Groundwater Prospecting Using Vertical Electrical Sounding in Part of Paleocene Akinbo Formation, Eastern Dahomey Basin

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ABSTRACT
Application of Vertical Electrical Sounding (VES) in parts of Akinbo formation is aimed at delineating prospective aquiferous units with appreciable groundwater yield. Twenty (20) VES points were stationed in the area using Schlumberger configuration at a half-potential and half-current -electrode spacing range of 0.2 m – 15 m and 1 – 200 m respectively. Processing tasks involved resistivity curve generation from log-log plots of apparent resistivity against half-current electrode separation; partial curve matching of resistivity curve with the master curve to generate layering parameters; and computer iteration of generated parameters into curves, that was subsequently matched with the resistivity curve for parameter standardization.A range of three to six geo-electric subsurface sedimentary strata were encountered; three (3) – four (4) on the western bloc, and three (3) – six (6) on the eastern bloc. On the western region, it revealed top to bottom, varied between 85 Ωm – 484 m, 59 Ωm – 268 Ωm (in the case of a four layered model), 306 Ωm – 2215 Ωm and 6 Ωm – 61 Ωm; with a corresponding thickness-range of 0.6 m – 1.9 m, 0.9 m – 6.8 m, 14.5 m – 37.2 m while the bottom stratum extends to infinity. Lithologic inference is topsoil, mudstone/sandy mudstone/clayey sandstone, fractured sandstone /sandstone and shale in the aforementioned order. Resistivity range on the eastern block is generally less than 100 Ωm with very seldom exceptions of 101 – 181 Ωm. This stratigraphy succession is inferred as a very thick shale-sequence with minor interbeds of mudstones, and pockets of sandy topsoil. Towards the basal part, the sequence became slightly calcitic. Thickness of this sequence extends to infinity with respect to the electrode spread. Longitudinal conductance of the formation generally ranges from 0.01 – 12.1 mho; 0.01 – 0.04 mho on the highly-vulnerable sandy western bloc, and 3.59 – 12.1 mho for the strongly-protected shaly eastern bloc. Anisotropy coefficient of the formation ranges 1.02 – 2.25 with a mean value of 1.32, indicative of a low groundwater-yield sequence. As deduced from the geo-electric parameters, lithofacies and hydro-stratigraphic variation has been established between the dry shale/mudstone succession of the eastern bloc and few unconfined low-yield shale/sandstone sequence of western part with a delineated aquifer thickness of 6.5 – 37.2 m. Prospecting efforts should be concentrated towards the southwest where appreciable thickness of sandstone can be readily delineated to function as aquifer.
Keywords: *Groundwater, Electrical Resistivity, Schlumberger, Lithofacies, Aquifer*

INTRODUCTION

Groundwater exploration either in a sedimentary or basement formation depends on delineating weathered or fractured rocks as well as saturated formations respectively. Though, there are diverse sources of water; rivers, pond, stream; none is as clean as groundwater because it has a great natural microbiological quality and some chemical quality for man consumption (Gleick, 1993). In search for a good water, it requires detailed geophysical investigation of the aquifer, the spatial location is also important to characterize the potential zones in the prospecting area. To avoid wastage of money and human effort, a detailed method is required for assessing formation parameters before embarking on drilling process. This will ensure a prospective productive well is sited where the aquifer has adequate thickness and good water quality (Adeniji et., al , 2013).

The urge to sustain groundwater need by people has empowered the application of appropriate geophysical and or hydrogeologic search (Umah and Eyankware, 2022; Kirsch, 2006) to locate areas of high quality and reliable groundwater prospect, it will also assist in characterizing seasonal changes in the subsurface aquifer (Webb *et al.*, 2011). As a result of high rate of urbanization and industrial activities around Sagamu where the study area is located, there is rapid increase in the population of the resident; hence the need for development of a sustainable water supply. Electrical resistivity method (one of the geophysical methods of prospecting) has been widely used in groundwater investigations because of its ability to map resistivity variations, give geological insight and fluid content as far as groundwater exploration is concerned (McNeil, 1990; Herkenrath *et al.*, 2013) . The commonly used technique of the electrical resistivity method is the vertical electrical sounding (also called Schlumberger sounding) is effective for groundwater studies due to its simplicity, required less man power and easy data interpretation. The technique is widely used used in hard and soft rock areas (McNeil, 1990). It is capable of determining the resistivity soundings of the study area without prior information of the location. Groundwater potential investigation was carried out by Benson *et al.*, 1997; Osinowo and Olayinka, 2012 used integrated geophysical methods (Electromagnetic and electrical resistivity) at Ijebu Ode transition zone,southwestern Nigeria to delineate low, medium and groundwater potential areas located in the northern, central and southern part of the study area. The low groundwater resource potential in the study area is due to less permeable lateritic overburden. In this research, a detailed geophysical survey of the study area was done to determine the geoelectric parameters (e.g resistivity, depth and thickness)of subsurface layers and the hydrogeological properties. This research work aimed at mapping the subsurface around sotubo Sagamu and delineate the possible groundwater potential zones for exploration. Electrical resistivity method was adopted as the major exploration method because its capable of revealing the subsurface information on layer by layer basis by passing electrical current down the subsurface. From literature, this method has been adopted successfully by several researchers.

Location and Accessibility

The study area is geographically positioned between longitudes E003.593925° – E003.605055° nd latitudes N06.807689° – N06.815161° (figure 1) along Sagamu – Ikorodu expressway, Sotubo, Southwestern Nigeria. Accessibility in the area is readily opened up for field data acquisition through interconnected network of major and minor routes. Majority of the minor routes linked the expressway.

Physiographic Settings

Surface elevation ranges between 36 m in the northern and eastern margins to 78 m in the southern and western part (figure 2). Relief features include a steep 20 – 30 m diagonal slope running from the northwest to the southeast.

Geology – Eastern Dahomey Basin

Origination of Dahomey basin can be narrowed down to the stress responses associated with the lithospheric divergence of the African and South American plate during the Cretaceous. The continuous detachment of the plates consequently opened up the South Atlantic sea, which greatly influenced sedimentation into the basin. Dahomey basin is a regional coastal rift basin stretching from eastern Ghana to southwestern Nigeria. Structurally, it is an arcuate embayment opened to the Gulf of Guinea with its axis of symmetry around the Nigerian-Benin republic boundary.

The eastern sector of the basin, known as eastern Dahomey basin, is underlain by lithologies of three major era (figure. 3), namely; the Cretaceous group, Tertiary group and the Quaternary alluvium. The Cretaceous group, locally known as Abeokuta group, is the oldest lithostratigraphic division within the basin. It chronologically consists of the Ise, Afowo and Araromi formation. Ise formation is an uplifted and partly eroded interbed of conglomerate or conglomeratic sand and kaoline or kaolinitic sand, deposited in the Neocomian (Omatsola and Adegoke, 1981). It rests on the crystalline basement of southwestern Nigeria with sparse occurences of iron ore cappings on the continental sequence. In the Maastrichrian, the basin experienced a seaward depositional shift which eventually sedimented Afowo formation in a rather transitional enviroment. Afowo sequence is an interbed of sandstone/sand, shales and clay/claystone with heavy bitumen and some sandstones. The topmost formation within the Cretaceous group is Araromi formation, with a range of Maastrichtian to Paleocene (Billman, 1992; Adegoke and Ajayi, 1988) . Prolonged sedimentation during this period deposited argillaceous clastics (shale and fine grained sand/sandstones) and thick interbeds of limestones, clay and lignitic bands as the depositional environmental shited tremendously from fluvial or lacustrine to deltaic conditions.

Tertiary group unconformably overlies the Abeokuta group. Along the eastern sector of the basin, the Tertiary group is known as Imo group, and comprises of two lithostratigraphic unit which are; Ewekoro and Akinbo formation. Ewekoro formation is a grayish white or ocassionally greenish limestone stratum or strata (Adegoke and Ajayi, 1988), precipitated in the Paleocene during the shallow marine incursionfrom the Atlantic into the basin. Thickness of this formation varied between 11 m – 12.5m.

Facies changes is prominent within the formation with three variants identified by Dada *et al.*, 1995 and one additional unit by (Adegoke and Ajayi, 1988) namelyred phosphatic biomicrite, algal biopharite, shelly biomicrite and Sandy Biomicrosparites. Akinbo formation is a prominent lithostratigraphic unit(Holt, 1982) directly overlying Ewekoro formation. It constitutes the upper part of the Imo group, and are largely deposited on the western part in the Mid to Late Paleocene.The formation is majorly a sequence of dark, pale – greenish grey, laminated, slightly gluauconitic and highly fossiliferous marine shales with minor claystone lenses. Active marine sedimentation continued in the Eocene with the deposition of phosphate-bearing shale and interbedded sandy units identified by (Jones and Hockey, 1964) as the Oshosun or Ilaro formation.

The formation is thickly developed towards the basin axis, attaining a thickness of about 400 m coastward. It is believed to be overlain by the unfossiliferous Benin sand formation (Adegoke and Ajayi, 1988) – also referred to as Coastal plain sand. The coastal plain sand is also believed to be the youngest Tertiary sediments with an age range of Oligocene – Pleistocene. Lithologic components of the coastal plain sands include soft, very poorly sorted clayey sands, pebbly sands, sandy clay and rare thin lignites; occassioned by the presence of yellowish and whitish cross-bedded sands and clays. A similar stratigraphic unit with almost

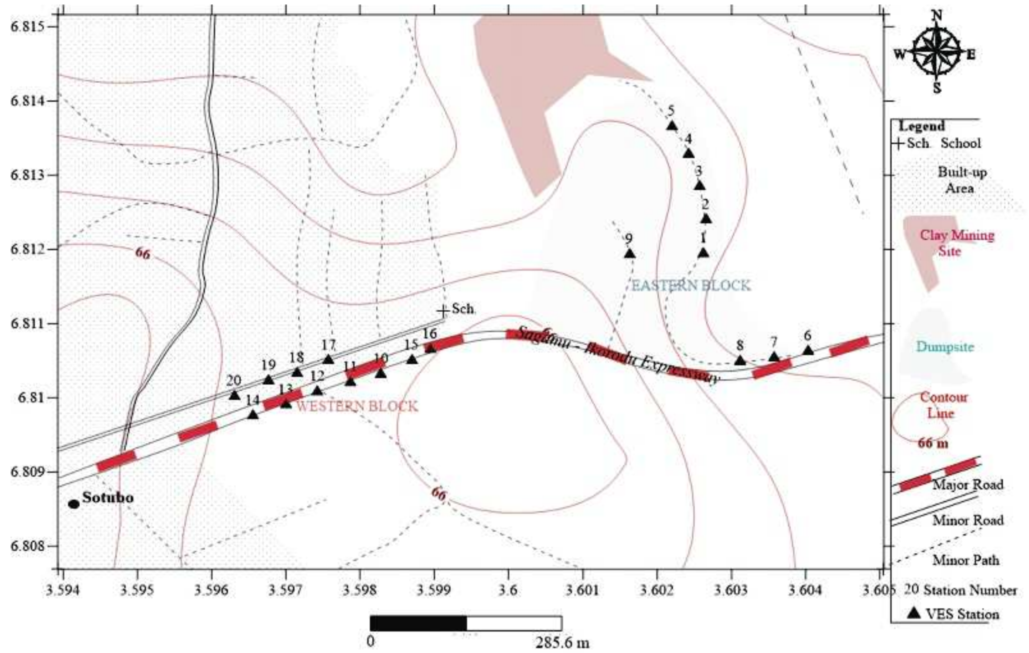

Figure 1: Location and Accessibility Map

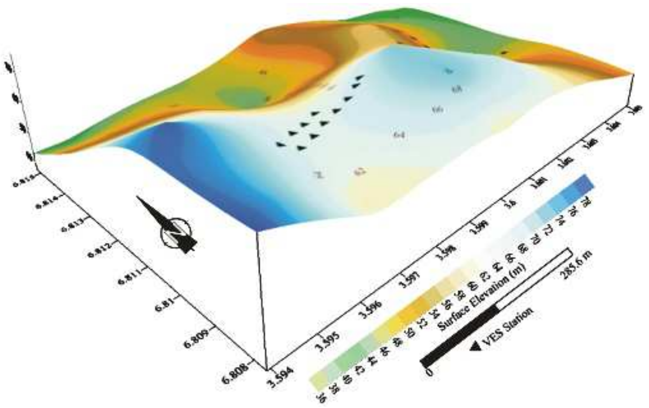

Figure 2: Relief Map

the identical lithologic components is Recent alluvium. The Recent alluvium, by the virtue of its stratigraphic position, is conceived to be the youngest unit stratum within the basin. A Quaternary age is assigned to the alluvium.

On the basis of stratigraphic delineations and geographic positioning within the basin (Rahaman, 1988) , the investigated sequence falls within the Paleocene Akinbo formation . Vast exposures of mudstone and sandy mudstone strata of about 5 metres has been mapped at the clay-dredging site in the eastern part of the area. Subsurface occurrences of very thick shale are further established using geophysical evidences.

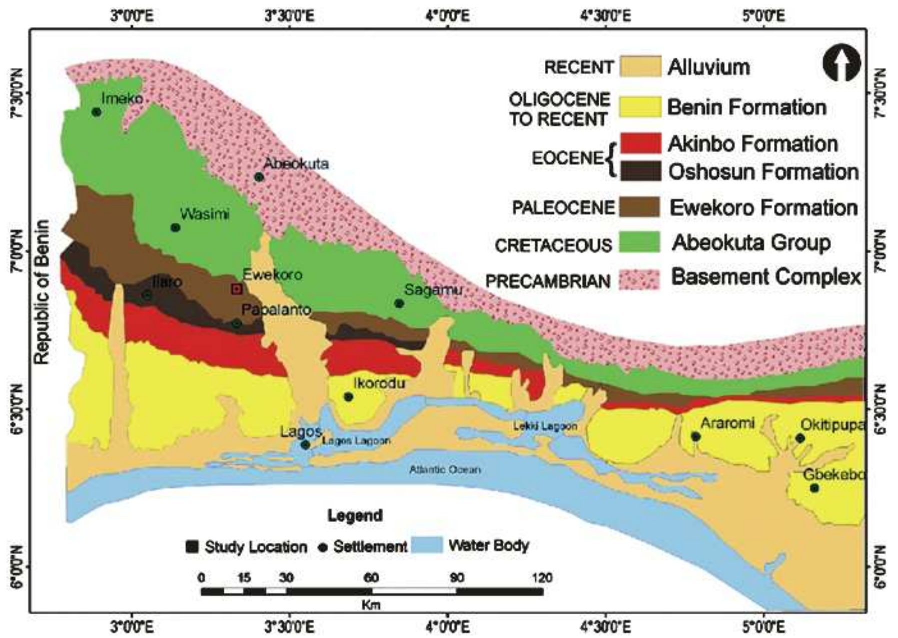

Figure 3: Geological Map of Eastern Dahomey Basin (Mosuro *et al.*, 2016)

MATERIALS AND METHODS

Electrical resistivity method is a routinely adopted geophysical method which involved the introduction of electric current into the ground, and measurement of potential developed within the geologic medium at the surface. The two physical quantities are fundamentally related by Ohm's law which states that; the magnitude of current (I) transmitted through a medium is directly proportional to the voltage (V) developed, with the constant of proportionality being resistance (R) in Ω.

$$V \propto I$$
$$R = V/I \qquad (1)$$

The true resistivity of a geologic body is conceptualized using an electrically uniform cube with length (L) and a crossectional (A) which upon the passage of current (I) through it, developed potential difference (V) between it opposite faces. Resulting resistance (R) of the cube is proportional to 'L' and inversely proportional to 'A' where ρ is the constant of proportionality in Ωm^{-1}.

$$R \propto L/A$$
$$\rho = R\frac{A}{L} \qquad (2)$$

Conduction of electric current through rocks could be electronic, dielectric but majorly electrolytic (Obasi *et al.*, 2022).

Rocks exhibit a broad range of resistivity values which approximately varied from <1 ohm metres to several hundreds of thousand of ohm. Considerable overlaps exist among rocks; with rocks of igneous origin commonly exhibiting greater resistivity range than other rock types. Sedimentary rocks offer the weakest range metamorphic types show considerable overlaps. Generally, the resistivity of a geologic body is influenced by mineralogical composition, age, pore fluid content, porosity and deformation history.

Field Procedure

Electrical resistivity method was employed for the investigation of the probed sedimentary formation due to its capability to respond to conductivity variation of its component strata with depth. Vertical Electrical Sounding (VES) procedure was appropriately adopted to achieve the groundwater prospecting-aim of the reasearch. The establishment of VES station involved the use of manually configured four-electrode Schlumberger array connected appropriately to the cable reels terminal, and from the reels to the electrode terminals of a DC powered Igis resistivity meter. Two of the stainless steel electrodes functioned as the current electrodes while the other two performed the role of potential electrodes.

To avoid inaccuracies and assymetrical imbalance in electrode position-fixing, two metre rules with common origin from a selected VES station, were set out in opposite directions along a straight survery line until a predetermined half-length of 200 m was established on each side. Each side (also known as wing or flank) is 200 m long in order to accommodate the electrode spacing protocol designed for VES data acquisition. The adopted protocol for the current and potential electrode on each flank (i.e half electrode separation) was: 1 m/0.2 m; 2 m/0.2 m; 2 m/0.4 m; 3 m/0.4 m; 4 m/0.4 m; 6 m/0.4 m; 6 m,1 m; 9 m/1 m; 12 m/1 m; 15 m/1 m; 15 m/2.5 m; 20 m/2.5 m; 25 m/2.5 m; 32 m/2.5 m, 40 m/2.5 m; 40 m/5 m; 50 m/5 m; 65 m/5 m; 80 m/5 m; 100 m/5 m; 100 m/10 m; 120 m/10 m; 150 m/10 m; 150 m/15 m; 180 m/15 m and 200 m/15 m.

After the creation of the survey line, the current and potential electrodes were driven into the ground with the aid of sledge hammers at a starting half-electrode spacing of 1 m and 0.2 m on each flank. The crocidile clips at the tip of the cable reels were appropriately connected to the electrodes in readiness for the first measurement. With all necessary precautions observed, a known magnitude of current from the DC resistivity meter was transmitted into the ground via the outer current electrodes while subsequently noting the resulting potential difference (of the formation) developed between the inner potential electrodes. For the second measurement, the current electrodes were symmetrically extended to a half-spacing of 2 m while keeping the potential electrode spacing fixed, as documented in the Schlumberger protocol explained above. Still at a half-spacing of 2 m for the current electrode, the measurement was repeated at a wider potential-half spacing of 0.4 m for better reception of electrical signals. Symmetrical expansion of the current electrodes progessively continued to a half-spacing of 6 m before widening the potential-half spacing to 1 m. The array was further increasingly expanded in accordance with the protocol until the widest (last) electrode spacing was executed.

Data Processing and Interpretation

At the data processing stage, the major tasks entailed the transformation of apparent resisitivity datasets to true subsurface resistivity settings, and to convert the half-current electrode spacing to the thickness and depth of the geo-electric strata within the formation. Three major stages are involved in the accomplishment of this processing tasks, which are; curve construction, partial curve matching and computer iteration.

Resistivity curve is constructed by plotting the apparent resistivity dataset (on the y-axis) as a function of the half current electrode spacing (on the x-axis) on a log-log graph. Resulting resistivity curve directly reflected the apparent resistivity relations of the component strata within the probed formation. In a bid to calculate the layering parameters (i.e resistivity, thickness and depth), the curve was partially matched with an auxiliary curve near the origin, and then tangetially with the master curve along its segments. Calculated parameters were fed into the iteration program which during the iteration process transformed the parameters into a synthetic resistivity curve, superimposed and fitted to the apparent resistivity curves to generate an acceptable model after series of iterative adjustments.

RESULTS AND DISCUSSIONS

Logical inferences for groundwater occurrences are premised on the geo-electric parameters characterizing the formation with emphases laid on delineated lithostratigraphic units with intrinsic porosity and permeability for storage. Consideration is also given to anomalous resistivity discontinuities across the stratigraphic sequence, which may directly reflect the presence of structural discontinuities capable of initiating secondary openings. For ease of comparison, the area is strategically subdivided into two blocks, namely; the western and eastern blocs.

Fundamentally, a range of three (3) to six (6) geoelectric strata was revealed. The multilayered nature of the area generally reflected the diverse lithostratigraphic components distinguishable on the basis of contrasting electrical conductivity. Due to electrofacies changes, the areais interpreted along geologic traverses.

Table 1: Interpretation of Iterated Parameters of Vertical Electrical Soundings

VES STATION	LAYER NUMBER	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	LONGITUDINAL CONDUCTANCE	LONGITUDINAL RESISTIVITY (Ωm)	TRANSVERSE RESISTITY(Ωm)	ANISOTROPIC COETTICIRNT	CURVE TYPE	LITHOLOGIC INFERENCE
1	1	29	1.4	1.4	5.37	7.30	11.6	1.26	HK	Topsoil
	2	4	15.8	17.2						Shale
	3	16	22	39.2						Shale
	4	1	-	-						Shale
2	1	44	1.1	1.1	10.1	8.74	9.14	1.02	HA	Topsoil
	2	7	12.5	13.7						Shale
	3	9	74.5	88.2						Shale
	4	65	-	-						Calcitic Shale
3	1	16	1.1	1.1	10.0	4.08	4.32	1.03	H	Topsoil
	2	4	39.9	41						Shale
	3	67	-	-						Calcitic Shale
4	1	77	1.2	1.2	12.1	4.09	5.77	1.19	H	Topsoil
	2	4	48.4	49.6						Shale
	3	95	-	-						Calcitic Shale
5	1	133	1.0	1.0	8.46	4.11	7.71	1.37	H	Topsoil
	2	4	33.8	34.8						Shale
	3	99	-	-						Calcitic Shale
6	1	97	0.5	0.5	3.59	13.6	40.9	1.73	HKHK	Topsoil
	2	46	1.0	1.5						Mudstone
	3	109	4.7	6.2						Sandy Mudstone
	4	5	14.6	20.8						Shale
	5	47	28.2	49						Mudstone
	6	0.5	-	-						Shale
7	1	181	0.9	0.9	4.08	14.3	19.6	1.17	QHK	Topsoil
	2	64	3.4	4.3						Mudstone
	3	10	16.9	21.2						Shale
	4	16	37.3	58.5						Shale
	5	2	-	-						Shale
8	1	72	1.3	1.3	8.37	8.40	15.3	1.35		Topsoil
	2	47	12.4	13.7						Mudstone
	3	7	56.6	70.3						Shale
	4	133	-	-						Calcitic Shale

VES STATION	LAYER NUMBER	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	LONGITUDINAL CONDUCTANCE (mho)	LONGITUDINAL RESISTIVITY (Ωm)	TRANSVERSE RESISTITY (Ωm)	ANISOTROPIC COEFFICIENT	CURVE TYPE	LITHOLOGIC INFERENCE
9	1	54	1.2	1.2	9.59	4.19	16.6	1.99	QH	Topsoil
	2	47	11.0	12.2						Mudstone
	3	3	28.0	40.2						Shale
	4	77	-	-						Calcitic Shale
10	1	116	0.6	0.6	0.01	296	302.2	1.02	K	Topsoil
	2	306	29.4	30.0						Fractured Sandstone
	3	34	-	-						Shale
11	1	185	0.9	0.9	0.04	538	947	1.33	AK	Topsoil
	2	268	6.8	7.7						Clayey Sandstone
	3	1312	14.5	22.2						Sandstone
	4	9	-	-						Shale
12	1	252	0.8	0.8	0.03	744	1055	1.19	HK	Topsoil
	2	101	0.9	1.7						Sandy Mudstone
	3	1125	21.5	23.2						Sandstone
	4	34	-	-						Shale
13	1	255	1.0	1.0	0.05	644	909	1.18	HK	Topsoil
	2	137	2.2	3.2						Sandy Mudstone
	3	984	28.0	31.2						Sandstone
	4	12	-	-						Shale
14	1	85	1.5	1.5	0.04	652	991	1.23	K	Topsoil
	2	1042	26.7	28.2						Sandstone
	3	40	-	-						Shale
15	1	233	0.7	0.7	0.04	285	707	1.57	HK	Topsoil
	2	62	1.5	2.2						Sandy Mudstone
	3	863	8.3	10.5						Sandstone
	4	17	-	-						Shale
16	1	458	0.5	0.5	0.02	357	1814	2.25	HK	Topsoil
	2	59	1.1	1.6						Mudstone
	3	2215	6.5	8.1						Sandstone
	4	6	-	-						Shale
17	1	219	1.9	1.9	0.02	887	1197	1.16	K	Topsoil
	2	1299	18.3	20.2						Sandstone
	3	22	-	-						Shale
18	1	179	0.6	0.6	0.01	1713	2137	1.12	K	Topsoil
	2	2187	23.7	24.3						Sandstone
	3	61	-	-						Shale
19	1	223	0.7	0.7	0.04	1011	1068	1.03	K	Topsoil
	2	1084	37.2	37.9						Sandstone
	3	79	-	-						Shale
20	1	484	0.5	0.5	0.03	915	1367	1.22	HK	Topsoil
	2	241	3.3	3.8						Clayey Sandstone
	3	1542	23.8	27.6						Sandstone
	4	16	-	-						Shale

Traverse One

Traverse one (Figure 4) consists of VES stations 1, 2, 3, 4 and 5. Correlation of the stations revealed a range of three to four geo-electric strata. From top to bottom, the sequence majorly consists of 29 Ωm – 133 Ωm topsoil, 1.1 Ωm to 16 Ωm shale, 65 Ωm – 99 Ωm calcitic shale.

Thickness of topsoil ranges from 1 m – 1.4 m. The shale is 39.9 m in the northern part but progressively became thicker (to infinity) southward. The sequence is evidently a thick pile of shale strata of vary conductivity and plasticity. It is consequentially an unfavourable hydrogeological settings lacking the required lithology (aquifer) for groundwater accumulation.

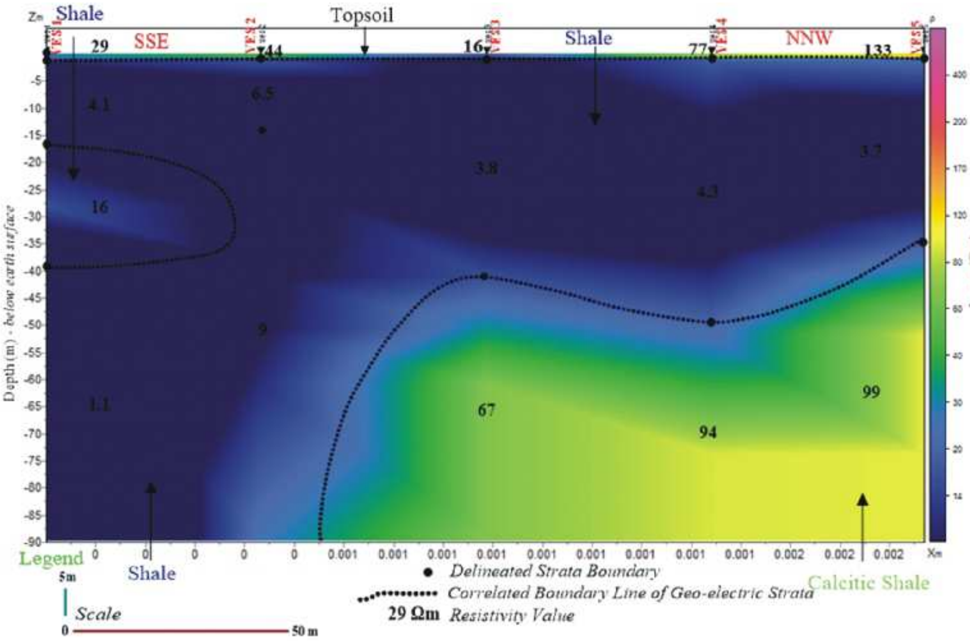

Figure 4: Geo-electric Section along Traverse 1

Traverse Two

VES 6, 7 and 8 (Figure 5) are correlated along traverse 2 with the resulting section constituted by a range of four to six geo-electric strata. Resistivity of the strata, from to bottom, varied from 72 Ωm – 181 Ωm for an inhomogeneous topsoil composed of mudstone and sandy mudstone; 46 Ωm for a 1 m-thick mudstone (revealed at VES 6), 47 Ωm - 109 Ωm for a relatively thicker mudstone between a depth interval of 1.3 m – 13.7 m; 0.5 Ωm – 16 Ωm for the anomalously conductive shale strata, inter-fingered between a depth interval of 20.8 m – 49 m (at VES 6) by 47 Ωm mudstone, and slightly became calcitic at VES 8 below a depth of 70.3 m. Similarly, the section revealed a very thick shale-preponderated sequence of relatively higher conductivity, with little or no groundwater prospect. Apparently, the absence of permeable stratum or strata within the sequence eroded the possibility of groundwater occurrence – with respect to the penetrated depth.

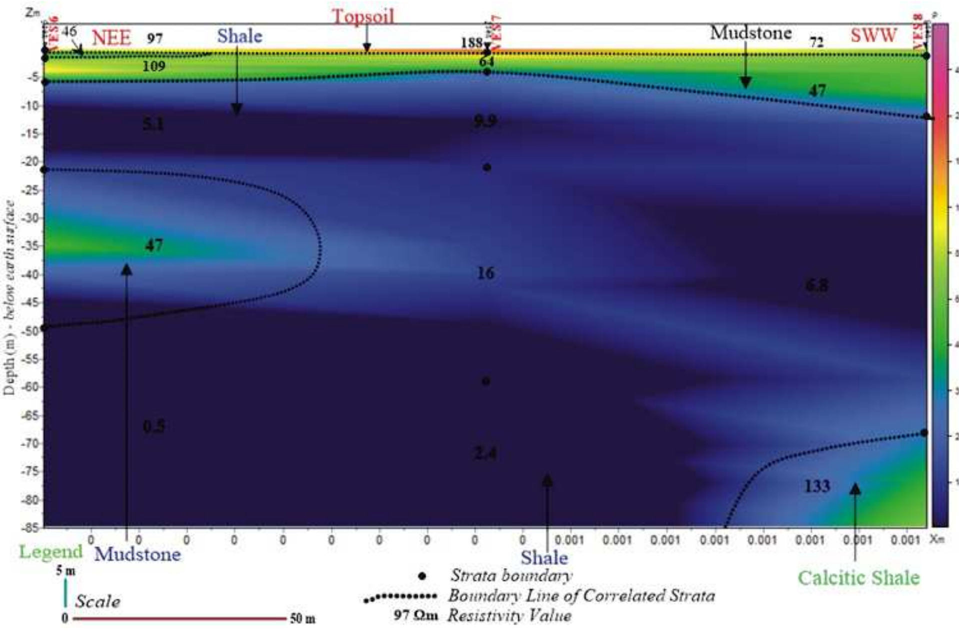

Figure 5: Geo-electric Section along Traverse 2

Traverse Three

Seven VES stations, namely; VES 16, 15, 10, 11, 12, 13 and 14 (Figure 6) built up the geo-electric section along traverse three. Revealed stratigraphy of the succession markedly consists of a range of three to four strata of contrasting resistivity. Resistivity of the strata varied between 85 Ωm – 458 Ωm, 59 Ωm – 137 Ωm (in the case of a four layered model), 863 Ωm – 2215 Ωm and 5.5 Ωm – 40 Ωm from top to bottom. Lithologic inference in aforementioned order is topsoil, mudstone/sandy mudstone, sandstone and shale/mudstone. The succession is abruptly disrupted by a vertical resistivity-anomaly of 306 Ωm, inferred as Fracture. Thickness varied between 0.5 m – 1.5 m for topsoil, 1.1 m – 1.5m for mudstone / 0.9 m – 2.2 m for sandy mudstone, 6.5 m – 28 m for sandstones while extending to infinity for the mudstone.

Due to lithofacies changes during deposition, the stratigraphy of this formation along traverse three differed remarkably with the delineation of 6.5 m – 28 m thick sandstone stratum confined at the base by the mudstone - with groundwater implications. The stratigraphic thickness of the sandstone affected the availability of sustainable groundwater, as areas underlain by thin sandstones within sequences are expectedly ineffective to sustain the required volume needed to yield a productive well. This problem is particularly imminent around the northeast margin of the traverse. About 150 m away from the northeastern margin, an impressive stratigraphic thickness of over 20 m is revealed southerly. Districts underlain by this hydrogeological setting experience huge quantity of groundwater in sunk boreholes at relatively cheaper drilling cost.

The groundwater prospect of the formation is additionally influenced by occurrences of structural discontinuity. Along this traverse, a vertical fracture deformed the sequence. This significantly opened up secondary voids for groundwater storage.

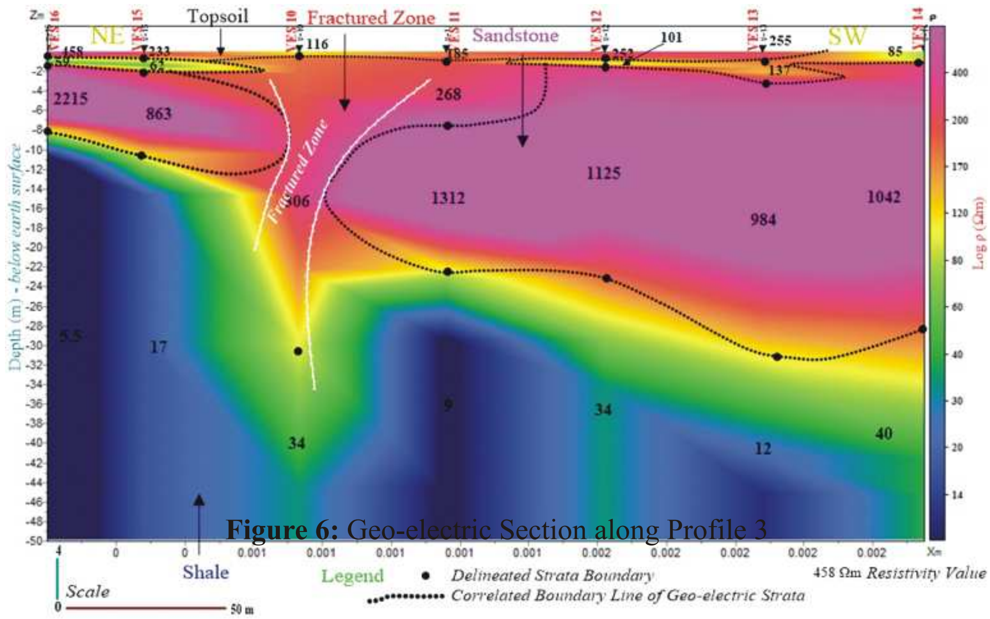

Figure 6: Geo-electric Section along Profile 3

Figure 6: Geo-electric Section along Profile 3

Traverse Four

Along traverse four VES 17, 18, 19 and 20 (Figure 7), the geo-electric sequence, from top to bottom, consists of a range of three to four strata, differentiated by a resistivity range of 79 Ωm - 484 Ωm, 241 Ωm (for four layered the model), 1084 Ωm – 2187 Ωm and 16 Ωm - 79 Ωm which is respectively interpreted as topsoil, clayey sandstone, sandstone and mudstones. Thickness of the topsoil varied between 0.5 m – 1.9 m, while the clayey sandstone is 3.8 m thick. More importantly, the sandstone stratum ranges in thickness from 18.3 m to 37.2 m and confined at the base by a very thick stratum of mudstone. The sandstone stratum along this traverse is appreciably thicker than that of traverse 3, with better groundwater potential. Traverse 4 is the most prolific spot within the study area

Lithofacies Changes and Hydrostratigraphy Implication

A recognizable lateral resistivity variation is apparent across the two blocks due to facies changes. Resistivity range of the topsoil (figure 8) on the eastern and western blocks is 16 Ωm – 181 Ωm and 85 Ωm – 484 Ωm respectively; an indication of an inhomogeneous top composed of mudstones and sandy mudstones on the eastern bloc but predominantly sandy on the western block. Lithofacies variation across the area is perfectly captured using the isoresistivity slice of the second to the last layer ($n - 1^{th}$), by revealing a resistivity variation of 3 Ωm – 47 Ωm (shale/mudstones) on the eastern bloc, and 863 Ωm – 2215 Ωm for sandstone lithology on the western block. Minor depiction of resistivity-drop within the sandstone ostensibly revealed brittle

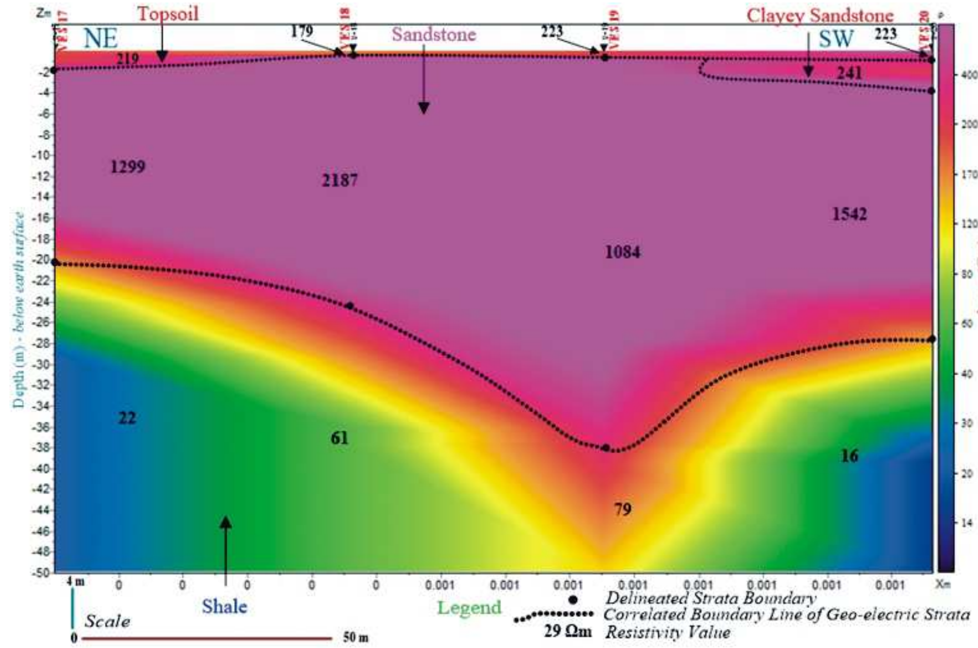

Figure 7: Geo-electric Section along Profile 4

deformation by fracture. The deepest isoresistivity slice cut through the formation i.e. last or nth layer, similarly, revealed resistivity range of 0.5 Ωm – 133 Ωm and 6 Ωm – 79 Ωm for the shale/calcitic shale dominated landscape of both the eastern and western blocks resistivity.

As expressly revealed from the vertical electrical sounding results, the lithologic succession of the area is majorly dominated by very thickshale and minor mudstone interbeds of varying conductivity due to compositional and textural differences, brought about by changes in depositional compositions coupled with sea level fluctuations. This pattern describes a typical Paleocene Akinbo formation (Mosuro *et al.*, 2016) with crucial groundwater consequences. Presence of an 8.1 m – 37.2 m thick sandstone stratum on the shale/mudstone strata set up an unconfined hydro stratigraphic setting on the western bloc. However, the capability of the sandstone (Figure 9) to function as aquifer critically depends on its stratigraphic thickness. The thicker the sandstone stratum, the higher its groundwater prospects and vice versa. Majority of the productive boreholes in the area are concentrated within the southwestern segment of the western blocks.

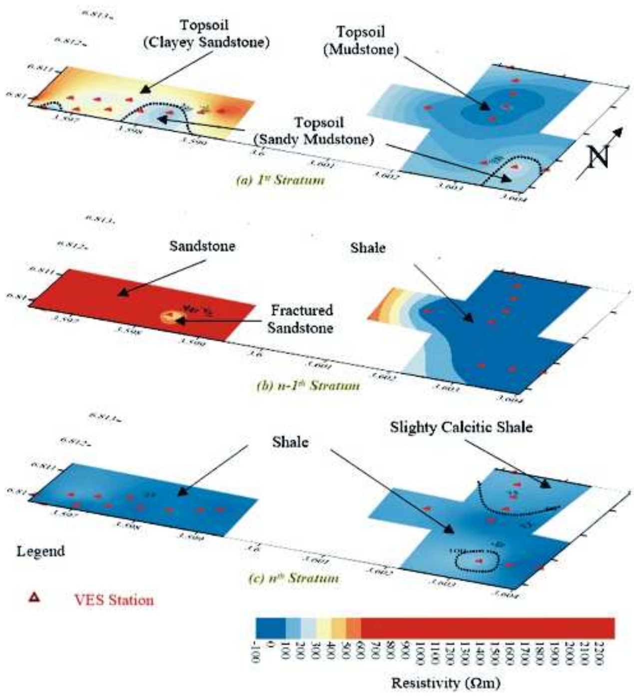

Figure 8: Stacked Isoresistivity Map

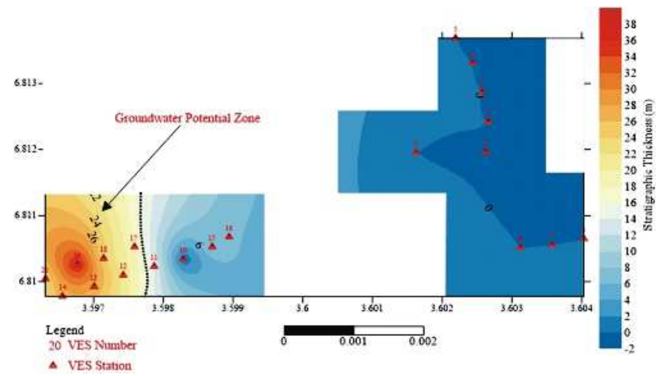

Figure 9: Isopach Map of Sandstone Aquifer

Protective Capacity

Longitudinal conductance of the formation generally ranges from 0.01 – 12.1 mho; 0.01 – 0.04 on the western bloc and 3.59 – 12.1 mho on the eastern block (Figure 10). This range in accordance with the classification scheme of (Oladapo *et al.*, 2004) implied a poor and excellent protective capacity of the western and eastern bloc respectively. The poorly protected western bloc is consequentially highly vulnerable to subsurface contamination due to the absence of impermeable geologic material to seal up the sandstone aquifer. This perhaps could be responsible for the tasty nature of water consumed by the inhabits of the area.

On the otherhand, the eastern bloc is exceptionally a strongly protected environment, if not one of the most protected segment of the the basin. It is absolutely a sequence of impermeable strata immune from subsurface contamination.

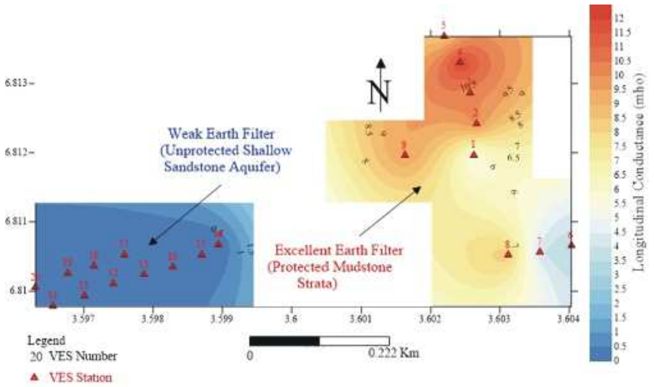

Figure 10: Protective Capacity Map

Coefficient of Anisotropy

An anisotropy coefficient of 1.02 – 2.25 (Figure 11) revealed a fairly moderate degree of inhomogeneity of the formation overlying the basal shale/mudstone stratum; which according (Olorunfemi, 2001) can be directly related to the groundwater yield index. A mean anisotropic coefficient of 1.32 generally classified the formation as a low-yield segment of the basin. Exception within the formation occurred around the eastern margin (VES 15 and 16) of the western bloc, and western part (VES 9) of the eastern part.

Application of anisotropic coefficient is significantly limited to heterogeneity assessment of the formation. At VES 9, the value fundamentally reflected the inhomogeneity of the shale and mudstone intercalations but never a convincing spot for groundwater.

CONCLUSION

Deduced geo-electric parameters from the area revealed

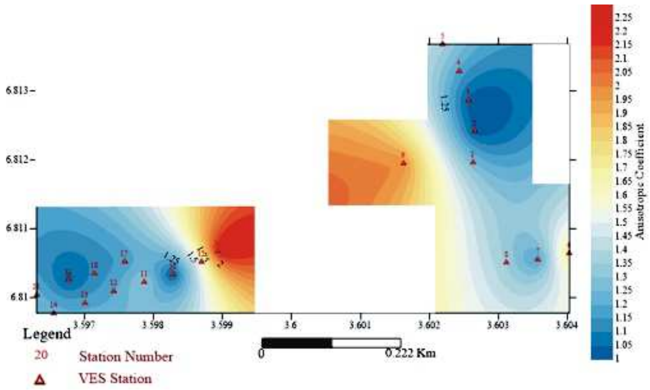

Figure 11: Coefficient of Anisotropy

a confined hydro-stratigraphic setting comprising of a very thick mass of basal shale and mudstone aquitards overlain by a 6.5 m – 37.2 m thick sandstone aquifer, largely characterized by a low groundwater yield. Around the southwestern margin, the aquifer is encouragingly prospective by the virtue of its thickness. However, the shallow stratigraphic position of this unconfined aquifer consequentially implied high vulnerability tendency.

Recommendation

Drilling operations in the area must be carefully preceded by detailed electrical or electromagnetic survey to ascertain the thickness the stratigraphic thickness of the sandstone. Prospecting efforts should be concentrated towards the southwest where appreciable thickness of sandstone can be readily delineated to function as aquifer.

Conflict of Interest

I hereby declare on behalf of the authors that no conflict of interest in the manuscript submitted as the content of the paper is strictly our work from the sourcing of data to analysis and interpretation, also the research is not sponsored by any financial institution, rather we used our personal money for the execution of the project. we got our data by carrying out the various survey using geophysical equipment we hired with our personal money. I will also wish to state here categorically that the paper has not been submitted in any journal institute before now.

The authors have declared no conflict of interest.

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