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Application of Electrical Resistivity Sounding Method for Groundwater Exploration in Ugboshi-Afe, Akoko-Edo, Southwestern Nigeria

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ABSTRACT: Schlumberger configuration of Vertical Electrical Sounding (VES) was deplored for groundwater exploration in Ugboshi-Afe study location. A total of nine (9) vertical electrical sounding (VES) locations, spread across the community were occupied to gain insights on the hydrogeological settings within the area. Quantitative computer interpretation of the data yielded three to six geoelectrical layers. The geoelectrical interpretation models were geologically interpreted as: clayey sand/sandy topsoil with resistivity values ranging from 54 Ohm-m to 424 Ohm-m, this is underlain by a relatively high resistivity layer (228-868 Ohm-m) interpreted as lateritic sand, and below this the low resistivity (21.38 Ohm-m – 42.4 Ohm-m) interpreted as clay, then the fractured/weathered geoelectric layer (95Ohm-m to 385Ohm-m), while the fresh basement has resistivity greater than 400 Ohm-m. Several maps such as fractured window thickness map, isoresistivity map of the fractured interval, overburden map were generated to investigate trends that may hold prospects for groundwater exploitation. Furthermore, hydro-resistivity parameters such as Total Transverse Resistance, Total Longitudinal Conductance, Resistivity Reflection Co-efficient and Resistivity Contrast values were calculated for further screening of the study site for groundwater development. The VES1, VES2, VES6 and VES7 locations were concluded as holding prospects for groundwater potentials in the study area.

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The importance of clean, portable water to human existence cannot be overemphasized. The safest source of water supply is groundwater with a natural protection against pollution (Ogundana and Talabi, 2014). Groundwater is the largest available reservoir of fresh water (Adepelumi, *et al.*, 2013). Groundwater originates largely from precipitation such as rain, snow, sheet and hail that soak into the ground and become the groundwater responsible for spring, wells and boreholes yields (Oseji, *et al.*, 2005). The groundwater bearing zone (aquifer) in the Basement Complex region, such as where Ugboshi-Afe (also known as Ugboshi Sale) is located, is found within the zone of secondary porosity and permeability resulting from weathering and fracturing. Field observations indicate that sources of water supply to Ugboshi-Afe community could range from pipe borne water (tap water), open hand dug well, rain harvest and streams. Out of all the sources mentioned, only rain harvesting and fetching water from the streams are the only functional options as the municipal water supply from Ojirami dam is either non-functional or moribund. Open hand dug wells on the other wells are shallow and mostly dry especially during the dry season. With

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the increase in population of this community, the demand for clean and portable water for domestic, agricultural and small-scale industrial use has grown over the years. From the foregoing, the need for evaluation of the geologic and structural controls of groundwater within the study location cannot be over emphasized. Groundwater occurrences in the crystalline basement terrain can be very irregular due to abrupt discontinuity in lithology, thickness, and electrical properties of the overburden and weathered bedrock (Satpathy and Kanungo, 1976: Offodile, 1983; Olorunfemi and Fasuyi, 1993).

Consequently, groundwater exploration within such geologic settings requires integration of geophysical data with geologic information to effectively characterize the hydrogeologic zones and to enhance successful identification of well locations (Omosuyi, *et al*., 2008). Several authors have contributed to the understanding of the groundwater investigation, exploration and structural delineation in the crystalline basement rocks in Nigeria, using electrical resistivity method of geophysical survey (Olorunfemi and Olorunniwo 1985; Olorunfemi (1990); Olayinka and Olorunfemi (1992); Olorunfemi and Olayinka (1992); Olorunfemi and Fasuyi (1993); Oladipo *et al*., (2005) Olayinka and Weller (1997); Ojo *et al*., (2011), Omosuyi *et al*., 2008; Talabi (2013) to mention a few. They concluded that aquifer in basement complex occur in the weathered and fractured zones/columns, and that highest groundwater yield in such terrains is found in areas where thick overburden overlies fractured zones. This work focused on the use of electrical resistivity sounding technique for groundwater exploration in Ugboshi-Afe, Akoko-Edo, Southwestern Nigeria.

MATERIALS AND METHODS

Location, Physiography and Local Geology: The study area is located within latitudes 7° 23' 49.9''N to 7° 24' 21.4'' N and longitudes 6° 03' 19'' E to 6° 03' 53.5''E. It is located in Akoko-Edo Local Government area, Southwestern Nigeria (Fig.1). It is accessible through Auchi-Igarra-Ibillo road. To the north of the study area are Ekpesa and Ibillo, to the north-western part is Ebune Ugbo while to the south of Ugboshi-Afe is Aiyegunle.

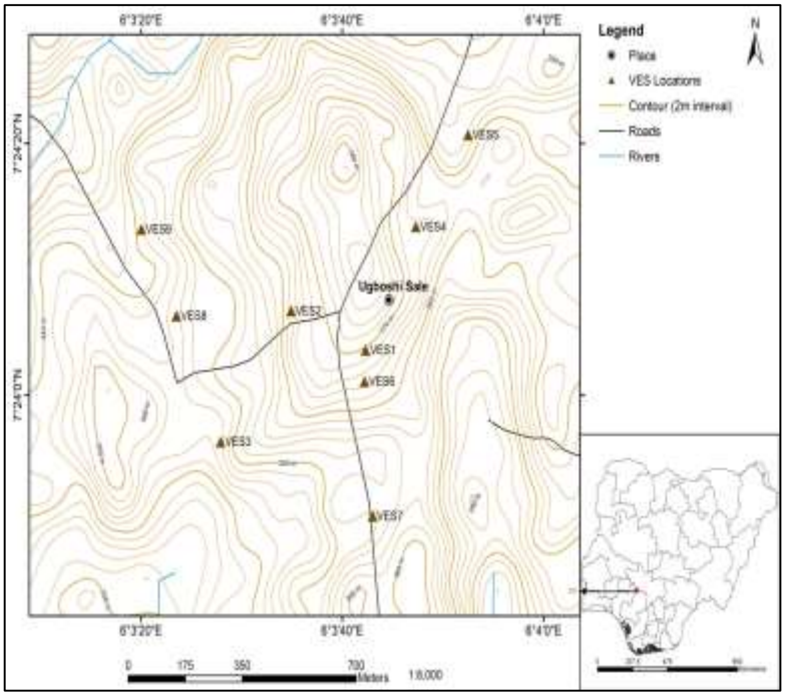

Fig.1. Topographical Map of Ugboshi-Afe and Environs. (after Farr and Kobrick, 2000)

Physiographically, Ugboshi-Afe is characterized by narrow valleys, hills and lowlands. The valleys are however, dry almost year round with the exception of the wettest months of the year. The topographical elevations of the study area as measured at the VES and other locations vary from 350m to 375m above mean sea level. The climate is tropical, typical of the sub-equatorial belt of the southwestern Nigeria, with average annual rainfall between 1000-1500mm and average annual temperature in the range of 25^0-27.5^0 C (Olorounniwo and Olorunfemi, 1987). Geologically, the study location is within the Igarra

Schist belt of the Precambrian Basement Complex of Southwestern Nigeria (Fig.2). Rahaman (1989), grouped the Basement Complex rocks of Nigeria into five (5) namely:

(i) Quartzite and quartz schist and small lenses of calcilicate rocks.

(ii) Slightly migmatised to unmigmatised paraschist and meta-igneous rocks.

(iii) Charnockitic rocks.

(iv) Older Granites which comprises of rock varying in composition from granodiorite to granite and potassic syenite.

(v) Unmetamorphosed doleritc dykes.

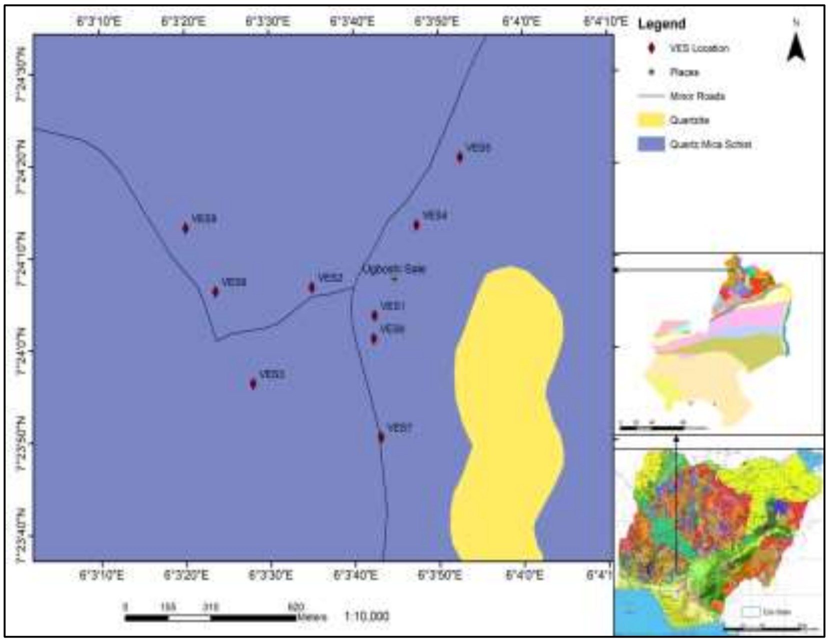

Fig.2. Local Geological Map of Ugboshi-Afe and Environs. (after NGSA, 2006)

The study area is locally underlain by the quartz mica schist and in places minor quartzite and schistose quartzite occur. The subsurface hydrogeologic condition in the area can be classified into two, the aquiferous zone within the weathered loose in-situ regolith overlying the fractured basement rocks and the aquiferous zone within the fractured system in the partially weathered basement (Adeniji *et al.*, 2013).

Methodology: The Vertical Electrical Sounding (VES) technique using Schlumberger array configuration was adopted for the subsurface geophysical investigation of the study area. The field instruments consisted of ABEM 1000 Terrameter with all the necessary accessories such as stainless steel electrodes, cable reels, electrical connectors' etc. A Global positioning instrument (GPS), Garmin GPS 73 model, was used for geoereferencing of VES locations and other points of interest. Nine (9) vertical electrical sounding (VES) locations were thus occupied in Ugboshi-Afe and environs. The maximum half-current electrode separation (AB/2) of 147m was attained at VES5, VES7, VES8 and VES9 locations. Spread lengths at other locations range between 136m and 200m. The range of the spread lengths (136m to 294m) with potentials for investigated depth range of 35m to 75m is considered adequate for groundwater potentials evaluation in the basement terrains such as the study location.

Field data acquisition involved passing electrical currents via a pair of steel electrodes (C_1 and C_2) into the ground and measuring of the resulting potential drop (pd) across another electrode pair, potential electrodes (P_1 and P_2), with all four electrodes symmetrically displaced linearly about a fixed center. Increasing depth penetration was gained through the successive symmetrical expansion of the acquisition spread about the fixed center (Fig.3) with the potential electrodes ($P_{1,}$ P_2) being practically fixed until it was necessary to expand them especially when the measured potential drop (pd) became too small for accurate determination. Field data acquisition was followed by the computation of the apparent resistivity which depends on the current input, the measured (pd) and electrode spacing factor (the geometric factor).

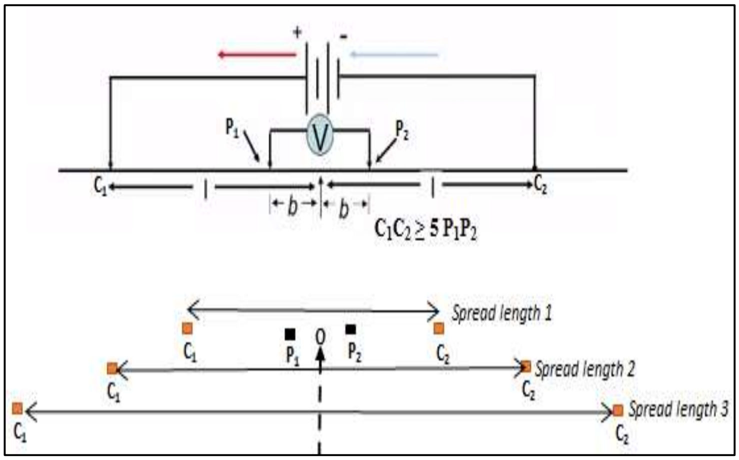

Fig. 3. Top: Schlumberger Array Geometry; Below: Field Electrodes Expansion.

The acquired data were subsequently plotted on double log papers for detection and removal of cusps that may not be related to underlining geology. Data reduction was followed by computer based interpretation using Interpex (IX1D) software.

The computation of hydro-resistivity parameters follows the works of Anudu *et al*., (2008), Anudu *et al*., (2011). The computed parameters are Reflection Coefficient, Resistivity Contrast, Total Transverse Resistance and Total Longitudinal Conductance. The following established computational relations were used:

Reflection Coefficient RC_{rf} ,$RC_{rf} = \left({\rho_n - \rho_{n-1}}/{\rho_n} + \rho_{n-1}\right)$ (1)

Resistivity Contrast $RC_{rs,}$ $RC_{rs} = \left({\rho_n}/{\rho_{n-1}}\right)$ (2)

Total Transverse Resistance T, $T = \sum h_i\rho_i = h_1\rho_1 + h_2\rho_2 + \cdots + h_n\rho_n$ (3)

Total Longitudinal Conductance S,

$$S = \sum\left({h_i}/{\rho_i}\right) = {h_1}/{\rho_1} + {h_2}/{\rho_2} + \cdots + {h_n}/{\rho_n} \quad (4)$$

Where: ρ_n =Resistivity $of\ the\ nth\ layer;$ $\rho_{n-1} = Resistivity\ of\ the\ (n-1)th\ layer$; $\sum$ = Summation; h_i = Thickness of the (i)th layer; i = 1, 2 3, etc.

RESULTS AND DISCUSSIONS

Resistivity Sounding Curves: Figure3 shows typical VES curves from the study area. Electrical resistivity curves primarily reflect variation in ground resistivity. The electrical resistivity contrast between discrete geoelectric layers, or lithologies in the subsurface are generally adequate to allow the characterization of the subsurface geoelectric layering (Barker, 1980; Dodds and Ivic, 1998; Lashkarispour, 2003). This further assists in reliable geological deductions that can lead to identification and discrimination between aquiferous and non-aquiferous layers. Sounding curve types graphically identified are A, H, and KH curves (Fig.4). The quantitative computer interpretation results show three to six geoelectrical layers (Table1). The geoelectric layers can be reduced to five geologically plausible layers namely: the clayey sand/sandy topsoil with resistivity values ranging 54 to 424 Ohm-m, this is underlain by relatively high resistivity lateritic layer (228-868 Ohm-m) and then the claye/y, low resistivity geoelectric layer with resistivity values ranging from 21.8Ωm to 42.4Ωm under VES6 and VES8 respectively, then the fractured/weathered geoelectric layer (39.25Ωm to 385.02Ωm), while the fresh basement has resistivity greater than 400 Ωm.

Hydrogeology Evaluation Maps: Groundwater production can be a point solution through a drilled well that is pumped. However, the well yield is a spatial solution as the pumped well draws water over a certain radius depending on the pump power rating, pumping duration as well as geological constraints such as structural and lithological constraints. Consequently, potential well efficiency is better investigated through evaluation of the spatial environment of the well that releases water to the pumping well. The use of hydrogeologically relevant maps are critical especially in the crystalline basement terrains where rock mass fluid accommodation space and flow are geologically discontinuous. Table2 presents the extracted data from the resistivity data inversion results that were used for the generation of the basement terrain hydroprospectivity maps at Ugboshi-Afe study location.

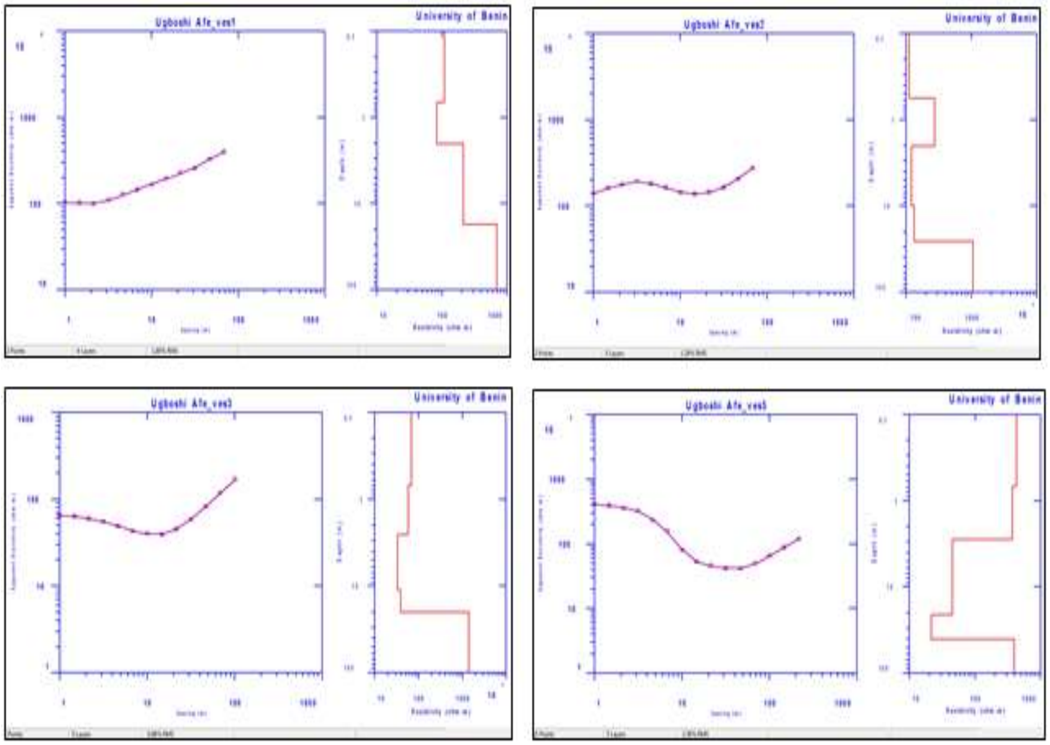

Fig.4. Typical Ugboshi-Afe Electrical Resistivity Curves.

Table1. Interpreted Geoelectric Models Parameters

Specific Layer Resistivity, Ωm								Layer Thickness, m					Depth to bottom of Layers, m				
Location (Ugboshi-Afe)	No of Layers	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	P_6	h_1	h_2	h_3	h_4	h_5	d_1	d_2	d_3	d_4	d_5
VES1	4	108.83	83.44	213.93	698.88	_	_	0.67	2.03	17.46	_	_	0.67	2.03	17.46	_	_
VES2	5	110.79	273.51	120.33	132.36	1043.5		0.56	1.47	7.86	15.7	_	0.56	2.04	9.89	25.58	_
VES3	6	68.22	57.63	32.72	39.25	1395.9	1507	0.69	1.87	8.45	9.14	5.95	0.69	2.56	11.01	20.15	25.04
VES4	3	209.56	868.98	2492.7	_	_	_	0.48	4.72	_	_	_	0.48	5.2	_	_	_
VES5	5	424.63	367.68	44.67	21.38	392.77	_	0.68	2.15	18.12	19.5	_	0.68	2.83	20.95	40.44	_
VES6	5	186.62	246.54	21.8	148.36	2140.5	_	0.48	1.52	6.52	8.64	_	0.48	2.00	8.52	17.16	_
VES7	5	261.6	45.08	27.93	385.02	1063.8	_	1.3	1.43	5.19	17.7	_	1.3	2.73	7.92	25.6	_
VES8	5	647.6	303.13	42.4	94.88	1145.8	_	0.24	3.01	7.01	24.1	_	0.24	3.24	10.26	34.34	_
VES9	5	54.95	228.7	112.08	191.91	419.45	_	0.32	0.91	135	3.56	_	0.32	1.23	2.58	6.14	_

Fractured Zone thickness/Overburden Thickness/ Basement Relief Maps: Fractured Zone thickness, Overburden Thickness and Basement Relief maps are critical maps that are indicative of the accommodation space capacity of the subsurface for groundwater storage in the basement environments. Fig.5a to Fig.5c are presentations of the fractured zone thickness, overburden thickness and basement relief maps of the study area. The fractured thickness map (Fig.5a) defines a east-west broad prospective trend that turns south-eastward. The trend may be a part of a more regional tectonic trend. The overburden thickness map (Fig.5b) indicates a southwest- northeast broad prospective trend marked by a central map area with the thickest overburden rock mass. The Basement relief map (Fig.5c) of the study area indicate a southern low relief with the deepest part in the south eastern part. The three fluid accommodation space indicator maps in the subsurface are not necessarily the same but they have common areas that may be accorded priority in groundwater development provided that other indicators such as wettability are also good over the same space.

Table2. Derived Hydroprospectivity Maps Parameters.

	Elevation (m)	Weathering front/Fractured zone (m)	Regolith/ Overburden (m)	Basement Topography (m)	Clay Thickness (m)	Depth to top of fractured zone(m)	Fractured window resistivity (Ωm)
VES1	361.0	17.46	17.46	343.54	2.03	2.03	213.93
VES2	362.0	15.69	25.58	336.42	0.00	9.89	132.36
VES3	351.0	9.14	20.15	325.42	17.59	11.01	39.25
VES4	375.0	4.72	5.20	369.8	0.00	0.48	868.98
VES5	361.0	5.95	20.95	320.56	37.61	19.09	401.7
VES6	352.0	8.64	17.16	334.84	6.52	8.52	148.36
VES7	358.0	17.68	25.60	332.4	5.19	7.92	385.02
VES8	357.0	24.09	10.26	322.66	7.01	10.25	94.88
VES9	360.0	3.56	2.58	353.86	0.00	2.58	191.91

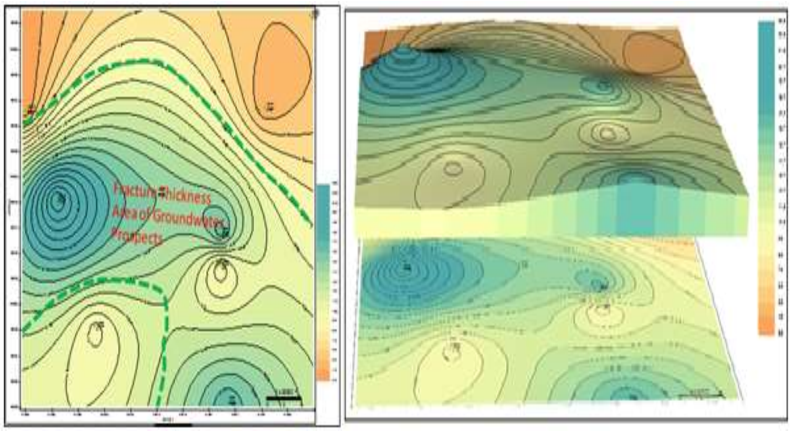

Fig.5a. Ugboshi-Afe Fractured Thickness Map (left: 2D, Right; 3D image)

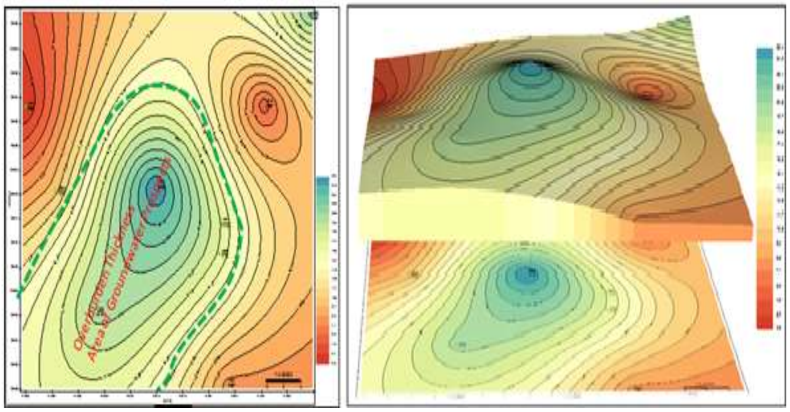

Fig.5b. Ugboshi-Afe Overburden Thickness Map (left: 2D, Right; 3D image)

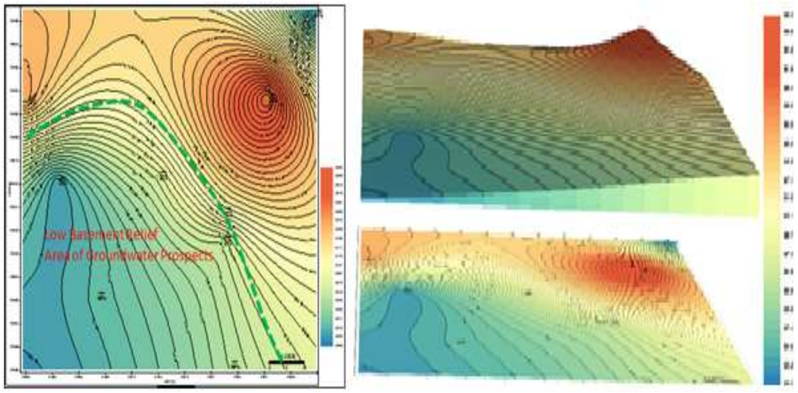

Fig.5c. Ugboshi-Afe Basement Relief (left: 2D, Right; 3D image)

Isoresistivity, Reflection Coefficient and Resistivity Contrast Maps: Isoresistivity map (Fig.6a) defines the areal distribution of the specific geoelectric layer resistivities of the interpreted fractured window thicknesses at different VES locations. Comparatively low resistivity region over such maps may indicate presence of fluid arising from improved electrolytic conduction in the subsurface. Fig.6a indicates that even outside of the significantly thick fractured zone interpretation shown in figure5a, groundwater can still be produced in the less thick area south west of the fractured thickness groundwater prospects area. Reflection Coefficient and Resistivity Contrast values at the fresh basement interface have been used as indicators of groundwater occurrence in the subsurface (Olayinka *et al.*, 2000; Anudu *et al.*, 2008, Anudu *et al.*, 2011). Two other hydro-resistivity parameters, the Total Transverse Resistance (T) and the Total Longitudinal Conductance (S) were computed (Table3) but used only for numerical validation. All the values of the Reflection Coefficient and Resistivity Contrast are below the threshold values of 0.9 and 19 respectively except at VES5 location where the values are marginally above the thresholds. It follows that on the basis of these parameters alone, all the geophysical data points, except VES5 location are prospective.

Table 3. Ugboshi-Afe Study Area Hydro-resistivity Parameters.

VES Location Label	Reflection Co-efficient	Resistivity Contrast	Total Transverse Resistance (T)	Total Longitudinal Conductance (S)
Ugboshi-Afe VES1	**0.53**	**3.267**	**3977.5**	0.11210
Ugboshi-Afe VES2	**0.77**	**7.884**	**3486.6**	0.19429
Ugboshi-Afe VES3	**0.84**	**11.240**	724.0	0.52269
Ugboshi-Afe VES4	**0.48**	**2.869**	**4202.2**	0.00772
Ugboshi-Afe VES5	0.90	18.371	2305.3	1.32471
Ugboshi-Afe VES6	**0.87**	**14.428**	**1888.3**	0.36606
Ugboshi-Afe VES7	**0.47**	**2.763**	**7356.7**	0.26843
Ugboshi-Afe VES8	**0.85**	**12.076**	**3650.7**	0.42953
Ugboshi-Afe VES9	**0.37**	**2.186**	**16039.7**	3.22498

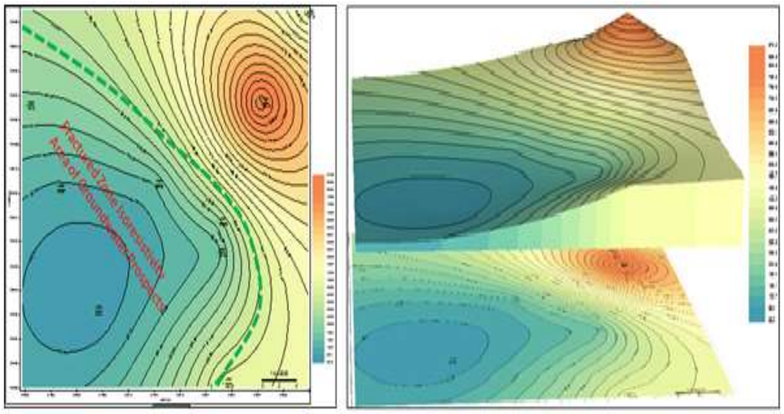

Fig.6a. Ugboshi-Afe Fractured Zone Isoresistivity Map (left: 2D, Right; 3D image)

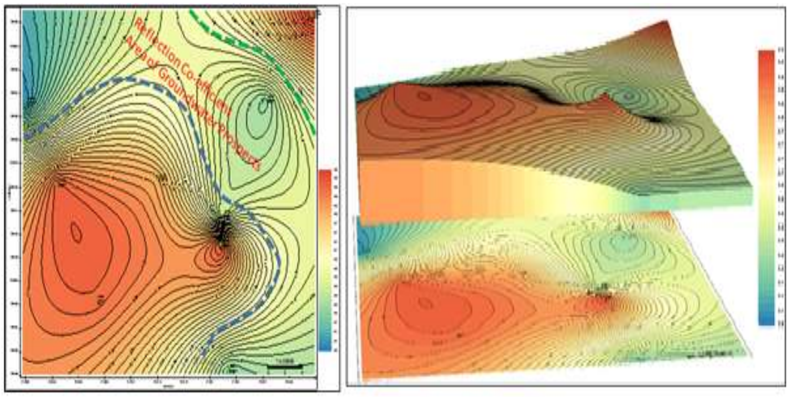

Fig.6b. Ugboshi-Afe Reflection Coefficient Map (left: 2D, Right; 3D image)

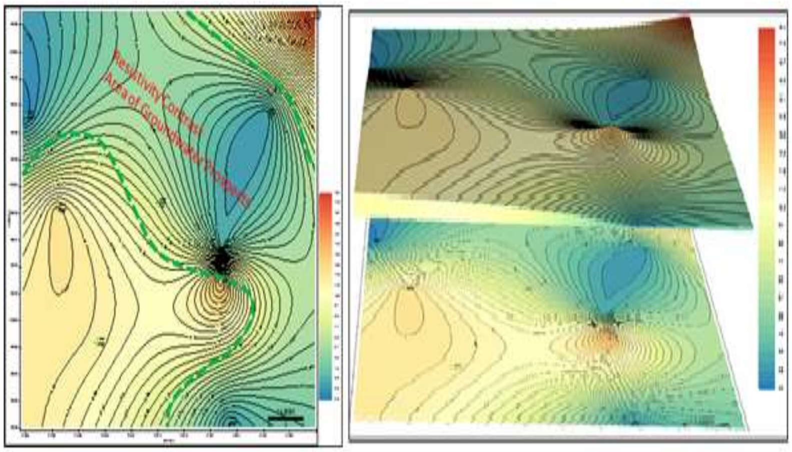

Fig.6c. Ugboshi-Afe Resistivity Contrast Map (left: 2D, Right; 3D image).

The isorestivity map (Fig.5a) correlates significantly with the basement Relief map (Fig.4c). An area with low basement relief and potentials for groundwater accumulation with good wettability index, low isoresistivity contour values is primal for groundwater well boring and development.

The correlation of the Reflection coefficient and Resistivity contrast is both numerically (Table3) and pictorially (Fig.5b and Fig.5c) evident. It is noted that the areal trends defined by these two hydro-resistivity parameters are similar to the trend defined by the fractured thickness map.

This implies that both potentials for groundwater occurrence (fractured, secondary porosity) as well as good potentials for flow into the bored wells to achieve optimal groundwater well production exist.

Table 4 summarizes the groundwater potentials at the VES locations on the basis of the subsurface groundwater storage potentials as well as groundwater occurrence and ease of flow to bored wells.

Locations with overall good potentials must combine both storage and flow attributes for successful groundwater development. On this basis, VES1, VES2, VES6 and VES7 are projected as high groundwater yield potential locations in Ugboshi-Afe and environs.

Table 4. Ugboshi-Afe VES Locations Potential Yields Evaluation

VES Location Label	Storage Potentials			Fluid saturation and Flow Potentials			Storage Potentials Frequency	Fluid saturation and Flow Potential Frequency
	Fractured Thickness	Overburden Thickness	Basement Relief	Isoresistivity	Reflection Co-efficient	Resistivity Contrast		
Ugboshi-Afe VES1	**P**	**P**	NP	**P**	**P**	**P**	2	3
Ugboshi-Afe VES2	**P**	**P**	**P**	**P**	NP	**P**	3	2
Ugboshi-Afe VES3	NP	**P**	**P**	NP	NP	NP	2	0
Ugboshi-Afe VES4	NP	NP	NP	NP	**P**	**P**	0	2
Ugboshi-Afe VES5	NP	NP	NP	NP	NP	NP	0	0
Ugboshi-Afe VES6	**P**	**P**	**P**	**P**	NP	**P**	3	2
Ugboshi-Afe VES7	**P**	NP	**P**	**P**	**P**	NP	2	2
Ugboshi-Afe VES8	**P**	NP	NP	**P**	NP	NP	1	1
Ugboshi-Afe VES9	NP	NP	NP	**P**	**P**	**P**	0	3

P = Potential; NP = No Potential

Geoelectric Sections: Two geoelectric pseudo-sections were generated for the study area. The sections show the subsurface variation in electrical resistivity with depth along the profiles and also attempt to correlate the geoelectric sequences across the profiles.

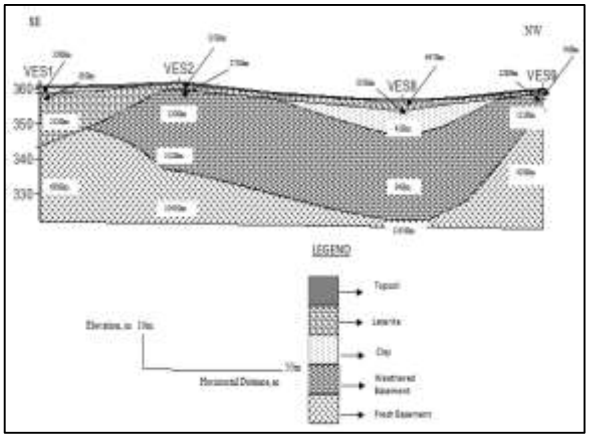

Fig.7a. SE-NW Geoelectric Profile of the Study Area

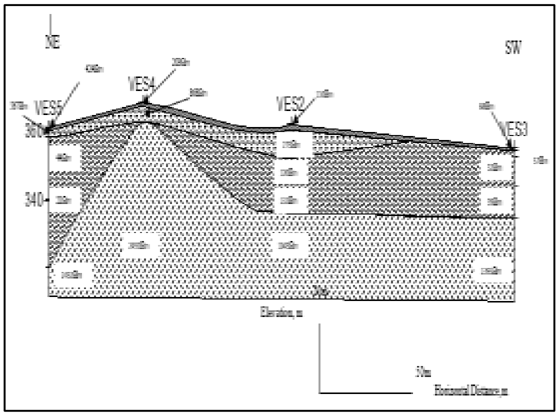

Fig.7b. NE-SW Geoelectric Profile of the Study Area

The first geoelectric profile, (Fig.7a), is from the southeastern to the north-western part of the area of study and it comprises of VES1. VES2, VES8 and VES9. The second, (Fig.7b)), runs from the northeastern to southwestern region, and it contains VES 5, VES4, VES2 and VES3. In the first pseudo-section the thinnest regolith is around VES9 while the thickest is at VES2. The basement topography seems to be near the surface at VES4 while the thickest overburden is at VES2 on the second geoelectric pseudo-section. Both geosections have the basement interpreted as the last layer with resistivity value greater than 400Ωm.

Conclusions: The use of geophysical tools, especially Electrical Resistivity methods, for assessing groundwater potentials in the basement terrains cannot be over emphasized as the results of this study have demonstrated. Two broad categories of criteria were used to screen groundwater potentials development at Ugboshi-Afe. The first category which consists of fractured basement thickness, overburden thickness and basement relief were used to screen areas of potential groundwater storage. The second category, consisting of Isoresistivity, reflection coefficient and resistivity contrast were used to investigate subsurface wettability and potentials for flow into bored holes. The results indicate VES1, VES2, VES6 and VES7 as the best start off locations for groundwater development in Ugboshi-Afe and environs.

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