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# Evaluation of Topsoil Competence, Aquifer Types, Groundwater Prospect and Flow Pattern using Geoelectric Characterization for Part of Ogbomoso, Nigeria

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## Abstract

*Part of Ogbomoso Southwestern Nigeria was assessed using electrical resistivity method with a view to obtaining the subsurface geoelectric parameters (resistivities and thicknesses), categorizes the topsoil into different competence zones and evaluates the aquifer types, groundwater prospect and flow pattern. Fifty-four Vertical Electrical Sounding (VES) data were quantitatively interpreted using the partial curve matching technique to obtain the preliminary layer parameters which were further refined through 1-D forward modelling WinResist software package. The resulting final layer parameters were used to generate 2D geoelectric sections, isopach and isoresistivity maps and subsequently used to categorize the study area into different topsoil Competence, Aquifer types and Groundwater Potential zones. Static water levels of hand-dug wells in the area were used to generate the groundwater flow pattern. Four subsurface geoelectric layers were delineated. These were the topsoil, laterite, weathered/partly weathered layer (main aquifer) and fractured/fresh bedrock. The resistivities and thicknesses of the layers were 76-1858, 649-2021, 17-880 and 260-33385 Ωm and 0.4-4, 0.7-1.9 and 1.9-25.2 m respectively. The groundwater flow pattern in the area was NE-SW. The study concluded that incompetent to highly competent topsoil, weathered bedrock (main) aquifer unit/partly weathered/fractured bedrock aquifer and generally low groundwater potential with NE-SW flow direction underlay the study area.*

**Keywords:** Geoelectric Characterization, Topsoil Competence, Aquifers, Groundwater Potential.

## Introduction

Characterization of an existing or a new site is very important in providing subsurface information that could assist civil engineers, builders and town planners in the design and siting of boreholes or foundations of civil engineering structures (Omoyoloye, *et al.*, 2008). In recent times, the collapse of boreholes and civil engineering structures has been on the increase for reasons associated with subsurface geology (Blyth and Freitas, 1988 and Omoyoloye *et al*., 2008). Faulting in rocks or where an area is underlain by thick stratum of clay can cause cracks in a building (Bayowa, et al., 2019). Previous workers over the years in geosciences have attributed these failures of foundations to lateral inhomogeneity of the subsurface, differential settlement and failures due to presence of geologic structures such as faults, joints, cavities beneath the buildings (Ako and Olorunfemi, 1989, Akintorinwa *et al*., 2009, Fadele, *et al.*, 2012, Adelusi *et al*., 2014 and Falae, 2014). However, such geologic structures are favourable to groundwater accumulation (Mallam and Ajayi, 2000, Tay, 2007, Mesbah, *et al.*, 2017 and Villalobos-Aragon, 2019).

Akowonjo area is a fast-developing residential community in Ogbomoso North Local Government Area, Oyo State, Southwestern Nigeria. Some buildings around the area show signs of foundation failure because of severe cracks on the buildings. Geological factors are suspected to be responsible for the foundation distress. Reconnaissance field survey showed that most hand-dug wells and boreholes in the study area could not yield enough water to well. This pose serious problem on inhabitants of the area on water usage for industrial and domestic purposes since most of the hand dug wells dry up during the dry season while some of the boreholes drilled in the area by private individual or public enterprise are not productive. Consequently, proper geophysical assessment of the area was undertaken not only to find out the cause(s)

of the geologic related problems but also to effectively characterize the area into different subsoil competence and groundwater potential zones for future engineering related programme in the area.
Geophysical methods such as the Electrical Resistivity (ER), Seismic refraction, Electromagnetic (EM), Magnetic and Ground Penetrating Radar (GPR) are used singly or in combinations for engineering site investigations/characterization (Burger, 1992). Geophysical methods are probably the most widely used to provide information on geological structures, lithologies and subsurface condition in-lieu of the large cost of an extensive programme of drilling. However, in this study, electrical resistivity geophysical method involving Vertical Electrical Sounding (VES) was employed. The method provides quick and inexpensive method for the assessment of various subsurface geoelectric characteristics related to the study of topsoil competence (Idornigie and Olorunfemi, 2006, and Akintorinwa *et al*., 2009) and aquifer types and their groundwater potentials (e.g. David and Ofrey, 1998). Nevertheless, success of VES for subsurface study can be hampered by interpretation problems inherent from errors due to the effect of dipping beds and/or errors due to principle of equivalence and suppression (Telford, *et al.*, 1990).

## Location, Accessibility, Climate, Relief, Vegetation and Geology of the Study Area

Akowonjo area is located in the Ogbosomo North, Oyo State, Nigeria. Akowonjo falls between Latitude 8° 08’ 51’’ N and 8° 09’ 13’’ N and Longitude 4° 16’ 11’’E and 4° 16’ 43’’E with an area extent of 0.99 $Km^2$ (Figure 1). The area is accessible by pathway and untarred roads. The climate is characterized by alternation of wet season lasting from April to October and dry season from November to March (Abuloye, et al., 2017). The terrain is gently undulating with topographic elevation ranging between 322 and 352m above sea level. The area lies within the tropical rain forest belt of hot, wet equatorial climatic region characterized by alternating wet and dry season. The vegetation is of the rain forest type that consists of thick vegetation comprising multitude of evergreen trees. Precambrian Basement Complex rocks (Obaje, 2009) underlie Ogbomoso town. The lithological units are quartzite, granite-gneiss and banded gneiss. The quartzites are light colour and may be part of the migmatite-gneiss quartzite complex, mainly composed of quartz. However, granite-gneiss underlie Akowonjo community (Afolabi, *et al.*, 2013).

## Materials and Methods of Study

Vertical Electrical Resistivity (VES) data were conducted randomly around the study area (Figure 1) to investigate the change in electrical conductivity with depth beneath in the area. The global positioning system (GPS) was used to geo-reference all VES stations while the ABEM SAS 1000 Terrameter was used for the resistivity data measurements. The Schlumberger array was used. The raw VES data obtained were plotted on bi-log paper while the resulting depth sounding type curves (Figure 2) were interpreted quantitatively by comparing the depth sounding curves with a set of master curves (Telford, *et al.*, 1990) through the conventional partial curve matching to obtain the starting model layer parameters resistivities and thicknesses).

The starting model parameters were refined using the WinResist version 1.0 1-D forward modelling software package environment to obtain the final layer parameters. The calculated final layer parameters for the obtained depth sounding curves were used to construct 2D geoelectric sections to show the true resistivities and depths of different layers beneath the survey area. Isopach and isoresistivity maps were also generated to demarcate the area into different subsoil competence, aquifer types and groundwater potential zones using Surfer 16 software package. The Static Water Level is defined as the difference between the Surface Elevation (m OD) and the depth to Water Table (m). That is, static water level (m) = Elevation of well (m) – (Length of well – length of water table of the well) (m). The static water level was used to generate the groundwater flow pattern in the study area using the Surfer 16 software package.

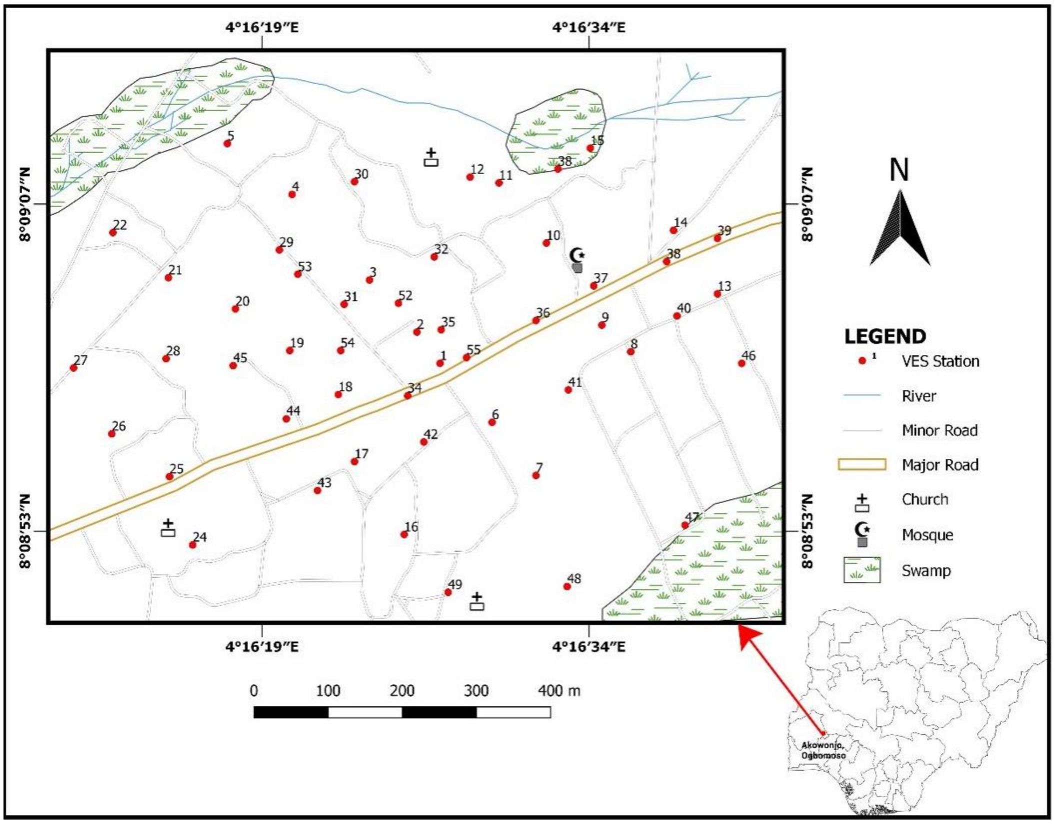


**Figure 1:** Base Map of the Study Area showing the VES stations (inset is the Administrative Map of Nigeria).

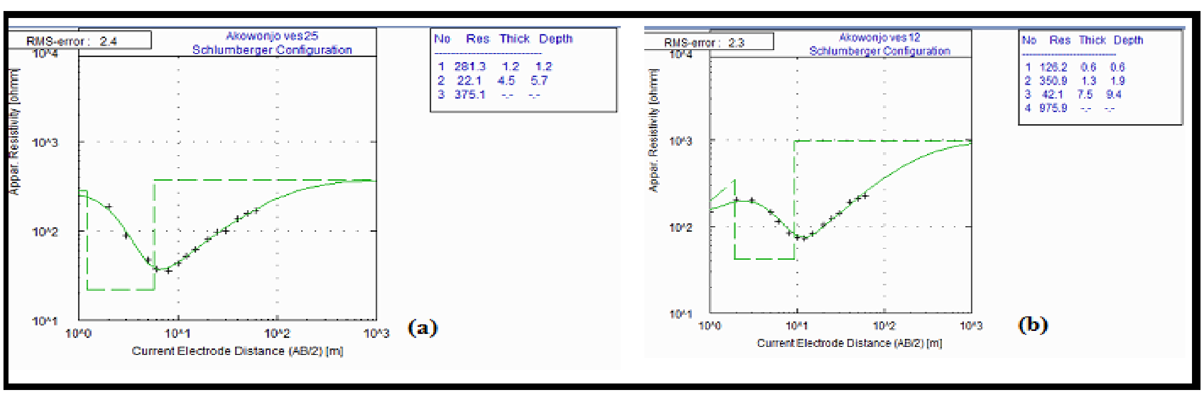


**Figure 2**: Typical Type Curves obtained in the Study Area (a) H-type (b) KH-type.

## Results and Discussion

### Field curves

Figure 3 shows the relative abundance of the sounding curves obtained in the study area. In increasing order of abundance QH, HA, KH and H type curves were delineated with H type curve most abundant. Based on the above type curves as summarized in Table 1, the geoelectric characteristics (resistivities and thicknesses) were used to generate geoelectric sections and categorized the study area into different subsoil competence, aquifer types and groundwater potential zones.

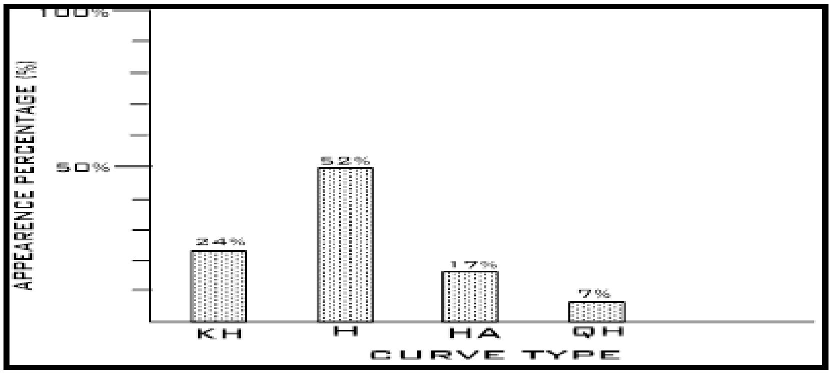


**Figure 3**: Bar Chart of Relative Abundance of the Type Curves obtained in the Study Area.

**The Geoelectric sections**

Figure 4a-c show the geoelectric sections which relate VES 24, 43, 17, 42, 6, 41, 8, 40 and 13 (SW-NE direction), VES 27, 28, 45, 19, 54, 2, 35, 36 and 9 (W-E direction) and VES 5, 4, 3, 52, 2, 1, 6, 7 and 48 (NW-SE direction) respectively. The geoelectric sections provide an insight into the geological sequence and structural disposition and aquifer types beneath the study area.

Generally, maximum of four subsurface geoelectric sequences were identified. The first layer constitutes the topsoil and is made up of sandy clay/clay/clayey sand/laterite with layer resistivity range between 76 and 1858 Ωm. The layer thicknesses range between 0.4 and 4.0 m. The second layer is the laterite with resistivity values that range between 649 and 2021 Ωm and layer thickness range of between 0.9 and 1.9 m. Summary of the Interpreted Results of the Sounding Curves is as contained in Table 1 (Appendix A).

The third layer which is weathered/partly weathered layer has resistivity value range between 17 to 880 Ωm. The thickness of the layer range between 1.9 and 25.2 m. The fourth layer is presumably the fractured/fresh bedrock with resistivity values range between 196 and 33385 Ωm. The geologic structural features observable beneath the sections is the basement depressions beneath VES 8, 45, 19, 2, 36, 4, 3, 52 and 2. It is apparent from the sections that the aquifer types in the area include the weathered/partly weathered and fractured basement bedrock.

**Topsoil Competence Zoning**

Figure 5 shows 3D view of topsoil competence map of the study area. The map was generated based on different ranges of topsoil resistivity values in the area as contained in Table 2 (Idornigie and Olorunfemi, 2006). The topsoil competence within the study area includes incompetent, moderately competent, competent and highly competent. It is apparent that the central part of the area is characterized by incompetent subsoil having resistivity values ranged between 71 and 100 Ωm. The Southern, Southeastern and Northwestern parts are underlain by moderately competent subsoil with resistivity value range of between 117 and 340 Ωm. At Northwestern and Northeastern parts of the study area, competent topsoil is delineated with resistivity value ranged between 363 and 750 Ωm. However, at the extreme flank of Northwestern and Northeastern part of the study area, highly competent topsoil of >750 Ωm can be delineated.

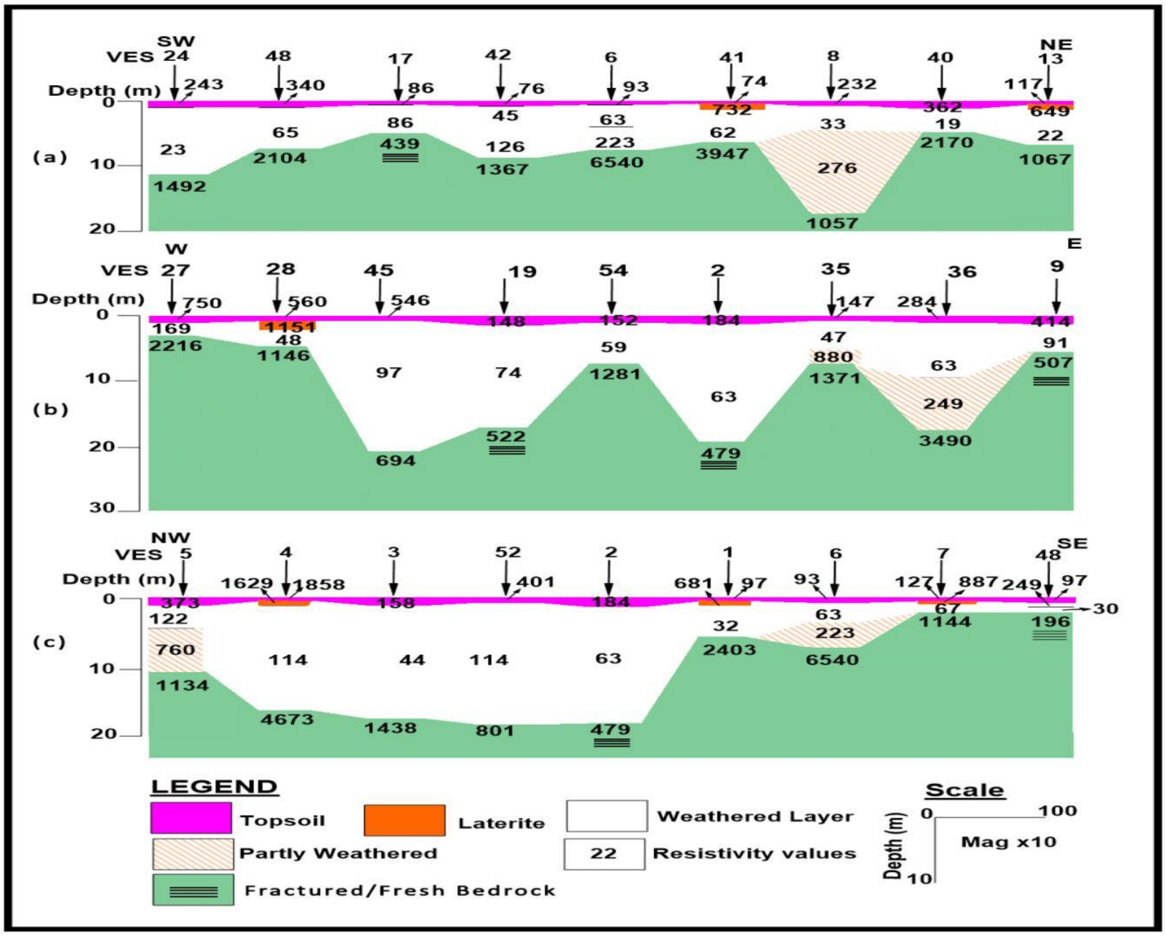


**Figure 4**: Geoelectric Section along (a) SW-NE (b) W-E and (c) NW-SE Directions.

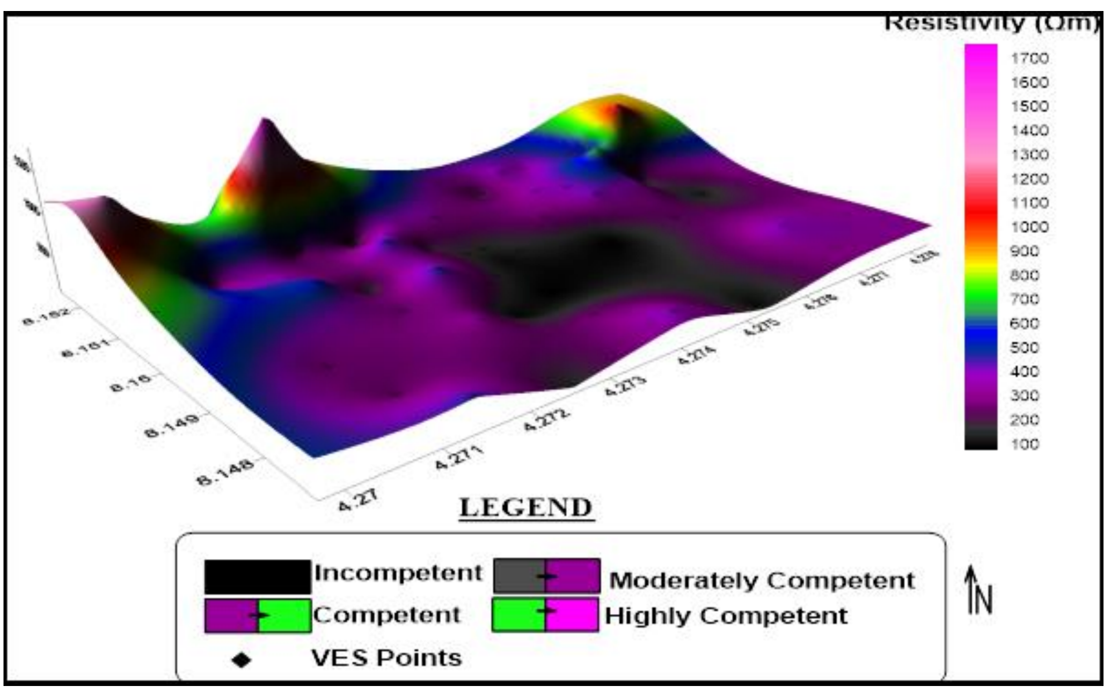


**Figure 5**: Topsoil Competence Zoning Map of Study Area.

**Table 2:** Topsoil Competence Rating

| Resistivity Range (Ωm) | Topsoil Lithology | Competence Rating |
|---|---|---|
| <100 | Clay | Incompetent |
| 100-350 | Sandy clay | Moderately Competent |
| 350-750 | Clayey sand | Competent |
| >750 | Sand/Laterite/Bedrock | Highly Competent |

Source: Idornigie and Olorunfemi, (2006)

**Characteristics and Hydrogeologic Significance of Aquifers in the Study Area**

Figures 6 and 7 show the isopach and isoresistivity maps with hydrogeologic significance of the main aquifer unit (weathered layer) in the study area. The weathered layer thickness varies from 0.5 m to 25 m but generally <12 m. The resistivity values of the weathered layer vary between 10 and 240 ohms-m but generally <100 ohm-m. This is an indication that weathered layer in the area is typical of clay in most places.

The thickness and nature (based on resistivity values) of aquifers are important parameters in groundwater prospect evaluation of an area (Omosuyi, *et al.*, 2008 a & b). However, the nature of an aquifer takes the lead. An aquifer should be able to store and transmit water to well in economic quantity. The thickness of the aquifer unit with low percentage of clay in its intergranular space can be used to infer on the quantity of groundwater in an aquifer formation. That is, thin aquifer layer of high clay percentage would give a corresponding low groundwater potential, hence, low quantity. Thick aquifer unit with low clay percentage would yield enough water to well while thick aquifer unit with high percentage of clay will also give low groundwater yield. However, evaluation of groundwater potential based on aquifer thickness alone may not yield the desired result; hence, the use of aquifer resistivity values.

The isopach map of the weathered layer in the study area depicts that the area can be zoned into four groundwater potential which include high groundwater potential (> 18 m), moderate groundwater potential (12-18 m), low groundwater potential (6-12 m) and very low groundwater potential (<6 m) zones based on modification of Olorunfemi, 2008 (Table 3).

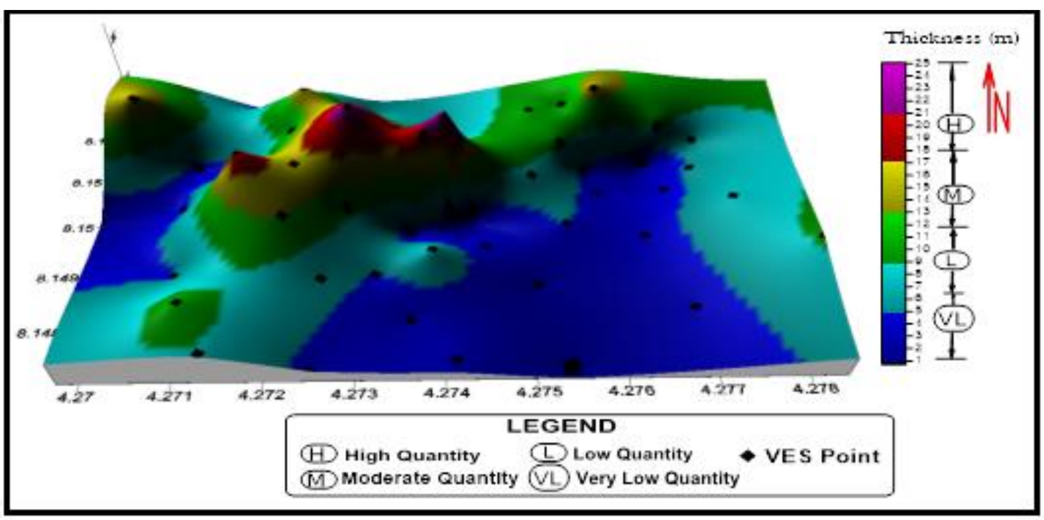


**Figure 6:** Groundwater Potential of the Study Area based on thickness of Aquifer Units.

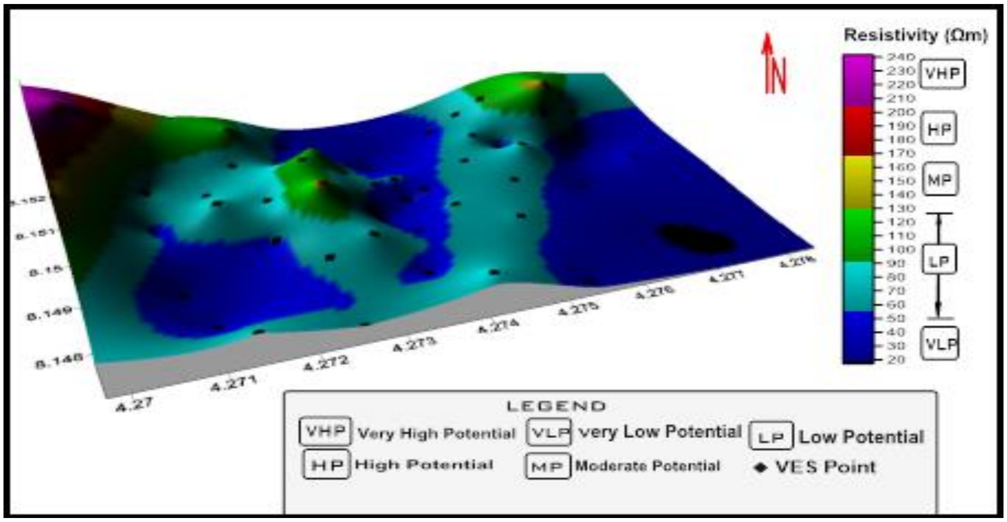


**Figure 7:** Groundwater Potential of the Study Area based on Resistivity of Aquifer Units.

**Table 3:** Parameter Threshold for Groundwater Potential Rating based on Aquifer Thickness

| Groundwater Potential Rating | Range of Aquifer Thickness (m) in the Study Area |
|---|---|
| High | >18 |
| Medium | 12-18 |
| Low | 6-12 |
| Very low | <6 |

Source: (Modified from Olorunfemi, 2008).

However, using the isoresistivity map of the weathered layer in the study area, the area can be demarcated into five different groundwater potential zones which include a very high groundwater potential (>210 Ωm), high groundwater potential (180-210 Ωm), moderate groundwater potential (130-180 Ωm), low groundwater potential (50-130 Ωm) and very low groundwater potential (<50 Ωm) zones (Table 4). The aquifer units around the study area are plastic clay/clay/sandy clay/clayey sand and sand. However, there are pockets of partly weathered and fractured basement bedrock in some places (Tables 1, 4 and Figure 7). This suggests that plastic clay/clay/sandy clay aquifer underlain better part of the study area with pockets of clayey sand and sand aquifer in few places. Clay soil is known to be porous but impermeable. Clay allows water to percolate but slow in release of such water to well. The poor yield and groundwater potential of hand dug wells and motorized boreholes experienced around the study area could be attributed to the fact that wells and boreholes are sunk within the thick stratum of plastic clay/clay/sandy clay in the area; hence, the generally poor/low groundwater potential of better part of the study area. However, few areas show high to very high groundwater potential.

**Table 4:** Parameter Threshold for Groundwater Potential Rating based on Aquifer Resistivity

| Aquifer Resistivity (Ωm) | Groundwater Potential Rating | Nature of Aquifer |
|---|---|---|
| > 210 | Very High | Sand |
| 180-210 | High | Clayey Sand |
| 130-180 | Medium | Sandy Clay |
| 50-130 | Low | Clay |
| < 50 | Very Low | Plastic Clay |

Source: Modified from Olorunfemi, (2008).

## Groundwater Flow Pattern

Figure 8 shows that the static water level in the study area vary between 318 and 362 m. It is evident from the figure that groundwater flows NE-SW from higher elevation (basement highs) T, W, X, Y and Z and empty into lower elevation basement depressions marked A, B, C, D and E. Most of the hand dug wells and motorize boreholes are suspected to sit on the low basement highs in the area.

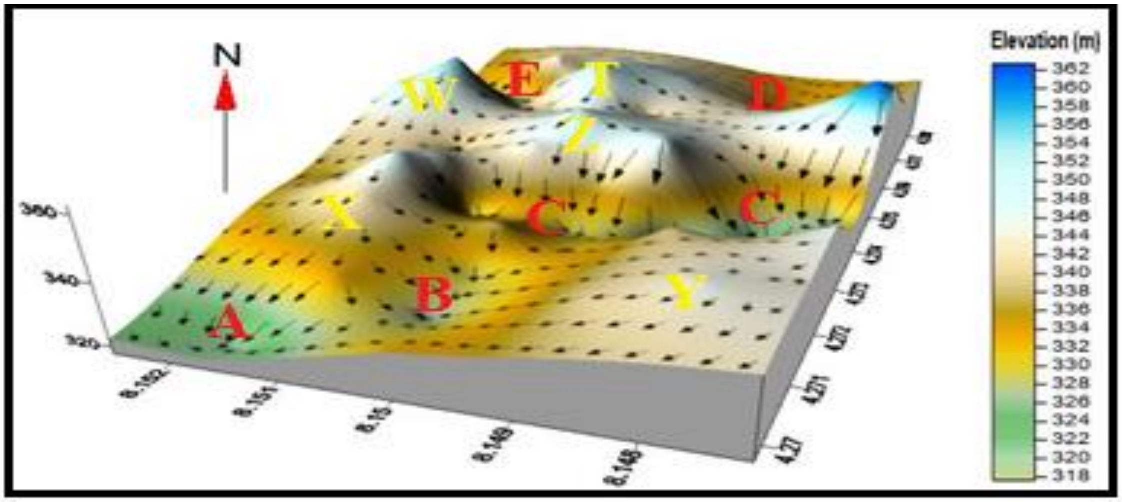


**Figure 8:** Groundwater Flow Pattern observed in the Study Area

## Conclusion

Geoelectric characterization of part of Ogbomoso, Southwestern Nigeria establishes four subsurface geoelectric layers: the topsoil, laterite, weathered bedrock (main aquifer)/partly weathered bedrock and fractured/fresh bedrock. The resistivities and thicknesses of the layers of between 76-1858, 649-2021, 17-880 and 260-33385 Ωm and 0.4-4, 0.7-1.9 and 1.9-25.2 m respectively were used to generate 2D geoelectric sections, isopach and isoresistivity maps for the area. Plastic clay/clay/sandy clay/clayey sand/ sand/laterite topsoil and plastic clay/clay/sandy clay/clayey sand/ sand weathered layer characterized the study area. The study concludes base on the findings that the area is underlay by incompetent to highly competent topsoil, weathered bedrock (main) aquifer unit and partly weathered/fractured bedrock aquifers. Generally low groundwater potential underlay better part of the study area however with high to very high groundwater potential in few places while the groundwater flow direction in the area is NE-SW. Thick stratum of plastic clay/clay/sandy clay could be responsible for the poor yield/groundwater potential of hand-dug wells and motorized boreholes experienced around the area.

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## Appendix A

**Table 1:** Summary of the Interpreted Results of the Sounding Curves.

| VES No. | VES Coordinate (Elevation) | R.M.S. Error | Geoelectric Parameters | | | | | Type Curve | Aquifer-type |
|---|---|---|---|---|---|---|---|---|---|
| | | | No of Layer | ρ (Ωm) | T (m) | D (m) | Inference | | |
| 1 | 08°09'00'' 004°16'26.7'' (349 m) | 2.4 | 1 | 97 | 0.4 | 0.4 | Topsoil | | |
| | | | 2 | 681 | 0.9 | 1.3 | Laterite | | |
| | | | 3 | 32 | 4.7 | 6.0 | Clay | KH | Weathered Aquifer |
| | | | 4 | 2403 | - | - | Fresh Bedrock | | |
| 2 | 08°09'02.5'' 004°16'24.4'' (342 m) | 2.6 | 1 | 184 | 1.4 | 1.4 | Top soil | H | |
| | | | 2 | 63 | 17.9 | 19.3 | Clay | | Weathered/Fractured Aquifer |
| | | | 3 | 479 | - | - | Fractured Bedrock | | |
| 3 | 08°09'04.9'' 004°16'22.2'' (350 m) | 3.0 | 1 | 159 | 1.3 | 1.3 | Top soil | H | |
| | | | 2 | 43 | 16.8 | 18.1 | Clay | | Weathered Aquifer |
| | | | 3 | 1499 | - | - | Fresh Bedrock | | |
| 4 | 08°09'07.1'' 004°16'20'' (340 m) | 3.3 | 1 | 1857 | 0.6 | 0.6 | Top soil | QH | |
| | | | 2 | 1629 | 1.0 | 1.6 | Laterite | | |
| | | | 3 | 114 | 15.3 | 17.0 | Clay | | Weathered Aquifer |
| | | | 4 | 4673 | - | - | Fresh Bedrock | | |
| 5 | 08°09'09.2'' 004°16'17.4'' (332 m) | 2.2 | 1 | 373 | 1.3 | 1.3 | Topsoil | HA | |
| | | | 2 | 122 | 3.6 | 4.9 | Sandy Clay | | Weathered/Partly Weathered Aquifer |
| | | | 3 | 760 | 6.5 | 11.4 | Partly Weathered Bedrock | | |
| | | | 4 | 1134 | - | - | Fresh Bedrock | | |
| 6 | 08°08'57.7'' 004°16'28.2'' | 2.5 | 1 | 93 | 0.5 | 0.5 | Topsoil | HA | Partly Weathered/Fractured Aquifer |
| | | | 2 | 63 | 3.5 | 4.0 | Clay | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | (348 m) | | 3 | 223 | 3.9 | 7.8 | Fractured Bedrock | | |
| | | | 4 | 6540 | - | - | Fresh Bedrock | | |
| 7 | 08°08’55.4’’ | 2.5 | 1 | 127 | 0.4 | 0.4 | Topsoil | KH | Weathered Aquifer |
| | 004°16’30.4’’ | | 2 | 887 | 0.3 | 0.7 | Laterite | | |
| | | | 3 | 67 | 1.4 | 2.1 | Clay | | |
| | | | 4 | 1144 | - | - | Fresh Bedrock | | |
| 8 | 08°08’58.3’’ | 2.5 | 1 | 232 | 0.6 | 0.6 | Topsoil | HA | Weathered/Partly Weathered Aquifer |
| | 004°16’35.2’’ | | 2 | 33 | 3.6 | 4.2 | Clay | | |
| | (347 m) | | 3 | 276 | 12.8 | 17 | Clayey Sand | | |
| | | | 4 | 1057 | - | - | Fresh Bedrock | | |
| 9 | 08°09’01.6’’ | 2.7 | 1 | 414 | 1.2 | 1.2 | Topsoil | H | Weathered/Partly Weathered Aquifer |
| | 004°16’33.4’’ | | 2 | 91 | 3.9 | 5.0 | Clay | | |
| | 356m | | 3 | 507 | - | - | Partly Weathered Bedrock | | |
| 10 | 08°09’04’’ | 2.5 | 1 | 363 | 2.0 | 2.0 | Topsoil | H | Weathered Aquifer |
| | 004°16’31.8’’ | | 2 | 77 | 9.9 | 11.9 | Clay | | |
| | (333 m) | | 3 | 4479 | - | - | Fresh Bedrock | | |
| 11 | 08°09’06.5’’ | 2.4 | 1 | 184 | 0.6 | 0.6 | Topsoil | KH | Weathered/ Fractured Aquifer |
| | 004°16’30.5’’ | | 2 | 675 | 0.9 | 1.5 | Laterite | | |
| | | | 3 | 43 | 10.6 | 12.1 | Clay | | |
| | (353 m) | | 4 | 260 | - | - | Fractured Bedrock | | |
| 12 | 08°09’0.2’’ | 2.3 | 1 | 126 | 0.6 | 0.6 | Topsoil | KH | Weathered Aquifer |
| | 004°16’39.2’’ | | 2 | 351 | 1.3 | 1.8 | Laterite | | |
| | | | 3 | 42 | 7.5 | 9.3 | Clay | | |
| | (343 m) | | 4 | 976 | - | - | Fresh Bedrock | | |
| 13 | 08°09’3.1’’ | 2.6 | 1 | 117 | 0.4 | 0.4 | Topsoil | KH | Weathered/Fractured Aquifer |
| | | | 2 | 649 | 0.6 | 1.0 | Laterite | | |

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|---|---|---|---|---|---|---|---|---|---|
| | 004°16’37.8’’ | | 3 | 22 | 5.3 | 6.3 | Clay | | |
| | (337 m) | | 4 | 1067 | - | - | Fresh Bedrock | | |
| 14 | 08°09’5.5’’ | 2.3 | 1 | 398 | 1.3 | 1.3 | Topsoil | H | Weathered Aquifer |
| | 004°16’36.5’’ | | 2 | 151 | 9.6 | 11.0 | Laterite | | |
| | (315 m) | | 3 | 1101 | - | - | Fresh Bedrock | | |
| 15 | 08°09’7’’ | 2.6 | 1 | 342 | 0.4 | 0.4 | Topsoil | KH | Partly Weathered/Fractured Aquifer |
| | 004°16’33.5’’ | | 2 | 1086 | 0.9 | 1.3 | Laterite | | |
| | | | 3 | 99 | 15.0 | 16.4 | Clay | | |
| | (334 m) | | 4 | 2051 | - | - | Fresh Bedrock | | |
| 16 | 08°08’52.9’’ | 2.4 | 1 | 267 | 1.8 | 1.8 | Topsoil | HA | Weathered/Partly Weathered Aquifer |
| | 004°16’25’’ | | 2 | 42 | 2.7 | 4.5 | Clay | | |
| | (399 m) | | 3 | 636 | 5.5 | 10.1 | Clayey Sand | | |
| | | | 4 | 2336 | - | - | Fresh Bedrock | | |
| 17 | 08°08’55.5’’ | 2.9 | 1 | 86 | 0.5 | 0.5 | Topsoil | H | Weathered/Partly Weathered Aquifer |
| | 004°16’23.5’’ | | 2 | 87 | 4.6 | 5.1 | Clay | | |
| | (320 m) | | 3 | 439 | - | - | Partly Weathered Bedrock | | |
| 18 | 08°08’58.8’’ | 2.4 | 1 | 450 | 1.0 | 1.0 | Topsoil | H | Weathered/Partly Weathered Aquifer |
| | 004°16’22.3’’ | | 2 | 142 | 9.7 | 10.7 | Sandy Clay | | |
| | (328 m) | | 3 | 416 | - | - | Partly Weathered Bedrock | | |
| 19 | 08°09’00.4’’ | 2.5 | 1 | 148 | 1.4 | 1.4 | Topsoil | H | Weathered/Partly Weathered Aquifer |
| | 004°16’20.1’’ | | 2 | 74 | 15.9 | 17.2 | Clay | | |
| | (338 m) | | 3 | 522 | - | - | Partly Weathered Bedrock | | |
| 20 | 08°09’02.4’’ | 3.9 | 1 | 380 | 0.4 | 0.4 | Topsoil | QH | Weathered/Partly Weathered Aquifer |
| | | | 2 | 136 | 1.4 | 1.8 | Laterite | | |

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|---|---|---|---|---|---|---|---|---|---|
| | 004°16'17.7'' | | 3 | 65 | 5.7 | 7.5 | Clay | | |
| | (340 m) | | 4 | 522 | - | - | Partly Weathered Bedrock | | |
| 21 | 08°09'03.7'' | 2.7 | 1 | 294 | 1.0 | 1.0 | Topsoil | H | Weathered /Fractured Aquifer |
| | 004°16'15.1'' | | 2 | 61 | 3.8 | 4.9 | Clay | | |
| | (334 m) | | 3 | 396 | - | - | Fractured Bedrock | | |
| 22 | 08°09'05.7'' | 2.1 | 1 | 1419 | 0.6 | 0.6 | Topsoil | H | Weathered Aquifer |
| | 004°16'12.5'' | | 2 | 240 | 17.2 | 17.8 | Sandy Clay | | |
| | (320 m) | | 3 | 1580 | - | - | Fresh Bedrock | | |
| 23 | 08°08'49.9'' | 1.4 | 1 | 467 | 0.4 | 0.4 | Topsoil | KH | Weathered/Partly Weathered Aquifer |
| | 004°16'13'' | | 2 | 880 | 1.5 | 1.9 | Laterite | | |
| | (344 m) | | 3 | 85 | 8.6 | 10.5 | Clay | | |
| | | | 4 | 489 | - | - | Partly Weathered Bedrock | | |
| 24 | 08°08'52.6'' | 2.4 | 1 | 243 | 1.0 | 1.0 | Topsoil | H | Weathered Aquifer |
| | 004°16'15.9'' | | 2 | 23 | 10.6 | 11.6 | Clay | | |
| | (345 m) | | 3 | 1492 | - | - | Fresh Bedrock | | |
| 25 | 08°08'55.5'' | 2.4 | 1 | 281 | 1.2 | 1.2 | Topsoil | H | Weathered Aquifer |
| | 004°16'15.1'' | | 2 | 22 | 4.5 | 5.7 | Clay | | |
| | (340 m) | | 3 | 375 | - | - | Fractured Bedrock | | |
| 26 | 08°09'58.6'' | 0.1 | 1 | 1196 | 1.3 | 1.3 | Topsoil | H | Weathered Aquifer |
| | 004°16'14'' | | 2 | 51 | 2.6 | 4.0 | Clay | | |
| | (335 m) | | 3 | 732 | - | - | Fresh Bedrock | | |
| 27 | 08°9'0.0'' | 2.3 | 1 | 631 | 0.9 | 0.9 | Topsoil | H | Weathered Aquifer |
| | 004°16'11.1'' | | 2 | 261 | 2.5 | 3.4 | Laterite | | |
| | (333 m) | | 3 | 2583 | 7.6 | 11 | Fresh Bedrock | | |
| 28 | 08°09'00.4'' | 2.5 | 1 | 560 | 0.6 | 0.6 | Topsoil | KH | Weathered Aquifer |

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|---|---|---|---|---|---|---|---|---|---|
| | 004°16’14.8’’ | | 2 | 1151 | 0.4 | 1.1 | Laterite | | |
| | | | 3 | 48 | 3.8 | 4.8 | Clay | | |
| | (326 m) | | 4 | 1146 | - | - | Fresh Bedrock | | |
| 29 | 08°09’04.8’’ | 1.9 | 1 | 313 | 1.1 | 1.1 | Topsoil | H | Weathered/Partly Weathered Aquifer |
| | 004°16’19.5’’ | | 2 | 71 | 10.1 | 11.2 | Clay | | |
| | (343 m) | | 3 | 504 | - | - | Partly Weathered Bedrock | | |
| 30 | 08°09’07.6’’ | 3.5 | 1 | 874 | 1.3 | 1.3 | Topsoil | H | Weathered Aquifer |
| | 004°16’22.8’’ | | 2 | 38 | 5.2 | 6.5 | Clay | | |
| | (336 m) | | 3 | 4167 | - | - | Fresh Bedrock | | |
| 31 | 08°09’02.8’’ | 2.5 | 1 | 481 | 1.3 | 1.3 | Topsoil | H | Weathered Aquifer |
| | 004°16’22.4’’ | | 2 | 112 | 23.9 | 25.2 | Sandy Clay | | |
| | (329 m) | | 3 | 1565 | - | - | Fresh Bedrock | | |
| 32 | 08°09’04.4’’ | 2.6 | 1 | 354 | 0.8 | 0.8 | Topsoil | QH | Weathered Aquifer |
| | 004°16’26.2’’ | | 2 | 129 | 2.0 | 2.8 | Laterite | | |
| | | | 3 | 17 | 5.8 | 8.5 | Clay | | |
| | (338 m) | | 4 | 627 | - | - | Fresh Bedrock | | |
| 33 | 08°09’07’’ | 1.0 | 1 | 409 | 1.2 | 1.2 | Topsoil | H | Weathered Aquifer |
| | 004°16.32.1’’ | | 2 | 68 | 9.8 | 11.0 | Clay | | |
| | (357 m) | | 3 | 1161 | - | - | Fresh Bedrock | | |
| 34 | 08°08’58.7’’ | 2.4 | 1 | 176 | 1.4 | 1.4 | Topsoil | H | Weathered Aquifer |
| | 004°16’25’’ | | 2 | 20 | 2.9 | 4.3 | Clay | | |
| | (338 m) | | 3 | 2394 | - | - | Fresh Bedrock | | |
| 35 | 08°09’0.3’’ | 2.4 | 1 | 147 | 0.7 | 0.7 | Topsoil | HA | Weathered/Partly Weathered Aquifer |
| | 004°16’27.7’’ | | 2 | 47 | 4.8 | 5.4 | Clay | | |
| | (354 m) | | 3 | 880 | 2.1 | 7.5 | Partly Weathered Bedrock | | |

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|---|---|---|---|---|---|---|---|---|---|
| | | | 4 | 1371 | - | - | Fresh Bedrock | | |
| 36 | 08°09’01.8’’ | 2.5 | 1 | 284 | 0.9 | 0.9 | Topsoil | HA | Partly Weathered/Fractured Aquifer |
| | 004°16’30.4’’ | | 2 | 63 | 8.9 | 9.8 | Clay | | |
| | (344 m) | | 3 | 249 | 8.0 | 17.1 | Fractured Bedrock | | |
| | | | 4 | 3490 | - | - | Fresh Bedrock | | |
| 37 | 08°09’03.2’’ | 2.9 | 1 | 395 | 0.4 | 0.4 | Topsoil | KH | Fractured Bedrock Aquifer |
| | 004°16’33.0’’ | | 2 | 2021 | 0.7 | 1.1 | Fresh Bedrock | | |
| | (343 m) | | 3 | 42 | 3.5 | 4.6 | Fractured Bedrock | | |
| | | | 4 | 958 | - | - | Fresh Bedrock | | |
| 38 | 08°09’04.1’’ | 2.3 | 1 | 726 | 0.7 | 0.7 | Topsoil | KH | Weathered/Partly Weathered Aquifer |
| | 004°16’36.0’’ | | 2 | 732 | 0.5 | 1.2 | Laterite | | |
| | | | 3 | 93 | 1.5 | 2.7 | Clay | | |
| | (357 m) | | 4 | 497 | - | - | Partly Weathered Bedrock | | |
| 39 | 08°09’5.2’’ | 2.0 | 1 | 1174 | 1.1 | 1.1 | Topsoil | HA | Partly Weathered/Fractured Aquifer |
| | 004°16’38.2’’ | | 2 | 62 | 4.3 | 5.4 | Clay | | |
| | (345 m) | | 3 | 318 | 5.7 | 11.1 | Partly Weathered Bedrock | | |
| | | | 4 | 2116 | - | - | Fresh Bedrock | | |
| 40 | 08°09’01.8’’ | 1.6 | 1 | 362 | 1.1 | 1.1 | Topsoil | H | Weathered Aquifer |
| | 004°16’36.5’’ | | 2 | 19 | 3.5 | 4.6 | Clay | | |
| | (350 m) | | 3 | 2170 | - | - | Fresh Bedrock | | |
| 41 | 08°08’59.0’’ | 2.5 | 1 | 74 | 0.4 | 0.4 | Topsoil | KH | Weathered Aquifer |
| | 004°16’31.8’’ | | 2 | 732 | 0.8 | 1.2 | Laterite | | |
| | | | 3 | 62 | 4.9 | 6.1 | Clay | | |
| | (341 m) | | 4 | 3947 | - | - | Fresh | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Bedrock | | |
| 42 | 08°08’56.5’’ | 2.8 | 1 | 76 | 0.6 | 0.6 | Topsoil | HA | Weathered/Partly Weathered Aquifer |
| | 004°16’25.9’’ | | 2 | 45 | 1.4 | 2.0 | Clay | | |
| | (351 m) | | 3 | 126 | 6.3 | 8.2 | Partly Weathered Bedrock | | |
| | | | 4 | 1367 | - | - | Fresh Bedrock | | |
| 43 | 08°08’54.9’’ | 2.7 | 1 | 340 | 1.3 | 1.3 | Topsoil | H | Weathered Aquifer |
| | 004°16’21.3’’ | | 2 | 65 | 6.2 | 7.5 | Clay | | |
| | (339 m) | | 3 | 2104 | - | - | Fresh Bedrock | | |
| 44 | 08°08’57.6’’ | 3.5 | 1 | 262 | 0.8 | 0.8 | Topsoil | QH | Weathered/Fractured Aquifer |
| | 004°16’19.7’’ | | 2 | 185 | 4.3 | 5.1 | Laterite | | |
| | | | 3 | 49 | 12.8 | 17.9 | Clay | | |
| | (332 m) | | 4 | 375 | - | - | Fractured Bedrock | | |
| 45 | 08°09’0.3’’ | 3.6 | 1 | 546 | 0.6 | 0.6 | Topsoil | H | Weathered Aquifer |
| | 004°16’17.8’’ | | 2 | 97 | 20.3 | 20.9 | Clay | | |
| | (329 m) | | 3 | 694 | - | - | Fresh Bedrock | | |
| 46 | 08°08’56.7’’ | 3.2 | 1 | 270 | 2.3 | 2.3 | Topsoil | H | Weathered/Partly Weathered Aquifer |
| | 004°16’42.3’’ | | 2 | 30 | 9.4 | 11.8 | Clay | | |
| | (335 m) | | 3 | 460 | - | - | Partly Weathered Bedrock | | |
| 47 | 08°08’53.5’’ | 2.5 | 1 | 413 | 0.9 | 0.9 | Topsoil | H | Weathered/Fractured Aquifer |
| | 004°16’36.7’’ | | 2 | 17 | 3.2 | 4.1 | Clay | | |
| | (330 m) | | 3 | 160 | - | - | Fractured Bedrock | | |
| 48 | 08°08’50.3’’ | 3.7 | 1 | 97 | 0.6 | 0.6 | Topsoil | KH | Weathered/Fractured Aquifer |
| | 004°16’26.8’’ | | 2 | 249 | 0.6 | 1.2 | Laterite | | |
| | | | 3 | 30 | 0.7 | 1.9 | Clay | | |
| | (327 m) | | 4 | 196 | - | | Fractured Bedrock | | |
| 49 | 08°08’50.5’’ | 2.7 | 1 | 408 | 2.2 | 2.2 | Topsoil | H | Weathered Aquifer |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 004°16’26.8’’ | | 2 | 93 | 3.2 | 5.4 | Clay | | |
| | (327 m) | | 3 | 33385 | - | - | Fresh Bedrock | | |
| 50 | 08°08’49.0’’ | 2.8 | 1 | 142 | 0.6 | 0.6 | Topsoil | KH | Weathered Aquifer |
| | 004°16’21.1’’ | | 2 | 365 | 1.0 | 1.6 | Laterite | | |
| | | | 3 | 55 | 10.8 | 12.4 | Clay | | |
| | (347 m) | | 4 | 1509 | - | - | Fresh Bedrock | | |
| 51 | 08°09’1.25’’ | 2.5 | 1 | 166 | 1.7 | 1.7 | Topsoil | HA | Partly Weathered/Fractured Aquifer |
| | 004°16’25.6’’ | | 2 | 38 | 2.9 | 4.6 | Clay | | |
| | (346 m) | | 3 | 70 | 22.2 | 26.8 | Fractured Bedrock | | |
| | | | 4 | 2879 | - | - | Fresh Bedrock | | |
| 52 | 08°09’03.7’’ | 3.3 | 1 | 401 | 0.8 | 0.8 | Topsoil | H | Weathered Aquifer |
| | 004°16’23.3’’ | | 2 | 114 | 18.6 | 19.4 | Sandy Clay | | |
| | (346 m) | | 3 | 802 | - | - | Fresh Bedrock | | |
| 53 | 08°09’32.6’’ | 2.2 | 1 | 201 | 4.0 | 4.0 | Topsoil | H | Weathered Aquifer |
| | 004°16’20.1’’ | | 2 | 46 | 10.1 | 14.1 | Clay | | |
| | (335 m) | | 3 | 933 | - | - | Fresh Bedrock | | |
| 54 | 08°08’59.4’’ | 1.8 | 1 | 152 | 1.1 | 1.1 | Topsoil | H | Weathered Aquifer |
| | 004°16’22.3’’ | | 2 | 59 | 6.1 | 7.3 | Clay | | |
| | (339 m) | | 3 | 1281 | - | - | Fresh Bedrock | | |