GROUNDWATER POTENTIAL AND VULNERABILITY STUDIES OF PARTS OF AGO IWOYE, SOUTHWESTERN NIGERIA USING ELECTRICAL RESISTIVITY METHOD

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ABSTRACT

Groundwater resources exploration within the Olabisi Onabanjo University campus, Ago–Iwoye was done with the aim of determining groundwater potential zones and the vulnerability of the aquifer in the area. Forty-one (41) Vertical Electrical Sounding (VES) were established using the Schlumberger array configuration with current electrode spacing varying from 1-100 m. The interpretation was done using partial curve matching and computer iteration technique with the aid of WinResist 1.0TM software programme. Parameters such as overburden thickness, basement resistivity, reflection coefficient and longitudinal conductance were derived. The geoelectric interpretation revealed that the area is underlain by three basic lithological layer grouping; topsoil (14 Ωm–316.2 Ωm), weathered layer (28 Ωm–302 Ωm) and basement rock (245 Ωm–986 Ωm). The resistivity curve types obtained were H and HK with percentage of 90%, and 10% respectively. The overburden thicknesses range between 5m–25m and reflection coefficient between 0.70–0.90. Groundwater potential of the area revealed that the eastern part was low, the western part was moderate while the central part showed high groundwater potential. The longitudinal conductance values range from 0.08–0.43 indicating weak to moderate protective capacity which suggest high vulnerability rate of groundwater in the study area.

Keywords: Contamination, Electrical Resistivity, Groundwater Potential, Vulnerability
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INTRODUCTION

The consideration of the various sources of water has revealed the qualitative advantage of groundwater over surface water because of the deeper aquiferous layer occurrence of the groundwater which makes the earth layer a protective material or filter against easy exposure to contamination process from human activities thereby making it an important renewable resource. For this reason, the importance of groundwater has been well known to be useful for several domestic and industrial activities. An essential component of groundwater development which has been a major concern is the identification of potential areas or regions mostly in areas where its demand is at a great rate or region where aquifer geometry doesn't follow a regular geological framework [1].

Generally, the hydrogeophysical aspect of geoscience has considered the geology of an area as one of the key factors which determines groundwater occurrences. Crystalline geological environment underlain with hard rocks reveal that groundwater is present within the basement rock underlying the regolith/unconsolidated materials known as overburden [2]. However, this does not follow a regular pattern because of the discontinuous geometrical nature of basement aquifers in the crystalline region [3] in which the nature of the basement rock can either be fractured or non-fractured. The consideration of previous research has clearly shown that the fractured basement rock has the harbor of considerable amount of groundwater in crystalline regions of the world.

Various reports on groundwater contamination showed that it is as a result of activities of human negligence which led to the discharge of contaminant into the earth surface that later percolate through the overburden layer to the aquiferous region [4]. This has therefore revealed that the successful development of groundwater does not only stop at its exploration, but also entails the understanding of the nature of overburden materials, which are essential determinants of the safety of the subsurface aquiferous layer from contaminant. This phenomenon is achievable by considering some geophysical indices which pronounced the protective capacity of the aquifer. In addition, groundwater is usually protected from pollution by natural barriers such as clayey layers, but in areas with thin weathered layers and where aquifers are in hydraulic continuity with the subsurface, groundwater might be at risk of pollution from surface sources [5].

The advancement in scientific development in aspect of research has provided several exploration methods ranging from remote sensing and electrical resistivity method for delineation of groundwater presence in many geological regions. The electrical method has been considered as one of the crucial non-invasive geophysical prospecting methods for the determination of the subsurface geology of an area; it has been used notably for the determination of the aquifer potential in the drilling of boreholes [6, 7]. The VES technique among different others is capable of delineating the depth to potential aquifer, depth to bedrock and it is cost effective [8, 9]. Vertical Electrical Sounding measures the physical property of rocks and soils which might be affected by the presence of water [10].

A hydro-geophysical assessment for groundwater is needed to decide the characteristics of the basement aquifer system, subsurface geology, weathering intensity, and structural disposition for the purpose of determining beneficial points or regions of groundwater accumulation as well as aquifer protective capacity of the overburden units in relation to its vulnerability around the main campus of Olabisi Onabanjo University for the purpose of water development.

Location and geology of the study area

The research location is the undeveloped section of Olabisi Onabanjo University campus, Ago-Iwoye, south-western, Nigeria, which lies between latitude of 6°55'25" to 6°56'0"N and longitude 3°52'0" to 3°52'38"E, covering an area of 1.26 square kilometer. Accessing the developed part of the school is via minor road while the undeveloped area where buildings are not sited is accessible by footpaths (Figure 1). Geographically, it lies in the tropical rain forest region of south western Nigeria, characterized by high evapo-transpiration and high relative humidity. This characteristic of the climatic condition resulted into the classification of the area into two basic seasons which include the dry and wet seasons which are experienced between September to October and November to March period of the year respectively. Record showed variation in temperature with season to range from 23°C to 25°C during the wet season and 23°C to 30°C in the dry season [11]. Water bodies flow configuration in the regional geography shows the study area exhibit a dendritic drainage pattern with presence of River Ome occurring as the major river, but only its tributaries is present in the study area.

Geologically, the study area falls within the crystalline basement complex of Southwestern Nigeria with a local geology of predominantly various grades and suites of gneisses (Figure 2) which include; Granite, porphyroblastic gneisses, Biotite gneisses, granite gneisses, and banded gneisses [12].

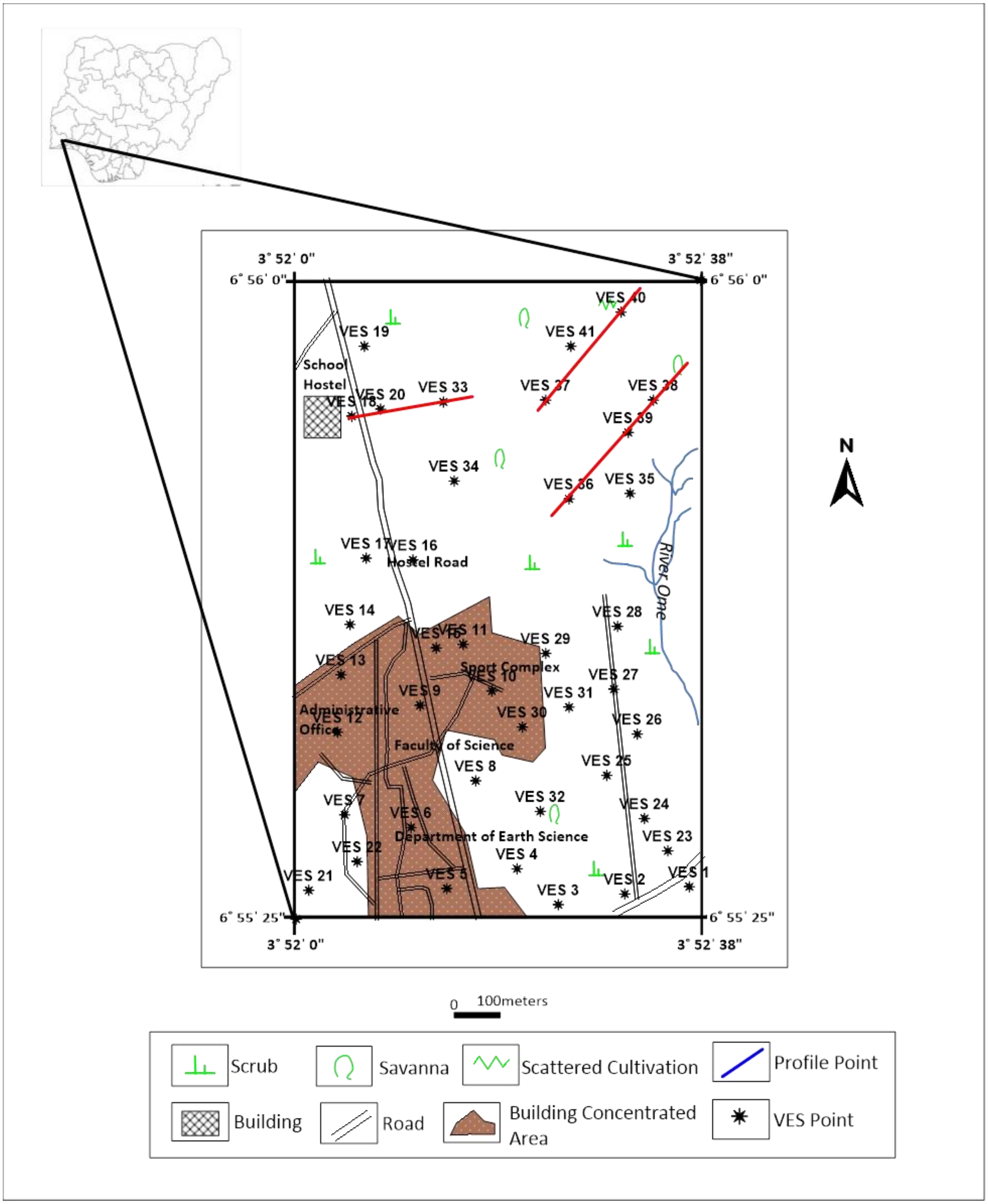

Figure 1: The location map showing developed and under developed regions of the study location.

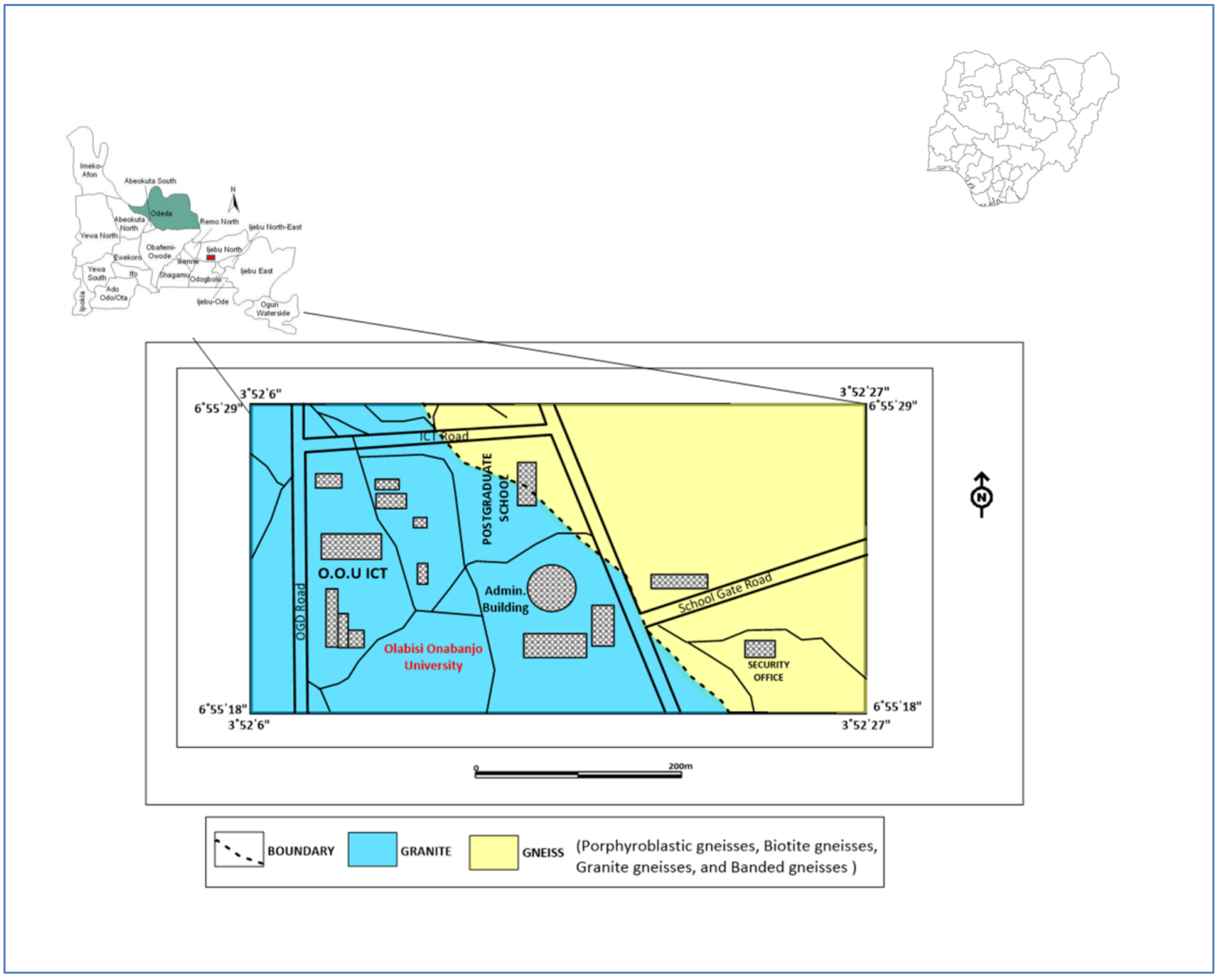

Figure 2: The location and geological map of the study location with insert map of Nigeria and Ogun State **(**after [13])

MATERIALS AND METHODS

The electrical resistivity method was employed during the course of this study using the ALLIED OHMEGA resistivity meter to establish a total of forty-one (41) VES points in the study area in order to determine the resistivity variation of the subsurface regolith and rock in with respect to depth. The field procedure entailed maximum current electrode spacing (AB/2) range of 1-100m with the potentia electrode (MN) place between the far-end current electrode (AB) as illustrated in Figure 3. The resistace value was recorded for several current electrode position for the estabished points in the study area. The obtained resistance values from the instrument was multiplied with the electrode array geometric factor (G.F) using the formula of [14] to obtain the apparent resistivity value (equation i). Further interpretation entailed the plotting of the apparent resistivity values against the current electrode spacing on a bi-log paper where a standardized model curve was correlated with the fied curve through the process of partial curve matching [15, 16, 17] to determine the geoelectric parameters. Computer iteration on the derived geoelectric parameters (layer resistivity, thickness and depth) was done using the WinResist 1.0TM software of [18] to obtained migrated models of the geoelectric parameters.

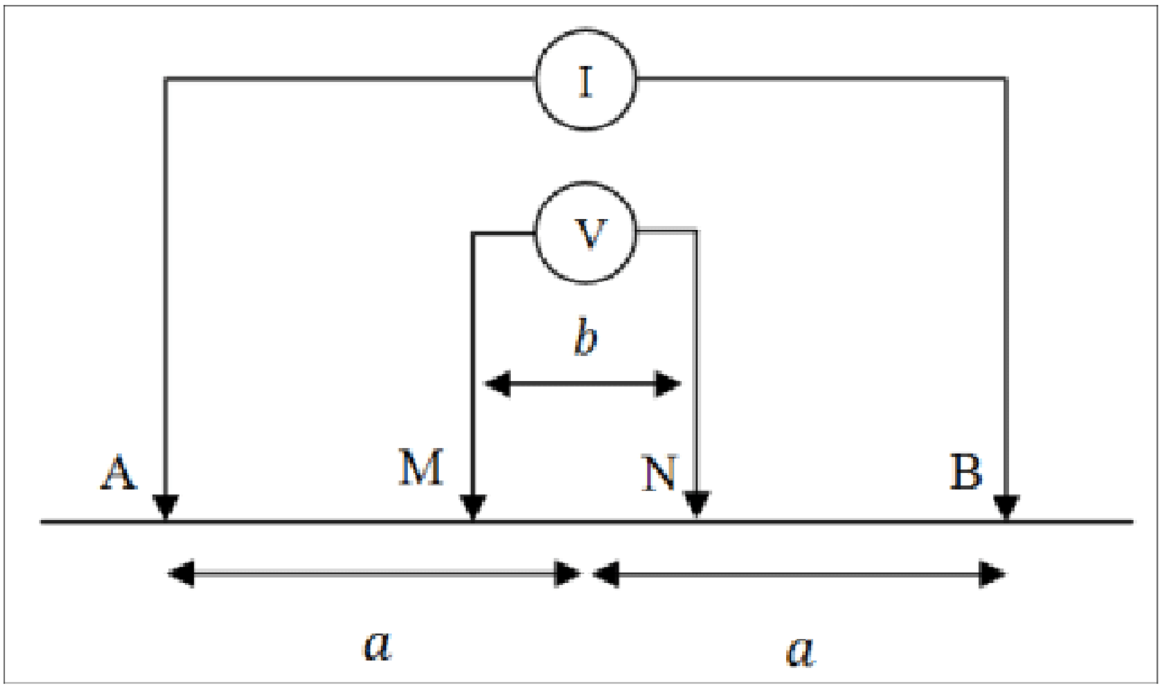

Figure 3: Field diagrammatic illustration of Schlumberger array configuration.

Apparent Resistivity $(\rho a) = \left(\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right) \times \pi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (i)$

(Pa=resistivity (Ωm), AB = current electrode spacing (m), MN = potential electrode spacing (m), π =3.142)

The reflection coefficients (r) of the study area was calculated using the method of [18], [19] and [20] (equation ii).

Reflection Coefficients (r)=$\frac{(\rho n - \rho(n-1))}{(\rho n + \rho(n-1))} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (ii)$

Where ρ_n is the layer resistivity of the nth layer, ρ(n-1) is the layer resistivity overlying the nth layer.

Longitudinal Conductance (S) according to [21] showed that the protective degree of an aquifer may be expressed directly proportional to the ratio between the thickness and resistivity (equation iii). It thus enables the estimation of protection of groundwater from contaminants [5, 22, 23].

Longitudinal Conductance (S) = $\frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \ldots\ldots . + \frac{h_n}{\rho_n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (iii)$

Where h_1, h_2, h_3 and h_n are layer thicknesses (m) and ρ_1, ρ_2, ρ_3 and ρ_n are layer resistivity (Ωm).

Using [23] and [5] classification, the longitudinal conductance over the study area was divided into good, moderate, weak, and poor protective capacity correlating with low, medium, high and very high vulnerability respectively.

RESULTS AND DISCUSSION

The interpretation of forty-one (41) VES conducted in the study area delineated 3-4 lithologies as H (90%) and KH (10%) geophysical curve types (Figure 4). The subsurface layers within the study area include; topsoil, weathered layer (Clay, Sandy Clay, Sand) and Basement rock which could be either fresh or fractured, and have a corresponding resistivity value range of 14 Ωm–316 Ωm, 28 Ωm–302 Ωm, 245 Ωm–986 Ωm respectively with a thickness value range of 0.9-2.8 m, 2.6-20.4 m, 4.5 m, 2.0-3.8 m and thickness of the basement couldn't be determined. The vertical variation of the subsurface lithological layer was presented in form of a geoelectric section image along traverse direction indicating the resistivity, depth and thickness of the identified and inferred geological layers. VES 36, VES 38, and VES 39 traversing from NE-SW direction make up the produce the geoelectric section. The topsoil layer has a resistivity value range of 123.7 Ωm–178.0 Ωm inferred as sandy clayey topsoil with a thickness of 1.1-1.2m. The second layer is a weathered layer with resistivity ranging from 40 Ωm–50 Ωm and has a thickness of 2.6-8.3 m. The fresh basement resistivity values range from 363 Ωm–554 Ωm with no presence of fracture observed. The thickest overburden of 6.6 m along Traverse 1 occurs at VES 39 showing that the overburden is generally shallow (Figure 5). Three (3) vertical electrical sounding points VES 37, VES 40, and VES 41 traversing from NE-SW direction formed Traverse 2 and revealed that the topsoil layer has a resistivity value range of 126.4 Ωm–138.6 Ωm with an approximate thickness value of 1.1-2.4 m. The weathered maximum overburden thickness of 9 m occurs at VES 37. Traversing from E-W direction is VES 18, VES 20, and VES 33 which formed Traverse 3 (Figure 6). The layer showed resistivity value range from 33 Ωm–39 Ωm and have thickness range of 2-8 m. The Fresh basement resistivity ranges from 453 Ωm–601Ω m. topsoil layer has a resistivity value range of 108Ωm–156Ωm and reveal a thickness value of 1.4-3.1m, the weathered layer resistivity value range from 28.0 Ωm–74.8 Ωm with thickness of 6.9-16.7 m while the basement rock resistivity values range from 255.8 Ωm–597.4 Ωm with overburden thickness of 11.7 m at VES 18 (Figure 7). The general consideration of the overburden thickness showed the fresh bedrock is generally close to the surface at depth of 3.0-20 m.

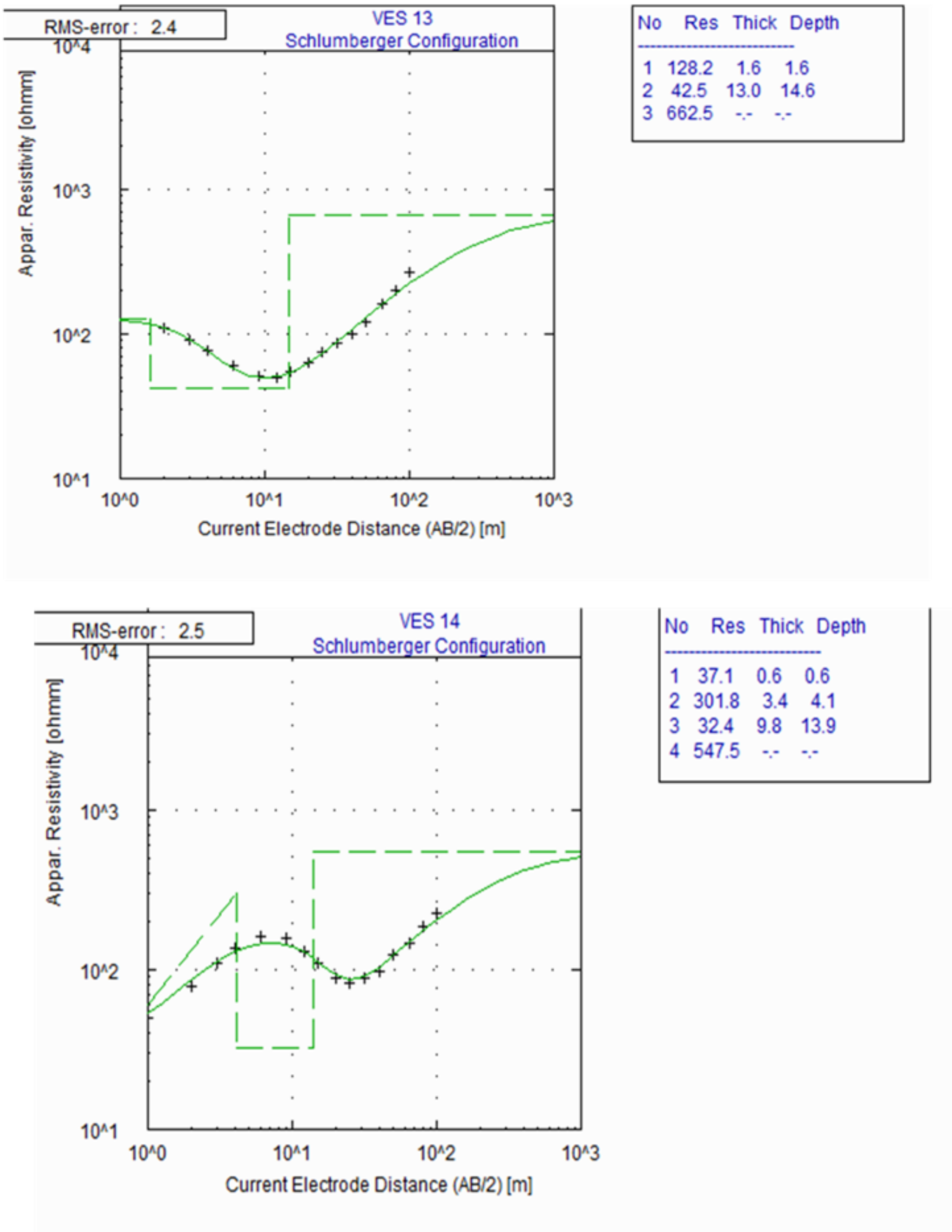

Figure 4: Iterated geophysical curve of VES 13 and VES 14 which are typical H and HK curve respectively.

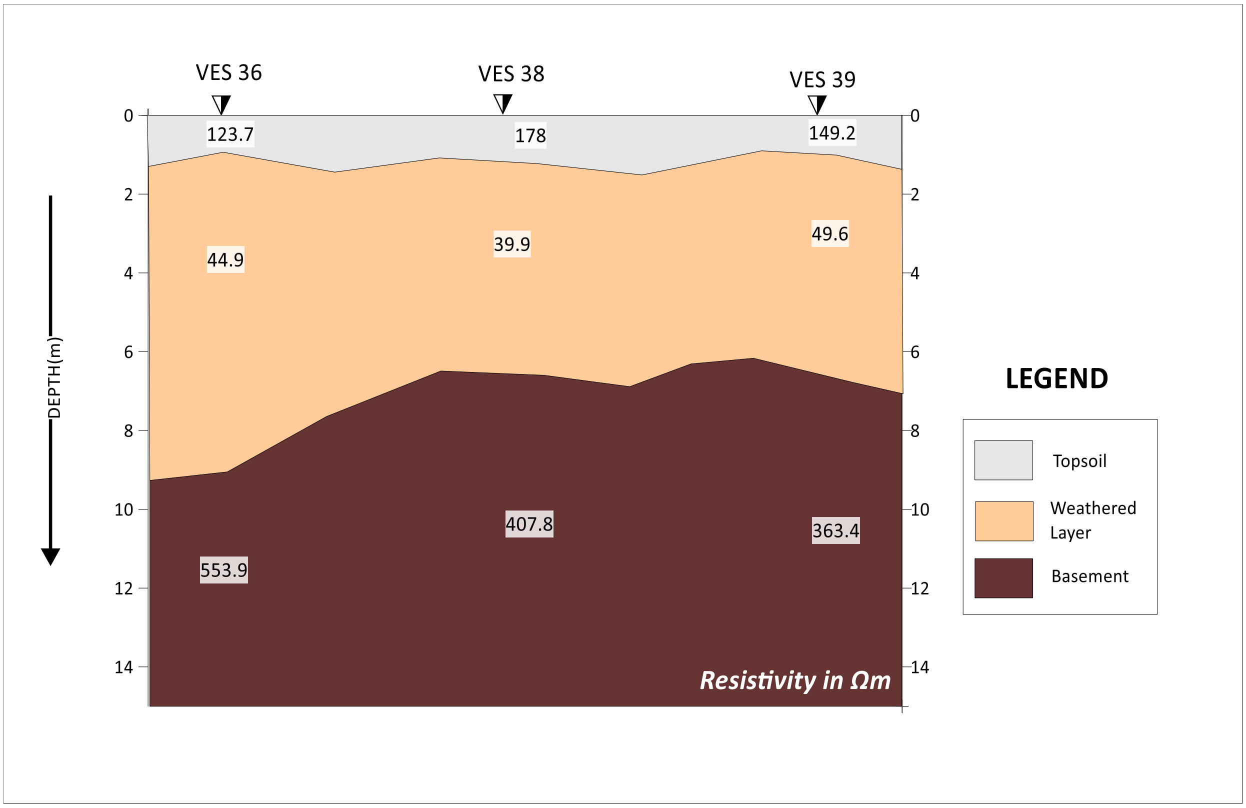

Figure 5: Geo-electric Section of Traverse 1.

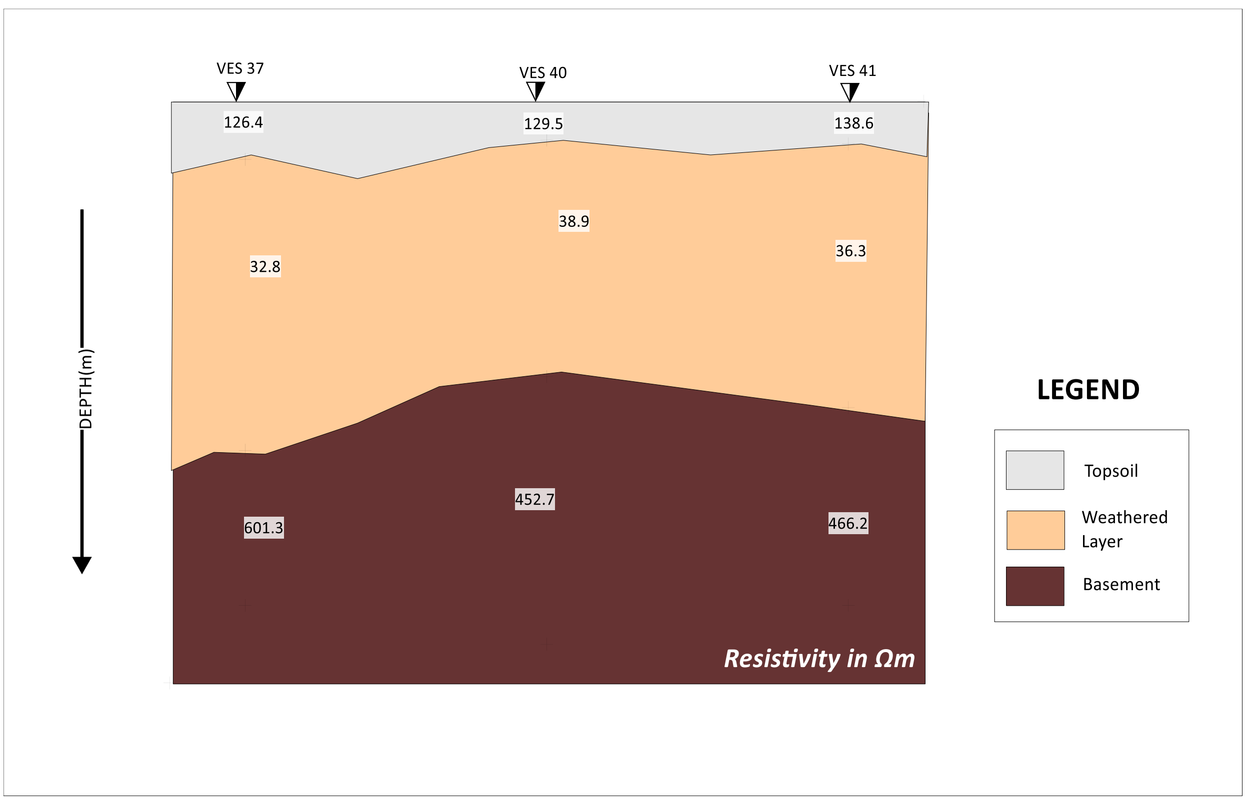

Figure 6: Geo-electric Section of Traverse 2.

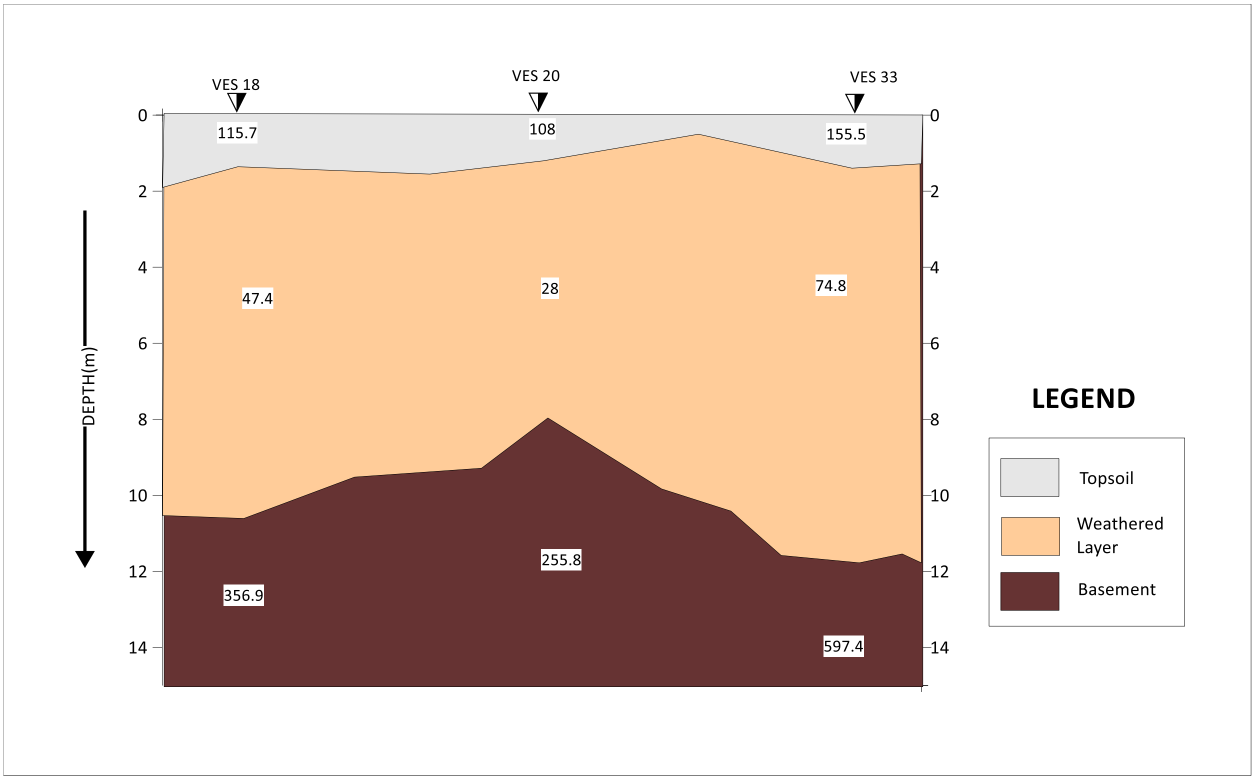

Figure 7: Geo-electric Section of Traverse 3.

Table 1: Groundwater potential parameter.

VES Point	Reflection coefficient	Basement resistivity value (Ωm)	Overburden thickness (m)	Groundwater potential
VES 1	0.78	580.1	9.5	Low Yield
VES 2	0.89	637.7	11	Low Yield
VES 3	0.77	309.5	9.8	Low Yield
VES 4	0.82	430	9.2	Low Yield
VES 5	0.81	456	8.1	Low Yield
VES 6	0.91	986.2	8.3	Low Yield
VES 7	0.81	522.5	5	Low Yield
VES 8	0.87	663	17.5	High yield
VES 9	0.86	666.2	6.9	Low Yield
VES 10	0.71	302	24.8	High yield
VES 11	0.83	942	15.4	High yield
VES 12	0.83	509.6	9.7	Low Yield
VES 13	0.88	662.5	14.6	Medium yield
VES 14	0.89	547.5	13.9	Medium yield
VES 15	0.9	520.5	9	Low Yield
VES 16	0.89	801.9	6.4	Low Yield
VES 17	0.75	333.4	9.9	Low Yield

Geoelectric parameters

Important geoelectric parameters; overburden thickness, basement resistivity and reflection coefficient used in the study of the groundwater potential is presented in Table 1. "The presence of fracture in the basement terrain does not depend solely on the absolute resistivity values of the basement but depend on its reflection coefficient values, which considers the resistivity of the overlying layer to measure the competence of the rock. An area of lower reflection coefficient value (<0.8) exhibits weathered or fractured basement rock thus, favors a high-water potential [17]". Therefore, areas with relatively lower reflection coefficient (i.e. <0.8) represents areas where the bedrock is fractured or intensely weathered. Also, the overburden thickness of a vertical electrical probe point has also served as a clue to determine groundwater potential. The calculated reflection coefficient value within the study location reveals a value range of 0.70–0.90. The 2D map showing its spatial variation in the study location (Figure 8) reveal the reflection coefficient is high in most part of the study location except at the northwestern and southeastern part of the study location.

The overburden thickness of the study location reveals a wide range of value between 5.0 m–24.8 m indicating a shallow to moderate overburden thickness. The 2D map showing its spatial variation in the study location (Figure 9) reveal the overburden thickness is high in the southern and southeastern part of the study location but decreases towards the northern, western and eastern part of the study area. The basement resistivity values in the study area range between 244.0 Ωm–986.2 Ωm. The 2D map showing its spatial variation in the study location (Figure 10) reveal the basement resistivity is high in most region of the study location except the southeastern and northwestern part of the study area indicating more of fresh basement rock while the low resistivity is experienced in the southeastern part indicating weathered basement rock. The three geoelectric parameters considered (overburden thickness, basement resistivity and reflection coefficient) were stacked together in order to provide a better view of the parameters and to observe its geospatial variation in the study area (Figure 11).

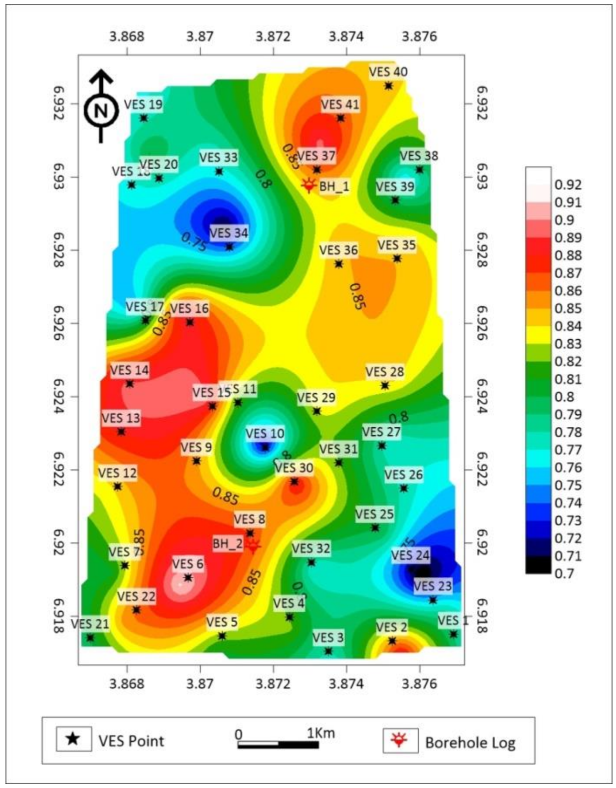

Figure 8: 2D Geospatial map of reflection coefficient.

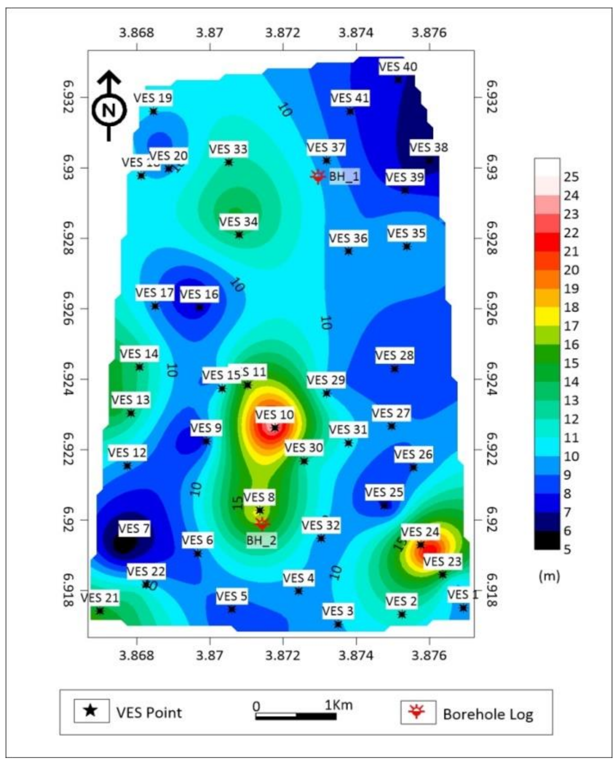

Figure 9: 2D Geospatial map of overburden thickness.

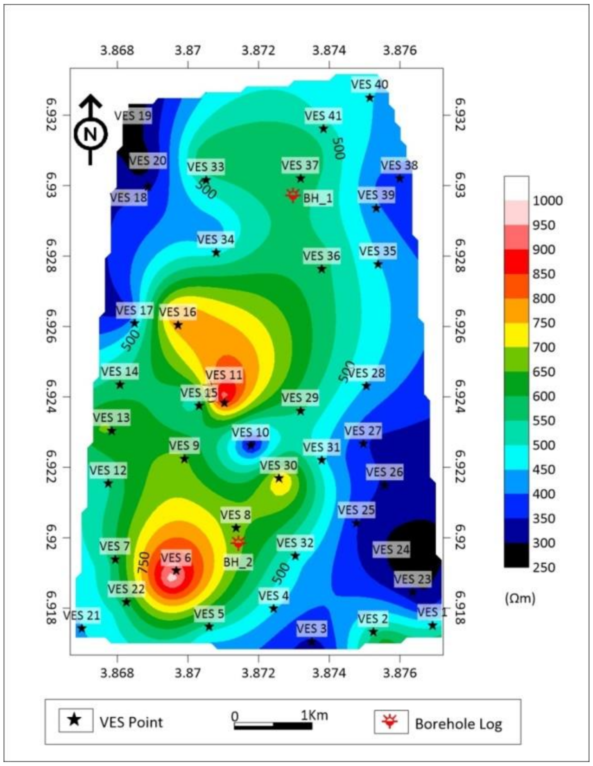

Figure 10: 2D Geospatial map of basement resistivity.

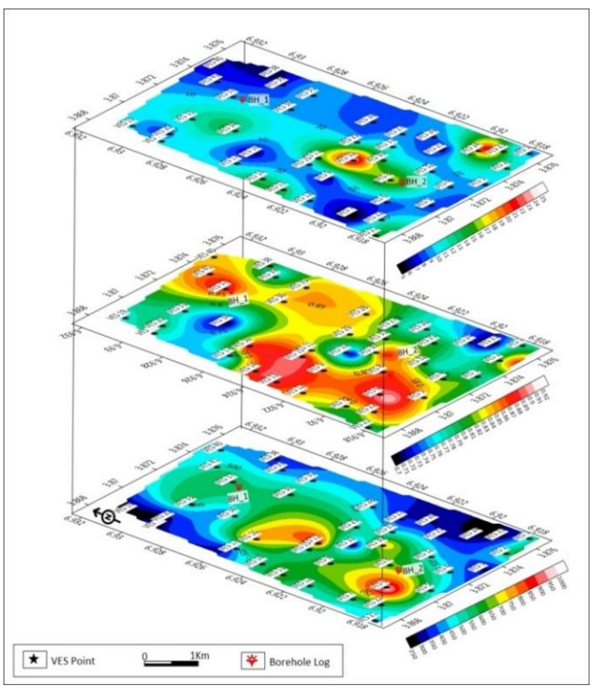

Figure 11: Stacked map of overburden thickness, basement resistivity and reflection coefficient in the study area.

Lithological Log information

Lithological log information of two boreholes was obtained from the recently drilled boreholes in the university environment through Ogun State Ministry of Water Resources. The first borehole (BH_1) falls within the northeastern part of the study area, the lithological measurement from the logging process indicated overburden thickness of 9m. The topsoil regolith is composed of sandy clayey layer from the surface after vegetative covers up to a depth of 1.5m; at this depth there is a change in lithology from the sandy clayey layer to a thick layer of clay (estimated to have a thickness 7.5m). Underlying this layer is a competent and non-fractured basement rock. There is however presence of fracture of 5m thickness at the depth of 33m encountered in this basement during the logging process. This borehole is usually abandoned during dry season as a result of very low yield and in the raining season, very few residents patronize it for their domestic use. The shallow overburden and the presence of non-substantial fracture are considered to be responsible for the low yield of water supply in this borehole. The second Borehole (BH_2) is located at the central region of the study area. The topsoil thickness is 2.3m and texturally composed of medium to coarse grain sandy clayey layer. The clayey layer occurred below the topsoil as the weathered material and has a thickness of 15.2 m indicating a thick overburden. Therefore, the overburden thickness of this borehole is 17.5 m. Underlying this layer is competent fresh bedrock rock; however, there is presence of fractures of 17 m in thickness at the depth of 34m during the logging process. The thick overburden and substantial thickness of the fracture in this borehole made its groundwater yield to be high (Figure 12).

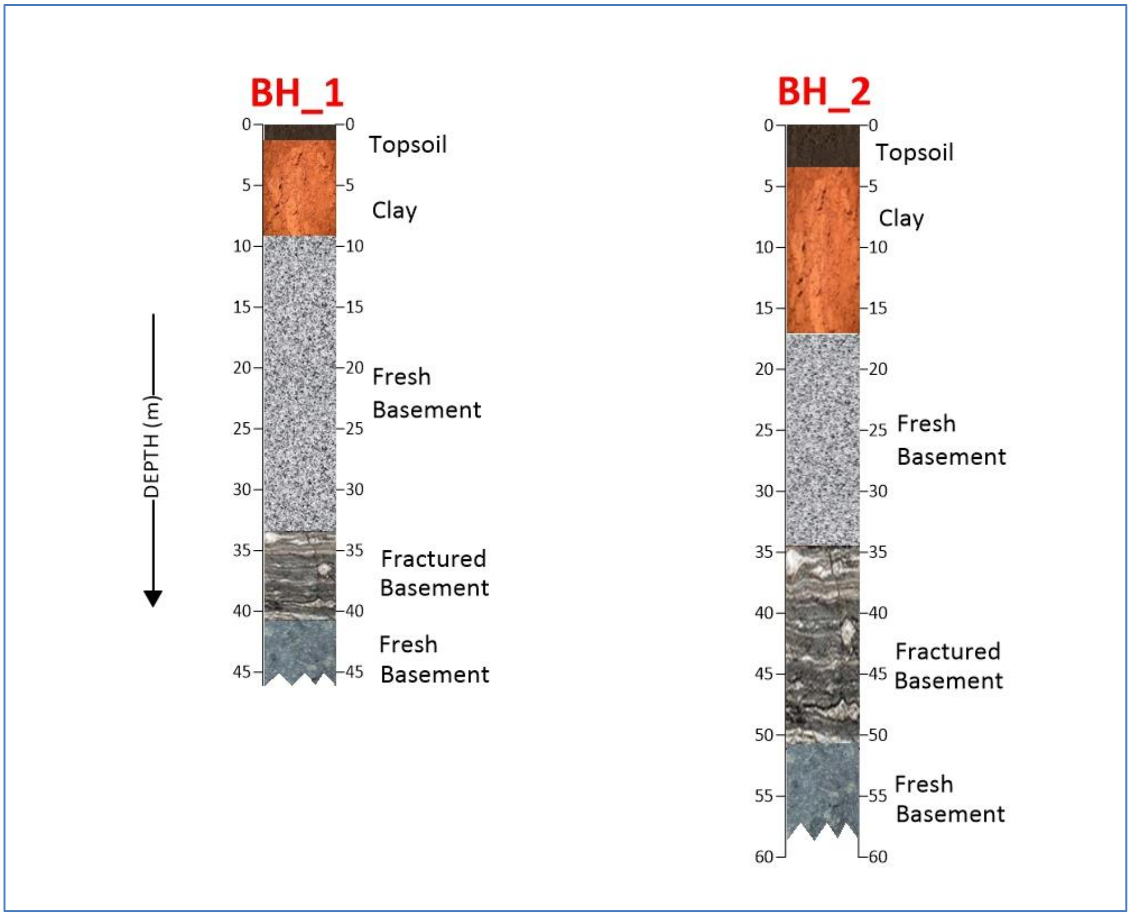

Figure 12: Lithological Log for borehole BH_1 and borehole BH_2.

Groundwater potential

Geoelectric parameters (overburden thickness, basement resitivity and reflection coefficient) are combined to delineate the groundwater potential of an area. Decrease in the reflection coefficient (usually <0.8) and relatively thick overburden (>10 m) enhance the productivity of boreholes in the basement complex terrain of southwestern Nigeria [23]. thick overburden is usually are usually associated with high groundwater potential [24]. For this research, areas with overburden thickness greater than 13 m and/or with reflection coefficient less than 0.8 are generally regarded as having high groundwater yield potential, overburden thickness greater than 13 but less than 30m and with reflection coefficient greater than or equal to 0.8 are generally regarded as having a moderate groundwater potential while areas with overburden thickness of less than 13m and/ or with reflection coefficient greater than or equal to 0.8 are considered as having low groundwater potential yield [5].

The distribution of the groundwater potential of the study area is presented in form of a map (Figure 13). The correlation of both overburden thickness and reflection coefficient is used to delineate low, moderate and high groundwater potential regions. High groundwater potential occurrence is observed at the southern to central part (VES 8, 10 and 11). There are also localized high potential occurrence at the southeastern (VES 24) and north-central area (VES 34). Majority of the central and western parts of the study area exhibited moderate groundwater yield. The low groundwater yield occurs at the northern parts and spreads to the eastern part, there are also occurrences at the southern parts as shown.

The groundwater potential map of this area however agrees with the borehole lithological information obtained, as the borehole BH_1 falls within the low groundwater yield area while the borehole BH_2 falls in the high groundwater yield area.

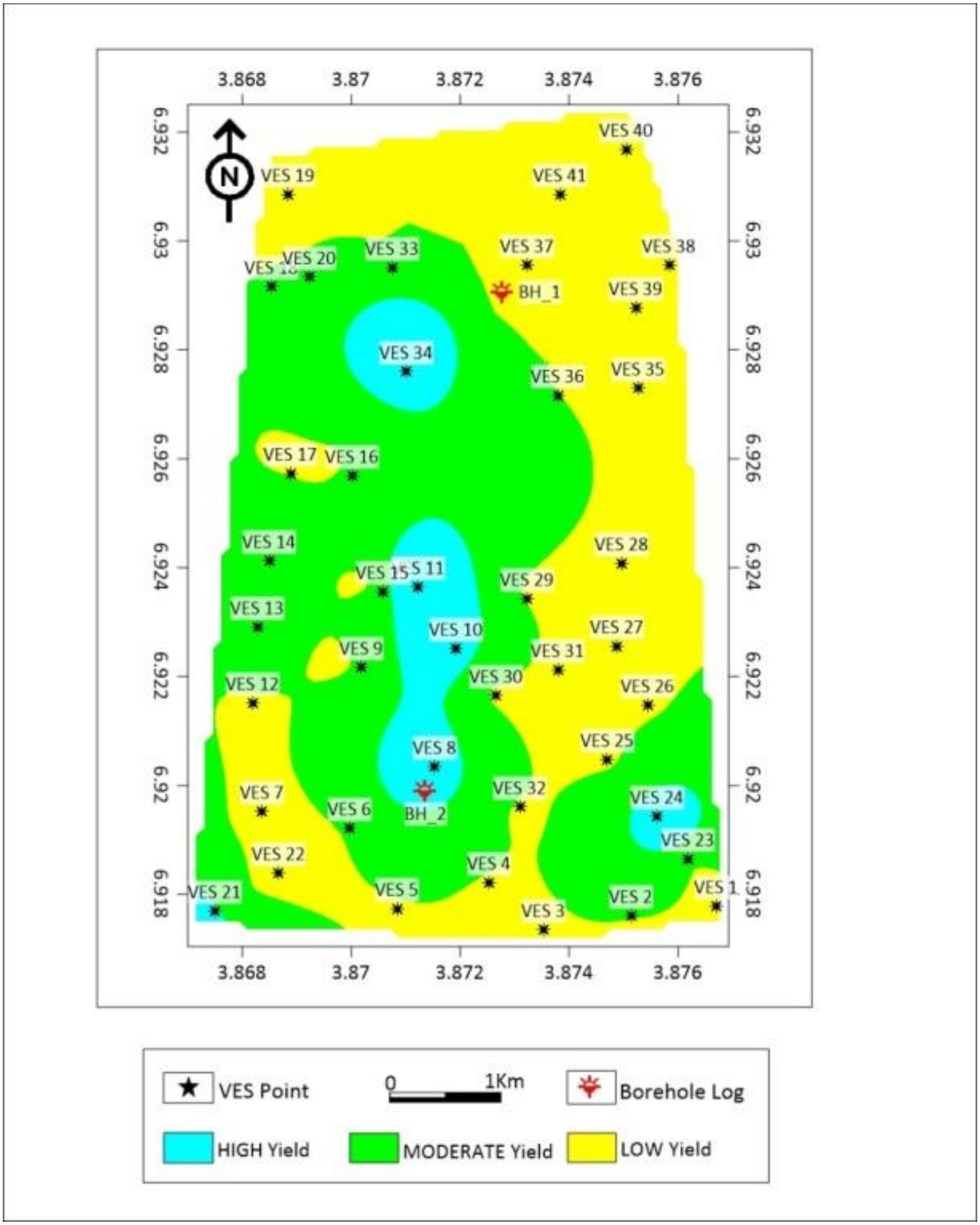

Figure 13: Groundwater potential map of the study area.

Aquifer protective capacity evaluation

The protective capacity is a litho-geophysical parameter (linking of porosity and permeability of subsurface to geological resistivity response). The protective capacity rating is derived from the empirical computation of the longitudinal conductance. Lithology with high porosity (sand) tends to have moderate-high resistivity value thereby indicating low protective capacity while lithology with low porosity (clay) have lower resistivity value and high protective capacity [4, 22]. Apart from the resistivity values, the thickness of the overlying layer also contributes to the rate of contamination; whereby high thickness of overlying lithology tends to hinder and reduce movement of contaminant.

However, there exist an inverse relationship between protective capacity and vulnerability. High protective capacity depicts low vulnerability while low protective capacity indicates high vulnerability. The comparison of the derived longitudinal conductance with the protective capacity rating according to [22] and [4] (Table 2) for the study area shows a poor, weak, moderate and good protective capacity rating and this however helps in classifying its vulnerability in terms of very high, high, medium, and low (Table 3). The longitudinal conductance value of the study area ranges between (0.08–0.43). Only one (1) VES station exhibited poor protective capacity, nineteen (19) stations indicated weak while twenty-one (21) stations showed moderate protective capacity rating. The map of the protective capacity (Figure 14) in the area revealed that majority of the area lies within weak protective capacity except some localized areas at the western, southern and southeastern parts of the study area which indicate moderate protective capacity. There is however an occurrence of weak protective capacity observed at VES 7 in the southwestern part. The plot of vulnerability map of the study area (Figure 15) revealed that the vulnerability of the area ranges between high to medium. The majority of the area indicated a medium vulnerability while some areas at the central, western and eastern areas indicated high vulnerability. There is no occurrence of low vulnerability found in the results. Thus, these results show that the study area is vulnerable to infiltration of leachate and other surface contaminants and this can affect the quality of water of the aquifer underlying the area in the subsurface [5].

Table 2: Modified longitudinal conductance/protective capacity rating and vulnerability rating [22, 4].

Longitudinal Conductance (mhos)	Overburden Protective Capacity Rating	Vulnerability Rating
<0.10	Poor	Very high
0.1–0.19	Weak	High
0.2–0.79	Moderate	Medium
0.8–4.9	Good	Low
5–10	Very good	Very low
>10	Excellent	Extremely poor

Table 3: Longitudinal conductance and protective capacity rating in the study area.

VES No	Longitudinal conductance	Protective capacity rating	Vulnerability rating
VES 1	0.12	Weak	High
VES 2	0.27	Moderate	Medium
VES 3	0.22	Moderate	Medium
VES 4	0.20	Moderate	Medium
VES 5	0.16	Weak	High
VES 6	0.16	Weak	High
VES 7	0.08	Poor	Very high
VES 8	0.35	Moderate	Medium
VES 9	0.12	Weak	High
VES 10	0.43	Moderate	Medium
VES 11	0.16	Weak	High
VES 12	0.19	Weak	High
VES 13	0.32	Moderate	Medium
VES 14	0.33	Moderate	Medium
VES 15	0.28	Moderate	Medium
VES 16	0.12	Weak	High
VES 17	0.18	Weak	High

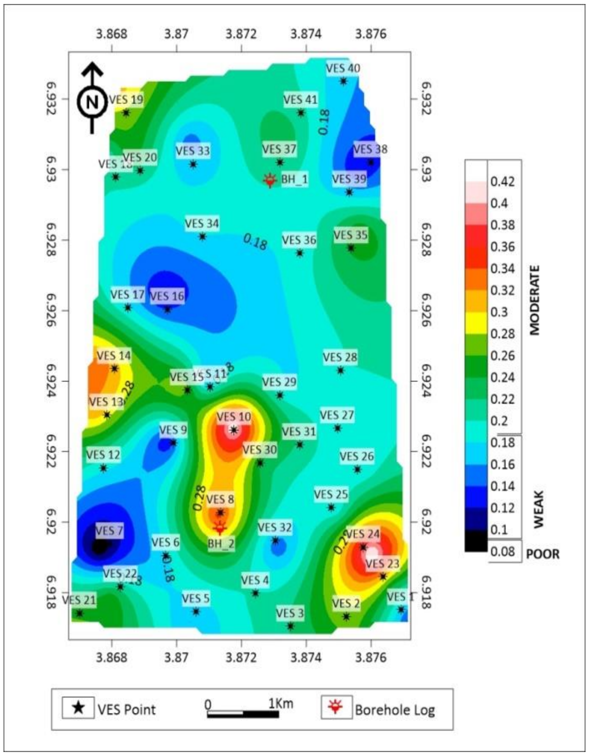

Figure 14: The map showing the protective capacity in the study area.

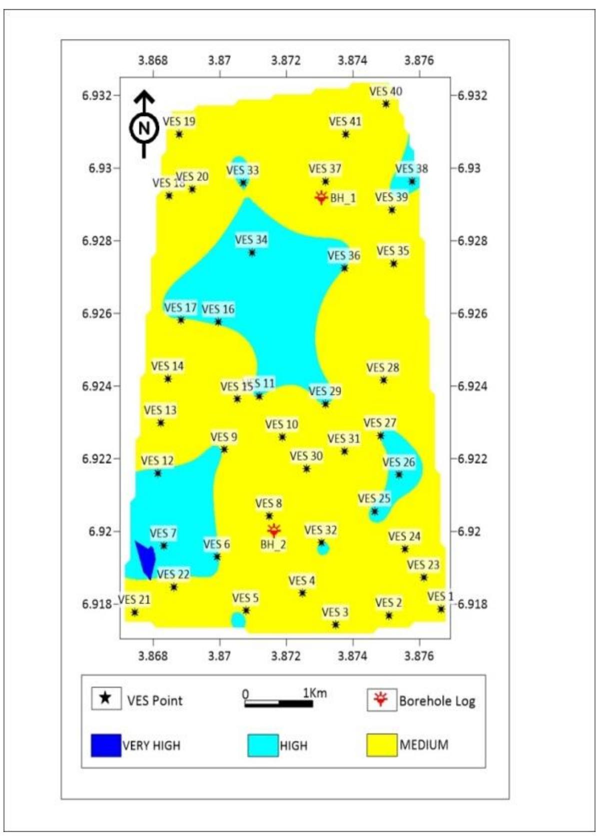

Figure 15: Vulnerability map of the study area.

CONCLUSION

The analysis of the geoelectric parameters for the delineation of groundwater potential in the study area showed that 80% of the area indicated low, 5% showed moderate and 15% have high groundwater potential in the region. The geospatial representation of these potentials reveals that the eastern parts have a low groundwater potential, the western part reveals moderate potential while that of the central part is high. The derived longitudinal conductance value which is a ratio of aquifer thickness to resistivity values was used to determine the protective capacity of the overlying aquifer layer and the vulnerability rating of the aquiferous layer. In this study, the central and part of the southwestern region reveal high vulnerability while other regions reveal medium vulnerability except for one location which indicated very high vulnerability. It is therefore evident that the groundwater in most parts of the area is moderately vulnerable to pollution perhaps from runoff water, sewage, indiscriminate waste disposal and other contaminants in the study area.

This research work has provided a clear insight of the lithological configuration of the subsurface soil and its implication to groundwater vulnerability rate and thereby recommend as a guide towards future citation of wells that would be free from groundwater contamination. However, other approach which entails the DRASTIC, GODT modes to groundwater venerability could also be used to complement this research.

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