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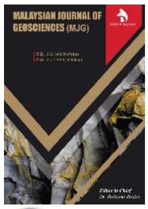

RESEARCH ARTICLE

GEOPHYSICAL MAPPING OF SELECTED DUMPSITE AND ABATTOIR OF GROUNDWATER CONTAMINATION AND THEIR IMPACT IN EFFURUN AND ITS ENVIRONS, SOUTHERN NIGERIA.

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ABSTRACT

This research evaluates groundwater quality in Effurun, southern Nigeria, particularly focusing on contamination from solid waste sources such as dumpsites and abattoirs in Osubi, Ugbomro, and Agbarho. The geophysical assessments to identify contamination levels in the study area were employed by integrating Wenner-Werner arrays and vertical electrical sounding (VES) data. Using the WINRESIST and RES 2D inversion software, resistivity models revealed significant contamination at values below 50 Ohm-meters, with lateral extents ranging from 49 to 85 meters and depths up to 6.39 meters. Notably, the Osubi abattoir exhibited the highest contamination level, while some areas in Ugbomro dumpsite and Agbarho dumpsite remained less affected. The findings highlight the vulnerability of unconfined aquifers characterized by weak protective layers. The subsurface pollution in the study areas necessitates urgent improvements in waste management and groundwater protection strategies. Additionally, the results from Dan Zarrouk parameters indicated low aquifer protective capacity in key areas, correlating with observed contamination. This study underscores the critical need for targeted interventions to safeguard groundwater resources amid rising industrialization and waste generation in the region.

KEYWORDS

Electrical resistivity, Groundwater Contaminant, Aquifer, Danzarouk parameter,

1. INTRODUCTION

Groundwater is an essential natural resource that plays a pivotal role in providing fresh water for various human activities, including drinking, irrigation, and industrial processes. According to the International Association, the study approximately one-third of the global population relies on groundwater as a primary source of water for these purposes (Hydrogeologists.,2020). In regions where surface water sources are limited, groundwater becomes particularly crucial, underscoring the need for its careful management and protection. Despite its importance, groundwater sources are increasingly under threat from various anthropogenic activities, including industrial operations, agricultural practices, urbanization, and the disposal of waste. These activities contribute to the contamination of groundwater, often leading to the deterioration of water quality and posing significant risks to human health and the environment.

Effurun, a growing urban area in Nigeria, is no exception to these challenges. Industrial activities, waste disposal from dumpsites, and operations of abattoirs, among other human interventions, threaten the quality of groundwater in this region. In particular, the leachate from municipal dumpsites and the discharge of waste from abattoirs have been identified as major sources of contamination in the area. Leachate, which is a byproduct of the decomposition of organic matter in landfills, contains hazardous chemicals that can percolate through the soil and pollute shallow aquifers, rendering groundwater unsafe for consumption. Effurun, with its dense population and increasing industrial activities, faces significant risks from these pollution sources, especially in areas near dumpsites and abattoirs.

Several studies have explored the impact of groundwater contamination from dumpsites and abattoirs in other regions, with a focus on understanding the movement of contaminants within the subsurface environment. For instance, research investigated the groundwater quality around dumpsites, revealing the potential for contamination through leachate infiltration (Hydrogeologists.,2020). Similarly, studies in Sapele, Delta State, by Oseji and Egbai.,2018 .,Okumoko Izeze .,2020). Have assessed the aquifer protective capacity and vulnerability to contamination, highlighting the need for more comprehensive investigations in areas with similar challenges. Also the research assessed subsurface layers for contaminants around Agbarho Abattoir employing Geoelectrical and Microbial method (Olaseni.,2020). The study showed that the contaminants exist and pose threat to groundwater in the study area due to the microbial values that fall below the WHO standard.

The current research aims to conduct a holistic assessment of the impact of dumpsites and abattoirs on groundwater quality in Effurun and its surrounding communities, specifically . The study will evaluate the vertical and lateral extent of contaminant plumes from these anthropogenic sources and assess the protective capacity of the aquifer. Electrical resistivity tomography (ERT), a geophysical method, will be employed to map the subsurface and identify the movement of contaminants. This method has proven to be effective in groundwater studies, allowing for the delineation of contamination boundaries without direct interference with the groundwater system.

The findings of this study will contribute valuable insights into the protection of groundwater resources in urban and industrialized regions, offering recommendations for mitigating the risks of contamination. As the demand for freshwater continues to rise, particularly in developing

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countries, ensuring the sustainability of groundwater resources through effective monitoring and protection strategies becomes increasingly critical.

This research is structured to include a reconnaissance survey of the study area, acquisition of geophysical data in 1D and 2D, interpretation of the data to determine contamination boundaries, and a detailed analysis of the results. The overall goal is to assess the potential impact of human activities, particularly those related to waste disposal and abattoir operations, on the groundwater aquifer and provide recommendations for improved groundwater management and protection in Effurun and its environs.

1.1 Geology Of The Study Area

The city of Warri is an oil hub within South-South Nigeria, with coordinates of 5°31'N and 5°45'E, Warri City is one of the major hubs of the petroleum industry in Nigeria. It is the commercial capital city of Delta State, with a population of over 311,970 people in 2006. The city has a modern seaport, which serves as the cargo transit point between the Niger River and the Atlantic Ocean for import and export (Okoh and Oghenetoja, 2016;Shaibu.,2023).

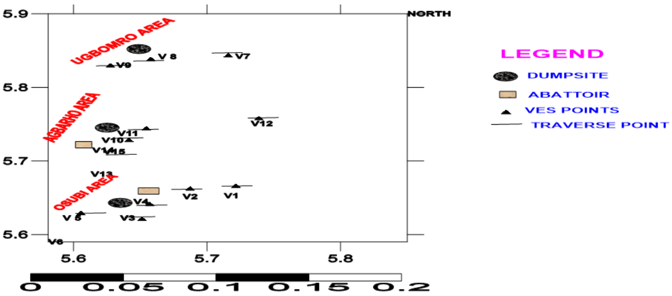

Figure 1: Basemap of the study area

The study area, in Agbarho, Ugbomro and Osubi communities is located in effurun, Delta State. The Geology of Effurun region is seen to be same as the Niger Delta. The Niger Delta underlies an area of about 256,000km^2, and was initially built over an older transgressive Paleocene protodelta (Short and Stauble, 1967).

2. Methodology

Two electrical resistivity methods were engaged in this research and they are explained as follows:

2.1 Vertical Electrical Sounding (VES) Resistivity Data

VES data was interpreted manually to obtain the resistivity model curve type which was curved matched to obtain the layer parameters. This model layer parameters were entered into the computer and curves were plotted using IPI2WIN interpretation software to obtain the true resistivity, layer thicknesses and depth; from which longitudinal conductance (S) were derived to evaluate the protective capacity of the overburden aquifer unit in the area from which useful geological interpretation was ma

2.2 2D Resistivity Data

2D data was inverted using Earth Imager 2-D software, which is a 2-D forward modeling program used to calculate the apparent resistivity pseudo section for the 2-D subsurface. The data was filtered using Krigging algorithm, which is a geo-statistical tool that provides estimated values from some sampled points using variogram model (Clark and Harper, 2000; Loke, 2004).

2D resistivity data was acquired using the 2D collation code for Wenner electrode array and loaded into the software program to obtain the 2D-depth resistivity structure using finite element method (FEM) model algorithm (Loke, 2002).

2.3 Dan zarrouk parameters calculation

The charts supplied by were used to deduce lithologies that corresponded to the geoelectric section (Loke.,1999 and Kearey e., 2002). For the analysis and comprehension of the geologic model, some factors linked to the different combinations of thickness and resistivity of the geoelectric layer are crucial (Zohdy et al., 1974; Maillet,1947). Dar Zarrouk's longitudinal (S) and transverse (T) parameters were derived via

$$S = \frac{h}{\rho} \quad (1)$$

$$T = h\rho \quad (2)$$

where h is the aquifer thickness and ρ is the aquifer resistivity

Longitudinal Unit Conductance (S) was calculated using equation 3.

The longitudinal conductance is equal to the number of layers (n).

$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_i}{\rho_i} + \frac{h_2}{\rho_2} + \cdots + \frac{h_n}{\rho_n}$ As proposed by Asfahani (2013);

Durotoye et al., 2022

K= $0.0538E^{0.0072\rho}$ As proposed by Durotoye et al., 2022 (3)

Where $^{\rho}$ is the aquifer layer resistivity

Transmissivity (T) is the product of the hydraulic conductivity (k) and the aquifer layer thickness.

T=K x h de. (4)

Table 1: Longitudinal conductance/protective capacity rating (after Oladapo and Akintorinwa 2007).

Total longitudinal unit conductance (mhos)	Overburden protective capacity rating
<0.10	Poor
0.1-0.19	Weak
0.2-0.69	Moderate
0.7-4.9	Good
5-10	Verygood
>10	Execellent

3. Results And Discusions

Integrated electrical resistivity arrays enhance accurate and effective interpretation of subsurface geological anatomies. The combination of wenner wenner array as presented in figures (2a-16) of this section and their corresponding vertical electrical sounding (VES) results are hereby discussed for detail understanding and insight. This involves the delineation of the lateral extent and the maximum depth of contamination in all the profile points. The points of low resistivity values below 50Ωm depict zone of subsurface contamination. Hence, the corresponding points of low resistivity values below 50Ωm in both wenner array and vertical electrical sounding arrays connote points on leachate contamination. Figure 2b represents the resistivity profile-1 in Osubi abattoir whose resistivity values range from about 32.90Ωm to 300Ωm. The contaminated zone in this profile could be seen on the lateral extent of 40.0m to 95m and a vertical depth of 6.39m. The vertical electrical sounding (VES) 1 profile generated revealed that the layer of contamination extend to the second layer of the geologic formation and ends at 6.4m. The layer of contamination is approximately inline with the Wenner array depth of contamination

Table 2: Summary of VES 1-D model, showing resistivity values, depth, thickness, and leachate-contaminated geo-electric layers

VES No.	RESISTIVITY	THICKNESS	DEPTH	INFERENCE
VES 1	79.0 28.3* 493.7 187.3	1.7 4.7 23.5	1.7 6.4 29.9	*leachate contaminated geo-electric layer
VES 2	42.8* 71.6 117.0 486.3	1.5 7.1 11.9	1.5 8.6 20.5	*leachate contaminated geo-electric layer
VES 3	47.3 59.5 969.5 323.0	0.7 8.2 26.0	0.7 8.9 34.9	*leachate contaminated geo-electric layer

Table 2 (Cons) : Summary of VES 1-D model, showing resistivity values, depth, thickness, and leachate-contaminated geo-electric layers

VES 4	24.9 31.5 1376.2 437.5	0.8 4.0 20.4	0.8 4.8 25.2	*leachate contaminated geo-electric layer
VES 5	78.8 41.5* 760.4 154.2	0.5 4.5 19.0	0.5 5.0 24.0	*leachate contaminated geo-electric layer
VES 6	57.2 140.7 477.7 406.1	0.6 5.6 20.1	0.6 6.2 26.3	
VES 7	182.0 434.8 971.2 208.1	1.2 6.5 17.9	1.2 7.7 25.6	
VES 8	310.8 444.0 78.2 996.2	1.2 8.4 15.1	1.2 9.6 24.6	
VES 9	46.5* 10.9* 1201.6 555.7	0.8 1.5 19.8	0.8 2.3 22.2	*leachate contaminated geo-electric layer
VES 10	10.2* 138.8 1276.6 1330.5	0.6 4.3 15.0	0.6 4.9 19.9	*leachate contaminated geo-electric layer
VES 11	77.0 218.6 393.2 552.8	0.6 13.6 17.5	0.6 14.2 31.8	
VES 12	384.8 1225.2 227.6 3981.6	1.2 6.9 12.3	1.2 8.1 20.4	
VES13	94.9 238.2 428.5 307.1	1.2 8.4 21.1	1.2 9.6 30.7	
VES14	27.4* 44.5 1149.8 234.2	0.7 4.8 20.7	0.7 5.5 26.1	*leachate contaminated geo-electric layer
VES15	8.4* 80.3 1834.3 542.3	0.5 6.1 25.3	0.5 4.2 32.3	*leachate contaminated geo-electric layer

3.1 Result of 2D inverse resistivity model for profile 1 (Osubi Abattoir) with VES point 1

Figure 2b represents the resistivity profile-1 in Osubi abattoir whose resistivity values range from about 32.90Ωm to about 300Ωm. The contaminated zone in this profile could be seen on the lateral extent of 40.1m to 90m and a vertical depth of 6.39m. The vertical electrical sounding (VES) 1 profile generated revealed that the layer of contamination extend to the second layer of the geologic formation and ends at 6.4m. The layer of contamination in 1d is approximately inline with the Wenner array depth of contamination.

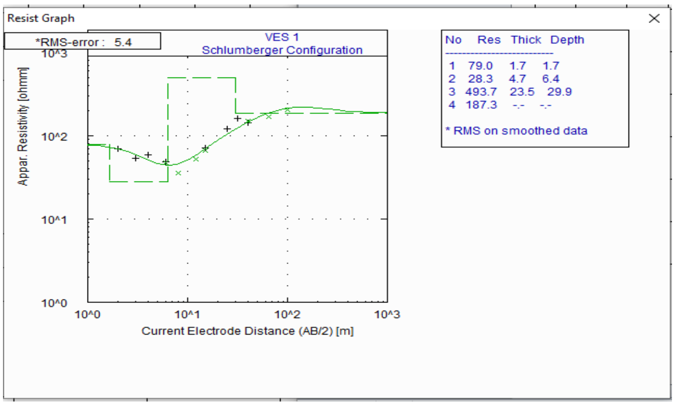

Figure 2a: VES point 1 for profile 1 (Osubi Abattoir)

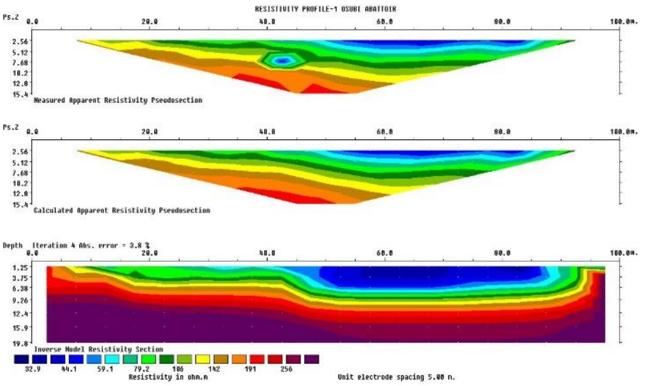

Figure 2b: 2D inverse resistivity model for profile 1 (Osubi Abattoir)

3.2 Result of 2D inverse resistivity model for profile 2 with VES point 2

Figure 3b represents the resistivity profile-2 in Osubi abattoir whose resistivity values range from about 43.9Ωm to 380Ωm. The contaminated zone in this profile could be seen on the lateral extent of 19.0m to 87.0m and a vertical depth of 1.5m. The vertical electrical sounding (VES) 2 profile placed on the horizontal distance of 60m revealed that the layer of contamination terminates at the first layer (top surface) of the geologic formation and ends at 1.5m.The depth of contamination is roughly in line with the Wenner array depth of contamination.

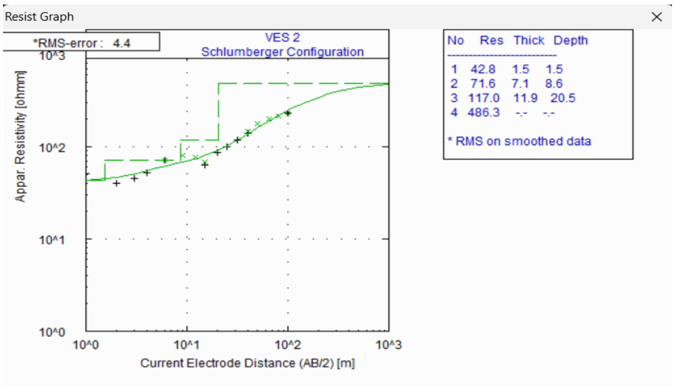

Figure 3a: VES point 2 for profile 2 (Osubi Abattoir)

Figure 3b: 2D inverse resistivity model for profile 2 Osubi Abattoir)

3.3 The result of 2D inverse resistivity model for profile 2 (Osubi dumpsite) with VES point3

Figure 4b represents the resistivity profile-2 in Osubi dumpsite whose resistivity values range from about 40.4Ωm to about 400Ωm. The 2D inverse resistivity model revealed slight contamination area possibility from the lateral extent of 16.0m to 83.0m and a vertical depth of 0.7m while the vertical electrical sounding (VES) 3 profile placed on the horizontal distance of 67m revealed that the layer of contamination extends to the first layer of the geologic formation and ends at 0.7m. The depth of contamination is roughly inline with the Wenner array depth of contamination

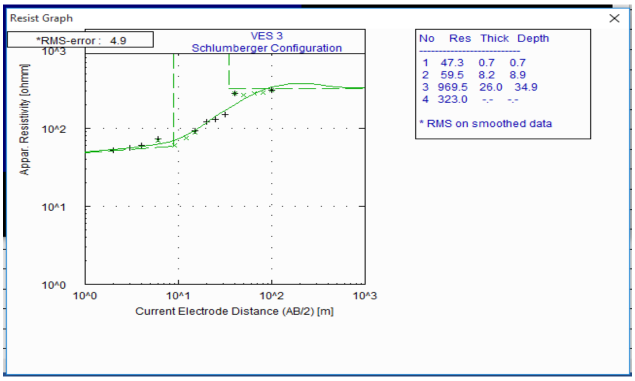

Figure 4a: VES point 3 for profile 2 (Osubi Abattoir)

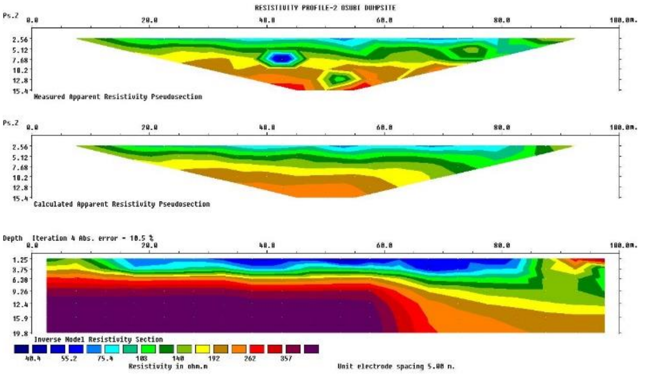

Figure 4b: 2D inverse resistivity model for profile 2 (Osubi dumpsite) with VES point 3

3.4 2D inverse resistivity model for profile 3 (Osubi dumpsite) with VES point 4

Figure 5b represents the resistivity profile-3 in Osubi dumpsite whose resistivity values range from 16.7Ωm to about 300Ωm. The leachate contaminated area covers a lateral extent of 49.0m to 87.0m and a vertical depth of 4.95m, while the vertical electrical sounding (VES) 4 profile placed on the horizontal distance of 82m revealed that contaminant terminates at the second layer of the geologic formation and ends at 4.8m. The depth of contamination is roughly inline with the Wenner array depth of contamination.

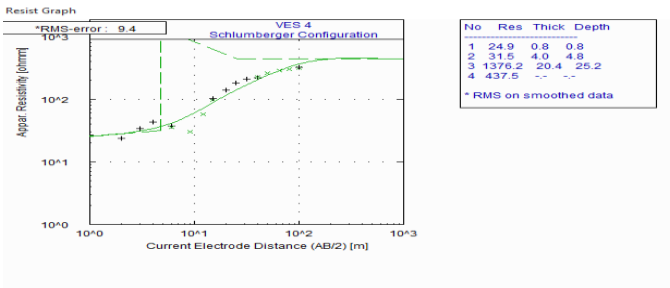

Figure 5a: VES point 4 for profile 2 (Osubi Abattoir)

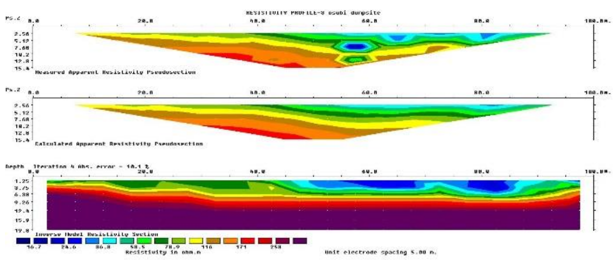

Figure5b: 2D inverse resistivity model for profile 3 (Osubi dumpsite) with VES point 4

3.5 Result of 2D inverse resistivity model for profile 4 (Osubi dumpsite) with VES point5

Figure 6b represents the resistivity profile-4 in Osubi dumsite whose resistivity values range from 46.2Ωm to about 350Ωm. The contaminated zone in this profile could be seen on the lateral extent of 15.0m to 86m and a vertical depth of 5.4m. while the vertical electrical sounding (VES) 5 profile placed on the horizontal distance of 74m revealed that the layer of contamination extends to the second layer of the geologic formation and ends at 5.0m. The depth of contamination is roughly inline with the Wenner array depth of contamination

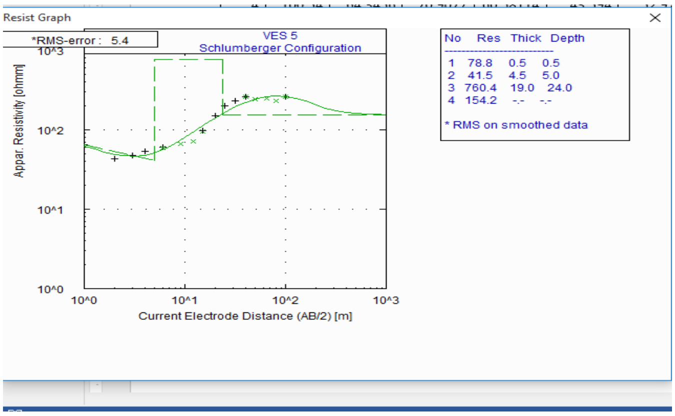

Figure6a: VES 5 point 5 for profile 4 (Osubi Abattoir)

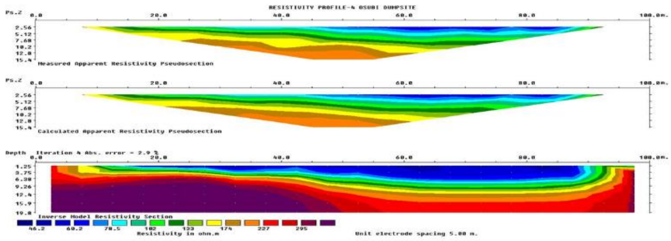

Figure6b: 2D inverse resistivity model for profile 4 (Osubi dumpsite) with VES point 5

3.6 Result of 2D inverse resistivity model for profile 4 (Osubi dumpsite) with VES 6 point 6

Figure 7b represents the resistivity profile in Osubi dumpsite control point resistivity values range from about 79.9Ωm to about 677ΩmIn this profile, there is no evidence of contamination, while the vertical electrical sounding (VES 6) profile placed on the horizontal distance of 85m revealed that there is no evidence of contamination. The depth of contamination is roughly inline with the Wenner array depth of contamination.

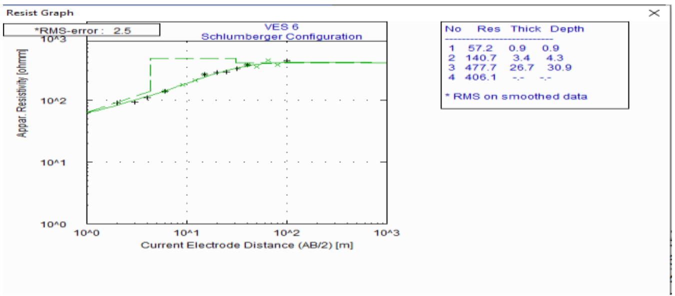

Figure 7a: VES point 6 for profile 2 (Osubi dumpsite control point)

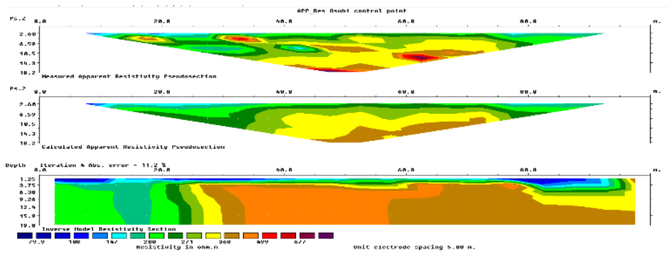

Figure 7b: 2D inverse resistivity model for profile 4 (Osubi dumpsite control point) with VES point 6

3.7 Result of 2D inverse resistivity model for profile 4 (Ugbomro control site) with VES point 7

Figure 8b represents the resistivity profile-4 in Ugbomro control site whose resistivity values range from 37.8Ωm to about 2000Ωm. This profile reveals no contamination of the subsurface layer which was also corroborated by the vertical electrical sounding (VES 7) with high resistivity range of values.

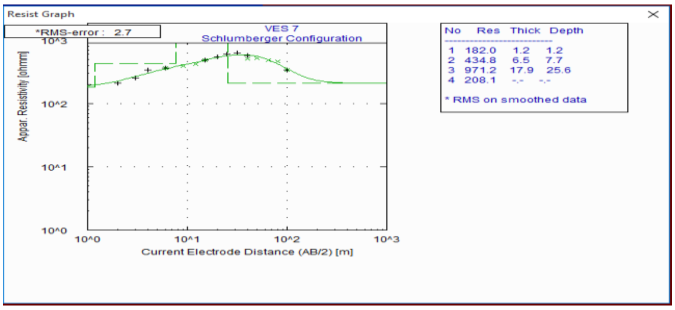

Figure 8a: VES point 7 for profile 2 (ugbomoro dumpsite control point)

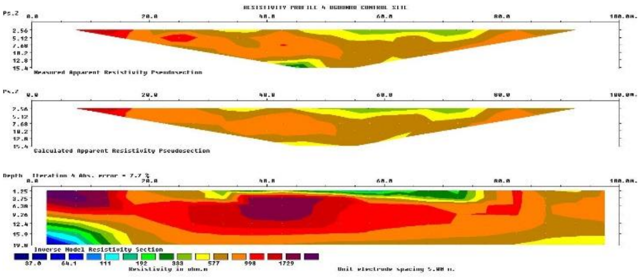

Figure 8b: 2D inverse resistivity model for profile 4 (Ugbomro control site) with VES point 7

3.8 Result of 2D inverse resistivity model for profile 1 (Ugbomoro dumpsite) with VES point 8

Figure 9b represents the resistivity profile-1 in Ugbomro dumpsite whose resistivity values range from 114Ωm to about 6200Ωm. This profile reveals no contamination of the subsurface layer which was also corroborated by the vertical electrical sounding (VES 8) with high resistivity range of values.

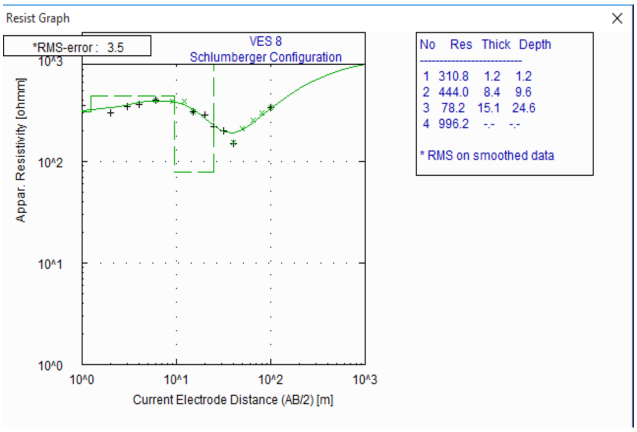

Figure 9a: VES point 8 for profile 1 (ugbomoro dumpsite)

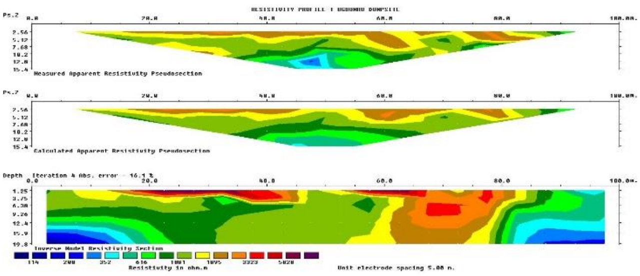

Figure 9b: 2D inverse resistivity model for profile 1 (Ugbomro dumpsite) with VES point 8

3.9 Result of 2D inverse resistivity model for profile 2 (Osubi dumpsite) with VES point 9

Figure 10b represents the resistivity profile-2 in osubi dumpsite whose resistivity values range from 42.2Ωm to about 300Ωm. The contaminated zone in this profile could be seen on the lateral extent of 8.0m to 16.0m and a vertical depth of 2.4m. The vertical electrical sounding (VES) 2 profile placed on the horizontal distance of 12m revealed that the layer of contamination extends to the second layer of the geologic formation and ends at 2.3m. The depth of contamination is roughly in line with the wenner array depth of contamination

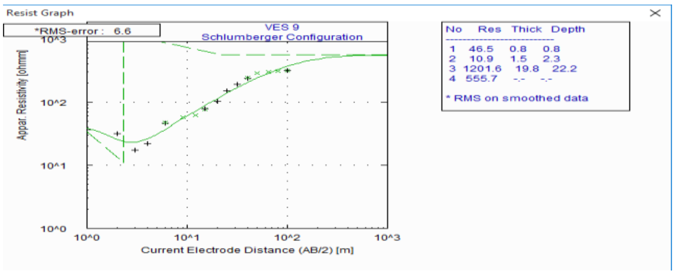

Figure 10a: VES point 9 for profile 2 (ugbomoro dumpsite)

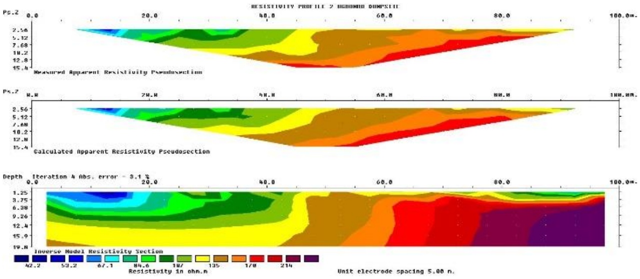

Figure 10 b: 2D inverse resistivity model for profile 2 (ugbomoro dumpsite) with VES point 9)

3.10 Result of 2D inverse resistivity model for profile 2 (Agbarho dumpsite) with VES point 10

Figure 11b represents the resistivity profile-2 in Agbarho dumpsite whose resistivity values range from 8.49Ωm to about 1311Ωm. The contaminated zone in this profile could be seen on the lateral extent of 65.0m to 95.0m and a vertical depth of m. The vertical electrical sounding (VES) 10 profile placed on the horizontal distance of 87m revealed that the layer of contamination is at the first layer of the geologic formation and ends at 0.6m depth. The depth of contamination is roughly in line with the wenner array depth of contamination.

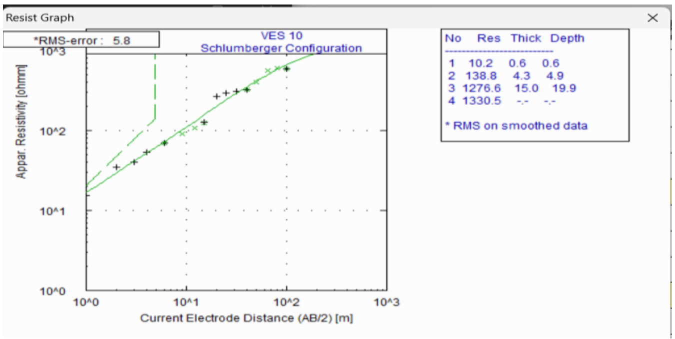

Figure 11a: VES point 10 for profile 2 (Agbarho dumpsite)

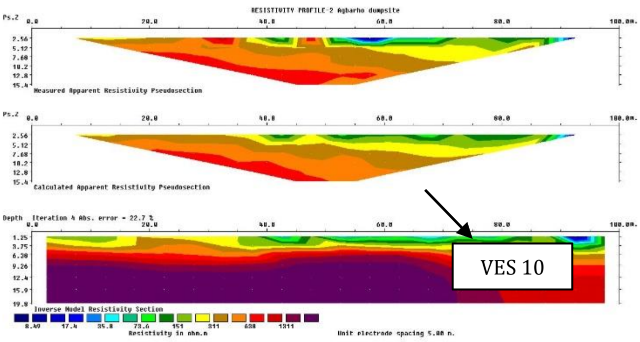

Figure 11b: 2D inverse resistivity model for profile 2 (Agbarho dumpsite) with VES point 10

3.11 Result of 2D inverse resistivity model for profile 1 (Agbarho dumpsite) with VES point 11

Figure 12b: represents the resistivity profile-1 in Agbarho dumpsite whose resistivity values range from 115Ωm to about 3000Ωm.The profile-2 on the 2D inverse resistivity model reveals no contamination of the subsurface layer which was also corroborated by the vertical electrical sounding (VES 11) with high resistivity range of values.

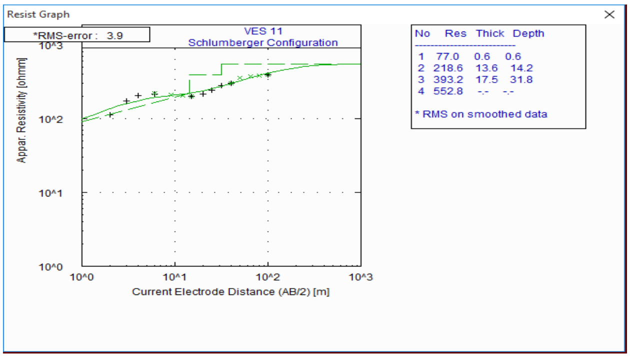

Figure 12a: VES point 11 for profile 1 (Agbarho dumpsite)

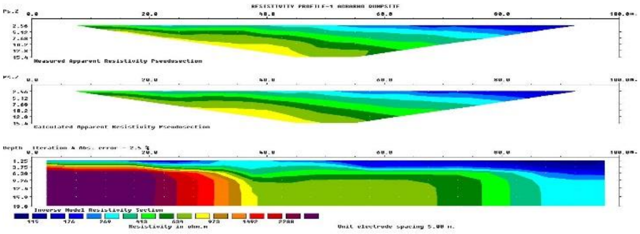

Figure 12b: 2D inverse resistivity model for profile 1 (Agbarhodumpsite) with VES point 11

3.12 Result of 2D inverse resistivity model for profile 1 (Agbarho dumpsite control site) with VES point 12

Figure 13brepresents the resistivity profile-3 in Agbarho control dumpsite whose resistivity values ranges from 426Ωm to about 1500m.This profile reveals no contamination of the subsurface layer on the 2D inverse resistivity model on profile 3 dumpsite which was also inline with the vertical electrical sounding (VES 12) with high resistivity range of values.

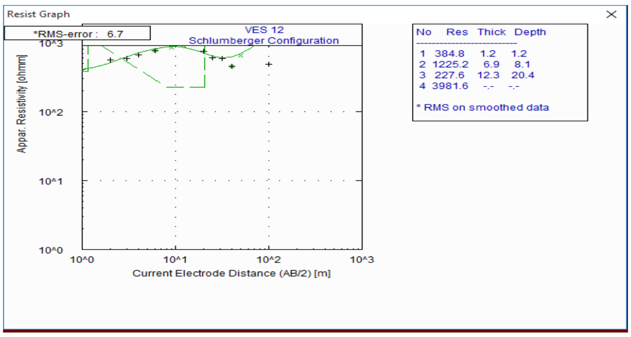

Figure 13a: VES point 12 for profile 2 (Agbarho dumpsite control site)

Figure 14b: 2D inverse resistivity model for profile 2 (Agbarho abattoir control site) with VES point 13

3.14 Result of 2D inverse resistivity model for profile 2 (Agbarho abattoir) with VES point 14

Figure 15b represents the resistivity profile-2 in Agbarho abattoir point whose resistivity values range from21.2Ωm to about 300Ωm.The contaminated zone in this profile could be seen on the lateral extent of 46.0m to 94m and a vertical depth of 6m.The vertical electrical sounding (VES) 14 profile placed on the horizontal distance of 87m revealed that the layer ofcontamination is at the second layer of the geologic formation and ends at 5.5m depth. The depth of contamination in profile-2 is roughly in line with the wenner array depth of contamination.

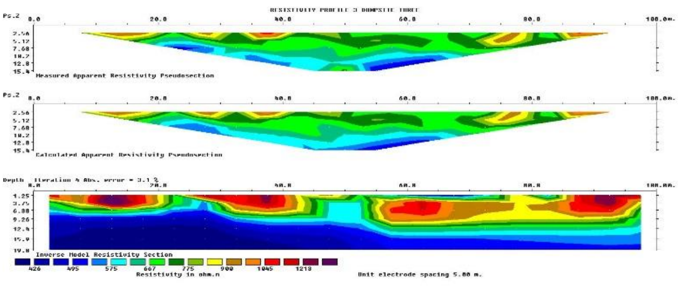

Figure 13b: 2D inverse resistivity model for profile 3 (Agbarhodumpsite) with VES point 12

3.13 Result of 2D inverse resistivity model for profile 1 (Agbarho abattoir control site) with VES point 13

Figure 14b represents the resistivity profile-1 in Agbarho abattoir control point whose resistivity values range from 122Ωm to about400Ωm.This profile reveals no contamination of the subsurface layer on the 2D inverse resistivity model on profile 1 which was also corroborated by the vertical electrical sounding (VES 13) with high resistivity range of values.

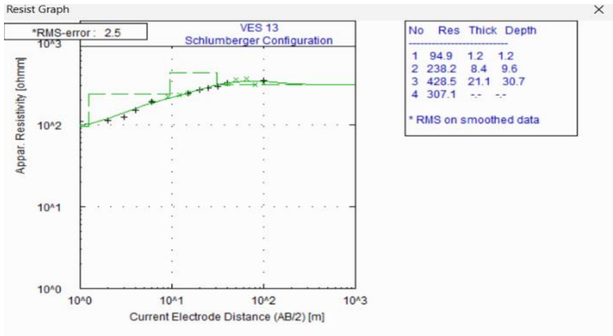

Figure 14a: VES point 13 for profile 2 (Agbarho Abattoir control site)

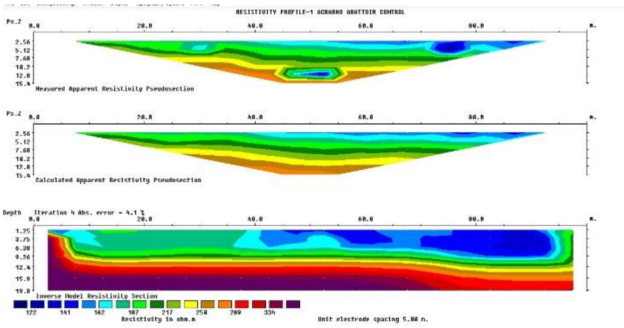

Figure 14b: 2D inverse resistivity model for profile 2 (Agbarho abattoir control site) with VES point 13

3.14 Result of 2D inverse resistivity model for profile 2 (Agbarho abattoir) with VES point 14

Figure 15b represents the resistivity profile-2 in Agbarho abattoir point whose resistivity values range from21.2Ωm to about 300Ωm.The contaminated zone in this profile could be seen on the lateral extent of 46.0m to 94m and a vertical depth of 6m.The vertical electrical sounding (VES) 14 profile placed on the horizontal distance of 87m revealed that the layer ofcontamination is at the second layer of the geologic formation and ends at 5.5m depth. The depth of contamination in profile-2 is roughly in line with the wenner array depth of contamination.

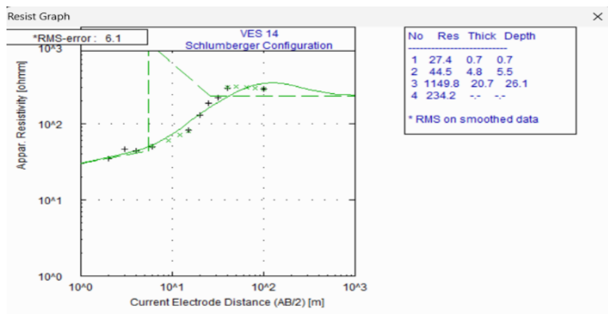

Figure 15a: VES point 14e for profile 2 (Agbarho Abattoir)

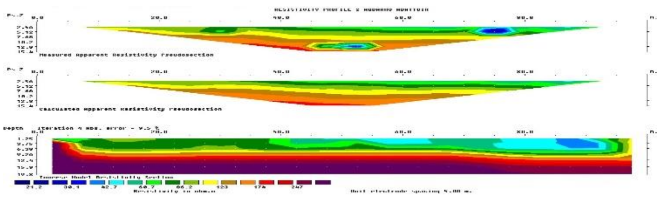

Figure 15b: 2D inverse resistivity model for profile 2 (Agbarho abattoir) with VES point 14

Figure 13b: 2D inverse resistivity model for profile 1 (Agbarho abattoir control site) with VES point 12

3.15 Assessment of the Impact of The Sources of Contamination In the Study Area

To evaluate the impact of the selected dumpsites and the abattoirs in the study area, Dan zarrouk parameters such as the Longitudinal unit conductance (S), hydraulic conductivity, K and transmissivity were adopted and calculated. The results were obtained from the primary resistivity parameters such as resistivity thickness and depth by performing system iteration using Winresist geophysical software for smooth curve with low root mean square value (see table 3). Surfer software was used to generate the spatial distribution maps of the second order parameters in the study area.

Table 3: Dar Zarrouk Parameter of the Study area

VES Points	Longitudinal Unit Conductance (S) mhos	Hydraulic conductivity (k)	Transmissivity (T)
VES/1	0.187597	0.001538232	0.035840797
VES/2	0.309314	0.00524625	0.174700113
VES/3	0.152614	5.00303E-05	0.001300788
VES/4	0.159113	2.67618E-06	5.4594E-05
VES/5	0.114779	0.000225461	0.004283766
VES/6	0.141111	0.000224489	0.004512238
VES/7	0.021543	4.94217E-05	0.00084511
VES/8	0.215875	0.030637767	0.462630283
VES/9	0.154819	9.40751E-06	0.000186269
VES/10	0.089803	5.48221E-06	8.22332E-05
VES/11	0.114513	0.003171591	0.055502849
VES/12	0.062792	0.010449493	0.128528765
VES/13	0.047909	0.002459784	0.051901439
VES/14	0.133413	1.366E-05	0.000282761
VES 15	0.135489	9.88718E-08	2.50146E-06
Min	0.021543	9.88718E-08	2.50146E-06
Max	0.309314	0.030637767	0.462630283
Aver	0.139502	0.00498363	0.081369841

3.16 Longitudinal Unit Conductance Parameter

Longitudinal conductance can help to define the degree of groundwater protection from vertical infiltration of pollutants. (Oni et al., 2017). It is usually denoted with S and ranges from 0.021543 to 0.309314mhos and a mean value of 0.139502mhos. The map revealed that the north eastern (which consists of V12 and V7) and the south western flank (made up of VES 10 and 13) are characterized with poor aquifer protective capacity while VES 1, 3, 5, 6, 8, 9, 11, 14 and 15) are made up of weak aquifer protective capacity. However, only VES 2 and 8 located at the south western and north western flanks of the map respectively revealed moderate aquifer protective capacity. It could be deduced that the aquiferous units of VES 5, 9, 10, 11,13,7, 12,3,14, 6 and 15 must have been responsible for the contamination delineated by the 2D inverse resistivity models in the study area due to the fact that they are characterized with poor and weak aquifer protective capacity while being sited on selected dumpsite and abattoir sources of ground water contamination.

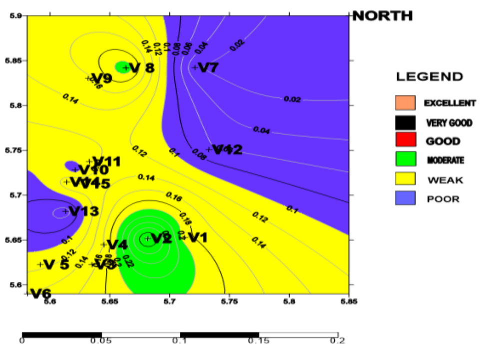

Figure 16 : Spatial Variation Of Longitudinal Conductance

4. Hydraulic Conductivity Parameter

Hydraulic conductivity, K ranges from 9.88718 $x10^{-8}$ and 3.06 x 10^{-2} with a mean value of 0.00498363. The hydraulic conductivity map revealed that the northwestern of the study area is characterized with high hydraulic conductivity while every other regions are of lower hydraulic conductivity values.

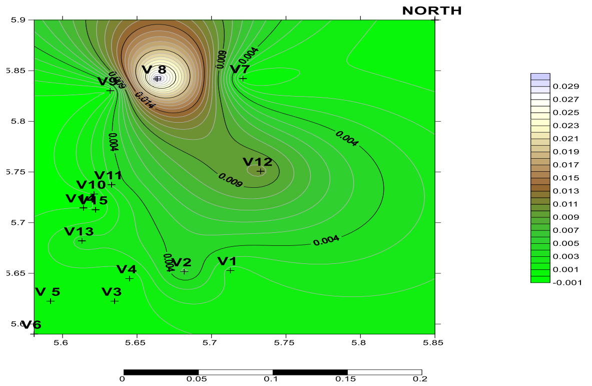

Figure 17 : Spatial Distribution Map Of Hydraulic Conductivity

4.1 Transmissivity Parameter

Transmissivity map of the study area showed that the northwestern part of the study area are characterized with high transmissivity while every other area have relatively lower transmissivity values compared with the northwestern flank. This implies that VES point 8, 9 and 12 have high ground water potential.

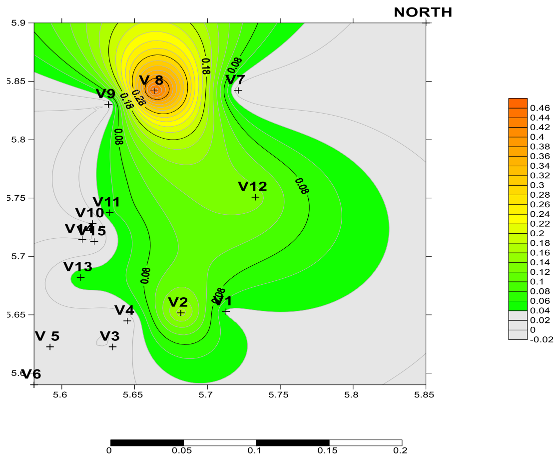

Figure 18: Spatial Distribution Map Of Transmissivity

The preliminary investigations in the study areas identified dumpsites and abattoirs at Osubi, Ugbomro, and Agbarho as potential sources of groundwater contamination. For the research, we integrated a Wenner array (2D) and vertical electrical sounding (1D) with a maximum spread of 100 m.. The 1D and 2D resistivity models generated from the study locations revealed resistivity values less than 50 Ohm-meters as points of groundwater contamination. The maximum lateral variation of contamination from all investigated points, as revealed in Figures 3b, has a lateral variation of groundwater contamination from 40.5 m to 95 m.

All of the 2D inverse resistivity models generated from the investigated data showed some levels of contamination (namely Figures 2b, 3b, 4b, 5b, 6b, 7b, 9b, 10b, 11b), while Figures 8b, 9b and 16b show no contamination.The maximum depth of contamination at all investigated points is 9.26m, as shown in Figures 4b, 7b, and 16b.The vertical electrical sounding (VES) interpretation results revealed that the contaminations have only penetrated a maximum of the second layer at all points.The study area is primarily characterized by unconfined aquifers and poor aquifer protection layers

5. Conclusion

The investigations have identified dumpsites and abattoirs in Osubi, Ugbomro, and Agbarho as significant contributors to groundwater contamination. Utilizing a combination of Wenner array (2D) and vertical electrical sounding (1D) techniques, the extent and depth of contamination have been mapped, revealing critical insights into the impact of these anthropogenic activities on groundwater quality. The resistivity models generated from the study indicate that areas with resistivity values less than 50 Ohm-meters are indicative of contamination.

RECOMMENDATIONS

- **Enhanced Geophysical Techniques**: Future studies should consider integrating additional geophysical methods, such as Ground Penetrating Radar (GPR) and electromagnetic surveys, to provide more detailed spatial resolution of contamination plumes and improve the accuracy of depth assessments. Combining these techniques with existing resistivity methods could offer a more comprehensive understanding of the contamination dynamics.
- **Hydrogeological Assessment**: Detailed hydrogeological studies should be conducted to understand the flow dynamics and transport mechanisms of contaminants within the aquifers. This includes investigating groundwater recharge rates, flow patterns, and the interaction between surface and groundwater systems.
- **Contamination Source Characterization**: Further research should focus on characterizing the specific types of contaminants present at each site. Chemical analysis of soil and groundwater samples will help identify the nature of the pollutants and assess their potential health risks.

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