

## **Integrated Use of Geo-electrical Resistivity Sounding and Hydrogeologic Investigation Methods for Groundwater Resource Development around Obu-Okpella South-Western Nigeria**

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**Abstract:** An integrated use of geo-electrical resistivity soundings and hydrogeologic methods were employed in the investigation for groundwater resource, evaluation and development around Obu-Okpella, near Buacement factory, South-western Nigeria. The study area is underlain by Basement Complex rocks which consist of migmatites, granite gneiss and pegmatites. A total of 35 vertical electric soundings (VES) and four exploratory boreholes were carried out in the study. The geo-electric resistivity sounding data were interpreted using IXD interperx software and the VES interpretation revealed 4 geo-electric layers/lithologic units from the geo-electric parameters. The geo-electric layers are- (1) Topsoil from 0 to 2.5m, (2) weathered basement from 3.3 to 49m, (3) Slightly weathered/Fresh basement from 5m to ∞, (4) Fractured basement (≥5 to 150m) and are characterised by resistivity value range of 14 to 297 ohm-m, 16 to 98 ohm-m, >1000 ohm-m and < 50 to 31056 ohm-m respectively. Four exploratory boreholes numbered BH1, BH2, BH3, and BH4 were drilled on VES 1, 17, 18 and 31 to a depth of 180, 150, 58 and 110m respectively. The VES interpretation and borehole lithologic logs were well correlated. The main aquifer is in the deep and highly fractured basement rocks with average depth of 50-150m. The pumping test results for the boreholes number BH1, BH2, BH3 and BH4 were 0.8l/s, 1.87l/s, 1.2l/s and 1.7l/s respectively with very maximum dynamic water level of <10m. Transmissivity value of the aquifer for BH1, BH2, BH3 and BH4 are 2.58m<sup>2</sup>/day, 21.43 m<sup>2</sup>/day, 55.62 m<sup>2</sup>/day, and 37.98 m<sup>2</sup>/day respectively indicates that the lithostrata constituting the aquifer is fair in transmitting the groundwater. With a volume of 12,000 l/day, 97,000 l/day, 91,000 l/day and 51,840 l/day for BH1, BH2, BH3 and BH4, the total volume of water for the four boreholes is 253,560 l/day.

**Keywords:** Obu-Okpella, Geo-electric/Hydrogeologic investigations, Borehole flow rates and transmissivity.

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### **I. Introduction**

Okpella is one of the rapidly expanding towns in the northeastern part of Edo State. It is strategically important because of its industrial mineral resources, which include marble and granitic rocks. The marble is being quarried for cement production by BuaCement Company Limited. The building of a new cement plant and its subsequent expansion over the last decade has resulted in the rapid expansion of the satellite settlements with increased population around the cement factory. As a result of the increase in population, water supplies for domestic and industrial purposes from boreholes with characteristically low yield have been overstretched and grossly inadequate. Geophysical investigations have been used overtime and successfully to determine the subsurface sequences, aquifer units and also to map its lateral and vertical extends (Olorunfemi, 1985; Omosuyi et al, 1999). Lithostratigraphic units from drilled boreholes have been used to identify aquifer units laterally and vertically (Longpia et al 2004).

Geophysical investigation using vertical electrical soundings (VES) technique and drilling of exploratory boreholes was used to evaluate the groundwater potential of the area for development of a sustainable small to medium water supply scheme.

### **Location and Physiography**

The study area is located between UTM co-ordinates of 212000 to 214000 Easting and 813200 to 814400 Northing. The climate falls within the warm-humid tropical climate region which is characterized by wet and dry season.

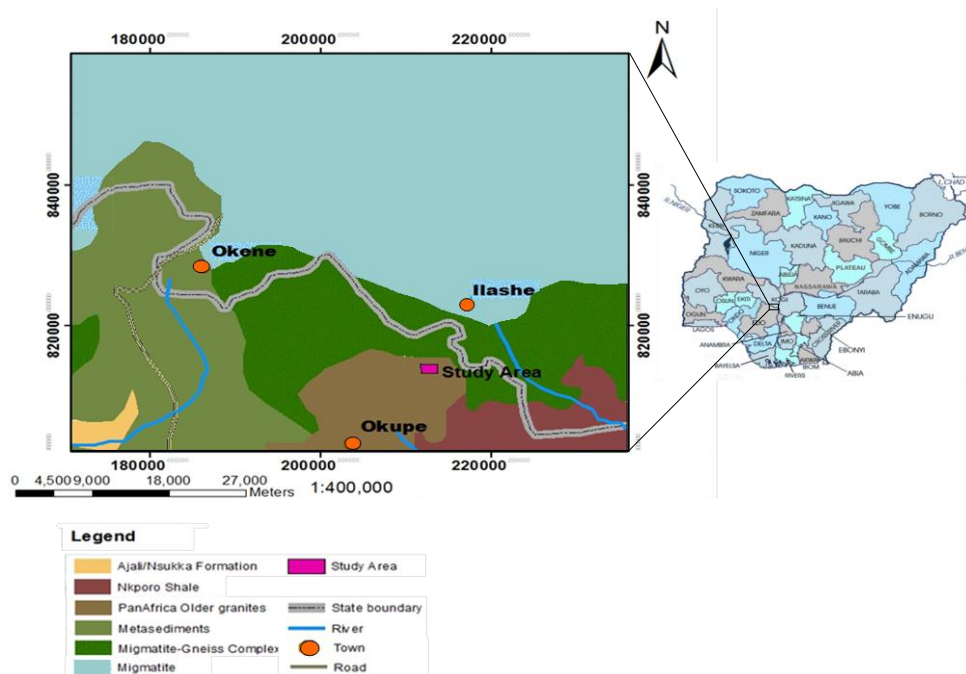


Fig. 1: Regional Geology of the Study area.

The vegetation cover is typically that of the Guinea Savannah and characterized by secondary vegetation of scattered trees, shrubs and grass savannah. Generally, the vegetation has been tempered by human activities mainly for agricultural purposes.

## Geology

### Regional Geology

The Pre-cambrian geology of the south-western Nigeria is part of the Basement Complex rocks of the south-west Nigeria. According to Rahaman (1989), five major groups of rocks have been recognized in the regional setting consisting of:

- i) Migmatized-Gneiss Complex
- ii) Slightly migmatized to unmigmatized paragneisses and meta igneous rocks which consists of pelitic schist, quartzite, amphibolites, talcose rocks, meta conglomerates, marbles, calc-silicate rocks,
- iii) Charnokitic rocks,
- iv) Older Granites comprising of rocks with granodiorite to true granite and potassium syenite.
- v) Unmetamorphosed dolerite dykes.

From Igara and further east around Okpella, the association of amphibolites (meta igneous and volcanic rocks) and the association of carbonates (marbles and calc-silicates rocks) and argillaceous rocks represent an eugeosynclinal and miogeosyncline sequence of sediments (Rahaman, 1989).

### Local Geology setting

Obu-Okpella and environs is underlain mainly by the Migmatite-Gneissic Complex and Older Granite (Fig. 1). The Meta sediments consist mainly of marbles and are being quarried for cement production. The Migmatite-Gneiss Complex is highly fractured and characterized by highly dissected stream/ rivers. The rivers appear to follow the lineaments or local structures.

## II. Hydrogeology

Hydrogeologically, the study area falls within the crystalline basement complex and are classified as poor groundwater regions (du Preeze and Berber, 1965). However, despite the relatively poor hydrogeological characteristics of these basement rocks, they have remained a very important source of water supply for more than half of the population of rural areas in Nigeria (Offodile, 2002).

The weathered regoliths usually consist mainly of clays, sands, sandy clays and where generally thick, constitute the aquifers (Offodile, 1983). Highly tectonised basement rocks with incipient fractures, joints and folds are potential groundwater storage and flow zones and is very significant in basement surveys for groundwater development (Omosuyiet al, 2003).

### III. Method of Study

#### Geophysical Survey

This study involved geo-electrical resistivity measurements across the accessible areas south of Buacem cement factory area (Fig. 2). The survey was conducted using the Schlumberger Array method. The current electrode (AB/2) and potential electrode separations (MN/2) was varied from 1.5 to 500m and from 0.5 to 55m respectively. The field readings were carried out using Allied Omega earth resistivity meter. A total of 35 VES were conducted around the area (Fig. 2). The field data was interpreted using a computer simulated program, Interpex (IXD) software.

The geo-electrical parameters of the VES interpretation were used to produce geo-electric sections along strategic profile. The VES locations co-ordinates were determined in the field by the use of Garmin Etrex 12 channel global positioning system. The maps were produced using Surfer 11 GIS program.

#### Hydrogeologic Investigation

Four exploratory boreholes were drilled on some selected VES locations which their interpretations revealed deep and fractured basements. A correlation of the VES interpretation and the drilled boreholes are as shown in Fig. 5.

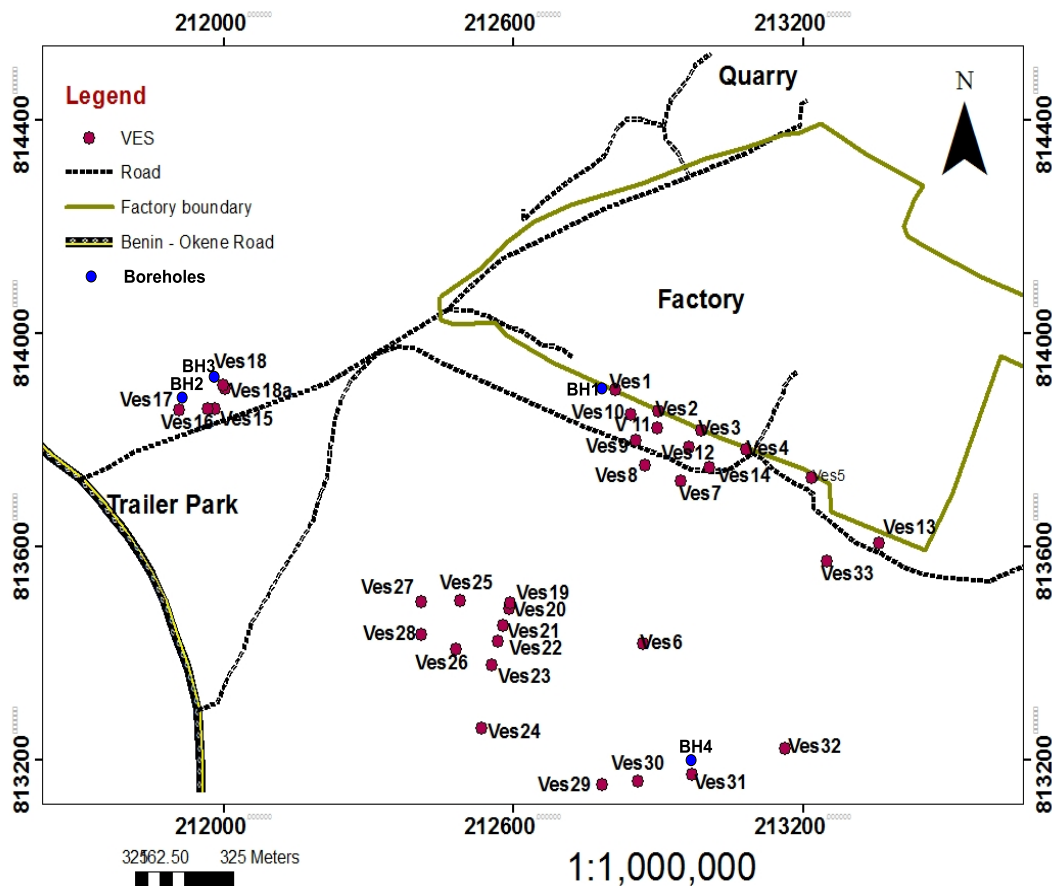


Fig. 2: Location Map of the Study area showing VES Locations

### IV. Results & Discussion

#### Geo-electric Resistivity Soundings and Interpretations

The computer model interpretation of the 34 VES are as shown in Table 1.

Table 1: Summary of VES Interpretation

VES No.	Depth (m) d1/d2-----dn	Resistivity (ohm-m) t1/ t2----- tn	Curve type
1	2.5/8.2/33.8/∞	110/72/727/92	KHK
2	0.8/4.0/16.6/∞	15/10/305/82	AK
3	3.2/17.0/34.8/114.8/∞	292/58/319/71/225	KHKA
4	0.6/13.7/23.0/49.7/∞	26/22/147/114/207	HKA

5	1.6/13.1/∞	33.7/22/462	HA
6	1.0/29.7/∞	51/28/1319	HA
7	0.8/17.8/∞	10/6/555	HA
8	0.6/49.7/∞	54/31/187	HA
9	0.8/5.1/33.8/∞	101/52/396/142	HKA
10	0.8/8.3/27.4/∞	92/35/789/127	HK
11	0.6/4.0/13.1/∞	26/10/656/229	HK
12	0.8/5.1/87.2/∞	37/17/266/255	HK
13	0.8/2.3/∞	34/50/1371	A
14	0.5/2.3/23.0/∞	49/24/261/72/204	AKA
15	0.6/2.0/∞	30/98/2736	A
16	1.0/6.7/95.4/∞	68/120/1030/515	AK
17	0.5/2.5/8.2/26.7/∞	38/93/359/238/1099	AKA
18	0.6/2.5/21/∞	75/90/1697/655	AK
19	1.0/6.6/∞	22/75/3075	A
20	3.2/8.3/∞	5/34/21941	A
21	0.6/4.2/17.7/121/∞	44/29/1287/209/603	HKA
22	1.2/10.3/∞	7/5/4525	HA
23	0.5/3.3/5.3/46.3/∞	51/22/178/36/811	HKA
24	0.5/3.3/5.3/46.3/154/∞	52/24/155/44/598/456	HKAK
25	1.3/17.7/121/∞	13/36/762/755	AK
26	0.5/3.3/1249/329/∞	43/27/1249/329	HAK
27	0.5/3.3/75/∞	128/74/7950/2129	HAK
28	0.6/3.3/22.5/∞	26/14/31179/12422	HAK
29	0.8/8.6/58.9/∞	684/85/2600/889	HAK
30	0.6/8.6/58.9/∞	26/45/73350/31056	AK
31	1.0/13.9/58.9/∞	85/21/368/165	HK
32	1.3/46.3/∞	29/16/185780	HA
33	0.8/4.2/13.9/121/∞	64/37/1210/104/290	HKA
34	1.6/17.7/154/∞	137/46/4503/3824	HAK

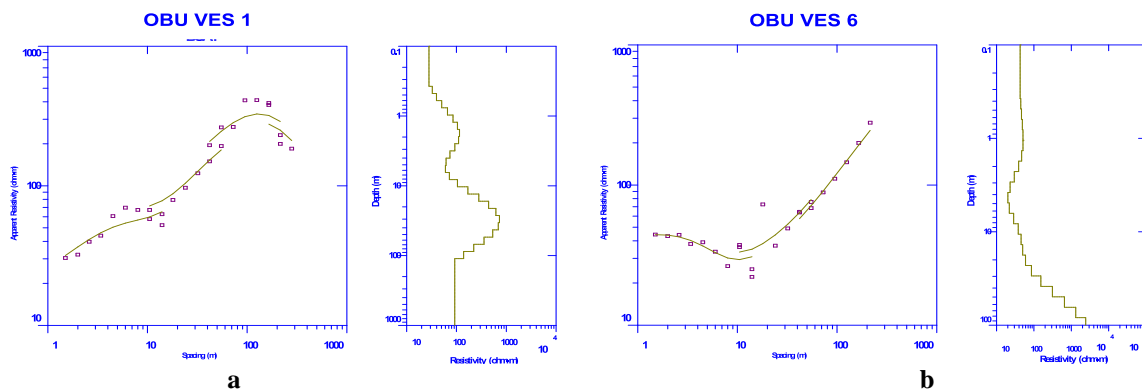


Fig. 3: Typical VES curves within the study area.

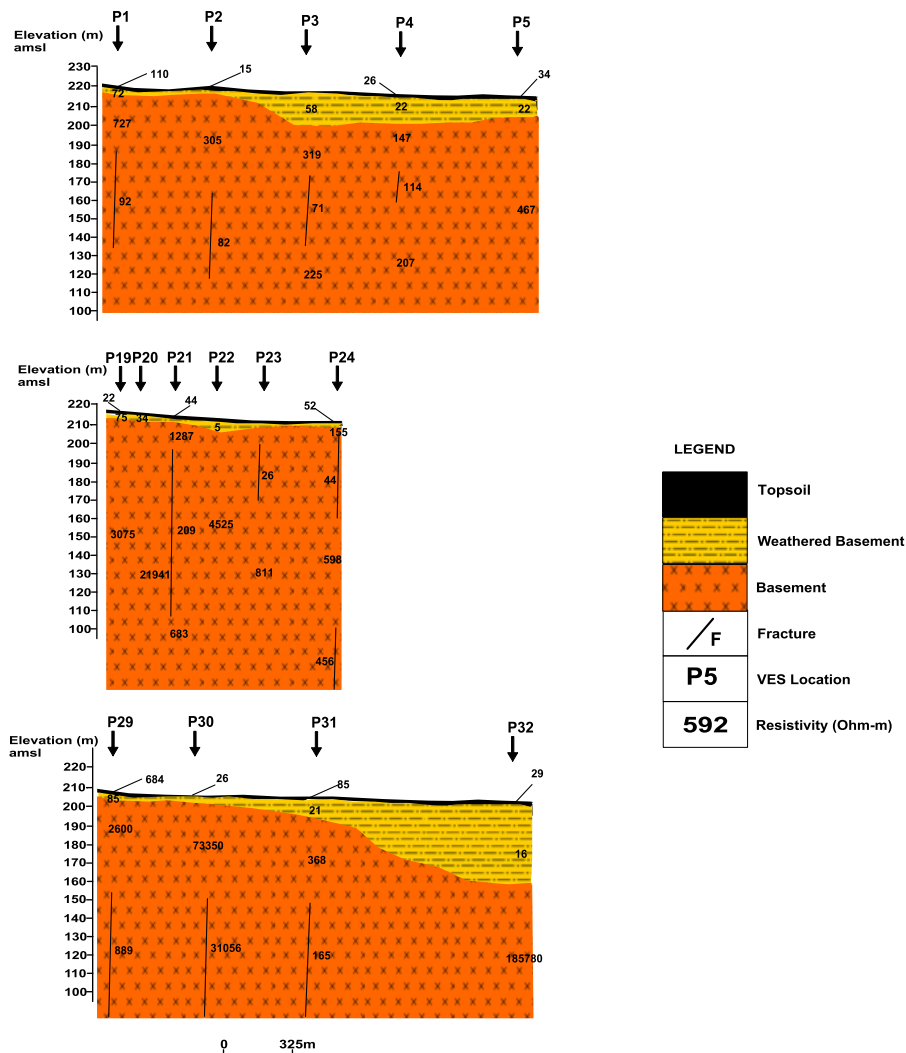
### Geo-electric Sequence

The VES data interpretation delineates four major lithologic/geologic units: (i) Topsoil, (ii) lateritic layer, (iii) weathered layer, (iv) bedrock and (v) fractured bedrock. The geo-electric sections were taken in three directions NW-SE, N-S and W-S (Fig.4) in an attempt to correlate the geo-electric sequence across the study area. The topsoil has variable thickness ranging from 0.5 to 3.2m and characterized by resistivity value of 14 to 297ohm-m. The layer thickness is variable from 0.5 to 3.2m.

The second layer is weathered basement consisting (sands, sandy clay and clays) with variable thickness from 3.3 to 49m and characterized by resistivity varies range from 16 to 98 ohm-m (Table 1& Fig.4). This layer is characterized by low to moderate resistivity. The low resistivity characteristics in this type of layers are most-likely, controlled by its water saturation (Omosuyiet'al, 2000).

The third layer is bedrock and is characterized by high resistivity values from >2600 ohm-m to infinity.

The fourth layer (Fig.4) which is fractured basement with variable depth of 7 to 150m revealed values of < 50 to 31056 ohm-m within the bedrock region and could be attributed to fracturing/shearing of the basement and possibly saturated by water (Olayinka&Olorunfemi, 1991, Longpiaet'al, 2013).



**Fig.4:** Geo-electric section in W-E and N-S directions.

**Groundwater Potential Evaluation**

**Significance of the weathered and fractured basement**

In crystalline basement hydrogeology, weathered overburden thickness with constituent material type, bedrock relief and structural settings are main factors in groundwater resources evaluation (Omosuyiet’al, 2003). The regolith and weathered basement layer and characterized by low to moderate resistivity, which may suggest saturation by water, constitutes the main aquifer (Balogunet’al, 2000). The bedrock relief/structures are very significant and hence the cardinal objective in basement groundwater surveys. Depressions filled with overburden materials and fractured bedrock constitute reliable and sustainable aquifer unit (Balogunet’al, 2000; Omosuyiet’al, 2003). In the groundwater potential assessment, geo-electric sections prepared from the geo-electric parameters of the geo-electric sounding interpretations were used. The lithologic and geoelectric sections revealed thin overburden which generally overlies the areas with isolated thick overburden in some areas. The main aquifer zones within the study area are the fractured basement. The thicknesses of the fractures are from 7m to 150m depth range (Fig. 4 and 5).

**Exploratory Drilling Program**

Four exploratory boreholes (BH1, BH2, BH3 and BH4) were drilled to various depths on VES 1, VES 18, VES 17 and VES 31 respectively (Fig. 5 and Table 2). The drilled lithologic/geologic logs revealed that the aquifers are within the highly fractured basement from 7m to 180m (Fig. 5). The fractures are possibly the main conduits for flow and storage of groundwater within the area.

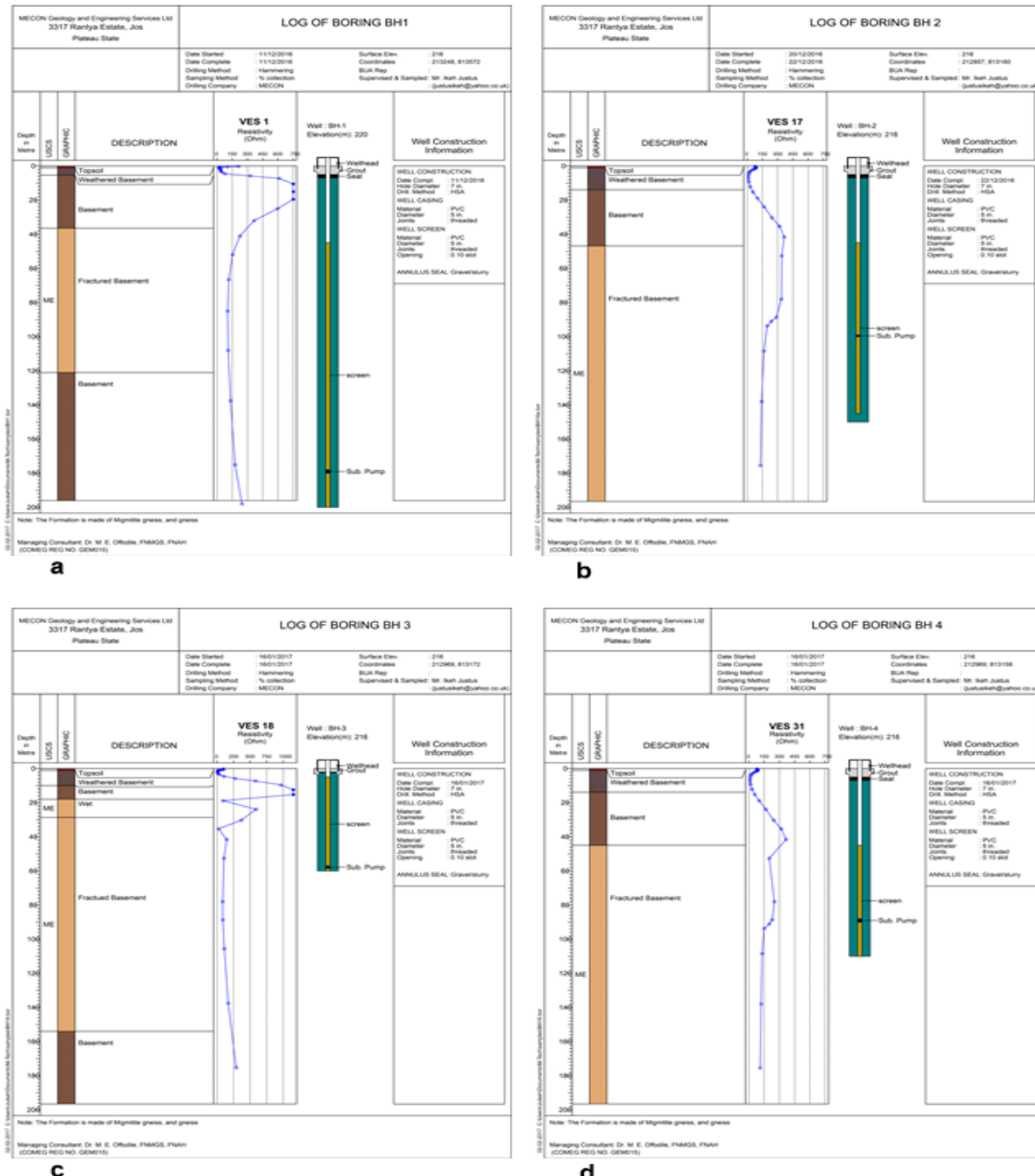


Fig. 5: VES-Borehole correlation (Source: Mecon Geology and Engineering Services Ltd.)

**Pumping Test**

Pumping test regime 2 horse power (1,348kw) pump for 24 hours period was carried out on the four exploratory boreholes and the hydrogeologic characteristics are presented in Table 2. The borehole flow rates are 1.4, 2.15, 2.0 and 2.08 litres/sec for the exploratory boreholes numbered BH1, BH2, BH3 and BH4 respectively. From pumping rate versus time and time-drawdown graphs (Fig. 6 and Fig. 7) for the boreholes shows that the boreholes pumping rates started with 1.4, 2.15, 2.0 and 2.08 litres/sec and stabilized at 0.18, 1.87, 1.79 and 1.97 litres/sec flow rates after 30, 5, 2 and 1.5 minutes for BH1, BH2, BH3 and BH4 respectively. The transmissivity values for the boreholes were calculated using Jacob method.

The Jacob equation is,  $T = \frac{2.3Q}{4\pi\Delta h}$   
 where, T = transmissivity (m<sup>2</sup>/day),  
 $\Delta h$  = slope of drawdown verses time(m)  
 Q = flow rate (m<sup>3</sup>/day).

The transmissivity values of 2.58m<sup>2</sup>/day, 21.43 m<sup>2</sup>/day, 55.62 m<sup>2</sup>/day, and 37.98 m<sup>2</sup>/day for BH1, BH2, BH3 and BH4 respectively were calculated from the Time-drawdown graphs (Fig. 7 and Table 2). The transmissivity value and groundwater potential evaluation of the exploratory boreholes (Table 3) is evaluated according to Reddy, 2014 classification method. Three of the boreholes potential water supply capacities

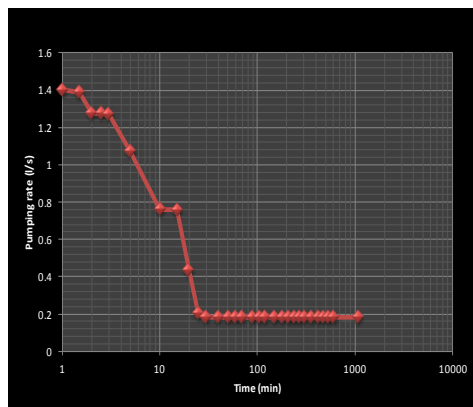
aresuitable for decentralized small community water supply schemes and for small to medium industries depending on water supply requirement.

**Table 2:** Summary of hydrogeologic characteristics of the exploratory boreholes around Obu-Okpella

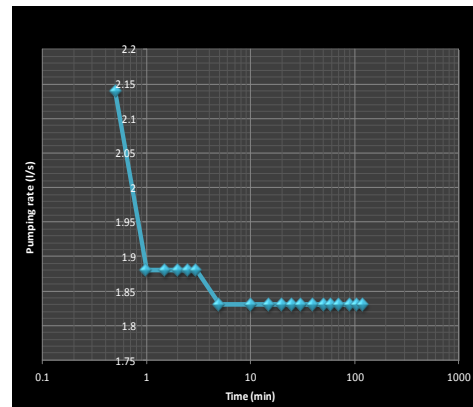
Borehole Number	Date of drilling	Total depth(m)	Aquifer type	Pumping time (hrs)	Initial yield(l/s)	Average Flow rate after stabilization (l/s)	Discharge (l/day)	Jacob equation ( $h_1 - h_2 = \frac{2.3Q}{4\pi T}$ )	Transmissivity, T (m <sup>2</sup> /day)
BH1	11/12/2016	198	Fractured basement	24	1.40	0.18	15,552	$0.96 - 0 = \frac{2.3 \times 15.552}{4} \times 3.142 \times T$ T= 2.58	2.58
BH2	22/12/2016	150	Fractured basement.	24	2.15	1.87	161,568	$0.66 - 0.06 = \frac{2.3 \times 161.56}{4} \times 3.142 \times T$ T= 21.43	21.43
BH3	16/01/2017	60	Fractured basement.	24	2.00	1.97	170,208	$0.56 - 0 = \frac{2.3 \times 170.208}{4} \times 3.142 \times T$ T= 55.62	55.62
BH4	16/01/2017	110	Fractured basement.	24	2.08	1.20	103,680	$0.56 - 0.06 = \frac{2.3 \times 103.680}{4} \times 3.142 \times T$ T= 37.98	37.98
<b>Total discharge (ΣQ)</b>							<b>451,012</b>		

**Table 3:** Transmissivity and groundwater supply potential evaluation.

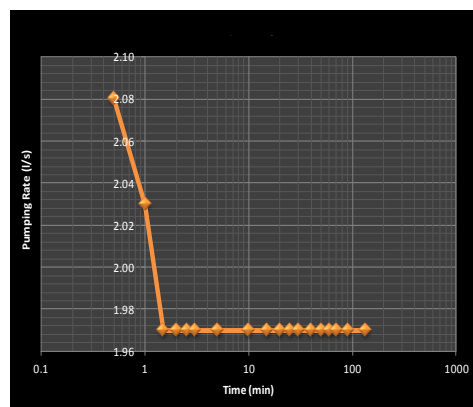
Borehole	Transmissivity (m <sup>2</sup> /day)	Magnitude	Ranking	Groundwater supply potential
BH1	2.58	Low	IV	Small withdrawal for local water supply, predominantly private.
BH2	21.43	Intermediate	III	Withdrawal for local water supply for small community.
BH3	55.62	Intermediate	III	Withdrawal for local water supply for small community.
BH4	37.94	Intermediate	III	Withdrawal for local water supply for small community.



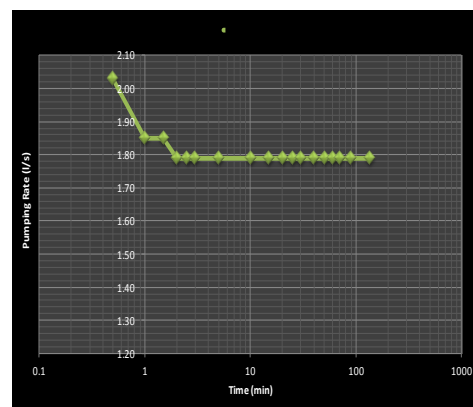
**a (BH1)**



**b (BH2)**



**c (BH3)**



**d (BH4)**

**Fig. 6:** Pumping rate verses Time graph



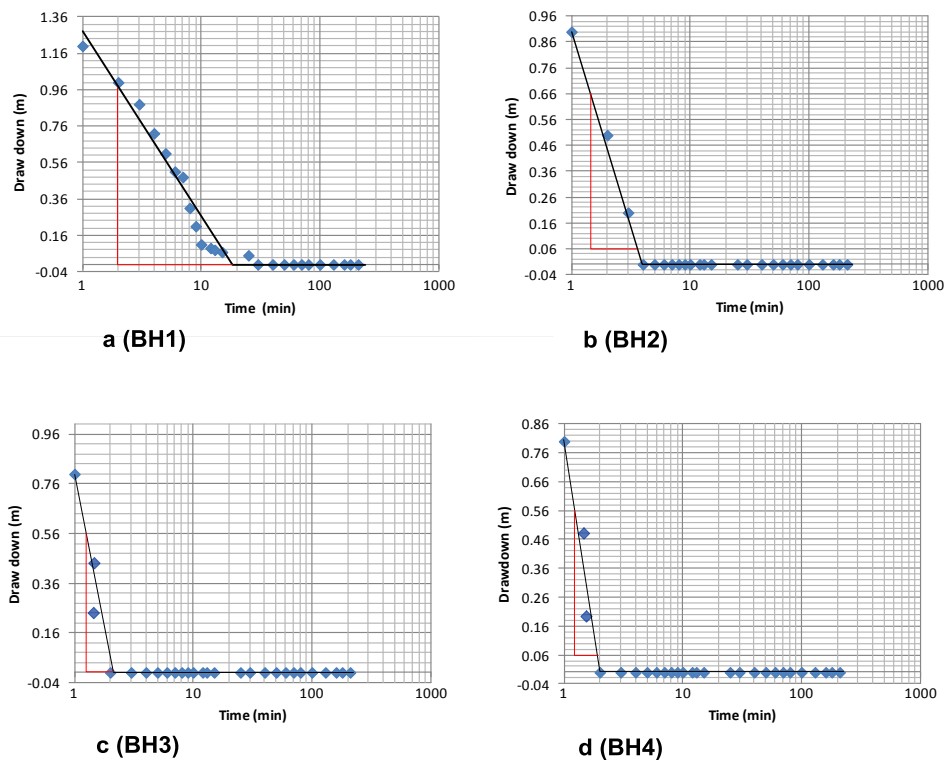


Fig. 7: Draw down versus Time graph

## V. Conclusion

An integrated geo-electric and hydrogeologic investigation methods were employed to explore the groundwater resources of Obu-okpella south of the Buacement factory. The geo-electric resistivity investigations revealed the generalized subsurface geo-electric layers/lithologic units to consists of –Topsoil (<2m), weathered basement(from 0.6 to 49m), fresh/fractured basement (consisting of sand/sandy clay) with resistivity value of 14 to 297 ohm-m, 16 to 98 ohm-m, > 2600 ohm-m and < 50 to 31056 ohm-m respectively. Exploratory borehole drilling numbered BH1, BH2, BH3 and BH4 were drilled to depths of 202, 150, 110 and 60m on VES No. 1, 18, 17 and 31 respectively to determine the hydrogeologic characteristics, especially yield etc. The borehole lithologic log correlated well with the geo-electric parameters derived from the geo-electric sounding interpretations.

From the pumping test, the flow rate and calculated transmissivity values are 0.18, 1.87, 1.97, 1.2 litre/sec and 2.58 m<sup>2</sup>/day, 21.43 m<sup>2</sup>/day, 55.62 m<sup>2</sup>/day and 37.98 m<sup>2</sup>/day for BH1, BH2, BH3 and BH4 respectively. The combine flowrates(output) of the boreholes is 451,012 litres/day.

Based on the geo-electric/hydrogeologic characteristics of the area, Obu-Okpella has a good groundwater potential. Ground water resources can be harness for domestic and industrial use. However, systematic and detail exploratory methods involving geophysical and drilling program will assist in the proper assessment of the groundwater resources for small and medium town water supply scheme.

## Acknowledgement

The authors wish to acknowledge the contributions of Mecon Geology and Engineering Services Nig. Ltd. for supplying the borehole lithostratigraphic logs and geophysical survey data used for this work.

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