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ELECTRICAL RESISTIVITY INVESTIGATION OF AQUIFER VULNERABILITY TO SURFACE CONTAMINANTS IN YENAGOA METROPOLIS, BAYELSA STATE, NIGERIA

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Abstract
Vertical electrical sounding, 2-D tomography survey and Dar-zarrouk parameters were used for the investigation of the aquifer subsurface layers, the protective capacity of the overburden layers and the vulnerability of the aquifer to surface contaminants in the area. Eleven (11) vertical electrical sounding (VES) were deployed using a maximum electrode separation, AB/2 of 200metres for the study. The VES data were interpreted using the IP12WIN software to delineate the aquifer into 4-5 geo-electric layers of silty-clay, clay, clayey-sand, fine-sand to coarse–sand. The aquifers zones were mainly of medium to coarse sand with average resistivity values of 1,800Ωm and average thickness of 10.3m. The average depth of the aquifer zone is 40m across the area. Dar-zarrouk parameters were employed to determine the protective capacity of the overburden layers and the vulnerability of the aquifer to surface contaminants. From the vulnerability ratings, the study area was classified mainly into high vulnerability and extremely high vulnerability zones. The 2-D tomography survey reveal zones of high resistivity and low resistivity values in the study area. The zone of high resistivity ranges from 460- 955Ωm and is refers as the non-contaminant zone. While the low resistivity zone range between 41 - 101Ωm and is refers as the contaminant zone. The result showed that the contaminant zone (leachate) is found at the depth of 7m. This means that the aquifer zone which is at the depth of 40m has not been affected.

Keywords: Groundwater, VES, ERT, geo-electric layers, aquifer vulnerability, resistivity, surface contaminants, Yenagoa.

INTRODUCTION
Groundwater is a major source of clean potable water for human consumption and industrial purpose, but in recent times this resource has been under increasing pressure all over the world arising from pollution from surface contaminants. Groundwater accounts for a significant portion of Nigeria's domestic and agricultural needs. According to the Nigerian Hydrological services Agency (NHSA), 2023), over 60% of the population of both urban and rural communities rely on groundwater for drinking and sanitation. In urban and semi-urban centres, private boreholes supplement municipal water systems, especially during dry season and also due to failure in Government water systems. However, groundwater development faces challenges such as poor sitting of boreholes, over- extraction of groundwater resources, and surface contaminants from industrial and domestic wastes (Nwankwoala, et al, 2023).

However, in the study area, the quality of the groundwater has been compromised due to anthropogenic activities. These anthropogenic activities range from indiscriminate sitting of refuse dumps, discharge of untreated solid wastes from soakaway and pit latrine, runoff from agricultural products and as well as exploitation and exploration of crude-oil. Therefore, it is imperative to determine the vulnerability of aquifer in the study area to surface contaminant so as to ascertain how vulnerable the aquifers are in the area.

Aquifer vulnerability is a measure of the rate at which the overburden layers of an aquifer can impede the flow of contaminants into the aquifer system. It is the summation of the ratio of the thickness of overburden formations to their resistivity (Bello, 2017). Therefore, it is important to know the protective capacity of an aquifer to have an idea of the quality of water it holds. This will guide borehole locations and the groundwater management in the study area.

Aquifer vulnerability indicates whether the physical and chemical characteristics of the subsurface will prevent the infiltration of toxic substances from the surface of the earth that can compromise the groundwater quality (Kekwaru, 2023).

Furthermore, in the study area there has been no detailed study of the protective capacity of the aquifer system that will serve as a guide for groundwater exploration and exploitation. This is why over the years, most boreholes drilled by successive Government, Organizations and individuals have failed or have been abandoned.

Thus, this research is aim at determining the protective capacity of the aquifer system with a view to evaluating the aquifer system to know aquifers that are less vulnerable to contaminant and the ones that are more vulnerable in the study area.

The evaluation of aquifer vulnerability can be determined by vertical electrical sounding (VES) method. The vertical electrical sounding (VES) is a surface geo-electric method of investigation and is the simplest method used in evaluation of aquifer system. The method is very useful in providing detailed information of the thickness, depth and resistivity of different conducting layers.

With increase in environmental awareness and control, electrical resistivity has become a fundamental and diagnostic tool to environmental studies especially to determine the subsurface resistivity distribution in the area requiring depth to water table, depth to bedrock and thickness of the subsurface. In this study it is the geo-electric method that was employed to evaluate the aquifer protective capacity, and the aquifer hydraulic properties.

GEOLOGY AND HYDROGEOLGY OF THE AREA

The study area is located between latitudes 4^0 49’22.316” N and 5^0 4’ 18.476”N and longitudes 6^0 14’5.921’’E and 6^0 25’10.645’’ E (Fig. 1). It is located within the lower section of the upper flood plain deposits of sub-aerial Niger Delta (Allen, 1965).

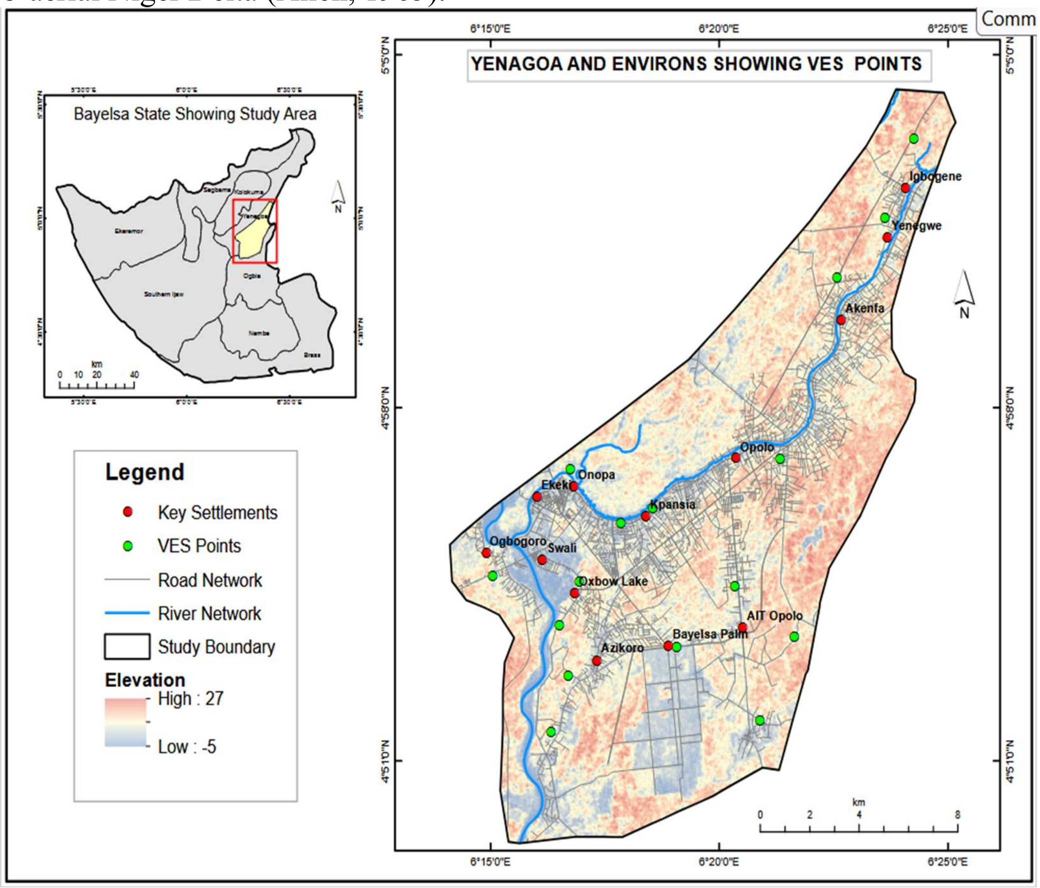


Figure 1: Map of the study area

Stratigraphically, the Niger Delta is divided into Akata, Agbada and Benin formations in order of decreasing age. The Akata formation is the oldest formation in the Niger Delta. It consists of massive dark gray shales which are deposited in marine environment. The age of the formation is paleocene to recent and its thickness is 0 to 625metres (short and stauble,1967). While the Agbada formation underlies the Benin formation. It consists of inter bedded shales and sands and is been deposited in fluvio-marine environment. The formation varies in thickness from 0 to 468metres (Peter, 1983).

The Benin formation consists of 90% of coarse sand with locallzed clay/shale interbeds (Allen, 1965). Its thickness is about 656metres and is overlain by quaternary deposits in some places (Akpokodje, 1990). The hydrogeology of the area has been described by various scholars which includes; Etu-Efeotor(1981), Akpokodje et al; (1990), Edet (1993). Udom et al; (1998,1999) and Nwankwoala et al; (2011,2012). The Benin formation is the water bearing zone of the area and is overlain by the quaternary deposit (40 to 150metres) thick which consist of alternating sequence of sands and silty clays with the latter become increasingly more prominent seawards. The clayey intercalations within the Benin formation have given rise to multi- aquifer system in the area (Etu –Efeotor 1981, Etu-Efeotor and Odigi 1983, Etu-Efeotor and Akpokodje, 1990). The Benin formation is highly permeable, prolific and productive, and is the most extensively tapped aquifer in the Niger Delta. The first aquifer is commonly unconfined while the rest are confined.

Overlying the Benin formation is the quaternary sediments, which consist of mainly silt, clay and sand of different sizes. Most boreholes are drilled within the quaternary sediments in the study area. The average depths of boreholes in the study area is between 30-40metres (Daniel et al, 2015). The static water level in the area ranges from 0-1metre during the wet season and 1-3metres during the dry season. The main source of recharge is through direct precipitation where annual rainfall is as high as 3000mm (Amajor and Ofoegbu, 1988). The water infiltrates through the highly permeable sands of the Quaternary sediments to recharge the aquifers. Groundwater in the first aquifer in the area occurs under water table conditions (Udom and Amah, 2006). The study area has been noted to have poor groundwater quality due to objectionable high concentration of certain groundwater parameters and encroachment of saltwater or brackish water into the freshwater aquifers (Udom,1999, and Nwankwoala et al; 2011).

MATERIALS AND METHOD

Geo-electric Data Acquisition

The study involved collection of field data through vertical electrical sounding (VES), 2-D tomography survey (ERT) and lithologic logs from existing and freshly drilled boreholes. These data were analysized and interpreted in relation to the geology of the area.

The main instrument used was the Abem terrameter SAS 1000 which digitally display the resistance values at each point and were subsequently recorded in a field note book.

The schlumberger electrode configuration with a maximum current electrode spread of AB/2, 200metres was used for aquifer delineation and aquifer parameters estimation. This arrangement consists of four electrodes arranged linearly around a central point. The outer electrodes A and B served as current electrodes while the inner electrodes M and N served as potential electrodes placed closely together. The field procedure was carried out by applying current to the ground through the current electrodes (A and B) and then measuring the resultant potential difference (ΔV) between the potential electrodes (M and N). The potential electrodes were relatively kept constant while the current electrodes were moved from one point to another so as to obtained information about stratification of the ground (Koefed, 1977).

A total of Eleven (11) vertical electrical soundings (VES) were carried out in the study area. A computer aided modelling technique using IP12Win software was employed for the data interpretation.

The Schlumberger configuration was employed not only because it was faster and less likely to be influenced by lateral variations but because it also required a lower number of operators. The geometric factor for the Schlumberger configuration was given by:

$$K = (a^2/b - b/4)\pi \quad 1$$

Where a and b are the current and potential electrode spacing respectively.

The apparent resistivity was evaluated using

$$pa = R \times K \quad 2$$

$$R = \Delta V/I \quad 3$$

Where R is the measured resistance in ohm(Ω) from the vertical electrical sounding, pa is the apparent resistivity in ohm- metre (Ωm), K is a geometric factor, ΔV is measured in volt, while I is measured in Ampere(Amp).

The apparent resistivity values obtained in the field was plotted against the electrode spacing (AB/2) on a logarithmic scale. This was done using the IP12WIN software computer programme which automatically calculate and display the true resistivity and thickness of the delineated subsurface layers.

The apparent resistivity values, which is a function of the electrode spacing were then converted to true resistivity values with a computer based software to provide the sounding curves. Both qualitative and quantitative electrical sounding curves interpretation were employed in the study.

The 2-D resistivity survey data was acquired using the MINI-RES resistivity metre which is a signal averaging system where consecutive readings are taken automatically and the results are average continuously. The continuously updated running average is displayed as resistance automatically. It uses a micro-processor to monitor and control all the measurement so as to ensure optimal accuracy. 3 profiles were carried out using the Wenner configuration within three different dumpsites. Profile 1 was along NE-SW direction at latitude 4.909530 and longitude 6.345190, profile 2 was on the NNE-SSW direction at latitude 5.033998 and longitude 6.316317 while profile 3 was on the NE-SW at latitude 4.966111 and longitude 6.278889. The 2-D resistivity tomography survey was deployed so as to determine the source, direction of leachate contaminants flow and depth of the contaminants.

The Dar-zarrouk Parameters of the study Area

Dar-zarrouk parameters were used in this study to determine the aquifer vulnerability. They were calculated from the field values of the resistivity and thicknesses of the delineated aquifer subsurface layers. They are defined by longitudinal conductance (S)and transverse resistance (R_T). The longitudinal conductance was regarded as the ability of the media to retard and filter percolating fluid which was considered as the protective capacity of the aquifer overburden and is expressed as:

Longitudinal unit conductance (S);

$$S = \frac{h}{p_i} + \frac{h}{p} + \frac{h}{p} + \frac{h}{p} + \frac{h}{p_n} \quad 4$$

$$S = \sum(h_i/p_i) \quad 5$$

Where h is the thickness of the layer and p is the resistivity of the layer. It is the first 3 or 4 subsurface layers that were used as overburden for the calculation.

RESULTS AND DISCUSSION

VES and ERT data Results presentation

The results of the vertical electrical sounding (VES) and the 2-D tomography survey (ERT) for the aquifer vulnerability analysis are presented in Table 1,2 and Figures 2 – 4.

Eleven (11) VES were carried out in the study area, the processed result obtained indicate a 4-5 geo-electric layers, where KHA, HA and KH are the dominating curve types. Table 1 and Figure 2 shows the typical sounding curves obtained at various locations across the study area. The subsurface layers of the study area broadly consist of silty-clays, clayey-sand, sandy-clay, fine-coarse sand.

From the quantitative analysis, the fourth and fifth layers were identified as the aquifer layers as evident in significantly high resistivity values. The fourth layer resistivity values range from 301Ωm to 8254Ωm with thickness ranging from 9.0 to 21m, occurring at an average depth of 30m from the ground surface. The lithological composition is inferred to be of fine –medium sand, which is assumed to be porous and permeable. The fifth layer has a thickness and resistivity values range between 14m to 23m and 740 to 9086Ωm respectively with a depth range of 35- 43m (Table 1). It is mainly composed of medium- coarse sand with inferred high porosity and permeability and is the prolific water bearing zone. This in line with the lithology of the boreholes in the study area. While layer 1,2 and 3 are regarded as the overburden layers of the aquifer zone and consist mainly of silty-sand, sandy-clay and fine sand (Table 1 and Fig 3).

The result of the 2-D electrical resistivity survey were divided into profile 1, 2 and 3. Profile 1: This profile is located within Gbarantoru dumpsite along NE-SW direction at latitude 4.909530 and longitude 6.345190 (Figure 4). It has a resistivity value ranging from 91Ωm -955Ωm and a lateral stretch of 140m. Two zones of high and low resistivity were identified beneath this profile. The high resistivity zone (deep blue) with resistivity value ranging from 460-955Ωm with a depth of 1.25-15.9m were identified, which is refer as the non-contaminant zone. The low resistivity zone (pink-dark red) with resistivity value ranging from 90Ωm-144Ωm and a depth range of 1.25m-6m. This is refer to as the contaminant zone with oblate shape pointing to the south. It is equally overlying the non-contaminant zone at various sections as shown in figure 4.

Profile 2: This profile is located within Okolobiri dumpsite along NNE-SSW direction at latitude 5.033998 and longitude 6.316317 (Figure 4). It has a resistivity value ranging from 56Ωm -618Ωm and a lateral stretch of 100m. Two zones of high and low resistivity were identified beneath this profile. The high resistivity zone (deep blue) with resistivity value ranging from 303Ωm-618Ωm with a depth of 1.25-19m were identified, which is refer as non-contaminant zone. The low resistivity zone (pink-dark red) has a resistivity value ranging from 56Ωm- 97Ωm and a depth ranging from 1.25m-6.30m. This is refer to as the contaminant zone which has an oblate shape pointing to the south. It is as well overlying the non-contaminant zone at various sections as shown in figure 4.

Profile 3: This profile is located within Onopa/Ovom dumpsite along NE-SW direction at latitude 4.966111 and longitude 6.278889 (Figure 4). It has a resistivity value ranging from 41Ωm -195Ωm and a lateral stretch of 76m. Two zones of high and low resistivity were identified beneath this profile. The high resistivity zone (deep blue) with resistivity value ranging from 190Ωm-166Ωm with a depth of 1.25-15.9m were identified, which is refer to as non-contaminant zone. The low resistivity zone (pink-dark red) with resistivity value ranging from 41Ωm- 101Ωm with a depth ranging from 1.25m-7.10m. This is as well refer to as the contaminant zone.

Thus, the 2-D tomography survey mapped and identified 2 distinct zones of non- contaminant and contaminant zones in the area. The result indicates that the contaminant zone (leachate) is at average depth of 7m over lying the non-contaminant zones at various sections in the area. This shows that the aquifer zone which at the depth of 40m is not affected by the leachate plumes. However, precaution should be taken to avoid the leachate from not migrating to the aquifer zone over a period of time.

Table 1: Lithologic delineation of aquifers in study area

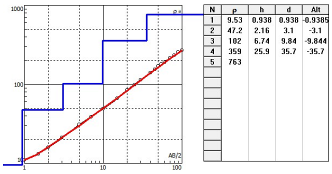
VES Points	Layer	Resistivity (Ωm)	Thickness (m)	Depth(m)	Lithology	Curve type
VES 1 Igbogene	1	9.5	0.9	0.9	Topsoil	AA P1<p2<p3<p4
	2	47.2	2.16	3.16	Clay	
	3	102	6.74	9.84	Clayey – sand	
	4	359	25.9	35.7	Fine–medium sand	
VES 2 Yenegwe	1	27.3	0.5	0.5	Topsoil	KHA P1<p2>p3<p4<p5
	2	168	2.6	3.1	Fine-Sand	
	3	86	4.4	7.5	Clayey – sand	
	4	559	9.2	36.3	Fine – sand	
	5	7184	19.6		Medium – coarse sand	
VES 3 Akenfa	1	125	0.5	0.5	Topsoil	KH P1<p2>p3<p4
	2	7499	1.28	1.78	Fine–medium sand	
	3	422	5.62	7.4	Medium-Sand	
	4	5828	19.4	26.8	Coarse-Sand	
VES 4 Opolo	1	58.1	0.50	0.50	Topsoil	AAK P1<p2<p3<p4>p5
	2	2021	1.34	1.84	Clayey – sand	
	3	3265	4.35	6.19	Fine–medium sand	

	4	8254	10.2	16.4	Medium-Sand	
	5	4793	19.1	35.5	Coarse-Sand	
VES 5 AIT-Opolo	1	10.1	0.5	0.5	Topsoil	
	2	107	0.87	1.37	Silty-Clay	KHA P1<p2>p3<p4<p5
	3	2.81	1.87	3.24	Clayey – sand	
	4	57	12	15.3	Clay	
	5	455	14.2	29.5	Fine–medium sand	
VES 6 Bayelsa Palm area	1	92.1	0.6	0.6	Topsoil	
	2	153	2.04	2.64	Clayey – sand	AAA P1<p2<p 3<p4<p5
	3	567	4.6	7.24	Fine–medium sand	
	4	2408	9.8	17	Medium sand	
	5	9085	15.4	32.4	Medium-coarse sand	
VES 7 Azikoro	1	32.3	0.5	0.5	Topsoil	
	2	2.04	2.52	1.75	Clayey-Sand	HK P1<p2<p3>p4
	3	6190	10.6	13.1	Medium-coarse sand	
	4	4217	16.5	29.6	Fine-medium Sand	
VES 8 Onopa	1	124	0.3	0.3	Topsoil	
	2	35.7	2.1	2.4	Clay	HA P1>p2<p3<p4<p5
	3	1024	5.5	7.9	Fine-medium sand	
	4	4754	8.6	16.5	Medium-Sand	
VES 9 Obogoro	1	60.2	0.82	0.82	Topsoil	
	2	183	1.14	1.96	Clayey sand	KH P1<p2>p3<p4
	3	71	8.76	10.7	Clay	
	4	135	14.1	24,86	Fine sand	
	5					
VES 10 Swali	1	482	0.85	0.85	Topsoil	
	2	2763	1.62	2.47	Sand-clay	KH P1<p2>p3<p4
	3	1285	8.02	10.5	Fine-medium sand	
	4	5472	21.9	32.4	Medium – coarse sand	
VES 11 Ox-Bow Lake	1	89.5	0.5	0.5	Topsoil	
	2	1352	`1.81	2.31	Fine sand	KHA P1<p2>p3<p4<p5
	3	121	4.85	7.16	Sandy-Clay	
	4	3451	12.4	19.5	Fine-medium sand	
	5	5646	20.3	39.8	Medium – coarse sand	

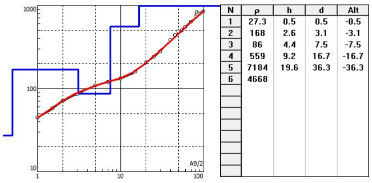
Table 2: Co-ordinates of VES locations in study area

S/N	VES LOCATION	VES CO-ORDINATES	
		Latitude (N)	Longitude (E)
1	Igbogene	5.055556	6.404167
2	Yenegwe	5.029468	6.39362

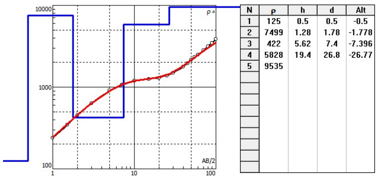
3	Akenfa	5.009417	6.376111
4	Opolo	4.949632	6.355296
5	AIT Road	4.907523	6.338889
6	Bayelsa Palm	4.887583	6.31775
7	Azikoro	4.877944	6.278194
8	Onopa	4.966111	6.278889
9	Obogoro	4.910833	6.250722
10	Swali	4.908889	6.282222
11	Oxbow Lake	4.894722	6.274917



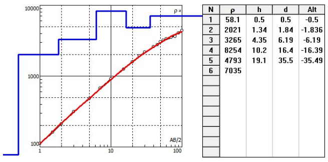
VES PLOT 1



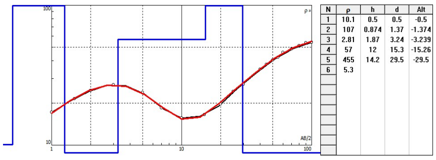
VES PLOT 2



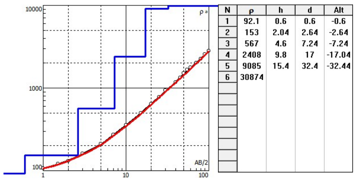
VES PLOT 3



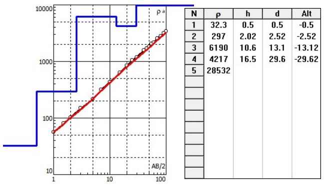
VES PLOT 4



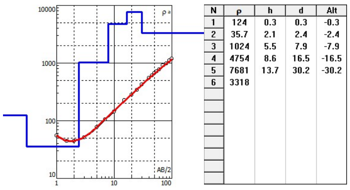
VES PLOT 5



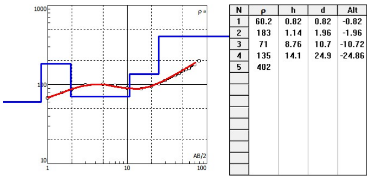
VES PLOT 6



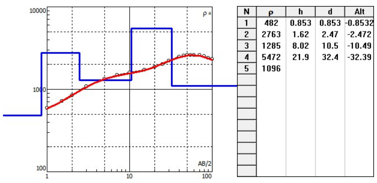
VES PLOTS 7



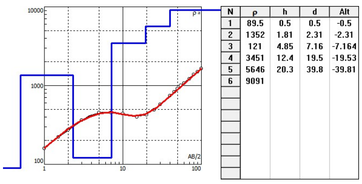
VES PLOTS 8



VES PLOTS 9



VES PLOT 10



VES PLOT 11

Figure 2: VES plots and obtained data of the study area

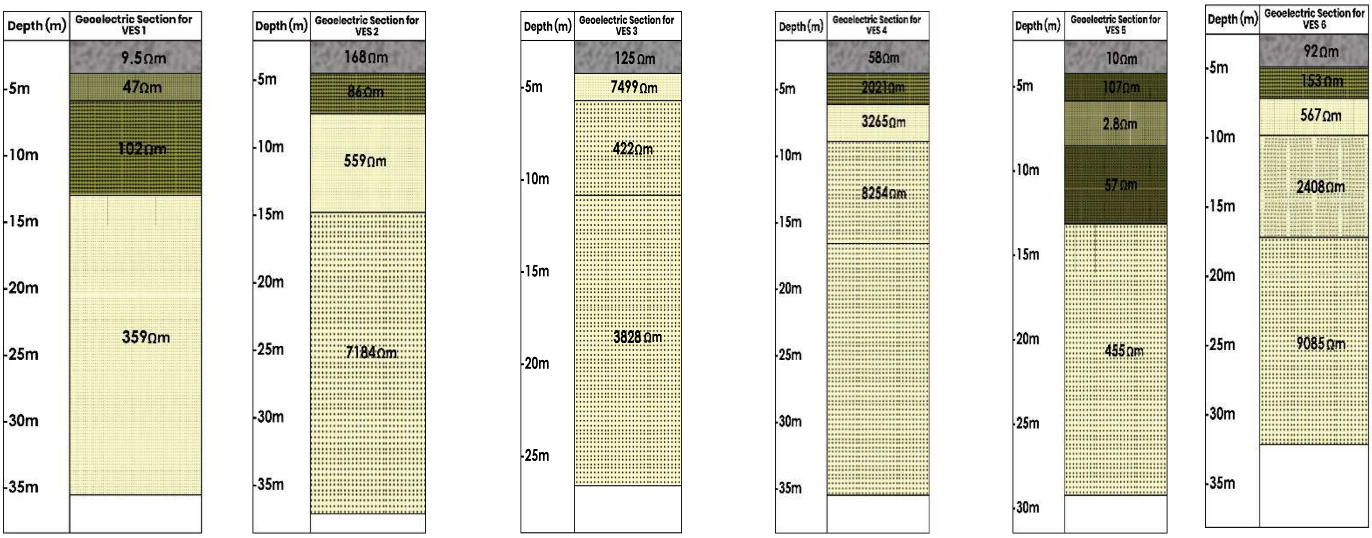


Figure 3a: Geo-electric sections 1 -6

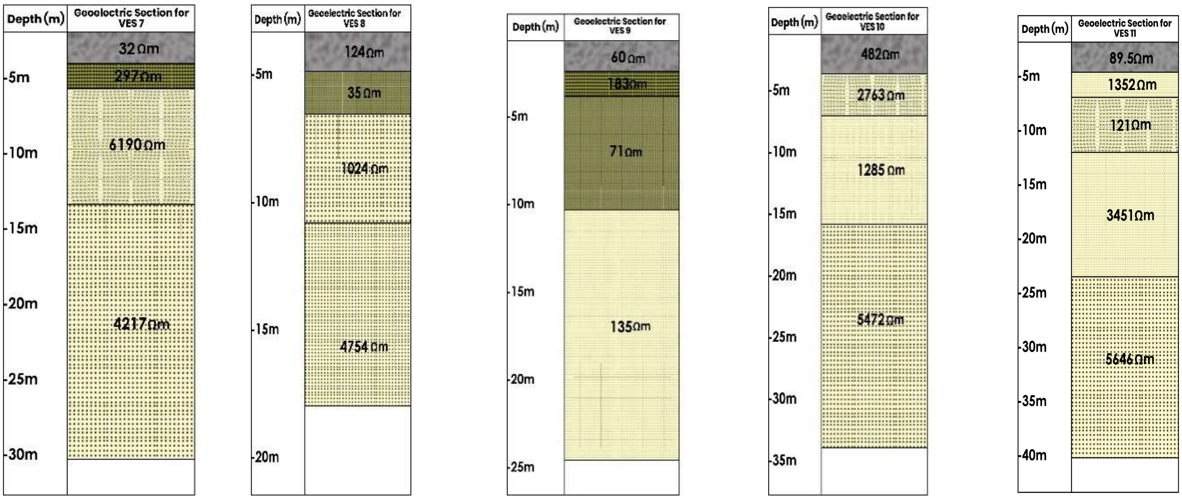


Figure 3b: Geo-electric sections 7-11

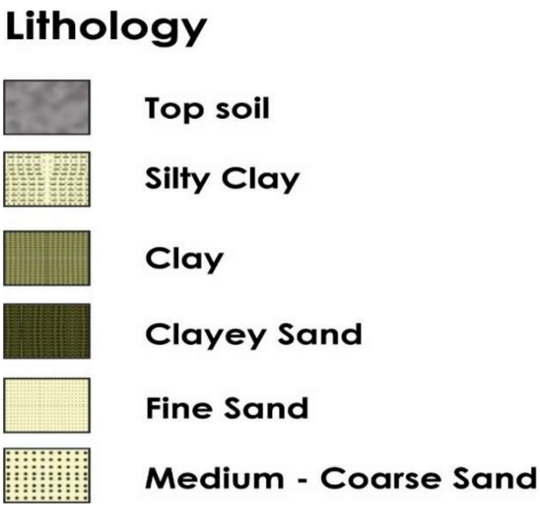
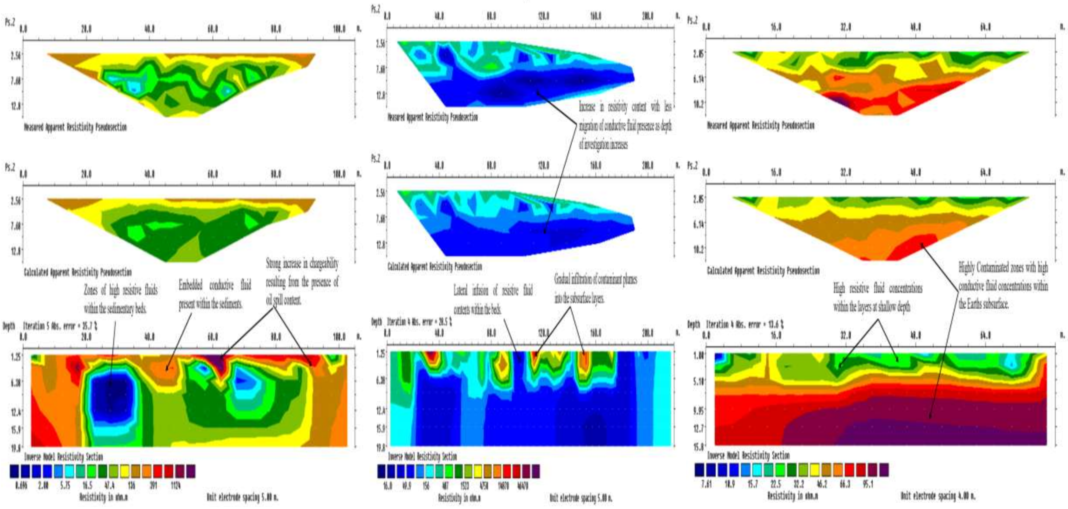


Figure 3: Geoelectric Sections of the study area



Profile 1 profile 2 Profile 3

Figure 4: 2-D tomography survey profiles of the study area

Aquifer Overburden Protective Capacity and Aquifer Vulnerability to Leachate Contaminants in Study Area

The results of the computed Dar-zarrouk parameters Bello et al;(2019) are presented in Table 3, while the aquifer protective capacity and vulnerability classification ratings (Atakpo et al, 2009) are shown in Table 4.

The result of the Dar-zarrouk parameters reveals that the total longitudinal conductance of the overburden protective capacity of the study area is rated poor and is ≤ 0.1(very low longitudinal unit conductance) but with few exception in some locations. Based on these values, as shown in Table 3, it is VES 3,4,5,6,7,8, 10, and 11 that are rated poor while VES 1, 2 and 9 were rated weak respectively. This suggest that the computed overburden layers of the area will not have significant amount of impermeable beds, therefore could be interpreted as zones of extremely high risks to aquifer contamination from leachate. This is in line with the interpreted geo-electric sections of VES 3, 4, 5, 6, 7, 8, 10 and 11 as shown in Figure 3. The overburden overlying the aquifer in this area is delineated to be 4-5 layers and consist of mainly of fine-medium sand (Table 1 and Figure 3. These formation cannot provide protection to the underlying aquifer due to the fact that fine-medium sand overburden is characterized with very low longitudinal unit conductance, thereby having no protection to the underlying aquifer. Thus, these formation will enhance the percolation of contaminants to the aquifer zone more easily since the overburden layers are porous and permeable. Based on the classification on Table 4, this area falls under extremely high vulnerability.

The findings of this work is in line with the works of Irunkwor et al (2022); in the study of electrical resistivity investigation for aquifer vulnerability to surface contaminants at dumpsites in Western Niger-Delta and Ogwah et al(2024); on Geo-electric investigation of Aquifer potentials and vulnerability at Ughelli, Niger Delta Region, where they found out that the overburden protective capacity of the area was rated weak and poor which implies that the aquifer zone will be highly vulnerable to contaminants.

Table 3: Computed aquifer overburden protective capacity and vulnerability to leachate contaminants according to Atakpo et al, (2009) in study area.

VES Points	Layer	Resistivity (Ωm)	Thickness (m)	Longitudinal Conductance of each layer (mho)	Total longitudinal conductance or $\sum(^h/_p)$	Aquifer protective capacity rating	Aquifer vulnerability rating
VES 1	1	9.5	0.90	0.094736	0.20656	Moderate	Moderate vulnerability
	2	47.2	2.16	0.045762			
	3	102	6.74	0.066078			

	4	359					
	5						
VES 2	1	27.3	0.5	0.018315	0.1014	Weak	High vulnerability
	2	168	2.6	0.015416			
	3	86	4.4	0.051162			
	4	559	9.2	0.016457			
	5						
VES 3	1	125	0.5	0.004	0.01748	Poor	Extreme high vulnerability
	2	7499	1.28	0.00017668			
	3	422	5.62	0.013317			
	4	5828					
	5						
VES 4	1	58.1	0.5	0.008605	0.003134	Poor	Extreme high vulnerability
	2	2021	1.34	0.0006630			
	3	3265	4.35	0.0013323			
	4	8254	10.2	0.0012357			
	5						
VES 5	1	10.1	0.5	0.04950	0.933	Good	Low vulnerability
	2	107	0.87	0.008130			
	3	2.81	1.87	0.66548			
	4	57	12	0.210526			
	5	455					
VES 6	1	92.1	0.6	0.0065146	0.032026	Poor	Extremely high vulnerability
	2	153	2.04	0.01333			
	3	567	4.6	0.0081128			
	4	2408	9.8	0.004069			
	5	9085					
VES 7	1	32.3	0.5	0.015479	0.023992	Poor	Extremely high vulnerability
	2	297	2.02	0.0068013			
	3	6190	10.6	0.0017124			
	4	4217					
	5						
VES 8	1	124	0.3	0.002419	0.06661		
	2	35.7	2.1	0.05882			

	3	1024	5.5	0.005371			
	4	4754					
	5						
VES 9	1	60.2	0.82	0.013621	0.14323	Weak	High vulnerability
	2	183	1.14	0.006229			
	3	71	8.76	0.12338			
	4	135					
	5						
VES 10	1	482	0.85	0.001763	0.00557	Poor	Extremely high vulnerability
	2	2763	1.62	0.0005863			
	3	1285	8.02	0.0062412			
	4	5472					
	5						
VES 11	1	815	0.5	0.005586	0.05644	Poor	Extremely high vulnerability
	2	1352	1.81	0.0013387			
	3	121	4.85	0.04008			
	4	3451	12.4				

Table 4: Aquifer protective capacity and vulnerability ratings (Bello et al, 2019)

Sum of longitudinal conductance(mho)	Overburden protective capacity rating	Vulnerability rating
5-10	Very good	Extremely Low vulnerability
0.7-4.9	Good	Low vulnerability
0.2-0.69	Moderate	Moderate vulnerability
0.1-0.19	Weak	High vulnerability
≤ 0.1	Poor	Extremely high vulnerability

CONCLUSION

The investigation revealed that the study area consists mainly of silty-clay, clayey-sand, fine-sand to coarse sand. The study shows that the aquifers zones were mainly of medium to coarse sand with resistivity values ranging from 230Ωm - 3,800Ωm and the aquifer zones depth ranges from 30m-43m.

Dar-zarrouk parameters were deployed to determine the protective capacity of the overburden layers and the vulnerability of the aquifer to surface contaminants. From the vulnerability ratings, the study revealed that the area is rated high vulnerability and extremely high vulnerability zones. The high vulnerability rating of the area is based on the fact that the protective capacity of the area is low. This implies that the overburden has no impermeable layers to retard the infiltration of surface contaminants to the aquifer zones. This will make the underlying aquifer in the area to be vulnerable to surface contaminant. The 2-D tomography survey revealed non-contaminant and contaminant zones, where the contaminant zone depth is located at 7m. However, since the depth of the aquifer zone in the area is delineated to be at 40m. This further implies that the underlying aquifer in the area is not affected by the leachate plumes, but precaution should be taken to avoid migration of the leachate into the aquifer system in the area.

RECOMMENDATIONS

1. There should be regular motoring of groundwater quality status in the study area.
2. Regular and proper sanitation practices with good waste management plans should be adopted in the study area that indicates poor and weak aquifer protective capacity ratings.

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