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BASEMENT AQUIFER POTENTIALS DELINEATION IN ABEOKUTA SOUTHWESTERN BASEMENT COMPLEX OF NIGERIA USING ELECTRICAL RESISTIVITY SURVEY

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Abstract: Electrical resistivity survey was carried out in some parts of Abeokuta, southwestern Nigeria with the aim of delineating the resistivity characteristics of the basement groundwater yield in the study area. The study area lies within the Southwestern Basement Complex of Nigeria and it is underlain by granite gneiss, biotite gneiss and porphyroblastic gneiss rock types. Thirty (30) Vertical Electrical Sounding (VES) points were probed using the Schlumberger configuration with maximum electrode spacing (AB/2) of 100 m. The VES data were plotted and were initially interpreted with the aid of partial curve matching approach, the results were further processed using the WINREST software to produce iterated curves which were used to delineate the respective layers, resistivity and depth of the subsurface. Iterated curves showed the presence of three (3) to five (5) inferred lithological units which include the topsoil (59.4 – 914.2 Ω m), the weathered layer which include clay/sandy-clay/sand (15.4 – 544.3 Ωm) and fresh/fractured basement (123.1 – 21858.5 Ωm). The overburden thickness ranges between 3.2 to 43.7 m; while reflection coefficient ranges between 0.71 – 0.99. The consideration of basement resistivity, overburden thickness and the reflection coefficient values were used to categorize the sample point into their yield potentials as either low, medium or high and it was used to generate a groundwater potential map for the area. The combination of these three resistivity survey parameters in predicting the water potential of the area therefore enhances the accuracy of the interpretation better than using one parameter for its prediction.

Keywords: Basement aquifer, basement resistivity, reflection coefficient, water potential

Introduction

The concept of the electrical resistivity method of geophysical exploration involve the introduction of electric current into the ground in order to map the variation in the electrical property of the subsurface materials (rock or soil) present (Keller and Frischknecht, 1966; Metwaly, 2012; Akhtar *et al*., 2018). This can easily be determined because of the variation in the behavior of the various rock types to electrical current. The successful measurement of this provides information on the form and electrical properties of such subsurface in homogeneities (Kunetz, 1966, Rhett 2001; De Pasquale *et al*., 2019). Application of the vertical electrical sounding (VES) technique has been greatly useful in several exploration works which include environmental, groundwater (Zohdy *et al.*, 1980; Olorunfemi *et al.*, 1993; 2004), Dam Site Investigation (Aina *et al.*, 1996) and contamination investigations (Afolabi and Olorunfemi, 2004).

Groundwater reserves are of vital importance in domestic, agricultural and industrial purpose hence there is need to carefully understand the geometry and properties of the aquifers in an environment (these properties vary from place to place or geological settings). Hence, the need to carefully understand these factors before reasonable inference is made. Exploring for groundwater in the hard rock geological terrain has been a challenging issue because the promising geological media that can serve as good aquifer is the fractured and fissured media, that is, groundwater potentials in this region depend mainly on the thickness of the weathered and fractured layer overlying the basement.

Highly weathered overburden and fractured zones of the basement rock usually serves as aquifer but due to the unpredictable nature of aquifer configuration in basement terrain, there is need to carefully examine other important factors such as the geology, hydrogeological and geophysical investigations for formation (Satpathy and Kanungo, 1976; Fadele *et al*., 2013). Notable research findings done by some hydrogeological and hydrogeophysical investigations include David and Ofrey (1989), Ajayi and Abegunrin (1990), Carruthers and Smith (1992), Dan-Hassan and Olorunfemi (1999), Adelusi and Folami (2000) and Bayewu, (2018), they reported that groundwater in hard rock terrain occur in the weathered and fractured zones/columns and the yield from this fractured aquifer zone is supplemented by the accumulated groundwater in the fractured zones of the basement rocks and also presence of thick overburden layer overlying the fractured basement rock.

The effective survey of groundwater in the basement complex territory involves a suitable knowledge of its hydrogeological features as a result of the intermittent characteristic of basement aquifers (Satpathy and Kanugo, 1976). Geoelectrical investigations offer an active means to image the subsurface and the groundwater region lacking a large number of observation wells (Prasanna *et al*., 2008). VES determines the thickness and resistivity of different horizontal or low-dipping subsurface layers, including the aquifer zone (Choudhury and Saha, 2004).

The visualization of subsurface fractured or weathered zone has been achievable using the geophysical method under several geological conditions. Although several geophysical methods can be used in groundwater exploration but the most widely and suitable method is the electrical resistivity method because of its simplicity in field operation in several terrain and its ability to conveniently map out the extent of subsurface layered strata. The best considered configuration of the electrical method is the Schlumberger configuration (vertical electrical sounding) which is capable of probing vertically down depth to reveal the subsurface lithology that may be present.

The ability of the VES technique to map the thickness and resistivity of different horizontal or low-dipping subsurface layers, including the aquifer zone (Choudhury and Saha, 2004) makes it more usable for groundwater exploration because typically, aquifer zones often characterized by relatively low resistivity values in the basement complex terrains are either fractures such as joints and faults or the weathered basements (DuPreez and Barbar, 1965; Olayinka and Olorunfemi, 1992; Olorunfemi and Olorunniwo, 1985).

Geophysical survey was carried out in some parts of Abeokuta, southwestern Nigeria in order to delineating suitable or favorable groundwater potential areas using electrical resistivity method (VES).

Location and geology of the study area

The study location lies within the southeastern part of Abeokuta, southwestern Nigeria between latitude 7˚7' N - 7˚10' N of the equator and 3˚18' E and 3˚21'E of the Greenwich Meridian. The area covers important settlements which include Olomore, Adigbe, Agbeloba, Ibara, Onikolobo with a good accessibility road networking which include an Express highway which links some major, minor roads and various footpaths (Fig. 1).

The area is located in the moderately hot, humid tropical climate zone of Nigeria. There are two distinct seasons: the rainy season which last from March/ April to October/November and the dry season which last for the rest of the year from October/November till March/April. The mean temperature ranges from 24 – 30^{0}C, thus the mean temperature of the study area is about 27^{0}C (Onakomaiya *et al*., 1992; Ogunrayi *et al*., 2016). The major river which is River Ogun is dendritic in nature and flows from the northeast to southwest and also serves as a tributary to the Atlantic Ocean. The study area is underlain by the Southwestern Basement rocks and consists of Granite gneiss, Biotite gneiss and Porphyroblastic gneiss as shown in Fig. 2. The western part is dominated by the granite gneiss and the central part of the area is occupied by porphyritic gneiss while the eastern part is predominantly biotite gneiss.

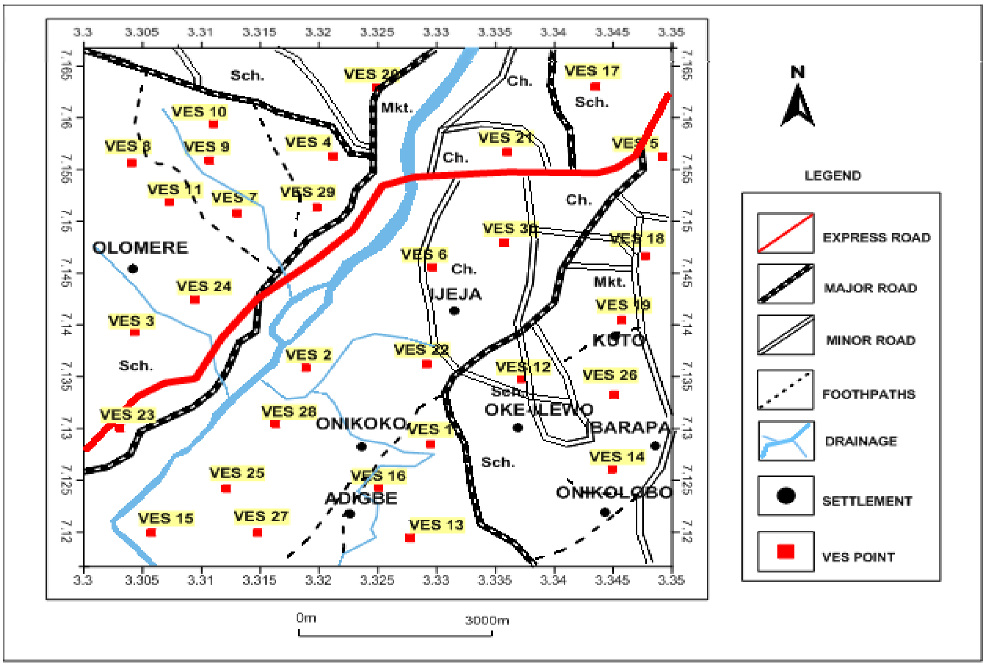

Fig. 1: Location map of the study area

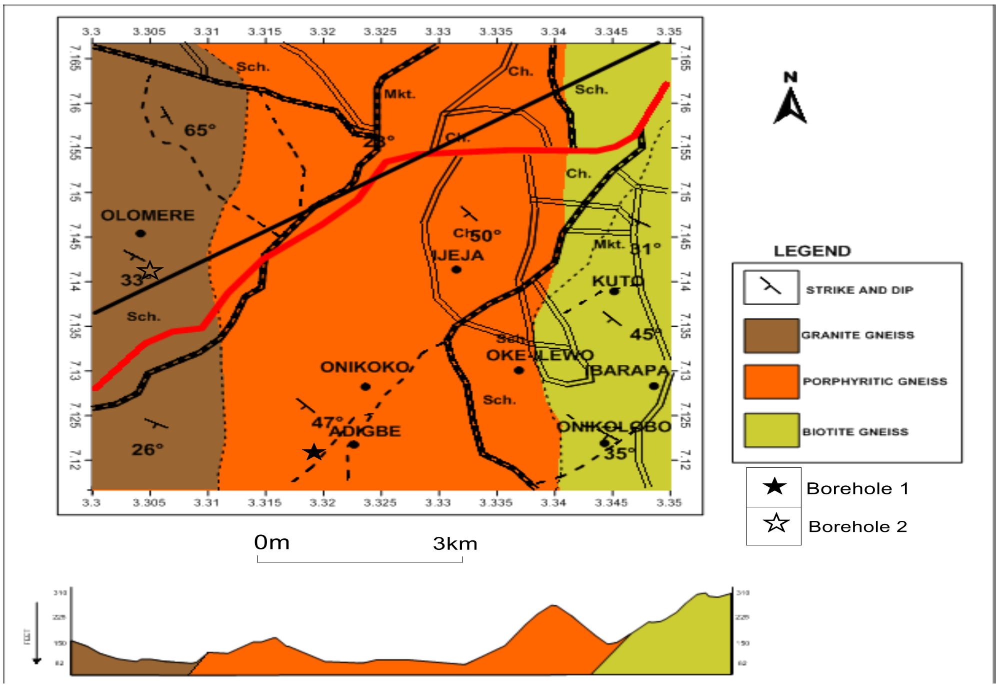

Fig. 2: Geological map of the study area

Materials and Methods

The study data acquisition was carried out with the aid of Allied Ohmega System resistivity meter. A total of thirty (30) Vertical Electrical Sounding point were established within the study area to a maximum (AB/2) spacing of 100 m and were evenly distributed as much as possible in order to cover the entire study area. This is done to investigate the subsurface electrical resistivity response by measuring the resistance via the passage of electrical current with a pair of currents and potential electrodes. The apparent resistivity values were obtained by further multiplying the resistances its corresponding geometric factor (G) using Zohdy *et al*. (1974) formula. The resulting apparent resistivity values were plotted on the vertical axis against electrode position (AB/2) on the horizontal axis on a log plot paper, the plotted points were well joined manually and they were interpreted using the partial curve matching techniques (Koefoed, 1979; Orellana and Mooney, 1966; Zohdy, 1965; Keller and Frischknecht, 1966) which are standardized pre-calculated curves and their auxiliaries. Information obtained (resistivity and thickness) were further processed using the 1-D inversion WINREST geophysical software program which is a computer based software the iteration, whereby the data obtained and the pre calculated geo-electric parameters from the partial curve matching stage is model and iterated using Vander Velpen (2004) to give the respective layer present, true resistivity, depth and thicknesses. Reflection coefficient (r) were determined using appropriate formula shown in equation 1, others such as the overburden thickness and basement resistivity were also put into consideration and are well represented geospatially using SURFER 14 software.

The reflection coefficient (r) of the study area was calculated using the formula in Olayinka (1996).

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

Where r is the reflection coefficient, ρ_n is the layer resistivity of the nth layer which is usually the resistivity of the basement, $\rho_{(n-1)}$ is the layer resistivity overlying the nth layer.

Results and Discussion

The interpreted data revealed the presence of six (6) geoelectric curve types which include H, HA, QH, KH, AA and AKH with a percentage ratio of 47, 20, 20, 7, 3 and 3%, respectively (Fig. 3). Typical iterated curves obtained from the computer iterated process for VES 1, 2 and 3 are shown in Fig. 4a & b, respectively. The inferred lithological layer obtained via the process of iteration reveal the presence of 3 – 5 lithological layers with resistivity ranging from topsoil (59.4 – 914.2 Ωm), the weathered soil layer which include Clay/Sandy-Clay/Sand (15.4 – 544.3 Ωm) and basement (123.1 – 21858.5 Ωm). The calculation of reflection coefficient helps in knowing the competence and freshness of the basement rock. Basement with high reflection coefficient values (>0.8) is considered to favour fresh basement while values <0.8 favour fractured basement (Olorunfemi and Okhue, 1992; Bayewu *et al*., 2017). The results obtained from interpreted VES curves are presented in Table 1 and comprises parameters such as the basement resistivity, overburden thickness and reflection coefficient of the area.

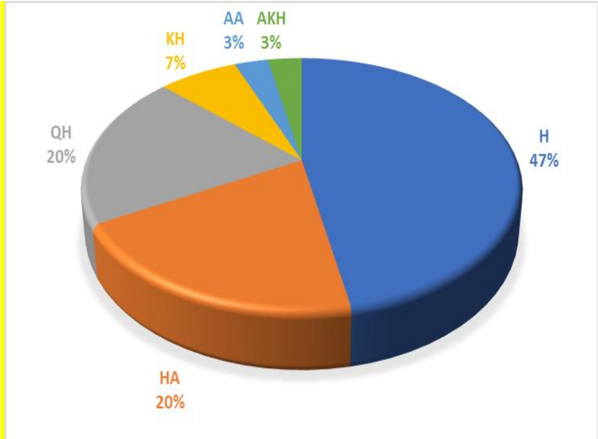

Fig. 3: Percentage occurrence of curve types in the study area

Table 1: Geoelectric parameters of the VES points

VES No.	Overburden Thickness (m)	Basement Resistivity (Ωm)	Reflection Coefficient
VES 1	3.20	1481.10	0.96
VES 2	7.50	3336.10	0.92
VES 3	20.50	123.10	0.81
VES 4	43.70	1844.70	0.90
VES 5	30.30	13955.80	0.99
VES 6	5.20	1537.60	0.83
VES 7	7.90	1663.70	0.89
VES 8	23.20	1298.50	0.90
VES 9	5.00	591.10	0.87
VES 10	9.70	524.40	0.84
VES 11	6.00	825.80	0.93
VES 12	28.90	5665.10	0.91
VES 13	21.20	499.20	0.81
VES 14	11.50	454.80	0.93
VES 15	15.00	21858.50	0.99
VES 16	4.50	1045.40	0.81
VES 17	9.90	471.90	0.72
VES 18	8.20	1528.50	0.95
VES 19	33.30	356.40	0.91
VES 20	39.70	1099.70	0.88
VES 21	35.90	712.90	0.80
VES 22	8.00	1929.40	0.96
VES 23	4.40	2493.00	0.98
VES 24	5.40	2697.40	0.92
VES 25	8.10	6985.60	0.97
VES 26	15.60	2346.30	0.99
VES 27	12.80	6133.80	0.99
VES 28	20.20	481.60	0.84
VES 29	9.20	2959.70	0.94
VES 30	14.40	1562.40	0.81

The geoelectric section plotted across part of the area revealed the overburden thickness of its subsurface and showed that VES 5 and VES 19 shows an appreciable high overburden thickness (>20 m), this area therefore shows a promising groundwater yield (Fig. 5).

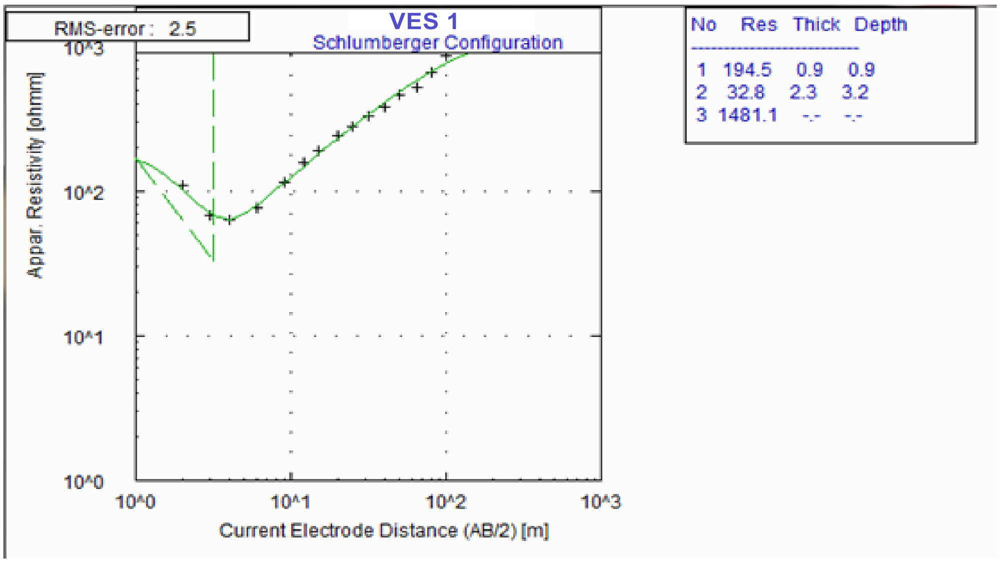

Fig. 4a: Iterated curves for VES 1 in the study area

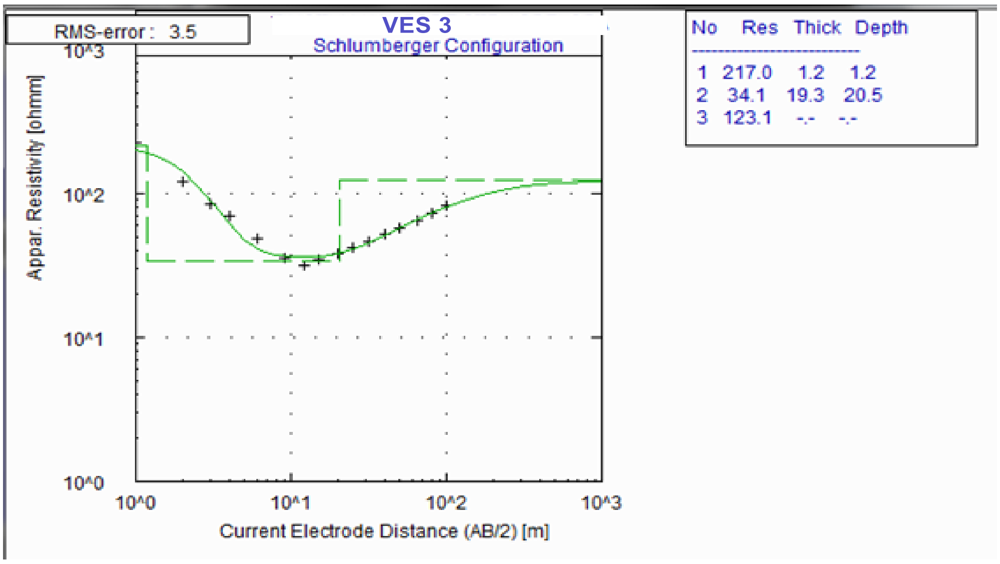

Fig. 4b: Iterated curves for VES 3 in the study area

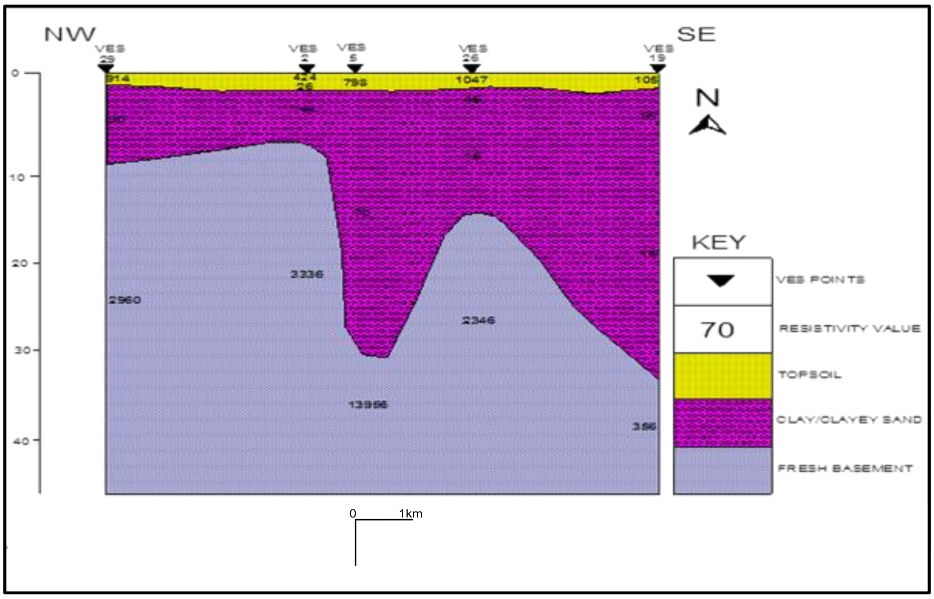

Fig. 5: Geoelectric section across traverse 1 showing the variation of the overburden thickness in the study area

An isopach map showing the variation of overburden thickness across the entire area of the study area is shown in Fig. 6. This map shows that overburden thickness varies from 3.2 – 43.7 m. The map shows low overburden thickness values in the central, southern and western part of the area (<20 m) but shows high value in the northern part and the eastern part of the study area (>20 m). Area with high overburden thickness tends to favor accumulation of groundwater, hence, are indicative of a good site for borehole drilling or for groundwater exploration while area with shallow overburden thickness might not be favorable to groundwater exploration yield, nevertheless the area can still have a good aquiferous yield if there is presence of fracture within the basement (Olorunfemi and Okhue, 1992). The isoresistivity map (Fig. 7) was produced in order to show the spatial variation in the resistivity value of the subsurface basement rock which serves as a good tool to distinguish high water-bearing zones from low water-bearing ones. Zones with relatively low resistivity values usually indicate fractured areas and favors groundwater yield, the low resistive region have a resistivity value range of 123.1– 525.2 Ωm. The overall observed resistivity value of basement rock resistivity ranges between 123.1 and 21858.5 Ωm. It can be observed that the resistivity value within the study area is generally high except some region in the northern part of the study area. The reflection coefficient map was also plotted, its values ranges between 0.71-0.99. High reflection coefficient values occur in most part of the study area except the northeastern indicating good aquiferous yield potential than other region with high reflection coefficient value (Fig. 8). The overburden thickness, basement resistivity and reflection coefficient map were stacked in Fig. 9 in order to directly visualize the variation in the respective property within the study area at a glance making it easy to map high and aquifer potential yield regions within the study area.

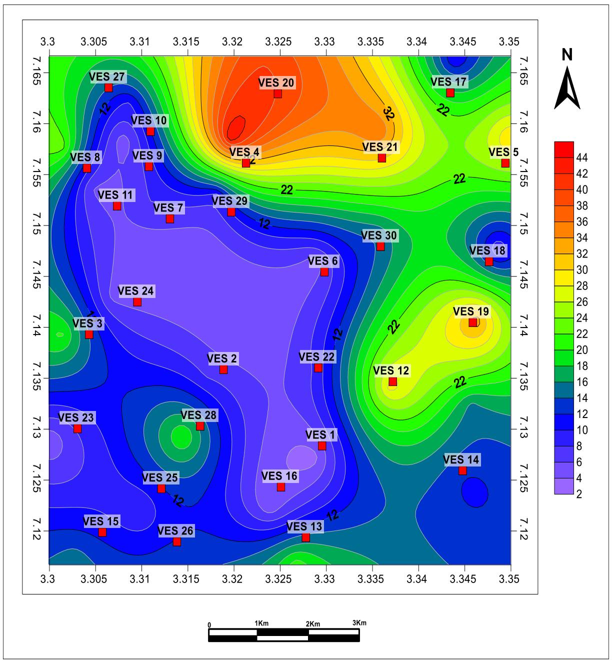

Fig. 6: Isopach map of overburden thickness of the study area

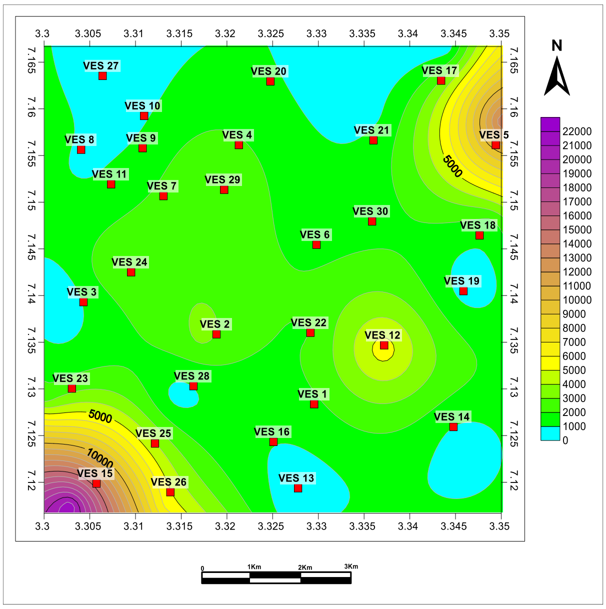

Fig. 7: Basement isoresistivity Map of the study area

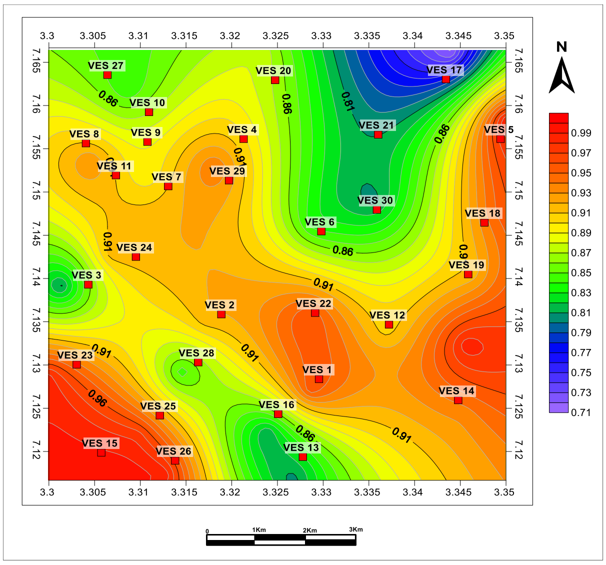

Fig. 8: Reflection coefficient Map of the study area

Modeling of groundwater potential areas

The most important parameter needed to be put into consideration during exploration in basement terrain include the understanding of the underlying rocks type within the study area (geology) and history and their post formation weathering process (Olorunfemi *et al*., 2004), some of the factors can easily be mapped and infer with the use of the electrical resistivity techniques. Hence in a study that involves groundwater exploration in a basement terrain, the most important geoelectric factors that influence borehole citing include the overburden thickness and the reflection coefficient value. The relationship existing between these factors is considered that as the reflection coefficient value decreases with high overburden thickness, the groundwater potential increases (i.e. high overburden thickness and low reflection coefficient value).The reflection coefficient has been greatly be appreciated in groundwater exploration in basement terrain because observed that the resistivity of the basement cannot be solely relied on to identify areas of promising aquifer within basement terrain, hence, the consideration of its reflection coefficient brought a better result which shows the degree of fracturing of the underlying basement better than depending solely on the resistivity values only (Olayinka, 1996; Bayewu *et al*., 2017).

These factors were carefully employed and were used to create a groundwater potential modelby categorizing of the study area into three basic subgroup which include; low, moderate and high groundwater potential yield (Table 2)

i) ***Area of low groundwater yield***: This are areas with overburden thickness equal or less than 10 m and reflection coefficient equal or greater than 0.8 (Overburden Thickness ≤10 m and Reflection coefficient is ≥0.8).

ii) ***Area of moderate groundwater yield***: These are areas with overburden thickness between 10 – 20 m and reflection coefficient greater than 0.8 (10 m ≥ Overburden Thickness ≤ 20 m and Reflection coefficient is ≥0.8).

iii) ***Area of high groundwater yield***: This are areas with overburden thickness equal or less than greater than 20 and reflection coefficient less than 0.8 (Overburden thickness ≥ 20 m and Reflection Coefficient <0.8).

Table 2: Model used in categorizing groundwater potential of the study area

	Over–burden	Reflection coefficient	Remarks
1	<10	>0.8	Area with low groundwater yield
2	10-20	>0,8	Area with moderate groundwater yield
3	>20	<0.8	Area with high groundwater yield

Table 3: Table showing the groundwater potential of the VES stations based on the model

VES point	Overburden thickness (m)	Reflection coefficient	Remark
VES 1	3.20	0.96	Low Yield
VES 2	7.50	0.92	Low Yield
VES 3	20.50	0.81	High Yield
VES 4	43.70	0.90	Medium Yield
VES 5	30.30	0.99	Medium Yield
VES 6	5.20	0.83	Low Yield
VES 7	7.90	0.89	Low Yield
VES 8	23.20	0.90	Medium Yield
VES 9	5.00	0.87	Low Yield
VES 10	9.70	0.84	Low Yield
VES 11	6.00	0.93	Low Yield
VES 12	28.90	0.91	Medium Yield
VES 13	21.20	0.81	High Yield
VES 14	11.50	0.93	Medium Yield
VES 15	15.00	0.99	Medium Yield
VES 16	4.50	0.81	Low Yield
VES 17	9.90	0.72	Medium Yield
VES 18	8.20	0.95	Low Yield
VES 19	33.30	0.91	Medium Yield
VES 20	39.70	0.88	Medium Yield
VES 21	35.90	0.80	High Yield
VES 22	8.00	0.96	Low Yield
VES 23	4.40	0.98	Low Yield
VES 24	5.40	0.92	Low Yield
VES 25	8.10	0.97	Low Yield
VES 26	15.60	0.99	Low Yield
VES 27	12.80	0.99	Medium Yield
VES 28	20.20	0.84	Medium Yield
VES 29	9.20	0.94	Low Yield
VES 30	14.40	0.81	Medium Yield

Using the three criteria mentioned above, the area was delineated to high, moderate and low groundwater yield, and this was used to produce a groundwater potential map for the study area (Fig. 10). From this map, areas within the central parts of the study area have a low groundwater yield, areas around the northern and eastern parts have a moderate groundwater yield while part of the southern, northern and western part of the study area shows a high groundwater potential. Generally, the groundwater potential yield of the area which are delineated to low, moderate and high based on the potential yield covers an average percentage area of 50, 40 and 10% respectively making the entire area to have a low to moderate groundwater potential yield. This is as a result of low overburden thickness associated with no presence of visible fracture and high reflection coefficient values (Table 3).

Lithological log information in two areas was obtained from Ogun State Ministry of Water Resources and they are the lithological logs from the drilling activities carried out in the area. The first borehole is located in Adigbe locality (Fig. 2), its log information is shown in Fig. 11 (Borehole 1), it is usually abandoned during dry season as a result of very low borehole water yield and even in the raining season, very few residents patronize it for their domestic use. The overburden thickness is 8.7 m (<10 m) and there was no visible occurrence of fracture. Borehole 2 (Fig. 11) is located in Olomore and showed a thicker overburden of 27.3 m, also there was a visible occurrence of fracture (about 6 m in thickness). The overburden thickness and the presence of fracture aid the yield of the borehole and therefore made it a productive one. The yield is perennial and majority of the residents in this area fetch their domestic water from it.

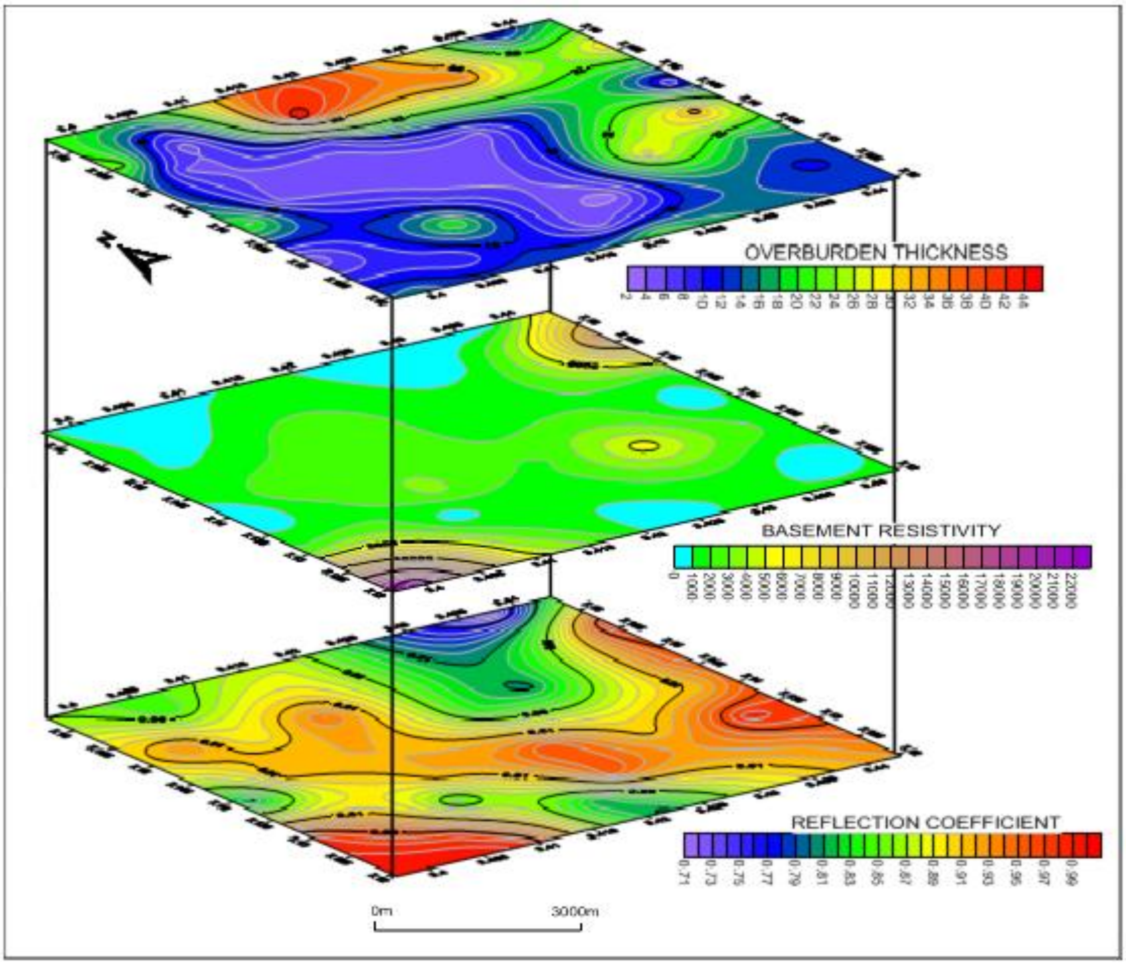

Fig. 9: Stacked map of overburden thickness, basement resistivity and reflection coefficient

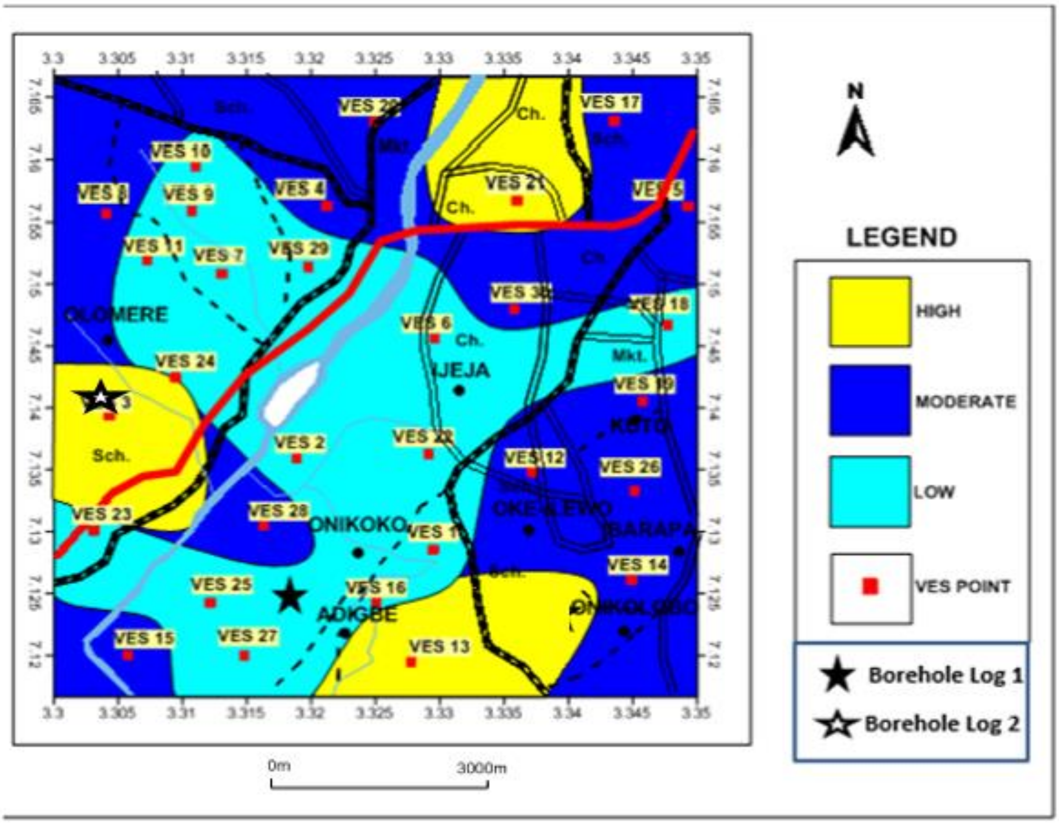

Fig. 10: Groundwater potential map of the study area

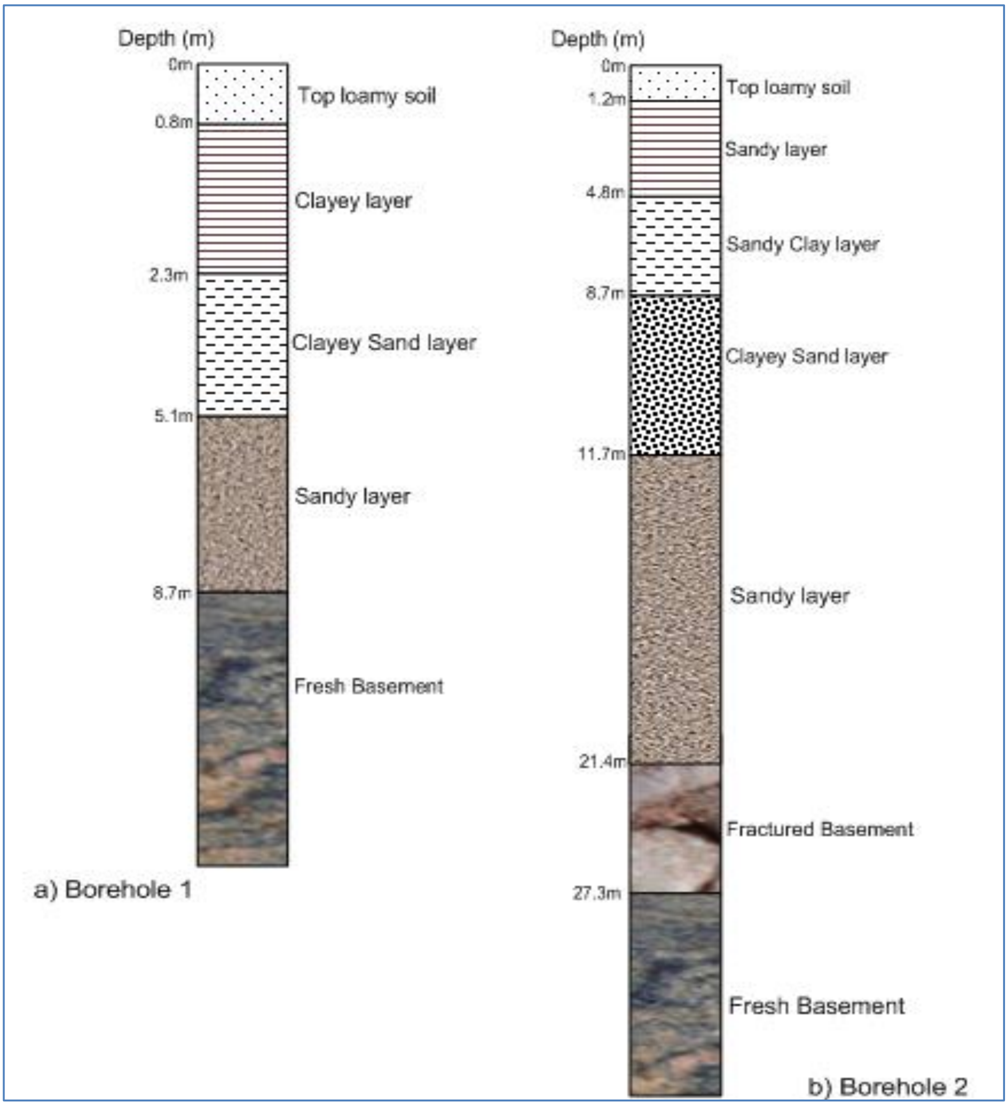

Fig. 11: The lithological log for borehole 1 and 2 in the study area

The hydrogeological implication of this is that the area tends to produce groundwater yield that may be limited to the aquifer of the overburden, only gaining its recharge from the runoff water and infiltration process. The groundwater map in this area however agrees with the lithological log information from borehole logs available. Borehole 1 which has low overburden thickness with no visible fracture falls within the zones of low groundwater yield on the groundwater potential map while Borehole 2 which shows high overburden thickness and presence of visible fracture falls within the high groundwater yield on the map.

Conclusion

The interpretation of the data obtained with careful consideration of the parameter for the delineation of groundwater in a crystalline basement complex reveal the regions within the central parts of the study area have a low groundwater yield; areas around the northern and eastern parts have a moderate groundwater yield while part of the southern, northern and western part of the study area shows a high groundwater potential. This agreed with the geology and the lithological log information in the area. Larger percentage of the area covered falls within the low to moderate groundwater yield and shows that the basement underlying the study area are yet to undergo appreciable tectonic activities that may have led to the creation of fracture in this rock, hence the aquiferous zone within the study area can be predicted to have its source from non-fractured basement rocks than fractured basement rock.

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