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Full Length Research Article

Determination of the Protective Capacity of the Aquitard Stratum in Some Coastline Towns of Delta State, Nigeria

Ochuko Anomohanran
Physics Department, Delta State University, Abraka, Nigeria.
[* Corresponding Author: mrochuko@yahoo.com; ☎: +2348039488655]

ABSTRACT: This study was aimed at determining the protective capacity of the aquitard stratum in some coastline locations in Delta State, Nigeria. This was carried out using the electrical resistivity method. A total of 13 vertical electrical soundings were conducted and data obtained were interpreted by partial curve matching and computer iterative technique. The result of the study show the presence of three to four geoelectric formations comprising top soil, sandy clay/clayey sand, fine sand and medium coarse sand. The aquitard resistivity ranged from 11.8 to 108.8 Ωm while the thickness ranged from 1.0 to 7.4 m. It can be concluded that the protective capacity of the aquitard in the area ranges from poor to moderate.
Keywords: Groundwater, Protective Capacity, Aquifer, Aquitard, Electrical Resistivity

INTRODUCTION

Poor quality water and inadequate water supply have accounted for a number of preventable diseases in many communities across the world. These factors have also affected agriculture in terms of the types of crops grown and yield as well as animals (Saeed and Khan, 2014). Many countries of the world which hitherto have enough water are now experiencing drought, leading to food shortages, famine and starvation in those areas and has affected the economic future of nations. Consequently many nations have now concentrated on groundwater as a reliable source of quality water (Fetter, 2007; Anomohanran, 2014a)

Many people also contribute to the shortage of quality water through the ways and manner water source are handled and the way we keep our environment. In other words, the people are making more of the water that is available to us unfit for use. The water in the world is limited while population is rising. Only about 2.5% of the world's water is not salty and two third of this is locked up in the icecaps and glaciers (Fetter, 2007).

Anomohanran (2013a) asserted that even though nature has endowed the world with so much water, pollution has continued to make good quality water unavailable for use. Some of this polluted water results from man use of the environment such as the way we disposed of our waste to leakage from sewage and underground oil pipes found over the oil rich Niger Delta. Other identified sources of groundwater pollution are agricultural chemicals and heavy metals (Anomohanran, 2013b).

Geophysical methods have been used to determine the thickness of the subsurface formations and to determine the materials they consist of (Ayolabi *et al*., 2009; Okiongbo *et al*., 2011; Anomohanran, 2013c). The geophysical method commonly used is the electrical resistivity method. This method probes far into the subsurface and determines the occurrence or otherwise of groundwater and its quality and quantity through the measurement of resistivity values (Ayolabi *et al*., 2010). The simplicity and cost effectiveness of the electrical resistivity method has lead many researchers such as Ujuanbi and Asokhia, 2005; Alabi *et al*., 2010; Alslaibi *et al*., 2011; Majumdar and Das, 2011; Anomohanran, 2013b; Anomohanran, 2013d) to adopt it in carrying out their various investigations on groundwater.

The surface geoelectrical method especially the vertical electrical sounding (VES) technique is a quantitative evaluation technique, non invasive and relatively cheap method used for locating sites and depths for groundwater exploration. It is used to provide an efficient and scientific basis for the location of prolific abstraction boreholes (Okiongbo and Akpofure, 2012). The technique is best adapted to evaluate the depth and resistivity of flat lying layered rock structures such as sedimentary beds or the depth to the water table. The Schlumberger array is the most commonly used configuration for VES investigation.

In considering the poor sanitation situations in many areas in the various locations under study, it is assumed that the groundwater quality could be compromised. Anomohanran (2013e) emphasised the need to guarantee quality groundwater which is done though the consideration of various aquifer characteristics and subsurface resistivity parameters. This is why it is necessary to find out the probability of the aquifer being polluted through the leakage of contaminants penetrating the aquitard formation and getting to the groundwater. This study was therefore carried out to evaluate the level of the protection of the groundwater in the study area and proffer ways to maintain its quality.

THEORY

The basic objective of electrical resistivity survey is to obtain the apparent resistivity (ρ_a) of the subsurface formations at the point of investigation. The equation that express this is obtained by considering the flow of electric current (I) around an electrode. If the electrode introduces a current at the surface of a uniform half-space, the potential at a distance d from the input electrode is given by the equation (Lowrie, 2004).

$$V = \rho \frac{I}{2\pi d} \qquad 1$$

Where
V = Electrical potential
ρ = Resistivity of the medium
d = Distance from the electrode

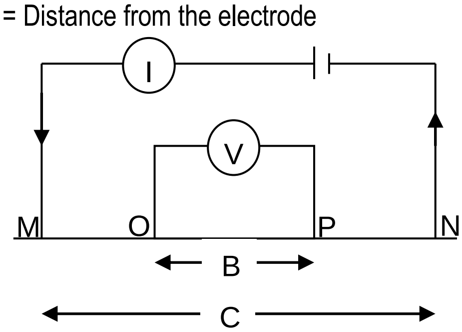

Figure 1: Schlumberger Array Arrangement

Considering a Schlumberger electrode arrangement as shown in Figure 1, the outer electrodes M and N are referred to as current electrodes while the inner electrodes O and P are the potential electrodes. At the potential point O, the electric potential due to the source point M is

$$\frac{\rho I}{2\pi d_{MO}} \qquad 2$$

The potential due to the point N is

$$\frac{\rho I}{2\pi d_{ON}} \qquad 3$$

Hence, the resultant potential at point O is obtained as

$$V_C = \frac{\rho I}{2\pi}\left(\frac{1}{d_{MO}} - \frac{1}{d_{ON}}\right) \qquad 4$$

In a similar way, the resultant potential at point N is

$$V_D = \frac{\rho I}{2\pi}\left(\frac{1}{d_{MP}} - \frac{1}{d_{PN}}\right) \qquad 5$$

The potential difference (V) between the points O and P as measured by the voltmeter V in Figure 1 is

$$V = \frac{\rho I}{2\pi}\left[\left(\frac{1}{d_{MO}} - \frac{1}{d_{ON}}\right) - \left(\frac{1}{d_{MP}} - \frac{1}{d_{PN}}\right)\right] \qquad 6$$

Given that $d_{MO} = d_{PN} = \frac{C-B}{2}$ and $d_{ON} = d_{MP} = \frac{C+B}{2}$

Then, equation 6 will become

$$V = \frac{4\rho I}{\pi}\left(\frac{B}{C^2 - B^2}\right) \qquad 7$$

Therefore, the apparent resistivity is obtained as

$$\rho_a = \frac{\pi V}{4I}\left(\frac{C^2 - B^2}{B}\right) \qquad 8$$

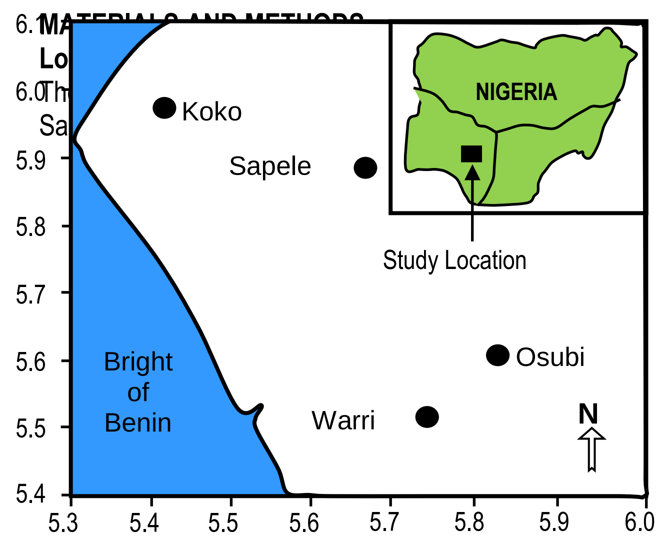

Figure 2: Location Map of the Study Area

Koko lies within latitude $5^0 58^/$ and $6^0 00^/$ N and longitude $5^0 23^/$ and $5^0 24^/$ E. Sapele lies within latitude $5^0 51^/$ and $5^0 57^/$ N and longitude $5^0 37^/$ and $5^0 42^/$ E. Warri lies within latitude $5^0 29^/$ and $5^0 33^/$ N and longitude $5^0 43^/$ and $5^0 46^/$ E. Osubi lies within latitude $5^0 34^/$ and $5^0 38^/$ N and longitude $5^0 47^/$ and $5^0 52^/$ E. These locations were selected using the non-probability convenience sampling method.

The areas experience moderate rainfall and moderate humidity for most part of the year. The climate is marked by two distinct seasons, the dry season which runs from November to April and the rainy season which runs from May to October. The natural vegetation is of rainforest with swamp forest in some areas. The study locations are within the Niger Delta region which is known to have resulted from the transportation of fine grained sediments eroded from the River Niger and its tributaries (Okiongbo and Akpofure, 2012). The geology of the Niger Delta comprises the Benin, Agbada and Akata formations. The Benin formation consists mainly of loose sand with occasional clay and lignite and is about 1800 m deep (Egbai, 2013; Anomohanran, 2014b). The Agbada and the Akata formations underlie the Benin formation. While the Agbada formation consists of intercalations of shale and sandstone, the Akata formation is made up of ninety percent shale. Both are over-pressured with the Akata serving as the source rock for hydrocarbon while the Agbada formation act as the reservoir rock (Anomohanran, 2014b; Ofomola, 2011; Akpoborie *et al*., 2011).

Data Acquisition

In carrying out this study, thirteen vertical electrical soundings were established in the four locations as shown in Figure 3.

The data were collected using the ABEM SAS 1000 Terrameter and applying the Schlumberger electrode configuration in line with the work of Anomohanran (2013a). A maximum current electrode separation of between 100 and 300 m was used depending on the available space. The data collected was subjected to partial curve matching and computer related interpretation to estimate the depth and resistivity of the various formations encountered. The protective capacity of the formation overlaying the aquifer was determined by using the relation which according to Atakpo (2013) is:

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \qquad 9$$

Where S is the protective capacity, h is the thickness of the confining bed and ρ is the resistivity of the confining bed.

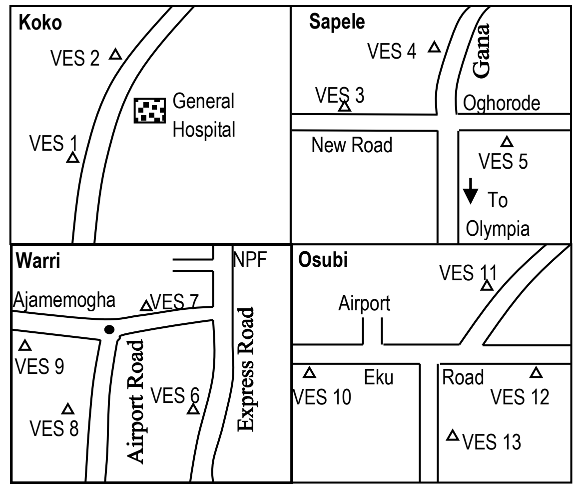

Figure 3: Map of Study Area Showing the Sounding Positions

RESULTS AND DISCUSSION

The data obtained from this study is presented as a plot of the apparent resistivity against half current electrode separation as shown in Figure 4. The curve types obtained for the various locations shows that Koko has A and H curve type while the curve type for Sapele are HA. The curve type for Warri are KH, HA, QH and AH while that of Osubi is dominantly KH type curves. This is in agreement with the work conducted by Atakpo (2013) and Egbai (2013).

The result of the true resistivity and depth of the various formations encountered as obtained from the computer iterative interpretation is presented as shown in Table 1. This shows that three geoelectric layers exist at Koko while Sapele, Warri and Osubi recorded four geoelectric layers each. The formations encountered are topsoil, sandy clay/clayey sand, fine sand and medium coarse sand. The aquifer layer at Koko is in the third layer with a resistivity ranging between 442 and 988 Ωm while the depth ranged between 1.6 and 1.9 m. The protective formation has a thickness ranging between 1.0 and 2.0 m while the resistivity ranged between 32 and 38 Ωm.

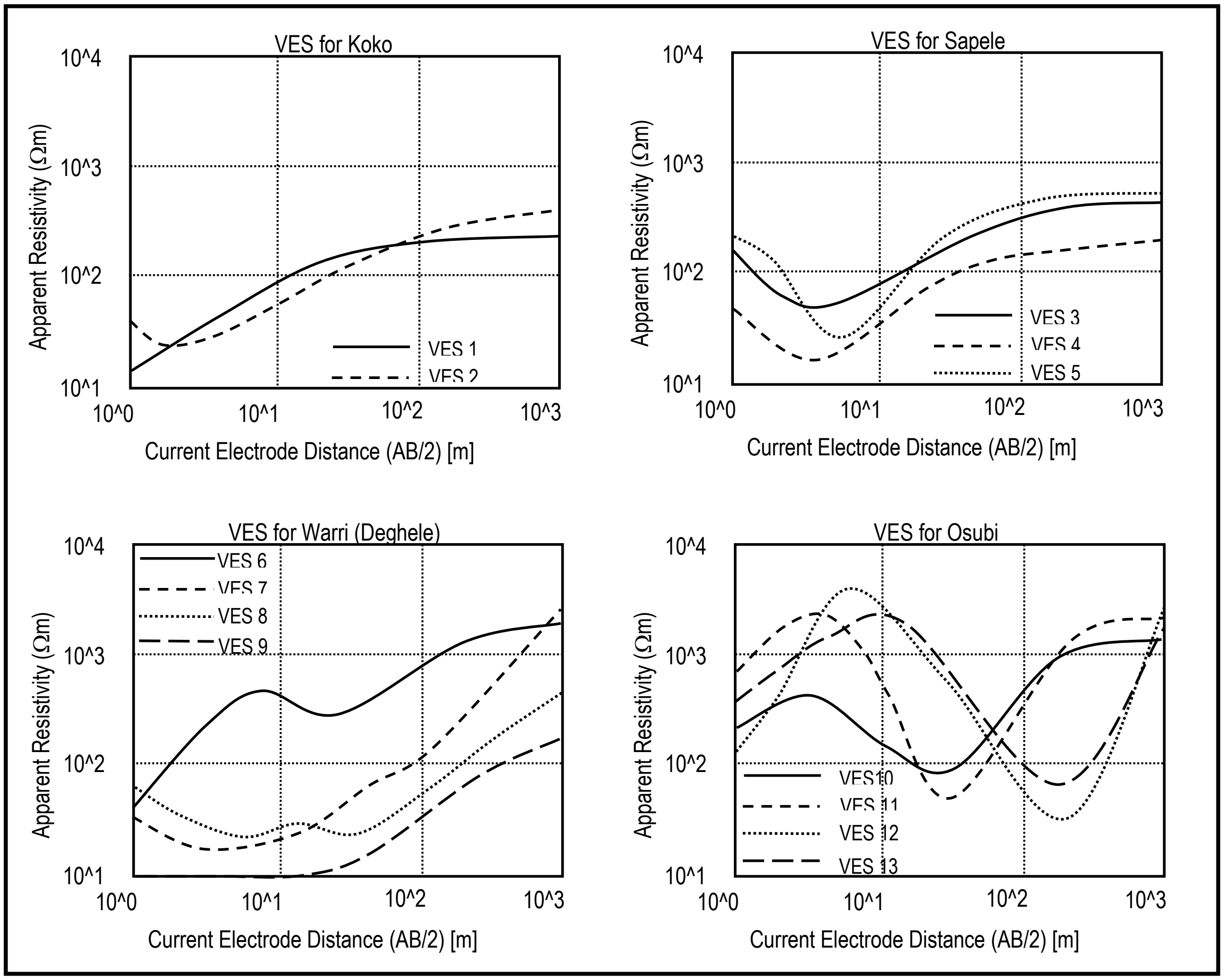

Figure 4: Vertical Electrical Sounding (VES) Curves Obtained from the Four Locations.

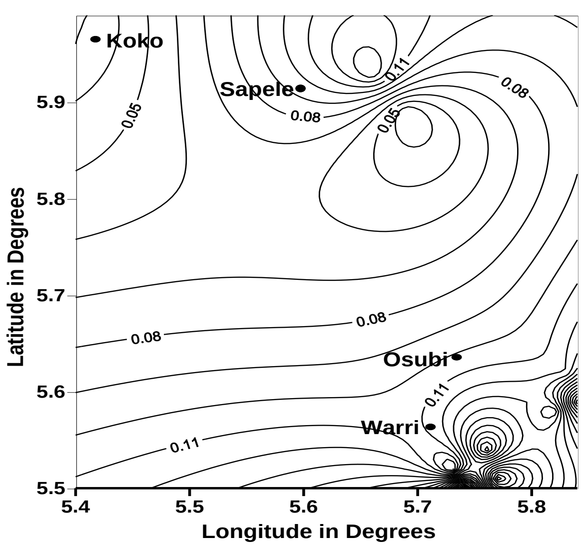

Figure 5: Contour Map Showing the Protective Capacity of the Study Area.

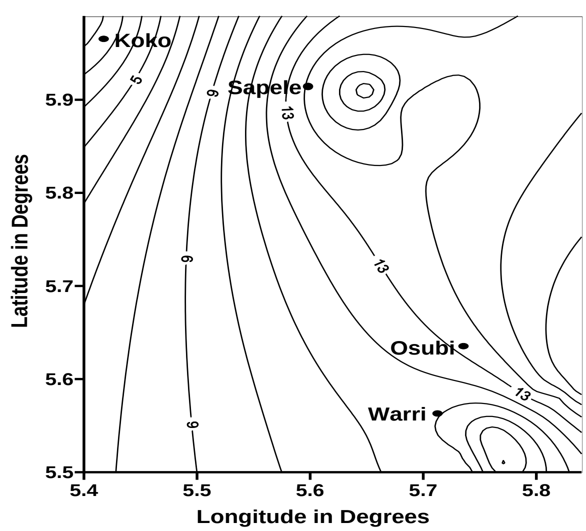

Figure 6: Contour Map Showing the Depth of the Aquifer Layer

Table 1: Vertical electrical sounding layer parameters for the various locations

VES SITE	VES NO	ρ_1 (Ωm)	ρ_2 (Ωm)	ρ_3 (Ωm)	ρ_4 (Ωm)	h_1 (m)	h_2 (m)	h_3 (m)	Curve Type
Koko	1	20	38	442		0.7	1.2		A
	2	52	32	987		0.6	1.0		H
Sapele	3	190	13	258	420	1.2	1.3	15.2	HA
	4	149	12	270	290	0.8	1.7	13.1	HA
	5	189	72	490	598	1.2	2.0	10.0	HA
Warri	6	49	190	109	1582	0.7	1.7	5.7	KH
	7	43	17	24	2708	0.7	2.5	5.0	HA
	8	78	55	23	526	0.8	4.0	6.6	QH
	9	23	29	90	307	1.5	4.0	6.7	AH
Osubi	10	200	333	88	1266	0.9	2.0	11.4	KH
	11	710	1545	60	3027	1.0	7.4	8.4	KH
	12	116	5171	44	4946	0.5	5.7	10.5	KH
	13	648	3728	83	3001	1.7	3.2	9.1	KH

ρ = layer resistivity and h = layer thickness

Table 2: Record of the protective capacity of the study area.

VES	Resistivity (Ωm)	Thickness (m)	Protective Capacity (Ω^{-1})
VES 1	37.7	1.2	0.03 (Poor)
VES 2	31.8	1.0	0.03 (Poor)
VES 3	13.0	1.3	0.10 (Weak)
VES 4	11.8	1.7	0.14 (Weak)
VES 5	72.0	2.0	0.03 (Poor)
VES 6	108.8	5.7	0.05 (Poor)
VES 7	24.0	5.0	0.21 (Moderate)
VES 8	23.2	6.6	0.29 (Moderate)
VES 9	90.0	6.7	0.07 (Poor)
VES 10	87.6	11.4	0.13 (Weak)
VES 11	95.9	8.4	0.14 (Weak)
VES 12	43.9	10.5	0.24 (Moderate)
VES 13	182.5	9.1	0.11 (Weak)

The aquifer layer at Sapele is located at the third and fourth layers with the fourth layer being more prolific. The resistivity range is between 290 and 598 Ωm while the depth range is between 13.2 and 17.7 m. The protective formation has a resistivity range between 12 and 72 Ωm while the thickness range is between 1.3 and 2.0 m.

The aquifer layer at Warri is located in the fourth layer with resistivity ranging between 307 and 2708 Ωm while the depth range is between 8.1 and 12.2 m. The resistivity of the protective layer ranged between 23 and 109 Ωm while the thickness ranged between 1.7 and 4.0 m.

The aquifer at Osubi is located in the fourth layer with a resistivity range of between 1266 and 4946 Ωm. The depth range of the aquifer is between 14.0 and 16.8 m. The protective layer for Osubi has a resistivity which ranged between 44 and 88 Ωm while the thickness ranged between 2.0 and 7.4 m.

The protective capacity of the study area was determined according to Okiongbo and Akpofure (2012) who put the protective capacity in the following scale: <0.1 as poor, 0.1-0.19 as weak, 0.2-0.69 as moderate and 0.7-1.0 as good. In using this standard, the protective capacity of the aquitard layer for the various locations was determined and the result presented in Table 2. The result shows that the protective capacity of the aquitard layer at Koko is 0.03. This depicts that the protection of the groundwater at Koko is poor. The protective capacity of Sapele aquitard is between 0.03 and 0.14. This implies that the protection of the groundwater at Sapele range from poor to weak. For Warri, the protective capacity of the aquitard layer ranges from 0.05 to 0.29. This indicates that the protection of the groundwater range from poor to moderate. The protective capacity of the aquitard at Osubi ranged from 0.11 to 0.24. This is an indication that the protection of the groundwater is from weak to moderate. This is in agreement with a similar study carried out by Okiongbo and Akpofure (2012) in Bayelsa, also located in the Niger Delta region. Their findings showed that the aquifer in Yenagoa City ranged between poor and weak and as such concluded that the aquifers are vulnerable to contamination from infiltration of leachate, refuse dumps and leakage from underground storage facilities. The findings of this study also agree with reports of a survey carried out in Amukpe by Atakpo (2013). He asserted that the protective capacity of the aquitard layer of Amukpe is poor and that the aquifer of the area is prone to contamination.

The contour map showing the protective capacity of the area under study is presented as shown in Figure 5. The depth to the aquifer layer for the various locations is presented as shown in Figure 6. Figures 5 and 6 will therefore be useful in making decision for best possible places to sink boreholes and the depth to drill. The implication of these findings is that the people who reside in these areas must be conscious of how they dispose of their waste, especially human waste and the building of landfill in order to protect the groundwater from contamination. Keeping to good environmental standard by these people is the only way to continue to protect the groundwater quality in these coastal communities.

CONCLUSION

This study meant to estimate the protective capacity of the aquitard in some coastline communities in Delta State have been carried out using geoelectric method. The results have shown that the resistivity of the aquitard layer range between 12 and 109 Ωm. The thickness of the aquitard ranged between 1.0 and 7.4 m. The protective capacity of the groundwater ranges from poor to moderate. It is therefore recommended that people who live in these areas must imbibe good environmental standard to guarantee the groundwater quality at all times.

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