

Hydrogeophysical assessment of existing boreholes field of Bayero University Kano new site campus, Kano State Nigeria

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Abstract:

Bayero University main campus in Kano State, Nigeria is bedeviled with the shortage of water supply to cater for its water needs, as the main source of supply is mainly boreholes-based stations. An estimate of more than 3 million liters per day is needed in the campus, but the supply from the three boreholes fields was estimated to be less than 600,000 liters per day making a shortfall of 2.4 million liters supply. A Build, Operate and Transfer (BOT) boreholes field is the largest with 15 boreholes of which only nine are functioning. However, there is no available geophysical and hydrological data of the boreholes to determine their capacity and productivity. The research aimed at using geophysical method in diagnosing the geological sections/layers of aquifers in the existing boreholes in the BOT fields. This is to understand whether the boreholes were drilled to maximum aquifer thickness or not. A geophysical survey using Vertical Electrical Sounding (VES) was conducted adjacent to each borehole to determine the drilled subsurface geoelectrical sections. The location of the boreholes was taken using Global Positioning System (GPS) and the resultant VES data was interpreted using Interpex 1XD resistivity software. The results show that there are four to five geoelectric sections inferred as topsoil, lateritic soil, clayey soil, highly weathered decomposed rock, fractures crystalline basement rock and fresh crystalline basement rock with varying thickness across the fifteen (15) VES data set. The results were correlated with the drilled boreholes depths, and it was found that there is a mismatch of some surveyed geoelectric depths with the drilled depths, indicating that some of the boreholes were not adequately drilled to maximum aquifer depths. The findings from this study is significant in the proper designing and management of borehole fields for optimum underground water supply in basement complex areas.

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1. Introduction

Water is essential to life and the available source of freshwater lies underground [1]. Increase in demand for water have stimulated underground water resources development, as a result, techniques for investigating the occurrence and movement of groundwater have been developed. Concepts of resources management have been established and research has contributed to a better understanding of the subject [1].

Water, which stands out amongst most fundamental segments of human presence and survival has its accessibility generally underestimated. This study focuses on the understanding of existing groundwater potential zones of a borehole field of BUK, the main campus, Kano state, North-West Nigeria. Adequate water supply posed a real problem in the main campus due to basement complex rocks aquifers underlying the locality, and the massive infrastructural development in the campus due to the establishment of more departments and faculties leading to a rapid increase in population and hence the need for more water supply [2].

Source of supply of water could be either ground water or surface water. However, surface water in some places is not perennial and it's not adequately reliable while on the other hand, groundwater resource is known to occur more widely than surface water [1].

This view has also been brought forward by other scholars including, Walton [3]. Despite this, groundwater availability is limited by so many factors. It is available only when the rock in the zone of saturation is permeable enough to transmit sufficient water to wells, spring or streams and, when the zone of saturation is perennial or at least last long enough in each season to allow for practical exploitation and when the chemical composition is within tolerable limit [3].

Groundwater includes all water found beneath the earth's surface. It is located in pores and fractured rock formation in the subsurface. It refers to all the water occupying the voids, pores and fissures within geological formations, which originated from atmospheric precipitation either directly by rainfall infiltration or indirectly from rivers, lakes or canals. Sands, gravel, sandstones, and limestone formations are the usual sources of ground water supply

though some may be drawn from impervious rocks such as granite when they have an over burden of sand or gravel [3].

Groundwater is an economic resource and more than 85% of the public water for consumption is obtained from groundwater [4]. In other to explore this natural resource for the benefit of sustaining life, various geophysical methods have been employed successfully. These methods include electrical resistivity, seismic refraction, electromagnetic, gravity and magnetic. The choice of method depends largely on the depth of investigation and sometimes cost [5]. Of all these methods used in exploring for groundwater, the electrical resistivity method has been the most widely used method. This is because the field operation instrument is unsophisticated, and the analysis of the data is less unwieldy and economical [6].

As a result of poor supply of pipe borne water in BUK, main campus, the students, lecturers living in staff quarters and Agricultural departments are confronted with insufficient potable water for domestic use as well as for agricultural purposes. This situation has led to high pressures of demand being placed on the existing boreholes drilled at BOT field. However, the breakthrough in the construction of boreholes hinges on the geology, structures and textures of the aquifers as it helps determining groundwater potentials. The study investigates the groundwater potential zones of BUK, main campus BOT field with the aim of understanding

the aquifer for groundwater development in basement terrain. It is also to understand the geoelectric sections of the drilled aquifers, to correlate the interpreted geoelectric sections with the drilled borehole depths and to understand the efficacy of the existing project and suggest ways in improving the borehole field for optimum productivity.

2. Methodology

The study area is in the southeast of the new campus land mass and is behind the staff quarters as shown in Figure 1. The borehole field contains fifteen (15) boreholes covering about 114,000 square meters. The field mapping of the area was carried out for reconnaissance of the existing boreholes and to determine the distance intervals of the boreholes.

2.1 Location, geology and hydrogeology

The study area is located between latitude $11^{\circ} 58' 44''$ and longitude $8^{\circ} 26' 20''$. This area is accessible by major roads through Gwarzo Road, along BUK main campus. The topographic map of the studied area is represented in Figure 1. The location of the borehole field (BOT) is to the southeastern part of the campus and have fifteen boreholes located with spacing ranging from 20 meters to maximum of 60 meters as shown in Figure 2.

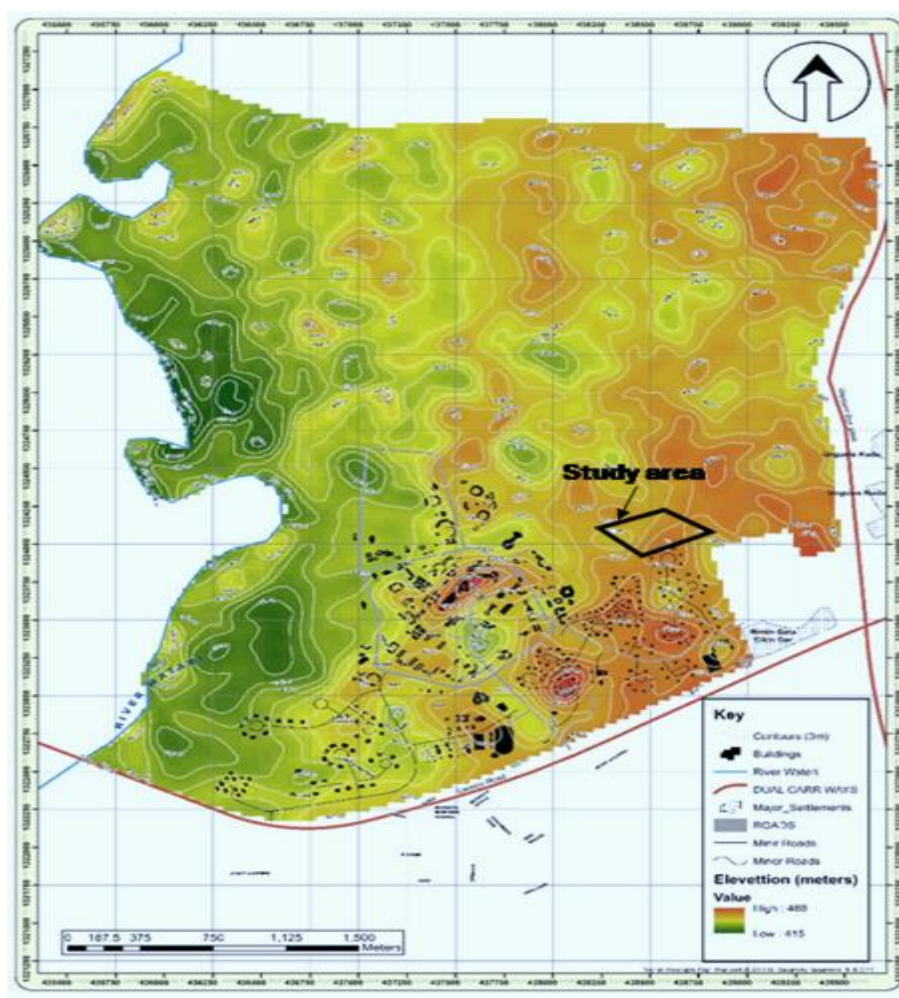


Figure 1: Topographic map of Bayero University, Kano land mass (after BUK Geography Department, GIS section)

Figure 2 shows the Location map of the borehole field showing the topography of the eastern part of the campus (after BUK Geography Department, GIS section) and satellite imagery map showing the location map of fifteen (15) number borehole drilled in the BOT borehole field. Figure 3 shows the political map of Kano State showing the

44 local government areas with Ungogo L.G.A the study area demarcated in black and the geological map of Kano showing the location of study area in Ungogo L.G.A. Note the basement rock type as coarse porphyritic biotite and biotite hornblende granite [2].

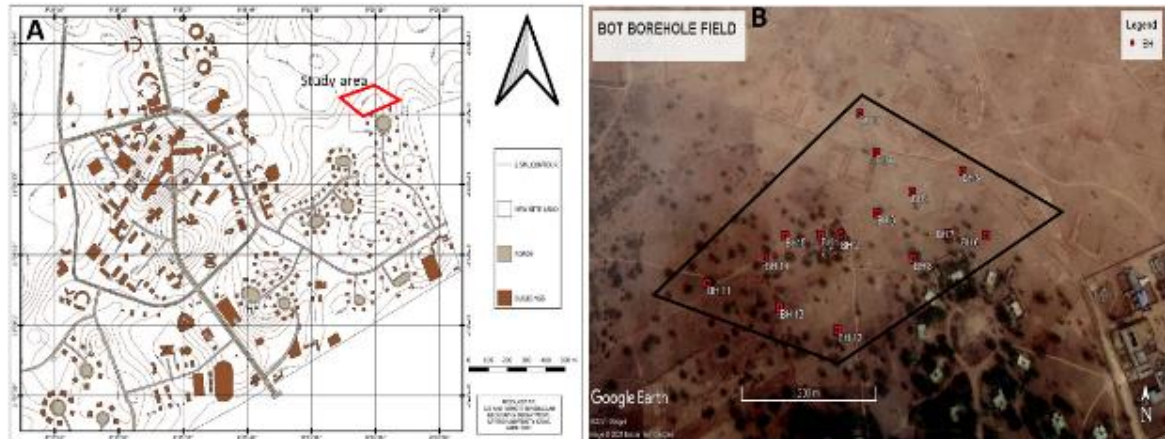


Figure 2: (a) Location map of the borehole field and (b) Satellite imagery map of the fifteen (15) borehole drilled in the BOT borehole field.

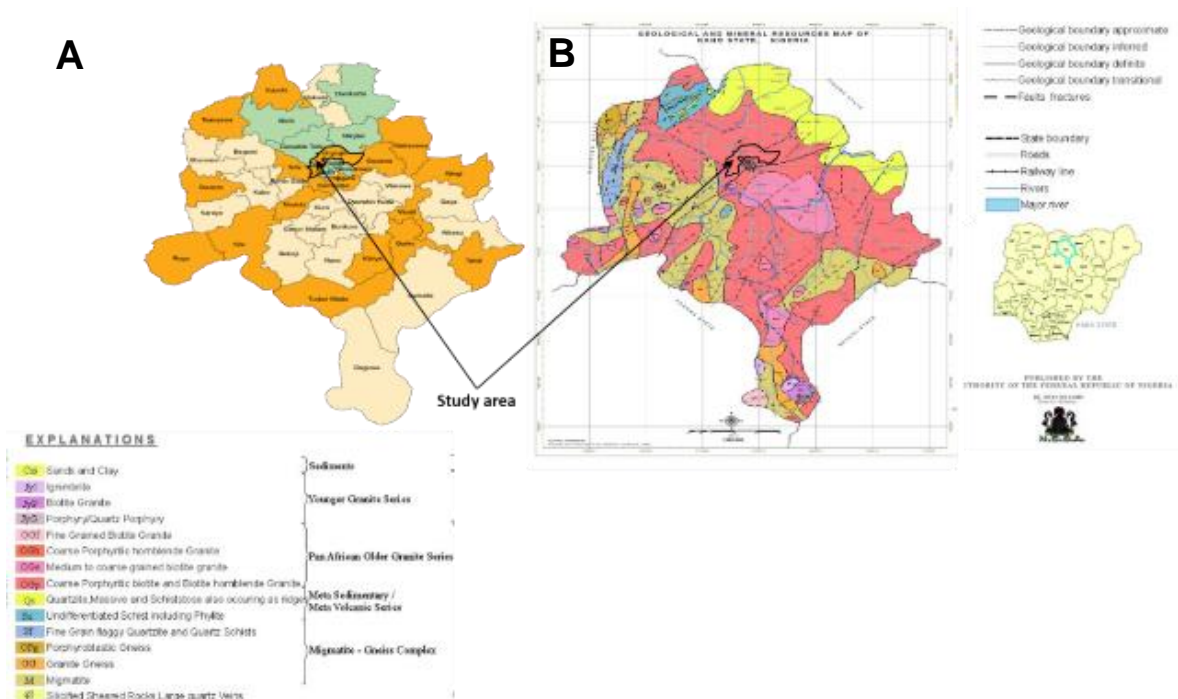


Figure 3: Map of Kano State with the 44 local government areas with the study area (Ungogo L.G.A.) demarcated in black (a) Political map and (b) Geological map

2.2 Data acquisition

The data acquisition in the study area was conducted using an Ohmega resistivity equipment. The equipment components include Resistivity meter, Cable reels, Hammers, Measuring tapes, Handheld GPS (Global positioning system) and Electrodes. A total of 15 VES points was sounded. The qualitative interpretation of the field data was done using a computer program known as IX1D v 2; to identify thickness and resistivity of different layers, to give

information on deeply weathered and fractured zones. The electrical resistivity method is a direct method of introducing current into the ground by means of two electrodes connected to the terminals of a portable source of electromagnetic force. The electrical properties of minerals such as electrical potentials, dielectrically constants are important in electrical prospecting. The electrical resistivity is the most important of all and it can yield the distribution of electric resistivity below the surface, which is dependent on

the size, shape, location and electrical resistivity of the subsurface masses. In terms of electrical resistance, magnetic susceptibilities or other properties, Geophysical method stand out to be the most reliable and accurate method of groundwater survey method as reported in Adetola [6], and Olorunfemi [7].

Electrical resistivity method is the most used geophysical method of groundwater survey, but there are other geophysical methods such as: Magnetic, Induced polarization, seismic, electromagnetic, and gravity method.

2.3 Principles of electrical resistivity method

Electrical resistivity method is the introduction of artificially generated currents by means of two electrodes and to measure the potential drop between a second pair placed in line between these two current electrodes [8]. The apparent resistivity is gotten from the magnitude of the potential drop, current and knowledge of the electrode separation. When current is been passed, the variation of the quantity with change in electrode spacing and position, the subsurface deductions can be made.

The total electric resistance of a material R and a cross-sectional area (A) and length L can be expressed as in equation 1:

$$P = RA/L \quad (1)$$

The unit of resistivity is an ohm-meter which is a function of the spread constant called geometric factor (K or G). From ohm's law, at constant temperature, the current (I) passing through a metallic conductor is proportional to the resistance and the applied voltage as shown in equation 2. Mathematically

$$I = V/R \quad (2)$$

Where I is the current, V is the potential difference and R is the resistance. Since the apparent resistivity (P_a) is directly proportional to the resistance (R), then:

$$P_a = KR \quad (3)$$

Where K is also a constant of proportionality known as geometric factor, P_a is the apparent resistivity, AB is the current electrode spacing and MN is the potential electrode distance.

2.4 Configuration of the Schlumberger Array.

In Schlumberger array shown in Figure 4, all the four electrodes are arranged in a line, similar to that of Wenner at first. Only two out of the electrodes i.e. (the electrodes supplying and receiving current) are moved. The spacing of the two potential electrodes is less than one fifth the distance between the center of the array and one current electrode. The potential electrodes are changed only when the signal becomes too weak to be measured. As the distance between the current electrodes is increasing, the depth to which the current penetrates increases as well. The apparent resistivity for Schlumberger configuration is done using this formula in equation 4.

$$P_a = \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \pi R \quad (4)$$

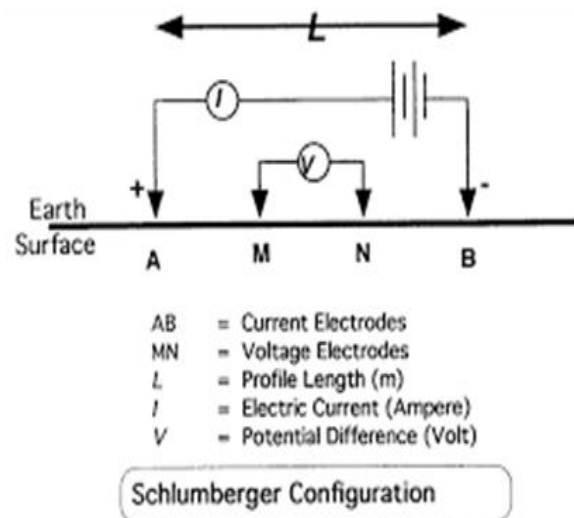


Figure 4: Schlumberger Configuration used in the study area [8]

2.5 Field Procedure for Schlumberger Array

In the Schlumberger method, the terameter is placed at investigation point, the electrodes are driven into the ground using a hammer and the cables are fervently connected to the resistivity meter. The two-potential electrode (P_1 and P_2) are placed on linear line with similar distance apart from the resistivity meter (the distance depends on the spacing of the current electrode). The two-current electrode (C_1 and C_2) are also placed on a straight similar distance apart (the distance helps in achieving deeper penetration as it steadily ascends). Calculated electric is then passed through the current electrodes (C_1 and C_2) and the drop in potential difference between the potential electrodes (P_1 and P_2) is also taken from the voltmeter. The apparent resistivity is then calculated using equation 5:

$$P_a = \frac{\pi \left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} R \quad (5)$$

Where P_a is the apparent resistivity, AB = current electrode spacing, MN =potential electrode spacing $R=V/I$ where V =potential difference, I =current and R =resistance.

The values of apparent resistivity are then plotted on a graph (field curve), the x-and y axis represent the logarithmic values of the current electrode half separation ($AB/2$) and the apparent resistivity (P_a) respectively.

2.6 Half Schlumberger (Hummel) Survey

The Hummel method of vertical electrical sounding was employed in groundwater exploration in both the crystalline basement and sedimentary terrains. This technique is recommended to Geoscientist for its efficiency in terms of quality of data obtained, ability to conduct sounding in congested or developed areas, time and cost effectiveness.

In the Hummel and "Half-Hummel" (modified Schlumberger) methods of vertical electrical sounding, the potential electrodes remain temporarily fixed while one of the current electrodes is kept fixed throughout the sounding operation at a distance equal to the mobile current electrode

spacing (known as the Half-Hummel method) or three times the mobile current electrode, that is, (Hummel array) and perpendicular to the line of electrode spread as shown in Figure 4. The geometric factor of the modified Schlumberger arrays was estimated to be twice that of the conventional Schlumberger array [9] that is Where K = geometric factor for conventional Schlumberger array, = geometric factor for Hummel and "Half-Hummel" (modified Schlumberger) arrays, = apparent resistivity, and = resistance of subsurface layer. Modified version of Schlumberger array was used in this study as shown in Figure 5.

Comparison between apparent resistivity Hummel array and Schlumberger array indicates that apparent resistivity both array is equal. Thus, the resistivity data from such measurements can be interpreted as normal sounding Schlumberger array curves and interpretations for both methods are same. Comparison between depth of investigation in Hummel and Schlumberger arrays formulae for depth of investigation as reported in Telford [8] are related in equation 4:

$$V_{P_1 P_2} = \int_{z=0}^{\infty} DIC = \frac{\rho l}{2\pi} \left[\frac{1}{a} - \frac{1}{b+c} - \frac{1}{a+b} + \frac{1}{c} \right] \quad (5)$$

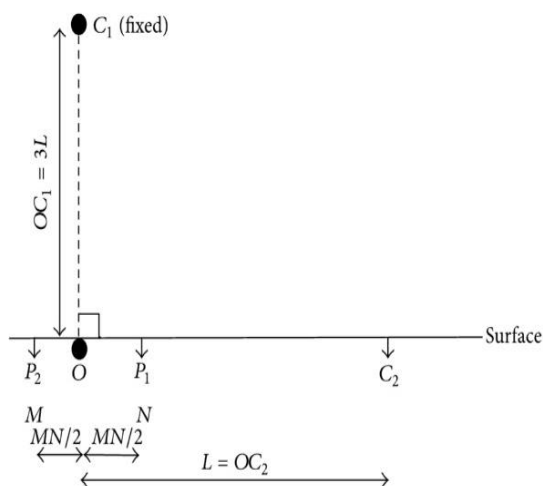


Figure 5: Half Schlumberger array

3. Result and discussion

3.1 Interpreted VES data

A total number of 15 VES resistivity data points were measured in BOT field Bayero University main campus shown in Figure 2. The VES data was interpreted using Interflex 1xD software Version 1.0. The results show that there are four to five geoelectric sections from topsoil, lateritic soil, clayey soil, highly weathered decomposed rock, fractures crystalline basement rock and fresh crystalline basement rock. The resultant interpreted curves are of H type with only one of K type as in Figures 7 and 8 and Tables 1 to 15. The interpreted data with their corresponding thicknesses and apparent resistivity of the layers were presented in Tables 1 to 15.

3.1.1 Topsoil (sandy, clayey or lateritic)

This is a surface dry layer of resistivity that ranges from 10s-ohm m to 100s-ohm m. Its thickness varies from

<1 to 3m. The low resistivity end is diagnostic of clayey soil and high resistivity (>50s to 100s ohm m) end indicates sandy soils. The topsoil resistivity values from the study area range from 19 (ohm-m) to 446 (ohm-m). However, a lateritic topsoil with a resistivity value of 868114 (ohm-m) was found in BOT VES 10 location with 0.253m thickness. The thicknesses range from 0.159m to 2.45m as shown in Figures 7 and 8 and Tables 1 to 15.



Figure 6: A pictorial presentation on carrying out resistivity survey using Hummel method conducted beside the existing borehole (0.5 meter).

3.1.2 Lateritic/sandy/clayey soil

This layer typically is characterized by high resistivity for a lateritic soil >1000s (ohm-m). However, sandy and clayey soil are found in this layer with resistivity of 1s (ohm-m) to 100s (ohm-m). Clayey soil has lower resistivity 1s to 10s (ohm-m), while sandy soil has 10s to 100s (ohm-m). The interpreted resistivity data from the study areas range from 3 (ohm-m) to 271 (ohm-m) for the clayey and sandy soil, while for the lateritic soil, it ranges from 1655 (ohm-m) to 3497 (ohm-m). VES points with lateritic layer two include VES 03, 05, 06, 09 and 15 as shown in Figures 7 and 8 and Tables 1 to 15.

3.1.3 Weathered/fractured crystalline rock

This layer is characterized by highly to slightly weathered (decomposed) crystalline rock and in some cases highly fractured rock. Resistivity values of 10s to few 100s are measured. The interpreted resistivity data from the study areas range from 5 (ohm-m) to 891 (ohm-m). Measured thicknesses range from 0.18m to 14.08m. In some places, fractured zones occur immediately beneath the weathered horizon. The fractured zones are difficult to detect geophysically, unless it is of greater thickness. Where the fractured zone is saturated, a high groundwater yield can be obtained from borehole penetrating such a sequence as reported in Todd and Mays [5] and can be seen in Figures 7 and 8 and Tables 1 to 15.

3.1.4 Fractured crystalline rock.

This layer, in most cases is the main aquifer in crystalline basement terrain. Resistivity values of 10s (ohm-m) to 100s (ohm-m) are found. The interpreted resistivity data from the study areas range from 22 (ohm-m) to 280 (ohm-m). Measured thicknesses range from 1.58m to 38.65m. This layer is termed as "Regolith" if the crystalline rock is highly weathered. Also, a slightly fractured crystalline rock may have resistivity of several >1000s (ohm-m) as can be seen in Figures 7 and 8 and Tables 1 to 15.

3.1.5 Fresh crystalline rock

This layer has a very high resistivity, several >1000s (ohm-m) with infinite thickness. But where it is fractured and saturated; the resistivity reduces. It is not a source of groundwater unless fractured. However, when the shape of the VES curves approaches a very steep gradient of about 45 The interpreted resistivity data from the study areas range from 23023 (ohm-m) to 121151 (ohm-m) indicative of fresh crystalline basement at depth as in Figures 7 and 8 and Tables 1 to 15.

3.2 Geoelectric layers and boreholes depths correlations.

The interpreted geoelectric section/layers compared and correlated with the drilled depths of the boreholes shows that nine out of fifteen boreholes show good correlation. Three boreholes show poor correlation while three shows moderate correlation. Thus, indicate such borehole points are not good for siting. BOT 1-6, 9, 12, and 15 shows positive correlation between the drilled depth and the surveyed geoelectric sections/layers. Three boreholes (BOT 8, 10, and 14) shows poor correlation between the drilled depth and the surveyed geoelectric sections/layers. Also, three boreholes (BOT 7, 11 and 13) show moderate correlation between the drilled depth and the surveyed geoelectric sections/layers as in Figures 7 and 8 and Tables 7, 11 and 13

Borehole drilled depth is 41m, geoelectric sections resolved 22.8 m at fresh basement, however two depleted points at 30 and 40 meters indicates a fracture zone. Therefore, the data shows good correlation as shown in Figures 7 and 8 and Table 7.

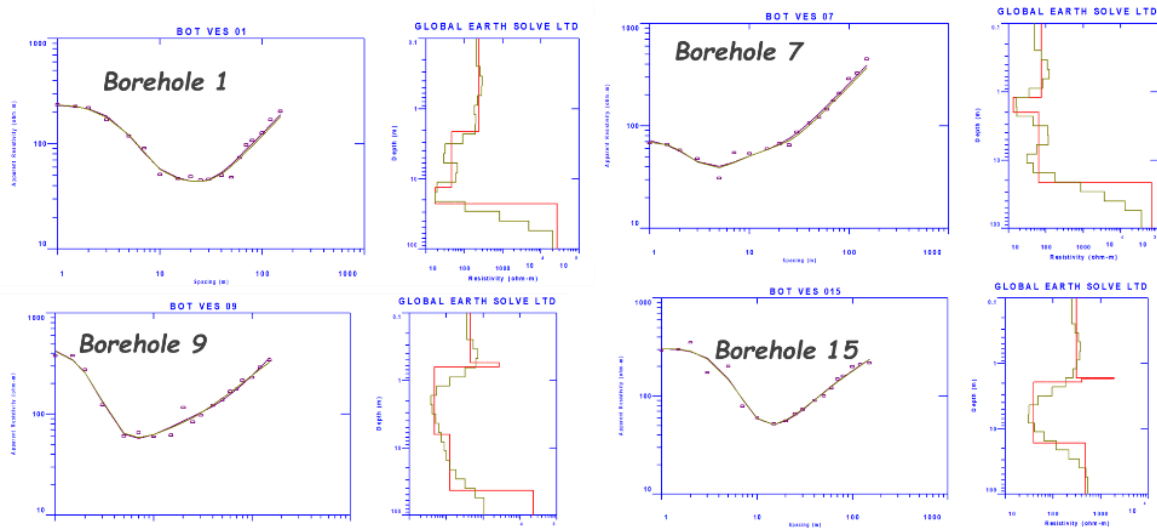


Figure 7: Geoelectric sections of boreholes 1, 7, 9 and 15; good sited but with shallow drilled depths unable to weathered and or fractured aquifers at depth

Table 1: Interpreted BOT borehole VES 01 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity (Ω -m)	Inferred Lithology	Curve Type
1	2.13	237.6	Topsoil	Type H
2	11.03	46.70	Clayey topsoil	
3	9.62	17.88	Weathered basement	
4	>22.8	26186.4	Fresh basement	

Prognosis: Borehole drilled depth is 41m, geoelectric sections resolved 22.8 m at fresh basement, however two depleted points at 30 and 40 meters indicates a fracture zone. Therefore, the data shows good correlation.

Table 2: Interpreted BOT borehole VES 02 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity (Ω -m)	Inferred Lithology	Curve Type
1	2.45	214.5	Topsoil	Type H
2	0.871	2.74	Clayey topsoil	
3	0.391	6.99	Clayey sandy soil	
4	>3.71	186.8	Fractured and weathered basement	

Prognosis: Borehole drilled depth is 41m, geoelectric sections resolved 3.71m of overburden. The last layer resistivity is 186.8 (ohm-m) is an indicative of weathered and fractured basement at depth. Therefore, the drilled depth and geoelectric sections show good correlation, but therefore should have been drill deeper than 41 meters.

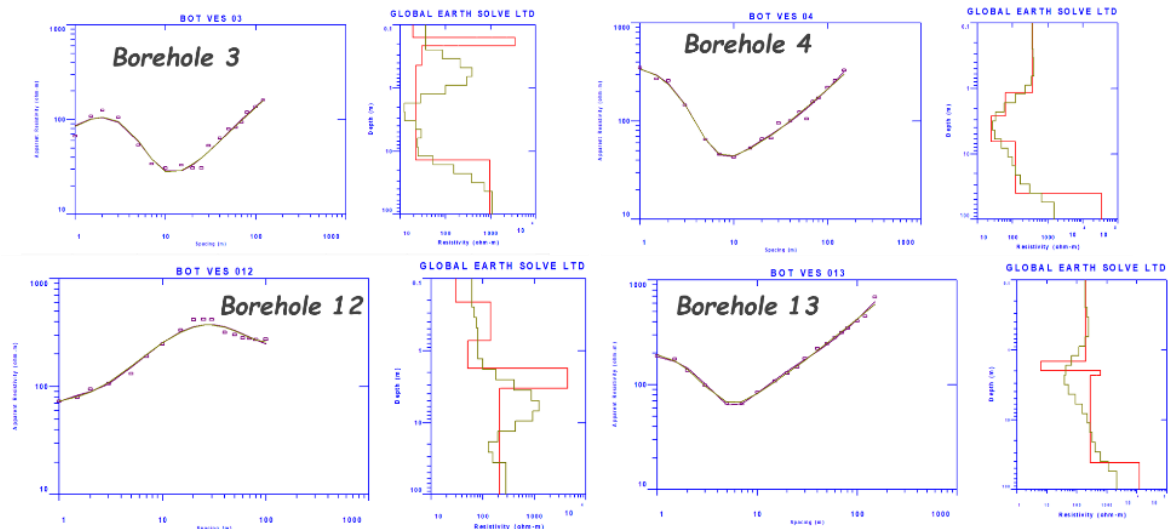


Figure 8 Goelectric sections of boreholes 3, 4, 12 and 13; wrongly sited with shallow depths to fresh crystalline basement devoid of yielding aquifers.

Table 3: Interpreted BOT borehole VES 03 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity(Ω -m)	Inferred Lithology	Curve Type
1	0.159	19.22	Topsoil	Type H
2	0.216	3497.4	Lateritic soil	
3	0.440	29.92	Sandy soil	
4	13.87	21.93	Highly weathered crystalline rock	
5	>13.87	965.2	Fractured/ weathered crystalline rock	

Prognosis: Borehole drilled depth is 42m, geoelectric sections resolved 13.87m of overburden. The last layer resistivity is 965.2 (ohm-m) is an indicative of weathered and fractured basement at depth. Therefore, the drilled depth and geoelectric sections show good correlation, but therefore should have been drill deeper than 42 meters.

Table 4: Interpreted BOT borehole VES 04 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity(Ω -m)	Inferred Lithology	Curve Type
1	1.16	370.6	Topsoil	Type H
2	1.46	62.41	Clayey topsoil	
3	3.92	24.18	Sandy soil	
4	33.66	121.2	Weathered basement	
5	>40.22	34133.9	Fresh basement	

Prognosis: Borehole drilled depth is 42m, geoelectric sections resolved 40.22m to fresh basement rock. The last layer resistivity is 34134 (ohm-m) is an indicative of fresh basement at depth. Therefore, the drilled depth and geoelectric sections show good correlation.

Table 5: Interpreted BOT borehole VES 05 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity(Ω -m)	Inferred Lithology	Curve Type
1	0.266	99.89	Topsoil	Type H
2	0.215	1654.1	Lateritic soil	
3	0.236	2.56	Clayey soil	
4	17.50	79.61	Weathered crystalline rock	
5	>18.21	198.6	Weathered crystalline rock	

Prognosis: Borehole drilled depth is 42m, geoelectric sections resolved 18.21m of overburden. The last layer resistivity is 198.6 (ohm-m) is an indicative of weathered and fractured basement at depth. Therefore, the drilled depth and geoelectric sections show good correlation, but should have been drill deeper than 42 meters to tap more of the fractured aquifer.

Table 6: Interpreted BOT borehole VES 06 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity(Ω -m)	Inferred Lithology	Curve Type
1	0.179	66.80	Topsoil	Type H
2	0.196	2315.2	Lateritic soil	
3	0.386	891.0	Sandy soil	
4	38.46	63.40	Highly fractured basement	
5	>39.22	23023.0	Fresh basement	

Prognosis: Borehole drilled depth is 42m, geoelectric sections resolved 39.22 m at fresh basement. Therefore, both the drilled depth and the geoelectric sections shows good correlation.

Table 7: Interpreted BOT borehole VES 07 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity(Ω -m)	Inferred Lithology	Curve Type
1	1.20	76.60	Topsoil	Type H
2	0.808	13.64	Sandy soil	
3	19.53	64.16	Weathered crystalline basement	
4	>21.54	67790.6	Fresh crystalline basement	

Prognosis: Borehole drilled depth is 42m, geoelectric sections resolved 21.54m at fresh basement. There is points depletion at 30 and 40m which is an indicative of fractured basement. Therefore, both the drilled depth and the geoelectric sections show moderate correlation.

Table 8: Interpreted BOT borehole VES 08 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity (Ω -m)	Inferred Lithology	Curve Type
1	0.349	120.3	Topsoil	Type H
2	0.392	1568.2	Lateritic soil	
3	1.42	4.82	Clayey topsoil	
4	16.97	243.3	Fractured weathered rock	
5	>19.14	30500.2	Fresh basement	

Prognosis: Borehole drilled depth is 44m, geoelectric sections resolved 19.4m at fresh basement Therefore, both the drilled depth and the geoelectric sections shows poor correlation.

Table 9: Interpreted BOT borehole VES 09 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity(Ω -m)	Inferred Lithology	Curve Type
1	0.543	445.5	Lateritic soil	Type h
2	0.839	2726.0	Clayey soil	
3	5.65	47.65	Sandy soil	
4	36.50	126.9	Fractured weathered rock	
5	>42.79	23137.7	Fresh basement	

Prognosis: Borehole drilled depth is 46m, geoelectric sections resolved 42.79m at fresh basement. There is point depletion at 20 which is an indicative of fractured basement. Therefore, both the drilled depth and the geoelectric sections shows good correlation.

Table 10: Interpreted BOT borehole VES 10 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity(Ω -m)	Inferred Lithology	Curve Type
1	0.253	868113.8	Lateritic Soil	Type H
2	1.92	271.2	Clayey soil	
3	14.08	35.11	Sandy soil	
4	>16.26	38620.9	Fresh basement	

Prognosis: Borehole drilled depth is 46m, geoelectric sections resolved 16.26m at fresh basement. Therefore, both the drilled depth and the geoelectric sections shows poor correlation. The borehole point is not a good site.

Table 11: Interpreted BOT borehole VES 11 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity(Ω -m)	Inferred Lithology	Curve Type
1	1.92	212.4	Topsoil	Type H
2	4.41	18.36	Clayey topsoil	
3	0.180	306.7	Weathered rock	
4	2.62	136.6	Fractured rock	
5	>9.14	3213.0	Fractured crystalline basement	

Prognosis: Borehole drilled depth is 43m, geoelectric sections resolved 9.14m at weathered regolith. The last layer resistivity is 3213 (ohm-m) which is an indicative of fractured crystalline basement.

Table 12: Interpreted BOT borehole VES 12 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity(Ω -m)	Inferred Lithology	Curve Type
1	0.211	29.94	Topsoil	Type K
2	0.519	140.1	Sandy topsoil	
3	1.03	51.98	Sandy soil	
4	1.58	4378.9	Fractured crystalline basement	
5	>3.34	212.2	Fractured basement	

Prognosis: Borehole drilled depth is 50m, geoelectric sections resolved 3.34 m overburden, while the last layer resistivity of 212.2 (ohm-m) is an indicative of fractured crystalline basement. Therefore, both the drilled depth and the geoelectric sections shows good correlation and the point is well sited

Table 13: Interpreted BOT borehole VES 13 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity(Ω -m)	Inferred Lithology	Curve Type
1	1.46	195.4	Topsoil	Type H
2	0.528	6.23	Clayey topsoil	
3	0.343	602.4	Weathered basement	
4	38.65	280.3	Fractured rock	
5	40.99	121151.1	Fresh basement	

Prognosis: Borehole drilled depth is 46m, geoelectric sections resolved 40.99m at fresh basement. The last layer resistivity is 12115.1 (ohm-m) is an indicative of fresh basement at depth. Therefore, the drilled depth and geoelectric sections shows moderate correlation

Table 14: Interpreted BOT borehole VES 14 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity(Ω -m)	Inferred Lithology	Curve Type
1	0.894	114.9	Topsoil	Type H
2	0.244	14.07	Clayey topsoil	
3	0.289	533.3	Weathered basement	
4	9.81	24.87	Fractured basement	
5	>11.24	70194.1	Fresh basement	

Prognosis: Borehole drilled depth is 42m, geoelectric sections resolved 11.24 m at fresh basement. Therefore, both the drilled depth and the geoelectric sections shows poor correlation.

Table 15: Interpreted BOT borehole VES 15 drill depth and geoelectrical depth correlation

Layer	Thickness (m)	Apparent Resistivity(Ω -m)	Inferred Lithology	Curve Type
1	1.66	309.3	Topsoil	Type H
2	0.0529	1937.5	Lateritic soil	
3	0.213	404.1	Weathered basement	
4	14.50	40.05	Fractured basement	
5	>16.43	477.9	Fresh basement	

Prognosis: Borehole drilled depth is 48m, geoelectric sections resolved 16.43 m at fresh basement. The last layer resistivity is 477.9 (ohm-m) depicting weathered and fractured crystalline basement. Therefore, both the drilled depth and the geoelectric sections show good correlation.

3.3 Borehole field, borehole spacing and radius of influence

Groundwater management requires the appropriate characterization of aquifers, based on an understanding of the hydraulic properties governing their hydrodynamics [10]. Radius of influence of a pumping well is the radial distance from the center of a pumping well to the point where there is no lowering of water table or potentiometric surface (The edge of cone of depression) [11]. To optimize borehole spacing in the design of borehole field for, practitioners commonly use transient hydraulic tests [12], which create a pressure disturbance in a well source. They then measure the piezometric variation in time and space through a network of observation wells around the pumping well [13]. The disturbance generated by a pumping test propagates outward from the pumping well over a distance called the "radius of action" [13] or the "radius of influence".

The BOT borehole field has a total number of 15 boreholes spaced between two boreholes with a minimum of 14 meters to maximum of 103 meters intervals as shown in Table 16 and Figure 9. Therefore, the boreholes were not uniformly spaced but rather randomly spaced within the area. Since the area is underling by crystalline basement aquifers that are generally localized unlike sedimentary aquifers that are regional in nature, determination of borehole radius of influence is subject to ambiguity. The best approach in the designing of borehole field in basement area is to conduct a detailed geophysical survey with a predetermined intervals and then select the best drilling for a test well. After drilling the well, a pumping test should be

conducted to obtain the necessary hydraulic aquifer parameters. Second borehole location can then be drilled as an observatory well and pump test together to determine the radius of influence between the two boreholes. As a rule of thumb, the minimum required interval for spacing two boreholes in the basement complex aquifer systems should from 50m to 100 m.

Note that the normal productive boreholes include BH 1, BH 2, BH 3, BH 7, BH 8, BH 9, BH 11, BH 14, BH 15. The non-functioning (dried??) boreholes are BH 4, BH 5, BH 6, BH 10, BH 12, BH 13.

Table 16: Details of 15 boreholes conditions at BOT water station main campus BUK. Source: Maintenance Service Department (MSD), BUK [14]

S/N	Boreholes Condition	Total Depth	Pump Position	Pump Capacity
1	Normal Yield	41m	40m	1hp
2	Normal Yield	41m	40m	1hp
3	Average Yield	42m	40m	1hp
4	Not working	42m	Nil	Nil
5	Not working	42m	Nil	Nil
6	Not working	42m	Nil	Nil
7	Productive	42m	41m	3hp
8	Productive	44m	48m	3hp
9	Normal	46m	45m	1hp
10	Not working	46m	Nil	Nil
11	Productive	43m	42m	1.5hp
12	Not working	50m	Nil	Nil
13	Not working	46m	Nil	Nil
14	Productive	42m	40m	1hp
15	Productive	48m	47m	1hp

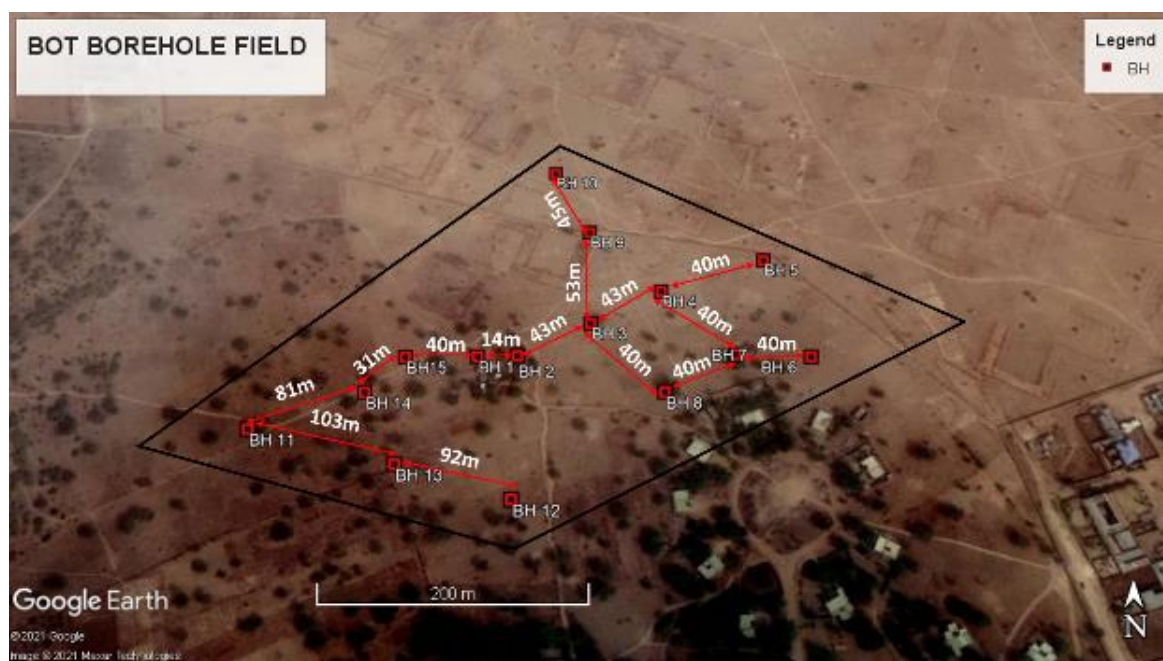


Figure 9 Satellite imagery map of the BOT borehole field in BUK new campus showing the spacing of the 15 Nos boreholes ranging from the lowest 14 meters to maximum of 103 meters from two spaced wells.

4. Conclusion

The interpreted geoelectric results obtained from the study area are presented in the Tables 1 to 15 and Appendix 1 which shows the relationship between the subsurface geoelectric sections and existing borehole drilled depths. Based on the information obtained, data interpretation and integration, the BOT borehole field is good to moderate in terms of groundwater aquifer system. There is a good positive correlation of the drilled depths and the surveyed geoelectric layers of the majority boreholes (nine out of fifteen). Four boreholes were wrongly sited and drilled and perhaps the reason why they are not functioning. Three boreholes were moderately sited to tap the fractured crystalline aquifers. This study was able to deduce the followings;

- 15 numbers of VES points was conducted adjacent to an existing 15 numbers of boreholes field of BUK main campus and geoelectric section/layers was obtained.
- The resultant geoelectric section/layers indicate the aquifers are of highly weathered to fractured basement.
- The interpreted data shows depth to fresh basement is variable but mostly within the range of 42 meters.
- Nine out of fifteen boreholes (BOT 1, 2, 3, 4, 5, 6, 9, 12, and 15) shows positive correlation between the drilled depth and the surveyed geoelectric sections/layers. Three boreholes (BOT 8, 10, and 14) shows poor correlation between the drilled depth and the surveyed geoelectric sections/layers. Also, three boreholes (BOT 7, 11 and 13) show moderate correlation between the drilled depth and the surveyed geoelectric sections/layers.

Recommendations:

This work mainly compared surveyed geoelectric sections/layers and the drilled depth of existing 15 Nos.

boreholes of BOT field of BUK main campus with the aim of understanding the potential of ground water source of the field. Hydrogeological data of the aquifer; including pumping test data (yield, draw down, dynamic water level recovery) was not available. It is therefore recommended that:

- All the fifteen boreholes should be dismantled and pump test to adequately determine all the hydraulic parameters; yield, draw down, dynamic water level, storage coefficient, hydraulic conductivity.
- Radius of influence of each borehole should be determine to understand if there is any interference between the boreholes in the field.
- Total capacity and productivity of all the boreholes in the field should be determine so as evaluate the efficacy of the project and for future plans and expansion.

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