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Geo-electrical evaluation of groundwater potential at Peace-Land Estate, Magboro, Southwestern Nigeria

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Abstract
Evaluation of groundwater aquifer distribution using electrical resistivity method was carried out within Magboro area of Ogun State to assess an alternative portable source of water for the populace in the region due to shortage of water supply. Twenty Vertical Electrical Sounding (VES) survey were carried out across the study area using the Schlumberger array configuration. Partial curve matching and computer iteration were used to quantitatively evaluate the data and generate the geoelectric sections using the WINRESIST software. The geoelectric sections generated from the resistivity results revealed four geoelectric stratum which are indicative of topsoil, sand, clay, and aquiferous sand. The topsoil thickness varies between 0.8 and 1.9 m with layer resistivity values that ranged from 99 to 666 Ωm. The second stratum consisted, of sand with resistivity values range of 100 - 185 Ωm and layer thickness values that varied between 8.5 to 12.7 m. The longitudinal conductance values of the topsoil range from 0.001 - 0.11 mhos at the study area. This is suggestive of poor protective capacity, thus the underlying sand is exposed to contamination from the surface. The third identified layer is indicative of clay materials with resistivity values ranged from 19 to 37 Ωm and layer thickness values that ranged between 18 to 50.5 m. This layer denotes the seal that could protect the underlying aquifer. The fourth horizon is presumably sand with resistivity values ranged from 104 to 231 Ωm. The overburden longitudinal conductance value at the third layer overlaying the aquifer units ranged between 0.9 - 2.10 mhos and mhos and are suggestive of a favourable assessment for protective capacity. Thus, the underlying aquifers units are safe from contaminant and could be considered suitable for probable groundwater development.
Keyword: Electrical resistivity, Geoelectric, Aquifer, Groundwater

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Introduction

One of the most essential natural resources, on upon which existence thrives is water use (Emenike *et al.,* 2017). Water demand at the study area is gradually increasing due to expansion and the increased number of the residence, while the available surface water (stream water and shallow well) cannot be relied upon because they are exposed to contaminants and also the supply is inadequate. Besides being susceptible to pollutants (Olajide *et al.,* 2020), extreme weather conditions also have an impact on the sources of the surface water that is available. (Adiat *et al*., 2012). To satisfy the water needs of the community and industry, it is essential to embark on alternative search for good and potable groundwater source for the imminent development in the area.

Groundwater study for domestic and industrial usages has significantly increased globally due to its immense benefit over other sources of water. Groundwater occurs generally as subsurface resource not in a single extensive aquifer but rather in numerous local aquifer systems (Vasanthavigar *et al.,* 2010). Water extracted from soil pore spaces, known as groundwater, is found mostly in subsurface but sometimes in defined channels, like those generated in karst formations, which are formed by the dissolving of soluble rocks like limestone (Shiklomanov, 1993).

Numerous studies have been conducted on evaluating the groundwater potentials using both surface and subsurface methods. A variety of geophysical methods, including the magnetic, electrical resistivity, gravity, electromagnetic, and seismic refraction methods, are used to investigate groundwater. The aquiferous layer and the geologic structure are delineated using these techniques (Wahab *et al.,* 2021; Abbey *et al.,* 2022; Araffa *et al.,* 2023).

Finding the area that is appropriate for groundwater development is made easier by using the resistivity approach for groundwater investigation (Olayinka *et al.,* 2004). The electrical resistivity technique is one of the most implemented approaches in geophysical campaigns for groundwater investigation. Its cost-effectiveness and efficiency in subsurface mapping serves as justification. (Adagunodo *et al.,* 2018). Although, Vertical Electrical Sounding (VES) determines the one-dimensional (1-D) resistivity disparities, it has been noticed to be very efficient for groundwater study in some sedimentary regions (Okunowo *et al.*, 2020; Omeje *et al.*, 2021; Oyeyemi *et al.*, 2023). The application of VES was conducted to investigate the groundwater yield and aquifer protective capacity of the aquifers in the South-western, Nigeria (Idowu and Ojo, 2024).

The study area (Figure 1.0) is known for its acute scarcity of water supply as a result of low yield hand dug wells particularly during dry season and the remoteness to river/streams. Peace-land estate has being a fast growing residential area due to the influx of people to the region. To meet the demands of the household, there is a strong demand for alternative water sources. In this study, electrical resistivity method using the VES was adopted to investigate and delineate the probable aquifer units for groundwater exploration at the investigated regions.

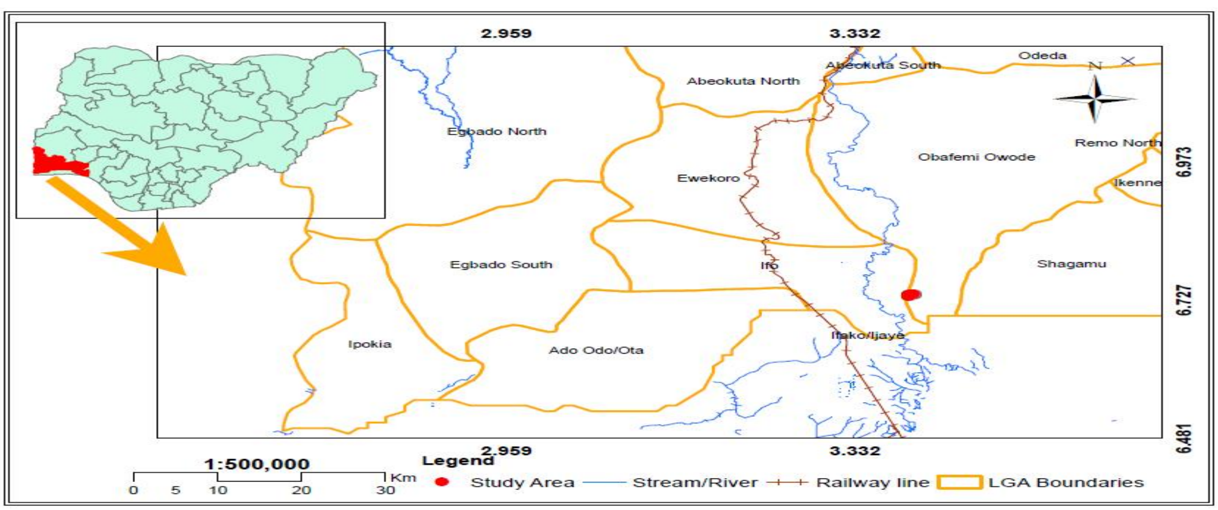

Figure 1.0: Map showing the remoteness of river to the study area.

Geology of the Study Area

The study area is situated within latitudes 6.734088N to 6.738233N and longitude 3.388701E to 3.39334E (Fig 2.0). Peace-land Estate is located within Magboro area, off Lagos – Ibadan expressway at Ifo Local Government Area (LGA) of Ogun State. The geology settings of the area are typical of Dahomey Sedimentary Basin. The study area is underlain by Ilaro Formation which conformably overlies the Imo group within the basin (Jones and Hockey, 1964). Ilaro Formation was subdivided into Ewekoro and Oshosun (Reyment, 1965) and later into the Ewekoro, Akinbo and Oshosun Ewekoro

Formation is overlain by a thick section of grey fossiliferous shales (about 100 meters) called the Akinbo shale. Massive, yellowish, fine to coarse, cross-bedded sandstones with thin clays and shales make up the Formation (Oduneye and Afolabi 2019). The Imo Group turns monotonously shaly towards the coast and East of Sagamu with thin bands of limestone and marl (Omatsola and Adegoke, 1981). Sandstone-dominated rock formations are significant aquifers because they often permit the infiltration of fluids and are porous enough to hold considerable amounts (Oduneye and Afolabi 2019; Olabode and Mohammed, 2016). But the Formation has poor groundwater potential because of the argillaceous nature of the rock. However, some thin lenses of sand have been reported confined by the clays and shale (Offodile, 2002). The study region lies in Nigeria's tropical rain forest zone, which is made up of trees and bushes. It is distinguished by a long wet season that lasts from April to September and a short dry season that lasts from November to March. An average temperature of 25° to 27°C can also be assigned to it. The topography is flat with elevation differential over long distances.

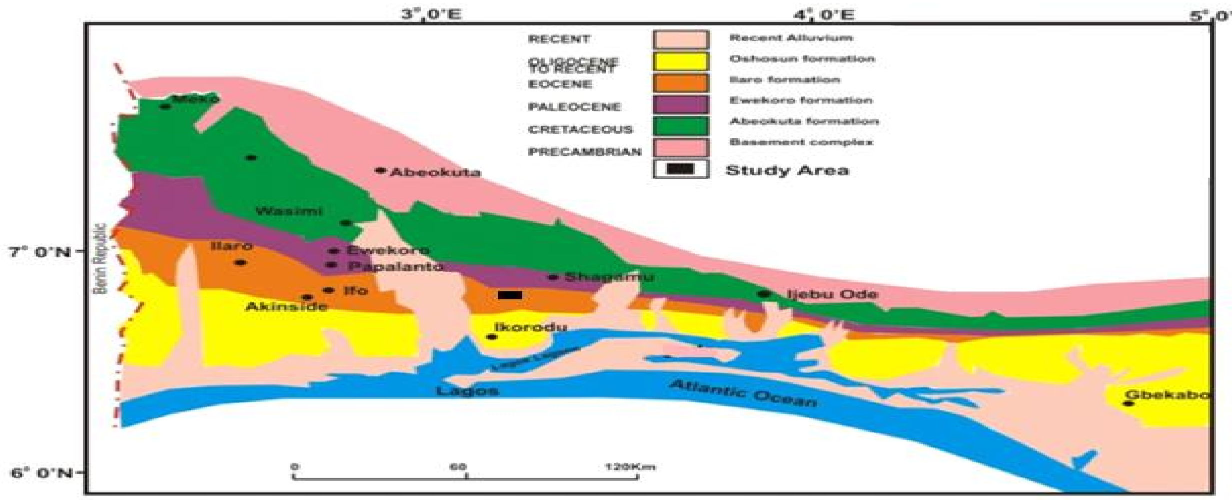

Figure 2.0: Geological Map of Eastern Dahomey Basin (Billman 1976.)

Materials and Methods

Electrical resistivity method of the investigation was carried out along four traverses. Schlumberger technique was adopted for the investigation. The current separation varied from 1 to 250 m step wisely along the investigated traverses (Figure 3.0). A total of twenty Vertical Electrical Sounding (VES) points were conducted using Pasi Resistivity Meter equipment (Plate 1.0). The acquired apparent resistivity data were analysed both quantitatively and qualitatively. Using the partial curve matching technique, the depth sounding curves were quantitatively interpreted (Bhattacharya and Patra, 1968) to estimate the initial geoelectric parameters**.** Thereafter, the true resistivity distributions of the study area were determined by inputting the initial generated model from partially curve matching into the computer to assist in the forward modelling inversion processing using WINRESIST iteration software. The inverted resistivity and thickness values obtained were constrained using borehole log. Thus, geoelectric sections were generated.

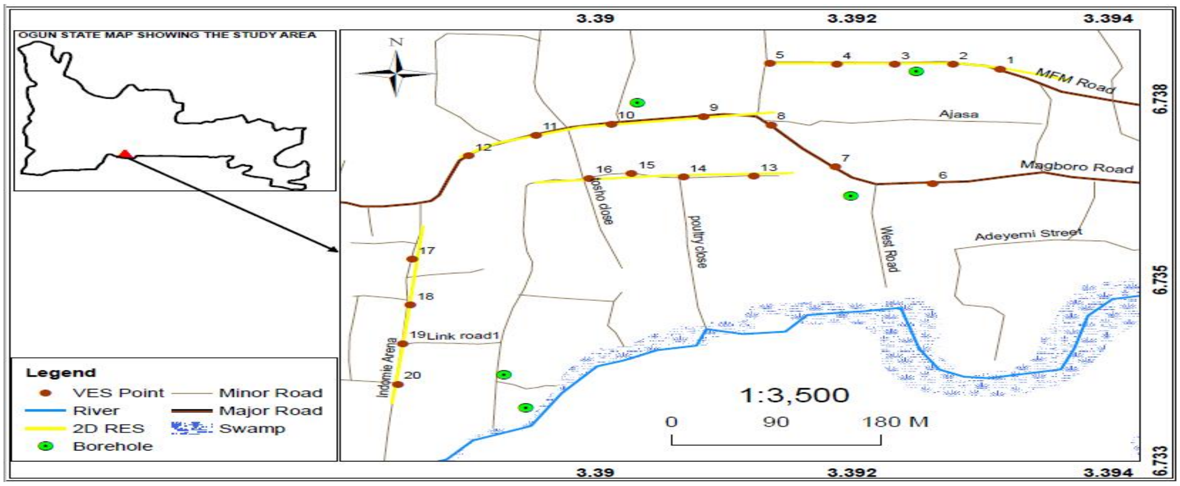

Figure 3.0: Base-map of the Study Area.

Plate.1.0: Instrumentation Setup and Acquisition of Vertical Electrical Sounding Data.

The values of the longitudinal unit conductance of the topsoil and overburden rock units in the area were used to calculate the aquifer protective capacity. The derived values were constraint using table 1. The following formula was used to determine the longitudinal layer conductance (S) of the overburden at each site (Abiola et al., 2009).

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \qquad (1)$$

The number of layers from the aquifer's surface to its top varies from i = 1 to n, where h_i indicates the layer thickness and ρ_i represents the layer resistivity.

Table 1: Modified longitudinal conductance/protective capacity rating *(Oladapo and Akintorinwa, 2007)*

Longitudinal conductance (mhos)	Protective capacity rating
>10	Excellent
5-10	Very good
0.8-4.9	Good
0.2-0.79	Moderate
0.1-0.19	Weak
<0.1	Poor

Resultsa and Discussion

The geoelectric sections were presented and discussed with respect to the traverses of investigation as illustrated in Figs 4.0 – 7.0 which were prepared from the integration of the borehole data and interpreted VES results. The protective capacity of the aquifers were determined as shown in Tables 2 and 3 while the isopach and 3D surface map of the aquifer distribution were presented in Figs 8.0 and 9.0, respectively.

Geoelectric section along traverse 1

This section indicated five VES points 1, 2, 3, 4 and 5 trending approximately in E-W direction as shown in Figure 4.0. It has four geo-electric layers. These layers consist of top soil, clay/shale and sand. The first stratum corresponds to top soil with thickness values that varies between 0.9 and 1.2 m with layer resistivity values that range from 99 to 105 ohm-m. The second layer consists of sand with resistivity values range from 117 to 185 ohm-m and layer thickness values varies between 8.5 and 11.5 m. The third horizon is suggestive of clay with the resistivity value that range from 19 to 26 ohm-m and layer thickness values varies between 18.7 and 41 m. This layer is suggestive of the seal that protect the underlying aquifer. Since the current stopped within the zone, it was unable to determine the layer thickness of the fourth lithologic unit, which is composed of sand with resistivity values ranging from 104 to 231 ohm-m. This horizon indicates the potential aquifer in the study area.

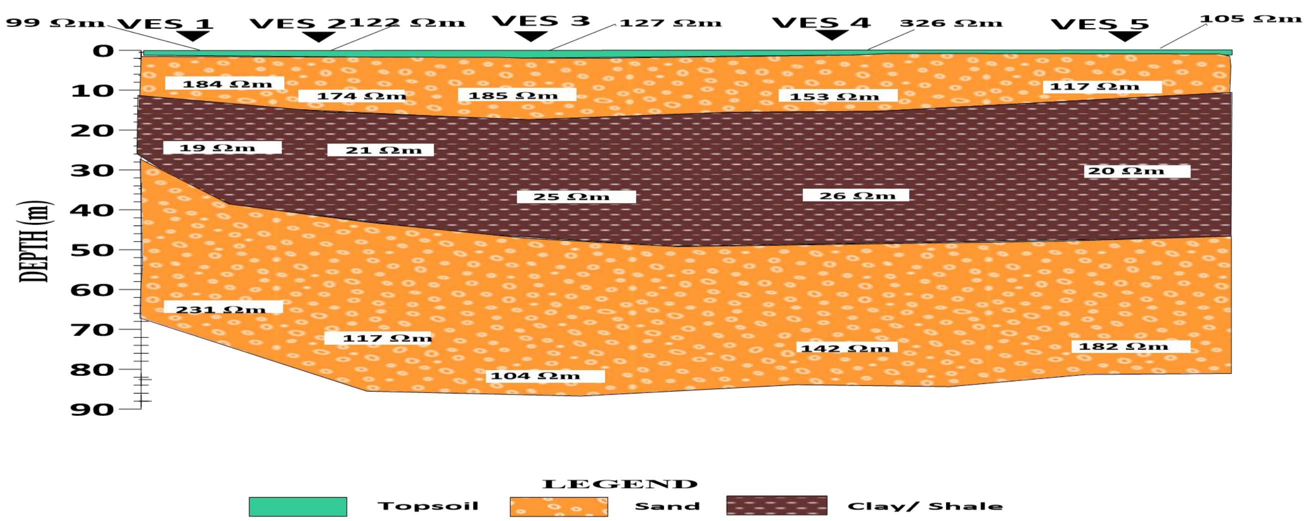

Figure 4.0: Geoelectric Section along traverse 1

Geoelectric section along traverse 2

This section represents eight VES points 6, 7, 8, 9, 10, 11, 12 and 13 trending approximately in E-W direction (Figure 5.0). Four geo-electric layers were depicted and the layers consist of top soil, clay/ shale and sand. The first layer corresponds to top soil with thickness values that varies between 1.0 and 1.9 m with layer resistivity values range of 99 to 409 ohm-m. The second stratum consists of clayey sand and sand with resistivity values vary between 100 and 161 ohm-m and layer thickness values varies between 9.1 and 12.3 m. The third identified layer is suggestive of clay with resistivity values range from 24 to 31 ohm-m and layer thickness values that range between 19.6 and 50.5 m. This layer is suggestive of the seal overlying the underlying aquifer. The fourth horizon constitutes sand with the resistivity values range from 139 to 180 ohm-m, but its layer thickness could not be ascertained because the zone was wherein the current ended. This layer is indicative of the potential aquifer in the area of investigation.

Figure 5.0: Geoelectric Section along traverse 2

Geoelectric section along traverse 3

This section comprised of three VES points 14, 15 and 16 trending approximately in E-W direction (Figure 6.0). This segment delineates four geo-electric layers, which consist of topsoil, clay/shale and sand. The first horizon comprises of the topsoil with thickness values ranging between 0.9 and 1.1 m having layer resistivity values range of 234 - 413 ohm-m. The second lithologic layer is characterized by sand with resistivity values range from 107 to 157 ohm-m and the layer thickness values varies between 8.9 and 12.7 m. The third identified geoelectric layer is indicative of clay with resistivity values range of 33 - 37 ohm-m and layer thickness range of 35.1 - 44.4 m. This layer is indicative of seal for the underlying aquifer. The fourth geoelectric layer comprised of sand with resistivity values that range from 123 ohm-m to 131 ohm-m. The layer thickness could not be ascertained as the current attenuated therein. This stratum indicates the potential aquifer in the investigated area.

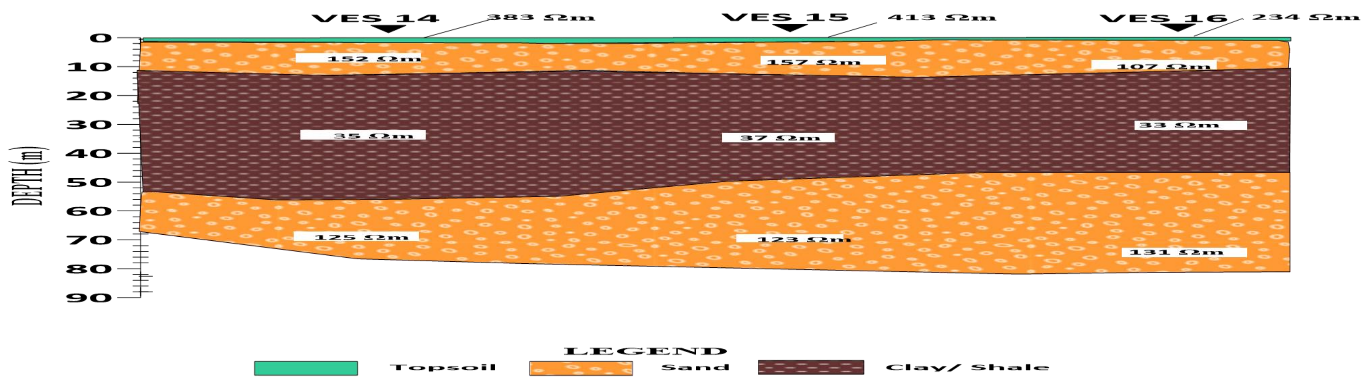

Figure 6.0: Geoelectric Section along traverse 3

Geoelectric section along traverse 4

This section comprises of four VES points 17, 18, 19 and 20 trending approximately in N-S direction (Figure 7.0). Four geoelectric layers were delineated which comprised of topsoil, clay and sand. The first layer comprised of the topsoil with resistivity values range from 297 to 666 ohm-m, and layer thickness values that vary between 0.8 and 1.3 m. The second stratum consists of sand with resistivity values range from 100 to 184 ohm-m and layer thickness values varying between 9.6 and 12.2 m. The third lithologic unit is suggestive of clay with resistivity values range of 25 - 31 ohm-m and layer thickness values varying between 41.8 and 45.9 m. This layer is indicative of seal that protect the underlying aquifer. The fourth delineated horizon is characterized by sand with resistivity values range from 127 to 148 ohm-m, but the layer thickness could not be ascertained due to termination of current within the zone. The stratum is indicative of the potential aquifer in the investigated area.

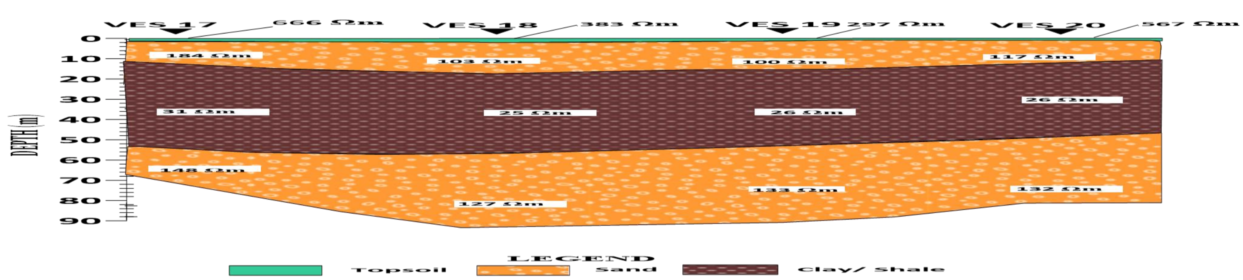

Figure 7.0:Geoelectric Section along traverse 4

Table 2: Topsoil longitudinal conductance of each VES station

VES Station	Resistivity	Thickness (m)	Topsoil Conductance	Protective capacity Rating
1	98.9	1	0.010111	Poor
2	121.8	0.9	0.007389	Poor
3	126.6	1.2	0.009479	Poor
4	326	1	0.003067	Poor
5	105.3	1	0.009497	Poor
6	98.5	1.5	0.015228	Poor
7	154.3	1.8	0.011666	Poor
8	178.3	1.9	0.010656	Poor
9	322.0	1.0	0.003106	Poor
10	99.0	1.2	0.012121	Poor
11	409.0	1.2	0.002934	Poor
12	357.0	1.3	0.003641	Poor
13	258.0	1.4	0.005426	Poor
14	384.0	1.1	0.002865	Poor
15	413.0	0.9	0.002179	Poor
16	234.0	1.0	0.004274	Poor
17	666.0	1.1	0.001652	Poor
18	383.0	1.1	0.002872	Poor
19	297.0.0	1.3	0.004377	Poor
20	597	0.8	0.001340	Poor

Table 3: Summary of the overburden longitudinal conductance

VES Station	Resistivity	Thickness (m)	Topsoil Conductance	Protective capacity Rating
1	19.0	18.7	0.984211	Good
2	21.0	44.7	2.128571	Good
3	25.0	53.3	2.132	Good
4	26.0	42.6	1.638462	Good

5	20.0	61.5	3.075	Good
6	31.0	19.6	0.632258	Good
7	24.0	50.5	2.104167	Good
8	27.0	38.5	1.425926	Good
9	25.0	42.1	1.684	Good
10	30.0	27.6	0.92	Good
11	29.0	38.1	1.313793	Good
12	33.0	39.4	1.193939	Good
13	31.0	38.2	1.232258	Good
14	35.0	48.5	1.385714	Good
15	37.0	54.4	1.47027	Good
16	33.0	38.4	1.163636	Good
17	31.0	45.8	1.477419	Good
18	25.0	44.8	1.792	Good
19	26.0	45.9	1.765385	Good
20	26.0	44.9	1.726923	Good

Topsoil and overburden protective capacity ratings Table 2 indicate that the conductance values of the topsoil fluctuate between 0.001 and 0.11 mhos. The adjusted longitudinal conductance/protective capacity grading in Table 1 demonstrates that these outcomes indicate a poor protective capacity rating. Because of this, the second layer—the sand—is susceptible to pollution. According to Table 3, the overburden longitudinal values range from 0.9 to 2.1 mhos. Because of its thickness and comparatively high longitudinal conductivity, the clayey overburden may operate as a protective layer over the underlying aquifer. This is indicates of good protective capacity rating, hence, it shows that the underlying sand layer is prevented from contamination.

Contoured Maps

Figures 8.0 and 9.0 shows the isopach and 3D surface map of the aquifer distribution of the sand layer beneath the clay formation. The depth to the top of the aquifer varies from 16 to over 70 m. It can be deduced that the depth to the top of the aquifer thickens towards the North-eastern and North-western region of the map. From the North central part of the map, towards eastern region and some section of Southwestern part of the map has depth to the top of aquifer thickness that varies from 52.3 to 55.2 m.

Figure 8.0: Isopach Map of Depth to Second Aquifer Distribution

Figure 9.0: 3D surface map of the aquifer distribution

Conclusion

The aquifers characterization and groundwater distribution within Magboro area of Ogun-State, Nigeria was carried out using electrical resistivity approach. The results obtained from the VES interpretation delineated four geoelectric layers in the study area which consists of the top soil, sand, clay/shale and sand as the subsurface geological formations. The findings of the study show that the first layer corresponds to topsoil with resistivity value range of 99 - 666 ohm-m and the thickness values varies between 0.8 and 1.9 m, The topsoil longitudinal conductance values range from 0.001 to 0.11mhos, this suggests that the layer has poor protective capacity thus; the underlying aquifer will be susceptible to contamination. The second stratum consists of sand with resistivity values range of 100 - 185 ohm-m and layer thickness values varying between 8.5 and 12.7 m. The third identified layer is indicative of clay materials with resistivity values varying between 19 and 37 ohm-m and layer thickness values that range from 18 to 50.5 m. The fourth horizon constitutes sand (aquiferous sand) with resistivity values range of 104 - 231 ohm-m. Since current stopped within the layer, it was impossible to determine how thick this layer was. The longitudinal conductance values of the overburden vary between 10.5 and 33.0 mhos thus, indicating a protection capacity rating of very good to exceptional. The third layer could serves as the seal that protect the underlying aquifer. Therefore, the second aquifer units are well protected free from contaminant and could serve as potential aquifer for ground water abstraction in the study area.

Conflict of interest: We have no conflict of interest.

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