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Geophysical and Borehole Log Evaluation of Groundwater Prospect in Parts of Lagos State, Southwestern Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author DVO helped in the collection of data and author OMO helped in the analyses and interpretation of data. Both authors read and approved the final manuscript.

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ABSTRACT

Twelve (12) vertical electrical sounding were obtained in parts of Lagos State. Nineteen (19) deep boreholes within the Dahomey basin using resistivity and natural gamma ray wirelogs data were obtained. The vertical electrical sounding obtained were interpreted by WIN resist software. Four layers were obtained from the correlated geo-electric section which are topsoil, sand, clay and sandy clay. The obtained borehole data were interpreted using the surfer 2012 software program. Lithological units and saturation fluids were delineated. The lithological logs showed the fluid contents have various aquifers. The results of the subsurface geophysical investigation carried out within the study area show geo-electric layers characterized by low to moderately high resistivity materials (7-1314) Ωm indicative of sand top soil with thickness ranging from (1.0-2.6) m. The second layer is characterized by low resistivity materials (1.0-34) Ωm, indicative of clay materials with thickness ranging from (5.1-191) m. The last layer is characterized by low to moderately high resistivity (0.4-900) Ωm, indicative of sand materials. The borehole data interpretation result shows

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that the study area is underlain by clays, sandy clays, clayey sand and sand. The clay occurs as lenses within the clay formation. Based on this, five (5) aquifers were delineated in the study area along traverse AB, five (5) aquifers delineated along CD, Six (6) aquifers along EF. One parametric VES and borehole were correlated and it shows the increment of the lithologic units almost at the same depth which allows for the correct interpretation of the subsurface. The sand layer constitutes the major units in the study area while sandy clay and clayey sand constitute the minor aquifer units. This research work revealed that fresh water can be tapped from the entire well in the study area at various depths depending on the area where the well is located.

Keywords: Geoelectric; wire logs; subsurface; lithological logs; aquifers.

1. INTRODUCTION

Groundwater exploration is gaining more and more importance in Nigeria owing to the ever increasing demand for water supplies, especially in areas with inadequate pipe-borne water supplies. Already, ten percent of the world's population is affected by chronic water scarcity and this is likely to rise to one-third by 2015 (WHO, 1996). The water scarcity experienced by the people led to the search for subsurface water supply because the surface waters which occur mostly as rivers are subjected to pollution. Generally, most of the rivers in Nigeria are highly polluted, the pollutants being inadvertently introduced by man via domestic waste, industrial and petroleum exploration activities. Despite the reported favourable groundwater situation in the world, the situation of Nigeria appears to be restricted by the fact that more than half of the country is underlain by sedimentary rocks and these rocks encompasses majorly shale, clays, sandstones and hard crystalline impervious rocks which are either igneous or limestone [1]. The first alternative man has is ground water which may be explained as water in the zone of saturation and from which wells, springs and underground run offs are being supplied. This water is trapped by geological formation [2]. The major problem of groundwater development in coastal environment such as Lagos State is the intrusion of saltwater into freshwater-bearing aquifers [3]. It has become a difficulty for groundwater developers to construct boreholes in areas adjoining the sea and lagoon without encountering saline water [4]. The study area is affected with saline water incursion which reduces the availability of fresh groundwater resources in the coastal aquifers. Due to the dis-uniformity in the groundwater prospect in the study area, it is necessary to carry out this study in order to delineate the depth to the incursion of the saline water, saline-fresh water interface, and the depth viable for groundwater prospect. Groundwater is said to be the most dependable resources to meeting rural water demand in sub-Saharan Africa. Consolidated sediments contain groundwater in the pore spaces of sandstones of fractures and weathered zones within limestone. Unconsolidated sediments occur throughout Africa and groundwater is found within sands and gravels. In many of the world's coastal areas, the sustainability of freshwater is threatened by salt water intrusion, which is the movement of saline water into fresh water aquifers. Groundwater is readily available in Lagos state but salt water incursion has made it very costly, making depth to fresh water/saline water interface at different locations within the state varies from one location to another and it is not well defined. Akinlalu and Afolabi [5] developed a design model for the boreholes located in the Island which includes gravel packing thickness of around 50 m from bottom of the hole and cement grouting to the surface of the borehole to avoid the contamination of the borehole and recommended that water wells be drilled to an approximate depth of 240 m and last 18 m be screened. Most times however groundwater resources are preferable to surface water resources on the basis of easier protection from pollution and better dependability during drought period. Ground water occurs in varied quantities in almost all rock formations. But to meet this requirement in any place, it has to occur in substantial quantity. For the purpose of this work, electrical resistivity method preferably vertical electrical sounding and borehole logs were adopted to investigate the groundwater occurrence in the study area. The aim of this research work is to delineate freshwater aquifers in the study area.

1.1 Location and Geology of the Study Area

The location of this study falls between the Lagos mainland and the Atlantic Ocean [6] involving Oniru, Ikoyi, Apongbon, Lekki, Ajah and Marina (Fig. 1). The Lagos metropolis is a zone of coastal creeks and lagoons [7,8, 9]. The study area falls between Latitude 06^0 25' and 06^0 27', and longitude 003^0 21' and 003^0 33', the area extent is about 502 Km^2. The elevation of the area falls between 13m to 24m above the mean sea level. The area of study is located within the coastal plain and lowland area of the south-western Nigeria with relatively flat but gently undulating terrain. Adegoke et al. [8]) recognized five geomorphologic sub-units in the coastal landscape which are the abandoned beach ridge complex, coastal creeks/lagoons, swamp flats, forested river flood plain and active barrier beach complex. The study area is situated within swampy terrain along the coastal area of Lagos state. The topographic elevation obtained at the suite averaged 45meters above mean Sea level. The location of the study area is within the coastal region of Nigeria with a climate of extensive wet season (April to October) and brief/short dry season (November to march). The average annual/yearly precipitation is in excess of 2000mm and serves as a good source of groundwater recharge/prospect. The area is susceptible to flooding after heavy rainfall during wet season. The geology of the area falls entirely within the Dahomey Basin (Fig. 2). The Dahomey Basin was formed following the break-up of the African and south American plates (Burke et al 1971). The Dahomey basin is partially separated from Niger Delta and the Eastern Nigeria sedimentary basin by a ridge of crystalline rocks. The earliest sediments in the area were deposited as a result of the first major marine transgression in south western in south western Nigeria [10]. The upper sediments in the Dahomey basin are recent. This is underlain by coastal plain sands the Quarternary Age. Basically the geologic sequence in the Dahomey Basin extends from Precambrian to recent. Recent sediments occur along the coastal belt and as alluvial deposits along the major rivers. Recent sediments generally occur as unconsolidated sands, clays and mud along the coastal plain sands otherwise known as the Benin formation was deposited during the late Tertiary-Early Quartenary period. The formation outcrops in the north east of the coastal belt and dips at low angle in the south west [11].

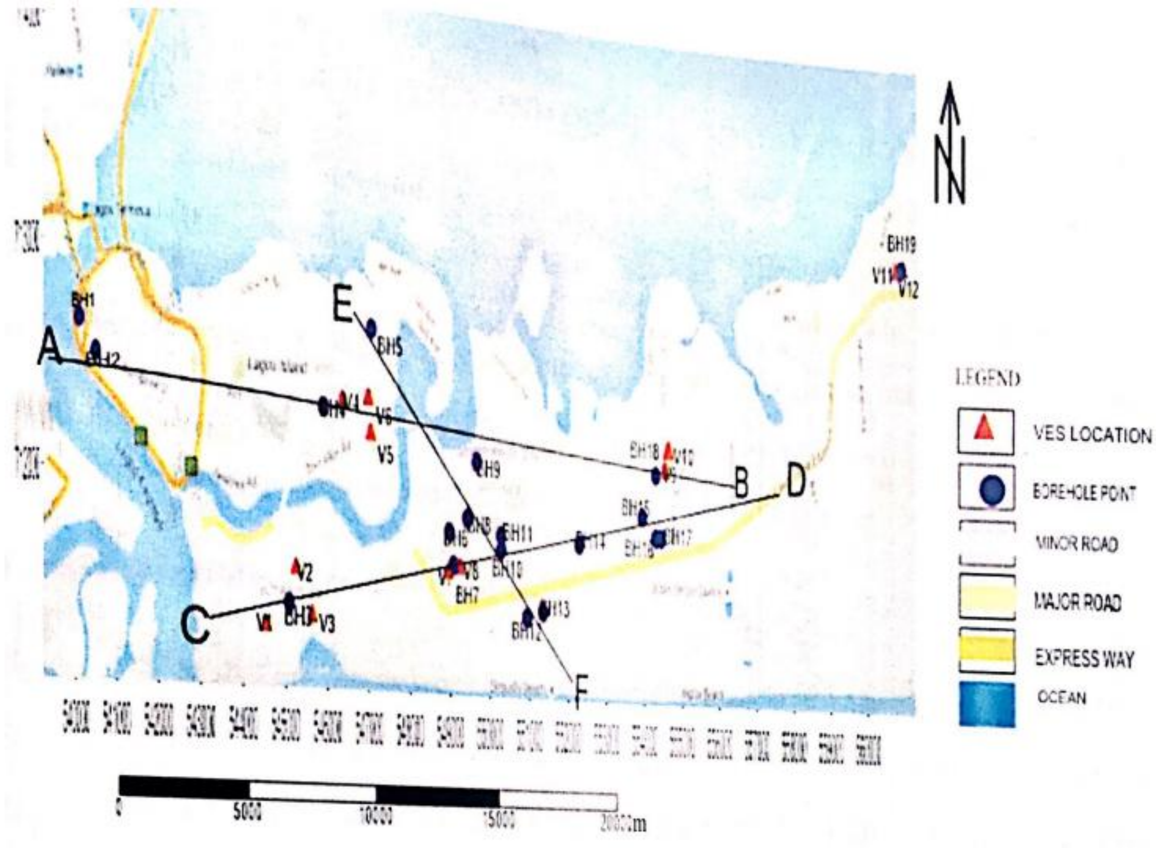

Fig. 1. Location and data map of the study Area (Adopted from Google map)

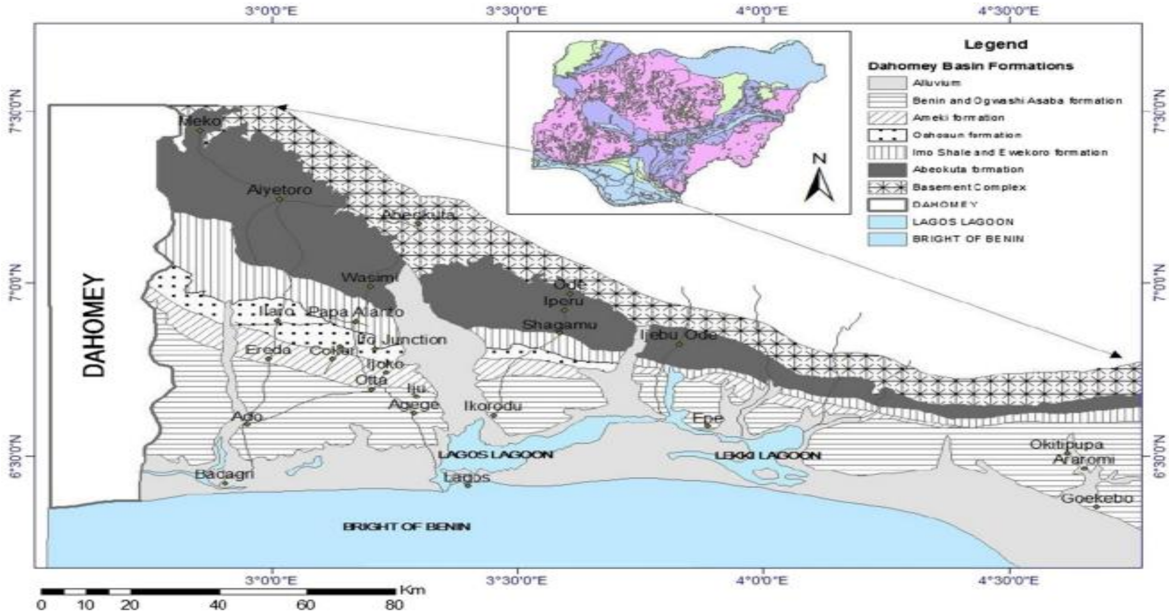

Fig. 2. Geological map of Lagos State (after NGSA 2015)

2. METHODOLOGY

Twelve (12) vertical Electrical sounding stations were occupied. The VES points were selected using random selection due to the large area of study. The VES stations were identified in the study area map as V1, V2...V12. The Schlumberger electrode configuration was adopted with current electrode separation (AB) ranging from a minimum of 2meters to a maximum of 300meters. The vertical electrical sounding data collected were plotted on a log-log graph with the aid of partial curve matching. The apparent resistivity was plotted on the Y-axis while AB/2 was plotted on the abscissa where AB i.e CE is the distance between current electrode A and B. The curves were plotted on the site (qualitative analysis) and interpretation was carried out using a set of master curves. Interpretation was done to determine the resistivity and thickness of each geo-electric layer. Computer iteration was carried out using WIN resist software, from which resistivity models and thickness of various layers were deduced. There are four types of curves that could be produced when plotting which are auxiliary curves K, Q, A and H curves. Combination of these curves are usually produced and used for quantitative interpretation. The data obtained from each station were plotted on a log-log graph paper to obtain a smooth curve for interpretation by manual partial curve matching. The partial curve matching technique involved the matching of successive segments of the field curve by a set of two-layer theoretical schlumberger curves [12]. Output from the quantitative interpretation was modeled using computer iteration. The Resist version 1.0 interpretation software was used for iteration and presentation of the curve. This was done to generate the geoelctric parameters (the layer resistivities and thicknesses) and also their lithologic units. The curves were interpreted qualitatively. Nineteen (19) borehole points were occupied. The logging was done immediately after the wells were drilled. The borehole points are identified in the study area map as BH1, BH2…BH19. The logs used consist of Long Normal (64”) which measures the formation water resistivity; R_w, Short Normal (16”) which measures the formation resistivity and mud filtrate resistivity, Single point Resistance (SPR) and Natural Gamma (NGAM) that identifies formation Lithology. The logs were interpreted to identify lithology encountered in the boreholes, determine saltwater and freshwater interface and delineate freshwater zones and their thicknesses [13, 5]. The field data acquired is through the logger software interface. The acquired data are then digitized using 1.0 m sampling interval after which a digitized log is produced by a computer software called Microsoft Excel. The borehole data were presented in form of graph or digitized logs with the aid of SURFER software program 12 and a computer application software known as Microsoft Excel. These software packages were used to delineate the subsurface geologic units in terms of the various lithologic units encountered in the boreholes. The results obtained were used to access the aquifer units and the general hydro-geologic conditions of the study area.

The borehole data produced as gamma ray data and resistivity data were plotted on log paper and bi-logarithm paper respectively. The geologic profiles for boreholes oriented in the same direction are established along with locations surrounding the boreholes and are denoted as traverses (i.e. A-B, C-D, E-F). Lithology is derived from NGAM log and the corresponding saturating fluids were gotten from the resistivity log. A baseline was drawn on the NGAM log, which is midway between the maximum and minimum NGAM signals. Where there are deflections to the left of the baseline; they are considered as sand. Meanwhile, when there are deflections to the right of the baseline, they are considered as clay. The mathematical expression for calculating the baseline is given as:

$$Baseline = \frac{(maximum\ common - minimum\ common)}{2} + minimum\ common$$

The ELOG and NGAM log are attached in a digitized form. The data was therefore interpreted with the aid of the SURFER 2012 software.

3. RESULTS AND DISCUSSION

Twelve (12) Schlumberger depth sounding points were covered within the study area. The data acquired were presented as sounding curves, geo-electric sections and maps. Table 1 shows the summary of the Vertical Electrical Sounding results in terms of geo-electric properties of the study area. These parameters were used to prepare geo-electric sections. Nineteen (19) boreholes were located within the study area. These borehole data were correlated along three (3) traverses for lithology and the fluids saturating the hole. One parametric VES and borehole log were correlated.

Table 1. Summary of interpreted vertical electrical sounding curves

VES No	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Curve types	Lithology	Fluids present
Agungi1 (V9)	1	27.9	1.2	1.2		Topsoil	Saline Water
	2	2	5.1	6.2	Q	Clay	Saline Water
	3	0.4				Clay	Saline Water
Agungi2 (V10)	1	222.9	1.2	1.2		Topsoil	Fresh Water
	2	59.2	8.9	10.2	QH	sandy Clay	Fresh Water
	3	2.7	191.1	201.3		Clay	Saline Water
	4	23.9	-	-		Clay	Saline Water
Ajah1 (V11)	1	198.3	3.6	3.6		Topsoil	Fresh Water
	2	86.2	40.5	44.1	H	Sand	Fresh Water
	3	162.4				Sand	Fresh Water
Ajah2 (V12)	1	147.3	4.1	4.1		Topsoil	Fresh Water
	2	150.2	0.2	4.3		Sand	Fresh Water
	3	59.7	40	44.3	KH	sandy Clay	Fresh Water
	4	140	-	-		Sand	Fresh Water
Ikoyi1 (V4)	1	119.3	0.5	0.5		Topsoil	Fresh

VES No	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Curve types	Lithology	Fluids present
							Water
	2	814.1	0.8	1.3		Sand	Fresh Water
	3	82.8	19.6	21	KQH	Sand	Fresh Water
	4	16.9	36.8	57.7		Clay	Saline Water
	5	317.2				Sand	Fresh Water
Ikoyi2 (V5)	1	288.5	1.1	1.1		Topsoil	Fresh Water
	2	16.8	9.1	10.3	QH	Clay	Saline Water
	3	1.4	98.1	108.4		Clay	Saline Water
	4	38.5				sandy Clay	Brackish/ Saline
Ikoyi3 (V6)	1	1314.2	1.5	1.5		Topsoil	Fresh Water
	2	201.2	2	3.5	QH	Sand	Fresh Water
	3	3.1	59.6	63.1		Clay	Saline Water
	4	115.7				Sand	Fresh Water
Lekki1 (V7)	1	65	4.1	4.1		Topsoil	Fresh Water
	2	181.9	11	13.4		Sand	Fresh Water
	3	12.5	43.1	56.4	KH	Clay	Fresh Water
	4	911.9				Sand	Saline
Lekki2 (V8)	1	39.1	4.1	4.1		Topsoil	Saline Water
	2	85.3	8.4	12.5		Sand	Fresh Water
	3	14.6	39.8	52.3	KH	Clay	Saline Water
	4	155.2				Sand	Fresh Water
VI1 (V1)	1	99	2.6	2.6		Topsoil	Fresh Water
	2	133.9	2.7	5.4	KH	Sand	Fresh Water
	3	5.1	26.6	32		Clay	Saline Water
	4	43.3				sandy Clay	Brackish Water
VI2 (V2)	1	7.6	2.1	2.1		Topsoil	Saline Water
	2	7	7.2	9.3		Clay	Saline Water
	3	13.7	34.7	44	HQ	Clay	Saline Water
	4	43.1				Sand	Fresh

VES No	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Curve types	Lithology	Fluids present
VI3 (V3)	1	122.1	1.6	1.6		Topsoil	Water Fresh Water
	2	33.8	8.1	9.6	HK	Clay	Saline Water
	3	120.5	17.1	26.8		Sand	Fresh Water
	4	4.3				Clay	Saline Water

3.1 Sounding Curves Section

Fig. 3 shows that the curve types identified ranges from H, Q, HQ, QH, HK, KH and KQH varying from three to five geo-electric layers. The KH curve is the predominant curve type constituting 33.33% of the totals, QH curve type constitutes 25% of the totals, H, Q, HQ, HK, and KQH curve types all constitute 8.33% each.

3.2 Geo-Electric Section

The geo-electric sections across the study are presented in Figs 4 and 5. Basically, four geo-electric layers were delineated beneath these sections. These are topsoil, clay, sandy clay and sand. The topsoil is the first layer. The resistivity values range from (7- 1314.2) Ωm with varying thickness (0.5 – 4.1) m. The topsoil is made of clay/sand layer (Figs. 4 &5). The second layer is characterized by resistivity values (2.0 – 814.1) Ωm with thickness ranging from 0.2-11.0 m. This layer is composed of clay, sandy clay, and sand (Figs. 4&5). The third layer is characterized by resistivity values which range from (3.1 – 162.4) Ωm, with thickness ranging from (17.1 – 191.1) m. This layer is composed of clay, sandy clay, and sand (Figs. 4&5). The last layer is characterized by (4.3 – 911.9) Ωm. The layer is made up of clay, sandy clay, and sand (Figs. 4&5). Two aquifers were delineated and presented in Fig. 6. The first aquifer layers were located at depth ranging from 3m to 24m below the ground level. It has a thickness of 21m with the resistivity varying from 85Ωm to 182Ωm (Fig. 6). The second aquifer layers were located at deeper depth with the resistivity ranging from 155Ωm to 911Ωm (Fig. 6).

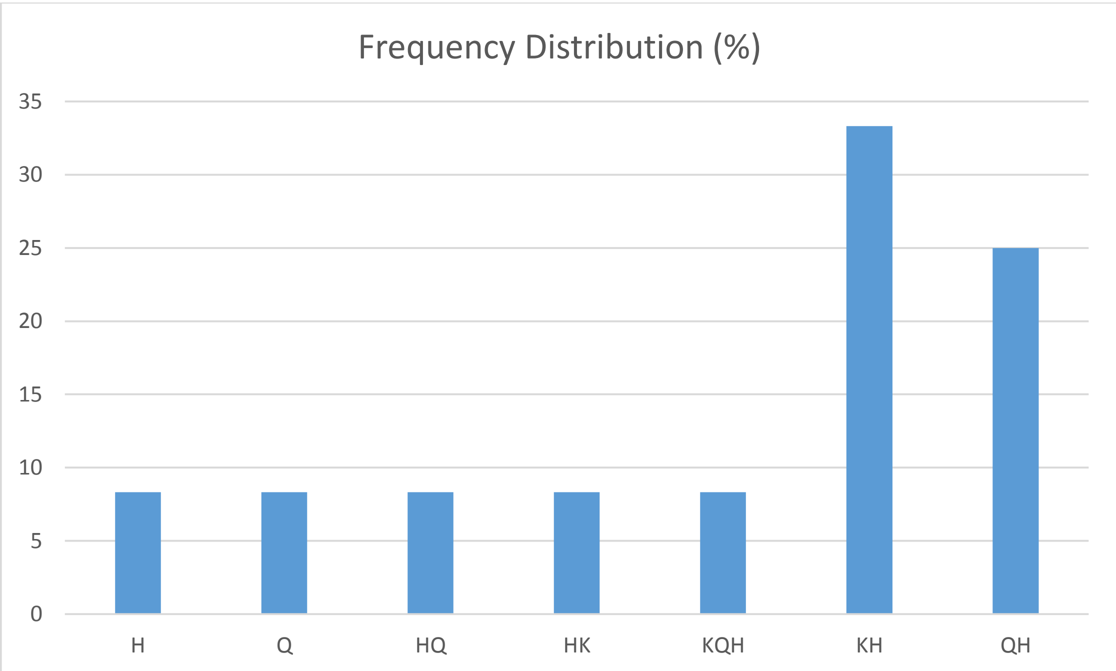

Fig. 3. Frequency distribution chart of observed curve types in the study area

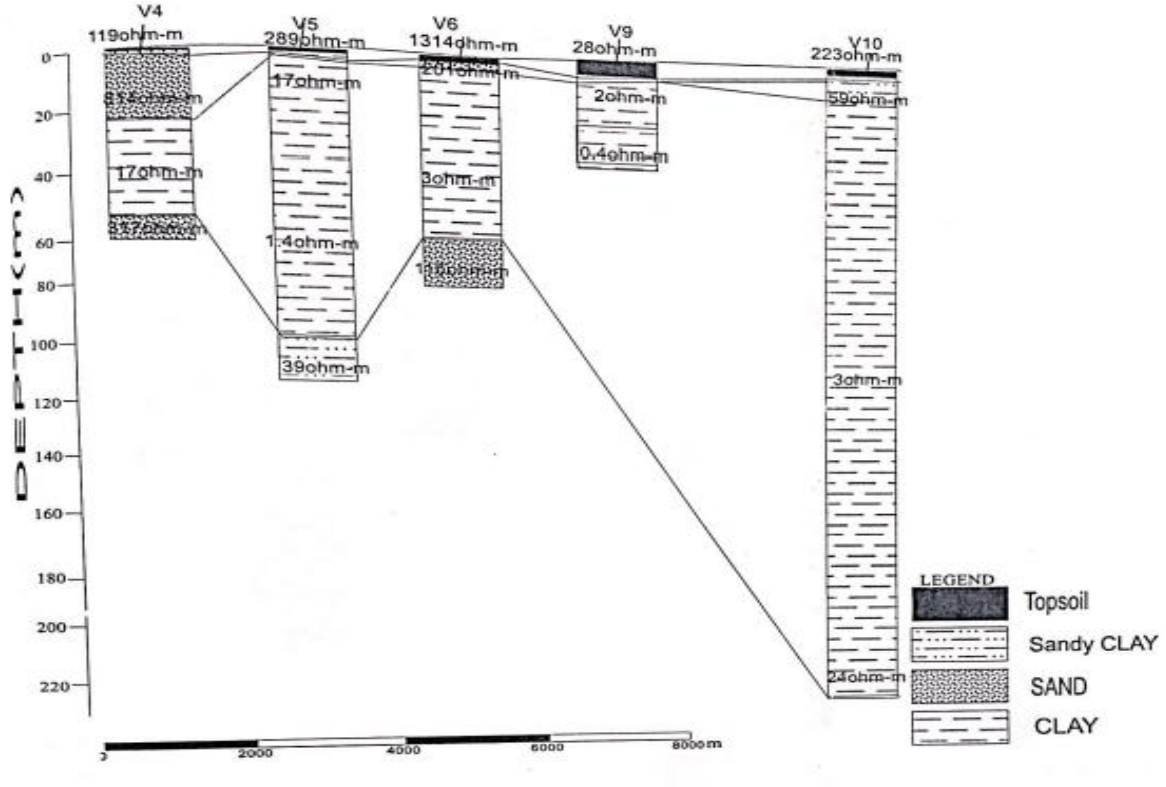

Fig. 4. Geo-electric section along traverse AB

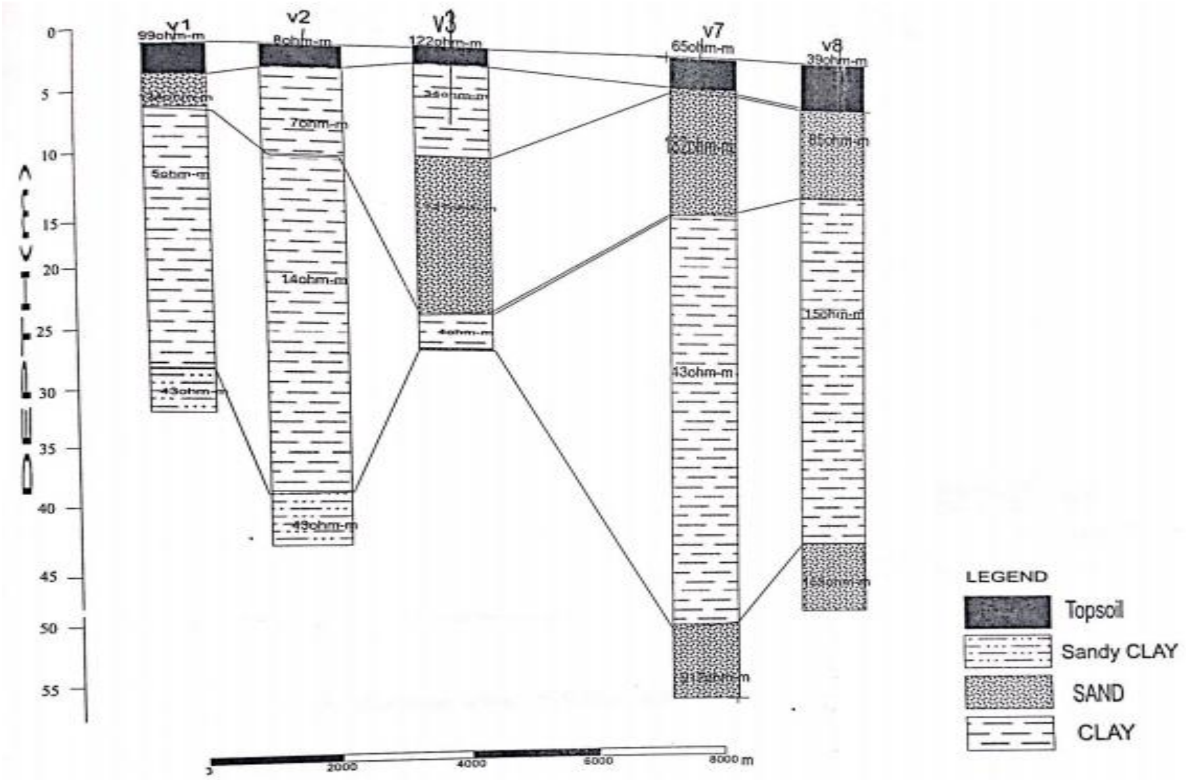

Fig. 5. Geo-electric section along traverse CD

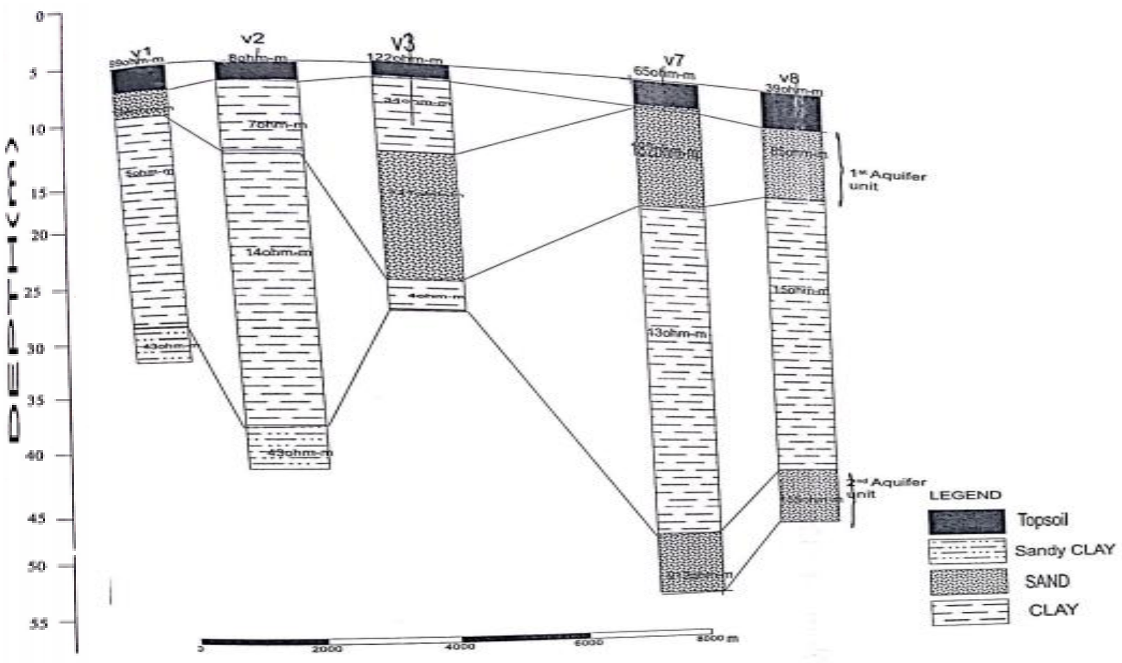

Fig. 6. Geo-electric section showing aquifer units delineated

3.3 Digitized Borehole Logs

The results obtained after the interpretation of the 19 borehole water wells are presented in Tables 2 – 4 which include information on the water bearing sands, the depth at which they occur, their resistivity and the different lithology for each well. Generally, the Lithology of the boreholes formation consists of sand, clay, clayey sand and sandy clay. The sand occurs as lenses within the clay formation and the clay occurring as lenses within the sand formation. In delineating the lithological units using the Natural gamma ray log, the shale baseline was calculated to be 50API. The deflection to the left of the shale baseline depicts sand while the deflection to the right depicts clay. The gamma ray values for sand, sandy clay, clayey sand and clay are 0≤25 API, ≥25≤50 API, ≥50≤75 API and ≥75≥100 API respectively. The major fresh, saline, and brackish water aquifer was identified in the log by using resistivity values ranging from 0≤80Ωm for saline water, ≥80≤100Ωm for brackish water and ≥100Ωm for fresh water. Table 2-4 illustrates the summary of the water bearing sands depth in the study area. *Along A-B axis, BH1 varies from 14 to 20m, 67 to 78m, 88 to 97m, 118 to 120m, 123 to 127m, 129 to 145m and 161 to 176m; BH2 varies from 13 to 28m, 60 to 64m, 74 to 88m, 90 to 114m, 121 to 144m, 148 to 154m, 160 to 166m and 172 to 190m; BH4 varies from 18 to 30m, 58 to 64m, 72 to 86m, 92 to 164m, 168 to 196m, 206 to 210m and 216 to 235m whileBH18 varies from 9 to 26m, 85 to 118m, 125 to 164m, 170 to 192m and 206 to 228m. Along C-D axis, BH3 varies from 10 to 22m, 30 to 52m, 58 to 70m, 72 to 96m, 136 to 144m, 148 to 198m and 202 to 237m; BH7 varies from 16 to 26m, 32 to 36m, 58 to 94m, 90 to 104m, 106 to 160m, 162 to 164m, 166 to 168m, 179 to 196m and 204 to 247m; BH10 varies from 8 to 40m, 53 to 54m, 56 to 69m, 70 to 82m, 88 to 116m, 118 to 140m, 148 to 140m, 148 to 172m, 192 to 194m and 200 to 225m; BH15 varies from 9 to 26m, 85 to 118m, 125 to 164m, 170 to 192m and 206 to 228m while BH14 varies from 12 to 38m, 124 to 142m, 143 to 168m, 190 to 192m and 198 to 206m. Along E-F axis, BH5 varies from 8 to 20m, 22 to 24m, 46 to 62m, 119 to 156m, 158 to 162m, 172 to 182m and 192 to 216m; BH8 varies from 8 to 26m, 34 to 40m, 125 to 132m, 144 to 150m, 156 to 164m, 168 to 170m and 174 to 190m; BH10 varies from 8 to 40m, 53 to 54m, 56 to 69m, 70 to 82m, 88 to 116m, 118 to 140m, 148 to 140m, 148 to 172m, 192 to 194m and 200 to 225m while BH12 varies from 16 to 34m, 88 to 102m, 104 to 120m, 124 to 152m, 154 to 158m, 160 to 162m and 164 to 191m.*

Table 2. Summary of water bearing sands and their Resistivity range for correlated well along A-B

S/N	Aquifers	Depth	Thickness (M)	Resistivity (Ωm)	Fluid
Marina (BH1)	1	14-20	6	≥80≤100	Brackish water
	2	67-78	11	≥80≤100	Brackish water
	3	88-97	5	≥80≤100	Brackish water
	4	118-120	2	≥80≤100	Brackish water
	5	123-127	5	≥100	Fresh water
	6	129-145	16	≥100	Fresh water
	7	161-176	15	≤80	Fresh water
BatoChem (BH2)	1	13-28	15	≤80	Saline water
	2	60-64	4	≤80	Saline water
	3	74-88	14	≤80	Saline water
	4	90-114	24	≤80	Saline water
	5	121-144	23	≥80≤100	Brackish water
	6	148-154	6	≥100	Fresh water
	7	160-166	6	≥100	Fresh water
	8	172-190	18	≥100	Fresh water
Seagate (BH4)	1	18-30	12	≤80	Saline water
	2	58-64	6	≤80	Saline water
	3	72-86	6	≤80	Saline water
	4	92-164	4	≤80	Saline water
	5	168-196	28	≥100	Fresh water
	6	206-210	4	≥100	Fresh water
	7	216-235	19	≥100	Fresh water
Arcadia (BH18)	1	08-26	17	≤80	Saline water
	2	85-118	33	≤80	Saline water
	3	125-164	39	≤80	Saline water
	4	170-192	22	≥100	Fresh water
	5	206-228	22	≥100	Fresh water

Table 3. Summary of water bearing sands and their Resistivity range for correlated well along C-D

S/N	Aquifers	Depth(m)	Thickness (m)	Resistivity (Ωm)	Fluid
Atlantic (BH3)	1	10-22	12	≤80	Saline water
	2	30-52	22	≤80	Saline water
	3	58-70	12	≤80	Saline water
	4	72-96	24	≤80	Saline water
	5	136-144	8	≥100	Fresh water
	6	148-198	8	≥100	Fresh water
	7	202-237	35	≥100	Fresh water
Yetville (BH7)	1	18-26	8	≤80	Saline water
	2	32-36	4	≤80	Saline water
	3	58-94	32	≤80	Saline water
	4	90-104	14	≤80	Saline water
	5	106-160	54	≤80	Saline water
	6	162-164	2	≥100	Fresh water
	7	166-168	2	≥100	Fresh water
	8	170- 196	26	≥100	Fresh water
	9	204-247	43	≥100	Fresh water
Okunde (BH10)	1	8-40	32	≥100	Fresh water
	2	53-54	1	≤80	Saline water
	3	56-69	13	≤80	Saline water
	4	70-82	12	≤80	Saline water

S/N	Aquifers	Depth(m)	Thickness (m)	Resistivity (Ωm)	Fluid
	5	88-116	28	≤80	Saline water
	6	118-140	22	≤80	Saline water
	7	148-172	24	≤80	Saline water
	8	192-194	2	≥100	Fresh water
	9	200-225	25	≥100	Fresh water
Vestril (BH15)	1	8-26	17	≤80	Saline water
	2	85-118	33	≤80	Saline water
	3	125-164	39	≤80	Saline water
	4	170-192	22	≥100	Fresh water
	5	206-228	22	≥100	Fresh water
Murphy (BH14)	1	12-38	26	≥80≤100	Brackish water
	2	56-60	4	≤80	Saline water
	3	124-142	18	≤80	Saline water
	4	143-168	25	≤80	Saline water
	5	190-192	2	≥100	Fresh water
	6	198-206	8	≥100	Fresh water

Table 4. Summary of water bearing sands and their Resistivity range for correlated well along along E-F

S/N	Aquifer	Depth (M)	Thickness (M)	Resistivity (Ωm)	Fluid
Onikoyi (BH5)	1	8-20	12	≤80	Saline water
	2	22-44	22	≤80	Saline water
	3	46-62	18	≤80	Saline water
	4	119-156	37	≤80	Saline water
	5	158-162	4	≥80≤100	Brackish water
	6	172-182	10	≥80≤100	Brackish water
	7	192-216	24	≥100	fresh water
Oniru (BH8)	1	8-26	18	≤80	Saline water
	2	34-40	6	≤80	Saline water
	3	125-132	7	≤80	Saline water
	4	144-150	6	≤80	Saline water
	5	156-164	8	≤80	Saline water
	6	168-170	2	≥100	fresh water
	7	174-190	16	≥100	Fresh water
Okunde(BH10)	1	8-40	32	≤80	Saline water
	2	53-54	1	≤80	Saline water
	3	56-69	13	≤80	Saline water
	4	70-82	12	≤80	Saline water
	5	88-116	2	≥100	Saline water
	6	148-172	24	≥100	Saline water
	7	192-194	2	≥100	Fresh water
	8	200-225	25	≥100	Fresh water
Palmspring (BH12)	1	16-34	18	≤80	Saline water
	2	88-102	14	≤80	Saline water
	3	104-120	16	≤80	Saline water
	4	124-152	28	≥80≤100	Brackish water
	5	154-158	4	≥80≤100	Brackish water
	6	160-162	2	≥80≤100	Brackish water
	7	164-191	27	≥100	Fresh water

3.4 Boreholes Correlated along the Sections Generated

The correlated boreholes along the sections (Figs. 11 – 13) delineated four aquifers. The first aquifer is sand having resistivity range of 0 - 80Ωm with thickness ranging from 8 – 60m indicative of saline water (Figs. 11 – 13). The second aquifer has resistivity values ranging from 80 - 100Ωm with thickness ranging from 30

– 170m indicative of saline/brackish water sand (Figs. 11 – 13). The third aquifer section AB has resistivity value above 0 - 80Ωm indicative of saline/brackish water while CD and EF has resistivity value above 100Ωm indicative of fresh water sand (Figs. 11 – 13). The fourth aquifer has resistivity value above 100Ωm indicative of the fresh water sand (Figs. 11 – 13). Generally, the third aquifer along sections CD and EF can be recommended as a groundwater prospect evaluation. Also the fourth aquifer along AB is best for groundwater prospect.

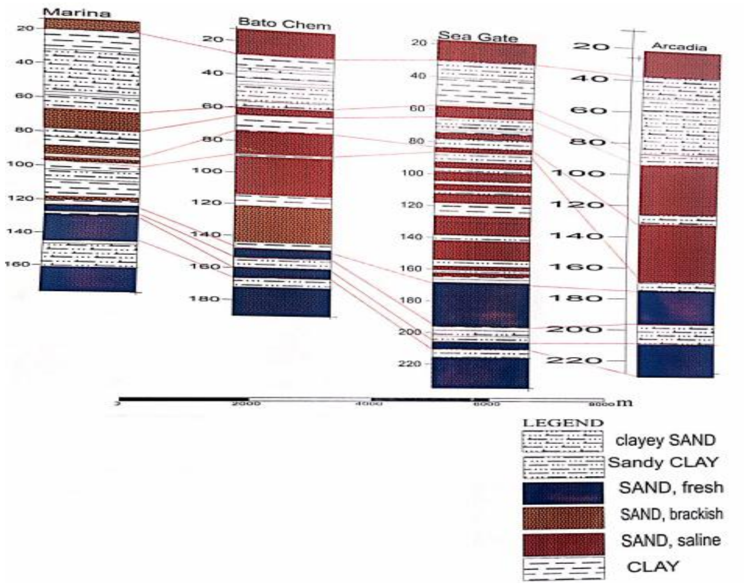

Fig. 7. Correlated Borehole Logs for section AB

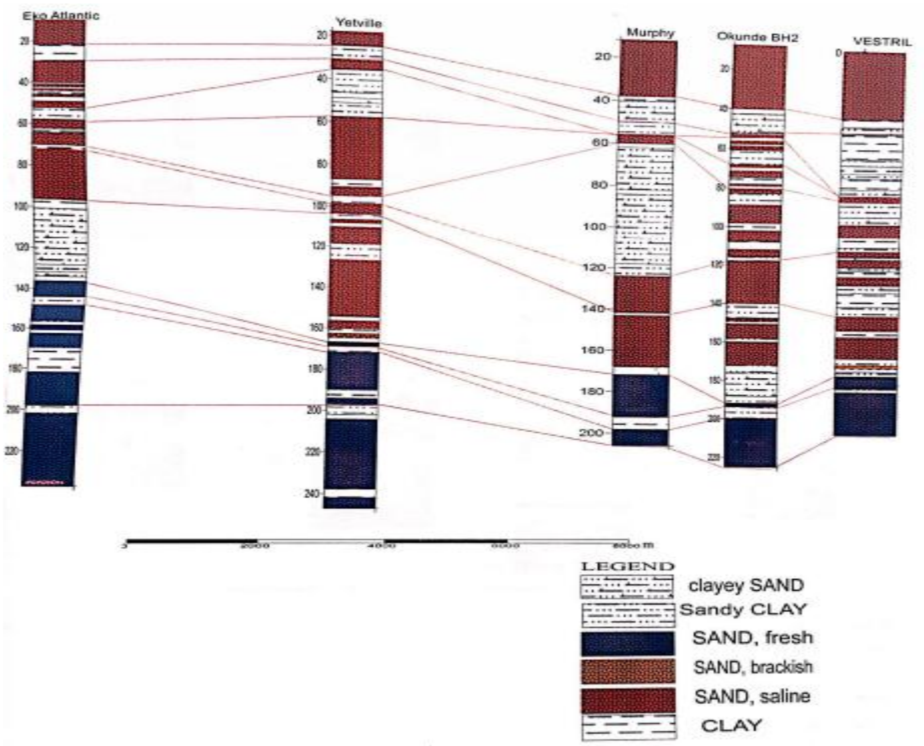

Fig. 8. Correlated Borehole Logs for section CD

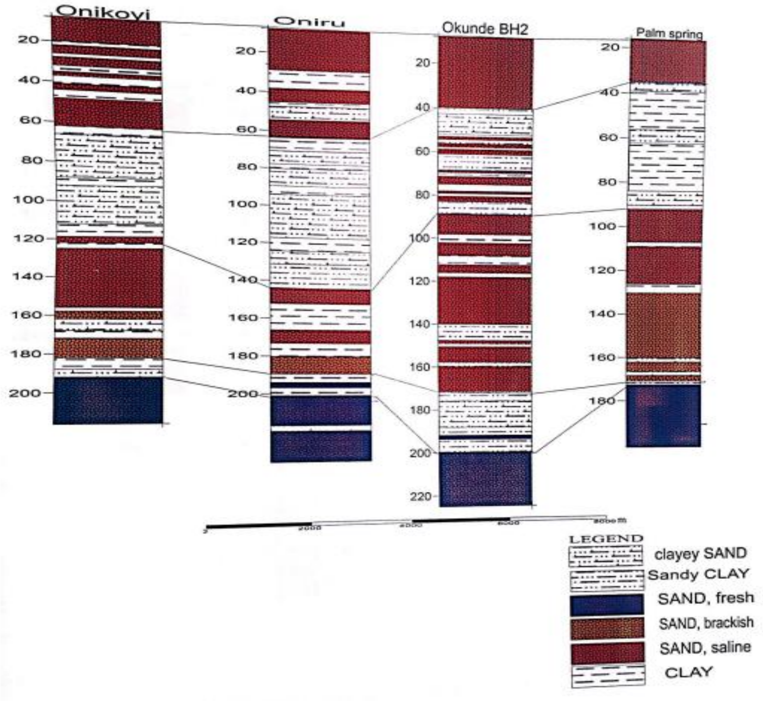

Fig. 9. Correlated Borehole Logs for section EF

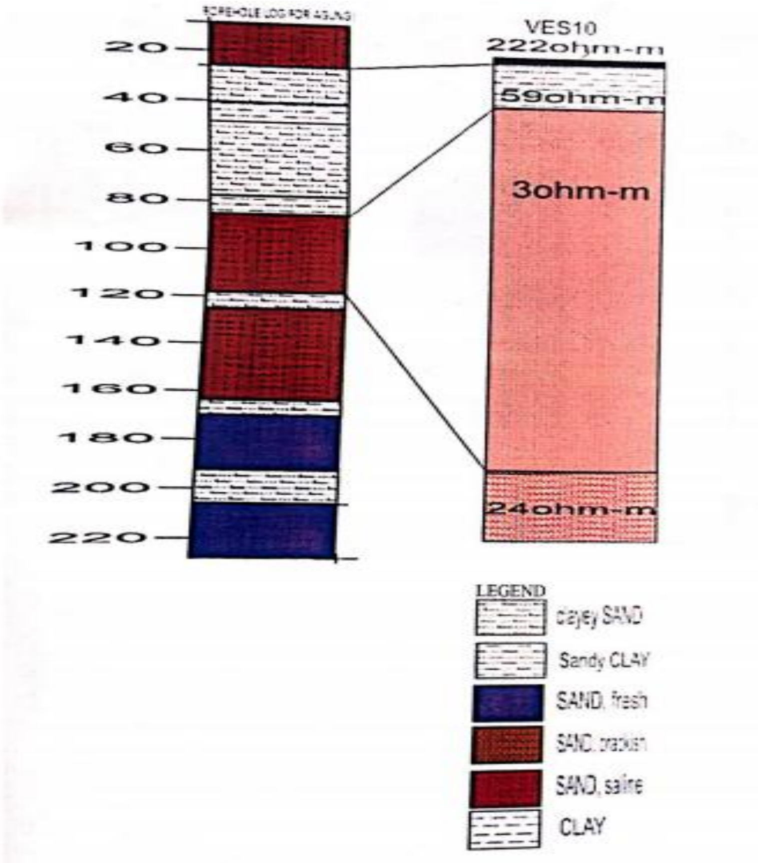

Fig. 10. Correlated parametric Borehole Log and VES 10 for Agungi (Arcadia)

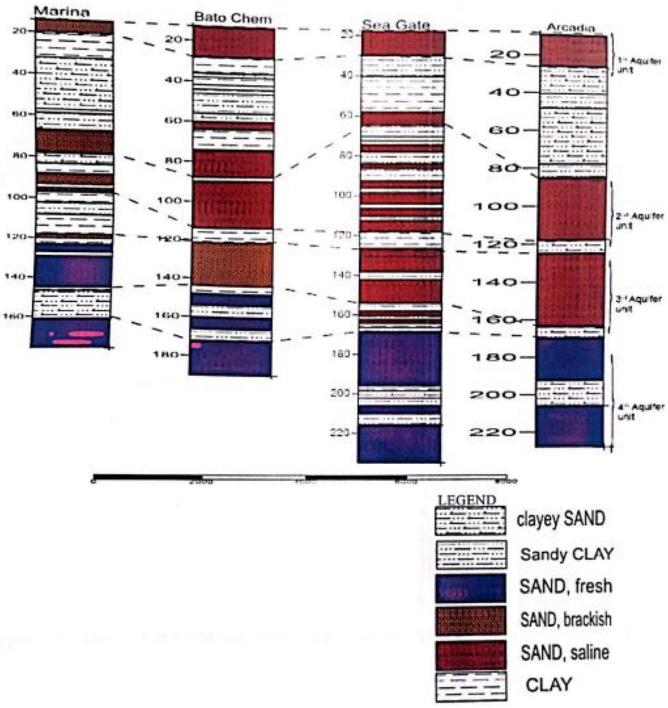

Fig. 11. Borehole Correlation showing delineated aquifer units along section AB

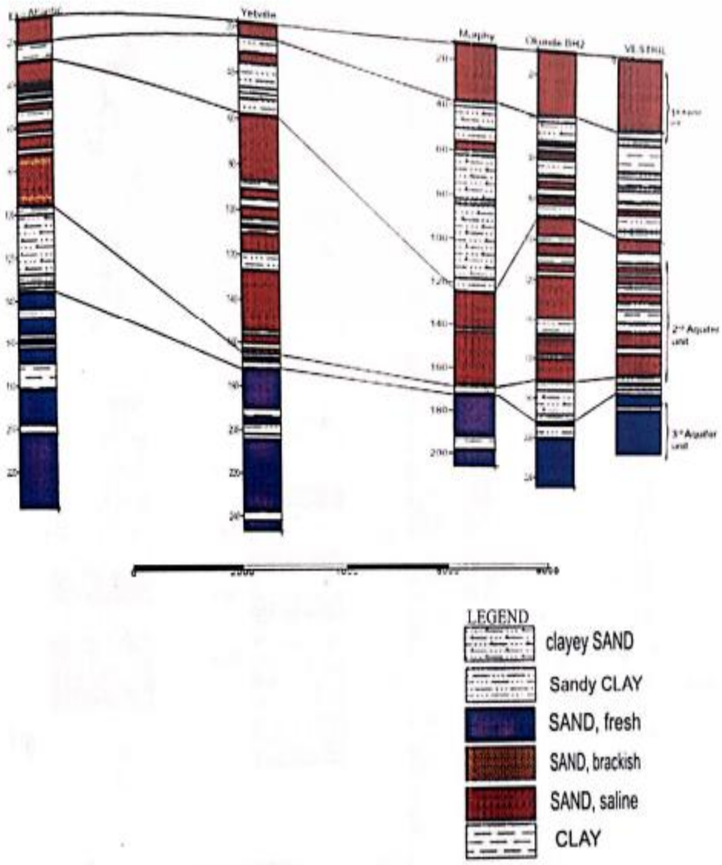

Fig. 12. Borehole Correlation showing delineated aquifer units along section CD

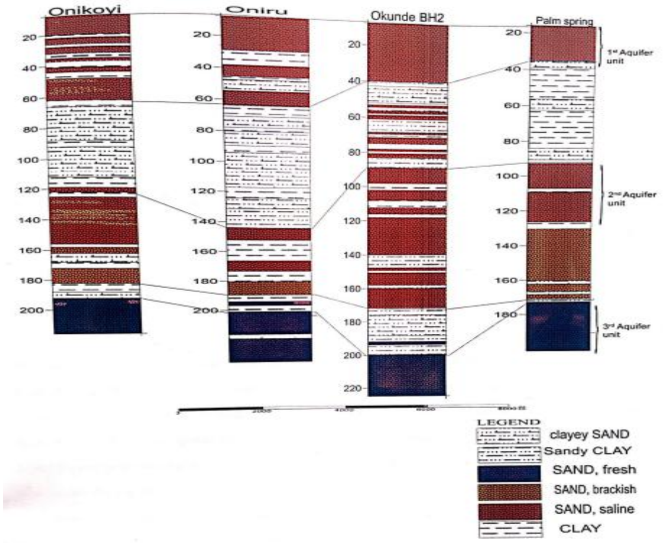

Fig. 13. Borehole Correlation showing delineated aquifer units along section EF

4. CONCLUSIONS

Vertical electrical sounding and geophysical borehole logs were deployed in the coastal area of Lagos State in order to evaluate the groundwater prospect in the area. The geophysical investigation involving the Vertical Electrical Sounding (VES) was done. The Schlumberger configuration was adopted complemented with borehole logs. Twelve (12) Vertical Electrical Sounding and Nineteen (19) borehole logs were obtained within the study area. This was done to delineate freshwater aquifer in the study area. The vertical electrical sounding obtained were interpreted by WIN resist software. Four geo-electric layers were delineated beneath these sections. These are the topsoil, clay, sandy clay and sand. The topsoil is the first layer. The resistivity values from 7- 1314.2 Ωm with varying thickness 0.5 – 4.1m. The topsoil is made of clay/sand layer. The second layer is characterized by resistivity values 2.0 – 814.1 Ωm with thickness ranging from 0.2- 11.0 m. This layer is composed of clay, sandy clay, and sand. The third layer is characterized by resistivity values which range from 3.1 – 162.4Ωm, with thickness ranging from 17.1 – 191.1m. This layer is composed of clay, sandy clay, and sand. The last layer is characterized by 4.3 – 911.9 Ωm. The layer is made up of clay, sandy clay, and sand. The borehole logs were interpreted in terms of lithological units and saturating fluids using the gamma ray logs and resistivity logs respectively. The aquifer units depicted along section AB, CD, EF were four, three, and three aquifers respectively. The first aquifer is sand having resistivity range of 0 - 80Ωm with thickness ranging from 8 – 60m indicative of saline water. The fourth aquifer has resistivity value above 100Ωm indicative of fresh water sand. Generally, the third aquifer along sections CD and EF can be recommended as a good groundwater prospect evaluation. Also the fourth aquifer along AB is best for groundwater prospect. It can be concluded that geophysical and borehole log have been used to evaluate the groundwater prospect within the investigated area.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Offodile ME. The Occurrence and Exploration of Groundwater in Nigeria Basement Rocks. J. Mining and Geology. 1983;20(1&2):131-146.
2. Palacky GJ, Ritsema IL, De Jong SJ. Electromagnetic Prospecting for Groundwater in Precambrian Terrains in the Republic of Upper Volta. Geophy. Prospect. 1981;29:932-955.

3. Adeoti L, Alile OM, Uchegbulam O. Geophysical investigation of saline water intrusion into freshwater aquifers: A case study of Oniru, Lagos State. Sci Res Essays. 2010;5(3):248–259.
4. Oladapo MI, Ilori OB, Adeoye-Oladapo OO. Geophysical study of saline water intrusion in Lagos municipality. Afr J Environ Sci Technol. 2014;8(1):16–30.
5. Akinlalu AA, Afolabi DO. Borehole depth determination to freshwater and well design using geophysical logs in coastal regions of Lagos, southwestern Nigeria. Applied Water Science. 2018;8:152.
6. Longe EO, Malomo S, Olorunniwo MA. Hydrogeology of Lagos metropolis. Afr J Earth Sci. 1987;6(2):163–174.
7. Pugh JC. A classification of the Nigerian coastline. J West Afr Sci Assoc. 1954;4(3):1–12.
8. Adegoke OS, Ako BD, Enu EI, Afonja AA, Ajayi TR, Emofurieta WO et al. Geotechnical investigations of the ondo state bituminous sands—volume I: geology and estimate. Geological Consultancy Unit, Department of Geology, University of Ife, Nigeria (Unpublished); 1980.
9. Adepelumi AA, Olorunfemi MO, Falebita DE, Bayowa OG. Structural mapping of coastal plain sands using engineering geophysical techniques, Lagos Nigeria case study. J Nat Sci. 2009;1:2.
10. Kogbe CA. The upper cretaceous abeokuta formation of south-western abeokuta formation of south-western Nigeria. Nigerian Field. 1974;4:4.
11. Offodile ME. An Approach to Groundwater Study and Development in Nigeria. Mecon Geology and Engineering Services Ltd., Jos; 1992.
12. Orellana E, Mooney HM. "Master Tables and Curves for Vertical Electrical Sounding over Layered Structures". Inteciencis, Madrib; 1966.
13. Kwader T. The use of geophysical logs for determining formation water quality. Ground Water. 1986;24:11–15.

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