Groundwater Exploration in Oke Ata Housing Estate, Abeokuta, Ogun State, Nigeria Using Electrical Resistivity Methods

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Abstract

The study evaluates groundwater potential in Oke Ata, Abeokuta North Local Government Area, Ogun State, Southwestern Nigeria, using Vertical Electrical Sounding and 2D Electrical Resistivity Imaging (ERI)techniques. The area is characterized by underlain Precambrian Basement Complex rocks of low porosity and permeability of South- western Nigeria. Eleven vertical electrical sounding (VES) using the Schlumberger electrode array and the five 2D resistivity imagining using the Werner electrode array were carried out. The results show four geo-electric subsurface layers which are topsoil, clayey sand, sandy clay, weathered layer, fractured/ fresh basement within the study area. The resistivity of the fractured/fresh basement ranges from 400 to 900Ohm-m.The overburden thickness in the study area varies from9.6 to 15.7m. The field data were employed to prepare the groundwater potential map that was used to classify the area into low, medium and high groundwater potential zones. The study revealed that 63.6% and 36.4% of the study area falls within the medium and low rated groundwater potential zone. The groundwater potential rating of the study area is considered moderate.

Key words: Resistivity; Groundwater Potential; Weathered parameters; Geo-electric layers

INTRODUCTION

Demand for exploration of groundwater has continuously be on increase due to its unalloyed needs. Among other sources of water, groundwater is most hygienic because it has an excellent natural microbiological and chemical quality for most applications (MacDonald *et al.,*2005). Groundwater is the water present beneath the Earth's surface in soil pore spaces and in the fractures of pores spaces within the rock formation. Groundwater therefore represents part of the subsurface water occurring in the zone of saturation (phreatic zone) below the water table. Groundwater is categorized as one of the chief natural resources

(Grönwall and Oduro-Kwarteng, 2018) and its source is rainfall and snowmelt (Calow *et al.,* 1997; Plummer *et al*.,2001). Favourable geologic material known as aquifer is the main target in groundwater prospecting. These favourable materials are sedimentary deposits or rocks that are sufficiently permeable to transmit economically significant quantities of water. This aquifer includes sandstone, well-jointed limestone, conglomerates, some well-fractured volcanic rocks (such as columnar basalt) and well-fractured crystalline rocks.

In the study area most of the hand dug wells and boreholes in the area are not yielding but those that were yielding only do so during rainy season which is not sufficient for the inhabitants. Resident may have to walk some meters away from their houses in search for water for domestic purposes. The increase in failure rate of groundwater exploration in basement complex aquifers has informed the necessity of geophysical survey before embarking on exploitation for successful borehole drilling (Dan Hassan and Olorunfemi, 1999; Inusa *et al.,* 2015).The electrical resistivity technique especially vertical electrical sounding (VES) method is becoming popular among methods useful in the study of environment, groundwater and other geophysical surveys because of its versatility (Zohdy *et al.*, 1980; Aina *et al*., 1996; Olorunfemi and Fasuyi, 1993; Olorunfemi *et al.*, 2004; Abubakar and Danbatta, 2012; Ismail and Yola, 2012; Akande *et al.,* 2016). The research was conducted to study the geophysical survey of groundwater potential and the aquifer distribution, with proper analysis on delineation of groundwater aquifer level in basement complex terrain.

Description, Location, Accessibility and Geology of Abeokuta

Abeokuta occupies about 40.63km^{2}areas lying within latitude 7˚10'N - 7˚15'N, and longitude 03˚7'E - 3˚26'E, and located at about 70 km north of Lagos. Abeokuta, being within the Basement Complex terrain of Southwestern Nigeria is characterized by different types of rocks viz; granite, granitic gneiss and pegmatite. The Basement Complex rock of precambrian age consists of older and younger granites, with the younger and older sedimentary of both tertiary and secondary ages which cover over 40% of land mass. The northern part was made up pegmatite while the southern and western parts were characterized by granitic gneiss of less porosity and quartzite intrusions which extends to transition zone with the sedimentary basin. (Ufoegbuna, 2009).

The rainy season span from March through October with rainfall varies between 750 mm-1000 mm and the dry season was from November to March with rainfall of 250 mm-500 mm (Akanni, 1992). The topography of the area is undulating with elevation ranging from 100 to 400 m above sea level.

The basement rock is made up of ancient gneisss-migmatite complex that could be classified into three divisions; granodiorites, Porphyritic granites, Quartz diorites and pegmatite due to the penetration of Pan-African bodies of granodiorites (Oyawoye, 1972).

The study area of research is located within the latitude 07˚07'34.0" and 07˚08'20.0", and longitude 03˚16'57.2" and 03˚17'41.6" (Figures 1 and 2). The study area is generally accessible by major and minor road and several footpaths, the major means of transportation is by road, the roads are tarred, the survey location can equally be accessed through a main road from Ita-Oshin.

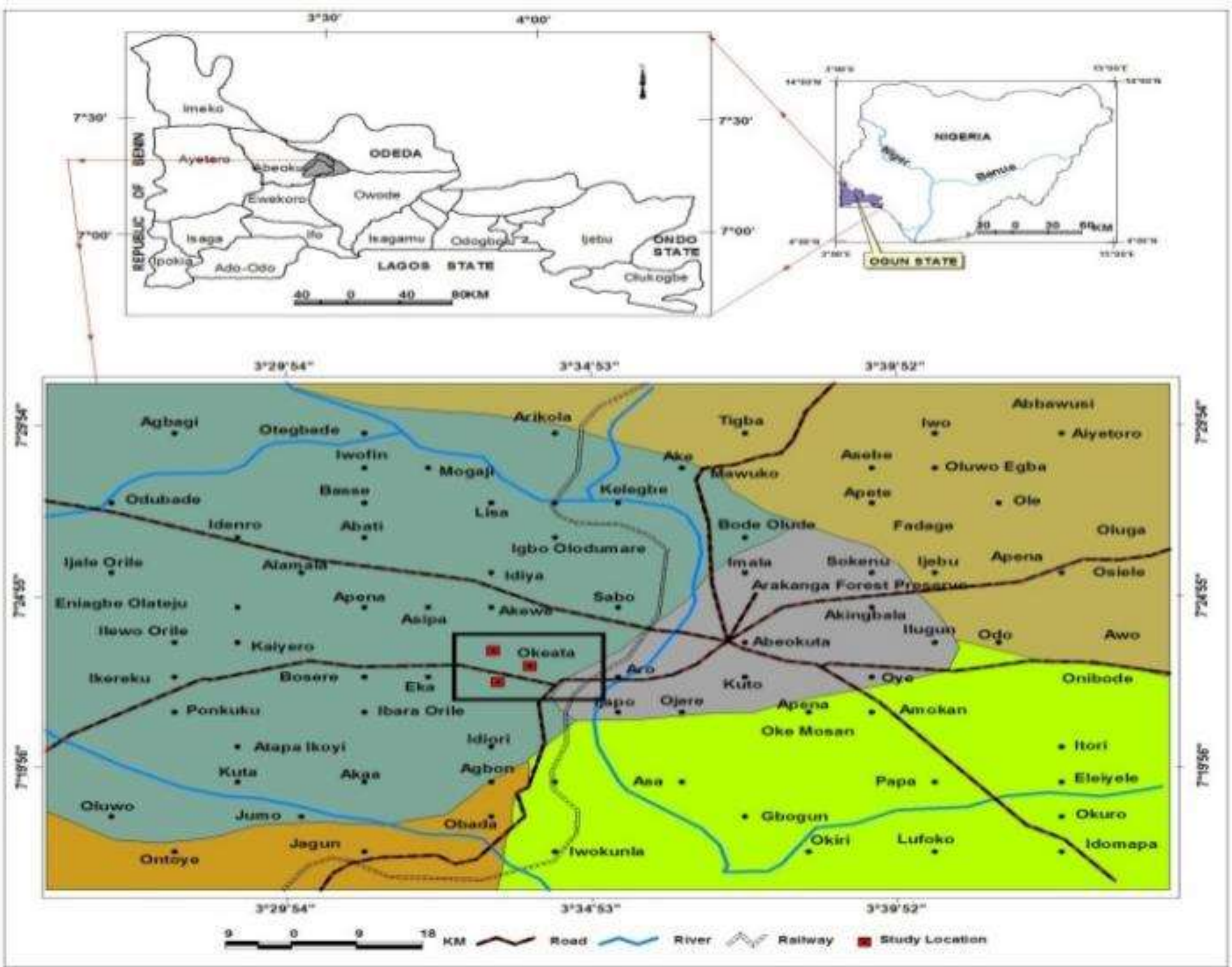

Figure 1: The study area

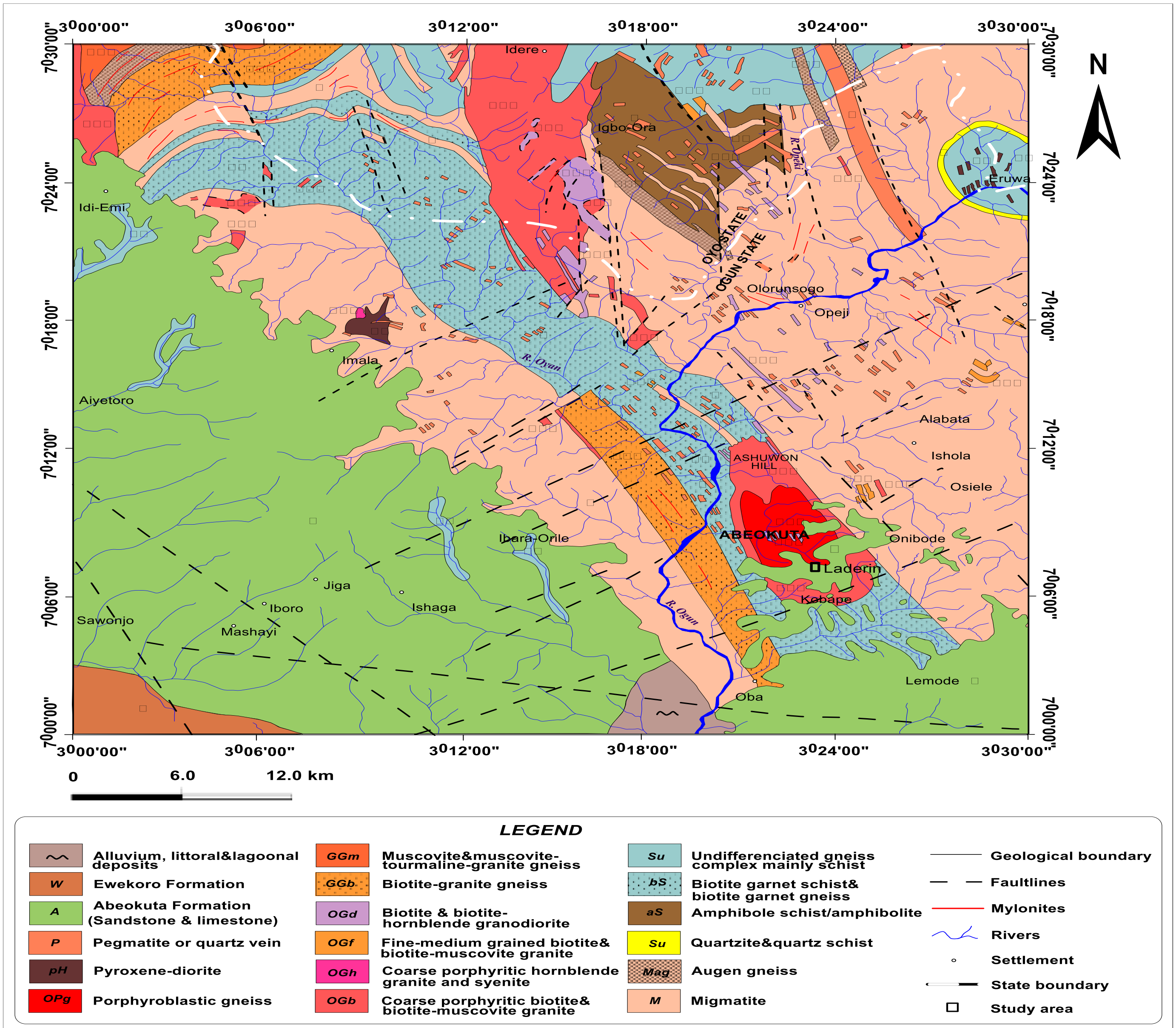

Figure 2: Geological Map of South-western Nigeria

METHODOLOGY

Electrical resistivity method is one of the most applied method for groundwater investigation among all surface geophysical techniques. It has been used in delineation of various aquiferous units in Basement Complex of southwest Nigeria (Olorunfemi and Olorunniwo, 1985; Olorunfemi and Opadokun, 1986). Various Authors (Zohdy,1964; Loke, 2001; Todd, 1980) have described literatures on application of electrical resistivity techniques, how it can be used to estimates thickness of overburden and weather/fractured with some level of precision, among other applications.

Wenner and Schlumberger electrode configuration methods are popularly employed (Zohdy et al., 1974) among all the configuration arrays. Schlumberger and Werner array configurations with a maximum current electrode spacing AB of 150 m were employed on the field survey. The subsurface resistance, R of each electrode combination was measured using an OHMEGA resistivity meter, from which the apparent resistivity was obtained by multiplying R and configuration factor.

WINRESISTandRES2DINV software were applied to process and interpret the data. The datum points were removed by filtration while true subsurface resistivity was estimated by inverting the data. Effects of large resistivity variations observed near the ground surface were reduced by model refinement option of the “Inversion Menu”.

RESULTS AND DISCUSSION

An interpretation of the field data using partial curve matching and Winresist softwaresimulation for eleven (11) VES points provide information ongeoelectric layers. The apparent resistivity were plotted (Figures 3 to 13); the half of the current electrode spacing on the log-log graph scale. And five (5) 2-D transverses were also obtained and interpreted (Figures 14 to 19).

VES 1

The curve type of VES 1 located (7°7’47.4’’N 3° 17’2.2’’E) within Oke-ata housing estate revealed three geoelectric layers; the topsoil, which has resistivity value of 191.3 Ωm and 1.5 m thick, the second layer and third layer which have resitivity value of 25.3 Ωm and 105 Ωm respectively. The second layer is 3.0 m thick and dominated by clayey sand formation while the third layer is overshadowed by saturated sandy clay formation.

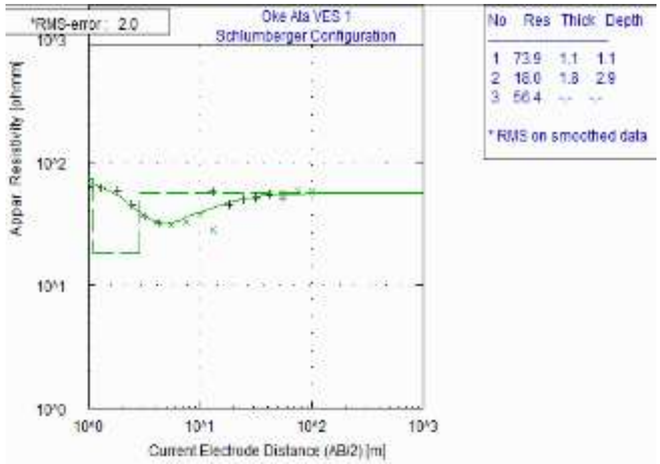

Figure 3: VES 1 curve

VES 2

The curve type of VES 2 located (7°7’42.2’’N 3°17’4.3’’E) within Oke-Ata housing estate revealed three geoelectric layers. The first layer is covered with topsoil with a resistivity value of 213.7Ωm and corresponding thickness of 1.1m. The horizon of second layer is dominated by clayey sand formation with a high resitivity value of 46.7Ωm and corresponding thickness of 8.5m. The third layer has a resistivity value of 117.6Ωm and is overshadowed by saturated weathered basement.

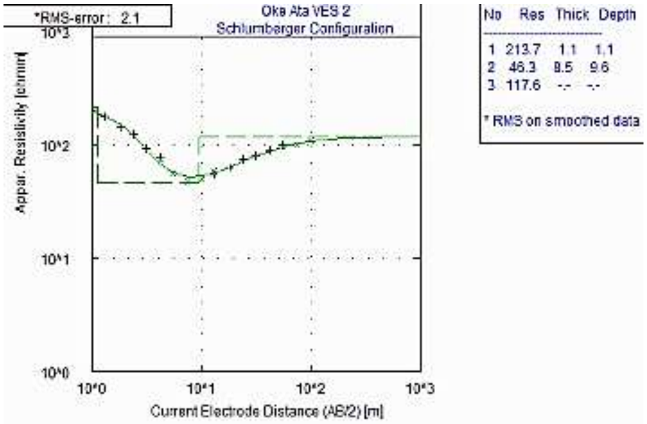

Figure 4: VES 2 curve

VES 3

The curve type of VES 3 located (7^{o}7'47.6''N 3^{o} 17'4.3''E) within Oke-Ata housing estate revealed three geoelectric layers. The first layer is covered with topsoil with a resistivity value of 206.6 Ωm and was 0.9 m thick. The horizon of second layer is dominated by clayey sand formation with a resitivity value of 67.8 Ωm and corresponding thickness of 6.8 m. The third layer has a resistivity value of 368.4 Ωm and is overshadowed by weathered basement .

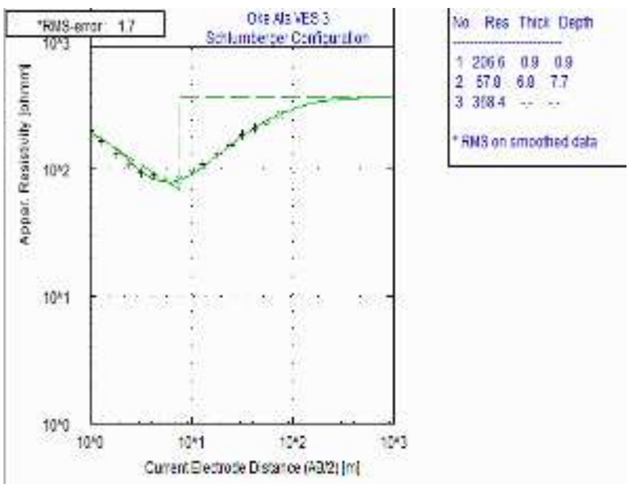

Figure 5: VES 3 curve

VES 4

The curve type of VES 4located (7^{o}7'49.7''N 3^{o} 17'9.2''E) within Oke-Ata housing estate revealed three geoelectric layers. The first layer is covered with topsoil with a resistivity value of 191.3 Ωm and corresponding thickness of 1.5 m. The horizon of second layer is dominated by clay formation with a resitivity value of 25.3 Ωm and corresponding thickness of 3.0 m. The third layer has a resistivity value of 105.8 Ωm and is overshadowed by sandy clay .

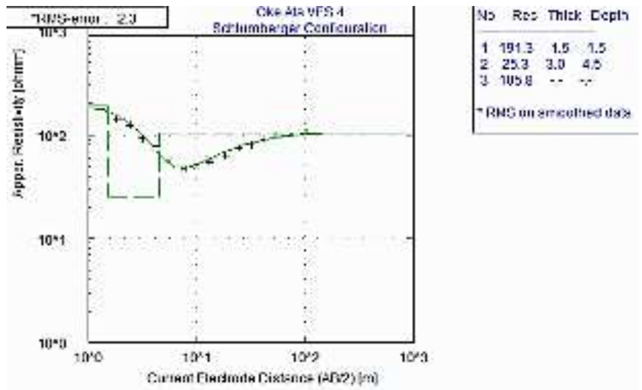

Figure 6: VES4 curve

VES 5

The curve type of VES 5located (7^{o}7'53.3''N 3^{o} 17'14.1''E) within Oke-Ata housing estate revealed three geoelectric layers. The first layer is 1.0 m thick and is covered with topsoil which has resistivity value of 244.0 Ωm.The horizon of second layer is dominated by clay formation with a resitivity value of 38.3 Ωm and corresponding thickness of 13.1 m. The third layer has a resistivity value of 105.8 Ωm and is overshadowed by weathered basement .

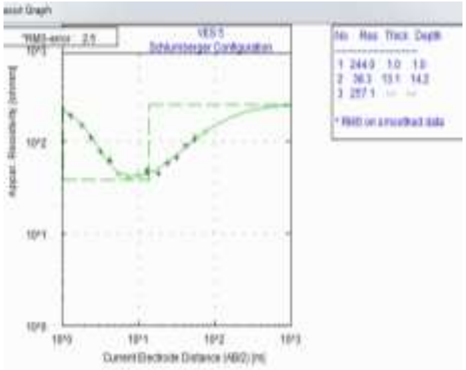

Figure 7: VES5 curve

VES 6

The curve type of VES 6located (7º7'47.3''N 3º 17'18.8''E) within Oke-Ata housing estate revealed three geoelectric layers. The first layer is covered with topsoil with a resistivity value of 239.6 Ωm and corresponding thickness of 1.1 m. The horizon of second layer is dominated by clay formation with a resitivity value of 37.4 Ωm and was12.9 m thick. The third layer has a resistivity value of 105.8 Ωm and is overshadowed by weathered basement .

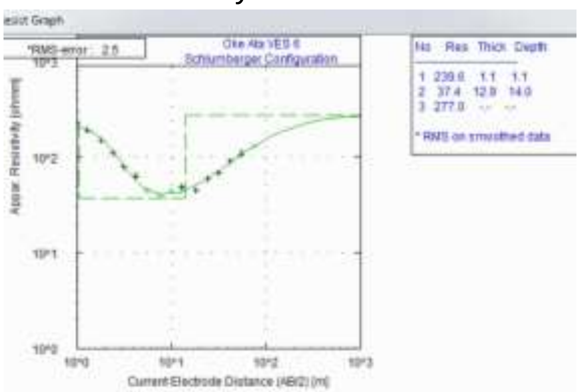

Figure 8: VES 6 curve

VES 7

The curve type of VES 7located (7º7'58.8''N 3º 17'18.9''E) within Oke-Ata housing estate revealed four geoelectric layers. The first layer is 0.3 m thick, covered with topsoil with a resistivity value of 395.2 Ωm . The horizon of second layer is dominated by clay formation with aresitivity value of 175.9 Ωm and corresponding thickness of 1.0 m. The third and fourth layers are dominated by clay and the weathered basement with resistivity value of 35.8 Ωm and 272.5 Ωm respectively. The third layer is 12.1 m thick.

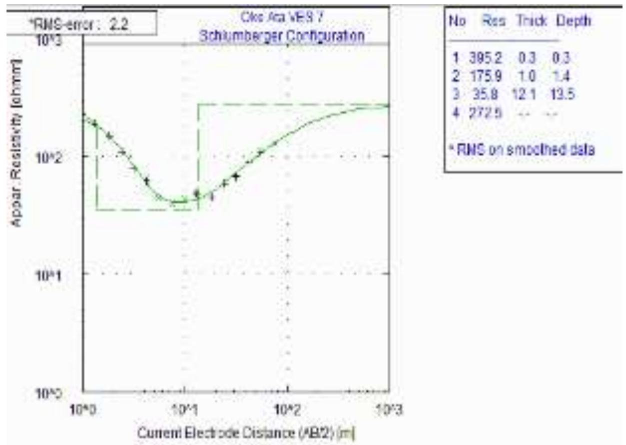

Figure 9: VES 7 curve

VES 8

The curve type of VES 8located (7º8'4.6''N 3º 17'15.2''E) within Oke-Ata housing estate revealed three geoelectric layers. The first layer is covered with topsoil with a resistivity value of 251.4 Ωm and corresponding thickness of 1.0 m. The horizon of second layer is 4.4 m thick and dominated by sandy clay formation with a resitivity value of 41.7Ωm. The third layer has a resistivity value of 34.4Ωm and is overshadowed by clay. The fourth layer which is the last layer is the fractured basement layer with resistivity value of 503.0 Ωm.

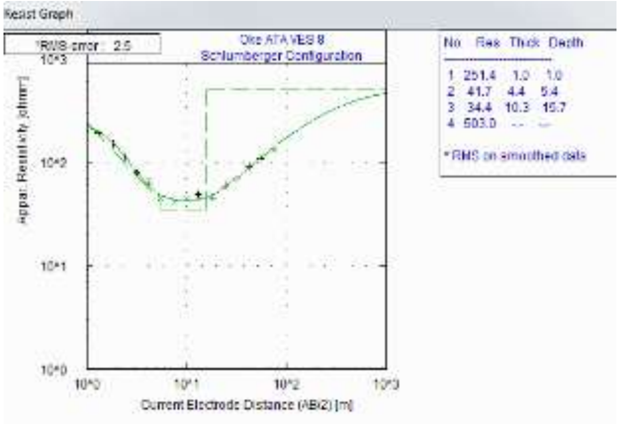

Figure 10: VES 8 curve

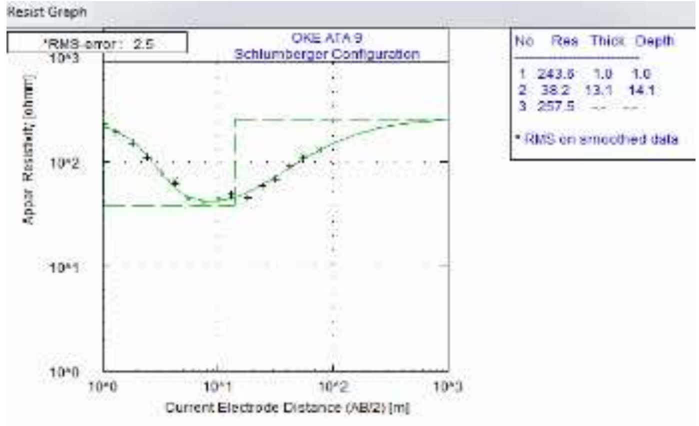

Figure 11: VES 9 curve

VES 9

The curve type of VES 9, located (7^{o}8’2.8’’N 3^o 17’26.9’’E) within Oke-Ata housing estate revealed three geoelectric layers. The first layer is covered with topsoil with a resistivity value of 243.6 Ωm and corresponding thickness of 1.0 m. The horizon of second layer is dominated by clay formation with corresponding thickness and a resitivity value of 13.1 mand 38.2 Ωm respectively. The third layer has a resistivity value of 257.5 Ωm and is overshadowed by weathered basement .

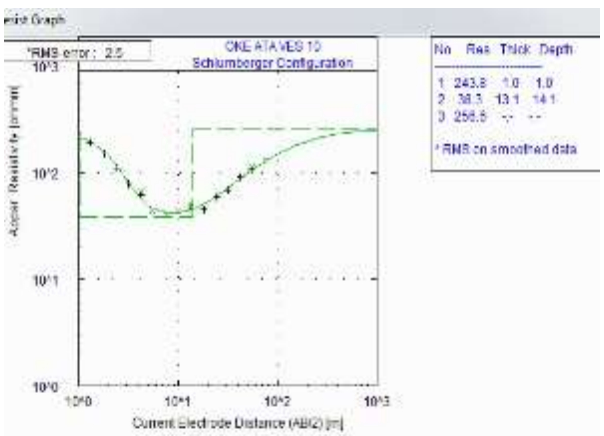

Figure 12: VES 10 curve

VES 10

The curve type of VES 10 located (7^{o}8’9.0’’N 3^o 17’34.4’’E) within Oke-Ata housing estate revealed three geoelectric layers. The first layer is covered with topsoil with a resistivity value of 243.8 Ωm and corresponding thickness of 1.0 m. The horizon of second layer is dominated by clay formation with a resitivity value of 38.3 Ωm and corresponding thickness of 13.1 m. The third layer has a resistivity value of 257.5 Ωm and is overshadowed by weathered basement.

VES 11

The curve type of VES 8 located (7^{o}8’5.6’’N 3^o 17’33.2’’E) within Oke-Ata housing estate revealed four geoelectric layers. The first layer is covered with topsoil with a resistivity value of 240.7Ωm and corresponding thickness of 1.1m. The horizon of second layer is dominated by clayey sand formation with a resitivity value of 37.2Ωm and corresponding thickness of 1.5m. The third layer has a resistivity value of 38.1Ωm and is overshadowed by sandy clay. The fourth layer which is the last layer is the weathered basement layer has resistivity value of 254.1Ωm.

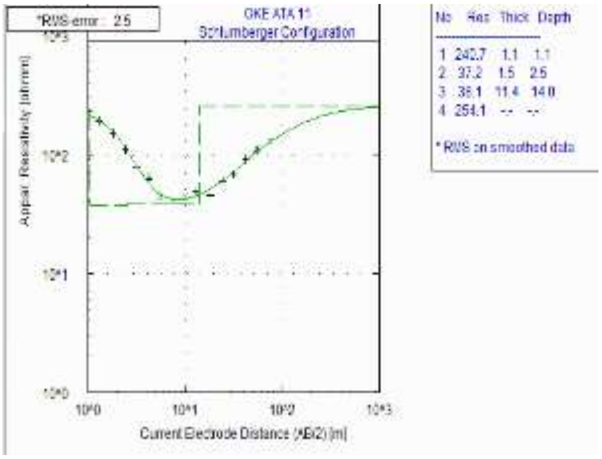

Figure 13: VES 11 curve

Profile 1

The inverted model section of 2-Dimensional imaging of profile 1 (Figure 14) showed thickness of top layer to be 2.5 m and resistivity values between 5 and 300 Ohm which is due to the presence of low lying coarse-grained banded gneiss outcrop. The maximum length of the profile is 100 m. The disparity in the values of resistivity depicts the in-homogeneity along the top layer. This layer is underlain by more conductive layer, which has resistivity value of between 10-Ohm-m and 180-Ohm-m and are of two parts; the lateral distance 10 to45.5 m and 60.5 to 100m has a resistivity value of 10 to 63 Ohm-m, which indicate the material is clay and 7.5 m thick. While lateral distance of 50 to 60 m has a resistivity value of 100 to 180 ohm-m with thickness of 4m. The material underlain by this layer is the clayey sand. The last layer which is between the lateral distance 40 to 100 mdirectly beneath the clayey sand layer is fresh basement rock with resistivity value of 890 Ohm-m and above.

Profile 2

The inverted model section of 2-Dimensional imaging of profile 2 with minimum electrode spacing of 5 m has maximum length of 100 m (Figure 15). The profile showed top layer of about 2m thick with resistivity values ranging from 20-Ohm-m to 98-ohm-m. The variation in the resistivity reveals the in-homogeneity along the top layer. This layer is underlain by more conductive layer, which has resistivity value of between 20to 90-Ohm-m and thinned out to 6 m thickness. It was deduced that the layer is wet clay/clayey sand. The fractured/weathered basement which has resistivity value of 75 to 150 Ohm-m with uniform thickness across the profile line was deduced to be below the clay/clayey sand layer. The deeper part which is highly resistive has a layer with resistivity of 1000 ohm-m and above

Profile 3

The inverted section of 2-Dimensional imaging of profile 3with minimum electrode spacing of 5 m has maximum length of 100 m (Figure 16).

The profile showed top layer of thickness of about 2mwith resistivity values between 10 and 60 Ohm-m. The variation in the resistivity reveals the in-homogeneity along the top layer. This layer is underlain by more conductive layer, which has resistivity value of between 40-Ohm-m to 70-Ohm-m with thickness 2m which a clayey sand. Between the lateral distances 0 m to 15 m and 40 m to 75 m is interpreted as weathered basement.

Profile 4

The inverted section of 2-Dimensional imaging of profile 4with minimum electrode spacing of 5 m has maximum length of 100 m (Figure 17). The profile showed top layer of about 2m thick with resistivity values ranging from 30 to 70-Ohm-m. The variation in the resistivity reveals the in-homogeneity along the top layer. This layer is underlain by more conductive layer, which has resistivity value of between 3 and80-Ohm-m that is suspected to be clay/clayey sand with thickness of about 5 m. Highly saturated/fresh basement is observed at distance 5 to 25 m and a small portion also at distance 45 m to 50 m with resistivity value of 40 Ohm-m and thickness of 3 m and 2 m respectively.

At lateral distance 30 m to 40 m at the bottom of the profile shows layer of high resistivity value of 700 0hm-m and above which is interpreted as the fractured basement zone.

Profile 5

Figure 18 showed the inverted section of 2-Dimensional imaging of profile 4with minimum electrode spacing of 5 m. The maximum length of the profile is 100 m. The profile showed top layer of about 3m thick with resistivity values ranging from 5-Ohm-m to 30-ohm-m. The variation in the resistivity reveals the in-homogeneity along the top layer. This layer is underlain by more conductive layer that has resistivity value between 12 and 20-Ohm-mwhich is about13m thick in a distance of 40 m- 60 m, the layer is inferred to be clay sand while between lateral distance 0 m to 35.5 m and 60.5 m to 100 m are layers underlined by clayey sand with resistivity ranging from 30 Ohm-m to 60 Ohm-m with thickness ranging from 5 m to 13 m. The layer at the bottom corner of the profile with resistivity value 50 ohm-m and above is interpreted as the highly weathered basement.

The profiles derive from 2-Dimensional geo-electrical survey have clearly delineated the variation and distribution of resistivity laterally. The high and low resistivity zones are identified from the 2-D profiles. The inversion results are able to show the water saturated zones in aquifer layer.

Groundwater Potential Evaluation

Table 1 shows the scheme for rating the groundwater potential as a function of depth to bedrock/ overburden thickness. The belt of overburden thickness < 10 m accounts for 36.4% and is the least prospect for groundwater development. The remaining 63.6 % of the study area falls between 10 and 20 m overburden thickness. The groundwater potential in the area is expected to be moderate and characterized by overburden thickness of 10 – 20m.

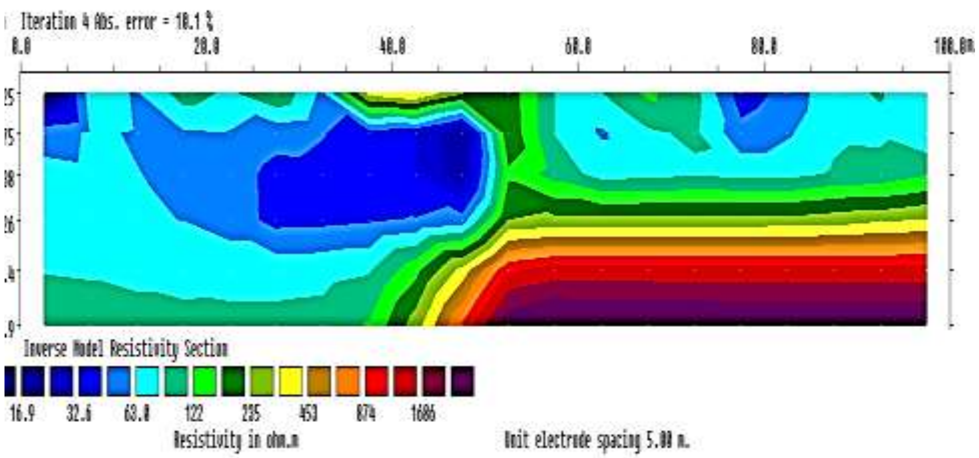

Figure 14: Inverse model resistivity section of profile 1

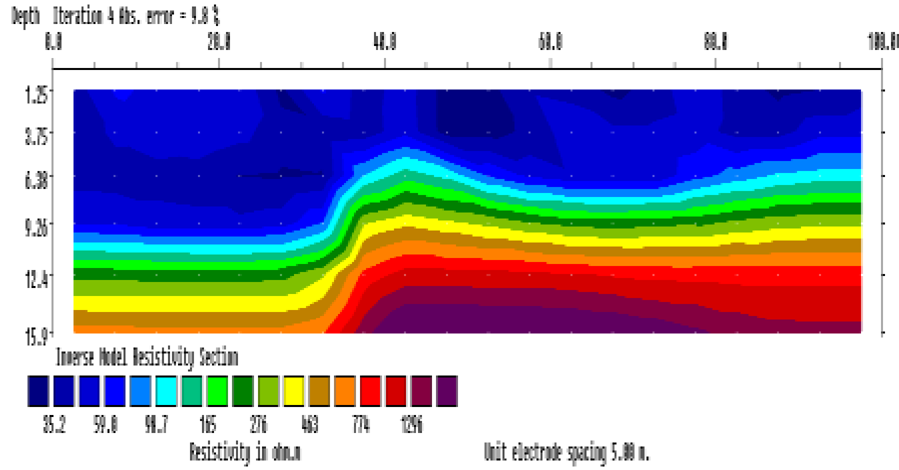

Figure 15: Inverse model resistivity section of profile 2

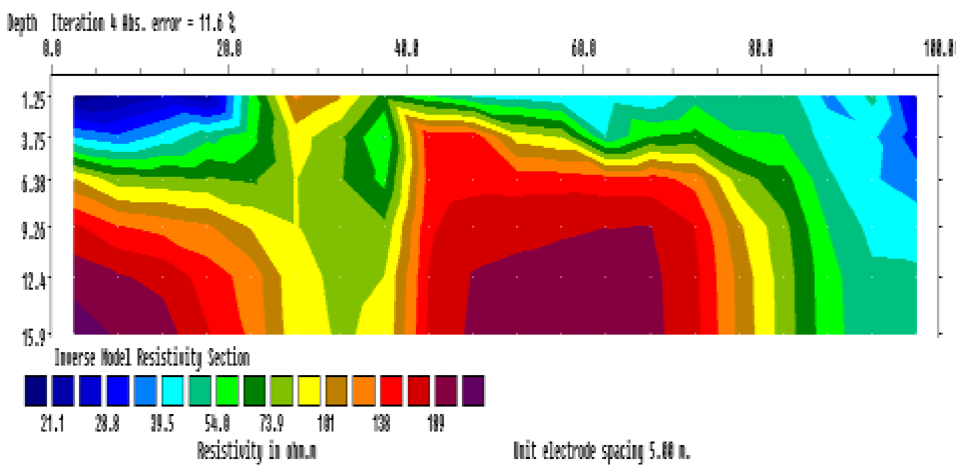

Figure 16: Inverse model resistivity section of profile 3

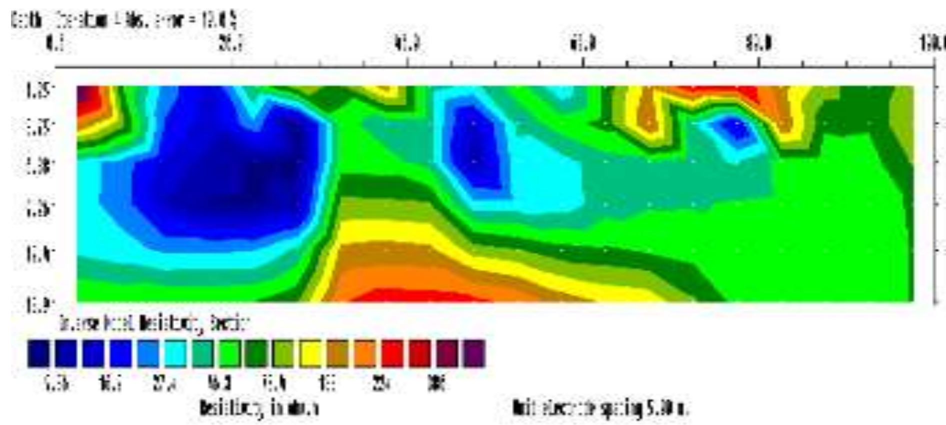

Figure 17: Inverse model resistivity section of profile 4

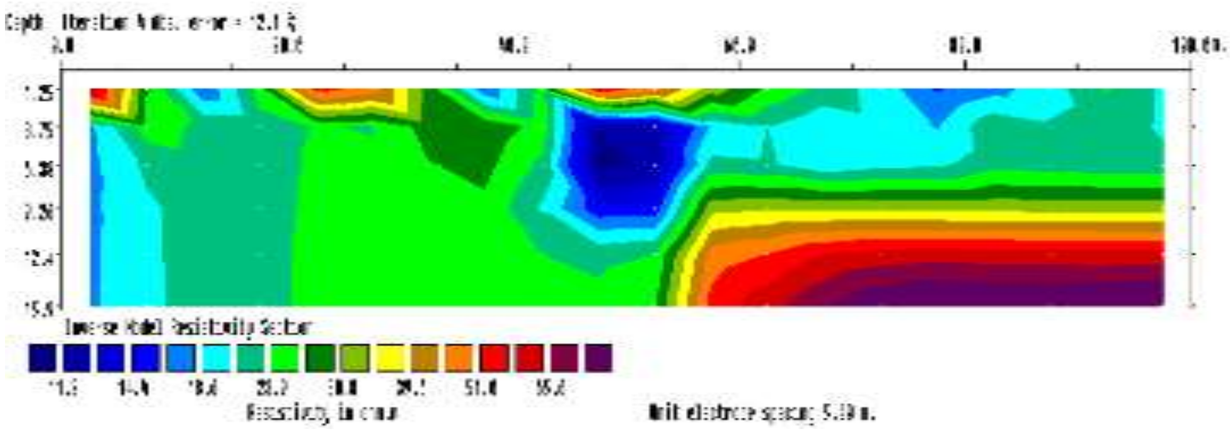

Figure 18: Inverse model section resistivity section of profile 5

Table 1: Aquifer potential as a function of the depth to basement

Depth to bedrock (m)	Weighting
< 10	2.5
10 – 20	5
20 – 30	7.5
>30	10

Olayinka *et al.*, 1997

Table 2 show the scheme of rating groundwater potential as function of weathered basement resistivity. Optimum weathering and groundwater potential is inferred from resistivity range between 20 and 100 Ohm-m while limited groundwater and presence of clay is suspected in resistivity below 20 Ohm-m. It could therefore be established that no part of the study area falls within the clay and limited groundwater potential rating. Optimum weathering and groundwater potential cover 9.1% of the study area, medium aquifer conditions and potential cover 45.4% while remaining 9.1% is basement.

Table 2: Rating groundwater potential in terms of weathered basement resistivity

Weathered basement Resistivity (ohm-m)	Aquifer Characteristics	Weighting
< 20	Clayey, limited groundwater potential	7.5
20 – 100	Optimum weathering and groundwater potential	10.5
100 –150	Medium aquifer conditions and potential	7.5
150 –300	Limited weathering and poor potential	5.0
>300	Negligible	2.5

Oyedele and Olayinka, 2012

CONCLUSION

The groundwater prospects of Oke Ata Housing Estate, Abeokuta North Local Government area, Ogun State, Nigeria was undertaken. Eleven (11) Schlumberger VES were employed to identify potential groundwater bearing and provide information on geoelectric layers in the study area. The interpretation of computer iterated sounding revealed that there were two to five geoelectric layers delineated, comprising of topsoil, weathered layer and fractured/fresh basement. The aquifer unit is found in the weather layer within the area, the yield depends on the quantity of the clay content present. The increase in the quantity of clay content reduce the groundwater yield. The groundwater potential map of the area was constructed using geo electrical parameters of the delineated aquifer of each VES.

The study revealed that about 63.6% of the study area have potential for moderate groundwater within thickness between 10 m and 20 m, while areas underlined by thickness < 10 m accounts for 36.4% with clayey and limited aquifer potential.

On the rating of weathered basement resistivity, Aquifer characteristics of optimum weathering and groundwater potential covers 45.4%, limited groundwater potential areas cover 9.1%, poor potential and moderate weathering covers 36.4% of the study area, while the remaining 9.1% of the study area falls on the basement terrain.

The study revealed that the area is reasonably supportive to groundwater exploitation since 56.67 % of the study area are within moderate groundwater potential with the remaining 43.33 % falls on the low or poor or limited groundwater abstraction.

The results of this study provide reliable information for an elaborate groundwater abstraction in the study area.

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