
ρ	45.84	542.7	1349	1355								
h	2.09	13.02	2.89									
d	2.09	15.11	18									
Ah	-2.0911	-15.1102	-18.004									

(c): Iterated field curve and Log Table for VES3 of Profile 3 at the College Farm



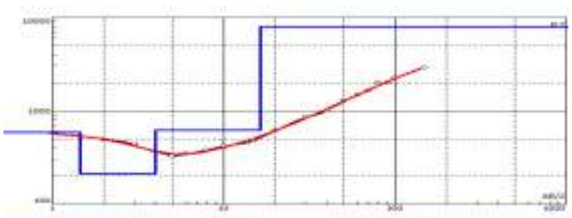
N	1	2	3	4								
ρ	42.7	561.01	1500	1531								
h	4.77	4.78	14.45									
d	4.77	9.55	24									
Ah	-4.7711	-9.5510	-24.0003									

(d): Iterated field curve and Log Table for VES4 of Profile 3 at the College Farm



N	1	2	3	4								
ρ	43.1	462.42	1116.7	1124								
h	4.17	1.61	172.22									
d	4.17	5.78	178									
Ah	-4.1730	-5.7804	-178.0004									

(e): Iterated field curve and Log Table for VES5 of Profile 3 at the College Farm



N	1	2	3	4								
ρ	45.2	565.19	1226.3	1230								
h	4.91	1.14	14.95									
d	4.91	6.05	21									
Ah	-4.9103	-6.0502	-21.0001									

Fig. 5 (a) and (b) showed Phase Pseudo cross-section and Chargeability Cross-section at VES points 1-5 along profile 3 at the College farm site in Mokwa. The subsurface first layer resistivity varies between (44.36 to 45.84) Ωm with the thickness of between (2 to 4.91) m and depth ranged (2 to 4.91) m. While chargeability varied between (0.51 to 11.20) msec. with thickness ranged (0.12 to 4.56) m and depth ranged (0.01 to 1.03) m for the first layer. The second layer exhibited a resistivity variation of (434 to 565.19) Ωm with thickness range of (1.14to13.02) m and depth ranged (5.78 to 15.11) m were delineated. While the chargeability variation was between (0.01 to 75.10) msec. with thickness ranged (0.75 to 19.96) m and depth ranged (8.02 to 20.01) m. For the third layer, the resistivity varied between (1116.70 to 1500) Ωm, while thickness varied between (2.86to 172.22) m and depth variation was (18 to 178) m for the third layer were delineated. The chargeability variation delineated was (23.30 to 79.00) msec. A dominantly low apparent chargeability values were observed from the shallow depth down to 16.0 m across VES points 2, 3 and 5. The water table was observed at a depth of 20 m. The delineated water bearing horizontal horizon (represented by green, gray, yellow and pink colorations) around VES point 3 with a reasonable thickness of 11.88 m appears to be the second most probable viable borehole point. The highest chargeability zone exhibited by the third layer was attributed to the fresh basement observed around VES points 2 and 5 with thickness ranged (7.68 – 174) m at depth ranged (21 - 178) m.

The interpretations of these phase Pseudo cross-sections and the Chargeability cross-sections enabled the derivation of three geologic sections (Nepal, Ananda, & Vijay, 2010). These geologic sections were; the topmost layer which consists mainly of sands and claystones followed by a formation of clayey sandstones, conglomerates, and a fresh transition zone/fractured layer, and the third section consisting of fresh basement. The qualitative interpretation indicated that the weathered/fractured basements constituted the main aquifer units delineated within the College farm.

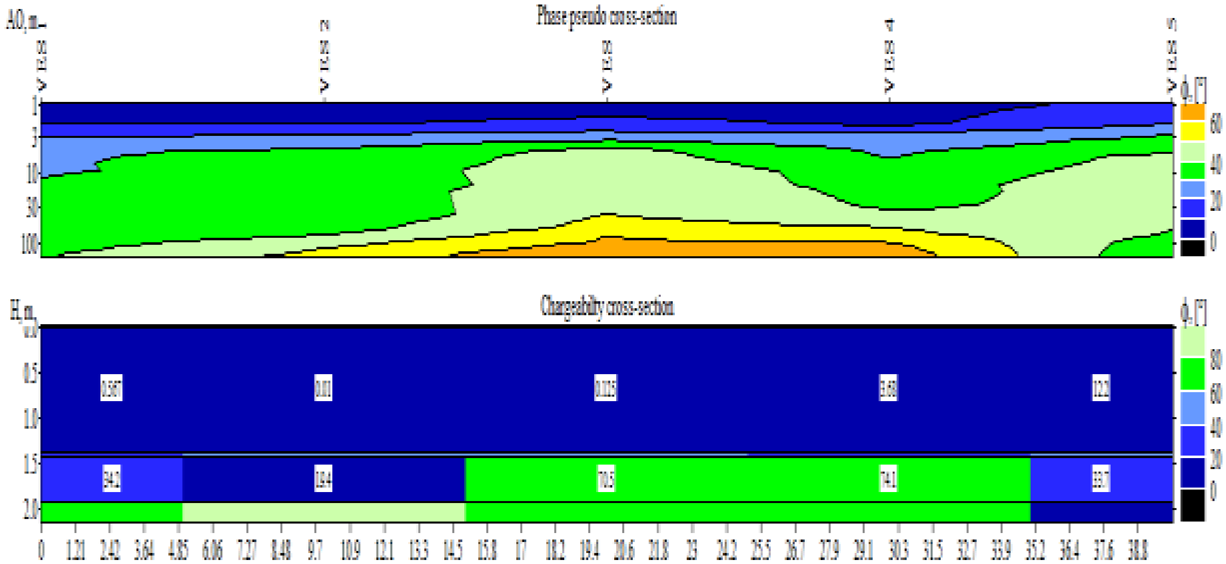


Fig. 5: Phase Pseudo cross-section and Chargeability Cross-section at VES points 1-5 along profile 1 at the College far site in Mokwa.

CONCLUSION AND RECOMMENDATIONS

In all the geologic layers, the delineated horizontal spatial patterns in the soil electrical properties exhibited weathered and fractured basement anomalies. These were the detected hydraulically active structures (aquifer components) which can strongly influence the groundwater yields within the study area because of their importance as water bearing units in basement Complex (Hasan, *et al.* 2019). From the result of the interpretations, the delineated areas within the farm site that has groundwater potential for domestic and irrigation purposes are VES points 4 & 5 along the first Profile, VES points 2, 3, 4 & 5 along the second Profile and VES points 3, 4 & 5 along the third Profile. Conclusively, the most viable location for drilling the proposed borehole at the College farm based on the thickness variations from (11.60 to19.21) m of the aquifer components and irrigational volume of water requirement are VES points 4 & 5 along the first profile which had the highest thickness of 19.21 m. The site recommendation for the borehole drilling point based on the aquifers thickness is in hierarchy of P1>P3>P2.

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