Scientia Africana, Vol. 21 (No. 1), April, 2022. Pp 37-52 *https://dx.doi.org/10.4314/sa.v21i1.4*
 ISSN 1118 – 1931

HYDROGEOPHYSICAL EXPLORATION OF GROUNDWATER POTENTIAL IN SOUTHWESTERN BASEMENT TERRAIN OF PART OF AGO-IWOYE, SOUTH WESTERN NIGERIA.

[1]Bayewu, O. O., [2]Oloruntola, M. O., [1]Mosuro, G. O., [1]Odugbesan, O. O., [1]Bakare, K. O., [1]Olukayode, O. O., [3]Adenuga, O. A., and [1]Oyebolu, O. O.

[1]Department of Earth Sciences, Olabisi Onabanjo University, Ago Iwoye, Nigeria.
[2]Department of Geosciences, University of Lagos, Lagos, Nigeria.
[3]Department of Physics, Olabisi Onabanjo University, Ago Iwoye, Nigeria.
*Corresponding email: odugbesanoluwadamilare@gmail.com

Received: 11-08-2021
Accepted: 03-01-2022

ABSTRACT

Electrical resistivity survey of Ago-Iwoye southwestern Nigeria was done with the aim of delineating potential zones for groundwater exploitation. The rock types present are mainly gneissic rocks; granite gneiss, banded gneiss, biotite gneiss and porphyroblastic gneiss.Forty five (45) Vertical Electrical Soundings (VES) of schlumberger array were carried out using maximum electrode spacing (AB/2) of 100m. The results obtained were interpreted using partial curve matching which serves as model input for the computer iteration using WINRESIST software to determine the resistivity, thickness and depth of each layer in the sub-surface.The identified curve types are H, KH, HKH, A, K and QH types while the H type curve is predominant. The three prominent geo-electric layers were inferred, these are the topsoil, weathered layer (sand/clay/clayey sand) and fresh/fractured bedrock with resistivity values of 33.4Ωm - 2266.3Ωm, 8.3Ωm - 1106.3Ωm and 68.4Ωm - 21729.6Ωm respectively. The isopach reveals overburden thickness range of 2m – 52m, bedrock resistivity ranges from 1000Ωm - 19000Ωm and reflection coefficient range from 0.62 -0.92.The study area is predominantly of low yield but areas in the northeastern and western part of the study area have high aquiferous groundwater potential areas are only noticeable in the northeastern and western part of the study area.

Keywords: Geoelectric layers, Groundwater, Electrical Resistivity, Isopach, Reflection coefficient, overburden thickness

INTRODUCTION

The study area, Ago-Iwoye town belongs to the tropical climatic environment indicating a considerable amount of annual precipitation thereby providing the people with a considerable amount of surface water occurrences but this type of water is undependable throughout the year because of the high population demand for water in their different activities. Hence, there is need to depend more on water held in saturated zone of the subsurface under the hydrostatic pressure condition known as the groundwater usually occurring below the water table (Haque *et al*., 2021; Ariyo *et al*., 2021).

An essential factor capable of influencing groundwater occurrence is the geological setting of the exploration area because of the differences in the hosting media (aquifer). Geologically, earth regions are considered to be made up of either soft rocks (sedimentary environment) or hard rocks (crystalline environment).

Exploration and exploitation works have been able to successfully delineate and differentiate between groundwater occurrences in both geological terrains. The aquiferous region in the sedimentary environment includes gravel, sandstone, conglomerates, and fractured limestone while that of the basement include the search for thick overburden layers and fractured rock of the subsurface.

Exploring for groundwater in basement region (as in this study) requires the adoption of either an active or passive method of geophysical exploration considering the amount this method has successfully recorded as they are most reliable and accurate in mapping subsurface layers, structural investigations and rock variation (Carruthers, 1985; Emenike, 2001) capable of serving as the aquifer in this region.

Geophysical exploration method includes electrical resistivity, gravity, seismic, magnetic, remote sensing, and electromagnetic and so on. The electrical resistivity method which measures the changes in the apparent resistivity of the subsurface appears to be the most promising method with great success and low cost for locating productive well. Vertical Electrical Sounding (VES) technique is adopted and this method can provide information on the vertical variation in the resistivity of the ground with depth and the Constant Separation Traversing (CST) provides a means of determining lateral interval variation in the resistivity of the ground Bayewu *et al*., 2018, Olayinka and Mbachi, 1992; Olorunniwo and Olorunfemi, 1987). In view of this, the exploration strength of the Vertical Electrical Sounding (VES) technique necessitates its adoption in the delineation of the groundwater potential zone in the study area which is Ago-Iwoye, Southwestern Nigeria.

Location and Geological setting

Ago-Iwoye in South-western Nigeria is located between latitude 6˚55'00" to 6˚57'00"North and longitude 3˚54'00" to 3˚55'00"East (Figure 1). The accessibility of the area is best described in terms of transportation network, which consists of minor roads linking major roads with foot paths across the study area. The geomorphological setting of the study area reveal moderate low hills forming ridges and undulated plain dotted with small isolated hills or hills rock are noticed generally within Ago-Iwoye. Drainage pattern is predominantly dendritic with presence of River Ome as the major river channel and vegetation falling under the tropical rain forest belt of Nigeria (Adeyemi and Salami, 2004). Ago-Iwoye is recognized to belong to the Monsoon climatic environment characterized by both wet and dry season. The wet season is experienced in late March or early April to late September or early November while the dry season occurs from early November/ late November to early March. The average precipitation range is 250-450mm attaining an average rainfall of 750-1000mm at a temperature of 27°C during the wet season. This area is geologically within the Precambrian Basement Complex terrain of Southwestern Nigeria with presence of Granite, Granite gneiss, Banded gneiss and Pegmatite rocks (Figure 2).

Scientia Africana, Vol. 21 (No. 1), April, 2022. Pp 37-52 https://dx.doi.org/10.4314/sa.v21i1.4
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

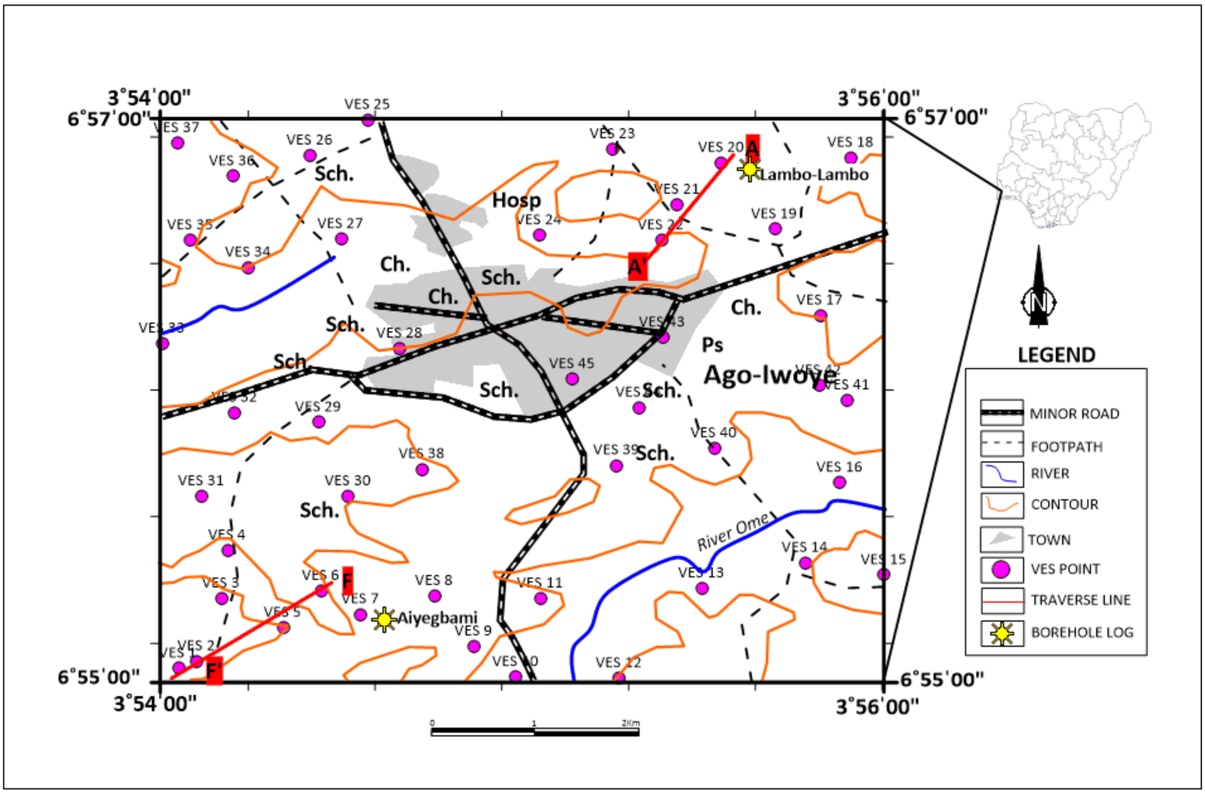

Figure 1: The map of the study area indicating established vertical electrical sounding (VES) points.

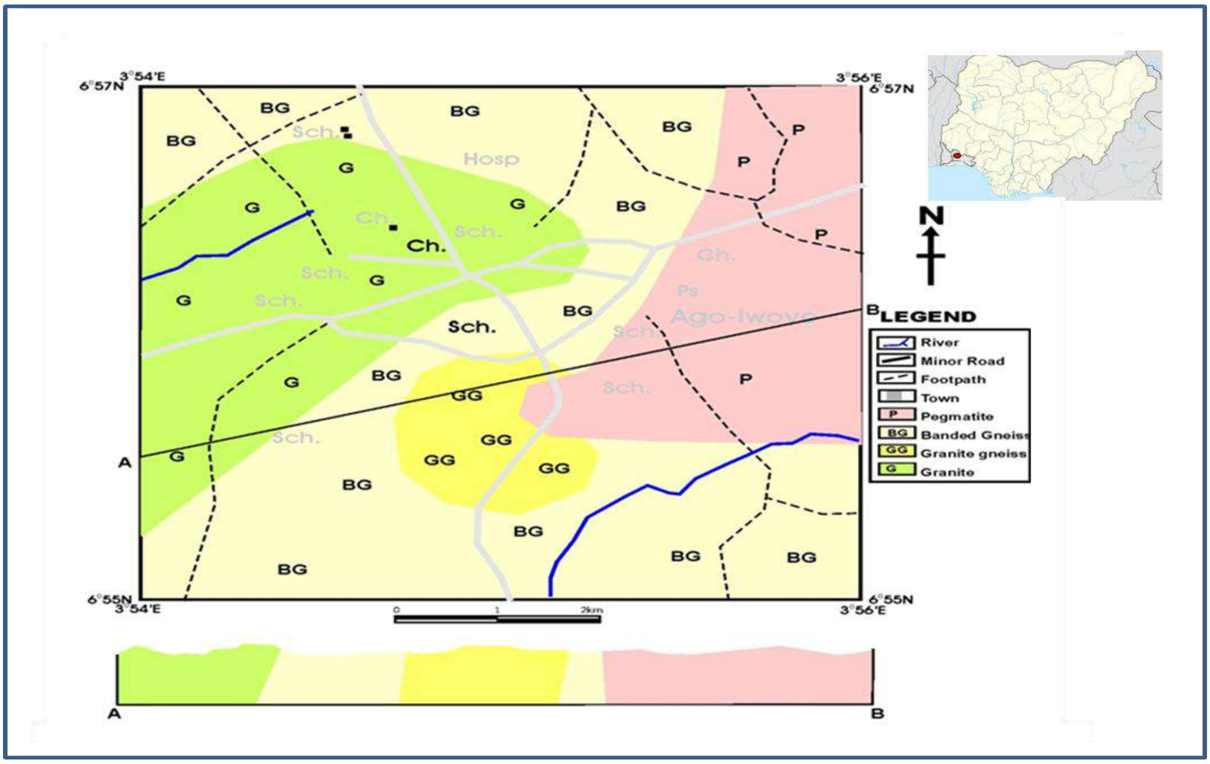

Figure 2: Geological map of the study area indicating various rock types present.

MATERIALS AND METHOD

The acquisition phase of this research entails the establishment and collection of VES data of forty five (45) points in the study location (figure 1). The maximum current electrode spacing $(\frac{AB}{2})$ was 100m using the Ohmega Ω Resistivity Meter the Schlumberger array configuration. Current were passed into the subsurface from the resistivity meter through pair of current electrode and the potential difference was measured at the electrode current end thereby generating the resistance value of the subsurface lithological unit which was later product with the appropriate Geometric Factor (G.F) for Schlumberger array configuration with reference to Zohdy *et al.*, (1974) formula (1) to generate the apparent resistivity of the subsurface. In attempt to convert the apparent resistivity to true resistivity, the partial curve matching approach was adopted, this entails the bi-logarithm plotting of apparent resistivity and current electrode spacing on the ordinate and abscissa respectively after which a curve will be generated by drawing the plotted points. The generated curve is matched with standardized series of curves that has been pre-calculated (Alfano, 1959; Crous, 1971; Zohdy, 1965; Flathe, 1963); this process is known as the curve matching technique in order to obtain the resistivity, depth and thickness of the entire respective layer in the subsurface. The depth and thickness information are converted to its true values by undergoing the computer iteration process using the 1-D WINRESIST computer software program to run inversion and generate model that reveal the true parameters of the subsurface (Ghosh, 1971). Quantitative interpretation approach was adopted using formula (2) taking into consideration the resistivity of the last layer and second to the last layer in order to determine the reflection coefficient of the established point.

Apparent Resistivity

$$\rho a) = \left(\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right) \times \pi \dots\dots\dots\dots\dots (1)$$

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

The reflection coefficient was calculated with the formula:

$$r = \frac{(\rho n - \rho(n-1))}{(\rho n + \rho(n-1))} \dots\dots\dots\dots\dots\dots (2)$$

(r = reflection coefficient, ρ_n = resistivity of nth / last layer, ρ (n−1) = resistivity of above the nth layer)

Two (2) lithological log information of drilling recovery for Lambo-Lambo and Ayegbami (areas within the study area) were collected from Ogun State Ministry of Water Resources for two community wells previously dug in the study area as this will serves as a physical evidence for the confirmation of the underlying lithological layer in the study area.

RESULT AND DISCUSSION

The processing of the subsurface model generated reveal a total of six (6) lithological curve geometry with their percentage occurrence are mainly H (62%), KH (20%), HKH (2%), K (2%), QH (9%) and A (5%) type (Figure 3), with most established points having 3-4 inferred layers with varying resistivity and depth for VES 1-VES 4 are presented in Figure 4a-d respectively. Inferred lithological

Scientia Africana, Vol. 21 (No. 1), April, 2022. Pp 37-52 https://dx.doi.org/10.4314/sa.v21i1.4
© Faculty of Science, University of Port Harcourt, Printed in Nigeria ISSN 1118 – 1931

units from the derived resistivity values in relation to the geology of the study location showed presence of topsoil, weathered layer (clay, clayey sand and sand) and basement (fresh and fractured basement). Resistivity range for the topsoil layer is 33.4Ωm-2485.3Ωm indicating a clayey to Lateritic topsoil layer, weathered layer comprising of clay, clayey sand and sand reveal a resistivity range of 8.3Ωm-102.6Ωm, 100.0Ωm-130.0Ωm and 199.4Ωm-784.8Ωm respectively while the basement rock for fractured and fresh basements showed resistivity range of 123.3Ωm-952.4Ωm and 993Ωm-15308.5Ωm respectively. The layer thickness observed for each successive layer revealed topsoil layer thickness range of 0.6m-1.7 while that of the weathered layer range from 2.4m-51.3m indicating a relatively varying thickness region while the thickness of the basement could not be determined (infinity). The subsurface diagrammatic view indicating vertical variation in the lithology, depth, thickness and resistivity values is presented using the geoelectric sectional diagram of traversable VES points in the study area (Figure 5 and Figure 6). Traverse A-A' (Figure 5) and Traverse F –F' (Figure 6) revealed a gradual increase in the overburden thickness from the northeastern region to the southwestern region of the study area, the topsoil have almost the same thickness from VES 20 to VES 22 for Traverse A-A' and from VES6 to VES 1 for Traverse F –F' respectively. The hydrogeological implication of this subsurface layering geometry gives an indication that the highest overburden thickness to the basement rock for the two profiles is noticeable in the eastern ad northwestern region of the study location with about 9.1m and 11.3m respectively.

Geoelectric Parameters

Evaluation for groundwater potential in a typical basement environment has identified some important geoelectric layering parameters as determinant factors that gives clue to aquiferous layer within the subsurface lithological unit. The geoelectric parameters widely used include the basement resistivity, overburden thickness and reflection coefficient which is mostly functions of resistivity and depth variation in lithological units.

The sum total thickness of lithological units overlying the subsurface aquiferous zone in an established vertical electrical sounding point is regarded as the overburden thickness (i.e addition of the thicknesses of the weathered earth materials). The overburden thickness has established a direct correlation with groundwater potentiality whereby high overburden thickness areas are associated with high groundwater potential in this tropical basement region (Akinrinade *et al.*, 2016). Overburden thickness in the study location range from 2.7m to 52.2m indicating a shallow to moderately deep basement rock occurrences and it also revealed an appreciable overburden capable of yielding a considerable amount of groundwater. The geospatial isopach map of the overburden thickness revealed that most areas possess thick overburden (>22m) except for some areas in the central and western areas of the map (Figure 7) which has lesser values. The basement resistivity is also capable of inferring regions underlined with hard/ crystalline rock (non-weathered underlying basement rocks) and weathered basement rock. Area with weathered basement rock revealed a drop in resistivity value than region underlined by non-weathered rock as the non-weathered rock can imply regions of low area of groundwater potentiality. Basement resistivity values in the study location range from 123.3Ωm-49600Ωm indicating varying resistivity values of the underlying rock types of the established geology of the study area (Figure 8). The predominant geospatial representation revealed low resistivity (<10,000 ohm meter) which serves as an indicator that can favor water bearing aquiferous layer. The small portion at the eastern and northwestern parts of the map indicate fairly high resistivity (>10,000 ohm meter) which can be an indicative of low water bearing aquiferous layer. However, the bedrock resistivity values cannot be solely used in determining the water potential of an area because of its ambiguity (Olayinka and Mbachi, 1992). The reflection coefficient, which is the function of the bedrock resistivity and the resistivity of its overlying layer usually, gives better information on presence of fracture in the subsurface which harbors the accumulation of water in the basement terrain. The reflection coefficient value ranges from 0.62 to 0.92. The geospatial maps revealed that it is higher than 0.82 on most parts of the map except for some parts in the northern and central parts of the map where reflection coefficient values are lower which is about 0.62 which is favorable for high ground water yield encouraging exploitation (Figure 9). The geospatial map of overburden thickness, basement resistivity and reflection coefficient of the study area were stacked together to enhance parameter comparison in relation to the range of value in Figure 10.

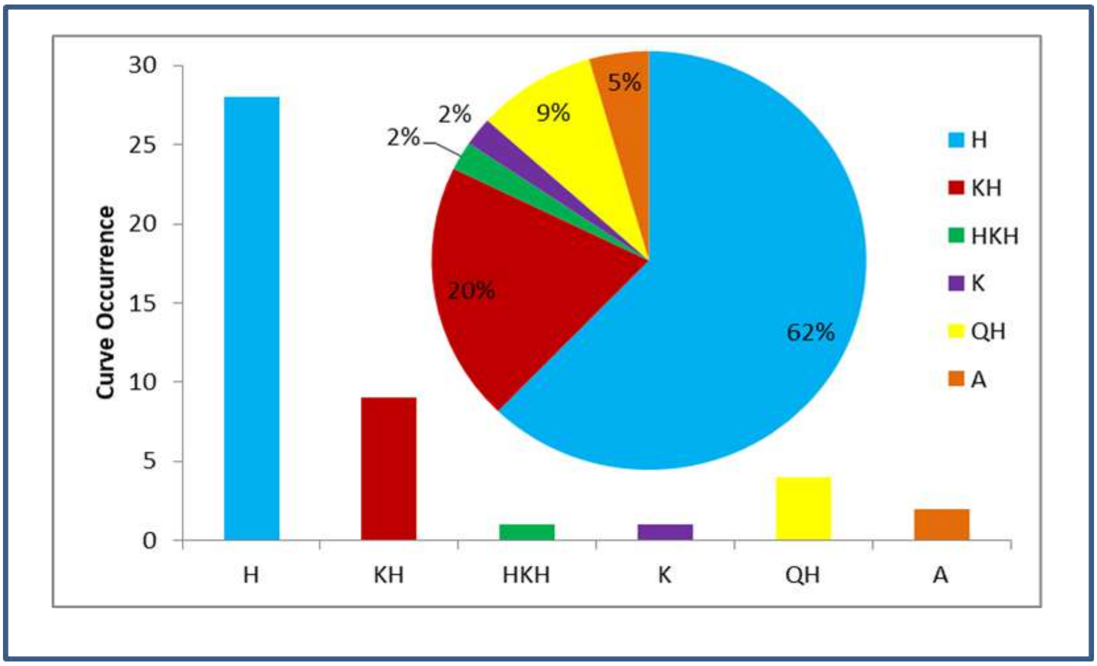

Figure 3:- Infographical summary of geophysical curve occurrence using bar and pie chart.

Scientia Africana, Vol. 21 (No. 1), April, 2022. Pp 37-52 https://dx.doi.org/10.4314/sa.v21i1.4
© Faculty of Science, University of Port Harcourt, Printed in Nigeria **ISSN 1118 – 1931**

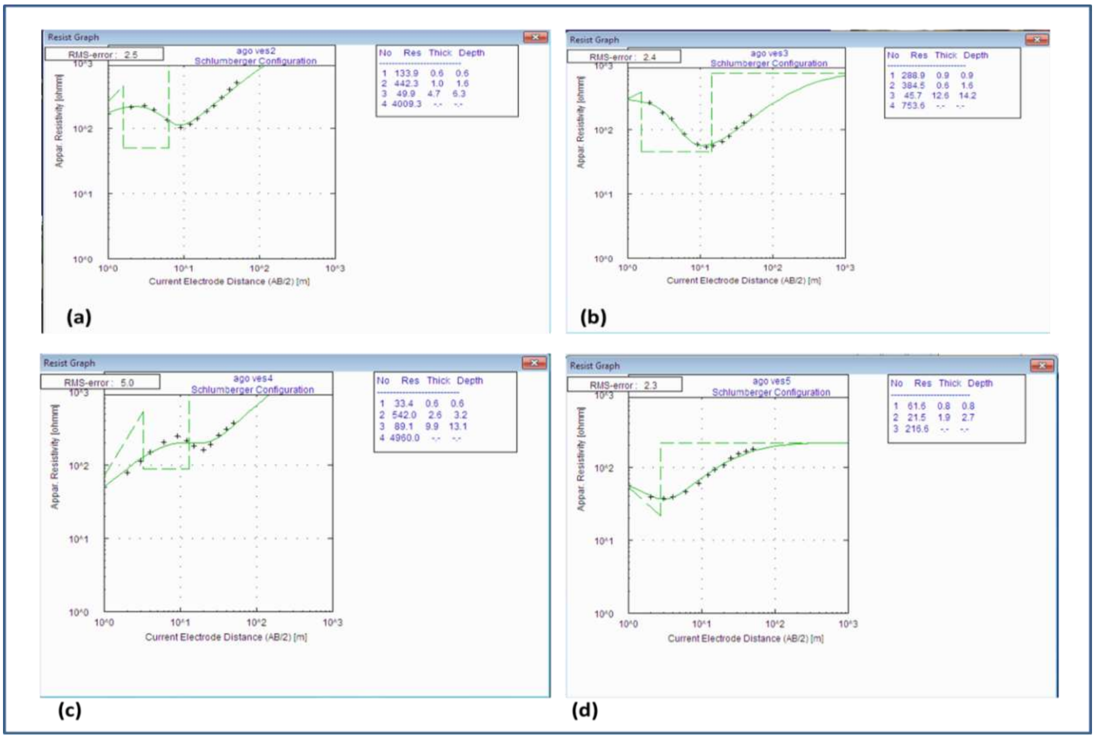

Figure 4a-d: - Generated iterated curve indicating geoelectric parameters (Resistivity, number of layers, thickness and depth for VES 1-4).

Table 1:- Geoelectric parameters of the VES points in the study area

VES Point	Basement Resistivity (Ωm)	Overburden Thickness (m)	Reflection Coefficient
VES 1	172.03	4.9	0.86
VES 2	4009.5	6.3	0.98
VES 3	753.6	14.2	0.89
VES 4	49600	13.1	0.96
VES 5	216.6	2.7	0.82
VES 6	2180.2	5	0.94
VES 7	3435.7	48.8	0.85
VES 8	1739	6.5	0.91
VES 9	618.4	3	0.91
VES 10	286.6	3.6	0.73
VES 11	285	8.4	0.85
VES 12	2331	23.8	0.95
VES 13	3868.1	20.6	0.90
VES 14	489.6	6.3	0.97
VES 15	1696	10.3	0.95
VES 16	1208	5.7	0.98
VES 17	3136.8	7.7	0.95
VES 18	6840.7	52.2	0.92
VES 19	966.8	6	0.94
VES 20	889.6	35.8	0.74

VES 21	3807.8	15.9	0.91
VES 22	2669.8	26.3	0.95
VES 23	880.9	8.8	0.69
VES 24	1440.1	6.7	0.64
VES 25	17746.4	19	0.99
VES 26	712.5	5.8	0.90
VES 27	1900	6.2	0.90
VES 28	1521.5	17.1	0.75
VES 29	1250.9	13.7	0.91
VES 30	746.3	4	0.90
VES 31	478.1	9	0.61
VES 32	158.3	12.1	0.98
VES 33	2898.7	44.4	0.86
VES 34	703.3	17.1	0.74
VES 35	5515.9	11.3	0.96
VES 36	1441	11.5	0.74
VES 37	916.2	7.2	0.64
VES 38	636.8	3.1	0.74
VES 39	1266	4.9	0.87
VES 40	21729.6	22.3	0.95
VES 41	1098.6	9.1	0.91
VES 42	1052.2	12.5	0.91
VES 43	952.4	5.1	0.83
VES 44	993	3.3	0.81
VES 45	123.3	7.3	0.70

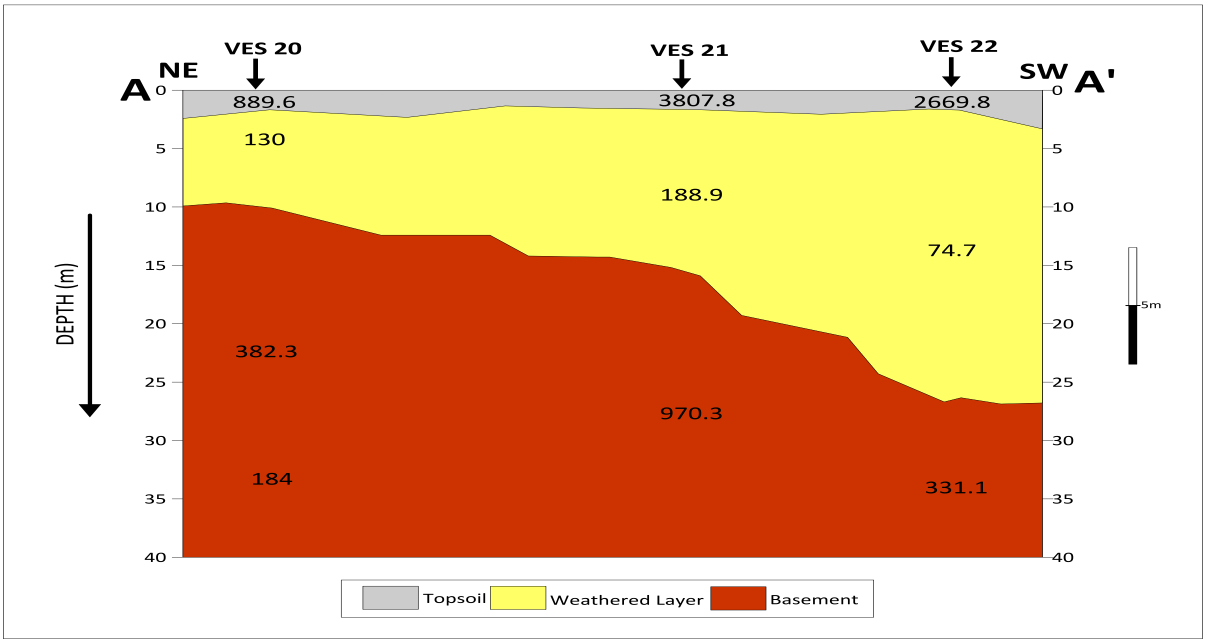

Figure 5:- The geoelectric section along traverse line A -A’

Scientia Africana, Vol. 21 (No. 1), April, 2022. Pp 37-52 https://dx.doi.org/10.4314/sa.v21i1.4
© Faculty of Science, University of Port Harcourt, Printed in Nigeria **ISSN 1118 – 1931**

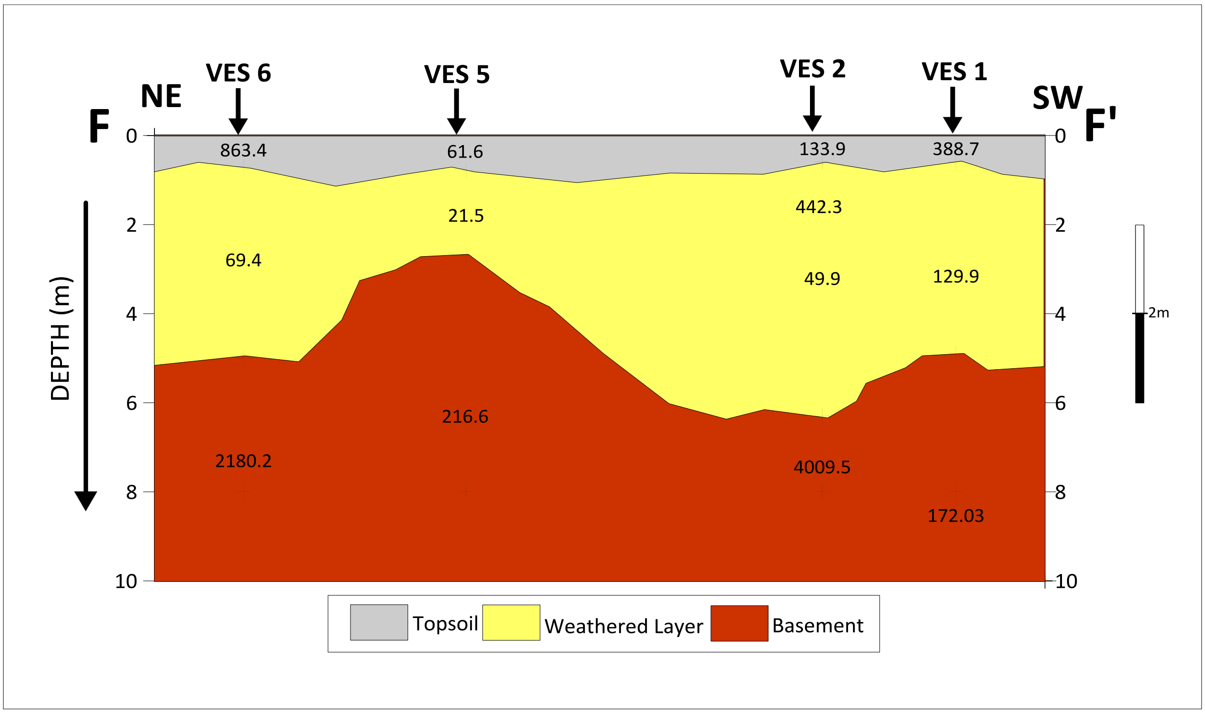

Figure 6:- The geoelectric section along traverse line F -F'

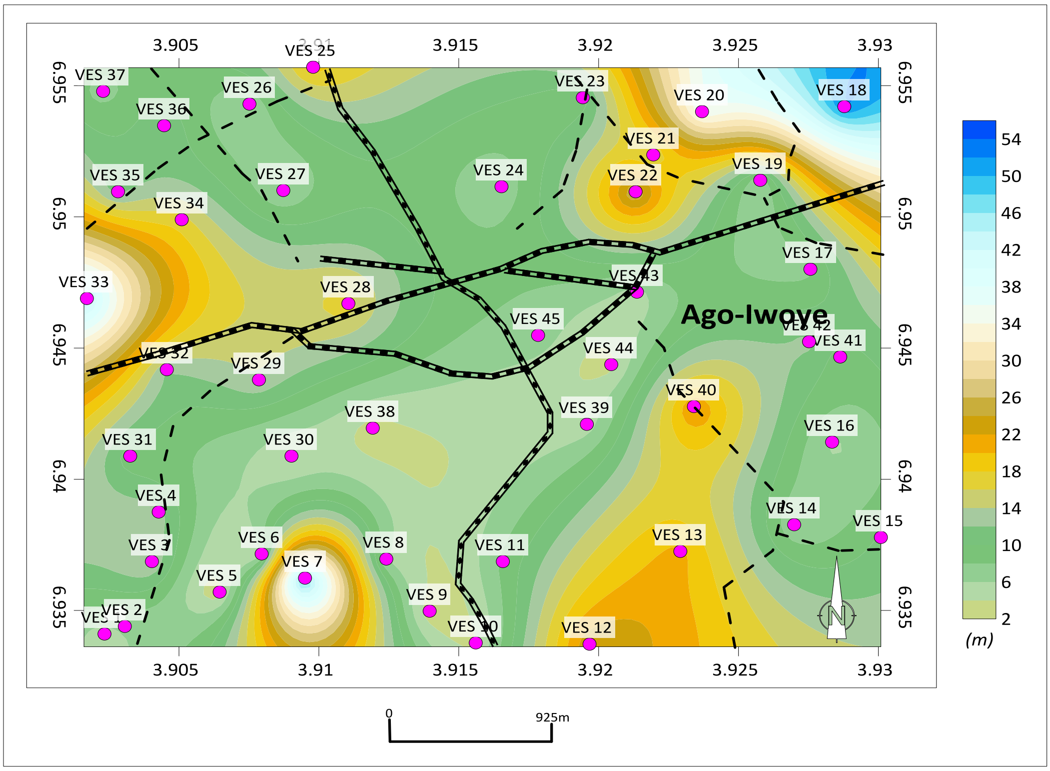

Figure 7: The Isopach map of the overburden thickness in the study location showing the VES points.

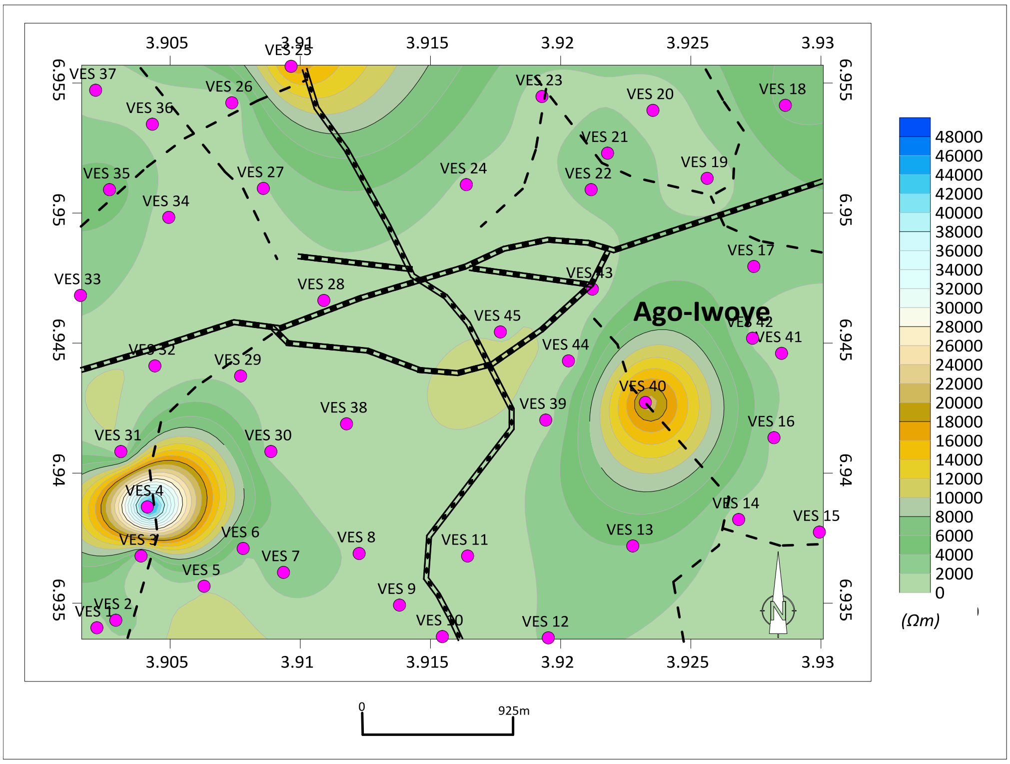

Figure 8:-Basement resistivity map of the study location showing the VES points.

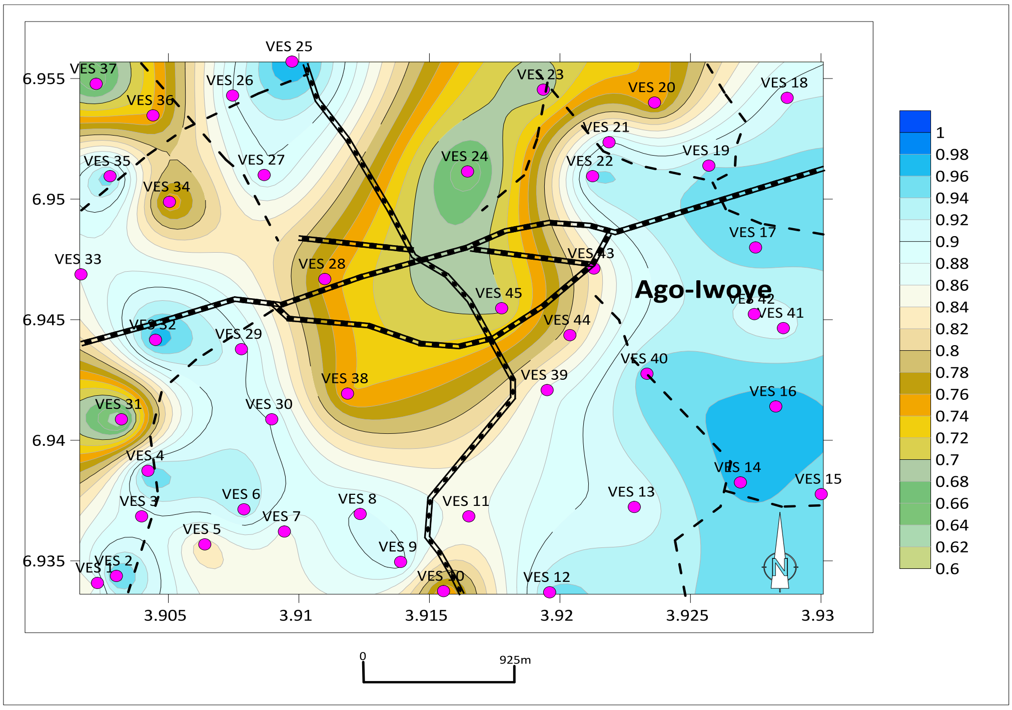

Figure 9:- Reflection coefficient of the study location.

Scientia Africana, Vol. 21 (No. 1), April, 2022. Pp 37-52
https://dx.doi.org/10.4314/sa.v21i1.4
ISSN 1118 – 1931

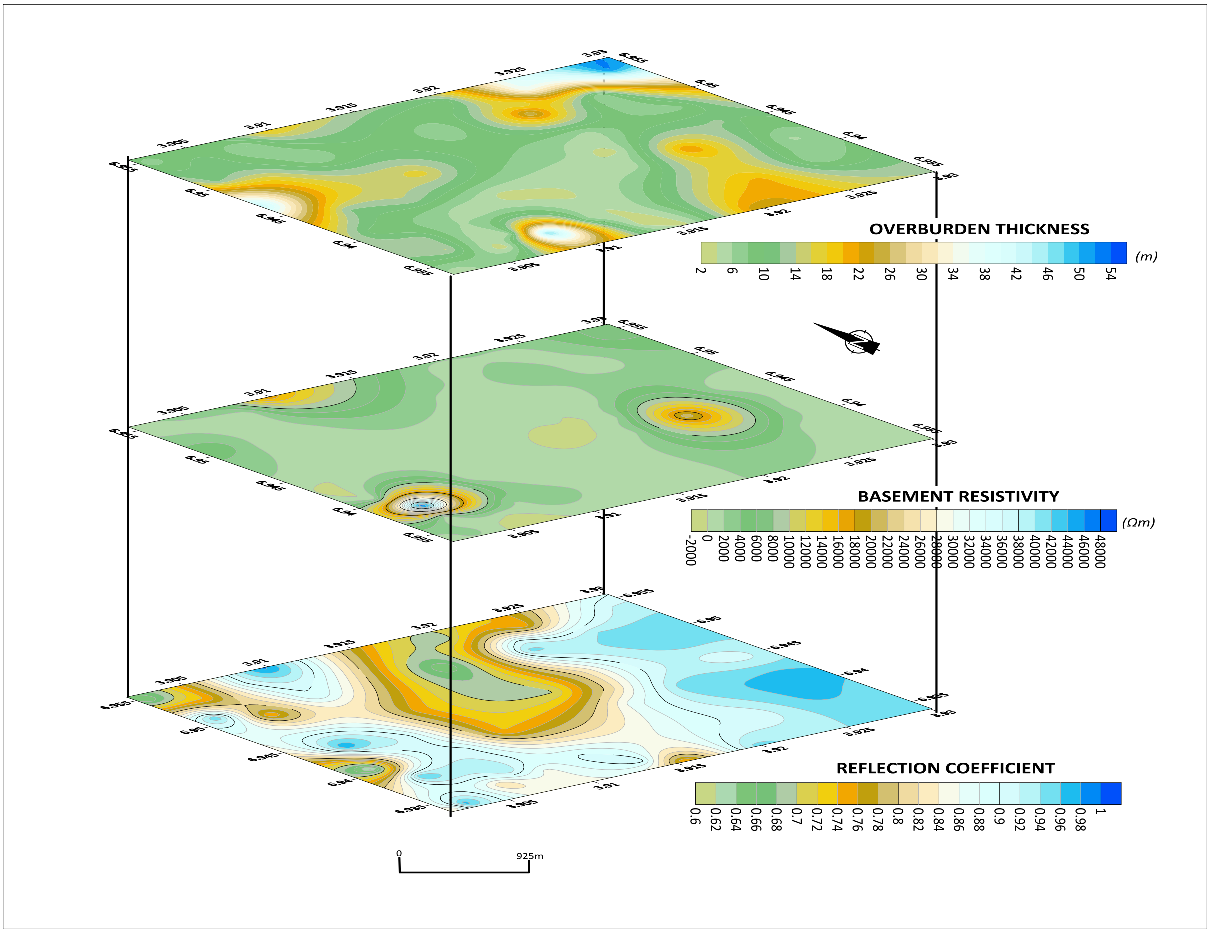

Figure 10:- Stacked map of overburden thickness, basement resistivity and reflection coefficient of the study area.

Delineation of Groundwater Potential Zones

Studying the condition of the basement rock underlying a crystalline basement environment is very essential in the delineation of groundwater potential. Hydrogeologically, they are relatively impermeable and they often have no primary porosity resulting from rock formation process, these characteristics (porosity and permeability) serves as the basis for which the hydrogeological potential of a rock is determined (Olayinka, 1996, Bayewu *et al*., 2017). The hydrogeologists therefore suggested that the major aquiferous zone in a crystalline terrain include fracture in the basement rock and tapping from the overlying weathered layer before the basement rock. The presence of fracture in rock is mainly due to post formation process (such as tectonics which involves series of tectonic movement's stages) capable of creating secondary porosity that in turn increases the groundwater potential of the rock. The weathered layer aquifer configuration resulted from the mineralogical framework of the rock undergoing weathering as weathering is more intense in rock containing ferromagnesian minerals than silicate rich mineral (Vinnarasi *et al.*, 2021). These two important hydrogeological factors can be inferred from geoelectric parameters obtained using the electrical resistivity method considering the overburden thickness and basement resistivity respectively and they can be incorporate to delineate the groundwater potential of the study location. On the basis of the integration of the overburden thickness and reflection coefficient, the groundwater potential of the study area is classified into three, which include area of high, moderate and low potential or yield (Table 2) and this parameters were carefully used to delineate the groundwater potential of each vertical electrical sounding point obtained in the study area (Table 3).

The groundwater potential of the study area reveals that groundwater potential is high in the northeastern and western part. Moderate groundwater potential region is noticeable in the western, and some part of Northeastern and southwestern part of the study location while the remaining part shows low groundwater potential (Figure 11). The potential yield delineation for low, moderate and high potential reveal a percentage of 58%, 17% and 2% respectively thereby indicating the study area can be characterized as low to moderate potential.

Lithological Log

Core sample recovery serves as a direct tool in hydro geophysical works and also other fields of geosciences as they are use as confirmation of geophysical method. Two (2) borehole logs was obtained at Lambo-Lambo and Ayegbami area of Ago-Iwoye with high materials recovery containing weathered materials in both well, with approximately high overburden thickness of >30m (Figure 12). Lambo-Lambo wells showed presence of clayey sand while it is absent in Ayegbami which showed mainly thickness of sand. This borehole has been giving a reasonable yield of water at an economic rate both in the wet and dry season which is due to the high overburden thickness of this area.

Table 2:- Groundwater Potential Classification Criteria (Bayewu *et al*., 2017)

	Overburden	Reflection coefficient	Remarks
1	<10	>0.8	Low groundwater yield
2	10--20	>0.8	Moderate groundwater yield
3	>20	<0.8	High groundwater yield

Table 3:- Groundwater yield potential classification of established VES point

VES point	Overburden Thickness	Reflection Coefficient	Groundwater Yield potential
VES 1	4.9	0.86	Low
VES 2	6.3	0.98	Low
VES 3	14.2	0.89	Moderate
VES 4	13.1	0.96	Moderate
VES 5	2.7	0.82	Low
VES 6	5	0.94	Low
VES 7	48.8	0.85	Moderate
VES 8	6.5	0.91	Low
VES 9	3	0.91	Low
VES 10	3.6	0.73	Low

Scientia Africana, Vol. 21 (No. 1), April, 2022. Pp 37-52 https://dx.doi.org/10.4314/sa.v21i1.4
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

VES 11	8.4	0.85	Low
VES 12	23.8	0.95	Moderate
VES 13	20.6	0.90	Moderate
VES 14	6.3	0.97	Low
VES 15	10.3	0.95	Moderate
VES 16	5.7	0.98	Low
VES 17	7.7	0.95	Low
VES 18	52.2	0.92	Moderate
VES 19	6	0.94	Low
VES 20	35.8	0.74	High
VES 21	15.9	0.91	Moderate
VES 22	26.3	0.95	Moderate
VES 23	8.8	0.69	Low
VES 24	6.7	0.64	Low
VES 25	19	0.99	Moderate
VES 26	5.8	0.90	Low
VES 27	6.2	0.90	Low
VES 28	17.1	0.75	Moderate
VES 29	13.7	0.91	Moderate
VES 30	4	0.90	Low
VES 31	9	0.61	Low
VES 32	12.1	0.98	Moderate
VES 33	44.4	0.86	Moderate
VES 34	17.1	0.74	Moderate
VES 35	11.3	0.96	Low
VES 36	11.5	0.74	Moderate
VES 37	7.2	0.64	Low
VES 38	3.1	0.74	Low
VES 39	4.9	0.87	Low
VES 40	22.3	0.95	Moderate
VES 41	9.1	0.91	Low
VES 42	12.5	0.91	Moderate
VES 43	5.1	0.83	Low
VES 44	3.3	0.81	Low
VES 45	7.3	0.70	Low

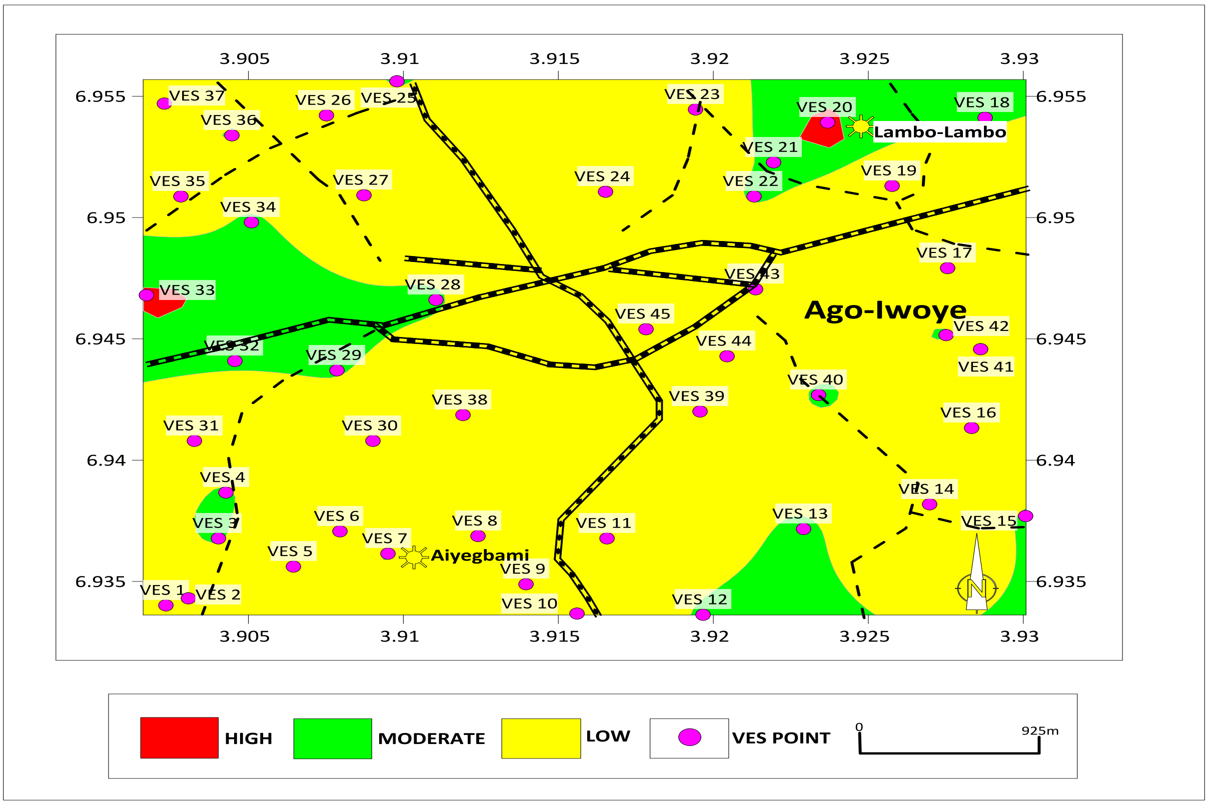

Figure 11:- Groundwater potential map of the study area.

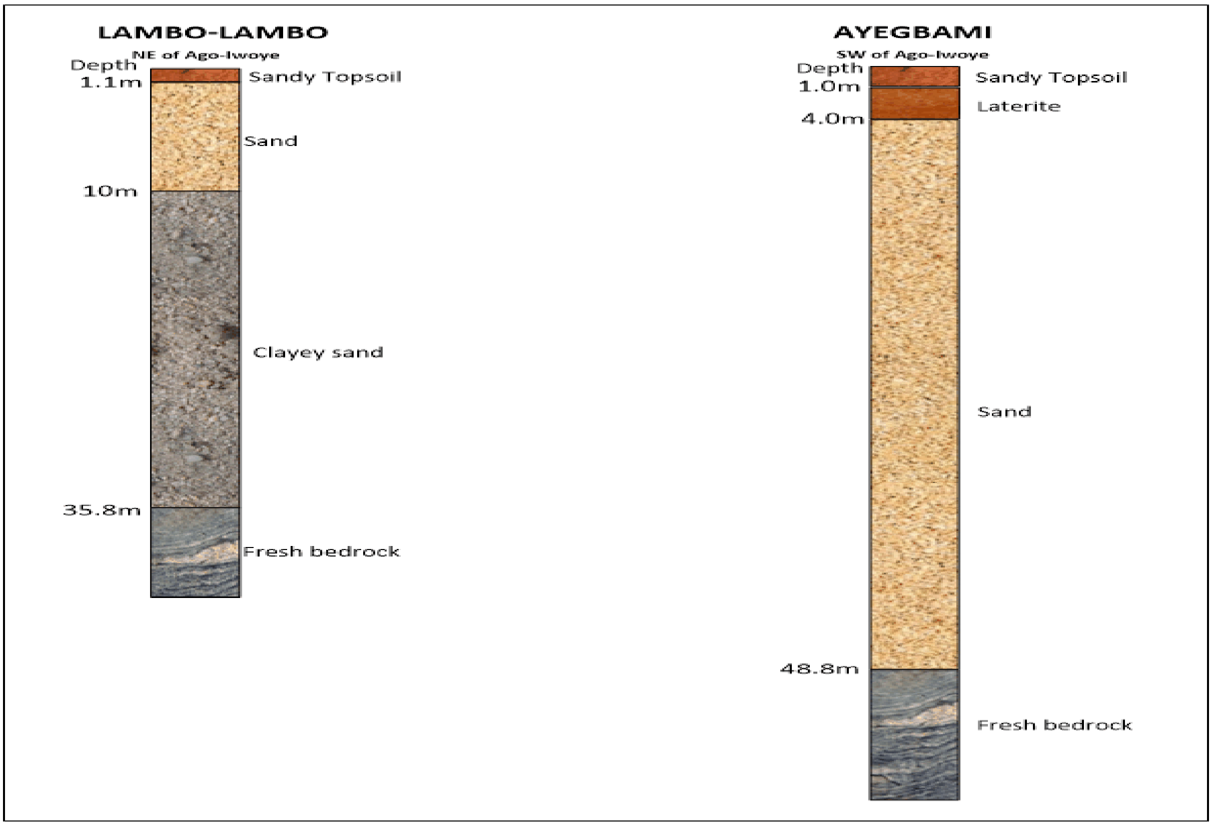

Figure 12:-The lithological log for borehole at Lambo-Lambo and Ayegbami in the study area

Scientia Africanâ, Vol. 21 (No. 1), April, 2022. Pp 37-52 https://dx.doi.org/10.4314/sa.v21i1.4
© Faculty of Science, University of Port Harcourt, Printed in Nigeria ISSN 1118 – 1931

CONCLUSION

Interpretation of results obtained from the geological information, geoelectric parameters and core lithology has revealed the condition of the subsurface and this has been used to infer the hydrogeological condition of the subsurface in the study area. The study area is predominantly of low yield based on the classification of groundwater yield potential for the study area. Fracturing and relatively moderate overburden increases the ground water potential in the eastern and western part of the study location. High aquiferous groundwater potential areas is only noticeable in the northeastern and western part of the study area as a local occurrence and this is due to the fracturing of the rock that has created secondary porosity by tectonism and also presence of overburden thickness to bedrock.

REFERENCES

Adeyemi, G.O. and R.O. Salami (2004) Some Geotechnical Properties of Two Termite-reworked Lateritic Soils from Ago-Iwoye, South-Western Nigeria Geotechnology, 133, pp. 35 – 41.

Akinrinade, O. J., and Adesina, R. B. (2016. Hydrogeophysical investigation of groundwater potential and aquifer vulnerability prediction in basement complex terrain–a case study from Akure, Southwestern Nigeria. Materials and Geoenvironment, 63(1), pp. 55-56.

Alfano, L., (1959) Introduction to the interpretation of resistivity measurements for complicated structural conditions: Geophysics Prospecting, 7, pp. 311-366.

Ariyo, S.O., Ajibade, O.M., Coker, J.O., Adeyemi, G.O., Oshagale, B. and Odugbesan, O.O. (2021) Hydrogeophysical Characterization of Aquifer for Groundwater Potential Evaluation at Ogbere, Southwestern Nigeria, Journal of Mining and Geology, 57(1), pp. 33-39.

Bayewu O. O., Oloruntola M. O., Mosuro G. O., Laniyan T. A., Ariyo S. O, Fatoba J. O. (2017) Geophysical evaluation of groundwater potential in part of southwestern Basement Complex terrain of Nigeria, Journal of Applied Water Science, 7, pp. 4615–4632.

Bayewu O.O., Oloruntola M O., Mosuro G.O., Laniyan T.A., Ariyo S.O., and Fatoba J.O. (2018) Assessment of groundwater prospect and aquifer protective capacity using resistivity method in Olabisi Onabanjo University campus, Ago-Iwoye, Southwestern Nigeria, NRIAG Journal of Astronomy and Geophysics, 7(2), pp. 347-360, DOI: 10.1016/j.nrjag.2018.05.002

Carruthers, R.M., (1985) Review of geophysical techniques for groundwater exploration in crystalline basement terrain: British Geological Survey, Regional Geophysics Research Group, Report, 85/3, pp 30.

Crous, C.M., (1971) Computer assisted interpretation of electrical soundings: Colorado School of Mines, Thesis T-1363.

Emenike, E.A., (2001) Geophysical exploration for groundwater in a Sedimentary Environment: A case study from Nanka over Nanka Formation in Anambra Basin, Southeastern Nigeria: Global Journal of Pure and Applied Sciences, 7(1), pp. 1-11.

Flathe, H. (1963) Five-layer master curves for the hydrogeological interpretation of geoelectric resistivity measurements above a two-story aquifer: Geophysical Prospecting, 11, pp. 471-508.

Ghosh, D.P. (1971) Inverse filter coeffecients for the computation of apparent resistivity standard curves for a horizontally stratified earth: Geophysical Prospecting, 19(4), pp. 769-775.

Haque, A., Salama, A., Lo, K., and Wu, P. (2021) Surface and Groundwater Interactions: A Review of Coupling Strategies in Detailed Domain Models. Hydrology, 8(1), pp. 35.

Olayinka, A. (1996) Carbon mineralization from poultry manure straw sawdust amended Alfisol. Ife Journal of Agriculture, 1, pp. 26-36.

Olayinka, A.I. and Olorunfemi, M.O. (1992) Determination of geoelectrical characteristics in Okene area and implication for borehole siting. Journal of Mining and Geology, 28, pp. 403-412

Olayinka, A.I., and Mbachi, C.N.C. (1992) A technique for the interpretation of electrical sounding from crystalline basement Areas of Nigeria. Journal of Mining and Geology, 27, pp. 63-69.

Olorunniwo, M.A., and M.O. Olorunfemi. (1987) Geophysical investigation for groundwater in Precambrian terrain, a case history from Ikare, Southwest Nigeria, Journal of African Earth Sciences, 6, pp. 787-796.

Vinnarasi, F., Srinivasamoorthy, K., Saravanan (2021) Chemical weathering and atmospheric carbon dioxide (CO_2) consumption in Shanmuganadhi, South India: evidences from groundwater geochemistry. Environ Geochemical Health, 43, pp. 771–790. https://doi.org/10.1007/s10653-020-00540-3 .

Zohdy, A. A. (1965) The auxiliary point method of electrical sounding interpretation, and its relationship to the Dar Zarrouk parameters. Geophysics, 30(4), 644-660.

Zohdy, A. A., Eaton, G. P., & Mabey, D. R. (1974) Application of surface geophysics to ground-water investigations.

Zohdy, A.A., Bisdorf, R.J., and Gates, J.S. (1994) A Direct Current Resistivity Survey of the Beaver Dam Wash Drainage in Southwest Utah, Southeast Nevada, and Northwest Arizona: U.S. Geological Survey Open-File Report, 94-676, pp. 87.