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Research Article

Investigation of the Aquifer Protective Capacity and Groundwater Quality around Some Open Dumpsites in Sapele Delta State, Nigeria

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Aquifer protective capacity and groundwater quality investigations around some open dumpsites were conducted along New Road Sapele, Delta State. Nine Schlumberger arrangements of vertical electrical soundings (VES) were carried out with a maximum electrode separation of 500 m, and obtained data were interpreted by partial curve matching and computer iteration using Win Resist software. 2D survey using nine dipole-dipole stations was also utilized to give resistivity map of the dumpsites, while standard laboratory methods were used to analyze the groundwater. The study shows four to five geoelectric sections. The aquifer is within the third, fourth, and fifth layers at a depth of 30 m. The overburden protective capacity from the total longitudinal unit conductance indicates that VES 1 and 5 are adequately protected with protective capacity of 0.7 to 0.9 mhos, VES 2, 3, 6, and 7 are moderately protected with conductance values of 0.2 to 0.69 mhos, VES 4 is weakly protected with values of 0.12 mhos, and VES 8 and 9 are poorly protected with values of 0.003 to 0.004 mhos. In the 2D imaging, VES 4, 8, and 9 show contaminant presence to the depth of 20 m while VES 3, 6, and 7 show contamination to a depth of 50 m. However, the aquifer shows good transmissivity, an indication that if it is contaminated, the contaminants will circulate the aquifer at a high rate. The groundwater flows in the northeast (NE) direction, thereby recharging river Ethiope. The study also shows the presence of lead (0.01 mg/l), nickel (0.02 mg/l), and cadmium (0.03 mg/l), which made it unsafe for drinking and use in other life-related activities. Groundwater should hence be sourced from a depth of about 45–50 m in order to tap from the uncontaminated aquifer.

1. Introduction

Almost every nation of the world is faced with environmental pollution challenges. Nigeria as a nation has a waste management challenge as a result of her population growth as well as industrialization [1]. Outbreak of epidemics as well as diseases has been traced to ways by which waste is disposed. Sapele town has pockets of open waste disposal units making the area prone to diseases. Also, surface and shallow groundwater pollution within the city of Sapele has been linked with high concentration of ions of nickel (Ni), cadmium (Cd), and suspended solids in the body of water from the decomposition of domestic and industrial waste [2].

Groundwater flow interaction or infiltration from precipitation usually occurs in landfills or open dumpsites. The dumped wastes gradually release the initial interstitial water (leachate), and some of its decomposed by-products get into water moving through the waste deposit. These leachates accumulate at the bottom of the wastes and percolates through the soil, migrate downward, and contaminate the groundwater. The leachate sometimes contains mainly organic carbon largely in the form of fulvic acids. It usually contains toxic substances, especially, when wastes are of industrial origin [3]. Such contamination of groundwater resource poses a substantial risk to people, animals, and the natural environment.

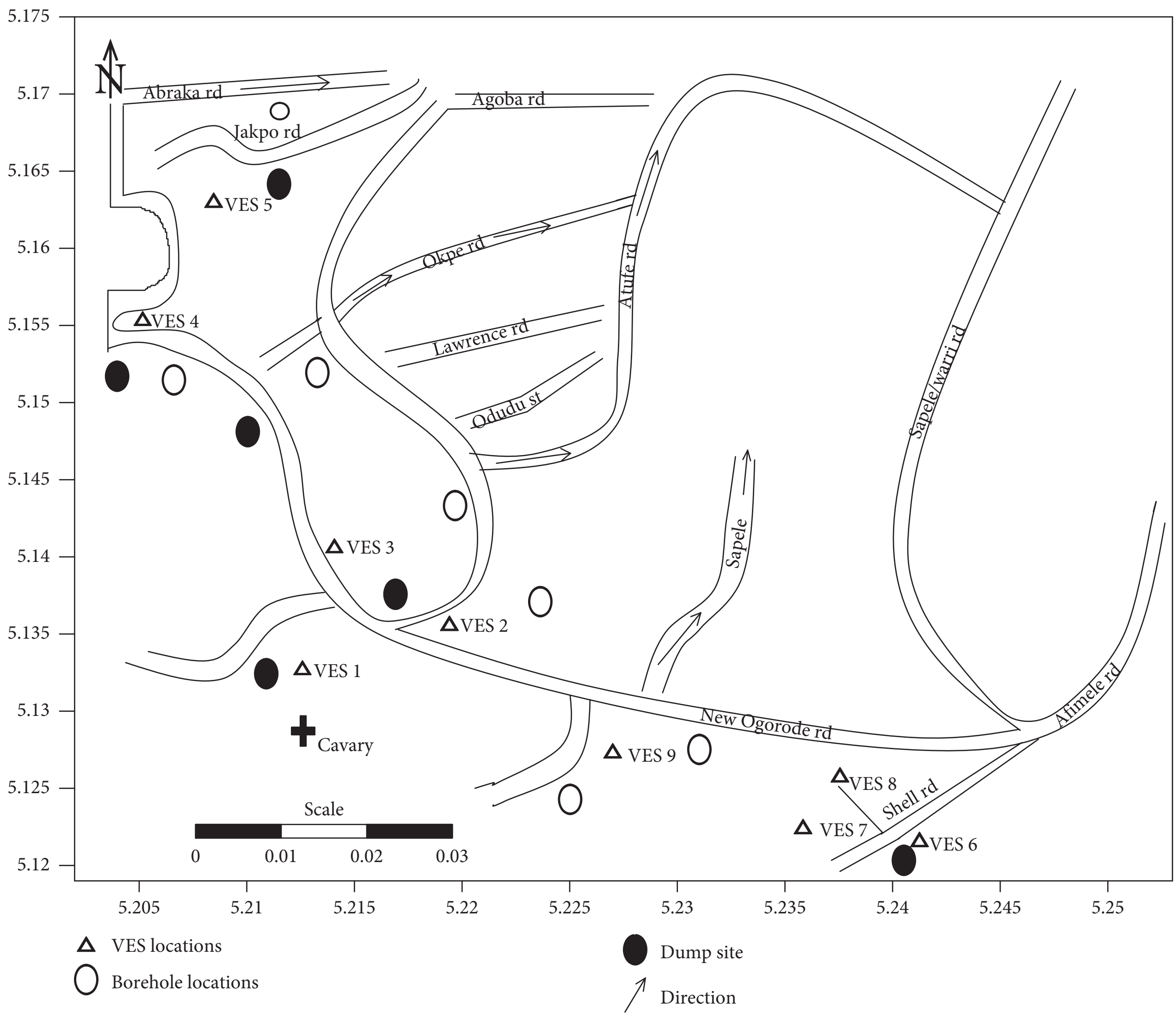


Figure 1: Base map of study area.

The area under investigation is fast growing in terms of population and business activities. Apart from the public boreholes providing water for the inhabitants, due to epileptic power supply, most persons still utilize water from hand dug wells in almost all their domestic and industrial purposes.

Due to the fact that the dumpsites are currently giving way to residential buildings, an evaluation of the aquifer protective capacity is thus important in this area to ascertain the portability of the water and know how vulnerable the aquifer is to contamination. This was achieved with the use of the electrical resistivity method. The electrical resistivity method involved the use of current which is introduced into the ground through a pair of electrodes (current electrode). While the resulting potential difference is measured by another pair of electrodes called potential electrodes, this may or may not be located within the current electrode [4].

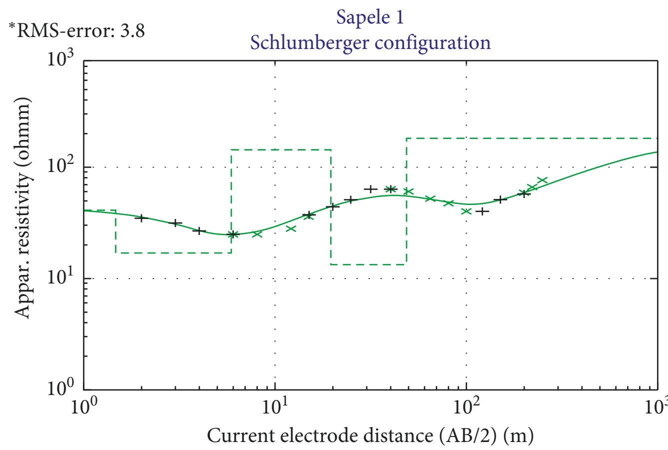
Atakpo [5] adopted the resistivity survey in his study of aquifer vulnerability investigation using geoelectric method in parts of Sapele Local Government Area of Delta State, Nigeria. He concluded that the resistivity survey revealed poor protective capacity (<0.1 mhos) in all parts of the study area.

Table 1: Parameters for calculating the apparent resistivity and thickness of various layers.

Layers	Resistivity	Thickness
1	ℓ	h_1
2	$\ell_1 \times \mathrm{K}_1$	$h_1 r \times D_{\mathrm{I}1}$
3	$\ell_2 r \times K_2$	$h_2 r \times D_{\mathrm{I}2}$
4	$\ell_3 r \times K_3$	$h_3 r \times D_{\mathrm{I}3}$

Egbai et al. [6] used the geoelectric method in evaluating the aquifer vulnerability at Igbanke, Orhionmwon Local Government area of Edo State, Nigeria. The result they obtained shows poor and weak protective capacity rating in almost all parts of the study area.

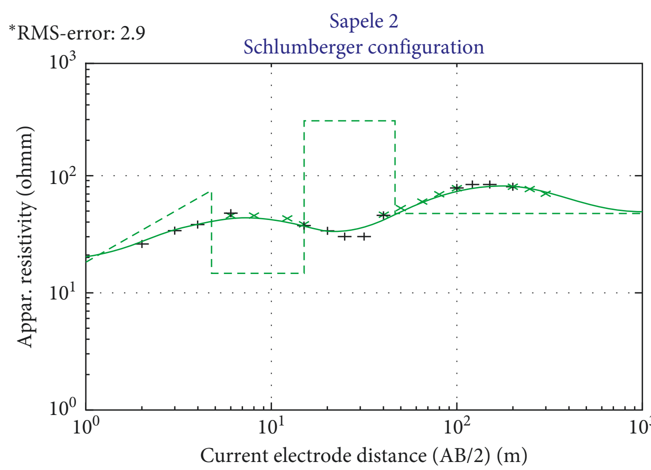
Oladunjoye et al. [7] used integrated 2-dimensional resistivity imaging and geochemical analysis in



No.	Res	Thick	Depth
1	41.5	1.5	1.5
2	17.1	4.4	5.8
3	142.7	1.3.8	19.6
4	13.4	29.1	48.7
5	181.7	-.-	-.-

*RMS on smoothed data

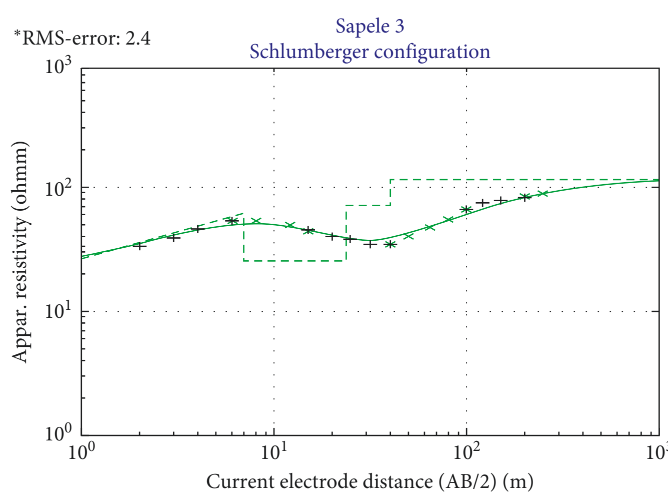
Figure 2: Typical hydrogeophysical sounding curve for Sapele VES 1.



No.	Res	Thick	Depth
1	18.0	1.0	1.0
2	75.8	3.8	4.7
3	14.7	10.2	14.9
4	293.5	31.1	46.0
5	47.2	-.-	-.-

*RMS on smoothed data

Figure 3: Typical hydrogeophysical sounding curve for Sapele VES 2.



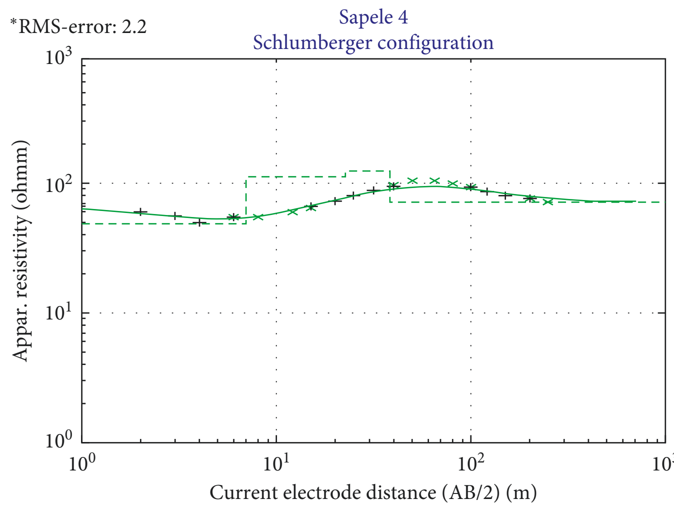
No.	Res	Thick	Depth
1	26.0	1.0	1.0
2	62.5	6.0	7.0
3	25.4	16.9	23.9
4	70.8	16.7	40.6
5	115.1	-.-	-.-

*RMS on smoothed data

Figure 4: Typical hydrogeophysical sounding curve for Sapele VES 3.

environmental impact assessment of waste disposal site in Ibadan, Southwestern Nigeria. The resistivity survey yielded low resistivity values at locations close to the septic tank and higher values further from it which revealed that the environment is impacted by the septic system.

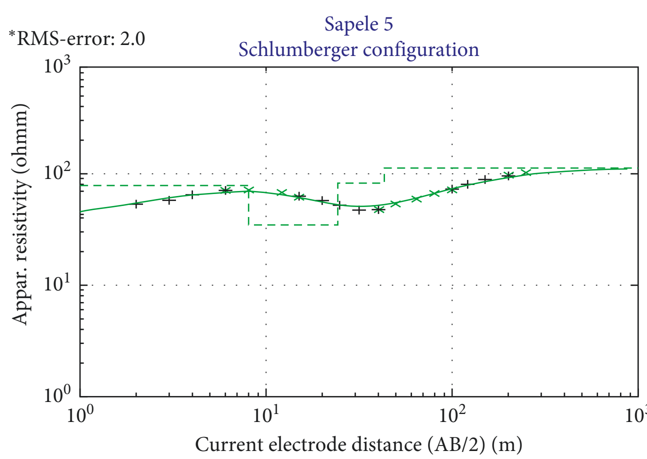
Atakpo [8] adopted the resistivity survey in assessing the contamination of groundwater by hydrocarbons in



No.	Res	Thick	Depth
1	65.1	1.0	1.0
2	49.2	6.0	7.0
3	111.5	15.4	22.4
4	124.8	15.6	38.1
5	71.8	-.-	-.-

*RMS on smoothed data

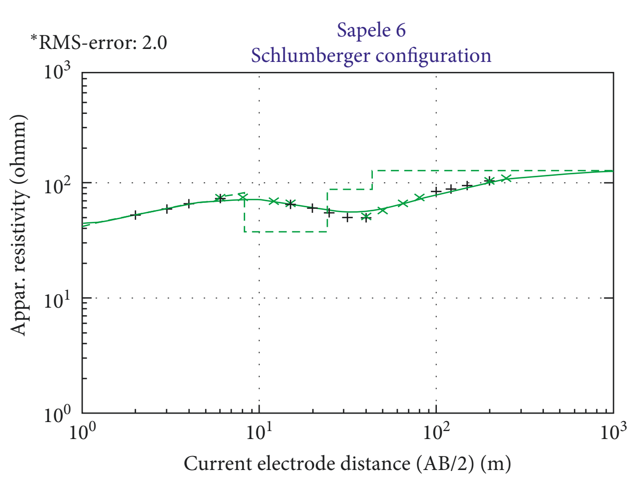
Figure 5: Typical hydrogeophysical sounding curve for Sapele VES 4.



No.	Res	Thick	Depth
1	45.6	1.0	1.0
2	78.5	7.0	8.0
3	35.0	16.2	24.1
4	83.3	19.0	43.1
5	113.9	-.-	-.-

*RMS on smoothed data

Figure 6: Typical hydrogeophysical sounding curve for Sapele VES 5.



No.	Res	Thick	Depth
1	41.9	1.0	1.0
2	81.8	7.3	8.3
3	37.6	16.1	24.4
4	89.5	18.8	43.2
5	126.3	-.-	-.-

*RMS on smoothed data

Figure 7: Typical hydrogeophysical sounding curve for Sapele VES 6.

Uvwiamuge locality, Delta State, Nigeria. The result revealed pollution of groundwater as a result of exploration and exploitation of petroleum in the area.

Ehirim and Ofor [9] used integrated 2D resistivity imaging and vertical electrical sounding (VES) in the study of aquifer vulnerability to surface contamination near two solid

Table 2: Geoelectric parameter and lithologic delineation the VES at Sapele.

S. no.	Layers	Resistivity	Thickness	Depth to bottom	Lithology	Curves
VES 1	1	41.5	1.5	1.5	Topsoil	HKH $\rho1 > \rho2 < \rho3 > \rho4 < \rho5$
	2	17.1	4.4	5.9	Clay	
	3	142.7	13.8	19.6	Clayey sand	
	4	13.4	29.1	48.7	Clay	
	5	181.7	Undetermined	Undetermined	Fine to medium sand	
VES 2	1	18.0	1.0	1.0	Topsoil	KHK $\rho1 < \rho2 > \rho3 < \rho4 > \rho5$
	2	75.8	3.8	4.8	Clayey sand	
	3	14.7	10.2	14.9	Clay	
	4	293.5	31.1	46.0	Fine to medium sand	
	5	47.2	Undetermined	Undetermined	Clay sand	
VES 3	1	26.0	1.0	1.0	Topsoil	KHA $\rho1 < \rho2 > \rho3 < \rho4 < \rho5$
	2	62.5	6.0	7.0	Clayey sand	
	3	25.4	16.9	23.9	Clay	
	4	70.8	16.7	40.6	Clay	
	5	115.1	Undetermined	Undetermined	Fine to medium sand	
VES 4	1	65.1	1.0	1.0	Topsoil	HAK $\rho1 > \rho2 < \rho3 < \rho4 > \rho5$
	2	49.2	6.0	7.0	Clayey sand	
	3	111.5	15.4	22.4	Fine to medium sand	
	4	124.8	15.6	38.1	Fine to medium sand	
	5	71.8	Undetermined	Undetermined	Clay	
VES 5	1	45.6	1.0	1.0	Topsoil	KHA $\rho1 < \rho2 > \rho3 < \rho4 < \rho5$
	2	78.5	7.0	8.0	Clayey sand	
	3	35	16.2	24.1	Clay	
	4	83.3	19.0	43.1	Clay	
	5	113.9	Undetermined	Undetermined	Fine to medium sand	
VES 6	1	41.9	1.0	1.o	Topsoil	KHA $\rho1 < \rho2 > \rho3 < \rho4 < \rho5$
	2	81.1	7.3	8.3	Clayey sand	
	3	37.6	16.1	24.4	Clay	
	4	89.5	18.8	43.2	Clay	
	5	126.3	Undetermined	Undetermined	Fine to medium sand	
VES 7	1	71.0	0.7	0.7	Topsoil	AAA $\rho1 < \rho2 < \rho3 < \rho4 < \rho5$
	2	235.3	5.8	6.4	Clay	
	3	127.1	15.6	22.0	Clay	
	4	122.3	20.9	42.8	Fine to medium sand	
	5	522.5	Undetermined	Undetermined	Medium sand	
VES 8	1	207	1	1	Topsoil	KHA $\rho1 < \rho2 > \rho3 < \rho4 < \rho5$
	2	374.3	7.3	8.2	Medium	
	3	175.8	17.8	26.0	Fine to medium sand	
	4	349.7	19.7	45.7	Fine to medium	
	5	624.9	Undetermined	Undetermined	Medium sand	
VES 9	1	312.1	1.1	1.1	Topsoil	HAA $\rho1 > \rho2 < \rho3 < \rho4 < \rho5$
	2	134.2	5.2	6.3	Fine to medium sand	
	3	349.9	11.7	18.1	Fine to medium sand	
	4	711.6	17.2	35.2	Medium sand	
	5	919.2	Undetermined	Undetermined	Medium sand	

waste landfill sites in Port-Harcourt municipality, River State, Nigeria. They concluded that the soil and the groundwater system may have been contaminated to depths exceeding 31.3 m in the sites.

Nwankwor [10] employed 2D resistivity survey for groundwater exploration in hard rock terrain: a case study of Magdas observatory, Unilorin. Nigeria. The analysis of resistivity and thickness maps reveal that the Western parts of the study area have relative low resistivity in the fractured weathered rocks.

Egbai and Efeya [11] used the geoelectric method for investigating saltwater intrusion into freshwater aquifer in Deghele community of Warri South Local Government Area of Delta State. They opined that the intrusion of saline water into the aquifer is due to the closeness to the sea.

This study is important because it discusses the study area's topography, lithology, groundwater flow, and the protective capacity of the aquifer as well as the groundwater portability. Due to the increasing demand for portable water especially as the area under study has being transformed to residential area, it is considered that predrilling and hydrochemical study should be carried out to obtain detailed information on aquifer conditions of the area before sitting borehole.

Table 3: First-order geoelectric parameter and Dar Zarrouk parameter of the study area.

S. no.	Protecting layers	Protecting layers resistivity	Thickness	$(\rho/n) = \overline{R}$	$H_T = h_i + h_2 \ldots$	Longitudinal conductivity of protecting layers = h_T/R	Protective capacity rating
VES 1	1	41.5	1.5	53.75	48.8	0.9079	Good
	2	17.1	4.4				
	3	142.7	13.8				
	4	13.7	29.1				
VES 2	1	18.0	1.0	36.17	15	0.4147	Moderate
	2	75.8	3.8				
	3	14.7	10.2				
VES 3	1	26.0	1.0	184.7	40.6	0.2198	Moderate
	2	62.5	6.0				
	3	25.4	16.9				
	4	70.8	16.7				
VES 4	1	65.1	1.0	57.15	7	0.1225	Weak
	2	49.2	6.0				
VES 5	1	45.6	1.0	60.6	43.2	0.7129	Good
	2	78.5	7.0				
	3	35.0	16.2				
	4	83.3	19.0				
VES 6	1	41.9	1.0	161.3	24.4	0.6909	Moderate
	2	81.8	7.3				
	3	37.6	16.1				
	4	89.5	18.8				
VES 7	1	71.8	0.1	147.7	139.13	0.3004	Moderate
	2	235.3	5.8				
	3	127.1	15.6				
	4	122.3	20.3				
VES 8	1	207.0	1.0	207	1	0.0048	Poor
VES 9	1	312.1	1.1	312.1	1.1	0.0035	Poor

The study therefore is aimed at investigating leachate generation and migration paths around some open dumpsites in Sapele using both Schlumberger arrangement of Vertical Electrical Sounding and 2-dimensional survey of dipole-dipole stations as well as geochemical analysis of groundwater using standard laboratory methods. This research will also enable one to delineate the favorable hydrogeological area/region for portable/productive aquifer hence recommends suitable location boreholes could be drilled for potable and sustainable water supply to individuals and government involved in borehole installations.

2. Location and Geology of the Study Area

The study area (Sapele) is located within longitudes 5°37′E to 5°44′E and latitudes 5°51′N to 5°52′N in Sapele Local Government Area of Delta State, Nigeria (Figure 1). It is within the Niger Delta basin. The area displays the characteristic features of seaward sloping flat with elevation of about 10–13 m above sea level. It is of equatorial climate made of two main seasons, the wet and dry season. The wet season begins from April and ends in September while dry season begins from October and ends in March.

The low lying depression swamp is of fresh water with typical rain forest vegetation. The stratigraphic traps are the Akata formation overlain by the Agbada formation. The Benin formation is the youngest, and it is the prolific aquifer. However, the formation is masked in the Sombrero–Deltaic plain by a sequence of silts, medium to coarse grained sands, sandy clays, and clay bands. This sequence is indistinguishable from the underlying Benin formation in borehole sections and is indeed the present day expression of this formation. The problem though is that the clay bands are not uniform in thickness, and many boreholes have been abandoned because the entire clay sequence could not be penetrated in order to access the underlying water bearing sandy layers or the aquifer [5].

3. Methodology

The methods consist of two stages. First is the electrical resistivity method where electric current was introduced into the ground. Second was the collection of water sample from areas around the dumpsite for analysis. The Electrical resistivity survey method employed is the vertical electrical sounding (VES) and horizontal profiling techniques. The Schlumberger configuration was adopted for the vertical electrical sounding with a maximum current electrode separation AB of 500 m, which was deemed sufficient in allowing a depth penetration of 250 m (AB/2) and dipole-dipole configuration with electrode spacing of 10 m. Potential electrode separation was increased several times during the sounding at MN/2 equals 1.0 m to 20 m. The procedures include the introduction of current into the earth and measurement of the potential between two electrodes resulting from an applied current through two

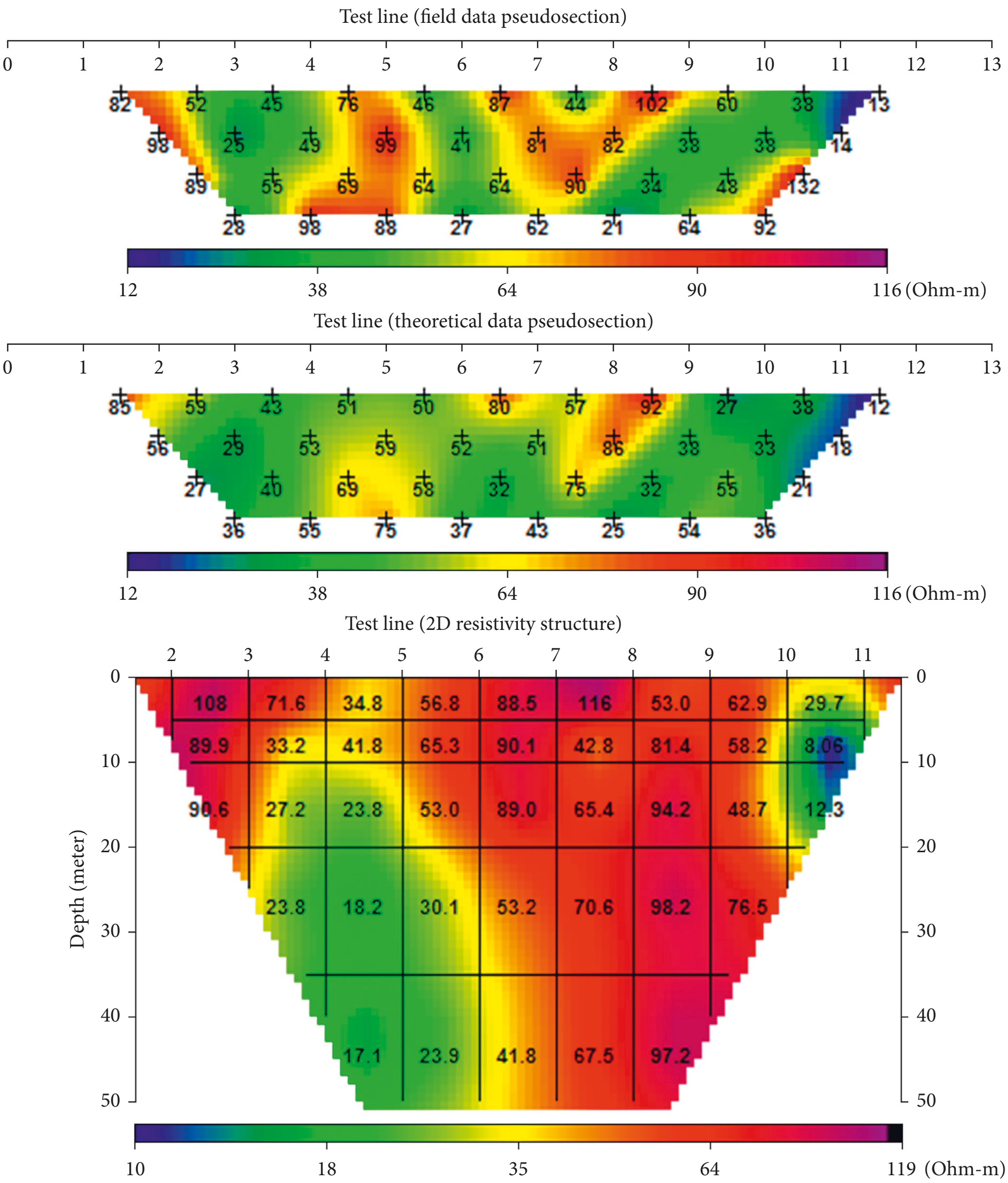


Figure 8: Inverted 2D resistivity structure along profile 1.

other electrodes collinear with the potential electrodes. The distance of the fixed electrode from the two current electrodes was equal and was connected to the terrameter via point AB on the terrameter. Similarly, two potential electrodes of equal spacing and on opposite side of the fixed electrode were connected to the point MN on the terrameter.

Nine vertical electrical soundings and nine dipole-dipole surveys were conducted within the dumpsite area. This method does both profiling and sounding at the same time. The dipole-dipole method is sometimes referred to as 2D resistivity surveying.

Six hand dug wells around the dumpsites in Sapele were selected for the study. Depth to water level in each of the dug wells was measured with the measuring tape. A Germin model GPS instrument was used to determine well coordinates and elevation. The sampling procedure consists of collecting replicate samples into sterilized polyethylene bottles. The set of samples designated for selected cations analysis were immediately stabilized with acid at different specific temperatures. Electrical conductivity and total dissolved solids were measured in situ using the HACH Conductivity/TDS meter. The pH was determined by means of a Schott Gerate model pH meter, and temperature was determined using mercury-in-glass thermometer calibrated in 0.2/C units from 0°C to 100°C.

4. Presentation of Results

The field data acquired using ABEM SAS 1000 Terrameter gave the value of the apparent resistivity in ohm meter (Ωm) at each electrode spacing (AB/2). This was plotted on a bi-log

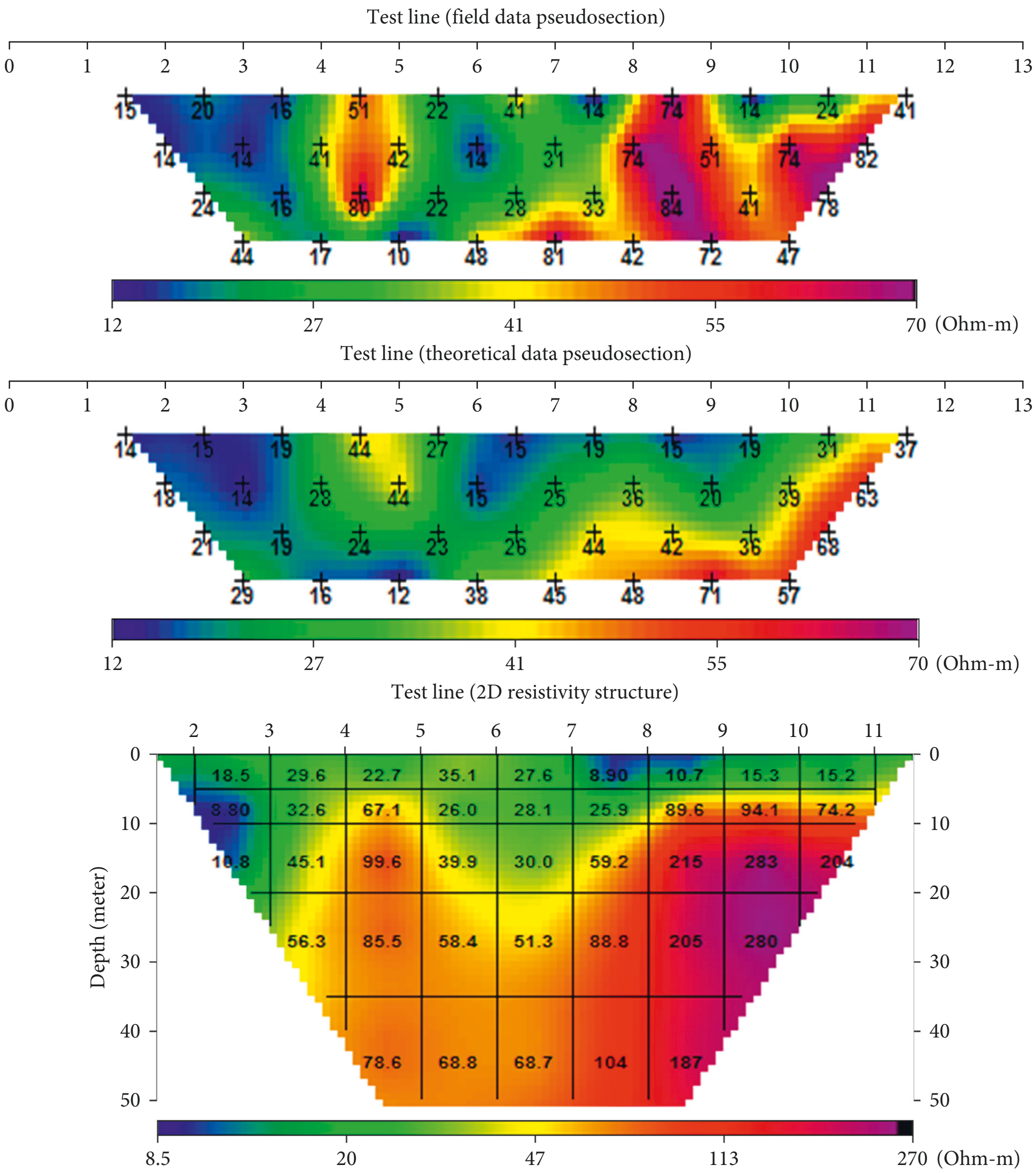


Figure 9: Inverted 2D resistivity structure along profile 2.

or log-log graph paper with the apparent resistivity (ρa) on the vertical axis and the electrode spacing (AB/2) on the horizontal axis.

The curves obtained from the plot of the VES were interpreted quantitatively using partial curve matching and computer iteration. The VES partial curve matching was done by matching segment by segments of field data curve using both the theoretical master and auxiliary curves (ascending or descending curve type). The procedures are as follows:

(i) An appropriate master curve either ascending or descending depending on the orientation and shape of the field curves was chosen.

(ii) The apparent resistivity (ρa) plotted against AB/2 on the transparent paper as obtained in the field was superimposed on the master curve to ascertain the curve of best fit.

(iii) The axis of the master and field curve was kept parallel, while the transparent paper with the curve on it is moved on the various master curves until a satisfactory curve of the best fit was obtained.

(iv) The line where the field curve fits was traced out and the point where it starts to deviate was marked with a cross (+) sign, and the number assigned to that line was marked as K_1.

(v) The marked field curve was placed on an appropriate auxiliary curve, and the cross (+) point was traced vertically to derive the depth index (D_1).

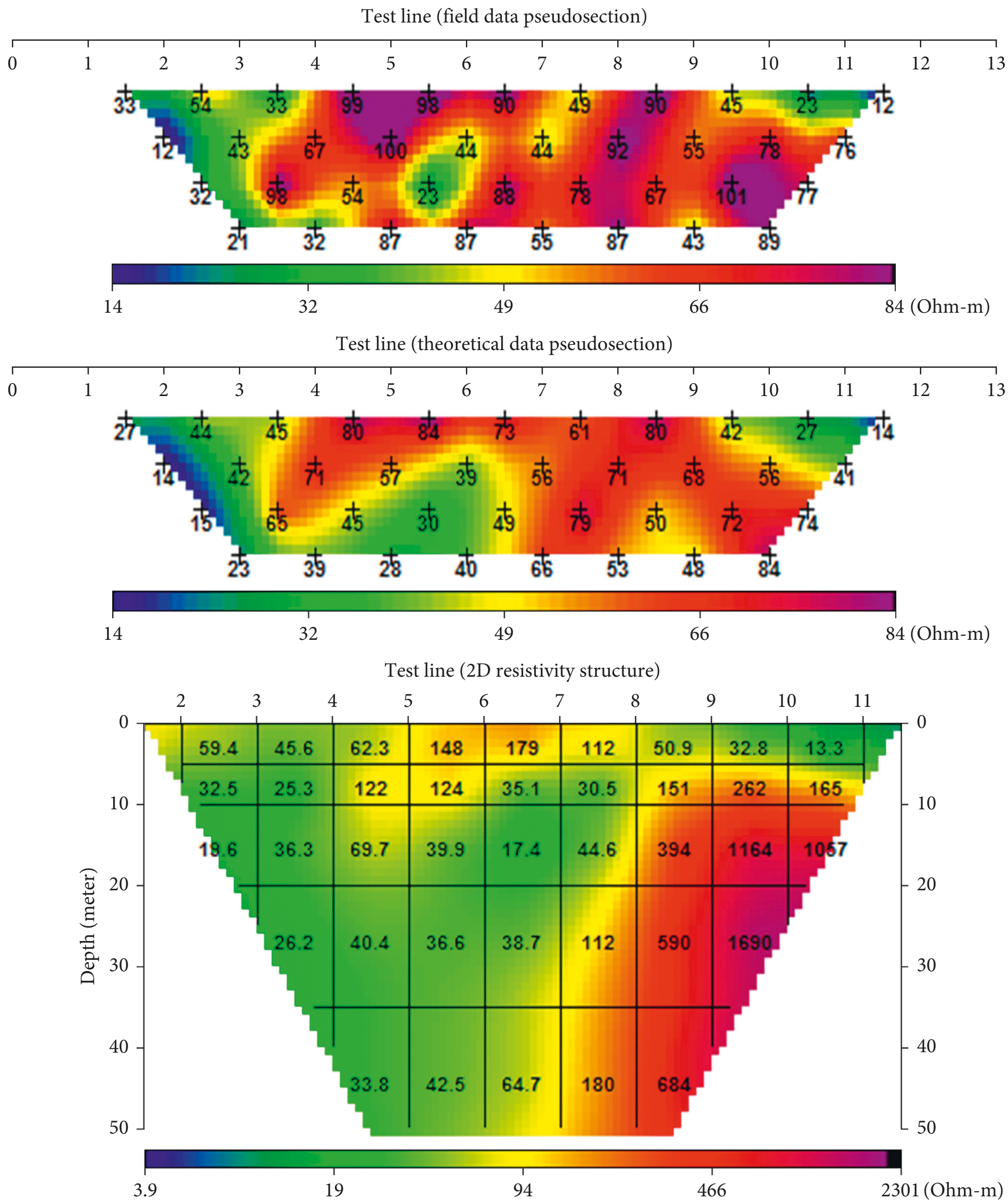


Figure 10: Inverted 2D resistivity structure along profile 3.

(vi) After getting the K and D_1 values, the transparent paper was placed with the field curve on the bi-logarithm paper, and the point marked K_1 was traced both vertically and horizontally to obtain its apparent resistivity (ℓ_a) and thickness (h), respectively.

(vii) The real resistivity and thickness of each layer were calculated using the parameters in Table 1.

The thickness and resistivity values obtained from the partial curve matching were imputed into the software program (Win Resist) in a computer as model parameters. The process is now run by the program as a routine which in turn displayed an automatically plotted graph with an error tolerance limit set for the program iteration, and when this is done or achieved, the model match becomes the interpreted layer parameters as shown in Figures 2–7 for VES 1 to VES 6 as displayed examples.

5. Data Analysis and Interpretation

Results were analyzed to determine the aquifer potential and delineate the lithology of the study area. The resistivity values and depths obtained after iteration were used to interpret the lithology of the study area which showed four to five layers as shown in Table 2. The first layer is the topsoil and has resistivity of 18.0 Ωm–71.0 Ωm in VES 1 to VES 6 while VES 7 to VES 9 have high resistivity values of between 71.8 Ωm – 312.0 Ωm at the top soil with an average thickness of 1 m. In VES 1 to VES 6, the second layer has resistivity values of

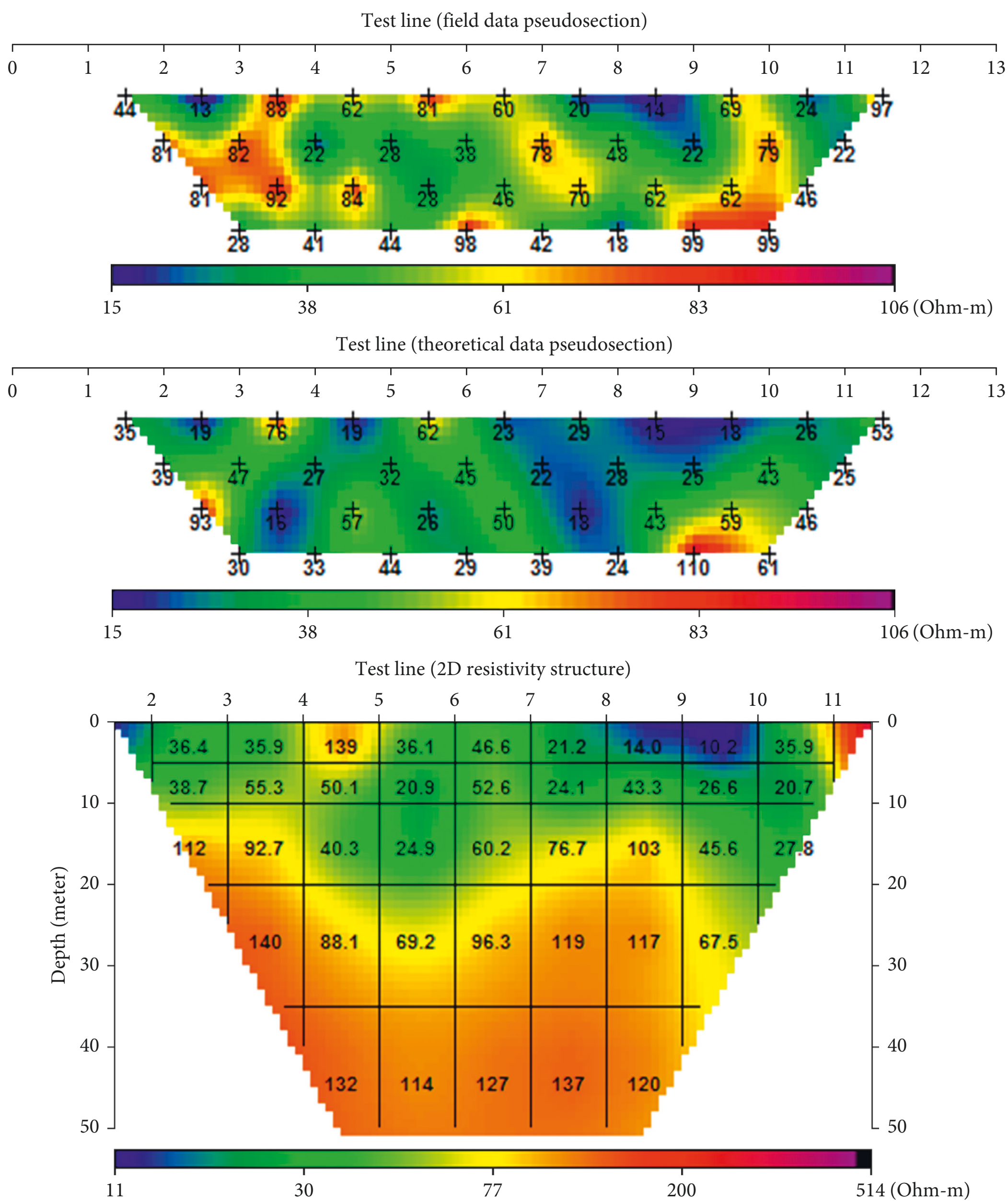


Figure 11: Inverted 2D resistivity structure along profile 4.

17.0 Ωm–81.0 Ωm with an average thickness of 6 m which indicate clay formation. The third layer has resistivity of 14 Ωm–142 Ωm and an average thickness of 16 m showing a clayey sand formation while the fourth and the fifth layers has an alternation of clay and fine sand formation with resistivity values of 13.4 Ωm–293.0 Ωm with average thickness of 25.0 m. The fifth layer thickness could not be ascertained as the current terminated at this point. Meanwhile, VES 7 to VES 9 have an alternation of fine to medium sand formations at the 2nd, 3rd, 4th, and 5th layers with resistivity values of 122.0 Ωm–919.2 Ωm and thickness of 20.0 m except the fifth layer that is not determined. The aquifer zone lies within the third, fourth, and fifth layers at a depth of about 30 m and below.

Table 3 shows first-order geoelectric parameter and Dar Zarrouk parameter of the study area. The longitudinal conductance (mhos) ratings were modified by Oladapo et al. [12] as follows: >10, excellent; 5 to 10, very good; 0.7 to 4.9, good; 0.2–0.69, moderate; 0.1 to 0.19, weak; <0.1, poor and were used for the interpretation of the protective capacity of the layers.

The longitudinal conductance values obtained showed that the study area is adequately protected except for VES 8 and 9 that are unconfined. The high value of the protective capacity is as a result of the presence of significant amount of clay as an overburden impermeable material in the study area, thereby not enhancing the percolation of contaminants into the aquifer. The aquifer in study area is therefore

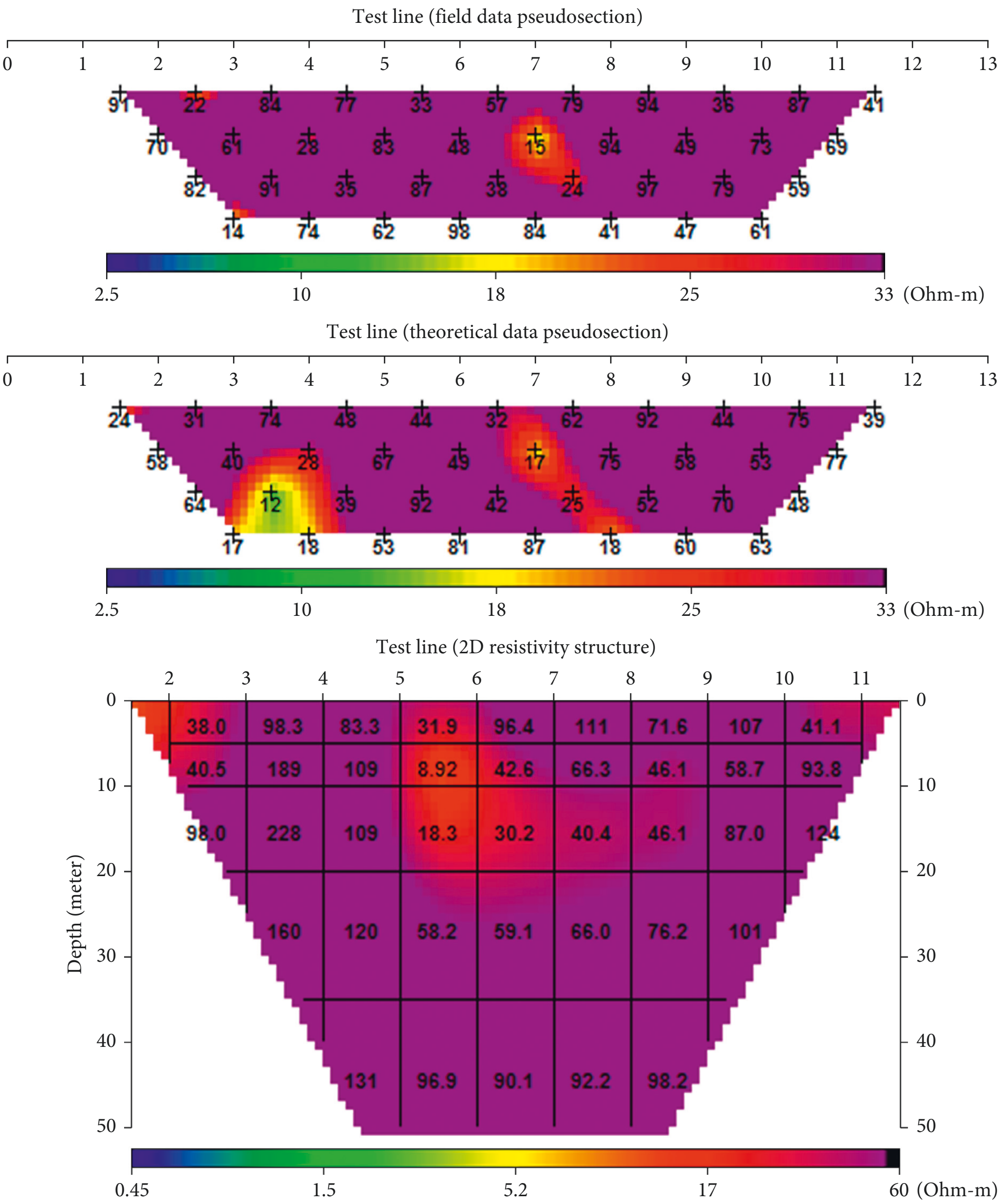


Figure 12: Inverted 2D resistivity structure along profile 5.

not prone to contamination from the waste in the dumpsite.

Samples of the results of the 2D resistivity inversion of the study area in Sapele are shown in Figures 8–14. The profile length is 110 m and about 20 m from the adjacent profiles. Sharp high and low resistivity values can be observed at different locations in the 2D image suggesting leacheat plume in the aquifer at various depths.

In profile 1, the resistivity of the topsoil ranged from 29.7 to 116 Ωm and thickness of 0.7 m, the resistivity of the second layer ranged from 8.0 to 89.9 Ωm and thickness of 7 m, the resistivity of the third layer ranged from 12.3 to 94.2 Ωm with thickness of 10 m, and the resistivity of the fourth layer ranged from 18.2 to 98.2 Ωm with thickness of 15 m. Leacheat plume can be delineated at the second and third layer as blue coloured zone, and the area can be said to be moderately protected.

In profile 2, the resistivity of the topsoil ranged from 8.9 to 35.1 Ωm and thickness of 0.6 m, the resistivity of the second layer ranged from 8.80 to 94.1 Ωm and thickness of 6.6 m, the resistivity of the third layer ranged from 10.8 to 283 Ωm with thickness of 10 m, and the resistivity of the fourth layer ranged from 51.3 to 280 Ωm with thickness of 10 m. Leacheat plums can be delineated at layers 1, 2, and 3, indicating a weak protection as the lecheat move downwards.

In profile 3, the resistivity of the topsoil ranged from 13.3 to 179 Ωm and thickness of 1 m, the resistivity of the second layer ranged from 30.5 to 262 Ωm and thickness of 7 m, the resistivity of the third layer ranged from 17.4 to 1164 Ωm

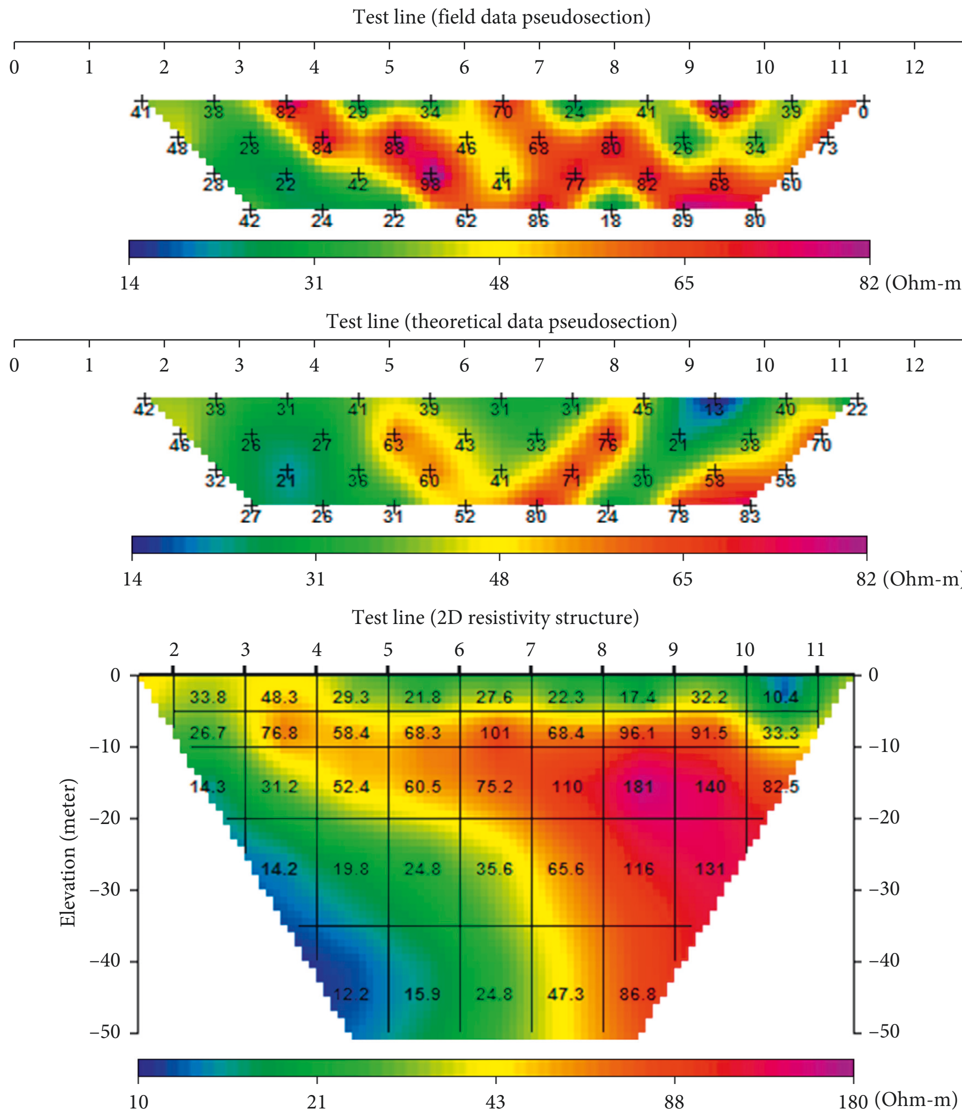


FIGURE 13: Inverted 2D resistivity structure along profile 6.

with thickness of 10 m, and the resistivity of the fourth layer ranged from 26.2 to 1690 Ωm with thickness of 10 m. The absence of visable leacheat plum as well as resistivity values indicates that the aquifer in this location is moderately protected.

In profile 4, the resistivity of the topsoil ranged from 10.2 to 139 Ωm and thickness of 1 m, the resistivity of the second layer ranged from 20.9 to 55.3 Ωm and thickness of 6 m, the resistivity of the third layer ranged from 24.9 to 112 Ωm with thickness of 10 m, and the resistivity of the fourth layer ranged from 67.5 to 140 Ωm with thickness of 10 m. There is a sharp delineation of lecheat plum at layers 1, 2, and 3 which is as well moving downward, indicating a poorly protected aquifer.

In profile 5, the resistivity of the topsoil ranged from 31.9 to 111 Ωm and thickness of 0.3 m, the resistivity of the second layer ranged from 8.92 to 189 Ωm and thickness of 6 m, the resistivity of the third layer ranged from 18.3 to 228 Ωm with thickness of 10 m, and the resistivity of the fourth layer ranged from 58.2 to 160 Ωm with thickness of 10 m. Delineation of lechate plum around layer 1, 2, and 3 suggest that the profile is weakly protected.

In profile 6, the resistivity of the topsoil ranged from 10.4 to 48.3 Ωm and thickness of 0.6 m, the resistivity of the second layer ranged from 26.7 to 101 Ωm and thickness of 6.4 m, the resistivity of the third layer ranged from 14.3 to 181 Ωm with thickness of 10 m, the resistivity of the fourth layer ranged from 14.2 to 131 Ωm with thickness of 10 m. This area can be said to be poorly protected as the leacheat plum can be observed running through the entire layers at specific points and a movement part indicating the invading of entire aquifer with time.

In profile 7, the resistivity of the topsoil ranged from 19.3 to 186 Ωm and thickness of 1 m, the resistivity of the second layer ranged from 27.6 to 241 Ωm and thickness of 7 m, the resistivity of the third layer ranged from 19.4 to 152 Ωm with thickness of 10 m, and the resistivity of the fourth layer ranged from 16.4 to 96.6 Ωm with thickness of 10 m. This profile can be said to be moderately protected as there is no

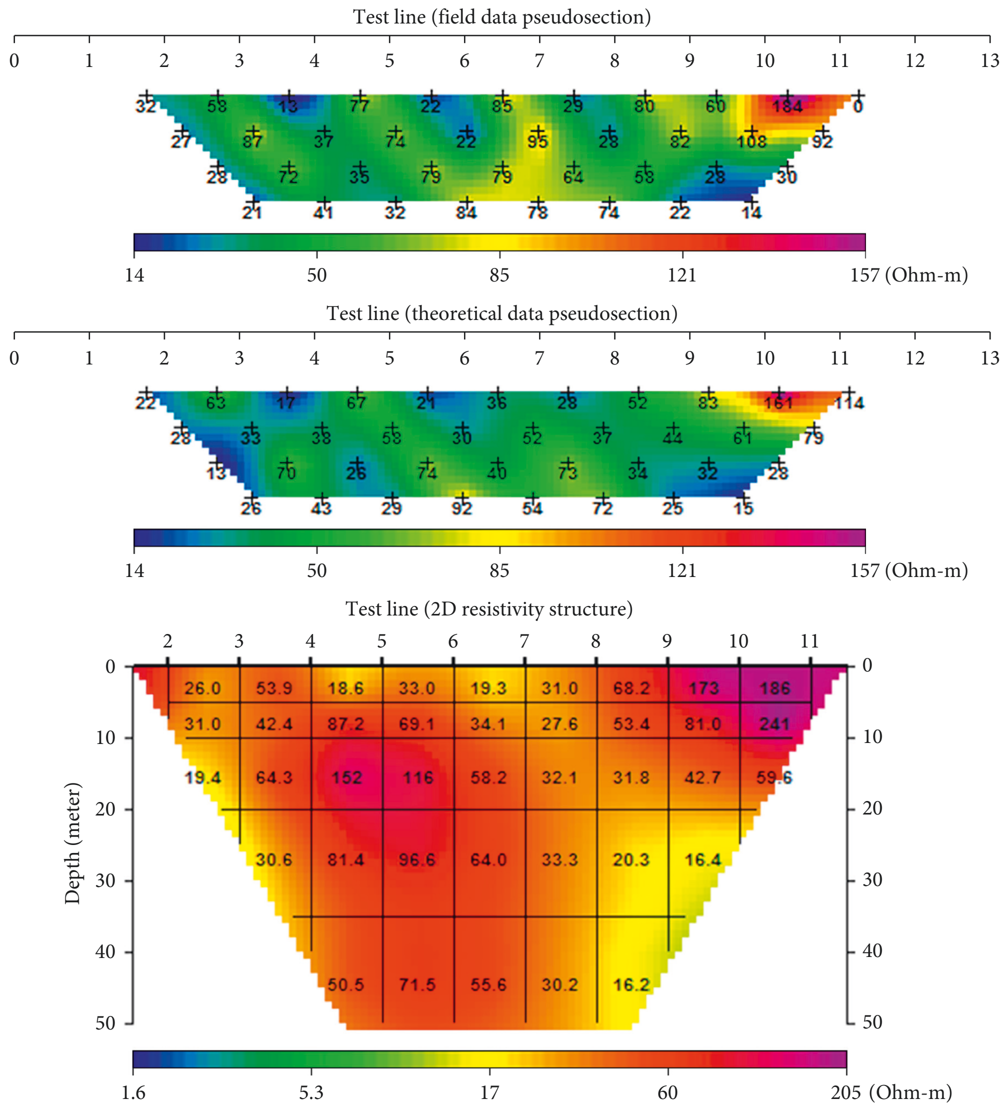


Figure 14: Inverted 2D resistivity structure along profile 7.

Table 4: Field data acquired for the head, elevations, and depth to water level in hand dug well.

S/N	Latitude	Longitude	Elevation E (m)	Depth to water level in hand dug well D_{WL} (m)	Elevation of hydraulic head $H = E - D_{WL}$ (m)
1	N05°51.613′	E005°41.573′	13	5.80	7.20
2	N05°51.752′	E005°41.55′	12	5.32	6.68
3	N05°51.624′	E005°41.572′	9	5.20	3.80
4	N05°53.057′	E005°40.865′	9	6.20	2.80
5	N05°52.937′	E005°41.198′	8	5.10	2.90
6	N05°53.051′	E005°40.865′	7	5.80	1.20
7	N05°40.761′	E005°40.763′	10	5.40	4.60
8	N05°53.057	E005°40.865′	10	2.00	8.0
9	N05°53.051′	E005°40.865′	10	2.00	8.0

clear delineation on lecheat plum but the low resistivity at the top of the profile still suggest an invasion subsequently.

In profile 8, the resistivity of the topsoil ranged from 10.3 to 90.3 Ωm and thickness of 1 m, the resistivity of the second layer ranged from 6.55 to 34.4 Ωm and thickness of 6.8 m, the resistivity of the third layer ranged from 8.29 to 50.2 Ωm with thickness of 10 m, and the resistivity of the fourth layer ranged from 24.3 to 114 Ωm with thickness of 10 m. Bluish to faint blue coloured zone in layer 1, 2, and 3 indicates that the profile is poorly protected.

In profile 9, the resistivity of the topsoil ranged from 7.26 to 44.5 Ωm and thickness of 1 m, the resistivity of the

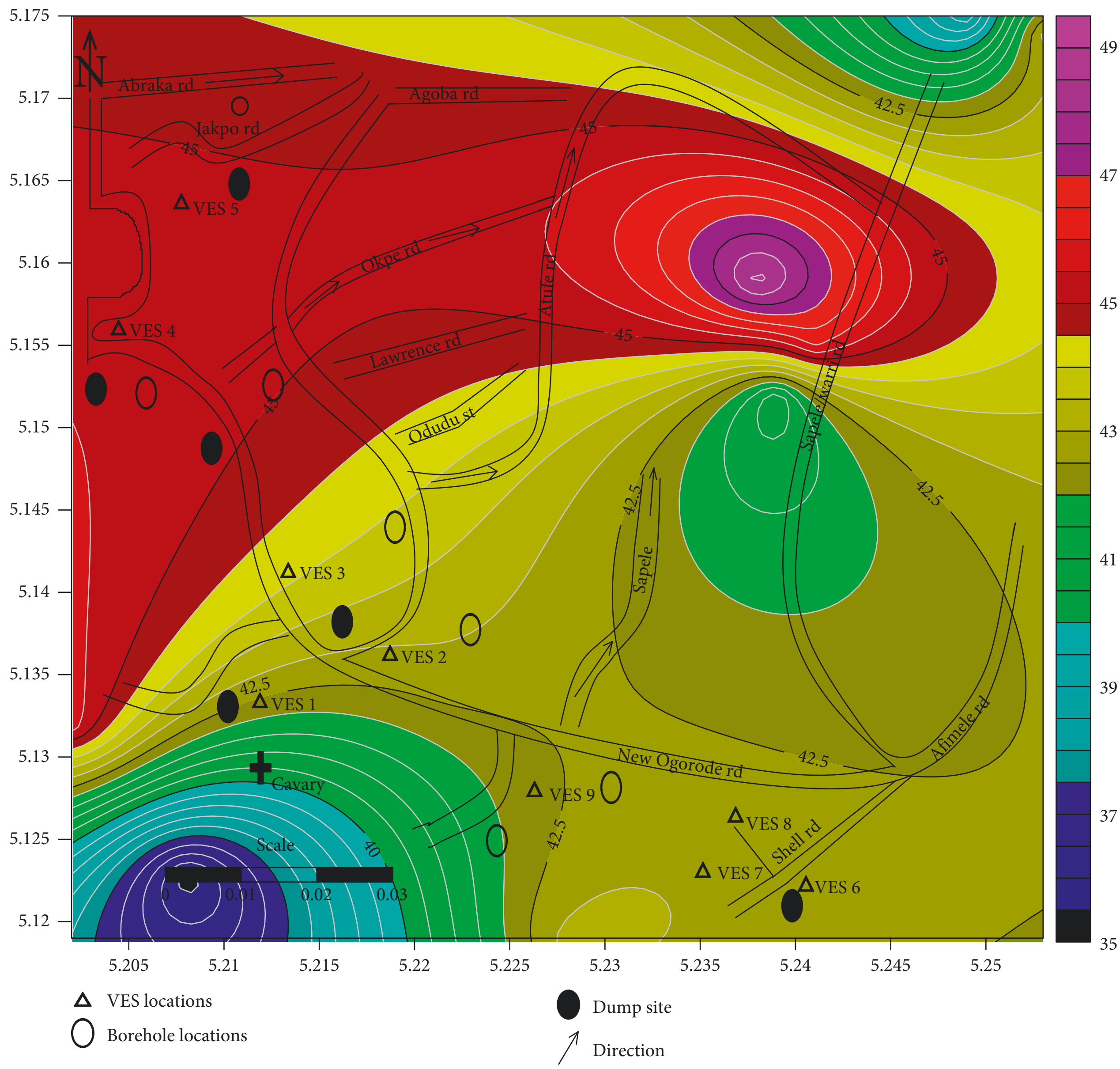


Figure 15: Contour map of the depth to aquifer.

second layer ranged from 14.6 to 50.1 Ωm and thickness of 7 m, the resistivity of the third layer ranged from 20.2 to 116.0 Ωm with thickness of 10 m, and the resistivity of the fourth layer ranged from 17.7 to 178 Ωm with thickness of 10 m. The interpretation shown in all the 2D images indicates that the average depth of penetration of leachate is approximately 20 m with exception at profile 7 where it runs through 50 m.

Table 4 shows the parameters to determine the direction of groundwater flow in the study area. Depth to water level, elevation, and the coordinates of the hand dug well were measured and contoured in the map generated from these parameters, using a sufer 8 software program, thereby generating groundwater surface maps. Figure 15 shows groundwater flow direction in the study area. The direction of groundwater movement is understood from the fact that groundwater always flows in the direction of decreasing head. The arrow in the map shows the flow direction of the water in new road axis of Sapele. From Figure 16, it can be inferred that the water flows in the NE direction recharging the river Ethiope. Profiles 7, 8, and 9 fall within the most depressed area of the map and also show evidence of facts as their protective capacity is poor (Figure 17) and groundwater seems to be most contaminated.

6. Physicochemical Analysis of Ground Water

The collected samples were analyzed for different physicochemical parameters such as pH, electrical conductivity, temperature, TDS, NH^{4+}, Al^{3+}, Zn^{2+}, Ni^{2+}, Fe^{2+}, Pb^{2+}, and Cd^{2+}, and the results were compared with the Standard Organization of Nigeria guidelines [13] for potable water.

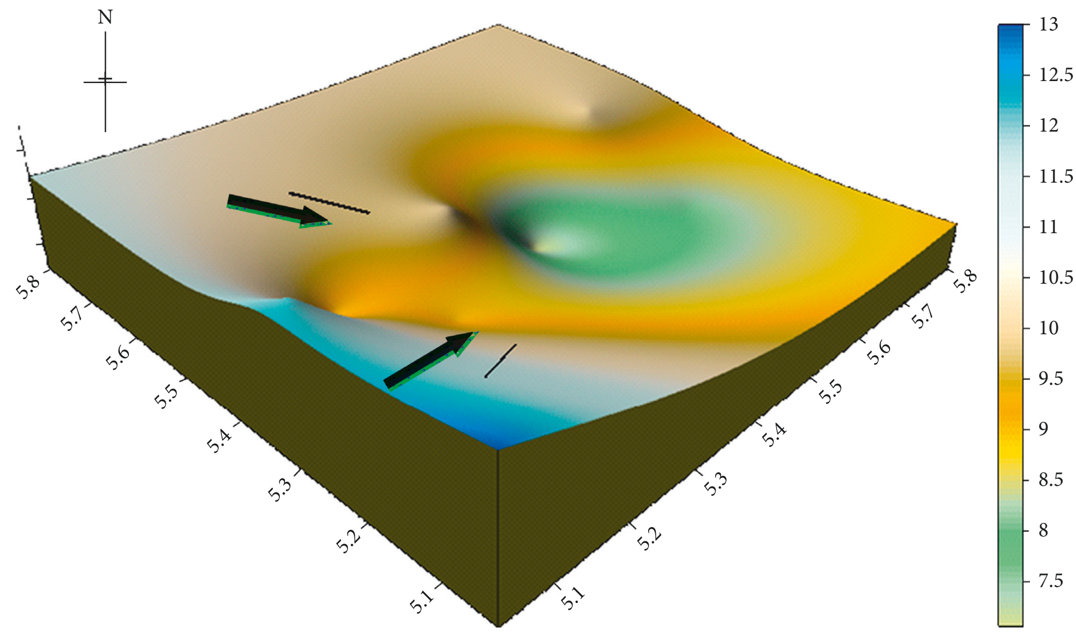


Figure 16: Ground water flow direction.

The quality of any water resources is its suitability for the intended use. This is thus a function of the physical, chemical, and biological (bacteriological) characteristics of the water which in turn depends on the geology of the area and impacts of human activities [14]. The results of the laboratory measurements of pH, conductivity, temperature, and total dissolved solids (TDS), as well as major ions NH^{4+}, Al^{3+}, Zn^{2+}, Ni^{2+}, Fe^{2+}, Pb^{2+}, and Cd^{+2} are presented in Table 5. These constituents have the following ranges in the water: pH 6.45–6.70 (mean 6.58), conductivity 90.12–92.67 μS/cm (mean 91.40 μS/cm), temperature 28.40–28.47°C (mean 28.44°C), TDS 86.50–87.53 mg/l (mean 87.01 mg/l).

The pH range of 6.45–6.70 revealed slightly acidic groundwater in the area. Standards Organization of Nigeria (SON) [13] puts the acceptable range of pH in drinking water at 6.5–8.5. With respect to this standard, groundwater samples in BH1–BH6 need no treatment in terms of the pH level. The slight acidity in groundwater in the area may be due to the oxidation of dissolved ferrous iron or the presence of organic matter in the soil, or it could even be associated with gas flaring in the area [15]. This phenomenon releases CO_2 into the atmosphere and during precipitation, this gas can enter atmosphere, and during precipitation, this gas can enter underground to reduce pH. Acidic waters promote the growth of iron bacteria which cause incrustation of pipes. Results of the study reveals that the electrical conductivity (EC) values range between 90.12 and 92.67 μS/cm with a mean value of 91.40 μS/cm. These values are lower than the stipulated value of 1400 μS/cm by SON [13] in drinking water. Electrical conductivity up to 2000 μS/cm is permissible for irrigation [16]; hence, the water would not be injurious to crops in the area. According to Langenegger [17], the importance of EC is its measure of salinity, which greatly affects the taste and thus has a significant impact on the users' acceptance of the water as potable. The values of temperature ranged from 28.40 to 28.47°C with a mean value of 28.44°C. Total dissolved solids (TDS) show values in the range of 86.50–87.53 mg/l, with an average of 87.01 mg/l. These values are within acceptable limits. Values up to 500 mg/l are satisfactory for domestic purposes [18]. NH^{4+} ions show values in the range of 0.05–0.06 mg/l with a mean value of 0.06 mg/l. Al^{3+} ions show values in the range of 0.06–0.07 mg/l with a mean value of 0.07 mg/l; Zn^{2+} ions show values in the range of 0.57–0.63 mg/l with a mean value of 0.60 mg/l; Ni^{2+} ions show values in the range of 0.36–0.38 mg/l with a mean value of 0.37 mg/l; Fe^{2+} ions show values in the range of 0.60–0.61 mg/l with a mean value of 0.61 mg/l; Pb^{2+} ions show values in the range of 0.64–0.66 mg/l with a mean value of 0.65 mg/l; and Cd^{2+} ions show values in the range of 0.13–0.14 mg/l with a mean value of 0.14 mg/l. All cations studied show harmful level in the water sample.

7. Conclusion and Recommendations

From the study carried out, the values obtained from the VES interpretation indicate that the aquiferous zone is located at depths that ranged from 25 to 30 meters with thickness of between 18 and 20 m. This correlated well with the driller's log at new road axis of Sapele. However, the dipole-dipole study revealed that most of the aquifer is contaminated because the ground water contains lead, nickel, and cadmium whose health implication on consumption is very disastrous to life. The study also revealed a flow direction of the groundwater to be in the northeast direction emptying its contents into the river Ethiope.

Since open dumpsites are linked with environmental contaminations and is of a huge concern, it is

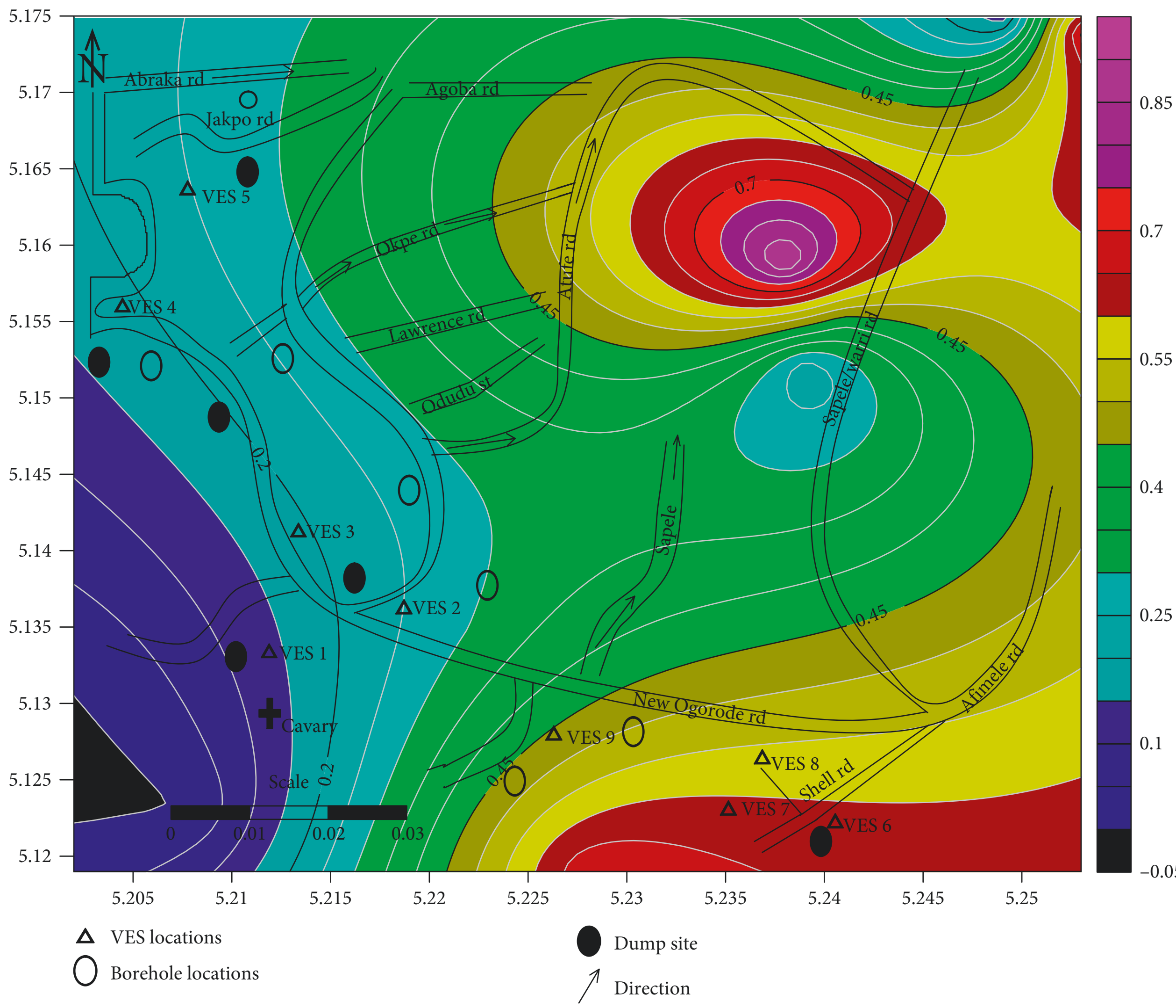


Figure 17: Contour map of the aquifer protective capacity of the area.

Table 5: Concentration of constituents in groundwater in the study area.

Borehole	pH	EC (μS/cm)	Temperature (°C) (mg/L)	TDS (mg/L)	NH^{4+} (mg/L)	Al^{3+} (mg/L)	Zn^{2+} (mg/L)	Ni^{2+} (mg/L)	Fe^{2+} (mg/L)	Pb^{2+} (mg/L)	Cd^{2+} (mg/L)
BH1	6.81	88.42	28.50	82.45	0.08	0.07	0.70	0.45	0.76	0.79	0.17
	6.50	86.21	28.42	82.22	0.06	0.07	0.60	0.43	0.76	0.78	0.16
BH2	6.73	98.54	28.81	99.62	0.05	0.08	0.40	0.37	0.73	0.79	0.19
	6.60	95.26	28.80	96.12	0.04	0.06	0.40	0.35	0.71	0.76	0.17
BH3	6.81	94.45	28.23	88.62	0.08	0.07	0.50	0.48	0.67	0.74	0.16
	6.57	96.12	28.16	87.16	0.07	0.06	0.40	0.45	0.65	0.73	0.16
BH4	6.57	87.11	28.45	92.25	0.05	0.06	0.60	0.52	0.75	0.69	0.15
	6.21	82.67	28.34	95.24	0.04	0.05	0.50	0.50	0.75	0.65	0.14
BH5	6.55	91.22	28.13	82.14	0.05	0.05	0.80	0.24	0.36	0.47	0.07
	6.41	89.24	28.12	79.12	0.05	0.04	0.80	0.22	0.35	0.45	0.06
BH6	6.71	94.12	28.76	80.12	0.06	0.08	0.80	0.23	0.39	0.46	0.08
	6.42	93.24	28.56	79.12	0.06	0.07	0.70	0.22	0.35	0.46	0.07
Max	6.70	92.67	28.47	87.53	0.06	0.07	0.63	0.38	0.61	0.66	0.14
Min	6.45	90.12	28.40	86.50	0.05	0.06	0.57	0.36	0.60	0.64	0.13
Range	0.25	2.55	0.07	1.03	0.01	0.01	0.06	0.02	0.01	0.02	0.01
Mean	6.58	91.40	28.44	87.01	0.06	0.07	0.60	0.37	0.61	0.65	0.14
SON permitted limit (2007)	6.5–8.5	1000	25	500	*0.5	0.2	3	0.02	0.3	0.01	0.003

recommended that boreholes should be drilled to a depth of more than 50 m to tap from the uncontaminated aquifer. A prospective analysis on the study area should be carried out to ascertain leacheat flow rate, as this will help in determining aquifer safety with time, and the state government should encourage transition from open dumpsites to sanitary landfills with better protection for the environment and the people.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Supplementary Materials

The field data acquired using the ABEM SAS 1000 terrameter gave the value of the apparent resistivity in ohm meter (Ωm) at each electrode spacing (AB/2). This was plotted on a bi-log or log-log graph paper with the apparent resistivity (ρ_a) on the vertical axis and the electrode spacing (AB/2) on the horizontal axis. The thickness and resistivity values obtained from the partial curve matching were imputed into Win Resist software program in a computer as model parameters. The process is run by the program as a routine which in turn displayed an automatically plotted graph with an error tolerance limit set for the program iteration, and when this is achieved, the model match becomes the interpreted layer parameters as shown in Figures 18–20. The inverted 2D resistivity structures along profiles 8 and 9 are displayed in Figures 21 and 22, respectively. Depth to water level, elevation, and the coordinates of the hand-wells in the study area were measured and contoured in the map generated from these parameters, using a sufer 8 software program, thereby generating groundwater surface maps (Figure 15). The arrow in the map shows the flow direction of the water in new road axis of Sapele. From Figure 16, it can be inferred that the water flows in the NE direction, thereby recharging the river Ethiope. Profiles 7, 8, and 9 fall within the most depressed area of the map and also show evidence of the facts as their protective capacity is poor (Figure 17), and groundwater seems to be most contaminated. The collected samples were analyzed for different physicochemical parameters such as pH, electrical conductivity, temperature, TDS, NH^{4+}, Al^{3+}, Zn^{2+}, Ni^{2+}, Fe^{2+}, Pb^{2+}, and Cd^{2+}, and the results were compared with the Standard Organization of Nigeria guidelines (2007) for potable water. These constituents have the following ranges in the water: pH 6.21–6.81 (mean 6.57) revealed slightly acidic, conductivity 82.67–98.54 μS/cm (mean 91.38 μS/cm), temperature 28.13–28.81°C (mean 28.43°C), and TDS 79.12–99.12 mg/l (mean 87.01 mg/l). Results of the study reveals that the electrical conductivity (EC) values range between 82.67 and 98.54 μS/cm with a mean value of 91.38 μS/cm, and this is permissible. All cations studied show harmful level in the water sample. (*Supplementary Materials*)

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