HYDROGEOPHYSICAL INVESTIGATIONS OF GROUNDWATER SYSTEMS IN OTUKPO, BENUE STATE, NORTH-CENTRAL NIGERIA

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Abstract
Hydrogeophysical investigation employing electrical method was adopted for groundwater exploration in Otukpo. Data collected from geophysical investigations and from one borehole were used in this research. Six (6) Vertical Electrical Soundings (VES) were carried out in the study area using the Schlumberger configuration of electrical resistivity method with a maximum AB/2 of 600m. Qualitative and quantitative interpretations of the data were carried out employing the traditional curve matching and the digital computer iteration methods. The VES readings from shallow subsurface to the depth of about 500m of the VES stations ranges from 3 Ωm to 1250 Ωm, interpreted in the area as loess sand, silty-sand, clay, shale and sandstone from top to bottom based on the resistivity data. The deeper groundwater system in the area is confined at an approximate depth of 500m. A shallow seasonal unconfined aquifer (aquitard) and a deeper confined aquifer are the two principal types of aquifer existing in the study area. Future borehole in the area that would tap water from the confined aquifer likely to be terminated at a depth of about 450 m to 500 m. Based on the detailed geophysical investigations which confirmed the sandstone formation.

Keyword: Otukpo, Groundwater Systems, Geophysical investigations

Introduction

The use hydrogeophysical methods in groundwater investigation has been on the increase due to the desire to reduce the risk of drilling abortive boreholes and also to offset the costs associate with poor groundwater exploration and exploitation (Amadi *et al*, 2012; Reinhard, 2006; Dwain, 2015). Groundwater as a precious natural resource is scarce and unevenly distributed within the Benue Trough in general and Lower Benue Trough in particular (Offodile, 2002). The sedimentary frame work of Otukpo is the factor controlling the distribution of groundwater in the area. The local geology contributes to groundwater accumulation, movement and exploitation.

The search for the unevenly distributed groundwater resources by geophysical technique employing geoelectric method has very efficient in solving groundwater problem (Amadi *et al*, 2015; Philipp and Stefan, 2011). The increase in groundwater demand for various human activities in Otukpo and environs as a result of scarcity of surface water has made groundwater exploration and exploitation a necessity. Due to poor knowledge of the subsurface geology in the area, majority of the borehole drilled in the area has been abortive, while the successful ones have low yield. As a result of the upsurge in population coupled with the increase in the number of agro-based cottage industries, the need to understand the subsurface configuration of the aquiferous unit in Otukpo and environs cannot be overemphasized.

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 (Reinhard, 2006; Dwain, 2015; Unuevho *et al*, 2016). Understanding the local geology will lead to delineation of the aquifers in the area, and it will greatly reduce the high rate of borehole failure in the area. This is the crust of the present research.

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 $7^0$08"N to $7^0$15"N and longitude $8^0$05"E to $8^0$15"E on an average altitude of 270m above sea level (Fig. 1). 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^oC to 33^oC (Nigerian Metrological Agency, 2018). 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.

Otukpo is underlain by Cretaceous sediments of the Benue Trough. The Benue Trough has often been described as an intracontinental Cretaceous basin (Obaje, 2009). 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 (Nwajide 2013). 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 (McDonald el al, 2008; Reyment, 1965). The lithologic unit that characterise the area includes clay, shale, sandstone and limestone (Offodile, 2002).

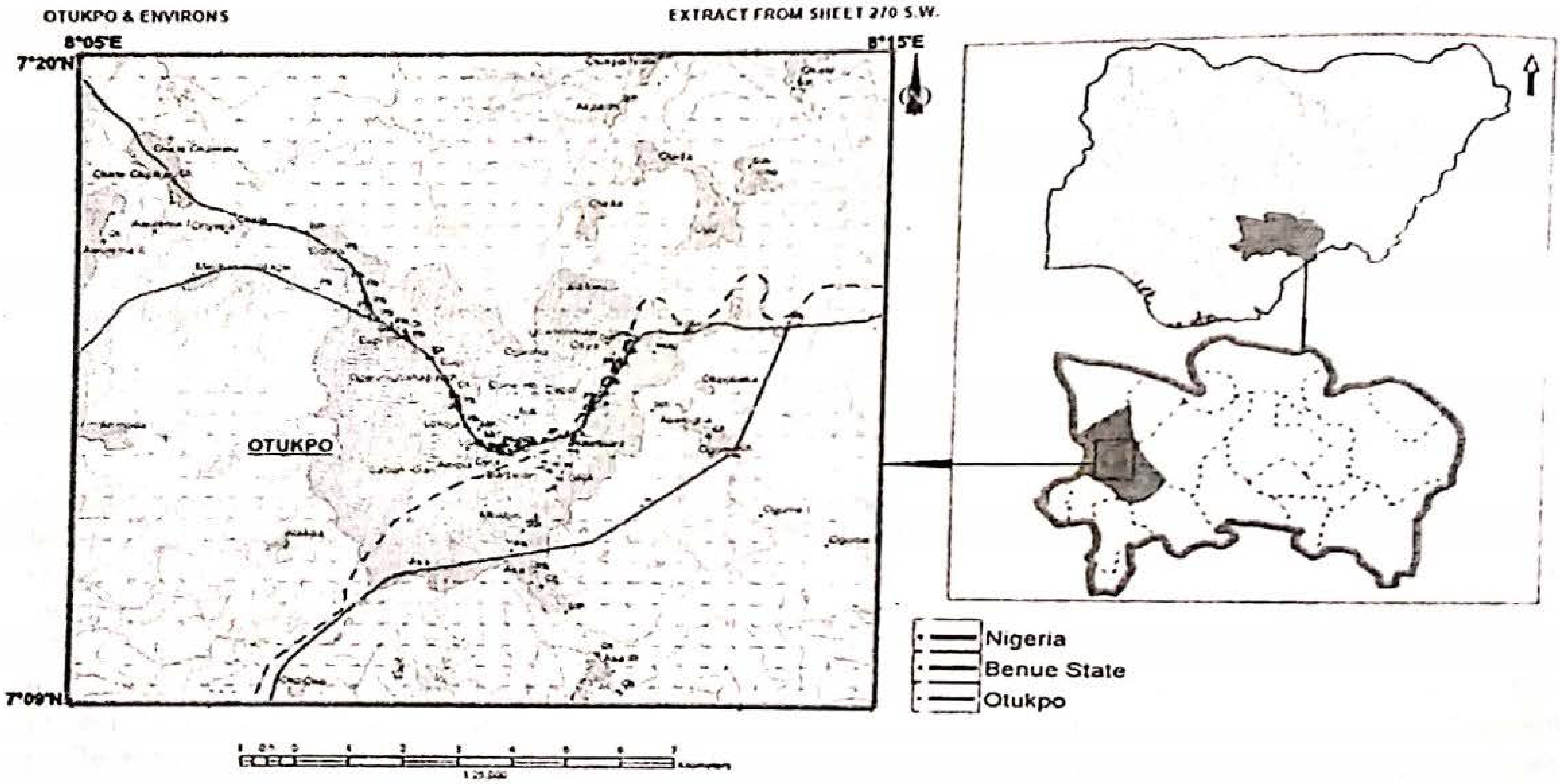

Fig. 1: Location Map of the Study Area

Materials and Methods

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. A fact map of scale 1:25,000 was developed from a topographic map of scale 1:50,000 of Otukpo Sheet 270 SW. ABEM SAS 4000 Terrameter, a digital signal enhancing device incorporated with a microprocessor was used to obtain the geophysical data.

With the collinear arrangement of four electrodes, the current electrodes A and B on the outside while the potential electrodes M and N on the inside, Schlumberger configuration was used for the one dimensional IP and Vertical Electrical Soundings (VES) of the deeper subsurface. A number of key geological and cultural factors were considered prior to the establishment of the geoelectric methods, these includes: nature of the target, anticipated depth of burial of target, measurement station interval and calibration of the data. A maximum AB of 1,200m (AB/2=600) was investigated and a total of six (06) sounding stations were evenly established within the study area. The parameter used in qualifying the IP and VES are the normalized chargeability measured meters per second (msec) and the apparent resistivity measured in Ohms meter respectively. The IP (chargeability) is collected using conventional electrical resistivity electrode configuration where the voltage between electrodes is measured as a decay function with time as the current is switched on (Bleil, 1953). Qualitative and quantitative interpretations of the obtained data were carried out; generating the geoelectric model curves using the computer iteration technique (Winresist software) by Van der and Sporry, (1992) for the resistivity data and chargeability value in msec was ploted against the electrode separation in meters using the Microsoft Excel program for the IP data. A 120m borehole was drilled to calibrate the geophysical data obtained and also to ascertain the lithology's underlying the near subsurface of the area.

Results, Interpretations and Discussions

A careful analysis of the resistivity and chargeability in the 1D result (Table 1) shows that the observed low resistivity values did not reflect distinct and relatively high chargeability values. Clay is expected to produce high chargeability anomaly due to cation exchange capacity and higher conductance surface and minerals which help in the particle charging process but in this case negative chargeability values were recorded. The low-resistivity and negative chargeability layers corresponds to pure clay/shale layers while low-resistivity and medium to high chargeability layers depicts saturated sandstone layer.

Table 1: Apparent Resistivity and Chargeability Data

LAT.		7°16"11.6'		7°12"07.9'		7°10"18.1'		7°13"14.5'		7°20"02.4'		7°13"11.3'	
LONG.		8°10"27.1'		8°07"43.0'		8°08"17.9'		8°06"52.2'		8°15"13.3'		8°09"25.9'	
		OTK 01		OTK 02		OTK 03		OTK 04		OTK 05		OTK 06	
AB/2	MN/2	ρa	IP	ρa	IP	ρa	IP	ρa	IP	ρa	IP	ρa	IP
1	0.3	500	1.61	139	1.117	700	2.86	99	1.16	230	0.93	220	0.89
2	0.3	849	2.7	175	1.73	950	3.81	88	1.43	355	1.32	338	1.16
3	0.3	920	3.11	202	1.79	846	4.42	74	2.05	511	1.28	499	1.36
4	0.3	861	3.69	209	1.98	419	4.04	57	-0.6	646	2.73	647	1.57
4	1	860	3.83	209	1.79	419	4.38	57	0.29	646	2.15	647	1.62
6	1	710	4.12	216	2	129	-13.1	43	-0.39	724	2.17	671	1.99
8	1	515	4.65	227	2.21	51	44.3	22	172	733	2.71	660	2.31
10	1	334	4.87	234	2.79	27	68.9	18	75.6	707	2.97	578	2.95
12	1	226	0.83	218	4.49	21	26.6	17	34.6	690	3.21	438	2.71
15	1	127	-5.31	169	4.78	14	82.37	14	8.86	661	3.66	289	5.44
20	1	79	-91.1	100	20	8	25	11	6.32	524	3.96	219	9.02
20	5	79	-17.3	100	8.36	8	22	11	6.32	524	3.81	219	4.69
25	5	45	31.3	62	3.66	5	100	9	-5.69	378	4.18	145	4.88
30	5	32	25	37	4.47	3	22.1	8	-7.08	272	4.95	95	5.38
35	5	24	8.15	22	-4.14	3	25.2	7	-9.65	158	3.98	65	11.6
40	5	19	74	14	-17.4	3	2.5	6	-42.4	140	10.1	32	11.6
50	5	11	-130	9	-11.3	6	-205	5	-116	73	15.9	9	9.23
60	5	9	-100	8	36.4	6	-108	5	-50	42	-2.63	8	3.65
80	5	9	-84.5	6	-43	6	-451	4	-121	18	-21.7	6	-51.2
80	10	10	-34.1	6	-5.74	6	-419	4	-115	18	-7.21	7	-22.8
100	10	8	-246	5	-40.9	7	-320	4	-136	10	-11	6	-10
125	10	8	-258	5	-49.7	7	-481	5	-191	6	-9.5	5	-30.6
150	10	8	-272	4	-50	9	-306	5	-143	3	-10.79	5	-145
150	20	10	-252	5	-38	9	-552	5	-70	3	-34.8	5	-96
200	20	9	-270	6	-117	9	-289	7	-42.9	3	-36.9	6	-12.7
250	20	9	-272	7	-12.3	10	-280	8	-50.9	3	-318	7	-87.7
300	20	13	-273	9	18.6	10	-278	12	-47.9	5	-23.99	8	-157
350	20	18	-430	15	16.2	13	-262	13	-40	6	-634	12	-264
400	20	28	-89	21	-121	21	-205	15	13	22	-243	18	-112
400	50	30	-90	21	-133	21	-291	15	11	22	-187	18	-98.5
500	50	38	54	30	10	34	10.2	13	54	32	301	24	51.05
600	50	29	94	42	15.2	82	44.5	11	98	45	400	38	66.9
600	80	167	105		56.3	82	52.3		100			38	

AB=Current Electrode MN=Potential Electrode K=Constant ρa=Apparent Resistivity

The Otukpo subsurface characterization indicated that the top part of the near subsurface is composed of laterite and silty-sand at variable locations. The apparent resistivity of these top layers ranged from 103.0 Ωm to 1462.0 Ωm, while the values of normalized chargeability ranged from 0.83 msec to 75.6 msec. The middle of the aquifer system consisted of a layer with high pure clay/shale content, and the resistivity ranged from 2.0 Ωm to 49.0 Ωm, while the normalized chargeability is between the ranges of -2.63 msec to -634 msec. The bottom of investigated subsurface consisted of a layer with resistivity ranged from 24 Ωm to 194 Ωm, while the normalized chargeability is between range of 10 msec and 400 msec. The presence of saturated sandstone deposits at the bottom layer might be responsible for the approximate increase in the apparent resistivity and an abrupt change from negative to positive normalize chargeability.

The results of normalized chargeability show a clear trend of decreasing (negative) values in layers with high clay/shale content, and lower positive values when coarse material of sandstone is the main lithological content at the bottom. This is supported by the findings of Torleif and Meng, (2015) and Ian and Ian (2019). Resistivity values at the top layer might be associated with lateritic soil and silty-sand; at the middle layers it might be attributed to clay/shale while at the bottom layer it is attributed to saturated sandstone.

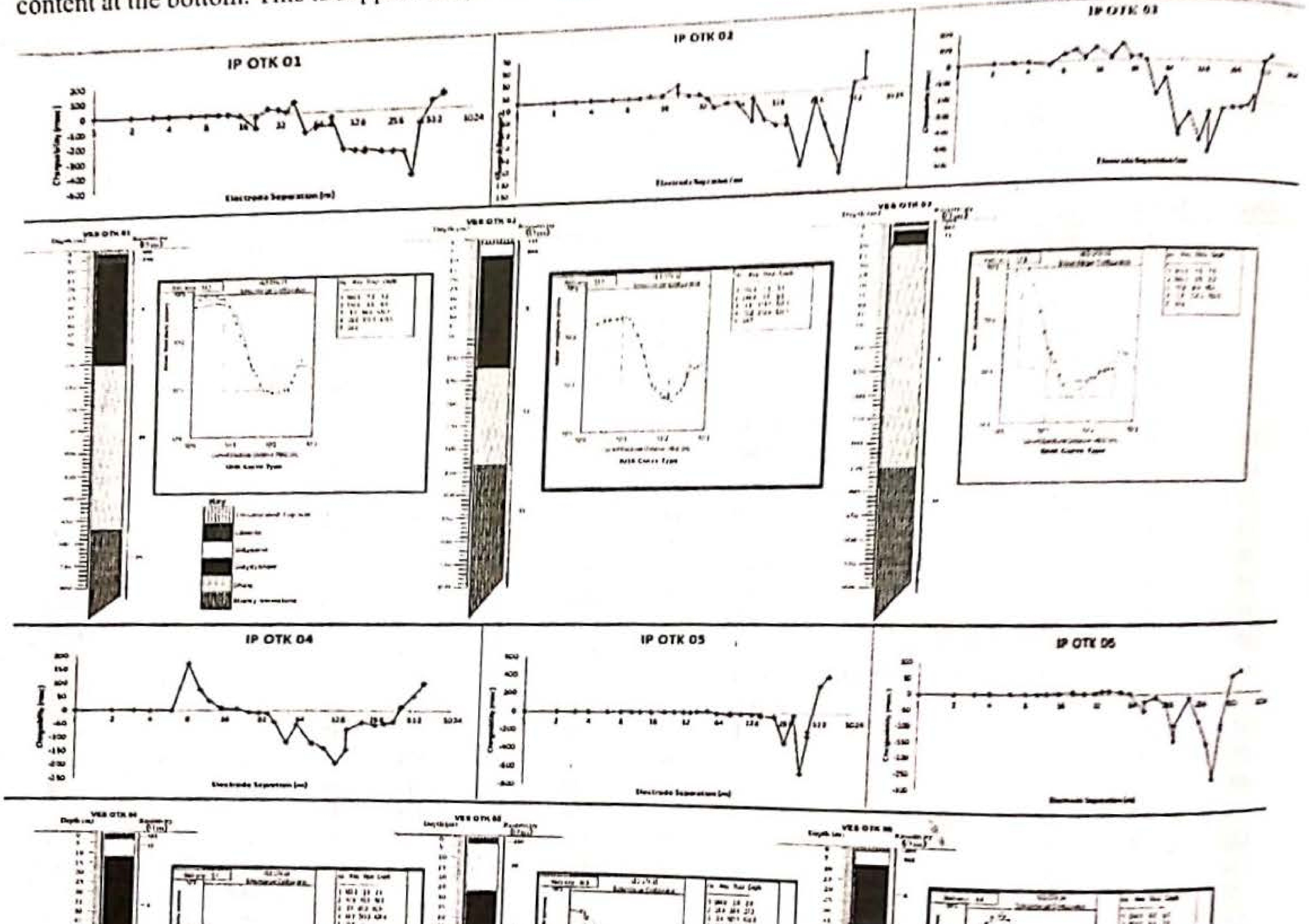

Fig. 2: Chargeability, VES Model Curve and Geoelectric Layers.

The VES results reveal that all the curve types possess five (5) distinctive layers. The morphological analysis of the field curves gives QH, QHK, KHA and KQH curve types. This curve types are synonymous to sedimentary environment indicating inhomogeneity in the subsurface materials.

Conclusion

Lithological in homogeneities of Otukpo subsurface have been unravelled through hydrogeophysical investigation. The electrical methods of IP and resistivity were used for the subsurface investigation

The paradoxical behaviour of the subsurface showing strong negative chargeability responses may be attributed to the effect of highly conductive zone made up of pure clay shale concentrations within the study area. The groundwater system of Otukpo is composed of two aquifer types; the shallow unconfined aquifer and the deep confined aquifer. The shallow unconfined seasonal aquifer (1m to < 25m) is recharged by precipitation. The confined aquifer is deeply seated at about 450 m to 500 m beneath the surface. The aquifer is confined at the top by thick layer of impermeable clay/shale materials. The shallow unconfined aquifer can sustain domestic use for a season while the deep confined aquifer will sustain commercial applications. The difficulty in drilling through the thick shale is discouraging the harnessment of the deep confined aquifer.

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