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HYDROGEOPHYSICAL EVALUATION OF SALTWATER IN SOME COMMUNITIES ALONG BENIN RIVER

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ABSTRACT

Fresh water can be found in salt water environment. The search for potable water in communities [Koko, Obonteghareda, Ebokiti, Bateren, Ogborode (Escravos Beach), Otunla, Daleketa and Ogbaghoro] along Benin River surrounded by saline water environment inspired this research. The research was done in eight communities but detailed work was on six communities. Development of the fresh water aquifer has not been encouraged in these areas because of the technical problems involved. Vertical Electrical Sounding (VES) is a technique for locating ground water and is quite effective for hydro-geophysical evaluations. VES was conducted with Schlumberger array using ABEM 1000 Terra-meter in the area. Field data were interpreted using the IP12WIN software in eight communities in the study area. This research has proved, these areas have fresh water surrounded by saline water. A total of 18 VES in each community were carried out using the Schlumberger spread of 1m-1000m.The results obtained showed the presence of saltwater in Benin River with low resistivity of 4 – 1670Ωm. Results are between four to seven geo-electric layers made up of sand, sandy-clay and clayey-sand. The derived geo-electric sections from VES curves showed the presence of freshwater in the saltwater environment.

INTRODUCTION

Salt water is defined as water that contains significant amount of dissolvedsodium chloride (NaCl), the concentration is expressed in parts per million (ppm) of salt. In this case, the concentration is the amount (by weight) of salt in water, as expressed in "parts per million" (ppm). If water has a concentration of 10,000 ppm of dissolved salts, then one percent of the weight of the water comes from dissolved salts. The salinity concentration level used by United States GeologicalUSGS (2008) Survey classifies saline water in three categories. Slightly saline water contains abound 1,000 to 3,000 ppm, moderately saline water contains about 3,000 to 10,000 ppm and highly saline water has abound 10,000 to 35,000 ppm of salt. Seawater has a salinity of about 35,000 ppm, equivalent to 35 g/L, (http://en.wikipedia.org/wiki/Saline_water).

Fresh water is naturally occurring water on the earth's surface in ice sheets, ice caps, glaciers, bogs, ponds, lakes, rivers and streams, and underground as groundwater in aquifers and underground streams. Fresh water is generally characterized by having low concentrations of dissolved salts and other total dissolved solids (http://en.wikipedia.org/wiki/Fresh_water).Field trips were made to different riverine communities: Koko, Obonteghareda, Obaghoro, Daleketa, Otunla, Bateran, Ebokiti, Ebrohomi (Benin Rivers). These areas are saline water environment. This research is to search for possible fresh water aquifer in these localities. Fresh water and salt water has a lot to do in the lives of fishes, organisms that live in water, animals that live in water and even human beings that live in such locations. Terrameter was used in acquiring the data. The main aim of this research was to locate fresh water in salt water environment and suggest a solution on how people around such vicinity can have good water. In doing this the lithology of the area was studied, and how the locations were evenly distributed. This was done by generating the geological base map.

The Communities within the studied area are accessible through the rivers, creeks and creeklets as shown in the map (Figure 1). The area lies within the equatorial climate region in southern Nigeria (Niger Delta). Temperature and humidity are high with low annual range of temperature. Rainfall nearly all year round with a high annual total of over 1500mm. The area is influenced by the North-east and South-west winds which influence the climate of Nigeria. (Egwebe *et al* 2003).

This formation which comprises chiefly sand and clay directly overlies the Benin formation which constitutes vast and elaborate aquifer of the Niger delta basins of southern Nigeria. This area possesses the typical geology of the Niger Delta's three subsurface stratigraphic units. These three formations were laid down under the continental, transitional and marine environments respectively. It is underlain by the continental sands of the Benin formation. The geology of the Niger Delta has been extensively described by several authors including, (Etu-Efeotor *et al*1990), (Short *et al* 1967), (Asseez, 1979). The subsurface sedimentary sequence has been subdivided into three stratigraphic units -the Benin, Agbadaand Akata formations (Akomenu, 1983). The Benin formation consists of sand, gravely sand, sandy clay and clay intercalations. The formation is known for its high aquifer potential. The lithological units of this area are generally composed of sands and clayey sand.

The Niger Delta (75,000km^2) comprises a thick (up to 9000m) sequence of clastic sediments subdivided into the Akata, Agbada and Benin Formations in ascending order, (Allen,1965). Sands of the Benin Formation constitute aquifers which have been exploited for water supply, although in parts of the delta many of them have been abandoned due to high salinity. Interpretation of 267 oil well logs for delineating the fresh water-bearing aquifers is reported here (Oteri, 1983). While fresh water sands occur at the upper zone of the Benin Formation in most places, saline water sands were found at the upper zone at depths (ranging from 30 to 947m) in two well-defined areas, underlain by fresh water sands. The saline water is thought to be connate. The fresh water/saline water interface has been mapped throughout the eastern Niger Delta and is found to be deepest (2237 m) 44 km west southwest of Port Harcourt, (Oteri,1988)

In terms of hydrogeology, the water table in the Niger Delta is very close to the ground surface ranging from 0-9m below the ground level. The aquifer in this area obtains steady recharge by direct precipitation, though some proportion of the rainfall is lost by runoff and evapotranspiration, Egwebe and Ifedili (2004). Freshwater and seawater come in contact with each other. The constant mixing implies that during both the dry season and the rainy season, the region is drained by several groundwater types resulting from water mixing. (Egwebe, 2004)

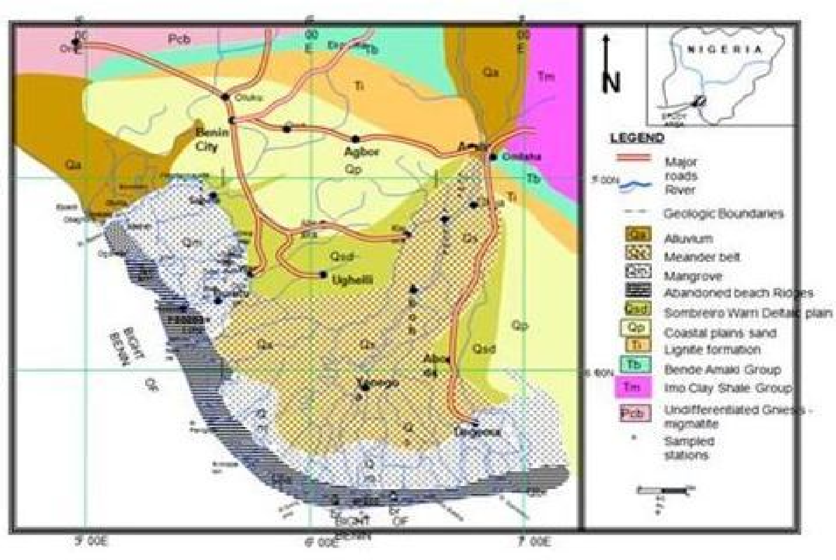


Fig 1: Map of study area showing sampled areas and geology

METHODOLOGY

Freshwater and seawater come in contact with each other, and the constant mixing implies that during both the dry season and the rainy season, the region is drained by several groundwater types resulting from water mixing. Two major types of resistivity survey can be distinguished. The electrical profiling and vertical electrical sounding or depth probing of the earth is homogenous, the resistivity measured is called the true resistivity or apparent resistivity. This shows various formations having weighted average of resistivity. The electrical resistivity method is used, due to high resolution power in respect of the particular problem encountered in prospecting for freshwater. However electrical method can provide data on water quality, which is one of the reasons why electrical method have been so successful in ground water exploration, with vertical electrical sounding being the most used electrical method, because it enables qualitative interpretation of measured apparent resistivity data to be made

VERTICAL ELECTRICAL SOUNDING (VES)

In VES, the aim is to observe the variation of resistivity with depth. It is the use of electrical method with depth control; in which electrode spacing is increased to obtain information from greater depth at given surface location. It is used for detecting changes in the resistivity of the earth with depth beneath the given location. It is also used to determine the resistivity of flat lying layers of rock structures like sedimentary beds or depths of water table. The principles of the VES are based on the fact that the wider the current electrode separation, the deeper the current penetration. As such, the apparent resistivity values observed at large separation are governed by the resistivity of the deeper layer. Eighteen vertical electrical sounding were carried out in eight different locations using Schlumberger array with maximum electrode spacing of 681m.

RESULTS AND DISCUSSION

Measurements from the different field.

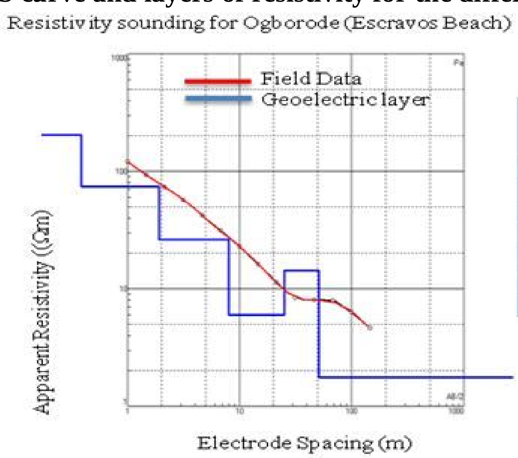
Table 1: Measurements recorded from Koko, Obontegareda, Obaghoro, Daleketa, Otunla fields

koko		Obonteghareda		Obaghoro		Daleketa		Otunla	
AB/2	ρ_a	AB/2	ρ_a	AB/2	ρ_a	AB/2	ρ_a	AB/2	ρ_a
1	4510	1	1360	1	3010	1	866.85	1	2.05
1.47	4350	1.47	1160	1.47	2720	1.47	724.04	1.47	1.76
2.15	4010	2.15	819.11	2.15	2150	2.15	483.9	2.15	1.34
3.16	3480	3.16	423.55	3.16	1320	3.16	214.17	3.16	0.916
4.64	2870	4.64	157.5	4.64	560.1	4.64	53.03	4.64	0.622
6.81	2310	6.81	47.8	6.81	139.24	6.81	5.21	6.81	0.493
10	1710	10	13.12	10	30.57	10	1.27	10	0.495
14.7	1060	14.7	4.5	14.7	9.06	14.7	0.799	14.7	0.594
21.5	573.5	21.5	2.44	21.5	4.45	21.5	0.939	21.5	0.79
31.6	333.75	31.6	2.27	31.6	3.19	31.6	1.03	31.6	1.08
46.4	288.49	46.4	2.28	46.4	2.73	46.4	1.18	46.4	1.52
68.1	307.4	68.1	2.6	68.1	2.67	68.1	1.46	68.1	2.14
100	360	100	3.37	100	2.89	100	1.95	100	3.06
147	431.75	147	4.68	147	3.39	147	2.65	147	4.34
215	497.99	215	6.59	215	4.26	215	3.66	215	6.06
316	539.73	316	9.28	316	5.68	316	5.04	316	8.34
464	541.29	464	12.34	464	7.33			464	11.23
681	507.46								

Table 2: Measurements recorded from Bateran, Ebokiti, Ebrohimi fields

Bateran		Ebokiti		Ebrohimi	
AB/2	ρ_a	AB/2	ρ_a	AB/2	ρ_a
1	1670	1	1350	1	1147
1.47	1560	1.47	1040	1.47	995.53
2.15	1350	2.15	605.17	2.15	732.76
3.16	1030	3.16	209.83	3.16	431.41
4.64	656.54	4.64	40.58	4.64	100.45
6.81	338.74	6.81	5.02	6.81	75.76
10	180.36	10	2.16	10	24.14
14.7	93.99	14.7	1.68	14.7	8.52
21.5	40.94	21.5	1.44	21.5	4.06
31.6	10.4	31.6	1.18	31.6	2.55
46.4	3.05	46.4	1.3	46.4	2.35
68.1	1.9	68.1	1.69	68.1	2.62
100	2.35	100	2.37	100	3.25
147	3.34	147	3.25	147	4.45
215	4.77	215	4.46	215	6.45
316	6.83	316	6.16	316	9.09
464	9.59	464	8.42	464	12.93
681	13.16	681	11.32		

VES curve and layers of resistivity for the different fields

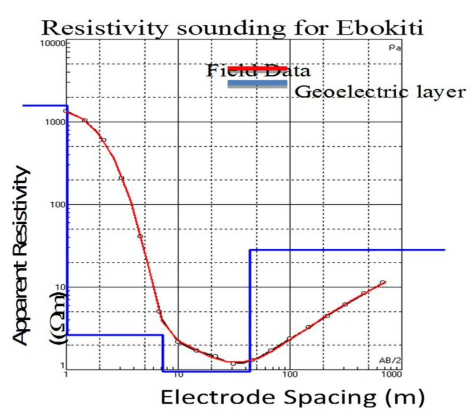


Ogborode (Escravos Beach)

N	ρ	h	d	Alt
1	203.9	0.3897	0.3897	0.3897
2	74.07	1.527	1.916	-1.9163
3	26.09	6.103	8.019	-8.0195
4	5.994	17.09	25.11	-25.109
5	14.19	26.21	51.31	-51.315
6	1.756			
Error 1.21%				

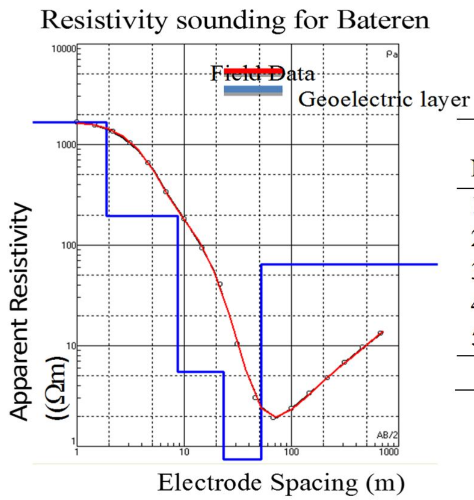
Fig 2: VES curve and layers resistivity for Ogborode (Escravos Beach)

Four geo-electrical layers were delineated in this location. It had a peak resistivity value of 203.9 Ωm and a least resistivity of 1.756Ωm. It had a type-QQ curve (Fig 2). The Curve depicts an area typical of salt water of its low resisitvity (Fig. 9), https://www.researchgate.net/post.



EBOKITI				
N	ρ	h	d	Alt
1	1572	1.01	1.01	-1.009
2	2.62	6.25	7.26	-7.255
3	0.952	36.3	43.5	-43.51
4	28.4			
	Error = 2.62%			

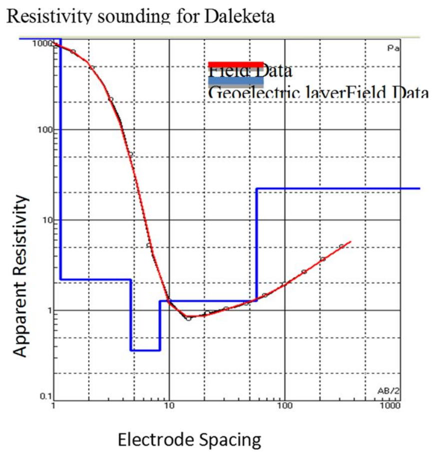
Fig 3: VES curve and layers resistivity for Ebokiti. Type H-Curve



BATEREN				
N	ρ	h	d	Alt
1	1670	1.867	1.867	-1.8674
2	193.7	6.791	8.659	-8.6588
3	5.469	14.72	23.38	-23.383
4	0.744	29.23	52.61	-52.613
5	64.38			
	Error = 1.35%			

Figure 4: VES curve and layers resistivity for Bateren.

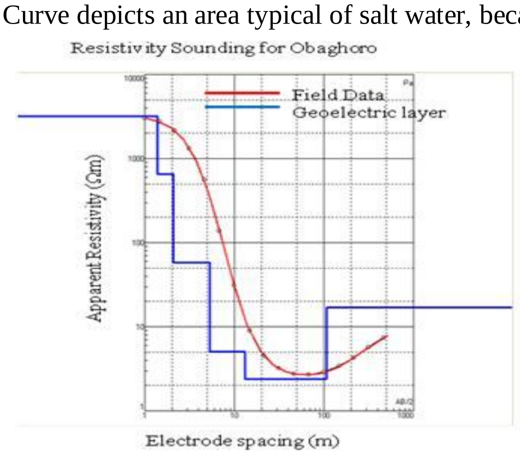
From the electrical conductivity (Fig.4), Bateran is freshwater at the top, soil beneath is saltwater and freshwater are found thereafter. The curve is of type H.



DALEKETA				
N	ρ	h	d	Alt
1	1012	1.14	1.14	-1.142
2	2.21	3.48	4.62	-4.623
3	0.36	3.71	8.34	-8.338
4	1.27	48.4	56.7	-56.7
5	22.2			
	Error = 3.51%			

Figure 5: VES curve and layers resistivity for Daleketa

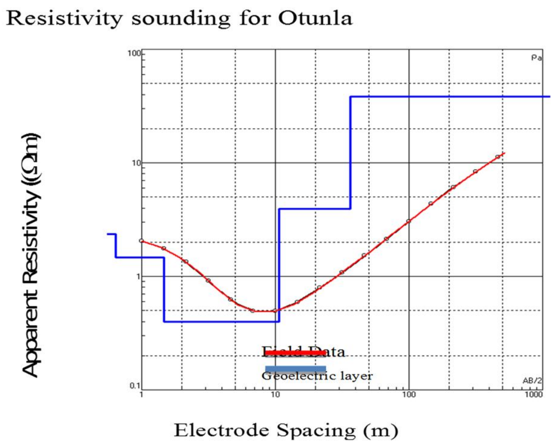
Five geo-electrical layers were delineated in this location. It had a peak resistivity value of 1012 ohm meter for the first layer and a least resistivity of 0.36 Ωm. It had a type-H curve. The Curve depicts an area typical of salt water, because it is majorly low resistivity (Fig. 5)



OBOTEGHAREDA				
N	ρ	h	d	Alt
1	3186	1.384	1.384	-1.3839
2	654.8	0.7021	2.086	-2.0859
3	57.76	3.28	5.366	-5.3656
4	5.082	7.836	13.2	-13.202
5	2.406	94.13	107.3	-107.33
6	17.06			
	Error = 0.808%			

Figure 6: VES curve and layers resistivity for Obaghoro

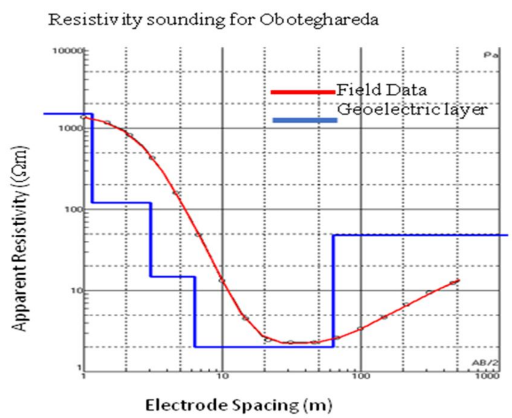
Obaghoro has six geoelectric layers majorly low resistivity indicating mainly salt water (Fig 6)



OTUNLA				
N	ρ	h	d	Alt
1	2.379	0.6411	0.6411	-0.6411
2	1.473	0.8208	1.462	-1.462
3	0.3964	9.198	10.66	-10.66
4	3.951	25.92	36.58	-36.58
5	38.13			
	Error = 0.388%			

Figure 7: VES curve and layers resistivity for Otunla

This location had peculiar Resistivity. As expected, the TDS gave the resistivity an arbitrary push. The observed peak resistivity is 3.951 Ωm and the lowest value of 0.396 Ωm giving it its unique property of a brackish environment (Table 4) also confirmed from the Type HA curve obtained from the analysis of the field for this location, (Fig. 7)



OBOTEGHAREDA				
N	ρ	h	d	Alt
1	1512	1.155	1.155	-1.1547
2	121	1.872	3.027	-3.0268
3	14.72	3.256	6.283	-6.2831
4	2.003	57.23	63.51	-63.511
5	47.75			
	Error = 0.947%			

Figure 8: VES curve and layers resistivity for Obonteghareda

From the electrical conductivity table, Obonteghareda is fresh water environment. The lowest resistivity reading is 2.003. The curve is of type H. Five geo electric layers were delineated

Table 3: Curve and fluid types.

S/N	Location	VES Nos/BH Nos	Curve Type	Number of Layers	Resistivity summary	Total Depth	Fluid Type	Screen Type
1.0	Obaghoro	1/3	KQHA	6	$\rho_1 > \rho_2 < \rho_3$	107	FW	TTOb
2.0	Daleketa	1/1	HKH	5	$\rho_1 > \rho_2 < \rho_3$	56	SW	ThOb
3.0	Otunla	½	HKQ	5	$\rho_1 > \rho_2 < \rho_3$	37	FW	ThOb
4.0	Ebokiti	½	HA	4	$\rho_1 > \rho_2 < \rho_3$	43	SW	ThThOb
5.0	Ogborode	1/3	HKQ	6	$\rho_1 > \rho_2 < \rho_3$	51	FW	TTOb
6.0	Bateran	1/3	KHA	5	$\rho_1 > \rho_2 < \rho_3$	53	SW	ThOb

FW – Freshwater; SW – Saline water/Saltwater; TOb – Thick Overburden Up or Below; TTOb – Thick Overburden Up and Below; ThThOb – Thin Overburden Up and Below; ThOb – Thin Overburden Up or Below. Above are the six locations where detailed work was done as stated in the abstract.

VES: DELINEATED LITHOLOGIC SEQUENCE FOR THE LOCATIONS

The interpretation went further to generate geologic sequence based on the available borehole SP and resistivity logs from boreholes in the area of study and selected boreholes within close proximity to serve as control.

The geo-sequencing is the best method for a thorough layer identity. The VES, the logs and the Sieve analysis are simultaneously aligned and analyzed to get a true layer identity.

Ogborode, (Escravos beach) is a well populated coastal community with a lot of activities. The location had 6 thick delineated VES layers, with well distributed Resistivity for the respective layers. The fifth layer (Figure 9) which coincided with the depth of perforation for the water depth is well confined within freshwater bearing sand. This layer is confined within medium thick overburden and also underlain by a well sorted medium thick layer of clay also, hence the observed lower resistivity of about 1.7 Ωm below the water formation. Although there are much tidal effects in this location, as there is continuous bathing of the formation by salt water from the Atlantic, yet its unusual resilience is not far from the fact that there is a reversed hydraulic head as a result of its tight intercalated sand-clay layers. Hence the infiltration –drain gradient is low since there is a generally poor permeability and porosity cross plot for locations with similar litho sequence, (Oteri 1988). Moreover, even the observed dissolved solids and chloride concentration is not above normal (W.H.O.1996). Though there may be pockets of saline sands this was as a result of wash-ins from surface through the top before the first bed of screening material.

Similarly, Ebokiti, is located on 5.49N and 5.01E. It has four thick delineated VES major layers (Figure 3) with highest and lowest resistivity values at about 1572Ωm and 0.95Ωm respectively. The borehole depth in this location was found to be 135m below the usual upper aquifer system. The identified lithologies showed an intercalation of sand, silty sand and silty clay sequence. Unlike its counterpart (Ogborode) which has series of confining units of finely sorted screening material of clay this has just silty clay of very little thickness. The first perforation was at the bottom of the recent or top of the upper aquifer system. Most likely, a second perforation was done in the next thick aquifer silty sand of about 50m. The third was supposedly in the bottom of the upper aquifer system; the screen was placed in the upper second aquifer system. This layer is underlain by a well sorted sand hence the water has little or no confining units. There is a high hydrogeostatic pressure which gives rise to a severe infiltration. High chloride concentration and the TDS of the aquifer system is faster in filtering than in draining out since the thick interbeds of silty sand and sandy silt which has high porosity and low permeability than normal sand units. The hydraulic and tidal effects here are enormous, hence most communities have saltwater.

Bateren (Utonbaterentie) is located on 5.48N and 5.06E. This is a Benin river bank community. It is well known for its rich agricultural soil. Five VES layers were delineated in this location. Layers 1 and 2 had high resistivity (Figure 4) and this is not abnormal since the presence of coarse deposits which usually are much more resistive than the finer grained deposits lined the topmost layer especially when the pore water is saline this is confirmed by the lithologies from the BH (Figure 9). However, the only resistivity above 100Ωm was in the topmost layer, incidentally, this could be the result of the presence of coarse deposits which usually are much more resistive than the finer grained deposits which lined the topmost layer where the pore water is not saline. However, the layer which coincided with the depth of perforation for the water depth is well confined within freshwater bearing sand in the upper aquifer system. This layer is confined within medium thick overburden of silty clay and also underlain by a well sorted medium thick layer of silty clay also hence the observed lower resistivity of about 1.7Ωm below the water formation. Though there is much saline washing in this location, the medium thick bed of silty clay and silty sand serves as a top screening material and the immediate underlying layer of moderately sorted sand houses the reservoir of water. Below this mass of aquifer is an aquitard made up of silty clay of infinite thickness. Hence its perforation is at the base of the – top of the lower aquifer system and yet its body of freshwater is not affected by the infiltration experienced at the far bottom or top most layers.

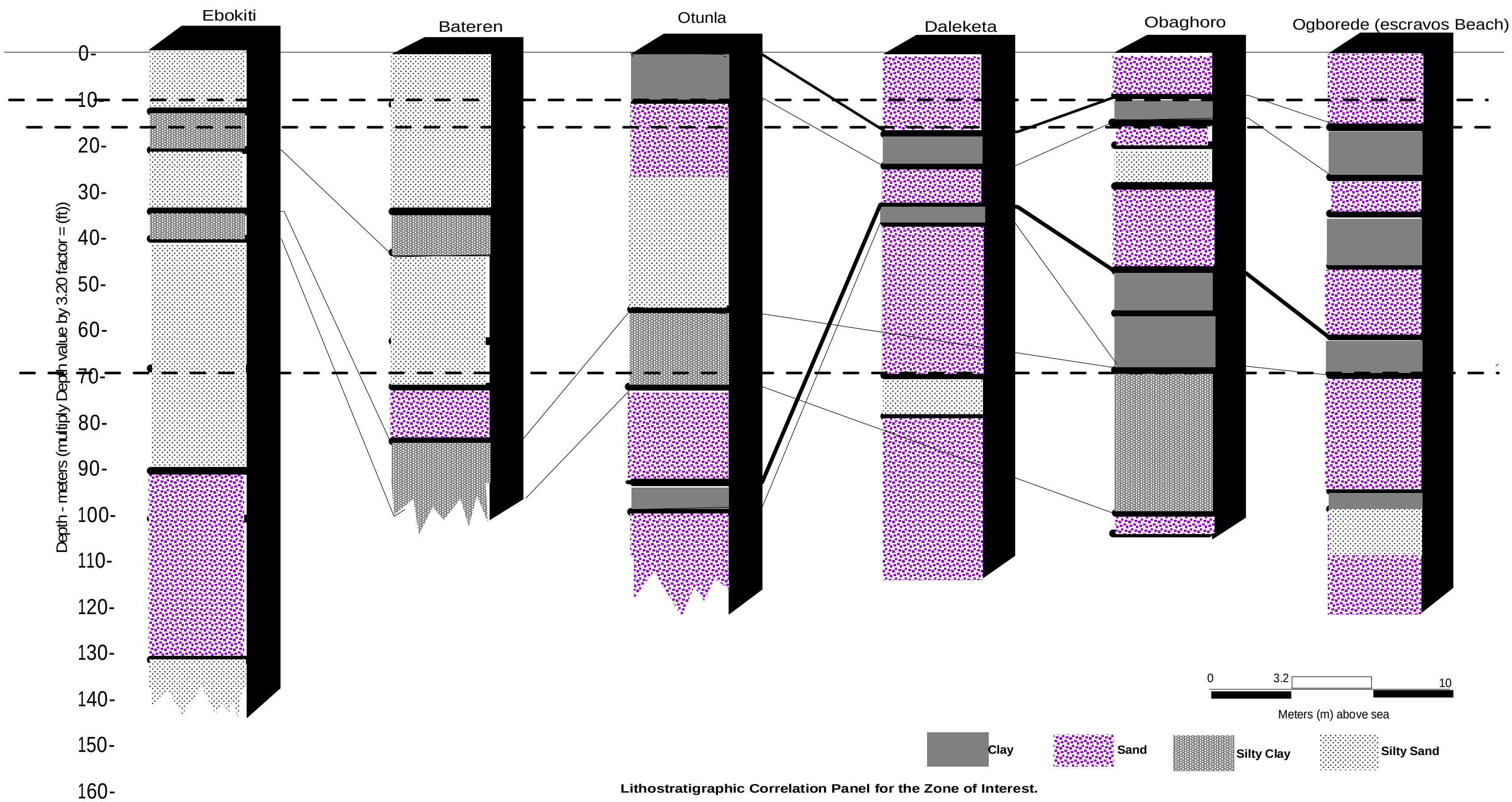


Figure 9: Lithostratigraphic Correlation Panel

Daleketa is a riverine community, it is located on 5.49 N and 5.05 E, and the community is surrounded with much vegetation with little or no evidence of surface geologic mega structures. Five VES layers were delineated in this location, the first layer had somewhat only high resistivity and the second layer to the fifth layer had real low resistivity (Figure 5) and this is not abnormal since the presence of coarse deposits which usually are much more resistive than the finer grained deposits lined the topmost layer especially when the pore water is saline this is confirmed by the lithologies from the BH (Figure 9). However, the lithologies identified show a significant intergrading of silty material and little clay. The major constituent is sand and is well dispersed in the borehole; hence the final aquifer for a prolific yield is exposed to top and bottom infiltration of saline water. The immediate overlying material is silty sand and it’s of very small thickness and on top of that is another thick layer of moderately sorted well rounded sand. Least to say the only encountered screening material of fine clay is just immediately after 16m – 22m and 33m to 35m of drilling. Unfortunately, the perforation is well below the third layer of sand which places it in the lower aquifer system.

This exposure to basal infiltration is the bane of the observed saline variations in this location. Though surface drain in is also part of the system of infiltration, yet hydraulic effect from the base remains the major contributor to its saline intrusion.

Obaghoro is a near coastal community with a lot of fishing activities and salt milling, it is located on 5.47 N and 5.03 E. Six VES layers were delineated in this location, its first and second layers were really resistive with no much thickness (Figure 6). Meanwhile, the borehole lithologies, show an intercalation of sand-clay and silty clay. The only silty sand was encountered between 20m and 25m depth of drilling. The VES curve pointed to a freshwater and was confirmed by the borehole detailed analysis and well log (Figure 9). The major units in this location are thick material of fine well sorted clay which prograded with depth. Incidentally, this is the reason for its very freshwater even when it’s situated at the coast of the sea or at the heart of the salt water. The borehole depth is 98m. The prolific aquifer is on the thickest layer of sand well confined between clay–silty sand and clay-clay screening materials. In addition, one cannot help conclude that its freshwater retainability could also be the timely perforation which was done at the upper aquifer system and in between confined units of clay. Hence the surface drain-in and hydraulic infiltration from the bottom are to a great extent, out rightly shut off. Apart from having the lowest chloride concentration (36.9mg/l) though within WHO limits (0.02mg/l to 250mg/l), (W.H.O 1996), it has very little TDS (Table 4) which may also stem from the fact that as one progress seawards, the ionic contents from hinterlands settle and simmer off along the way. However, it seems the draw down is faster in this location than any other location. Consequently, has the later effect of faster vertical upcoming which may directly shift the transition zone and this will result in the gradual intrusion of saline water into the aquifer.

Otunla is a Benin river community, located on 5.58 N and 5.20 E almost at the bank and has a lot of activities. The location had 5 thick delineated VES major layers. It had virtually very low resistivity values. The total borehole depth in this location was found to be 110m which went below the usual upper aquifer system. Otunla is almost a repeat of Daleketa except that the clay here is at the very top of the lithologies and it’s about 10m thick with a smaller clay layer of about 3m at the base of the borehole. Unfortunately, the perforation is in the lower aquifer system and the confining layer below does less than required to stand off the infiltration. Hence the high value of TDS and chloride concentration.

Fresh ground water comes in contact with saline ground water at the seaward margins of coastal aquifers. This vertical hydraulic interaction is a gradual process. Hence the gradual increase in chloride concentration as we progressed seawards along the Benin River from Obontaghareda to the coastal location of Ebokiti.

The seaward limit of freshwater in a particular aquifer is controlled by the amount of freshwater flowing through the aquifer, the thickness and hydraulic properties of the aquifer and adjacent confining units, and the relative densities of saltwater and freshwater, among other variables. Because of its lower density, freshwater tends to remain above the saline (saltwater) zones of the aquifer, although most often, in multilayered aquifer systems, seaward-flowing freshwater can discharge upward through confining units into overlying saltwater. Table 4 is the chemical constituents of water from wells sampled in the studied areas. This was necessary to know the quality of water.

Table 4: Chemical constituents of water from wells sampled in the study area

Location	Alkalinity field $CaCo_3$(mg/L)	Bromide (mg/L)	Chloride (mg/L)	Iodide (mg/L)	Silicate (mg/L)	Sulphate (mg/L)
Daleketa	230	6.92	2,140	0.033	13.1	250
Bateren	170	.19	41.9	0.099	14.5	<.1
Ogborode	170	.16	36.9	0.072	21.3	<.1
Obaghoro	160	.19	42.9	0.071	22.2	0.2
Otunla	660	.15	75.7	0.022	16.3	0.5
Ebokiti	190	10.04	3,050	3.06	19.3	259

CONCLUSION

The vertical electrical sounding investigations of the area have provided valuable information on the nature of the subsurface layer and also a possible or likely thickness or depth of aquifer in the study area. The results obtained showed the presence of saltwater in parts of Benin Rivers with low resistivity across the communities which range from 14.7Ωm – 68.1Ωm. This research recommends strongly that, government can still get fresh water, from the findings of this research, as fresh water can be drilled from borehole. All hope is not lost for those communities.

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