Minimizing Ambiguity Using Geo-electrical Investigations: Implications for Understanding the Hydro-geologic Setting of a Complex Sub-surface Geology in Oderigha and Environs, Southeastern Nigeria

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ABSTRACT

Geo-electric investigations using the schlumberger array was carried out in order to understand the hydro-geologic setting in Oderigha and environs. Soundings were made in 18 different locations in the study area to obtain depth to aquifer units, and thickness of aquifer units. The simulated results from the VES points reveal the presence of 4-5 geo-electric layers. The top layer comprises clay, sand, siltstone intercalations. Layers underneath the top soil are the silty shale, shale, water saturated shaly sandstone and sandstone aquifer. The area is also characterized with high depth to sandstone aquifer which varies from 100m to 240m. The aquifer is overlain by a massive embedded shale conductive layer. At the extreme of North Eastern part of the study area, depths to aquifer are at about 3m to 40m, with VES location 15 having a thickness of about 17m. Aquifer thickness in the study area varies from 17m to 120m. Cross sectional analyses of AA^1, $BB^1$and CC^1 in the study area reveals that, VES no. 2, 14, 9, 18 and 11 will be the best locations to drill boreholes for sustainable groundwater development in the area of study to serve the communities. It is also observed that this VES points are located close to the communities. Aquifer resistivity value along the cross sections varies from 689Ωm to 66.94Ωm. The transmissivity varies between $3.5x10^{-2}m^2/s$ to $4.68x10^{0}m^2/s$, above the aquifer units in the study area is a widely distributed thick saturated shaly conductive layer. Borehole construction in the area must be preceded by a detailed geophysical survey with current electrode spacing of at least 600m and above.

Keywords: Aquifer units, hydro-geologic, aquifer resistivity, geo-electric layer, sub-surface, water table, transmissivity.

1. Introduction

The role of groundwater to nations, states, communities and individual households cannot be overemphasized. Hence, the quest for good quality water has been on the increase to sustain life. This increase has become more evident with the recent increase of massive surface water pollutions, especially in Nigeria. More so, the reasonable drift from ordinary search of surface water to prospecting, exploring and exploitation of sub-surface or groundwater potentials for steady and reliable supply (Odong, 2013).

The most useful and relatively inexpensive techniques in groundwater geophysical exploration, is the Electrical Resistivity technique, because the resistivity of rocks is sensitive to its ionic content (Alile, et al., 2011). The method allows a quantitative result to be obtained by using a controlled source of specific dimensions. Records show that the depths of aquifers differ from place to place because of variation in geo-thermal and geo-structural occurrence (Okwueze, 1996).

Groundwater supply and sustainability in Oderigha and environs has often failed, leaving the people in dare need for portable drinking water as the surface waters in the area are highly polluted. The massive failure of groundwater supply and sustainability in the area is because of the complex sub-surface geology (Okereke, et al., 1998), therefore, the need to minimize or reduce ambiguity with geo-electrical investigation of the subsurface in the area for understanding of the hydro-geologic setting as to aid aquifers (groundwater potential) to be properly delineated, if present at all. The study is within latitudes $5^{0}55^{1}$N to $6^{0}00^{1}$N and longitudes $8^{0}15^{1}$ E to $8^{0}20^{1}$E.

The objective of this research is to map out the conductive non-auriferous zones constituting an ambiguity to the understanding of the hydro-geologic setting in the area. It will also, clearly detect the deep seated aquiferous zones and provide data for the development of boreholes in the area. The study will attempt to map out the sub-surface geologic boundaries from their resistivity's and use same to determine geo-electrical parameters and establish the geo-electric sections and also evaluate the aquifer parameters. Hence this research will characterize the aquifer dimensions in the area, for substantial groundwater development at any particular point in time. The contour map of the water table with reference to mean sea level (MSL), and aquifer transmissivity will be attempted.

The clastic beds in the study area can be ascribed to the Ezillo Formation. The Ezillo Formation comprises mostly dark gray shale with fine sandstone and siltstone intercalations in the lower part, and an upper unit that is highly bioturbated, fine medium sandstone, similar to the sandstone of the Amaseri Formation. The Ezillo Formation between Appiapum and Ikom was deposited in a deltaic coastal plain, in brackish marshes and inter-distributary bays (Barth, et al., 1995, Odong, 2013). A major river (Cross River) exists in the study area into which minor streams empty their loads. The said streams often dry up during drought (dry season). The streams in the north western part of the map flows north ward into the major river. Other available streams in the study area, flows in the NE-SW direction, to meet the Cross river outside the study area. Topography of study area is undulating, with elevations varying at about 100ft – 380ft (Odong, 2013)

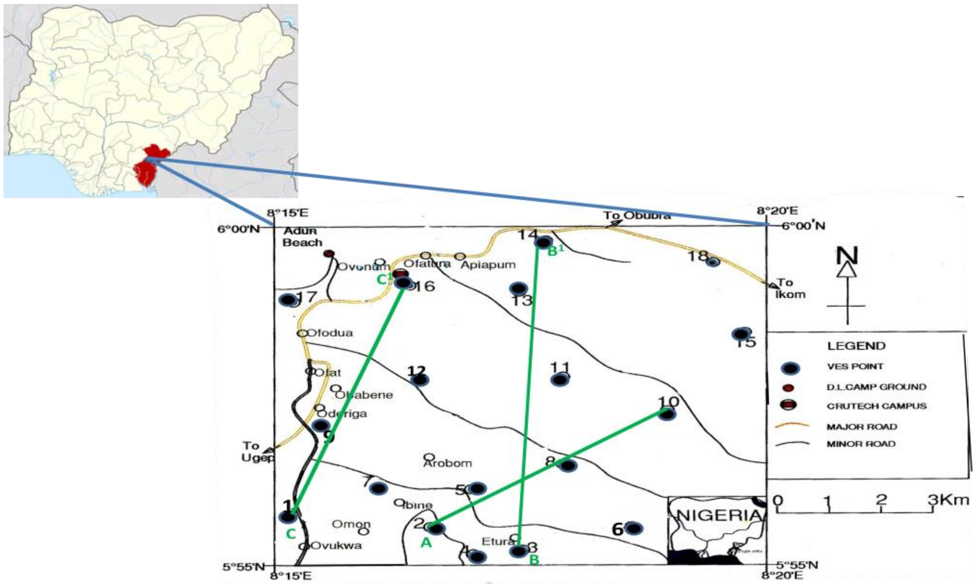


Figure 1: Location map of study area showing VES points

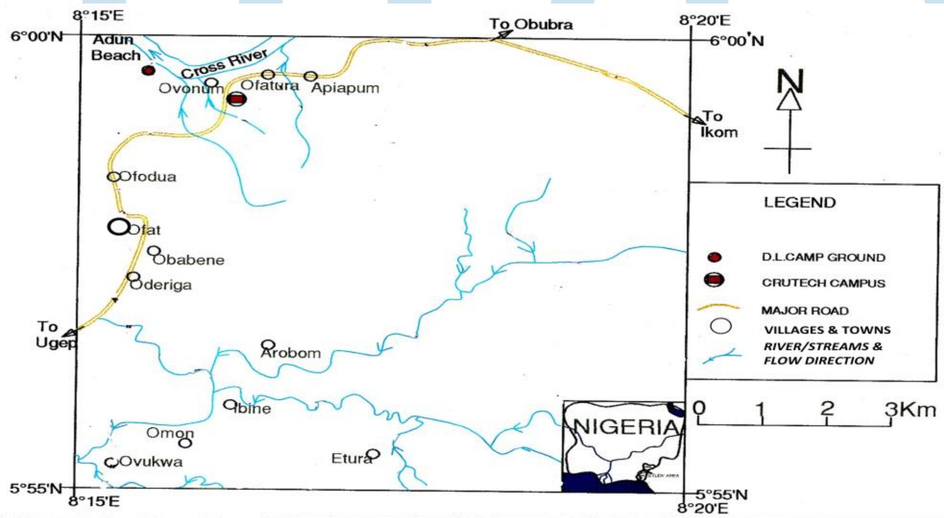


Figure 2: Drianage map of study area (Odong, 2013).

2. Material and methods

The IGIS resistivity meter with model SSR-MP-ATS was used to measure the apparent resistance of the ground as direct current passes through it. IGIS resistivity meter, SSR-MP-ATS performs automatic recording of both voltage and current, stacks the results, computes the resistance in real time and digitally displays it on its screen.

The Schlumberger array of electrodes was applied in the field for acquisition of data. Soundings were performed at 18 locations with maximum current electrodes separation ranging of 600m.

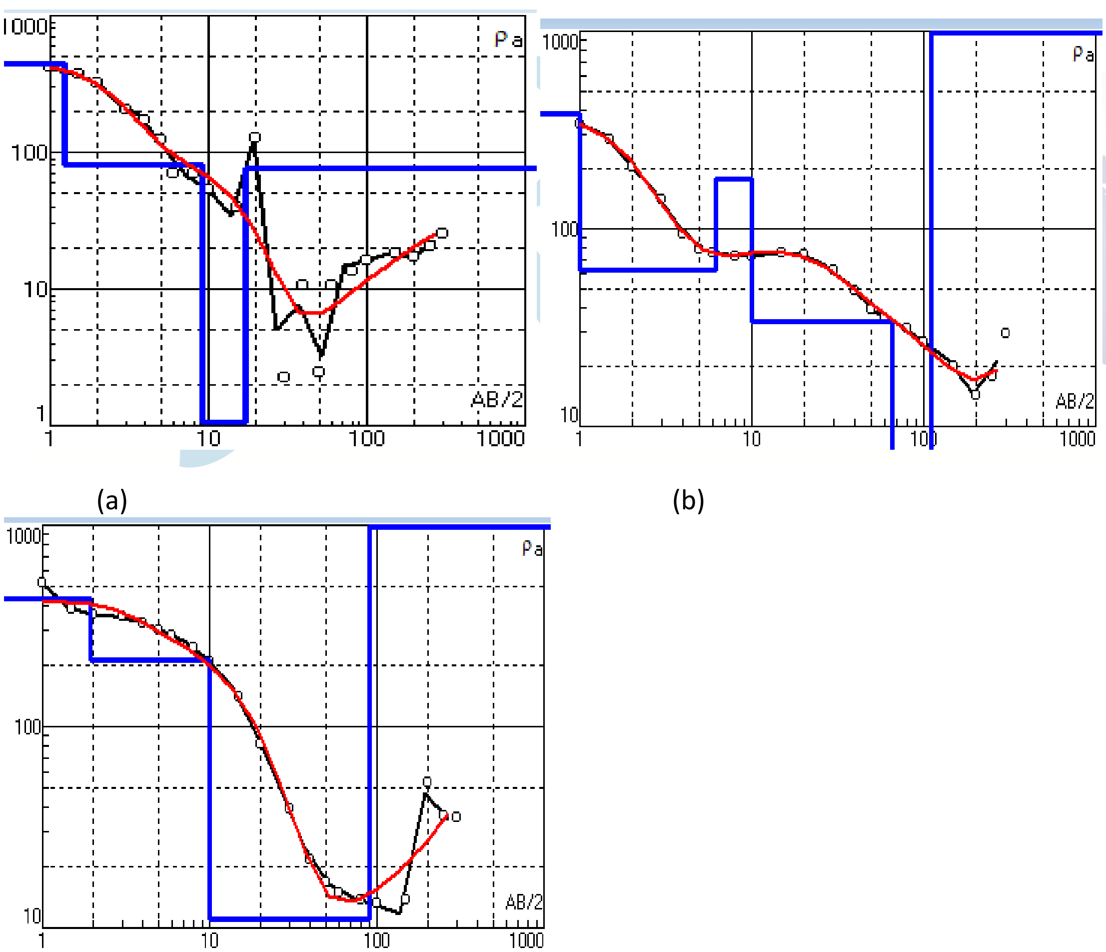
The observed field data was converted to apparent resistivity by multiplying with the Schlumberger geometric factor. The geometric factor for the Schlumberger array is given by:

$$G = \frac{\pi}{2l}(L^2 - l^2)$$

Where L= half current electrode spacing, l = half potential electrode spacing

The apparent resistivity data were plotted against the half current electrode spacing in meters in the horizontal axis. The resistivity data were further interpreted using IPI2Win inversion software package (Bobachev, 2002 and Odong, et. al 2013).

The curves resulting from the plots of some of the VES points are given below in figure 3.



(a) (b) (c)

Figure 3: VES curves (a) (b) (c) representing plots for VES (3), (9), and (11).

Geo-electric and geologic sections were interpreted. Figure 4, shows examples of the geo-electric and geologic sections. The figures contain all the inferred geologic layers in the area.

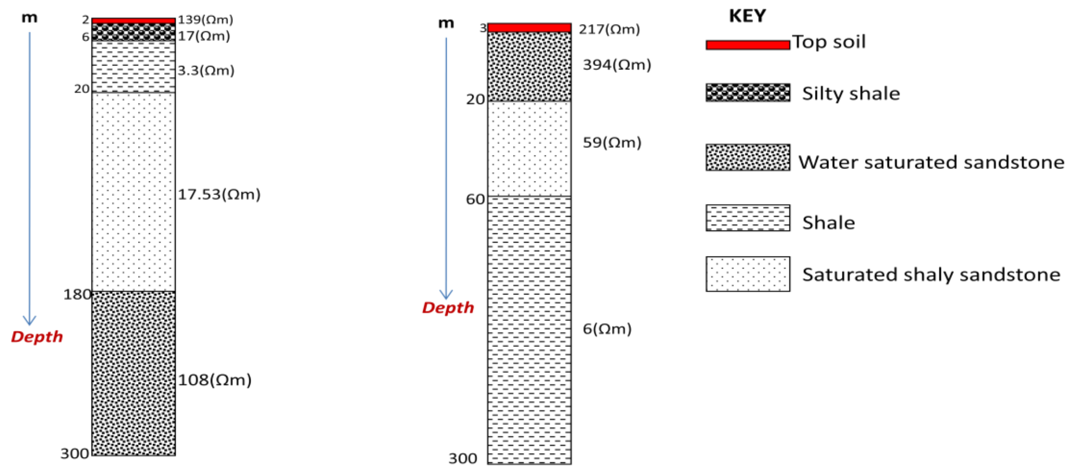


Figure 4: Geo-electric and inferred geologic sections for VES 3 & 15 respectively

3. Result and Discussions

A representation of the geologic sections across the cross sections AA[1], BB[1] and CC[1] are given below in figure 5. It is observed from the cross section AA[1] that VES No.10 has the thickest shaly conductive layer and the highest depth to the aquiferous zone. The silty shale/sand intercalation layer pinches out at VES No.10. VES No.2 has the lowest topography, the shallowest depth to aquifer zone and the best location to drill a borehole along the cross section. Its aquifer zone also has the highest resistivity value as compared to VES No. 5, 8 and 10 along the cross section. Fig.5b represents a cross section along BB[1]. The VES No. with the thickest shale layer is VES No.8, and the VES number with the highest depth to the aquiferous zone. The silty shale/sandstone pinches out at VES No.14. VES No.14 has the least thickness for shale conductive layer and the shallowest depth to aquifer zone. The aquifer zone is overlain and underlain by aquitard (shale layer). VES No.14 is most preferred to drill a borehole along the cross section as it will also be relatively less expensive. Fig. 5c is a representation of the cross section along line CC[1]. VES No.16 has the thickest shaly conductive layer and the highest depth to aquifer. VES No.9 has the highest elevation value along the cross section. It also has the shallowest depth to aquifer and the least thickness of the massively embedded shale conductive layer in the cross section. It is the best location for borehole drilling across the section.

The summary of results of the aquifer parameters integrated from the geo-electric sections in the study area is presented in table

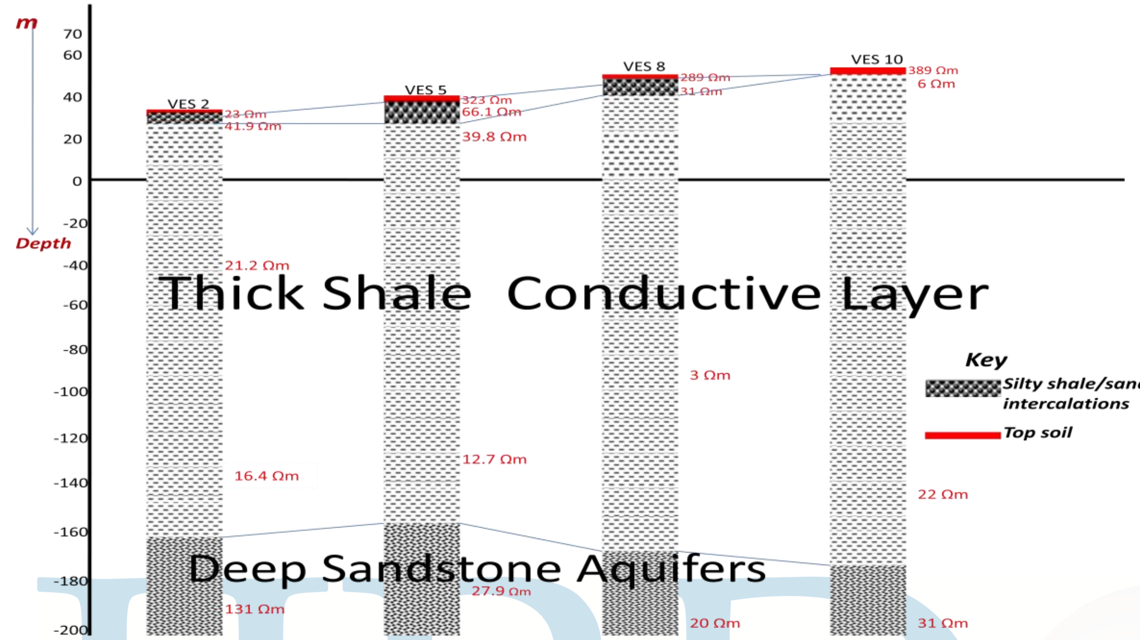


Figure 5a: Comparison of interpreted geologic sections along line AA[1]

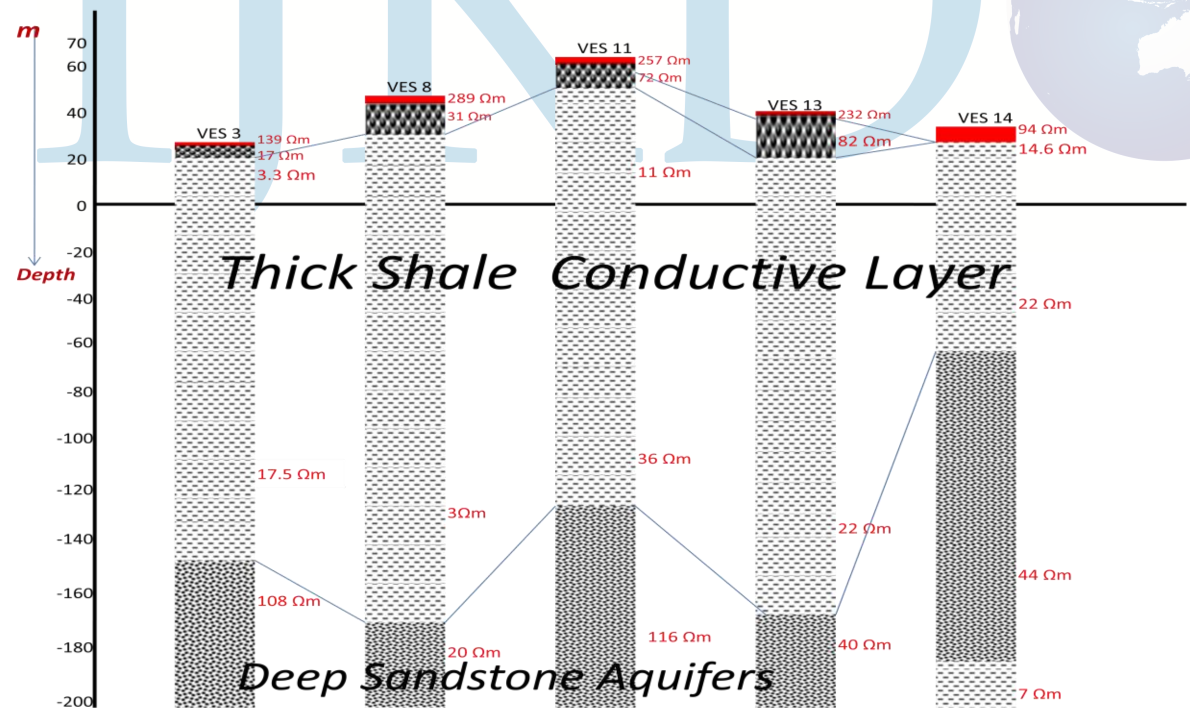


Figure 5b: Comparison of interpreted geologic sections along line BB[1]

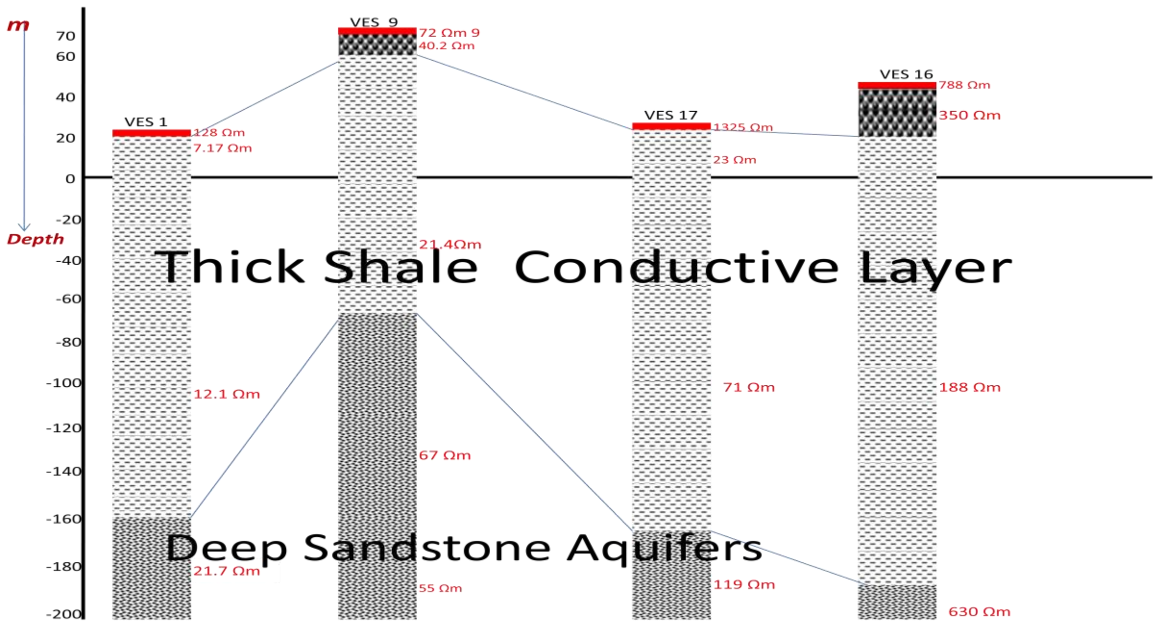


Figure 5c: Comparison of interpreted geologic sections along line CC[1]

Table 1: Summary of results of the aquifer parameters integrated from the Geo-electric sections in the study area

VES NO.	Depth to Aquifer (m)	Aquifer thickness (m)	Apparent resistivity (ohm-m)	Conductivity (ohm-m)	Transverse resistance (ρxh)	Longitudinal conductance (h/ρ)	Hydraulic conductivity (m/s)	Transmissivity (m^2/s)
1	200	100	21.72	0.046	2172	4.60	0.046	4.6
2	200	100	130.54	0.0087	13054	0.77	0.021	2.1
3	180	120	108	0.0093	12960	1.11	0.025	3.0
4	220	80	59	0.017	4720	1.36	0.035	2.80
5	200	100	27	0.036	2793	3.58	0.044	4.4
6	220	80	78.8	0.013	6304	1.02	0.031	2.48
7	240	60	11.6	0.086	696	5.17	0.049	2.94
8	220	80	20	0.050	1600	4	0.047	3.76
9	140	120	66.94	0.015	8032.8	1.79	0.033	3.96
10	240	60	31	0.032	1860	1.94	0.043	2.40
11	200	100	116	0.009	11600	0.86	0.023	2.30
12	200	100	689	0.0014	68900	0.15	0.0004	0.04
13	220	80	40	0.025	3200	2	0.040	3.2
14	100	120	44	0.023	5280	2.72	0.039	4.68
15	3	17	394	0.0025	6698	0.043	0.0032	0.054
16	240	60	630	0.0016	3780	0.09	0.00058	0.035
17	200	100	119	0.0084	11900	0.84	0.023	2.3
18	40	85	197	0.0051	16745	0.43	0.013	1.105

Singh (2005) established a non-linear relationship between hydraulic conductivity (K) and apparent resistivity (ρ) given by

$$K = 0.0538e^{-0.0072\rho}$$

Where ρ equals the apparent resistivity of the formation, (Abdullahi, et al., 2011)

$$T = kb \qquad \text{(Ekwe, et al., 2006)}$$

Where T = transmissivity (m^2/sec) and b= aquifer thicknesses.

In the study area, high apparent resistivity values vary from 689Ωm to 108Ωm. The low resistivity values varies from 11.6Ωm to 31Ωm in VES points 7, 8, 15 and10, this nearly follows NE-SW direction. The probable aquifer transmisivity map of the study area is given in figure 6.

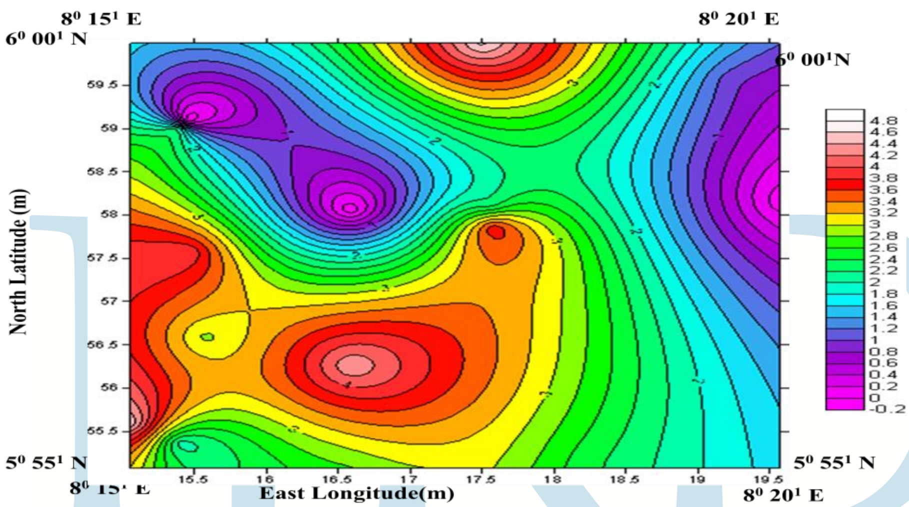


Figure 6: Aquifer transmissivity map

The transmissivity varies between $3.5 \times 10^{-2}\ m^2/s$ to$4.68 \times 10^{0}\ m^2/s$. It is observed that areas where we have high resistivity values turns out to be areas where we have low transmissivity values and vice versa. In VES 3, though the resistivity value is high, yet the transmissivity is relatively high. This is due to the high value of aquifer thickness in that aquifer unit. Figure 7, is a 3D map of the probable aquifer transmisivity surface distribution and water table map, values in the area.

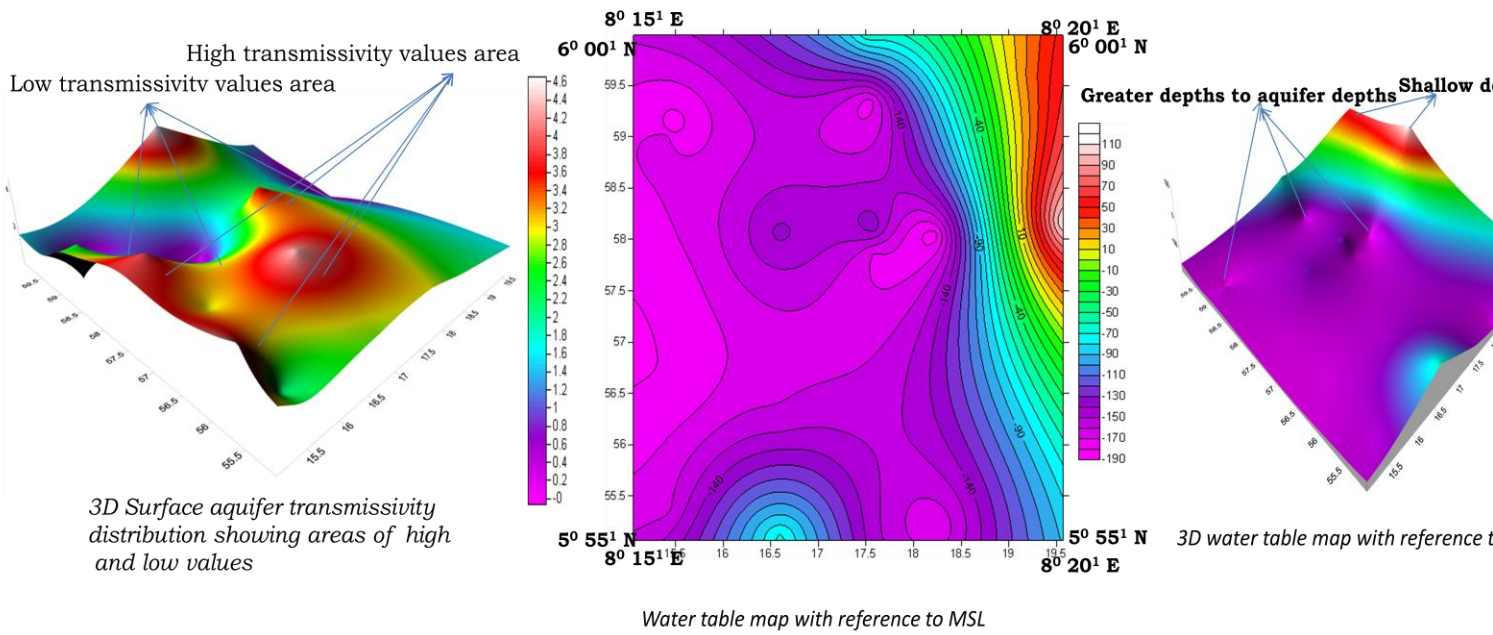


Figure 7: 3D transmisivity and water table map with reference to MSL

In the upper north east area of the study map, where we have VES 15, 18, and 14, there are relatively shallower aquifers when compared to the other VES points in the study area. VES 15 has the shallowest depth to aquifer, which is at about 9.8ft. The aquifer which is inferred to be a perched aquifer has a thickness of about 55.7ft (17m), this is relatively small when compared to other aquifer units in the study area.

Aquifer thickness in the study area varies from 17m to 120m. The smallest aquifer thickness is in VES point 15 where we have the inferred perched aquifer. A diagrammatic comparison of the aquifer thicknesses, depth to aquifer and aquifer resistivity's across cross sections AA^1 and BB^1 is given below in figure 9.

Considering cross section AA^1, it is evident that the aquifer resistivity across the cross section decreases in the SW-NE direction. That is, from VES No.2 to 8. At VES No.10, the resistivity value increases and peaks in VES No.15 if the cross section were to be continued to 15.VES 12 has the highest aquifer resistivity value (689Ωm) in the study area, with depth to aquifer and aquifer thickness of about 200m and 100m respectively.

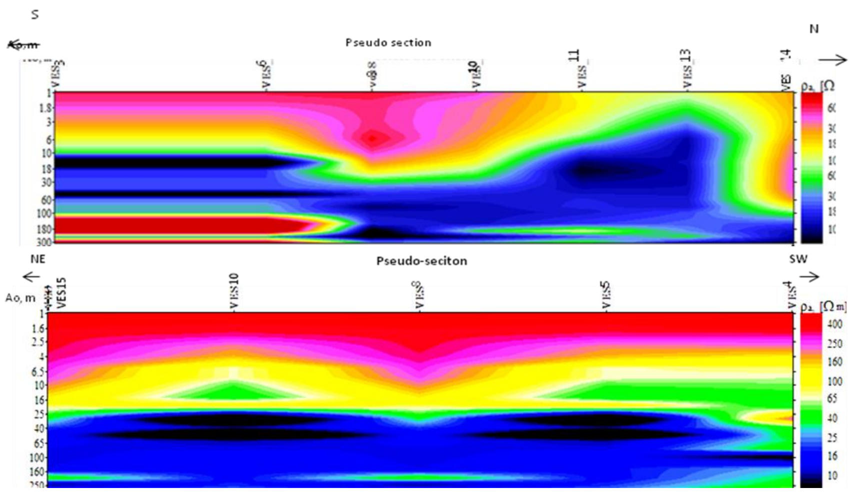


Figure 10: (a), (b), attempts to give the appearance of the subsurface along cross sections BB[1], and AA[1]. (Odong, 2013).

The method adopted in the investigation of the study area, has helped in the identification of aquifer units, and has provided an understanding of the hydro-geologic setting of the complex sub-surface geology. Shallow aquifers exist in the upper north eastern part of the study area. The aquifer units in the area are capable of yielding good water for human use. Except for the inferred shallow aquifer (perched aquifer) in VES 15 which can easily be polluted/contaminated by contaminated surface runoff water in the area.

The aquifer with the highest thickness is found in VES point 9, located in the Western part of the study area close to Oderigha community. This aquifer unit will have a high yield of groundwater. The depth to aquifer is about 140m, which is relatively shallow as compared to VES points 7, 6, 8, 13 and 16. VES point 14 has an aquifer thickness of about 120m and a depth to aquifer of about 100m. Boreholes drilled in VES point 14 will be capable of serving the inhabitants of Northwestern part of the study area and VES point 9 and 2 can serve the inhabitants of the western and Southern part of the study area respectively. Other boreholes can be drilled in VES point 18 and 11 to support the aquifers at VES point 2, and 9 for maximum supply of groundwater in the entire study area. It is important to note that the aquifer units are overlain by thick massive shale layers in the area.

4. Recommendation

Consequently, VES no. 2, 14, 9, 18 and 11 will be the best locations to drill boreholes for sustainable groundwater development in the area of study to serve the communities. It is also observed that this VES points are located close to the communities.

The VES method has also provided an understanding of why boreholes in the area often fail to yield water for commercial use. The wide spread of thick saturated shaly sandstone layer, has often been misleading to be prolific aquifer units to most borehole drillers.

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