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Geology and Correlative Analysis of Borehole Logs with Geo-electric Sections of Some Parts of Ibadan, Southwestern Nigeria

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ABSTRACT

The property of rocks varies from one geological location to another or even disappears laterally, and these properties are important factors in determining groundwater quantity. This makes this research work focused on the correlative analysis of lithologies and borehole logs with geo-electric sections in the basement terrain of Ibadan, southwestern Nigeria, using Borehole logging and geophysical electrical method. Twenty-two vertical electrical sounding stations and borehole Logsare acquired within the study area with a maximum Schlumberger electrode separation of 100m. The data are interpreted qualitatively and quantitatively by partial curve matching and computer iteration to obtain the first-order geo-electric model parameters. The results of the geo-electric investigation reveal some lithological Layers such as topsoil, clay, weathered laterite basement, and fresh basement. At the same time, those from boreholes include topsoil, loamy soil, friable brown soil, clayey-sand, sandy-clay, laterite weathered basement/saprolite, and Fresh Basement. Electrical resistivity and borehole logs correlation revealed: poor, poor-moderate and moderate-perfect correlations based on a comparison between the number of lithological layers encountered from both vertical electrical sounding derived lithology and those from borehole and depth of occurrence. The depth of water struck grouped into three 0 - 45 m, 45 - 70 m, and 50 - 100 m to bring out the most favourable depth of aquifer potential while three yields categories 0.5-2 lt/s; 2 - 4lt/s and 4 -12 lt/s are observed with the above depth classification respectively. Good yielding fractures increase with depth in the quartzite regions but decrease with depth in both gneisses and the schist rock bodies. The correlations between geo-electric sections and borehole logs have shown that the geoelectric section obtained from the vertical electric section cannot totally be substituted for borehole logging but can serve as alternative means of classifying the sub-surface lithologies in the absence of borehole logging.

Keywords: Borehole-log, Geoelectric-section, Groundwater quantity, Lithological-layer, Fracture, Yield

1. INTRODUCTION

Sourcing for groundwater requires the understanding of the geology, field disposition of rocks, structures and detailed geophysical investigation, which is aimed at mapping the secondary porosity (fracture) which constitutes the basement aquifers; also, to know the depths of geological structures (to get the true picture of the sub-surface). Therefore, a proper drilling method is required in such an area after the survey. But recently, drilling has been

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encountering some challenges due to some wrong geophysical survey reports that are recommended. These occur for the following reasons: fabricated equipment used by the geophysicist, interference filtering, the distance between the fixed probes and others. Regional geophysical resolution of the subsurface layers in terms of their resistivity, reflecting their water-bearing potential, can be fairly well understood. However, within the crystalline basement rock areas consisting of granites, gneiss, schist and basalts, the aquifer rock's constituting the aquifers are generally weathered or partially weathered in areas containing parts containing joints or fractures [1]. Compact hard sandstones, shale and limestone host the aquifers in bedding plain gaps and cavities [2].

The resolution, mainly identifying water-bearing zones, is quite satisfactory for the shallow aquifers. Thick partially weathered horizons are tracked by several jointed rocks, which show convincing geophysical anomalies of low resistivity, which are potential aquifers. [3, 4, 5] attempted to resolve the fractures. Surface resistivity investigations and interpretations do not show promising geophysical anomalies to delineate subsurface fractures. Thin sandwiched aquifers (bedding plain gaps and fractures), relative to thick overlying and the underlying subsurface layers, cannot be resolved by the principle of suppression. However, rock layers beneath are partially weathered, but the difference in rock grain sizes, saprolitic layer thickness and variation in mineralogical aggregation, indicate variations in their resistivities. The uniqueness and reliability of vertical electrical sounding data interpretation reduce due to the principle of suppression and equivalence [6]. Borehole logging is the perfect way to determine the lithological changes in the subsurface; it also provides precise information about the physical properties within the borehole environment [7].

Borehole logging can provide a wealth of information that is critical in understanding the subsurface conditions needed for groundwater and environmental studies. The different hydro-geological units in the subsurface display a wide range of capabilities to store and transmit groundwater and contaminants [8, 9, 10, 11]. Borehole logging provides the thickness of different geologic materials and helps determine the rock types, which can be determined from the drilling returns. The vertical electrical sounding data was correlated with the borehole log data to establish the effectiveness of the two techniques when choosing the site for borehole drilling. Therefore, this study was carried out to check the accuracy of vertical electrical sounding by comparing the results with borehole logs recovered from drilling.

1.1 Geomorphology of the Study Area

The study area lies within the southwestern Nigeria, which is located between longitude $7^0 30'00''$-$7^0 57'00''$ East of Greenwich meridians and latitude $3^0 75'00''$- $4^0 05'00''$ North of the equator, which falls within the Basement Complex (Figure 1**)** and it is accessible by Minor Road and Many Footpaths. The areas covered about 150 km^2 consisting of various communities and populations found in the southwestern part of Nigeria. The most significant part of the area is covered with weathered crystalline rocks, about 70%. The remaining 30% are covered with fresh basement rocks outcropped in different places hosting different aquifers. Groundwater problems start from its quality, lack of groundwater, and reduction in volume or quantity due to pressure from inhabitants and diverse populations surrounding these aquifers zones. The groundwater schemes are structured and varied based on the hydro-geological uniqueness of the crystalline basement rocks in the area. The distinctiveness of these groundwater systems and their water-bearing components or capabilities has influenced and controlled part of the factors governing the existing problems. Based on these factors and the multifarious and unpredictable inconsistent pattern been displayed by underground water incidence in the aquiferous zones or terrains. Therefore, the need for a pre-drilling exploration study is indispensable to the existing challenges. This result of the geophysical survey can be correlated with the geology/rock types present in the area to reach and get a valuable and effective solution. Hence, groundwater developments require a holistic approach by correlating borehole logs with the geo-electric sections.

2. Description and Geology of the Study Area

The geology of Ibadan varies between the meta-sediments of quartzite, banded gneiss, augen-gneiss and migmatites (Figure 1). However, the schist and the quartz schist are common and well exposed within the metropolis. The occurrences of several pegmatitic veins as an intrusion into the undifferentiated crystalline basement rocks exist for the proper study, and groundwater in different basement aquifers with different water was considered **(**Figure 1**)**. Comparison of well log data with geo-electric sections is unique when different rocks are examined, for their structures, fracturing pattern or degree, depth of fractures, water-bearing properties and capabilities with various hydraulic classifications. These rocks are intruded by pegmatite, quartz vein, aplite and doleritic dikes. Over 75% of the rocks in and around Ibadan are banded gneisses, while granite gneisses and quartzite also share the remaining quarter of the area. However, the Ibadan quartzite is relatively resistant to erosion than the deeply weathered gneisses, granite gneiss, amphibolite and dolerite. Except quartz schist hills and quartzite ridges, other exposed outcrops of other areas were covered by highly weathered rocks.

Laterites and other weathering products from rocks such as clays, gravel and sandy materials dotted the study area depending on the underlying bedrock. Groundwater flow in the saprolitic layer and soils derived from crystalline basement rock is strongly influenced by layering, weak horizons and fractures inherited from the fresh parent bedrock. Also, infilling fissures, fractures, and other large pores with pedogenically derived clays and Fe/Mn oxides also play major roles in controlling groundwater movement and groundwater flow. The litho logs and geo-electric sections observed in the study correspond to the incidence of hydrogeological zones where almost all of the fractures and other macro-pores are occluded with pedogenic clays and Fe/Mn oxides. However, thickness greater than 1m with various degrees of macro-pores infilling and different spatial arrangements which is related to the thickness of regolith layers found on the op or within the saprolites. Nevertheless, variations in laterites, soils with different lithologies that always correspond to changes in water movement and accumulation, suggest that underground water potential in this area is a result of the multifarious interaction of more than a few reasons, including parent bedrock lithology and the degree of infilling and the size of the macro-pores. Similarities between hydrogeologic conditions at different sites of the research locations in the weathered basement, clayey/clay, sandy and lateritic soil settings in Ibadan and weathered crystalline rock in the major part of the metropolis indicate that macro-pores infilling that play an important role in controlling groundwater potential and groundwater flow for a variety of different types of parent bedrock is adequately active and vigorous. Also, reliable groundwater potential was observed in thick regolith horizons, saprolitic layers and fractured bedrock in all geological settings are more active hydro geologically than the deeper bedrock system [12].

Saprolites is a chemically and partially weathered rock formed at the lower part of soil profiles and represent deep weathering of the bedrock surface. Its color is likely captured from ferric compounds found in humid tropical areas. Often, partially or poorly weathered saprolite grits present good and dependable aquifers that are capable of producing groundwater

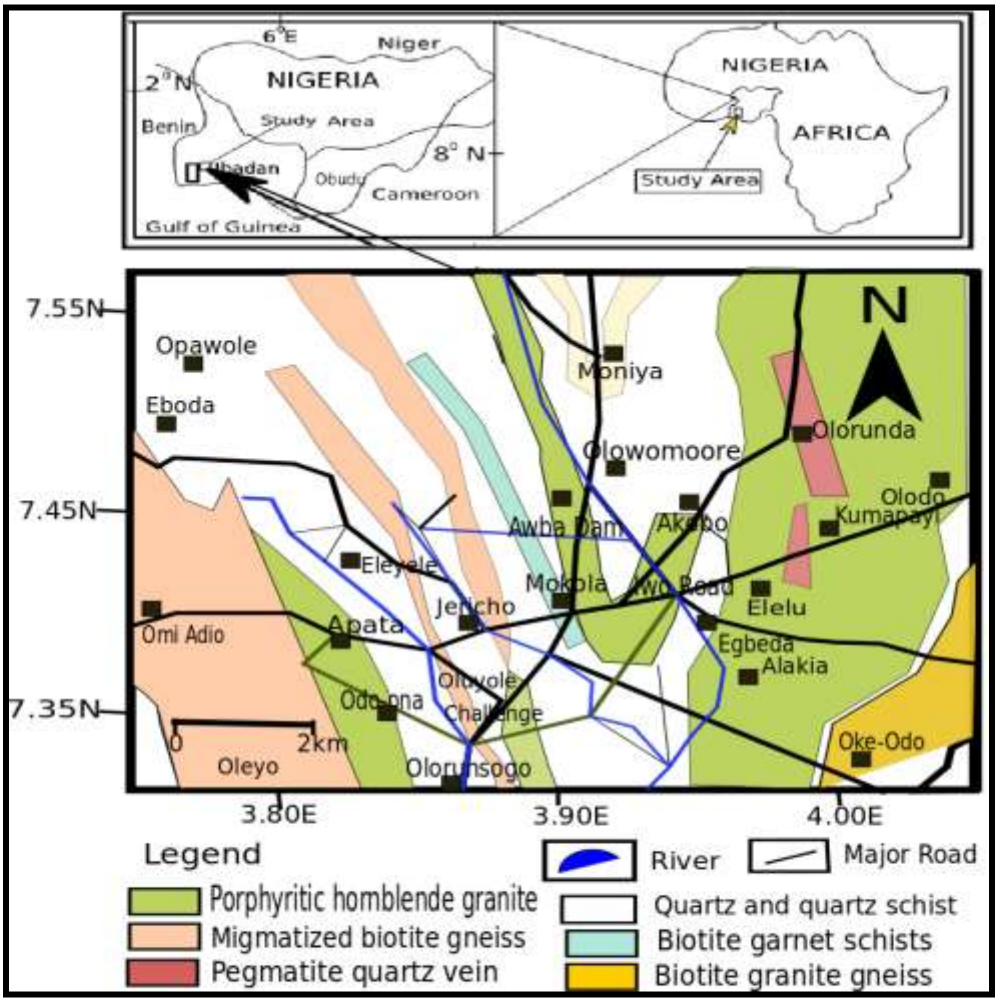

Figure 1-Geological Map indicating the various rock types in the study area

potentials [12, 13]. These attributes were observed virtually from all the borehole logs. Many secondary and supergene ores are formed around this zone, including Al_2O_3, Fe_2O_3, Au, Cu, U and heavy minerals in residual accumulations. Kaolinites [$Al_2Si_2O_5(OH)_4$] are formed within the saprolite. Both yellow and brown goethite [FeO(OH)], and red and gray to black hematite [Fe_2O_3], were found in the saprolitic horizon of the area. The [14] findings supported this conclusion. Most minerals found in this material are not stable. The unstable minerals include Cd, Co, Cu, Mo, Ni and Zn sulfides. These processes have been suggested to have been aided by leaching, dispersion, re-precipitation and hydrolysis [12]. Silica, iron and magnesium-rich oxide are significant in the saprolitic grits. Ca, Mg, Mn and Sr carbonates are highly soluble and strongly leached away.

Lateritic soils are found in humid tropical and equatorial regions. This layer is observed to be rich in iron and aluminium oxide which was derived from a wide variety of rocks weathering under strongly oxidizing and leaching conditions [15]. This was observed to be developed on most of the major rock types in Ibadan. Because of the high iron oxide content, all the laterites observed in the study area are of rusty-red coloration. The lateritic covers vary in thickness and textures. Some are soft and easily broken into smaller pieces, while others are firm, tough and physically resistant. Laterites are formed from weathering parent rocks through leaching, producing insoluble ions, mostly Fe^{2+} and Al^{3+}. At the reaction zones where rocks are in contact with water, laterites are progressively depleted of the easily leached ions of Na^+, K^+, Ca^{2+} and Mg^{2+} [16, 17]. The mineralogical and chemical compositions of laterites are parent rock dependent. It consists mainly of SiO_2, zircon, TiO_2, Fe_2O_3, SnO_2, $Al_2O_3.H_2O$ and MnO, but quartz is the most abundant relic mineral from the parent rock.

3. Materials and Methods

The well Logging techniques and vertical electrical sounding were used in the data collection for this research work, whereby both methods complement each other. The field study entailed collecting data during drilling from drilling returns/cuttings at the end of each penetration; each rod is about 5m (15ft). During the drilling process, the operator flushes out the cuttings after the end of every penetration, which enables to characterize the layer at each depth penetrated and identify aquifer zones at depth. It also helps describe soil texture (clay, sand) and colour. It also helps to know the presence of fractures and the location of different areas where the borehole was drilled, which was also noted. This was achieved with the Global Positioning System (GPS). In comparison, the geophysical survey reports of each area were collected from the field by geophysicist that surveyed each borehole drilled. The Vertical Electric Sounding (VES) technique utilized with the use of collinear arrangement of electrodes that will bring out vertical apparent resistivity as opposed to depth. This is designed to produce a 1-D model for the subsurface at a specific observation point. during the fieldwork for data acquisition, the Schlumberger electrode array was adopted. The electrode spacing ranges from 1, 2, 3, 4, 6, 9, 12, to 100m for AB/2 while MN/2 ranges from 0.25, 0.5, 1, 2.5 and 5m [18]. These processes have produced a sequence of potential differences obtained when successivegreater electrode spacing are achieved while maintaining a fixed central reference point. The induced current passes through progressively deeper layers at greater electrode spacing. The modifications at the deeper depth below the subsurface were commensurate with the potential difference measurements. Apparent resistivity values calculated from measured potential differences can be interpreted in terms of overburden thickness, water table depth, as well as the depths and thicknesses of subsurface strata. The data acquired were interpreted quantitatively and qualitatively via manual curve matching and computer iteration techniques. The manual partial curve matching technique matched the field curves with the standard master and auxiliary curves. The results obtained are input as a model for the computer iteration technique that produced the final resistivities and thicknesses of subsurface lithologies underlain each VES point.

Investigative drilling was adopted and conducted between 2015-2016 on various lithologic aquifers such as quartzite, banded gneiss, augen-gneiss and migmatites, schist, quartz schist and several pegmatitic bodies. The drilling activities were carried out using a Down the Hole (DTH) rig with a targeted depth of 45m - 100m. At the time of drilling, lithological samples from the boreholes were collected at an interval of 5m, washed and dried for megascopic study. The level and rate of drill bits were also observed and recorded. At the end of the drilling, Preliminary Yield Tests (PYT) of 60 minutes duration was carried out to know each well's discharge rate, drawdown and transmissivity.

4. Results and Discussion

4.1Resistivity and layers

Interpretation of the VES curves has permitted their classification into different resistivity type curves. [19] observed that the apparent resistivity curve obtained by sounding over a horizontally stratified medium is a function of resistivity and thickness of the component layers that characterize the medium and the electrode array employed in sounding. Twenty-two Schlumberger curves were obtained from the study areas. They reveal 3 to 7 geoelectric layers, 12 of which were H-type curves, while the remaining one is of Q, QH, HQH, QHH, and QHQ -type curves. The H-type curve, which typifies a Basement Complex environment and contains a low resistivity intermediate layer underlain and overlain by more resistant materials [20] was identified. Layers 1 and 2 are respectively, the high resistivity lateritic/sandy clay topsoil, and the low resistivity weathered basement (Table 1).

4.2 Correlation of Borehole Log with Resistivity Data

The Data collected from the Borehole Logging and the electrical Resistivity Data was processed and presented as geoelectric section and correlation. The correlations are grouped into poor, poor-moderate, and moderate-perfect correlations. Different lithological layers were encountered both from vertical electrical sounding and borehole logs. These include Clayey Sand, Clay, Lateritic Topsoil, Red Friable Soil, Weathered Basement, Sandy Clay, and Fresh Basement. Clayey sand indicates sands with high clay content. In the borehole logs, clayey sands appear as coagulated reddish clots of sands with resistivity values of 9 - 20 Ωm, while sandy clay specifies clays with high sandy content having resistivity values of 0.9 - 18.6 Ωm. In the borehole logs, clayey sands appear as coalesced reddish mass of sands within the soil profile. Clay in the litho-logs occurs as cumulate offine-grained materials of residual weathering that are very sticky and elastic when wet and are generally characterized by resistivity values of 0.0 - 0.6 Ωm. Lateritic soil occurs as a medium to coarse-grained material that are well-drained and also products of residual weathering. They have reddish coloration and resistivity values ranging from 0 - 1.5 Ωm. Friable soil in the lithologs are characterized by coagulated fragments which are not easy to disaggregate and they are characterized by resistivity values of 0 - 0.6 Ωm at areas where they are present. Saprolite signifies partly weathered rock formed from fresh crystalline and deep-seated weathering of rocks. These layers from the lithologs are composed of partly weathered materials of the rock units in the area. Their resistivities generally range from 5 - 35 Ωm in all the areas surveyed and resistivity of 15 - 40 Ωm was observed in hilly areas such as Mokola hill in the study area.

4.2.1 Poor Correlation

The correlation between the borehole log and resistivity geoelectric section in Figures 2-4 shows a poor correlation, with a variation in the number of lithological layers derived from vertical electrical sounding data interpreted and borehole log obtained from drilling exercise. Here, it was encountered 5 geoelectric layers from VES, while from the borehole log were 3 layers. There was also wide variation in depth of occurrence of these layers between the thickness determined from VES and borehole logging. This scenario was encountered in AS Estate, Olowomoore, Eboda, Gbadebo street, Soka and Elewura. For example, in AS Estate, the first layer is a lateritic topsoil layer to a depth of 5.0m

Table 1- The Geoelectric Parameters of the Study areas obtained from Interpreted VES Data

NO	LOCATIONS	RESISTIVITY (Ωm)	THICKNESS(m)	DEPTH(m)
1	Agala	159.4	1.8	1.8
		418.8	28.2	30
		339.7	------	------
2	Seven-up Academy	51.3	0.9	0.9
		88.4	6.2	7.2
		200.6	------	-------
3	IkumapayiOlodo	68.4	1.3	1.3
		52.9	4.3	5.6
		1548	------	------
4	Alakia	426.3	2.5	2.5
		81.3	1.2	3.7
		1349.6	-------	-------
5	Eleyele	18.2	0.9	0.9
		44.2	17.7	18.6
		536.7	45.6	64.2
		479	--------	-------
6	As Estate	198.9	1.2	1.2

		120.4	14.1	15.3
		1592.1	--------	-------
7	Olowomoore	24.7	0.6	0.6
		14.5	1.3	1.9
		46.8	3.2	5.1
		1152.9	-------	-------
8	Elelu	69.9	2.3	2.3
		29.7	14.4	16.7
		35.8	11.6	28.3
		90.8	--------	------
9	Eboda	685.3	0.5	0.5
		79.2	4.6	5.1
		27.7	9.6	14.7
		159.2	--------	-------
10	Afolabi Estate	508.3	0.6	0.6
		159.3	2.7	3.4
		303.8	4.9	8.3
		86.8	6.1	14.4
		1258.2	------	-----
11	OluyoleExtenion	396.1	2.5	2.5
		81.2	4.9	7.4
		3561.9	------	------
12	Ade-Owu Village	118.3	1.5	1.5
		50.1	3.1	4.6
		2720	------	--------
13	Banjo House 1	2510.5	0.6	0.6
		281.7	5.1	5.7
		316.7	2.7	8.4
		48.2	6.5	15
		12867.6	--------	-------
14	Banjo House 2	775.7	1.6	1.6
		38.9	5.7	7.3
		1078.4	-------	-------
15	Jiboye Omi-Adio	500.2	1	1
		344.9	5.2	6.2
		772.4	--------	------
16	Elewura Challenge	57.5	1.5	1.5
		47.2	0.6	2.1
		169.9	1.2	3.3
		27.1	11.9	15.2
		4591.5	-------	-------
17	Oke-Odo	43.9	2.3	2.3
		425	3.3	5.6
		28.6	8.9	14.5
		3444.8	-------	--------
18	Egbeda	155.6	0.9	0.9
		52.8	6	6.9
		927.8	-------	------
19	Moniya	140.4	0.7	0.7
		52.8	6.5	7.2
		927.8		------
20	Mokola	140.4	0.7	0.7

		52.8 927.8	6.5 -------	7.2 ------
21	Gbadebo street Mokola	101 56.9 38.3 103.6 23.8 57.9 2260.5	1.1 0.9 1.5 7.2 8.4 30.1 -----	1.1 2 3.5 10.7 19.1 49.1 ------
22	Soka	111.2 234 25.2 14505 875.2 7971.3	0.5 0.8 4.3 33.7 48.6 -------	0.5 1.3 5.8 39.5 62.5 -------

and 2.0m for the borehole and resistivity geoelectric section, respectively. The second layer of the borehole log is the red friable soil which is not present in the VES-derived lithology. The third layer is sandy clay to a depth of 20.0m and 15.3m, respectively. The fourth layer encounter in the borehole log is the Weathered basement to a depth of 20-30.0 but absent in the Resistivity geoelectric section.

4.2.2 Poor-Moderate Correlation

The correlation between the borehole log and resistivity geoelectric section encountered in Seven Up, Eleyele, Eboda, Adeowu, Jiboye, Oke-Odo, Egbeda, Mokola, are classified as poor-moderate correction in the sense that it was just a slight variation in lithological layers derived from both borehole log and vertical electrical sounding results. In this section, we encountered slight variation in the numbers of lithological layers derived from VES and borehole logs. In some cases, we have more layers identified in VES than the borehole, while in some locations, the reverse is the case. For example, at Jiboye Omi-Adio, three lithological layers were encountered, but wide variation in depth of occurrence. The first layer of the Borehole Log and geoelectric section shows a Lateritic Layer of 10.0 and 1.0m, respectively. The second layer is clay occurring at depths of 10.0m - 15.0 and 1.0-6.2m, respectively. The last weathered layer was encountered at 15.0 and 6.2m, respectively **(**Figures 5-8**)**.

4.2.3 Moderate - Perfect Correlation

The correlation between the Borehole log and Resistivity Geoelectric section in Agala, Elelu, Afolabi, Banjo house, Ikumapayi Olodo, Alakia, and Oluyole in the Figures 9 - 12 below shows a moderate Correlation with the same number of lithological Layer for both the Borehole Log and Geoelectric resistivity Log, whereby, the same lithology occurs down depth, but there is variation in

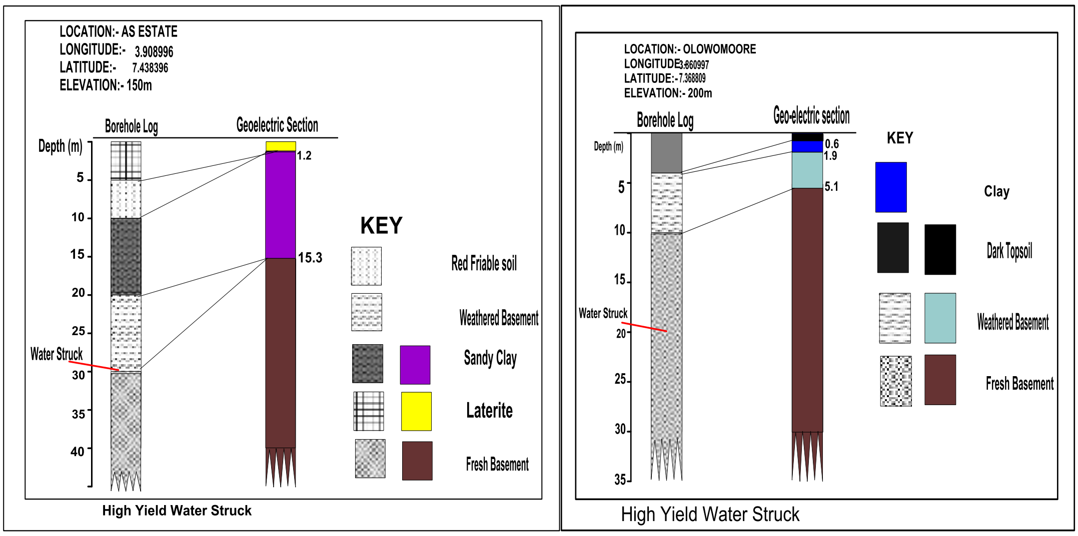

Figure 2-The Borehole Log and the Geoelectric resistivity Section of AS Estate and Olowomore

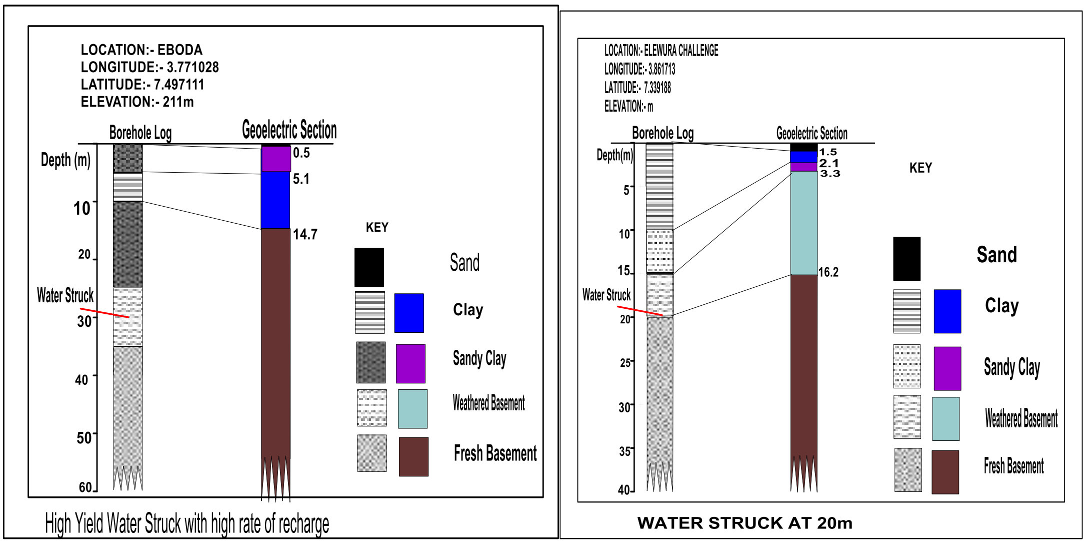

Figure 3-The Borehole Log and the Geoelectric resistivity Section of Ebodaand Elewura

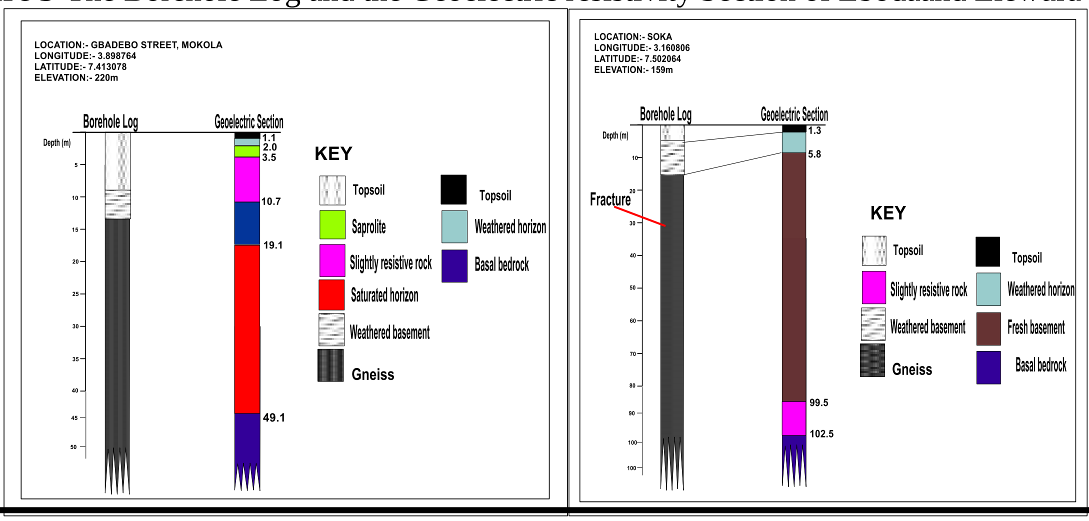

Figure 4-The Borehole Log and the Geoelectric resistivity Section of Gbadebo street, Mokola and Soka

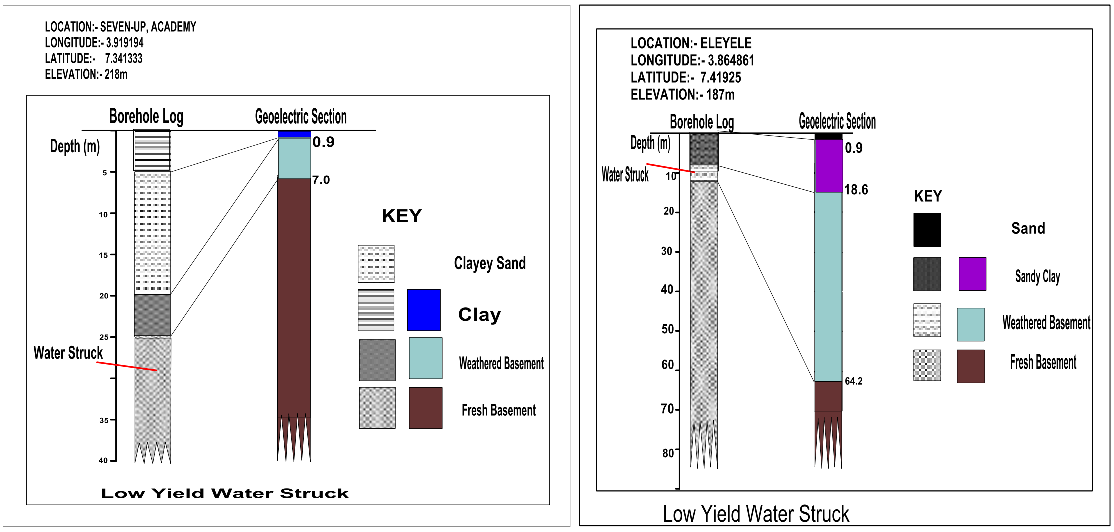

Figure 5-The Borehole Log and the Geoelectric resistivity Section of Seven Up Academy and Eleyele

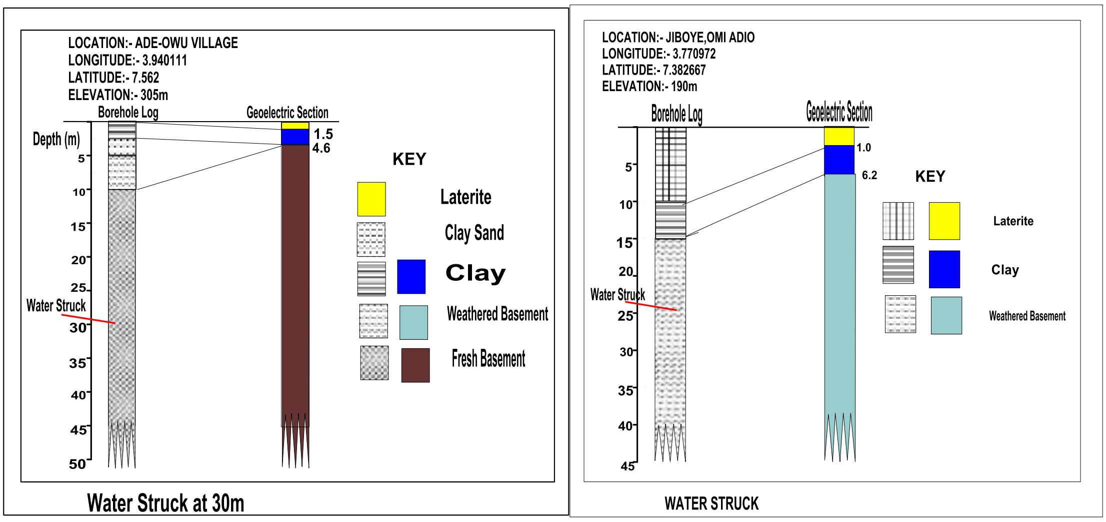

Figure 6-The Borehole Log and the Geoelectric resistivity Section of Ade-0wu village and Jiboye, Omi-Adio

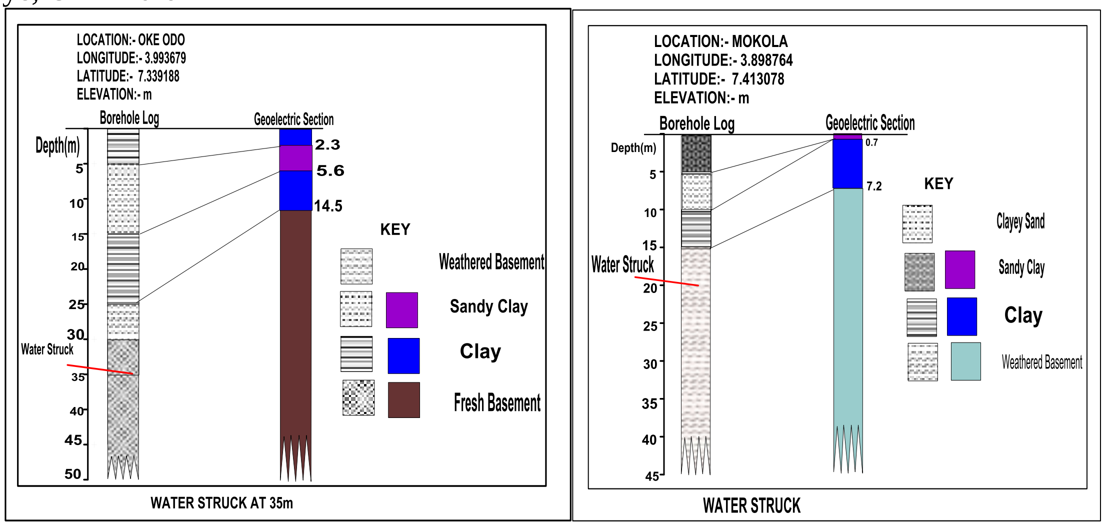

Figure 7-The Borehole Log and the Geoelectric resistivity Section of Oke-Odo and Mokola

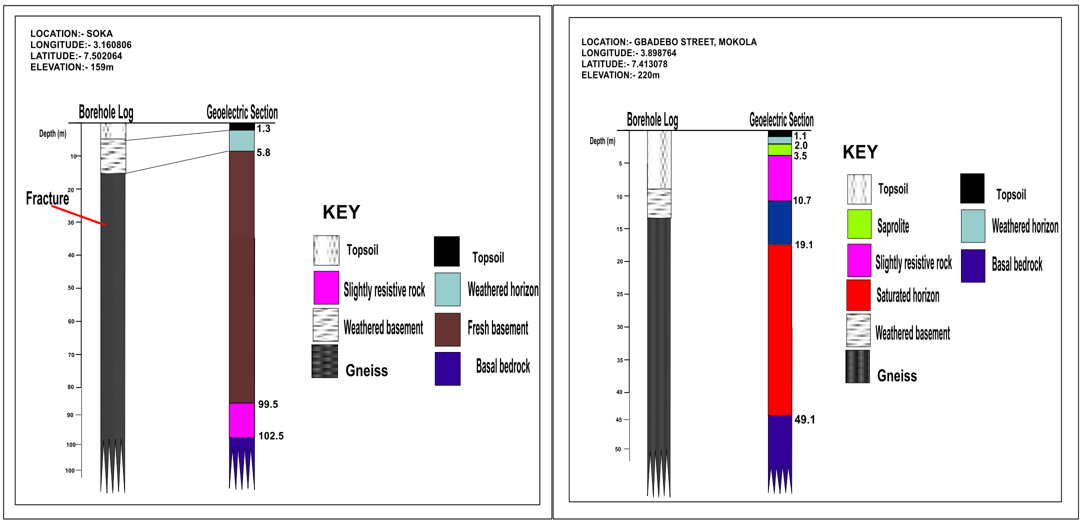

Figure 8-The Borehole Log and the Geoelectric resistivity Section of Soka and Gbadebo Street,Mokola

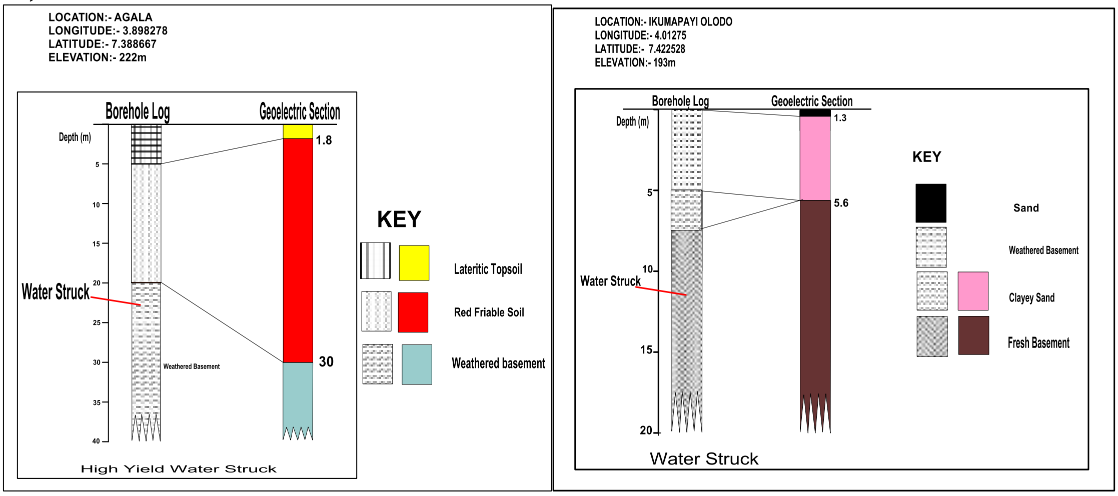

Figure 9-The Borehole Log and the Geoelectric resistivity Section of Agala and Kumapayi Olodo

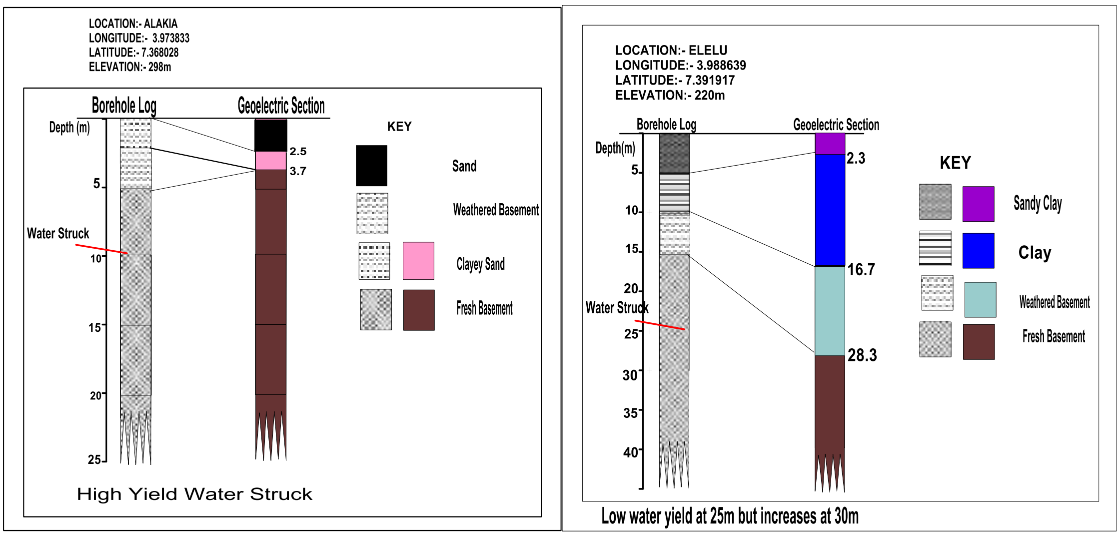

Figure 10-The Borehole Log and the Geoelectric resistivity Section of Alakia and Elelu

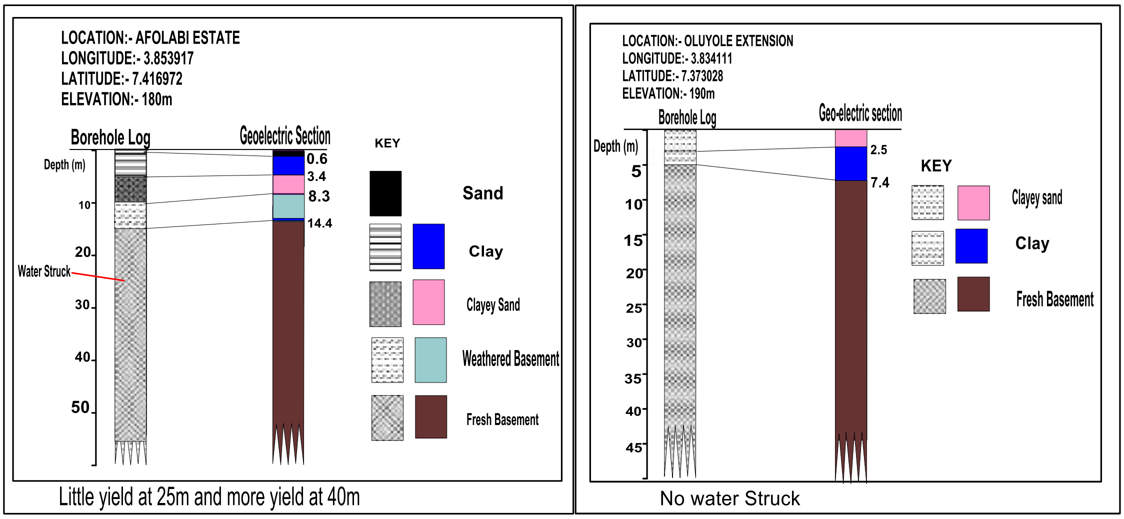

Figure 11-The Borehole Log and the Geoelectric resistivity Section of Afolabi Estate and Oluyole Extention

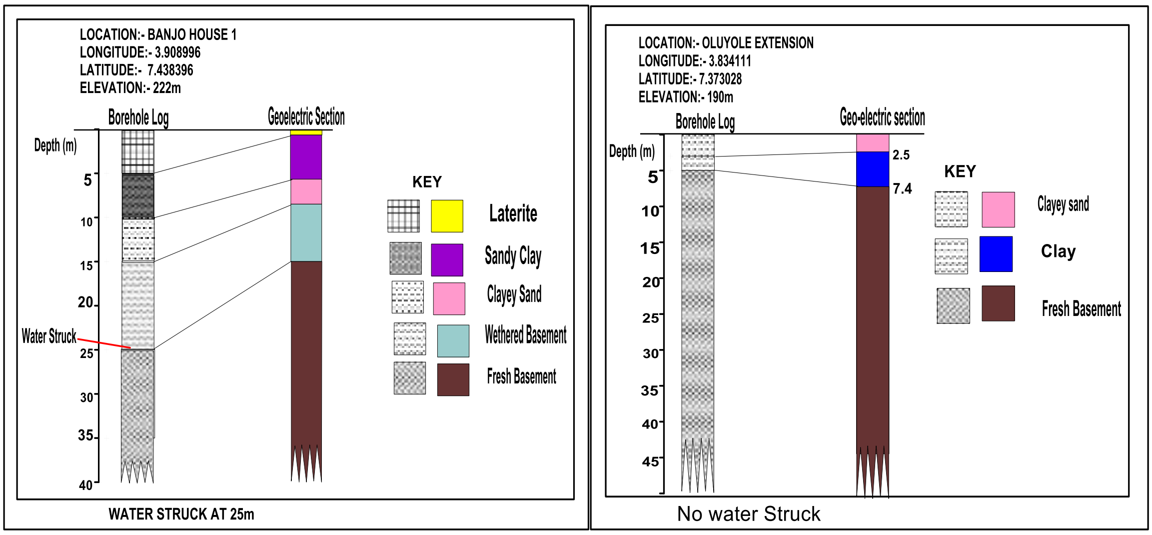

Figure 12-The Borehole Log and the Geoelectric resistivity Section of Banjo House 1 and Oluyole Extention

the depth of formation. For example, in the Oluyole extension, the correlation between the Borehole log and Resistivity Geoelectric section shows a moderate-Good Correlation with a total of 3 lithological Layer for both the Borehole Log and Geoelectric resistivity Log, whereby the same lithology occurs down depth. There is variation in depth of formation. The first layer of the borehole Log and Geoelectric section shows a Clayey Sand Layer to a depth of 3.0m and 2.5m, respectively, from the surface. The second layer is a Weathered Basement with a depth of 3.0-5.0m and 2.5m-7.4m, respectively. The last layer, the fresh basement, was encountered at 5.0 and 7.4m, respectively.

4.2.4 Discussions

The fracture nature and character encountered in boreholes at different depths in varying geological terrain were observed during drilling from the depth in which water is struck and borehole logs. The incidence of fractures where water is struck and their lithologic thickness varied greatly in the area's closely gapped boreholes [21], which also signifies varying groundwater production revealed during drilling. Field observation revealed that fracturing degree or the levels of fracturing in the quartzite are high, and these were encountered between the depths of 0.0 and 62.5 m at Soka and Mokola. The fracturing of the gneisses is not the same and/but occurs at shallow depth at Elewura - Challenge encounter. The prospect of encountering fractures is reduced considerably at Amuloko within the granite gneiss. The reduction in the number of fractures concerning depth is due to the "closure" of these fractures due to the increase of lithostatic twist [22].

According to reports by [23]; the yield of a saturated aquifer decreases with depth due to varying factors which include: (i) the falling degree of weathering and production of thin regolith layer, (ii) a decrease in porosity and permeability with depth and (iii) the closing of fractures with depth. The discharge is observed and grouped into depth ranges of 0 - 45 m, 45 - 70 m, and 50 - 100 m to bring out the most favorable depth of aquifer potential. Further observation made during drilling operations and borehole logging specifies that good yielding fractures increase with depth in the quartzite regions but decrease with depth in both Gneisses and the Schist rock bodies. Three categories of yields such as 0.5-2 lt/s; 2-4lt/s, and 4-12lt/s were observed within the above depth classification range, respectively. The yield considerably reduces concerning the depth range greater >100 m unless in the quartzite regions. Various aspects revealed that the boreholes in the quartzite, migmatites and gneisses have higher average yields production at greater depths. This greatly correlated with the geo-electric sections of moderate- perfect at Oluyole, Agala, Ikumapayi Olodo and Alakia as examples. At the same time, the granite-gneiss shows a reduction in the yield at the continuous rate at Amuloko.

Weathering of rocks played an important role in groundwater accumulation in Ibadan and its environs; this has been shown in the area. This simply correlated with the geo-electric sections conducted in this study. The percentage of weathered to fresh basement rocks is 80% - 20%, signifying that most rocks were extensively weathered, especially the migmatites, gneisses, and the schists. The southwestern part of Nigeria has a humid tropical climate which implies thicker weathered regolith in areas with higher rainfall and, in turn, higher yield [24]. However, because of the climatic conditions and hence, the nature of rocks containing ferromagnesian minerals in most rocks is susceptible to weathering. It was also observed from boreholes that have a high thickness of weathered regolith, which are not high-yielding types. This observation during drilling and borehole logging correlated with the geo-electric section results. Hence, this indicates that, apart from climate, the fracturing pattern and its interconnectivity play a very important function in the basement crystalline rocks [25].

5 Conclusion

Generally, the natures of rocks containing ferromagnesian minerals in most rocks are susceptible to weathering; this is revealed in boreholes with high thickness of weathered regolith, which correlated with the geo-electric sections of some areas. The incidence of fractures where water was struck, and their lithologic thickness varied slightly, while the fracturing pattern and connectivity play a vital role in basement crystalline rock aquifers. Various aspects revealed that the boreholes in the quartzite, migmatites and gneisses have higher average yields production at greater depths; this greatly correlated with the geo-electric sections of moderate- perfect at Oluyole, Agala, Ikumapayi Olodo and Alakia areas.

Furthermore, from these correlations, it could be observed that on many occasions, lithological layers obtained from vertical electrical sounding based on variations in layers resistivity can be misleading if not properly handled and interpreted by competent Geophysicists. On many occasions, it may be difficult to access borehole logs because many drillers are not Geoscientists and are careless in preserving those logs during drilling. In conclusion, the correlations between geoelectric sections and borehole logs have shown that the geoelectric section obtained from the vertical electric section cannot be substituted for borehole logging but can serve as alternative means of classifying the subsurface lithologies in the absence of borehole logging. This work has also established that a combination of vertical electric sounding derived lithological layers and borehole log gives a better interpretation of subsurface layers in a particular environment.

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