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Geophysical study of the aquifer characteristics and its environmental implications along River Ethiope, Delta State, Nigeria.

[1]Otobo Egwebe and [2]U. Okezie
[1]Department of Physics, University of Benin, Benin City.
[2]Department of Physics and Energy Studies, Western Delta University, Oghara.

Abstract

Geophysical survey was carried out in order to study aquifer characteristics (such as the depth, thickness and nature of soil materials above it) in the major communities along River Ethiope. Schlumberger vertical electrical sounding was conducted at Ugbomaya, Ajagolo, Ogegere, Abraka, Obiaruku and Ulogwe-Isumpe towns. The resistivity soundings were carried out with half current electrode spacing in the range 1-681m and six point per decade. The results were used to determine the depth, the percentage of clayey soil above the aquifer within the depth of investigation.The results showed a fresh water aquifer at depths, 20-55m, a subsurface with 100 percent of sandy soil in 64 percent of the locations investigated and 14-26 percent of clayey soil in 36 percent of the investigated locations.

Keywords: Vertical electrical sounding, Schlumberger configuration, aquifer characteristics, environmental implications, Ethiope River, Delta State.

1.0 Introduction

The superiority of the geoelectric method over other geophysical methods in the groundwater research is confirmed by the work of [1]. The ability of the resistivity method to furnish information on the subsurface geology unobtainable by other methods in groundwater studies was reported [2,3,4,5,6,7,8].They also attested to the ability of the electrical techniques been successfully utilized in: assessing water supply potential in basement aquifers [9], exploring aquifer boundaries in the plains of Yemen [10], and the assessment of the groundwater resources potentials within the Obudu basement area of Nigeria [11].

The earlier workers [12,13] used this method to identify the depth /thickness of the near surface fresh water above the salt water layer with the depth to the deep fresh water aquifer below the salt water in the saline water environment along the Benin and Forcados rivers. In [14],the depth/thickness of the near surface fresh water above the brackish water zone with the depth to the deep fresh layer below the brackish water horizon along the brackish water environment along the Warri river. Also in [15], the depth/thickness of the near surface aquifer below a clayey soil was reported along river Niger. Though, the region along the Ethiope river like that along the Niger river is fresh water environment which makes it better than the Benin, Forcados and Warri rivers in terms of fresh water availability there is need to find aquifers within the Benin Formation of the Niger Delta basin that are naturally sealed from pollution through vertical and horizontal flow of pollutants. Moreover, the depths to the aquifer within the Benin Formation as reported in [4,5,6,7,8] will be compared with the depths to the same aquifer identified in this work (especially those locations within the neighbourhood of River Ethiope).

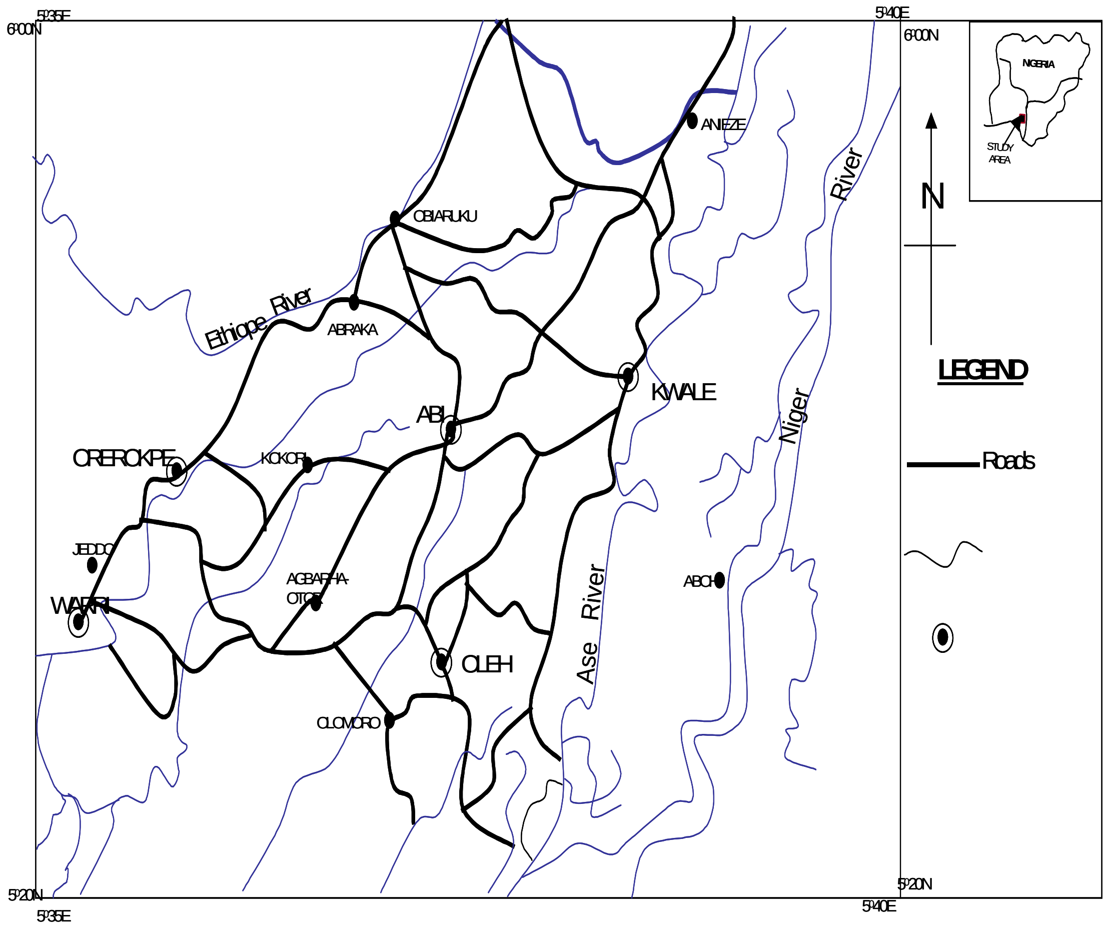
[1]e-mail: oegwebe@yahoo.com

The study reported here was carried out primarily using geophysics to determine the aquifer characteristics such as depths, and the nature/thicknesses of soil materials above the recommended aquifer for the purpose of potable water production.

2.0 Brief geology and hydrogeology of the study area

The study area is underlain by the continental sands of the Benin Formation (Figure 1). The geology of the Niger Delta has been extensively described by several authors including [16,17]. The subsurface sedimentary sequence has been subdivided into three stratigraphic units : the Benin, Agbada and Akata Formations. 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 area has a flat topography and is situated by the bank of Ethiope river.

Figure 2.1: Map showing the study area



3.0 Theory

For resistivity measurements several types of electrode arrangements can be applied. However, when the earth could be approximated to be composed of horizontally stratified isotropic, and homogeneous media in such a way that the change of resistivity is a function of depth, the Schlumberger configuration is the most widely used array which could provide useful information in solving hydrogeological problems. An important aspect of the Schlumberger is the less sensitivity of this array to the influence of near surface lateral heterogeneities and easy recognition of their effects [18,19,20,21]. Besides smoothing interpretation techniques are much more developed for the Schlumberger array.

In resistivity sounding, four electrodes are earthed along a straight line in the order AMNB (with AB as current electrodes and MN as potential electrodes). The apparent resistivity for Schlumberger array is calculated according to:

$$\ell_a = \left(\frac{a^2}{b} - \frac{b}{4}\right) \cdot \frac{\Delta v}{I} \quad (3.1)$$

where a = half current electrodes spacing

b = half potential electrodes spacin ΔV

ΔV and I represent the potential difference in milliVolts and current intensity in milli Amperes respectively.

The technique of data interpretation used involves seeking a solution to the inverse problem namely the determination of the subsurface resistivity distribution from surface measurements.

A very good solution to the inverse problem is the kernel function. It is used in interpreting apparent resistivity measurements in terms of lithology variation with depth. The function assumes the earth to be locally stratified, inhomogeneous and isotropic layers, and unlike apparent resistivity function, it is independent of electrode configuration. It cannot be measured in the field but has to be obtained from the transformation of measured apparent resistivities. The kernel function utilized in this work is derived after [22, 23], if the observed apparent resistivity is given by

$$\lambda_a(r) = r^2 \int_0^\infty \lambda T(\lambda) J_1(\lambda r) d\lambda \quad (3.2)$$

then the kernel function is given by [23] as: $$T(\lambda) = \int_0^\infty \frac{1}{r} \lambda_a(r) J_1(\lambda r) dr \quad (3.3)$$

where J_1 is the first order Bessel function of the first kind and $T(\lambda)$ is the transformed resistivity data.

4.0 Methods

The vertical electrical sounding (VES) using the Schlumberger array was employed for this study, details of the method have been documented [24]. Thirteen (13) Schlumberger soundings were conducted using the ABEM SAS 300C Terrameter and the SAS 2000 Booster.

Measurements were taken at expanding current electrodes distance such that the injected electrical current penetrate greater depths. The maximum current electrodes separation (AB) was 1362m (or AB/2 was 681m) and at six points per decade. The operation and efficiency of the six points per decade in subsurface study in the Niger Delta have been documented [12,13,14,15,25,26,27] the end result of the field measurement is the computation of the apparent resistivity (ℓ_a) using equation (3.1).

The apparent resistivity values were plotted against the half-current electrode spacing, a, using log-log sheet. These plots were interpreted by the well-known method of partial curve matching, and the results were subjected to computer assisted iterative interpretation. The computation employs a 9-point digital linear filters [28]. The resulting sets of layer parameters were interpreted in terms of their lithologic equivalents called the geoelectric sections.

5.0 Results and discussion

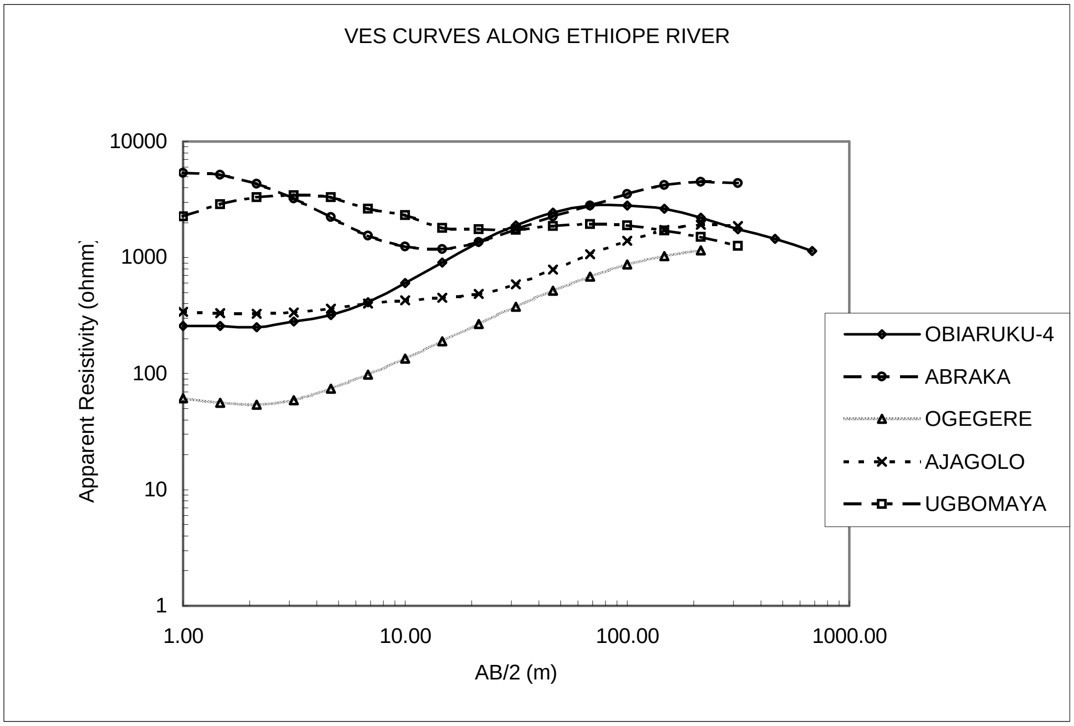
The results of previous works as presented in Tables 5.1, 5.2, 5.3 and 5.4 [12,13,14,15] showed: that the saline water environment along the Benin river has a near surface fresh water aquifer of thicknesses (with depths in bracket),1.0-9.7m (0.2-1.5m), and deep fresh water aquifer of depths, 100-218m with a sandwiched saline water aquifer of thicknesses, 65-209m; the saline water environment along the Forcados river has a near surface fresh water aquifer of thicknesses (with depths in bracket), 0.8-

10.8m (0.3-1.4m), and a deep fresh water aquifer of depths, 66.8-198.5m, with a sandwiched saline water aquifer of thicknesses, 64.8-187.8m ; the brackish water environment along Warri river has a near surface fresh water aquifer of thicknesses (with depths in bracket), 0.5-3.2m (1.0-47.6m), and a deep fresh water aquifer of depths, 33.4-237.4m, with a sandwiched brackish water aquifer of thicknesses, 11.3-202.8m. The fresh water environment along the Niger river has recommended aquifer at depths 22-34m with an overlying clayey soil of thicknesses 0-10.8m, also the results recommended the deep confined fresh water for large scale water supply and the near surface unconfined fresh water aquifer (with water purification mechanism in place) for only domestic water supply. In Table 5.5, the results of

previous workers [4,5,6,7,8,12,13,14,15] were summarized for easy comparison with results obtained in this study especially in Delta central where the major part of river Ethiope lies. Also in Table 5.5, the regions underlain by the Anambra basin the recommended aquifer depths are 100-191m [6,7] and the saline/brackish water areas of rivers Forcados, Benin and Warri [12,13,14] where the recommended aquifer depths are 70-218m (since the top aquifer is saline or brackish) within the Benin Formation of the Niger Delta basin.

However, the results of the geophysical investigation are as presented in Figure 5.1 and Table 5.6, Figure 5.1 reflects the multi-layered nature of the study area which is typical of the Niger Delta Basin by the multi-segmented field curves. The initial rise in the field curves indicates the presence of dry thick sand overburden over the aquifer which is shown by the bell end.

The depth to the aquifer is 27m in Ogegere,30m in Abraka and Ajagolo, it also ranges from 30-32m in Ugbomaya and 20-34m in Obiaruku. The percentage of sand within the depth investigated is 100 percent in Obiaruku, Ajagolo and Ogegere, 74-100 percent in Abraka, Ugbomaya and Ulogwe-Isumpe. The clay presence in Abraka is 23-24 percent, in Ugbomaya is 0-14 percent, in Ulogwe-Isumpe is 26 percent and zero percent of the total depth investigated in Obiaruku, Ajagolo and Ogegere. Moreover apart from the aquifer identified by the bell shaped rightmost segment of the VES curves (Benin Formation), there are some shallower aquifers at depths bellow 15m which are not recommended for exploitation because of the absence of a thick overlying clayey soil of thickness above 5m [29] and they are therefore not naturally sealed and consequently exposed to pollution through vertical and horizontal flow of pollutants. The depths to the aquifer recommended in river Ethiope are 20-34m which are within the depths of 2-35m recommended in any fresh water areas of the Niger Delta basin where the study area lies.



VES CURVES ALONG ETHIOPE RIVER
10000
1000
100
10
1
Apparent Resistivity (ohmm)
1.00
10.00
100.00
1000.00
AB/2 (m)
OBIARUKU-4
ABRAKA
OGEGERE
AJAGOLO
UGBOMAYA

Figure 5.1: VES curves for Abraka, Ugbomaya, Obiaruku,Ajagolo and Ogegere,Delta State.

Table 5.1: Summary of VES results along the Benin River and its Environs [12]

Location (Communities along Benin river)	**VES No.**	**Max. AB/2 Value (*m*)**	**No. of Layers**	**Curve shape**	**The thickness (depth in bracket) of near surface fresh water aquifer (*m*)**	**Depth to the deep fresh water aquifer (*m*)**	**Total Depth penetrated (*m*)**
Koko	1B	666	6	QHAK	7.3 (1.5)	217.6	217.6
Obonteghareda	2B	440	5	QQH	1.2 (1.0)	Not penetrated	67.5
Obaghoro	3B	430	6	KQHA	2.3 (1.3)	141.7	141.7
Ebrohimi	4B	316	6	QHKH	4.8 (1.3)	126.2	126.2
Daleketa	5B	316	6	QHKH	1.2 (1.1)	Not penetrated	68.2
Otunla	6B	464	6	QHAA	None	Not penetrated	45.9
Bateren	7B	681	6	QQKH	9.7 (0.9)	102.5	102.5
Ebokiti	8B	681	6	HQKH	1.0 (0.2)	100.0	101.9

Table 5.2: Summary of VES results along the Forcados River and its environs [13]

					Thickness of near	**Depth to the deep fresh**	

Location	VES No.	Max. AB/2 (*m*)	No. of Layers	Curve shape	surface fresh water aquifer (*m*)	water aquifer (*m*)	Total Depth penetrated (*m*)
Ogulagha	1.	100	5	KQH	7.5m	Not penetrated	45.7
"	2.	"	5	KQH	1.2	"	17.4
"	3.	"	6	KHKH	1.8	"	17.8
"	4.	"	5	QQH	2.3	"	37.8
"	5.	"	15	KQH	2.0	"	31.2
"	6.	"	4	QQ	0.8	"	16.5
"	7.	"	4	QQ	1.1	"	29.8
"	8.	"	5	QQQ	0.9	"	27.3
Yobebe	1	"	5	KQH	10.8	"	61.7
"	2	"	5	KQH	1.4	"	27.7
Okunti	1	1000	7	AKHAA	9.7	198.5	198.5
Burutu	1	681	6	QHAK	2.0	66.8	107.8
Kautu	1	316	6	KQHK	2.3	80.3	97.7

Table 5.3: Summary of VES results in the communities along the Warri River [14]

Location	Max. AB/2 Value (*m*)	VES No.	Curve Shape	Thickness of first aquifer (*m*)	Depth to the first aquifer (*m*)	Thickness of second aquifer (*m*)	Depth to the second aquifer (*m*)
Ogbe-Ijoh	417	1	AKQ	87.6	1.3	Not penetrated	Not penetrated
Ugbodede	650	2	KHKQQH	1.0	0.8	36.2	38.3
Egbokodo	650	3	HKHA	22.1	3.2	>103.3	70
Omadino	681	4	KQQH	16.8	0.5	Not penetrated	>202.8
Ode-Itsekiri	681	5	QHKHA	8.36	2.7	11.31	30.0

Table 5.4: Results of the interpretation of some VES curves along River Niger [15].

Location and VES No.	Curve shape	Total Depth penetrated (*m*)	Depth to the recommended aquifer (*m*) with the thickness(*m*) in bracket	Depth to the clayey soil above the aquifer (*m*).	Thickness of clayey soil above the aquifer (*m*).
Anieze	AKQ	23.10	23.10(16.80)	No clayey soil	No clayey soil
Obeza	HKHK	51.10	18.00(33.10)	0.80(clayey-sand)	1.92(clayey-sand)
Asaba-Okpai	HKHK	78.79	32.79(46.50)	0.85(clay)	1.11(clay)
Akashakpu	KHK	48.02	24.22(14.40)	2.25(clay)	2.57(clay)
Obodo-Oyibo	KHAK	54.65	21.65(33.00)	3.15(clayey-sand)	5.00(clayey-sand)
Okpai	KHA	32.45	29.45(14.13)	1.58(clay)	3.74(clay)
Oluchi	KHAK	60.71	34.71(26.00)	1.08(clay)	6.88(clay)
Umu-Ugboma	KQHA	40.08	22.83(17.25)	2.03(clay)	1.80(clay)
Iyede-Ame	AA	34.75	27.65(16.15)	0.90(clayey-sand)	1.62(clay)
Umuti-Aboh	AKH	75.43	25.67(68.75)	No clayey soil	No clayey soil
Aboh	QHA	34.20	34.20(20.25)	3.15(clay)	10.80(clay)

Table 5.5: Summary of results of some interpreted VES curves in Delta State[4,5,6,7,8,12,13,14,15]

Delta South		Delta Central		Delta North	
Location	**Depths (*m*)**	**Location**	**Depths (*m*)**	**Location**	**Depths (*m*)**
Forcados River	66.8-198.5	Ethiope river	20-34	Niger River	18.0-34.7
Warri River	30.0-202.8	Ughelli	5.0-7.0	Amai	14.0-35.0
Benin River	100-217.6	Ajomata	29-34	Kwale	52.0-60.0
Warri	6.5-8.0	Abraka	29-30	Otue-Ogume	72.0-84.0
		Jeddo	11.0-15.0	Umunede	89.0-115.0
Oleh	8.0-10.0	Ogegere	26-33	Obiaruku	45.0-50.0
		Osubi	9.0-13.0	Aboh	24.0-34.0
		Oviri-Olomu	8.0-10.0	Issele-Uku	120.0-135.0
Ozoro	9.0-12.0	Ajagolo	28-32	Ibusa	100.9-118.7
Burutu	70.0-100.0	Kokori	13.0-18.09	Onitsha-Ugbo	152.4-191.2
Olomoro	10.0-15.0	Afiesere	9.0-11.0	Issele-Azagba	118.4-188.2
Egbokodo	10.0-13.0	Agbarha-Otor	11.0-18.0	Ogwashi-Uku	134.0-156.0
Esravos river	80.0-151.0	Ekakpamre	8.5-11.0	Obodo	153.0-168.0
		Eremukowharien	9.0-14.0	Asaba	35.0-48.0
		Sapele	6.0-8.0	Agbor	65.0-100.0
		Isiokolo	9.0-12.0	Ozanogogo	90.0-120.0
		Otujeremi	10.0-13.0	Ukwu-Nzu	127.0-138.0
		Otokutu-Agbarha	13.0-15.0	Ubulu-Uku	140.0-160.0

Table 5.6: Results of the interpretation of some VES curves in the study area.

Location and VES No.	**Curve shape**	**Total Depth penetrated (*m*)**	**Depth to the Aquifer (*m*) and its apparent resistivity (Ω *m*) in bracket.**	**Percentage of sandy soil within the depth investigated**	**Percentage of clayey soil above the aquifer.**
Abraka – 1	AAK	40.72	29(3300)	76.79	23.21(clayey-sand)
“ –2	AAK	55.04	30(5250)	75.93	24.07(clayey-sand)
Ugbomaya –1	AAK	30.76	31(1350)	100	No clayey soil
“ -2	AAK	75.86	32(2400)	100	No clayey soil
“ -3	AAK	119.19	30(2078)	86.04	13.96(clayey-sand)
Obiaruku – 1	AAK	112	26(350)	100	No clayey soil
“ - 2	AAK	258.64	33(1800)	100	No clayey soil
“ - 3	AK	62.80	20(100)	100	No clayey soil
“ - 4	AAAK	157.69	31(2291)	100	No clayey soil
“ - 5	AAK	74.15	34(6000)	100	No clayey soil
Ajagolo –1	AAAK	47.26	30(2550)	100	No clayey soil
Ogegere –1	AAK	27.03	27(1900)	100	No clayey soil

Ulogwe-Isumpe-1	AAAK	192.18	55(4690)	74.03	25.97(clayey-sand)

6.0 Conclusion

The results of the interpreted VES data revealed an unconfined aquifer which is recommended for water production. Water intercepted at 20-34m deep is an aquifer that may not dry up for a long time after borehole completion and since only 31 percent of the locations have thick clay overlying this aquifer, aquifers at depths below 50m are better for water production along Ethiope river because the thick overburden is a natural filter against pollutants. The results also exposed the presence of white sharp sands deposit from the river at commercial quantity along the river for future large scale sand mining as confirmed by the presence of local mining operation. From the study, the geophysical investigation is recommended as a pre-condition for borehole drilling to establish the depths and subsurface lithology before drilling. The study therefore stands as a reliable guide for groundwater development in this part of Delta State where source of potable water that are naturally protected from pollution is a major problem in most of the towns.

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