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Basement Groundwater Potentials Evaluation Using Resistivity Method: Ogugu and Environs, Akoko-Edo, Southwestern Nigeria as A Case Study

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ABSTRACT

Groundwater development within the Basement Complex terrain relies on the existence of discrete secondary porosity of the basement rock mass in the subsurface. A total of twelve geoelectric sounding locations were occupied at and around Ogugu to evaluate the groundwater potentials of Ogugu and adjoining areas. Field data were acquired using Schlumberger array. The data were interpreted using RES1D and Interpex software for model convergence consistency tests. The results of the interpretation yielded a five to six electrostratification of the subsurface within the depth resolution of the attained maximum spread. The geoelectric layers were resolved into four to five geologic layering at the Vertical Electrical Sounding (VES) locations. The topmost layer represents the topsoil which is underlain by wet lateritic layer. Below this is the clayey layer followed by the fractured basement and fresh basement layers. Several hydrogeologically significant maps: Fractured zone thickness (FZT) map, Overburden thickness (OBT) map, Clay thickness (CT) map and Isoresistivity (IR) map were generated. Hydro-resistivity parameters such as Total Transverse Resistance (TTR), Total Longitudinal Conductance (TLC), Resistivity Reflection Co-efficient (RRC) and Resistivity Contrast (RC) were computed and used together with the generated maps to evaluate the groundwater potentials of the Ogugu community and environs through the prospectivity ranking of the VES locations for optimal boreholes siting. The ranking shows the topmost five locations to be VES3, VES5, VES6, VES7 and VES10.

1. Introduction

The importance of groundwater to the growth and health of people living in the rural or remote areas, particularly in the developing world cannot be over emphasized. Water generally is needed for drinking, sanitary and agricultural uses. Groundwater remains the first choice of clean, potable water in many of such areas. Groundwater development in areas underlain by crystalline rocks is particularly challenging because of the discrete porosity and restricted permeability of crystalline rocks. The challenge notwithstanding, several groundwater development schemes have been delivered worldwide via careful screening using tools such as geophysical methods (Foster, 1984).

Electrical geophysical methods, typically VES deployed in the Schlumberger configuration have proven versatile in the search for groundwater in the Basement Complex terrains (Olorunfemi and Olorunniwo, 1985; Olayinka, 1992; Olayinka and Olorunfemi, 1992; Aina et al., 1996; Dan-Hassan and Olorunfemi, 1999; Olayinka et al., 2000; Salami and Babafemi, 2016; Salami and Ogbamikhumi, 2017; Salami and Babafemi, 2020).

Hydrogeologically, water in the basement rocks can be found in the weathered overburden or the fractured zones. Previous works such as David and Ofrey (1989), Ajayi and Abegunrin (1990), Dan-Hassan and Olorunfemi (1999), have demonstrated that the groundwater yields in the Basement Terrains are dependent on the combined thickness of the weathered and fractured zones. Ogugu and environs seat on parts of the Basement Complex rocks of western Nigeria and its environmental areas are hydrogeologically constrained by the geology.

2. Location and Local Geology

The study area, Ogugu, an agrarian settlement, is located in Akoko Edo Local Government Area of Edo State, Nigeria. Neighboring communities include Onumu to the South and Ibillo to the North. The community is accessible mainly through the road that links the trunk Igarra - Ibillo road. Ogugu is bounded by latitude 7^0 22'49.3" to 7^0 23'12.5" and longitude 6^0 5'49.2" to 6^0 07' 02" (Fig. 1).

Topographically, Ogugu is located within the lower parts of an otherwise hilly environment. The northern parts are marked by segmented stream channels which are suggestive of structural controlled flow regime. Altogether the streams for a sub-parallel drainage pattern with a major east-west flow and subsidiary southern tributaries flows.

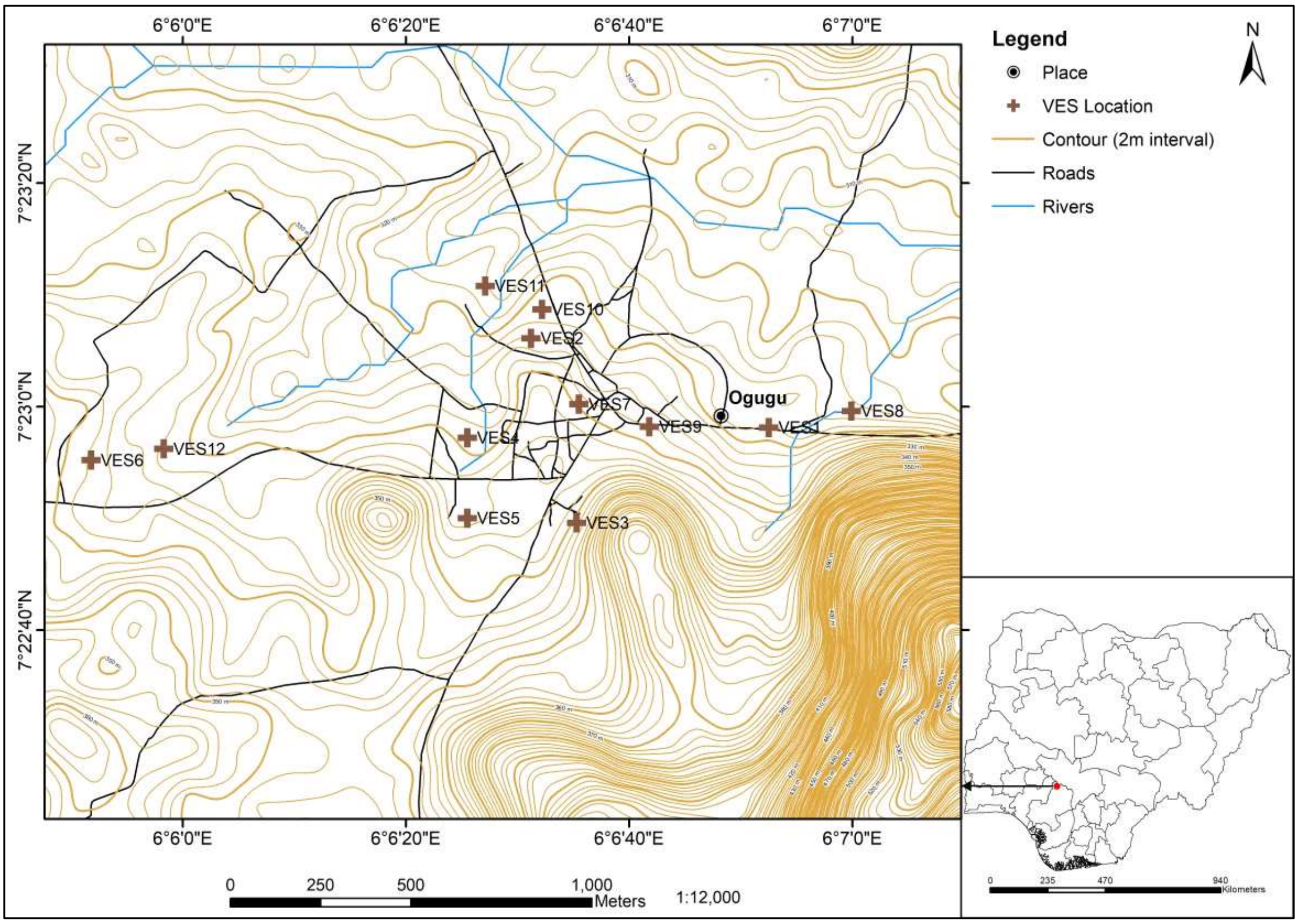

Fig. 1. Topographical Map and VES Data Acquisition Locations

Geologically, the study area lies on a part of the Basement Complex of Southwestern Nigeria. Several authors including Rahaman (1989), Boesse and Ocan (1992), and Odeyemi (1999) have expounded on several aspects of the Basement Complex geology of Nigeria and Igarra Shcist belt in particular.

Rahaman (1989) classified the Basement Complex rocks of Nigeria into five (5) groups namely:

i) Migmatite-gneiss complex which comprises of gneisses such as biotite and biotite hornblende gneisses. Other rocks within the group include quartzite and quartz schist with small lenses of calcilicate rocks.
ii) Slightly migmatised to unmigmatised paraschist and meta-igneous rocks. Pelitic schists, quartzites amphiboles, metaconglomerates, marbles and calc-silicate rocks are members of this class of rocks.
iii) Charnockitic rocks.
iv) Older Granites which comprises of rock varying in composition from granodiorite to granite and potassic syenite.
v) Unmetamorphosed dolerite dykes.

Ogugu is underlain by the older granites (Adamellites), quartzite and quartz mica schists (Fig.2).

3. Study Methodology

VES using Schlumberger array was engaged for this study. Schlumberger array has proven to be a field data acquisition friendly method in terms of ease of field operations, field time and costs without any comparatively significant compromise on technical demands of resolution and depth of penetration for a given spread length. The field data acquisition was carried out via the passage of electric current into the ground through a pair of electrodes (Current electrodes, A and B).

The response potential drop, pd, of the earth to the passage of current was measured using another pair of electrodes, potential electrodes (M and N). All the electrodes are linearlly disposed and centered mid-way between the inner potential electrodes. Increasing depth of penetration is gained by symmetrically expanpding the outer current electrodes while the potential electodes were kept fixed for a number of measurements.

The potential electrodes were expanded when the measured potential drop, dp, beccame too low for instrumental accuracy calibration. The theory and practice of Electrical Resistivity Method (ERM) have been treated in many standard works such as Keller and Frischnecht (1966), Sharma (1976), Koefoed (1979), Telford et al., (1990), and Parasnis (1996) among others.

The general VES field set up and Schlumberger configuration are illustrated in Fig. 3.

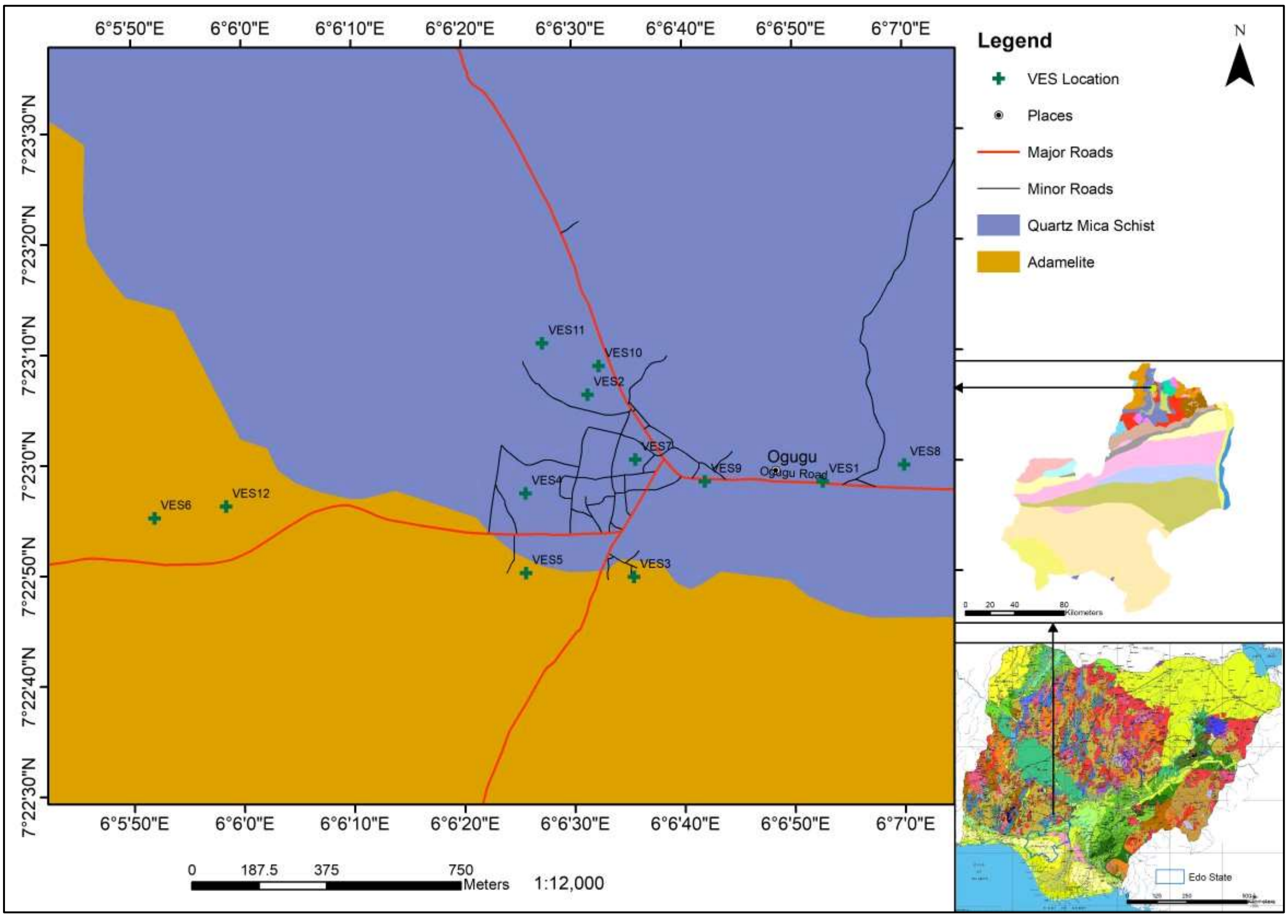

Fig. 2. Local Geological Map of Ogugu and Environs

The Agbada Formation is primarily composed of shale below, with alternating layers of sand and shale above, representing the unmediated offshore and continental shelf environment. It is characterized by fossils at the base, which diminishes upward. The Agbada Formation exists in the subsurface of the entire Delta region and may be continuous with the Eocene to Oligocene of Ogwashi-Asaba and Ameki Formations. It is roughly 10,000ft thick, with ages ranging from the Eocene in the north to the Paleocene in the south, and Recent in the Delta subsurface.

The study area is underlain by the Benin Formation. The Benin Formation was first described by Tattam in 1943 as a coastal plain sand. It stretches southward past the coast and from the west throughout the entire Niger Delta region. The formation is predominantly composed of sands (90%), with few shale intercalations. The sands vary in color, dirty white to light grey to greyish brown. They are pebbly to fine grained, coarse grained, sub-angular to highly rounded, poorly sorted, and occasionally contain wood fragments and lignite streaks.

Shale occurring closer to the base is grayish-brown, sandy to silty, and has some plant debris in it. Its subsurface age is Oligocene in the north and gradually younger in the south. It spans from the Miocene to the Recent, generally. Very little hydrocarbon accumulation has been linked to this stratum, which is likely 1800 meters thick (Kogbe, 1989). The Niger

Delta Basin's geological map is displayed in Fig. 3. A total of twelve (12) VES datasets were acquired during this study (Fig. 3). The half-spread length for the acquired data ranges between 68.1 meter and 147 meters with a minimum at VES7 location and the maximum at VES1 and VES9 locations. The field data acquisition was followed by data reduction, consisting of field data plot in Microsoft Excel software, observation and adjustment of spurious spike data points. This was followed by computer based iterative interpretation following the ideas of Zohdy (1989). RES1D and Interpex (IX1D) softwares were used for interpretation model convergence and consistency tests.

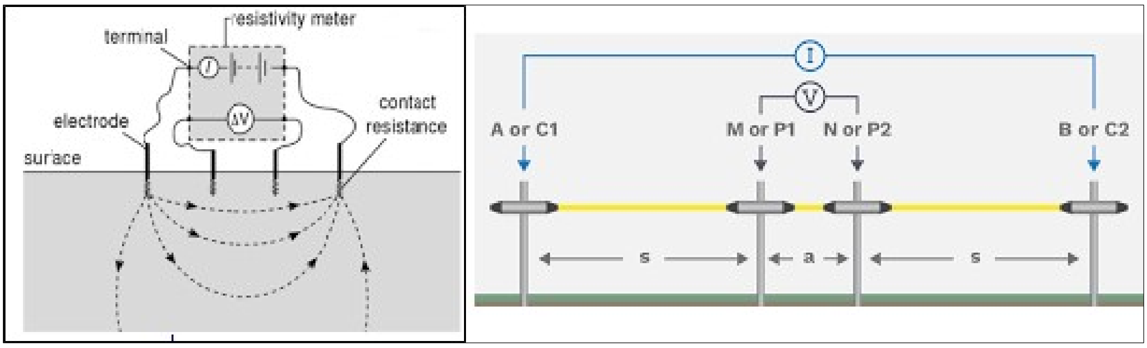

Fig. 3. General Field Data Acquisition Lay Out (Left) and Schlumberger Electrodes Configuration (Right), (after Advanced Geoscience, Inc.)

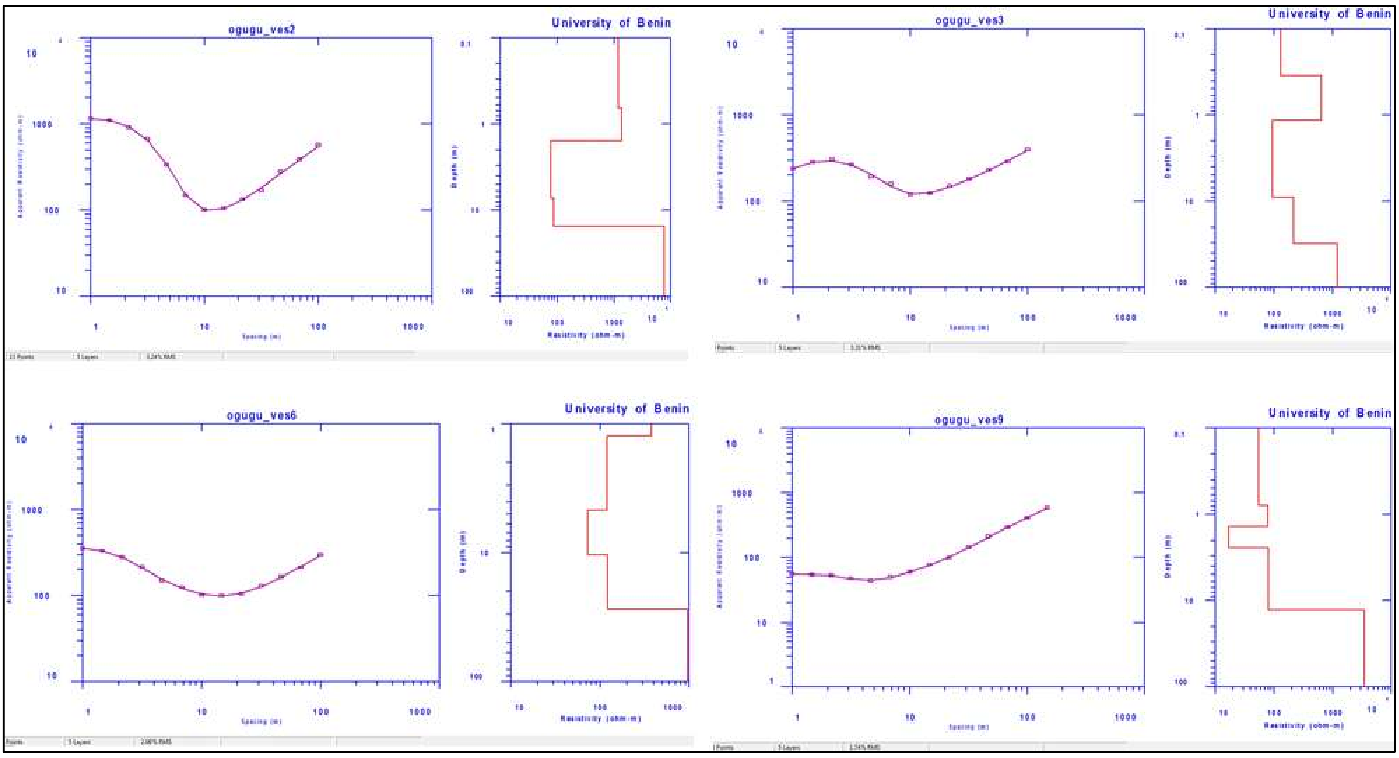

Fig. 4. Typical Ogugu Study Location Resistivity Curves: top left: VES2; top right: VES3; Bottom left: VES6 and Bottom right: VES9

The computed parameters are Reflection Coefficient, Resistivity Contrast, Total Transverse Resistance and Total Longitudinal Conductance. The computations were carried out using the following established relations:

Reflection Coefficient (RCrf) $= (\rho n - \rho n\text{-}1) / (\rho n + \rho n\text{-}1)$ (1)

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

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

Total Longitudinal Conductance (LC) $= S = \sum (h_i / \rho_i) = h_1 / \rho_1 + h_2 / \rho_2 + \ldots + h_n / \rho_n$ (2)

where, ρn = Resistivity of the nth layer; ρn-1 = Resistivity of the (n-1) th layer; ρi = Resistivity of the (i) th layer; ∑ = Summation; h_i = thickness of the (i)th layer and i = 1, 2 3, etc.

4. Results and Discussion

The results of the inversion of the acquired field data are presented graphically in Fig. 4 and the corresponding interpreted geoelectric models are presented in Table 1. The resistivity curves are essentially HA curves. The angles of ascent of the right segments of the curves which are below 450 and depths of the bowls may indicate possible potential productivity at all the locations. The results of the extraction of hydrogeological mapping parameters are presented in Table 2 while the hydro-geological evaluation maps are presented in Figs. 5 and 6. The clay thickness map shows two comparatively higher thickness trends running north-east to south-west and south-east to north-west with both intersecting at the center. This region marks the maximum groundwater protection potential area with the low permeability of clay rock.

Table1. Interpreted Geoelectric Models for VES1 to VES12

			Specific layer resistivity (Ωm)						Layer thickness (m)					Depth to bottom of layer (m)				
VES Station	Location	No of layer	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	h_1	h_2	h_3	h_4	h_5	d_1	d_2	d_3	d_4	d_5
1	Ogugu	5	634.77	193.87	15.52	439.12	24522.00	-	0.78	2.95	3.74	4.67	-	0.78	3.73	7.47	12.15	-
2	Ogugu	5	1178.70	1372.60	77.16	86.53	7698.20	-	0.65	0.92	5.63	8.02	-	0.65	1.57	1.57	15.22	-
3	Ogugu	5	132.13	645.75	95.16	217.94	1207.40	-	0.35	0.80	7.84	22.16	-	0.35	1.15	1.15	31.14	-
4	Ogugu	5	259.76	334.46	48.76	800.56	8610.00	-	0.35	1.76	10.68	7.64	-	0.35	2.12	2.12	20.43	-
5	Ogugu	5	804.40	457.80	45.60	349.83	1998.00	-	0.34	1.74	2.82	21.77	-	0.34	2.08	2.08	26.66	-
6	Ogugu	5	378.18	119.50	72.57	120.97	961.98	-	1.24	3.42	5.69	17.17	-	1.24	4.66	4.66	27.53	-
7	Ogugu	5	456.07	231.16	79.80	272.94	1009.00	-	0.37	1.85	2.61	25.67	-	0.37	2.22	2.22	30.50	-
8	Ogugu	5	1186.20	125.96	26.08	581.73	5470.70	-	1.25	4.94	4.91	7.34	-	1.25	6.19	6.19	18.45	-
9	Ogugu	5	54.73	79.44	17.04	80.98	3452.60	-	0.78	0.60	1.06	10.43	-	0.78	1.39	1.39	12.88	-
10	Ogugu	6	771.05	3536.70	74.86	68.11	373.96	2635.90	0.40	0.77	2.65	8.48	15.31	0.40	1.17	1.17	12.30	27.61
11	Ogugu	5	223.61	67.34	41.43	84.73	2739.30	-	0.74	1.89	2.93	16.65	-	0.74	2.63	.2.63	22.20	-
12	Ogugu	5	654.79	339.63	18.12	971. 93	92677.00	-	0.72	1.24	2.19	2.55	-	0.72	1.96	1.96	6.70	-

Table 2. Ogugu Hydrogeological Mapping Parameters

Location	Surface elevation (m)	Weathering front/ fractured zone thickness (m)	Regolith/overburden thickness (m)	Clay thickness (m)	Depth to top of fractured zone	Fractured Window resistivity
VES1	322	4.67	3.74	3.74	7.47	439.12
VES2	324	8.02	15.22	5.63	7.20	86.52
VES3	342	22.16	31.14	7.84	8.98	217.94
VES4	337	7.64	20.43	10.68	12.80	800.56
VES5	345	21.77	26.66	2.82	4.90	349.83
VES6	348	17.17	27.53	5.69	10.35	120.94
VES7	338	25.67	30.50	2.61	4.83	272.94
VES8	310	7.34	18.45	4.91	11.10	581.73
VES9	334	10.43	12.88	1.06	2.45	80.98
VES10	310	15.31	27.61	8.48	12.30	373.96
VES11	330	16.65	22.2	2.93	5.55	84.73
VES12	350	2.55	6.7	2.19	4.16	971.93

They also mark the maximum in-situ weathering profile that may be structurally controlled. The depth to the top of the fractured zone exhibits similar characteristic as the clay thickness map and together the trends mark areas of maximum protection of groundwater from surface anthropogenic impacts. The Isoresistivity map, fractured zone thickness map and the overburden maps (Fig. 5) all indicate a near central north-south to northwest- southeast trend of comparatively lower resistivity, higher fractured zone and overburden thicknesses. The fractured zone and overburden attributes are indicative of potential space for fluid accommodation while the comparatively lower resistivity over the same region suggests moisture presence.

The results of hydro-resistivity parameters' computations are presented in Table3. The Reflection Coefficient and Resistivity Contrast values are used to provide information on the potentials of basement rocks to support groundwater development. Generally, reflection coefficient values less than 0.9 and resistivity contrast values less than 19 may be indicative of high-water saturated fractures (Anudu et al., 2008; Anudu et al., 2011).

On the basis of the Reflection Co-efficient and Resistivity Contrast threshold values, VES3, VES4, VES5, VES6, VES7, VES8 and VES10 (Table 3) are interpreted as candidate locations for siting boreholes for groundwater exploitation. It is observed that these Basement Complex hydroprospectivity indices i.e. Reflection Coefficient and Resistivity Contrast, are consistent with each other. The VES locations where the Reflection Coefficients are less than 0.9 threshold values correlate with the locations where Resistivity Contrast values are less than the threshold value of 19. This is an important check on the consistency and usefulness of these parameters as screening factors in groundwater development plans.

Both Total Transverse Resistance (T) and Total Longitudinal Conductance (S) are derivative parameters for further screening of an area for rock mass flow capabilities (hydraulic conductivity, K) and regolith thickness (h_t) above fresh basement surface. Generally, areas having comparatively higher values of these parameters are more prospective for groundwater occurrence and development.

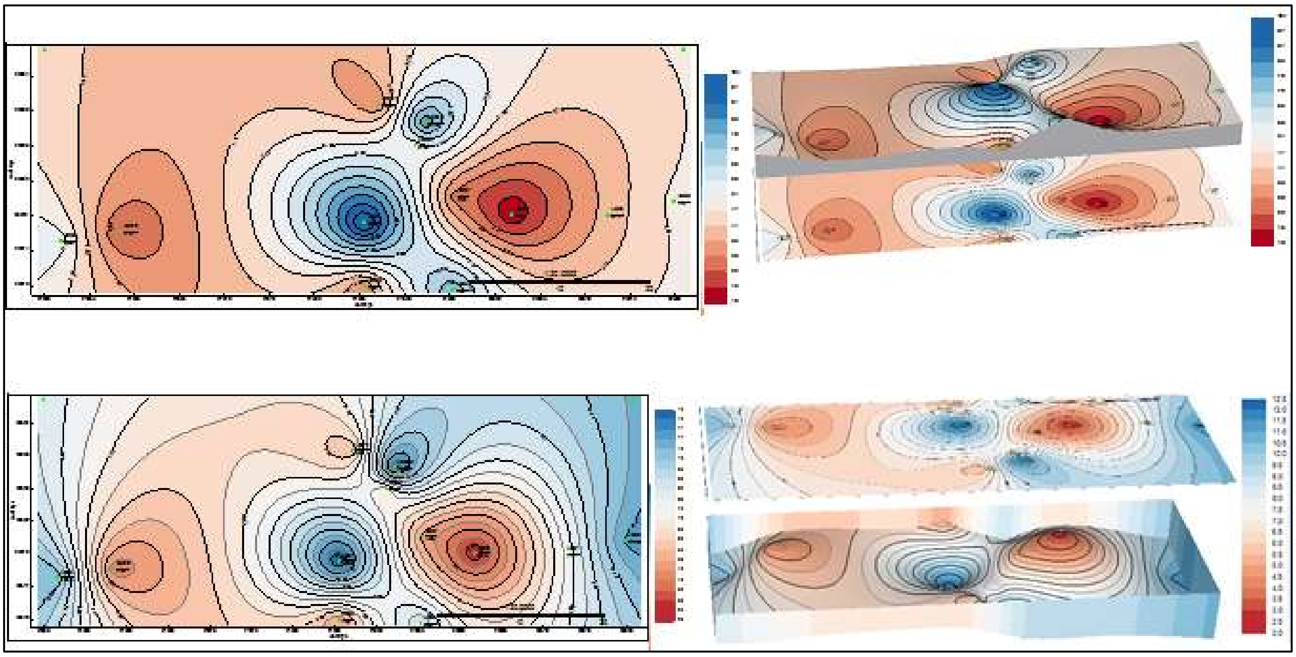

Fig. 5. Top: Clay Thickness Maps (left 2D; right: 3D) Bottom: Depth to Top Fractured Zone (left 2D; right: 3D)

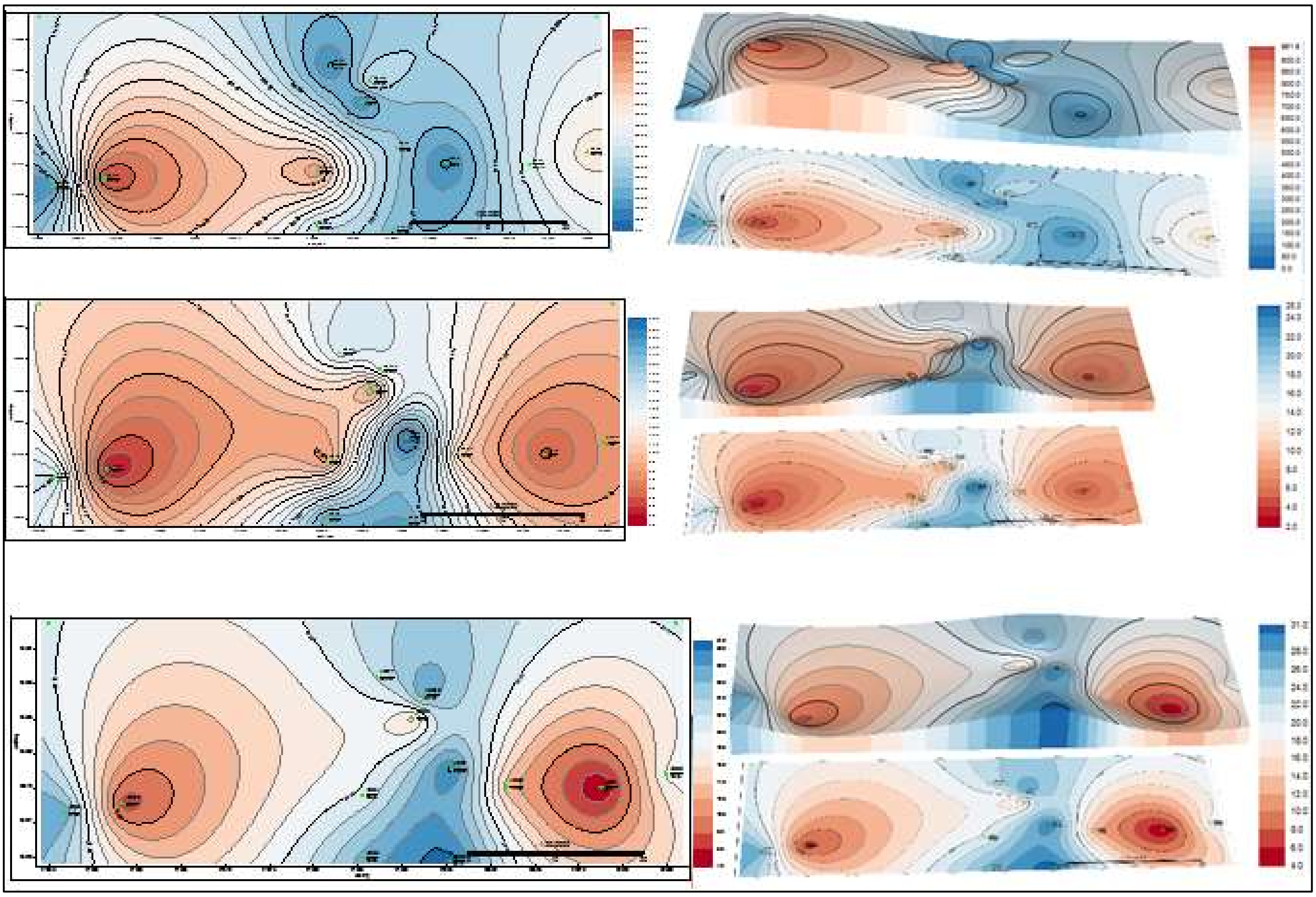

Fig. 6. Top: Isoresistivity map (left 2D; right 3D); Middle: Fractured zone thickness map (left 2D; right 3D) Bottom: Overburden thickness map (left 2D; right 3D)

Table 3. Hydro-resistivity Parameters of the Ogugu Study Area

VES Station	Basement Terrain Hydroprospectivity Indices (BTHI)			
	Reflection Coefficient	Resistivity Contrast	Total Transverse Resistance (T, Ohm-m^2)	Total Longitudinal Conductance (S, mho)
OGUGU VES1	0.96	55.84	3175.8	0.26806
OGUGU VES2	0.98	88.98	3157.2	0.16688
OGUGU VES3	**0.69**	**5.54**	**6138.5**	**0.18795**
OGUGU VES4	**0.83**	**10.75**	**7316.6**	**0.23518**
OGUGU VES5	**0.70**	**5.71**	**8814.5**	**0.12830**
OGUGU VES6	**0.78**	**7.95**	**3367.6**	**0.25224**
OGUGU VES7	**0.57**	**3.70**	**7811.0**	**0.13557**
OGUGU VES8	**0.81**	**9.40**	**6502.9**	**0.24116**
OGUGU VES9	0.95	42.64	953.0	0.21281
OGUGU VES10	**0.69**	**5.49**	**3807.6**	**0.16064**
OGUGU VES11	0.94	32.33	1824.9	0.29860
OGUGU VES12	0.98	95.35	3410.7	0.12824

Table 4. Ogugu VES Locations Potential Yield Ranking

VES Station	Ogugu VES Locations Potential Yield Ranking:			Y = Good	X = Poor	
	Isoresistivity	Fractured zone Thickness	Overburden Thickness	Reflection Co-efficient	Resistivity Contrast	Remark
OGUGU VES1	X	X	X	X	X	No Yield Potentials
OGUGU VES2	Y	X	X	X	X	No Yield Potentials
OGUGU VES3	Y	Y	Y	Y	Y	High Yield Potentials
OGUGU VES4	X	X	Y	Y	Y	Low Yield Potentials
OGUGU VES5	Y	Y	Y	Y	Y	High Yield Potentials
OGUGU VES6	Y	Y	Y	Y	Y	High Yield Potentials
OGUGU VES7	Y	Y	Y	Y	Y	High Yield Potentials
OGUGU VES8	X	X	X	Y	Y	Poor Yield Potentials
OGUGU VES9	Y	X	X	X	X	Poor Yield Potentials
OGUGU VES10	X	Y	Y	Y	Y	Medium to high Yield Potentials
OGUGU VES11	X	Y	Y	X	X	Low Yield Potentials
OGUGU VES12	X	X	X	X	X	No Yield Potentials

The results of computations of these parameters are observed to be consistent with each other, for example, correspondingly high values and with respect to locations that are defined as prospective by the pair of Reflection Coefficient and Resistivity Contrast parameters, Table 3. However, in this study, emphasis is on the directly inferred overburden thickness values extracted from the geoelectric models than the Total Longitudinal Conductance as an evaluation tool. This is so recommended for higher interpretational validity.

Table 4 presents the summary of the Basement Complex terrain hydroprospectivity Indices (BTHI) for Ogugu study location. The hydroprospectivity maps which are predictive and define trends such as fracturing that are more likely geologically controlled are used to generate prospectivity performances for isoresistivity, fractured zone thickness, and overburden thickness.

Results in Table 4 indicate VES3, VES5, VES6, VES7 and VES10 as high yield potential locations. VES4 and VES 11 are low yield potential locations, while VES8 and VES9 are poor yield potential locations. VES1, VES2 and VES12 are potentially barren locations for groundwater exploitation.

Outside of the VES control locations, further locations within the core of the belt consistently defined by the isoresistivity, fractured zone thickness and overburden maps can be used as borehole locations. The trend defined by these maps is geologically controlled (fracturing) with the thickness maps indicating subsurface space for fluid accommodation and comparatively low isoresistivity trend suggesting the wettability of the available fluid accommodation space.

5. Conclusion

The results of this study have demonstrated the usefulness of the Electrical Resistivity Methods in the screening of Basement terrain domains for groundwater development. The basement hydroprospectivity maps generated for Ogugu study location clearly define a zone marked by thick fractured zone thickness specifically and overburden thickness generally. The comparatively low isoresistivity values within the same trend defined by the fractured zone thickness suggests wettability and good potentials for groundwater development. The integration and good correlation of the results of computation of the hydro-resistivity parameters (Reflection Co-efficient, Resistivity Contrast, Total Transverse Resistance, Total Longitudinal Conductance) further added value to the results of the study. The topmost five VES locations, namely, VES3, VES5, VES6, VES7 and VES10 are suggested as start off locations for groundwater development in Ogugu and environs.

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