J. Chem. Soc. Nigeria, Vol. 45, No.5, pp 897 - 905 [2020]

Hydrogeophysical Investigation of Groundwater Systems in Otukpo, Benue State, North-Central Nigeria

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Received 01 July 2020; accepted 01 August 2020, published online 28 August 2020

Abstract
Hydrogeophysical investigation of groundwater systems in Otukpo, Benue State, Nigeria has been carried out using vertical electrical sounding (VES) technique to delineate the groundwater potentials across the study area. Ten (10) vertical electrical soundings were carried out during the geophysical survey using the Schlumberger configuration of electrical resistivity method with maximum current and potential electrode spacing of 600 meters and 80 meters respectively. The VES data was qualitatively and quantitatively interpreted using the conventional curve matching and computer iteration methods. The result of qualitative interpretation depicts that the VES curves obtained within the study area are mainly the QH and KQH which are typically indicative of a sedimentary terrain. The results of the quantitative interpretation reveal that the resistivity values from shallow subsurface to the depth of about 500 m of the VES stations ranges from 3 Ωm to 1250 Ωm. The VES results also show that the study is characterized by seven (7) different inferred lithological layers namely; topsoil, sand/silt, laterite, clay, shale, sandstone and the basement rock. The result also reveals that the depth to water-saturated unit ranges from 450 to 500 meters within the study area. Two distinguished aquifer types were obtained within the area namely; unconfined and confined aquifers. The findings reveal that the future borehole drillers should target the confined aquifers situated between the depths of 450meters to 500 meters beneath the surface for sustainable groundwater yield across the study area.
Keywords: Hydrogeophysics, Groundwater Systems, Vertical Electrical Sounding, Otukpo, North-central Nigeria

Introduction
The use hydrogeophysical methods for groundwater studies has been stimulated in part by a desire to reduce the risk of drilling dry or abortive boreholes and also a desire to offset the costs associate with poor groundwater exploration and exploitation [1, 2]. Groundwater as a precious natural resource is scarce and unevenly distributed within the Benue Trough; Lower Benue Trough in particular [3]. The lithology ofsedimentary frame work of Otukpo is the principle factor controlling the distribution of aquifer permeability and porosity in any given sedimentary setting, and it is serves as the dominant control over groundwater accumulation, movement and exploitation. The search for the unevenly distributed groundwater resources by geophysical technique employing geoelectric method has proven to be positively productive in resolving groundwater problem [4, 5, 6].

Furthermore hydrogeophysical explorations are an indirect method of obtaining generalized sub-surface geologic information by using special instruments to make certain physical measurements [1]. A requisite requirement for locating, assessing, development and utilizing groundwater resource is equipped with a detailed hydrogeological and hydrogeophysical knowledge of the subsurface to guide placement of boreholes or water wells [2]. There are four important techniques available for solving groundwater prospecting problem includes gravity, magnetic, seismic, and geoelectrical methods. Of these four methods, electrical resistivity method through its highest resolving power and economic viability gives accurate and reliable results in solving groundwater problems [7, 8, 9]. Groundwater investigation generally occurs within the upper few hundred meters below the earth's surface, and the use of geophysical exploration methods especially the electric resistivity method has become increasingly acceptable and popular [10, 11, 12]. In addition groundwater is considered as the safest form of water supply for domestic use due to the fact that it is not prone to pollution as other sources of water [13]. The occurrence and distribution of groundwater is primarily dependent on the local and regional geology of an area, geomorphology/weathering and precipitation. These factors determine the occurrence of groundwater and give rise to complex hydrogeological environment with variation in accessibility, quantity and quality of groundwater resources [14, 15, 16].

Consequently there is scarcity of groundwater as a means of potable water source in Otukpo and its immediate environs. The present failure rates, variability of yields in wells and maintenance problems of wells in the study area point to the need for greater understanding of the geological, geophysical and hydrogeological principles involved in search for groundwater resource. Official information from the Benue state ministry of water resources indicates that water boreholes drilled in Otukpo and its environs have not been successful. Water deveining (water-witching), insufficient VES data and improper correlation of the geophysical data with the local geology in the area were responsible for the high failure rate of water boreholes in the area. From the unpublished VES data obtained with respect to the study area; the VES data terminates at less than 150 m. Manual drilling (hand-turning) and truck mounted mud rotary drilling rigs were used for shallow depth penetration of less than 150 m. There is a relative shortage of potable water in the water supply system of Otukpo that has led to restrictions on water consumption.

Materials and Methods

Location and Geology of the Study Area

The study area is located within the southern portion of Benue State, Nigeria and it geologically falls within the Lower or Southern Benue Trough. It lies within latitude 7º08′N to 7º15′N and longitude 8º05′E to 8º15′E on an average altitude of 270m above sea level (Figure. 1). The area is generally low lying with few gently undulating ridges. The area is topographically part of sheet 270 SW and classified under the Lower Benue River Basin, hydrological area of Nigeria. The area is majorly drained by Okpokwu River which is a tributary of the Benue River. The area lies within the Guinea Savannah vegetation zone. The area has a mean annual rainfall range of 1500mm to 1800mm and a monthly temperature range of 25^{o}C to 33^{o}C [17].The prevalent climatic condition in the area comprises the rainy (March to October) and dry (November to February) seasons characterized by high temperatures, low pressure and high relative humidity throughout the year.

Geologically, Otukpo is underlain by Cretaceous sediments of the Benue Trough and it is classified geologically as the Lower or Southern Benue Trough and Lower Benue River Basin respectively. The Benue Trough has often been described as an intracontinental Cretaceous basin [18]. The basin is said to be occupied by up to 6,000m of marine and fluvio-deltaic sediments that have been compressionally folded in a nonorogenic shield environment [19]. The Cretaceous sediments of the Otukpo area are composed of the Asu River, the Eze-Aku and the Awgu groups which are presume to unconformably overlie the Precambrian basement rocks [20, 21]. The lithologic unit that characterise the area includes clay, shale, sandstone and limestone [3]. The folds, faults and fractures in the area are as a result of the major Santonian deformation in this area [19, 22].

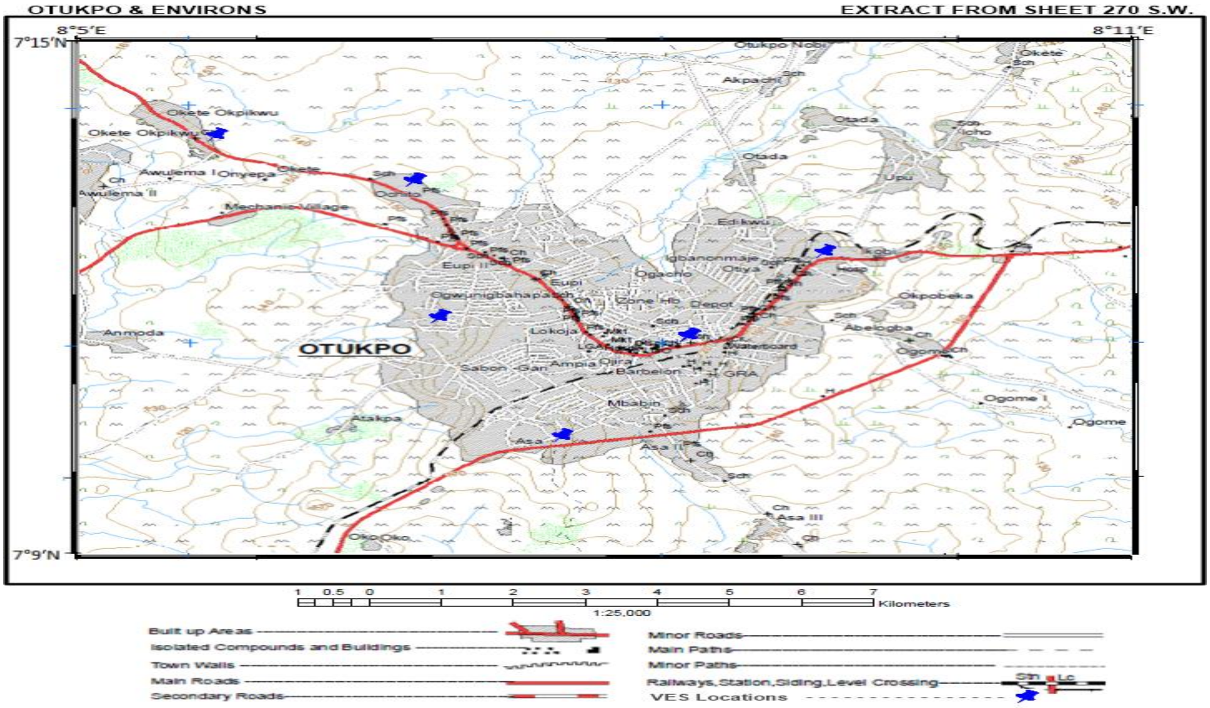

Figure 1: Map of Otukpo and Environs [22]

Fieldwork

Existing published literatures on the regional geology and hydrogeology of the study area were carefully studied. Reconnaissance preliminary assessment of the research area and terrain familiarization was carried out. Topographic fact map on a scale of 1:100,000 were used as a base map for the mapping exercise. Geophysical investigation employing the Electrical resistivity technique was used to characterise the subsurface resistivity distribution by making measurements on the ground surface. ABEM SAS 4000 Terrameter, a digital signal enhancing device incorporated with a microprocessor was used to obtain the geophysical data. Schlumberger configuration was used for the 1D Vertical Electrical Sounding (VES) of the deeper subsurface. A maximum AB/2 of 600m was investigated and a total of 10 VES stations were evenly established within the study area employing the Schlumberger configuration. Qualitative and quantitative interpretation of the obtained data were carried out, generating the geoelectric curves, using the traditional partial curve matching involving the master and auxiliary curves to acquire the different layers at various depth [23] and thereafter using the computer iteration technique (Winresist software) by [24] to generate resolution curves. Resistivity method was the choice for this investigation because resistivity doesn't measure a signal delay; it measures a material property and also the depth penetration capacity is much higher than with ground penetrating radar [25]. A borehole was drilled and record of lithological measurement as a function of depth (borehole logs) were taken to ascertain the lithology underlying the near subsurface in the study area. The geophysical data collected and the drilled borehole in this investigation are the only available subsurface information. They are not related to any other local geophysical information or technologically acquired data, except that which was acquired during this investigation. The interpretation of the measured data is supported by: (i). Experience from measuring practice with Resistivity in Nigeria since 2005 (ii). Discussions with residents and within the investigation team (iii) Comparison between geophysical investigations found in other subsurface surveys (iv) Observation of surficial conditions in the field [26].

Results and Discussion

The results obtained from the geophysical investigations and the lithological logs obtained from the drilled borehole were quantitatively and qualitatively interpreted.

Quantitative Interpretation

The geoelectric layer parameters (Table 1) and the model curves show five (5) geoelectric layers (Fig 2a & 2b). The first layer is the shallow subsurface layer composed of silt/sand with depth range of 0.5 m to 2.0 m and a resistivity range of 42 Ωm to1112 Ωm. The topmost layer is underlain by clayey/laterite layer which has a resistivity range of 19 Ωm to 1121 Ωm to the depth range of 3.9 m to 14.3 m and a thickness of 2.9 m to 13.7 m. The third layer is underlain by saturated and unsaturated clay with resistivity range of 04 Ωm to 128 Ωm extending to the depth 11.8 m to 18.3 m. The fourth layer is composed of shale which is intercalated with sandstone at greater depths with resistivity value range of 05 Ωm to 124 Ωm. the fourth layer is made up of saturated sandstone having a resistivity range of 08 Ωm to 584 Ωm to a fairly infinite depth.

Qualitative Interpretation

The resistivity structure at Otukpo is dominated by two coherent low resistivity layers that underlie the study area. The major curve types generated from the apparent resistivity plot of the area are the QH (Figure 2a) and KQH (Figure 2b) which are common curves in sedimentary terrain [27].

Correlation between Geoelectric and borehole logs

The lithological log of the drilled borehole revealed that the geology of Otukpo generally falls within the sedimentary formation of the Lower Benue Trough (Figure 3). It is part of the linear stretch of the sedimentary elongated trough like basin of the Benue Trough. The Lithologic unit of Otukpo subsurface consist of lateritic soil, clay, silts, sand and the succession of thick shale as the principle lithologic unit underlying the area as reveal from the borehole log. To verify the authenticity of the geophysical data a drilled borehole was terminated at 120m depth. The lithological log obtained from the borehole validates the predrilling geophysical survey data obtained.

Table 1. Geoelectric Layers Parameters

LAYERS	**VES 1 Okete**	**VES 2 St. Francis Gate**	**VES 3 Asa, Otobi Road**	**VES 4 Upu Road**	**VES 5 Ochito-Gana**	**VES 6 FRSC, Enugu Road**	**Lithology**
1 ℓ/T/d	**112/1.1/1.1**	**139/1.0/1.0**	**42/0.9/0.9**	**102/2.0/2.0**	**220/0.6/0.6**	**155/0.5/0.5**	Unsaturated top soil
2 ℓ/T/d	**121/2.9/3.9**	**290/6.9/8.0**	**1147/5.0/6.7**	**19/8.7/10.7**	**706/13.7/14.3**	**909/5.7/6.2**	Lateritic-Silt-Clay
3 ℓ/T/d	**92/7.9/11.8**	**09/21.1/29.1**	**128/8.4/15.1**	**13/69.6/18.3**	**04/123.3/137**	**18/8.4/15.1**	Shale-Silty-Clay
4 ℓ/T/d	**11/376.2/400**	**05/296/388**	**2.8/295/351**	**05/304.9/400**	**124/178/315.8**	**6/380.7/400**	Shale
5 ℓ/∞	**584**/∞	**72**/∞	**245**/∞	**10**/∞	**8.0**/∞	**190**/∞	Saturated Sandstone
CURVE TYPE	QH	KQH	QH	QH	KQH	KQH	

Key: **VES**= Vertical Electrical Sounding. **ℓ** =Resistivity(Ωm) / **T** =Thickness(m) / **d** =Depth(m)/ ∞=Infinity

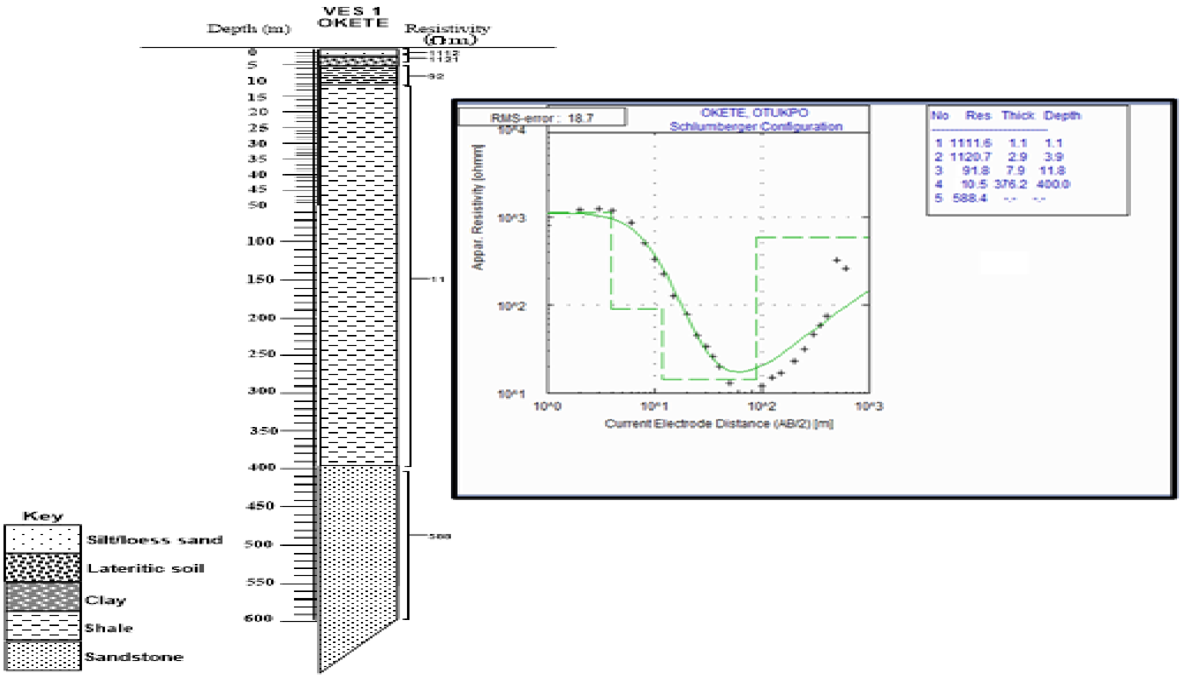

Figure 2a. Geoelectric Log and VES Model Curves (QH) of VES 1 (Okete)

The shale extent in Otukpo area is thick as indicated in the log and VES data. This could explain the rapid decrease in resistivity values in just a few hundred metres. The low values of the relative Root Mean Square (RMS) error show that the data quality is good and the result of the computer inverse is reliable. The lithostratigraphic profile of the subsurface was derived from the exploitation strata-log. From the exploitation borehole log (Figure 3), lateritic soil visibly serves as the top most layers in the area. The laterite is underlain by loess sandy soil to the depth of about 5 m. underlying the sandy soil is silty-sand extending to the depth of 10 m. Clayey soil is the lithological unit overlying the silty-sand to the depth of about 18 m.

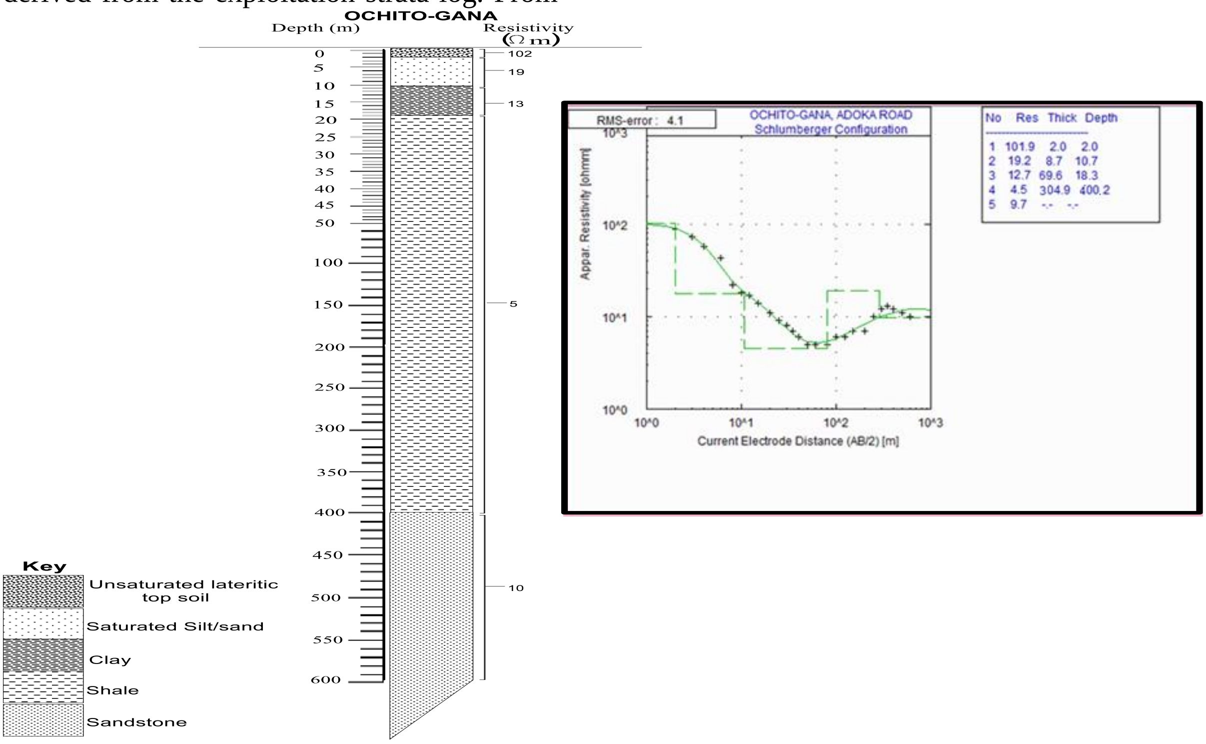

Figure 2b: Geoelectric Log and VES Model Curves (KQH) of VES 5 (Ochito-Gana).

The clay soil in the study area is exogenous in origin and possesses reasonable level of porosity but low in permeability. Underlying the clay is shale which extends to the total drill depth of 120 m where the drilling was terminated. The main constituents of the shale encountered in the study area is clay minerals believed to be formed as a result of chemical weathering that led to the disintegration of the parent rock. The shale encountered in the area is dark grey-black in colour (Figure 3).

Hydrogeological Implication of the results

Hydro-geologically, the investigation has revealed two aquifer types domicile in the area; the shallow unconfined seasonal aquifer and the deeply seated confined aquifer. The groundwater in the shallow unconfined seasonal aquifer is recharged by precipitation events as it travels through the fractured underlying laterite and discharges from springs and shallow wells domicile in the area. From the investigation it can be inferred that the subsurface model of Otukpo lithology could be in the descending order of top soil, sans/silt, laterite, clay, shale, sandstone and the basement crystalline rock (Figure 4).

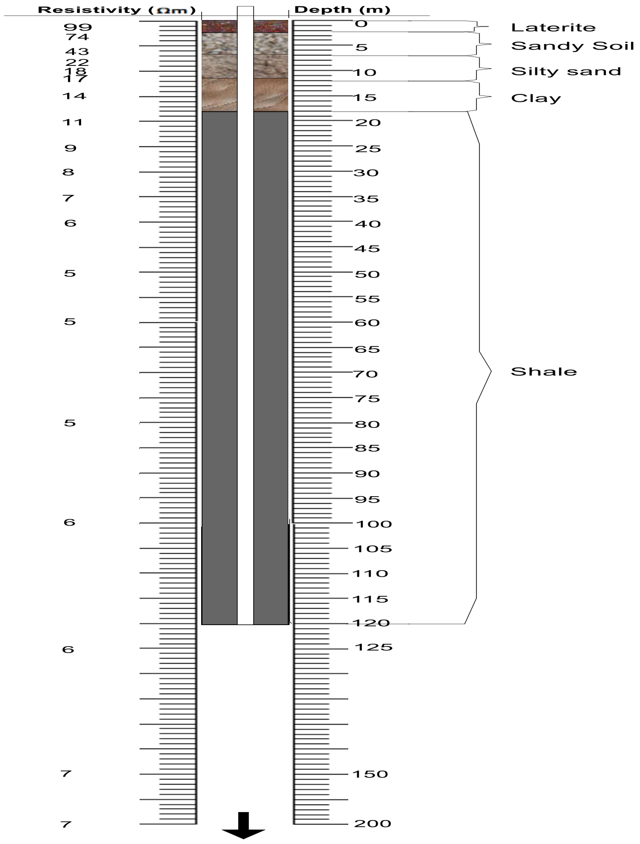

Figure 3: Borehole Lithological Log near VES 5

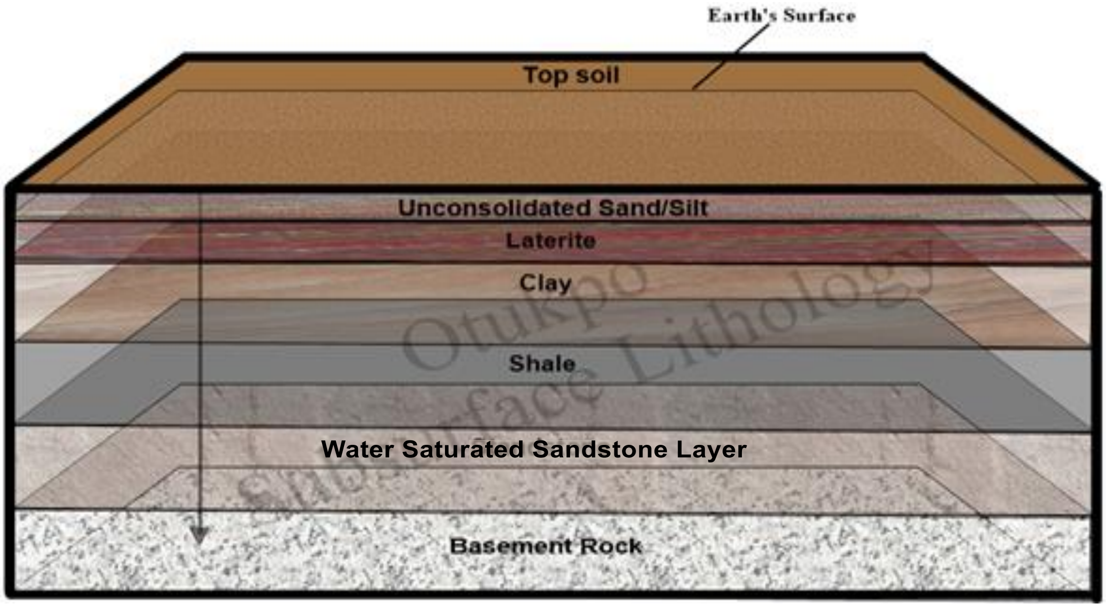

Figure 4: 3D Groundwater model within the study area

Conclusion

Hydrogeophysical investigation of groundwater systems employing the electrical resistivity method and the drilling of a boreholehas been carried out in Otukpo. Coherency was established between the pre-drilling geophysical investigation and actual findings which was verified through the drilling operations. The major aquifer in the study area is the saturated confined sandstone layer. The confined sandstone aquifer is deeply seated at about 450 m to 500 m beneath the surface.

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