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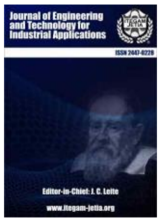

RESEARCH ARTICLE OPEN ACCESS

GEOPHYSICAL INVESTIGATION OF GROUNDWATER CONTAMINATION IN URBAN AREAS: A CASE STUDY OF ACTIVE DUMPSITES IN OYO TOWN, NIGERIA

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ABSTRACT

Environmental safety is a pressing global concern, particularly in Africa, where poor sanitation and contaminated water sources contribute to rising health issues. Active dumpsites are recognized as a source of groundwater pollution, yet their specific impact on water quality remains insufficiently documented. Therefore, this study aimed to evaluate potential groundwater contamination resulting from active dumpsites in the Ilaka area of Oyo town, Nigeria. Electrical Resistivity Tomography was established on two traverses at the study area with a total length of 150 m and 5 m electrode spacing. Eight Vertical Electrical Sounding points were sounded at the established profiles. The geoelectric sections revealed three distinct layers: the topsoil, the weathered layer, and the fresh basement. In Traverse One, the recorded layer resistivity ranges from 29 to 938 Ωm, while in Traverse Two, it ranges from 30 to 1243 Ωm. The corresponding layer thickness varies from 0.8 to 21 m in Traverse One and from 2.5 to 24 m in Traverse Two, indicating a shallow overburden thickness. The 2D image of ERT revealed extremely low resistivity values in all the traverses across the dumpsites which suggests the presence of clay formation underlying the topsoil which may have been trapped in the contaminant plumes. Groundwater from the study area was found to be free from contaminants.

I. INTRODUCTION

Groundwater is a body of water that is deeply-seated in soil from rain or other precipitation and migrates to fill openings in the bed of rocks and soil. It is adequately accumulated in and moves downward through pores in the geologic formation of the soil and rocks called aquifers [1]. Groundwater is a renewable resource, that completely renews itself over time. Although the rate of renewal varies greatly under some environmental conditions, aquifer recharges by rain and snow melt that seep down into the pores beneath the land's surface [2]. An aquifer is an underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials. Aquifers are generally made up of gravel, sand, sandstone or fractured rock. They allow the movement of water through their materials that have large connected spaces which make them penetrable. Aquifer's pore spaces and how well the pore spaces are connected determine the rate of flow of groundwater in the soil and rock. The exploration for clean groundwater is very significant, due to its countless advantages over surface water. However, the questions of exploration and production such as how much groundwater is available, and what is its quality? Need to be answered [3]. Groundwater can be explored using different methods. The four major groundwater exploration methods are the areal method, surface method, subsurface method and esoteric methods. Each of the above-listed groundwater exploration methods has different sub-methods under them. Geophysical methods play important roles in locating suitable and productive groundwater reservoirs. Electrical resistivity has been routinely used for subsurface investigation and exploration of groundwater [4]. Electrical resistivity can also be used for the assessment of the hydraulic conductivity of the aquifer, transmissivity of the aquifer, specific yield level of the aquifer and contamination of groundwater [5]. Electrical resistivity methods can be used to obtain details about a location in terms of depth and resistivity of subsurface formation more accurately, rapidly and economically [6],[7].

Groundwater usually moves slowly through pore spaces in rock, and this is filtered of many contaminants and some bacteria and viruses and this makes groundwater suitable as a drinking water resource. Despite this, it never implies that groundwater does not get contaminated; there are various cases worldwide where groundwater resources have been ruined by saltwater intrusion which is peculiar to coastal areas, as well as biological contaminants such as agricultural and industrial discharge, indiscriminate waste and sewage disposal among others. Groundwater contamination may be due to human activities. For example, when wastes generated by residents within a municipality are indiscriminately dumped in an open landfill, after some years, any uncontrolled dumpsites within the municipality undergo biological, chemical, geological and hydrogeological changes which often result in weathering processes and therefore, become point source of contamination of the aquiferous unit close to them and thereby resulting in groundwater contamination [8]. Contaminated groundwater is purely unsafe for consumption and greatly affects human health, even the environmental quality and socio-economic development negatively. The effects of exposure to contaminated groundwater by the populace include chronic and sub-chronic toxicity and carcinogenic effects depending on the type and nature of the contaminant present. Studies have shown that high levels of nitrate, trace metals and persistent organic pollutants cause major health risks to the human population [9], [10].

Pollution by heavy metals in the last decades has been of great concern because of their health hazards to man and other organisms when accumulated within a biological and food production system. For instance, Irrigation with groundwater contaminated by heavy metals and wastewater containing persistent contaminants can result in the accumulation of toxic elements in cereals and vegetables, causing health risks to humans [11],[13]. On the part of socio-economic, some billions of US dollars that can be utilized by worldwide associations and non-legislative offices for enhancing the prosperity of nearby neighbourhoods is fundamentally occupied for water-borne disease eradication. Numerous of these cases are available today in various Nigerian and international publications, the major concern remains how the problems could be fully addressed. It is on this note that this research was chosen to re-address the problem of groundwater contamination within the Ilaka community of Oyo Metropolis using the geophysical approach.

II. THEORETICAL REFERENCE

As interest in groundwater potential and the impact of contaminants from active dumpsites on groundwater continues to rise, several scholars have conducted extensive research to elucidate its multifaceted nature and impact. For [14] assessed the groundwater contamination around Ajakanga active dumpsite in Ibadan, South-western Nigeria using integrated electrical resistivity and hydro-chemical methods. A total number of ten traverses were established within and outside the dumpsite using Wenner array configuration with constant electrode spacing ranging from 5 to 25 m. The geochemical assessment of groundwater samples was also carried out in accordance with American Public Health Association (APHA) (2005) standards. It was concluded that low resistive zone with resistivity values < 20 Ωm was observed as an indication of leachate plume and 15.9 m as the maximum depth of investigation. It was also observed from the result of the physiochemical analysis that some of the hand-dug wells lie within the WHO (2007)/Nigerian standard for drinking water quality (NSDWQ) (2007) specification limit for drinking purposes except for those close to the dump site. For [15] conducted a geophysical investigation utilizing the Vertical Electrical Sounding (VES) method in the residential area of Aaba in Akure, employing a Schlumberger array. The choice of the study area stemmed from the prevalent water scarcity experienced by inhabitants, attributed to low yields from surrounding wells. The geoelectrical approach was selected due to its efficacy in elucidating subsurface geological characteristics. The study was structured to facilitate spatial mapping of geoelectrical parameters, with sixteen (16) VES points strategically acquired across four (4) traverses to ensure comprehensive coverage. Specifically, VES 2, VES 10, and VES 12 were executed in proximity to existing wells approximately 9 meters deep. Notably, this investigation represents the inaugural effort to evaluate the groundwater potential within the study locale. Despite initiatives such as the "water for life by 2015" campaign spearheaded by the United Nations, the persisting water scarcity in the area persisted through 2017.

Also carried out geophysical and hydro chemical investigation of Jembewon dumpsite located in basement complex area of Ibadan, South-western Nigeria using integrated electrical resistivity method with a view to assess the impact of effluent from the ancient dumpsite on the soil and groundwater system [16]. Dipole-dipole and vertical electrical sounding (VES) was carried out while the hydro chemical investigation of the area involves the physical, chemical and microbial analysis of water sample within the active dumpsite. It was concluded that the area was made up of maximum of four layer which are; the topsoil, the weathered layer, the partly weathered/fractured basement and fresh basement with the partly weathered/fractured basement constitutes the major aquifer unit. It was also suggested that the weathered layer and the overlying layers which were characterized by low resistivity value < 30 Ωm have been impacted by effluent from both the active and reclaimed dumpsites. However, the research suggested that the aquifer in the study area is safe from contaminant due to the fact that the suspected leachates are held within the weathered layer by the presence of suspected geological barriers.

Adopted the use of Vertical Electrical Sounding (VES) and 2-D resistivity imaging (employing Schlumberger and Wenner array configurations) to investigate and map the extent of leachate’s migration and its possible impacts on groundwater within Abata Asunkere dumpsite, Ilorin, Kwara State [17]. The 2-D resistivity imaging and VES data were processed using Res2D and IPI2Win software respectively. The outcome of this study was able to indicate that some regions around the dumpsite are susceptible to leachate’s contamination, which has tendencies to permeate the unconfined aquifers in the study area if not properly monitored and controlled.

II.1 SITE DESCRIPTION AND GEOLOGY

Oyo town is located in Oyo State, and lies within Latitude 7°47`02``N to 7°62`01``N and Longitude of 3°53`27``E to 4°00`00``E (Figure 1). The study area can be found within the humid and sub-humid tropical climate of southwestern Nigeria. It is well accessible as there are well-developed road networks in the town. The area is relatively rugged; characterized by an undulating surface topography. The elevation ranged from 270 m to 290 m (Figure 1). The vegetation cover is sparse in the developed section of the town but exist as a forest in the undeveloped area.

The study area experiences two seasons which are the rainy season which runs from March to October and the dry season which runs from early November to February. Oyo town is found within the basement complex area of southwestern Nigeria, containing distinguishable Gnesis-migmatite complex [18].

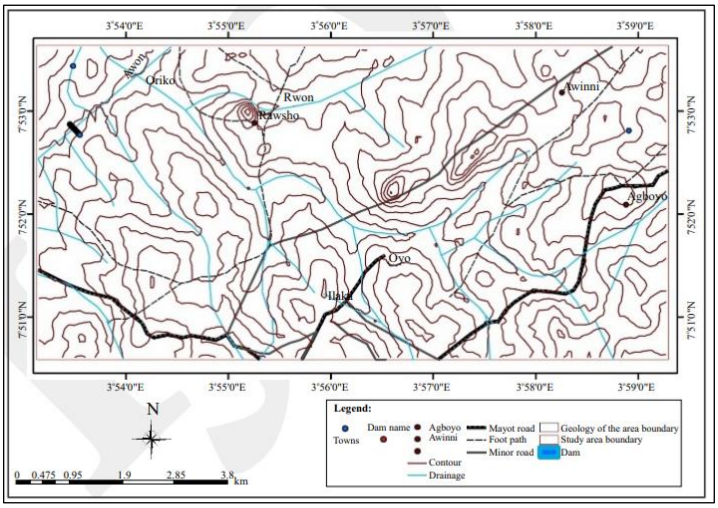

Figure 1: Topographic Map of the Study Area.
Source: [19].

III. MATERIALS AND METHODS

An integrated electrical resistivity method was employed for this survey. The following data were acquired from each of the approaches.

III.1 ELECTRICAL RESISTIVITY TOMOGRAPHY DATA ACQUISITION

Electrical Resistivity Tomography was carried out at Ilaka dumpsite using a dipole-dipole configuration. Two traverses were occupied at each location with a total length of 130 m at electrode spacing of 5 m as indicated in Figure 2.

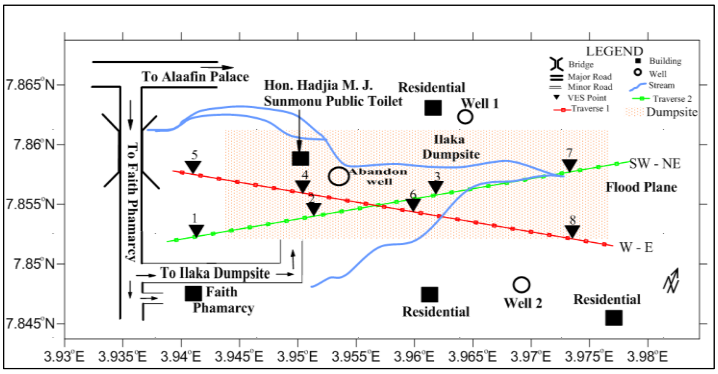

Figure 2: Base Map of Ilaka Dumpsite.
Source: Authors, (2024).

The two current electrodes occupy the first two stations (that is Positions number one and two) while the potential electrodes occupy the third and fourth positions. The data was taken by the instrument (R-50 resistivity meter) at the mid-point between the current and potential dipole. Then the potential electrodes move to position number four and five respectively.
This process continues as current electrodes remain in positions one and two and the potential electrodes move out one electrode spacing for each reading. The space between the second current and first potential increases by expansion factor n varies from 1 to 5 which represents the maximum depth of the probe. After attaining the expansion factor of n = 5, the current electrodes then move out a step from position one and two to position two and three respectively while the potential electrode comes back to position four and five. This cycle continues throughout the electrode array and the data were acquired.

III.2 VERTICAL ELECTRICAL SOUNDING (VES) DATA ACQUISITION

The vertical electrical sounding (VES) approach was carried out on the field at the established traverses in each location using the Schlumberger array. A total of three VES points at least was established on each traverse in all the locations as shown in Figure 2 using an R-50 DC resistivity meter. The current electrodes were moved between AB/2 of 1 to 65m while the potential electrodes varied from 0.5 to 5m that is, MN/2 of 0.25 to 2.5m. The apparent resistivity values in each VES data were computed using Equation 1.

$$\rho_{Sa} = R\frac{\pi(L^2 - l^2)}{2l} \tag{1}$$

Where;

$$\frac{\pi(L^2 - l^2)}{2l}$$

Is the geometry factor K

$$L = {}^{AB}/_{2}, \text{ and } l = {}^{MN}/_{2} \tag{2}$$

III.3 DATA PRESENTATION AND INTERPRETATION

In all, a total number of eight (8) VES points were established as a control to the results of Dipole-Dipole. The apparent resistivity values obtained from the data were then plotted against half of the current electrode spacing (AB/2) on a bi-log graph and the smooth curve was produced using a free hand sketch to give a typical Schlumberger curve for each location.

The conventional manual curve matching was used to obtain the preliminary layer parameter while a computer iteration of the preliminary layer parameter was also done using WinResist software. The iterated geo-electric parameters obtained from WinResist were later used to generate the geo-electric sections beneath each traverse using surfer 12.

IV. RESULTS AND DISCUSSION

IV.1 ELECTRICAL RESISTIVITY RESULTS

The results of the eight (8) VES points within the study area revealed varieties of H-type curves as shown in Figure 3a – 3h. It was also observed that the VES curves obtained from the study area indicate three layering models in terms of layer thickness and layer resistivity as shown in Table 1.

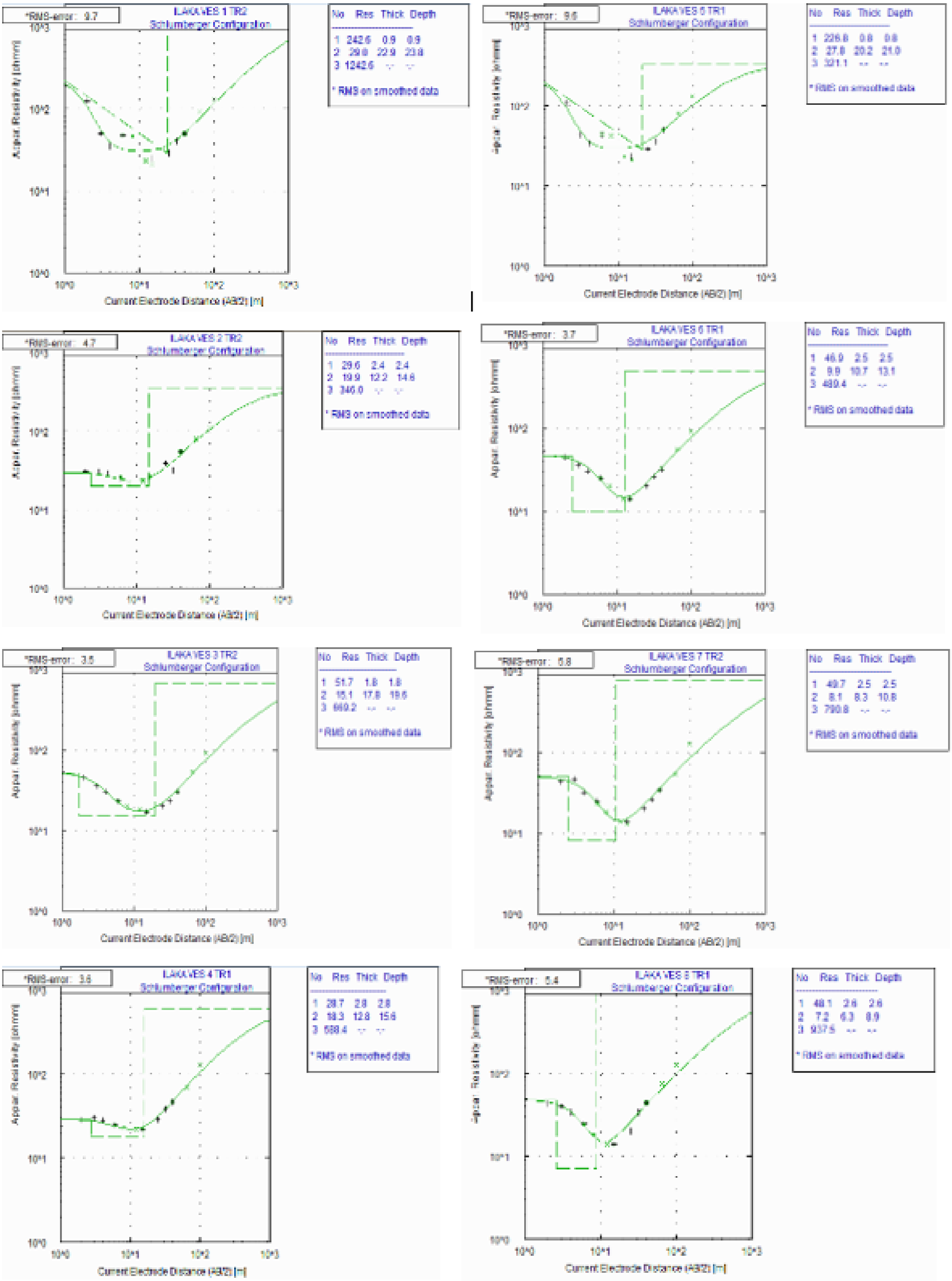

Figure 3a – 3h: Results from computerized sounding curve interpretation, the estimated geo-electric parameters and depth estimate. a) VES 1 (b) VES 2 (c) VES 3 (d) VES 4 (e) VES 5 (f) VES 6 (g) VES 7 (h) VES 8.
Source: Authors, (2024).

Table 1: Summary of Results of the Processes VES Data within Ilaka Dumpsite.

VES Station	Number of Layers	Curve Type	Layer Resistivity (Ωm)			Layer Thickness (m)		Depth to Bedrock (m)
			ρ_1	ρ_2	ρ_3	h_1	h_2	
1	3	H	243	29	1242	0.9	22.9	23.8
2	3	H	30	20	346	2.4	12.2	14.6
3	3	H	52	15	669	1.8	17.8	19.6
4	3	H	29	18	588	2.8	12.8	15.6
5	3	H	227	28	321	0.8	20.2	21.0
6	3	H	47	10	489	2.5	10.7	13.1
7	3	H	50	8	791	2.5	8.3	10.8
8	3	H	48	7	938	2.6	6.3	8.9

Source: Authors, (2024)

IV.2 GEO-ELECTRIC SECTION PARAMETERS AT ILAKA DUMPSITE

The geo-electric equivalence of the geologic sections of Traverse 1 and Traverse 2 across the dumpsite are depicted in Figures 4 and 5, respectively. In Traverse 1, comprising VES 4, VES 5, VES 6, and VES 8, with VES 5 serving as the control VES at a distance of approximately 60 m from the dumpsite, three distinct geologic sequences are delineated. These include the topsoil, clay layer, and the basement. The topsoil exhibits varying thicknesses from 0.8 m to 2.8 m and its corresponding resistivity values are between 29 Ωm to 227 Ωm indicating a sand lithology. The underlying clay layer displays low resistivity values between 7 Ωm to 28 Ωm and thicknesses from 6.3 m to 20.2 m, indicative of clay lithology. The basement layer, encountered at depths of 8.9 m to about 21 m, is characterized by resistivity values ranging from 321 Ωm to 938 Ωm, presumed to be infinite. In Traverse 2, connecting VES 1, VES 2, VES 3, and VES 7, with VES 1 as the control VES, similar geologic sequences are identified. The topsoil, ranging from the ground top to a depth of about 2.5 m, exhibits resistivity values of 30 Ωm to 245 Ωm, indicating a sand lithology. The underlying clay layer, with thicknesses varying from 8.3 m to 22.9 m and resistivity values between 8 Ωm and 29 Ωm, suggests the presence of clay lithology. The basement layer, encountered at depths of 10.8 m to about 24 m, displays resistivity values ranging from 346 Ωm to 1243 Ωm.

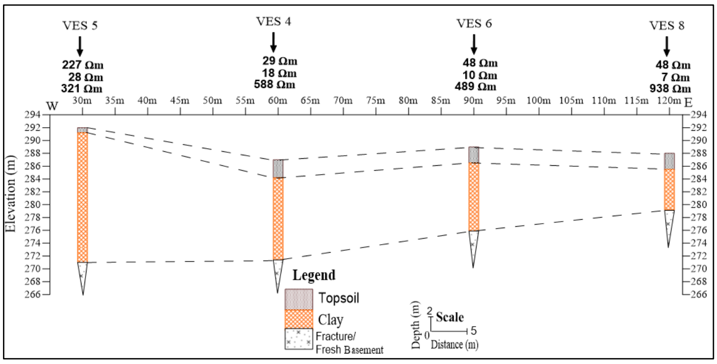

Figure 4: E–W Geo-Electric Section along Traverse One (TR1) of Ilaka Dumpsite.
Source: Authors, (2024).

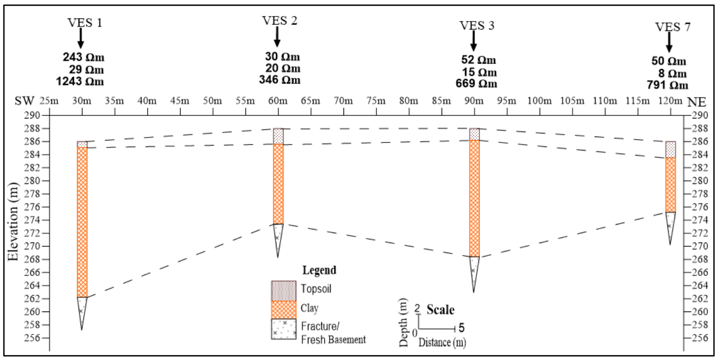

Figure 5: SW–NE Geo-Electric Section along Traverse Two (TR2) of Ilaka Dumpsite.
Source: Authors, (2024).

IV.3 ELECTRICAL RESISTIVITY TOMOGRAPHY AT ILAKA DUMPSITE

The result of 2D resistivity imaging obtained from the dipole-dipole electrode configuration of each traverse established across Ilaka dumpsite in the W – E and SW – NE directions were presented in Figures 7 and 8 respectively. Figure 6 shows a 2D image beneath the first traverse along the W – E orientation. From the result obtained, low resistivity values typically of clay lithology were observed underlying the dump site. Between the origin to about 35 m of the profile, it was characterized mainly by low resistivity values ranging from 2 Ωm to about 23 Ωm at both the near-surface, and middle layers. Between 40 m to about 90 m on the profile, a gradual variation in the resistivity values was observed at the near surface and the middle layer of these regions, there was an increase in resistivity ranging from 12 Ωm to 41 Ωm. Between 90 m to about 130 m, the overburden thickness was observed to be generally shallow, while the near-surface was characterized by layer resistivity of between 3 Ωm to about 12 Ωm. However, highly conductive zones delineated in most of the subsurface could be attributed to the hydration of the clay from the surrounding stream across the dump site.

Along the Traverse two (TR2), the 2D image beneath this traverse was established along SW – NE orientation according to Figure 7 between the origin and 45 m, the near-surface was characterized by low resistivity values ranging from 29 Ωm to 55 Ωm. This is indicative of the near-surface being sandy. The middle layer of this section has a layer resistivity value of about 8 Ωm to about 14 Ωm indicative of clay as a dominant material within the depth of about 5 m to 14.5 m and beyond this depth is the fresh basement at 15 m to 25 m. Between 45 m to about 75 m, the section is characterized by low resistivity values ranging from 12 Ωm to 68 Ωm at the near-surface. This layer is predominantly clay with a little presence of sand occurring from about 0.3 m to about 3.8 m.

The rest of the section is characterized by thick overburden between 30 m and 34 m, but with low resistivity varying between 1 Ωm and to a maximum of 16 Ωm. This section is predominantly clay/sandy clay. Between 75 m to about 130 m of the profile, the near-surface has characteristics of clayey material with a layer resistivity of between 2 Ωm to about 12 Ωm and a thin middle layer with a variation in layer resistivity between 7 Ωm and 17 Ωm having a characteristic of clay. The overburden is generally shallow at this section and ranges between 8.0 m and 18.5 m. The rest of the section has resistivity values ranging between 100 Ωm and about 180 Ωm. The observation of highly conductive zones delineated in most parts of the subsurface could be attributed to hydration and dispersed leachate plumes within the clay formation.

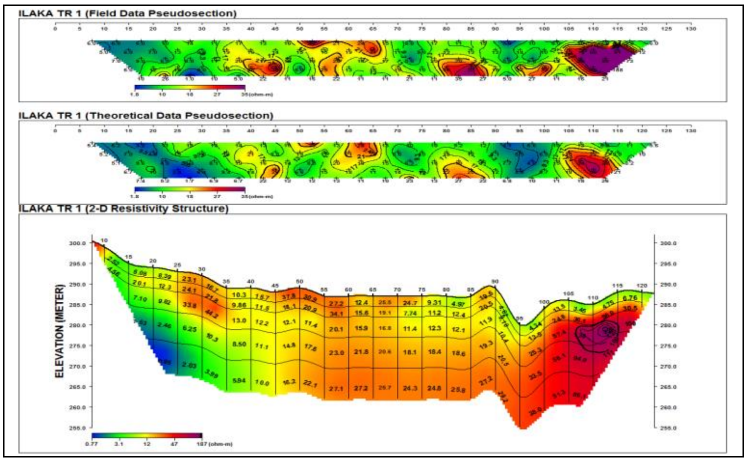

Figure 6: 2D Resistivity Image along W–E of Ilaka Traverse One (TR1) Dumpsite.
Source: Authors, (2024).

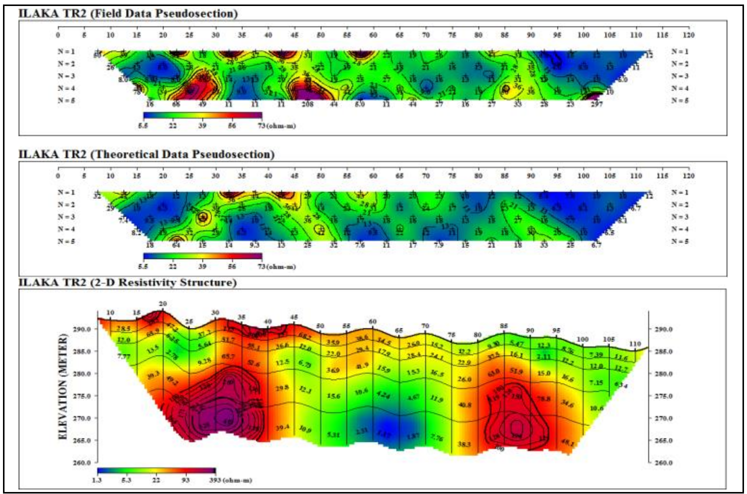

Figure 7: 2D Resistivity Image along SW–NE of Ilaka Traverse Two (TR2) Dumpsite.
Source: Authors, (2024).

IV.4 CORRELATION OF VES SECTION AND ERT IMAGE OF ILAKA DUMPSITE

The correlation of the VES section of Ilaka Traverse one with its corresponding Electrical Resistivity Tomography (ERT) image as shown in Figure 8, reveals that the majority of the profile is characterized by clay formation. This clay formation is likely influenced by leachate plumes and hydration by the stream traversing the dump site. The impermeable nature of clay inhibits further percolation of leachates into the aquifer unit, trapping them within the environment. Similarly, the comparison of the VES section of Ilaka dumpsite Traverse two with its ERT image, as shown in Figure 9, indicates that the profile is predominantly composed of clay formation, particularly in the second layer beneath the topsoil. This clay layer, influenced by dumpsite leachate, exhibits relatively low electrical resistivity values. Consequently, it can be inferred that clay's impermeable nature has trapped leachate plumes, preventing their further percolation into the aquifer unit.

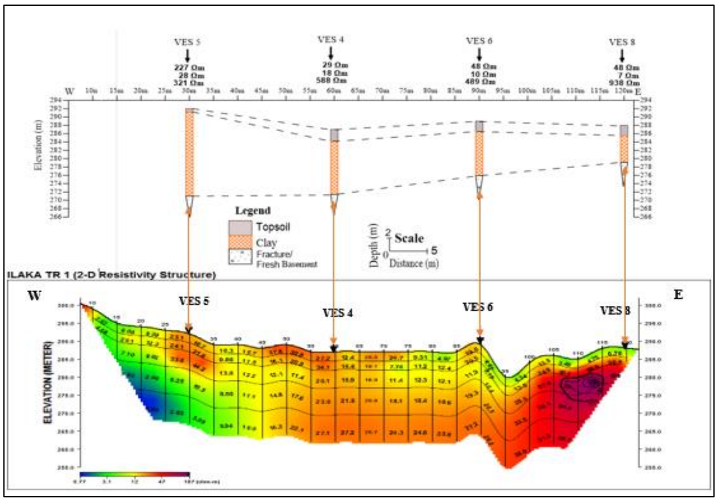

Figure 8: Correlation of VES Section with ERT Image for Traverse One.
Source: Authors, (2024).

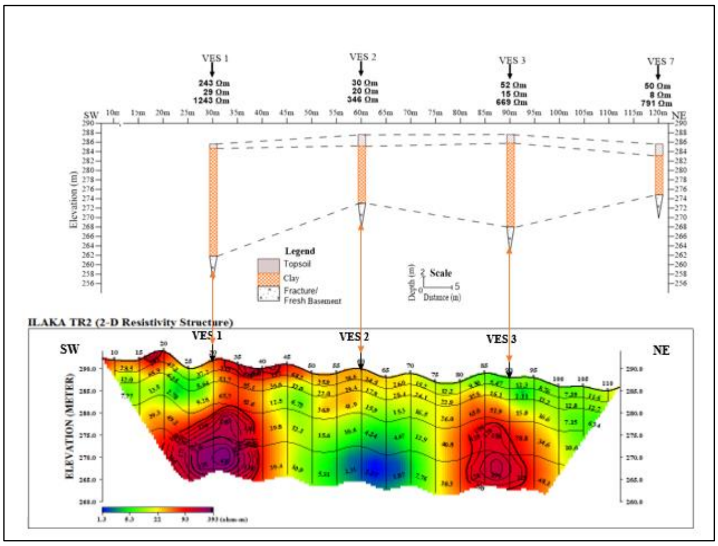

Figure 9: Correlation of VES Section with ERT Image for Traverse Two.
Source: Authors, (2024).

V. CONCLUSIONS

A geophysical survey was carried out within Oyo town to investigate the effect of some dumpsites on groundwater in Ilaka area of Oyo metropolis. The survey utilized an integrated approach which included geophysical methods involving 2D electrical resistivity imaging and vertical resistivity sounding (VES) within the study area. The geo-electric sections of the study area delineated three main subsurface geo-electric layers which include; the topsoil, the weathered layer and the last layer within the investigated depth which may be considered as the fresh basement. The topsoil is made up of clay/sandy clay with layer thickness ranging from 0.8 m to 2.8 m and layer resistivity values ranging from 29 Ωm to 245 Ωm, the weathered layer has layer thickness ranging from 6.3 m to 22.9 m and corresponding layer resistivity values ranging from 7 Ωm to 29 Ωm, while the last layer is characterized with layer resistivity values ranging from 321 Ωm to 1243 Ωm. The ERT image obtained from the processed data from the dipole-dipole revealed that the topsoil is composed of the contaminant plume from the dump site. However, this leachate was observed to have been prevented from infiltrating into the subsurface due to the predominant presence of clay underlying the dump site. Generally, some parts of the study locations were observed to be characterized by thin overburden thickness with the weathered layer constituting the major aquifer zone in the study area.

Therefore, from the results obtained from the geophysical analysis, it is evident that dissolved solid and contaminant plumes have in no way undermined the suitability and potability of groundwater in the study areas rather the streams have a greater influence on the well water obtained from the study area. It can be concluded that most of the surroundings within the study area are metres away from the dumpsites, in all the locations visited, may be suitable for groundwater development within the investigated depth.

VI. AUTHOR'S CONTRIBUTION

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Investigation: Ogunmola Olufemi Louis and Owolabi Dayo Testimony
Discussion of results: Kamaldeen Olasunkanmi Suleman and Ogunmola Olufemi Louis
Writing – Original Draft: Kamaldeen Olasunkanmi Suleman and Ogunmola Olufemi Louis
Writing – Review and Editing: Kamaldeen Olasunkanmi Suleman and Ogunmola Olufemi Louis
Supervision: Sunmonu Lukman Ayobami and Suleman Kamladeen Olasunkanmi
Approval of the final text: Kamaldeen Olasunkanmi Suleman, Testimony Dayo Owolabi, Olufemi Louis Ogunmola, Lukman Ayobami Sunmonu and Bola Abdulhamid Afolabi.

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