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Integrated resistivity study on the effect of dumpsite leachate on groundwater at Ezeani-Obimo, Nsukka, Enugu state Nigeria

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ABSTRACT

The effect of dumpsite leachate on groundwater at the Ezeani-Obimo community was performed by employing Schlumberger and Wenner configurations for four vertical electrical sounding (VES) and four electrical resistivity tomography (ERT). Four geoelectric layers were obtained and characterized by KH, AK, KH, and QH curve types. The first layer, second and third layer has resistivity values ranging from 21.2 to 7026.0 Ωm with thickness and a depth ranging from 0.5-31.6 m. The fourth layer has resistivity values ranging from 105.9 to 3355.4 Ωm with undefined thickness and depth values harboring all the aquifer units in the study area. Aquifer resistivity and thickness values vary from 105.9 to 3355.4 Ωm and 6.6 to 27.1 m while aquifer conductivity ranges from 0.0003 to 0.0094 $\Omega^{-1}m^{-1}$ increasing towards the E-W direction. The longitudinal conductance and transverse resistance values vary from 0.0024 to 0.0623 Ω^{-1} and 698.94 to 27178.7 Ωm^2 respectively. 2D ERT profiles show low resistivity in the eastern direction and a lateral spread of low resistivity value indicates that leachate flow is moving away gradually from the dumpsite to its outside environment. This study revealed that the layers harboring the aquifer in the area are significantly affected as a result of dumpsite leachate that accumulates on the surface. This result is beneficial for waste managers to take mitigation measures to prevent the risk of total contamination of the groundwater in the area in the nearest future.

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1. INTRODUCTION

Groundwater is an essential natural component of life that serves as an important resource in both urban and rural areas. Civilizations have flourished with the development of reliable water supplies but sadly the hazardous effect of civilization has also reduced the quality of groundwater. Water exists as groundwater and on the earth's surface as surface water. The quality of groundwater is generally considered to be better than that of surface water because the earth acts as a natural filter during the percolation, and surface water is more exposed to physical, chemical, and biological contaminants [1]. The factors that control the quality of groundwater are discharge-recharge pattern, the nature of the host and associated rocks, and natural or artificial contaminations [2]. Groundwater is constantly under threat from pollution caused by the numerous human activities in the environment impinging into the hydrological cycle [3], [4]. Wastes are disposed of at dumpsites located away from the residential areas although the reverse is the case in most areas. The era of population explosion and increased industrialization and urbanization results in an uncultured manner of citing dumpsites rendering the sites as a point source of groundwater contamination. Overtime when precipitation (rainwater) occur, it percolates through the wastes deposited at the dumpsite and result in leachate which is a fluid that passes through land or dumpsites and has extracted dissolved and harmful matter suspended from it [5]. Leachate plumes generated in dumpsite contain large amounts of organic and inorganic substances. When contaminant leachate get to the groundwater table, they affect the groundwater chemistry and reduce the quality of groundwater thus rendering the water unsuitable for individual and commercial applications [6]–[8]. The electrical conductivity of natural groundwater is small compared to that of some leachates and this difference enables contaminated plumes to be delineated using geophysical methods.

In hydro geophysical surveys, the flows of electric current are closely similar to that of groundwater in the aquifer and are known to flow from regions of higher potential to lower potential site and their rate of flow depends on the potential gradient. A vertical electrical sounding method utilizing Schlumberger electrode configuration has proven to be helpful in groundwater study [1], [9]–[11] and has also been widely employed in determining aquifer characteristics, geometry, and groundwater quality by analyzing apparent resistivity data from the field. The applications of indirect and non-invasive geophysical measurement can predict the distributions of the aquifer parameters more effectively.

However, the use of the electrical resistivity method in geophysical exploration helps in delineating the physical properties of anomalies within the earth subsurface while presenting relatively low-cost surveys. Resistivity method has been used by researchers [12], [13] to determine the influence of dumpsite leachate on aquifer focusing on geophysical method while a quite number of researchers [3], [14] [15] intensively focused on geophysical and Physico-chemical methods. The results from these various studies showed the subsurface and groundwater pollution levels and regions of high and low conductivity. The use of vertical electric sounding (VES) and electrical resistivity tomography (ERT) gives a detailed understanding of the hydrogeological characteristics of aquifer units and delineation of the contaminant plume [3]. 2-D resistivity imaging ERT has the capacity of detecting lateral and vertical resistivity changes to variations in fluid content, chemical composition, and contaminant migration [16]. This study was aimed at determining the effect of dumpsite leachate on groundwater repositories in other to assess its influence on aquifer resistivity using integrated electrical geophysical methods.

The dumpsite as shown in Figure 1 at Ezeani-Obimo serves as a major dumpsite for communities in Nsukka local government areas and its neighboring communities. The area is not a homogenous tableland but undulating hilly and valley terrain underlain by Nsukka formation which lies in the Anambra Basin. [17], [18], delineated that Nsukka formation has a shallow and perched aquifer system punctuated at the hilly part due to topography which is known to have a succession of sandstones, dark shales, and sandy shales [19]. They are usually underlain by clays and shales which hinder or support percolation. The soil type has been described as red soil with a texture that varies with depth. The climate belongs to the type described as having a definite wet and dry season. The wet season lasts from April to October, while the rest of the months experience the dry season. Location and geology of the survey Area: The study area (Ezeani-Obimo) is a rural community found in the Nsukka local government area of Enugu State, Southeastern Nigeria. Ezeani-Obimo shares a common boundary with Edem in the north, Lejja in the south, Agbaninguru in the east and Nkologu in the west. It lies within the geographical coordinates of $6°\ 48'30"\mathrm{N}$ to $6°\ 50'0"\mathrm{N}$ and $7°18'0"\mathrm{E}$ to $7°20'30"\mathrm{E}$, see Figure 2.

Figure 1. The dumpsite location image

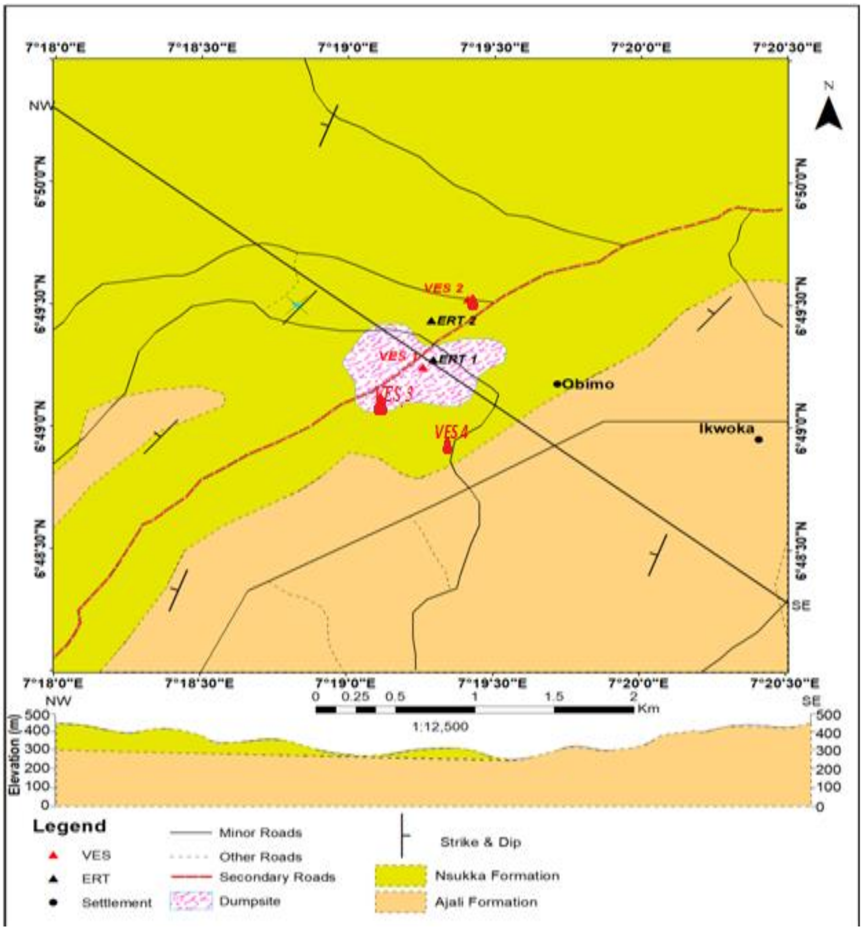

Figure 2. Geological map of Ezeani-Obimo showing the location of the dumpsite

2. MATERIALS AND RESEARCH METHODS

The resistivity readings were generated using the resistivity meter model SSR-MP-ATS instrument and its accessories to measure the potential difference across the electrodes implanted in the ground. The study employs Wenner configuration for the ERT data collection with equal electrode spacing (a) and profile spread ranging from 5 to 100 m, a total of four ERT profiles were obtained around the dumpsite. The Wenner electrode configuration is sensitive to vertical variations in the subsurface resistivity with high resolving power towards vertical changes in the subsurface [20]. The apparent resistivity values for the 2D resistivity imaging were obtained from the measured field resistance data using (1),

$$\rho_a = 2\pi a R, \quad (1)$$

where a is the electrode spacing and R is the field resistance. RES2DINV×32 version 3.71.115 software was employed in processing the computed apparent resistivity which gives the vertical and horizontal imaging of the subsurface strata. Schlumberger array was used for the four VES surveys within half current electrode spacing (AB/2) of 150 to 200 m and the half potential electrode spacing (MN/2) of 0.25 to 20.0 m. The (2) is used to compute the apparent resistivity (ρ_a) From the values of current (I) and voltage (V),

$$\rho_a = K\frac{V}{I} = KR_a \quad (2)$$

where K is the geometric factor controlled by electrode arrangement, R_a is the apparent resistance measured on the field. K is given as (3).

$$K = \pi\left[\frac{(AB/2)^2-(MN/2)^2}{MN}\right] \quad (3)$$

The calculated apparent resistivity was plotted on a bilog graph and then smoothened to remove noisy signatures using excel software. The computer modeling was performed using WinResist software by taking the calculated apparent resistivity values as input parameters which yielded a set of geoelectric curves, see Figures 3 and 4 of four to five geoelectric layers with values of resistivity, thickness, and depth of each geoelectric layer were obtained, see Table 1. Figure 5 is showing the field curve for VES 3 and Figure 6 is showing the field curve for VES 4.

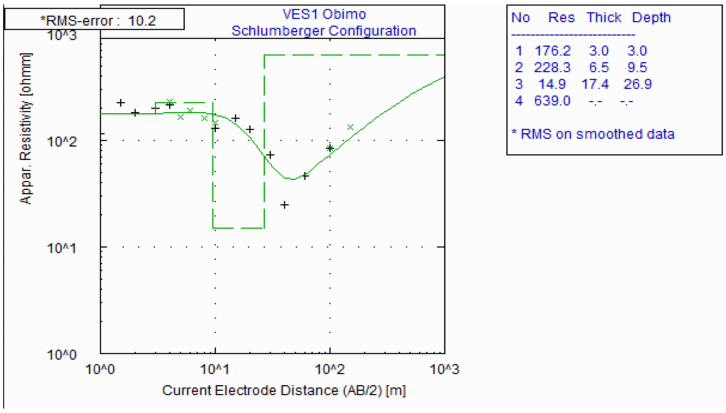

Figure 3. Field curve for VES 1

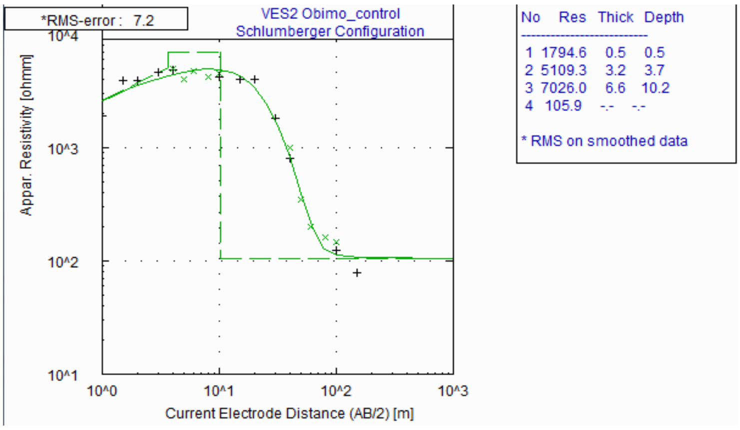

Figure 4. Field curve for VES 2

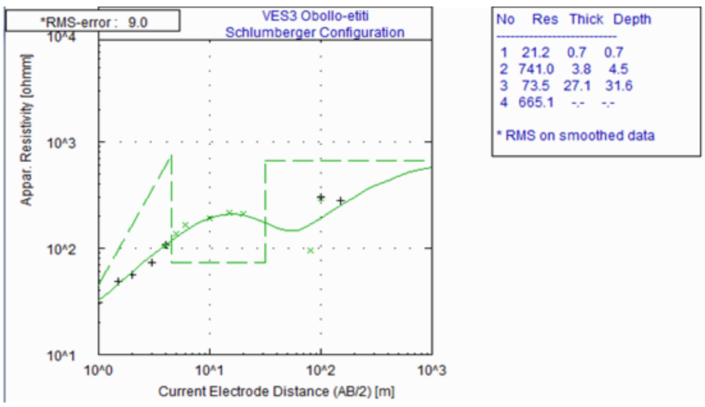

Figure 5. Field curve for VES 3

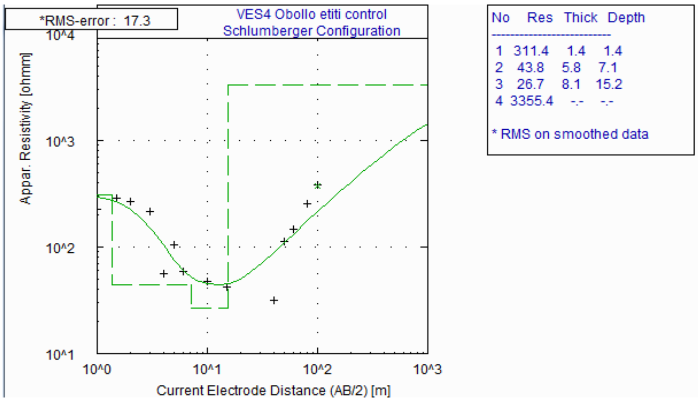

Figure 6. Field curve for VES 4

Table 1. Modified protective capacity rating using longitudinal conductance [21], [22]

Longitudinal conductance (mhos)	Protective capacity rating
>10	Excellent
5-10	Very good
0.7-4.9	Good
0.2-0.69	Moderate
0.1-0.19	Weak
<0.1	Poor

The aquifer resistivity and thickness were determined from Table 2 and geoelectric parameters longitudinal conductance and transverse resistance (Dar-Zarrouk parameters) were calculated from the values of the primary parameters (resistivity and thickness) presented in Table 3 using (4) and (5) respectively according to [9]. The longitudinal conductance (S) is obtained using the form.

$$S = \frac{h}{\rho} = h\sigma \tag{4}$$

While transverse resistance was calculated using.

$$T = \rho h = \frac{h}{\sigma} \tag{5}$$

The longitudinal conductance which is defined as the ratio of layer thickness to resistivity was used in assessing the protective capacity of the aquifer layer to determine the capacity of the aquifer layer to either obstruct or allow the infiltration of fluid (leachate) while transverse resistance is the product of layer resistivity and thickness. Classification of the aquifer's protective capacity is done considering the values of longitudinal conductance as shown in Table 1. A global positioning system was used in recording the resistivity survey location and topography. The aquifer conductivity was calculated using (6).

$$\sigma = \frac{1}{\rho} \tag{6}$$

Surfer 13 software packages were employed to carry out further qualitative analysis by contouring the obtained and calculated aquifer parameters to show their variation in the study area.

Table 2. Summary of result from resistivity survey

			Layer resistivity (Ωm)				Thickness (m)			Depth (m)			
Ves	Longitude (ºE)	Latitude (ºN)	ρ_1	ρ_2	ρ_3	ρ_4	h_1	h_2	h_3	d_1	d_2	d_3	Curve Type
1	7.3216	6.8209	176.2	228.3	14.9	639.0	3.0	6.5	17.4	6.0	9.5	26.9	KH
2	7.3205	6.8221	1794.6	5109.3	7026.0	105.9	0.5	3.2	6.6	0.5	3.7	10.2	AK
3	7.5530	6.8996	21.2	741.0	73.5	665.1	0.7	3.8	27.1	0.7	4.5	31.6	KH
4	7.5528	6.8994	331.4	43.8	26.7	3355.4	1.4	5.8	8.1	1.4	7.1	15.2	QH

Table 3. Calculated aquifer hydraulic parameters

VES Station	Longitude (ºE)	Latitude (ºN)	Elevation (m)	Aquifer Resistivity ρ_a (Ωm)	Aquifer thickness h (m)	Longitudinal Conductance S (Ω^{-1})	Transverse Resist T (Ωm^2)	Aquifer Conduct σ ($\Omega^{-1} m^{-1}$)	Protective Rating
1	7.3216	6.4915	434	639.0	17.4	0.0272	11118.6	0.0016	POOR
2	7.3205	6.4919	430	105.9	6.6	0.0623	698.94	0.0094	POOR
3	7.5530	6.8996	349	665.1	27.1	0.0408	18024.2	0.0015	POOR
4	7.5528	6.8994	346	3355.4	8.1	0.0024	27178.7	0.0003	POOR

3. RESULTS AND DISCUSSION

The one-dimensional resistivity data was processed with WinResist software for the qualitative interpretation and the result is presented in Table 2. The result reveals a total of four geoelectric layers across the study area and was characterized by the following geoelectric curve types KH, AK, KH, and QH respectively. The first layer has low resistivity values varying from 21.2 to 1794.6 Ωm with thickness and depth ranging from 0.5 to 6.0 m which indicates that the layer is mainly characterized by conductive materials. The highly conductive geologic formation might be a result of the percolation of leachate contaminants which penetrates the highly permeable top layer overlying the underlying layers. Below the uppermost layer lies a second layer with resistivity values that vary from 43.8 to 5109.3 Ωm with thickness and depth varying from 3.2 to 6.5 m and 3.7 to 9.5 m, respectively. The resistivity value of the third layer varies from 14.9 to 7026.0 Ωm with thickness and depth ranging from 6.6 to 27.1 m and 10.2 to 31.6 m, respectively. The fourth layer has resistivity values ranging from 105.9 to 3355.4 Ωm with undefined thickness and depth values and harbors all the aquifer repositories in the study area.

Aquifer resistivity layers and thicknesses were selected based on the layers with the highest thickness and were presented in Table 3 and also shows the calculated aquifer parameters to better understand the aquifer characteristics. Aquifer resistivity values vary from 105.9 to 3355.4 Ωm and an average value of 1730.65 Ωm while its thickness ranged from 6.6 to 27.1 m and the average of 16.85 m, respectively. The aquifer resistivity value suggests that the aquifer formation is composed of sand intercalated with clay. Aquifer resistivity was contoured and its variation across the study area is shown in Figure 7. Aquifer resistivity increases SN direction implying that the northern part is associated with high resistivity (low water content) values while the southern part has low resistivity (high water content). Figure 8 presents an aquifer thickness contour map revealing that aquifer thickness varies in the study area and increases NW to SE direction. SE part has low aquifer resistivity that corresponds to an area of high aquifer thickness is a good reservoir for water content implying possible leachate plumes accumulation [23]. Since high resistivity is dominant in the north corresponding to low thickness is an indication that the area is not favorable to the accumulation of contaminated fluid.

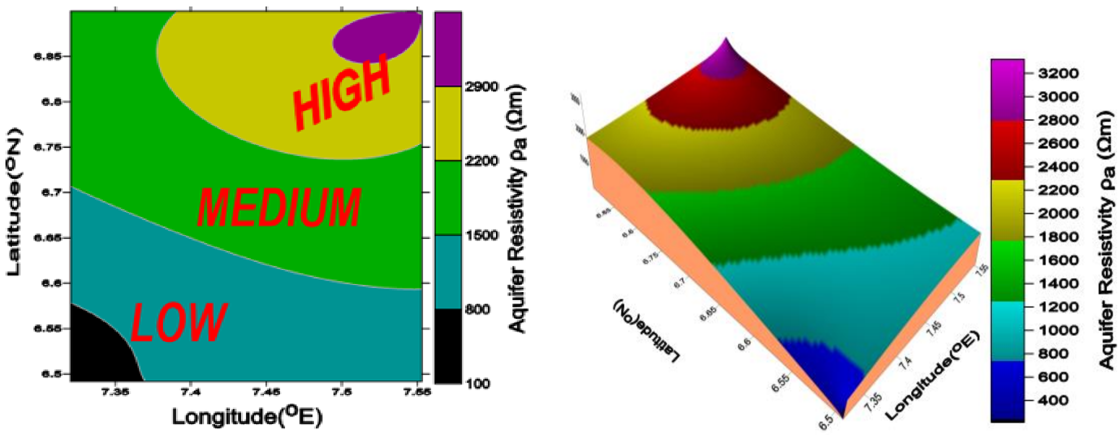

Figure 7. Aquifer resistivity 2D and 3D contour map

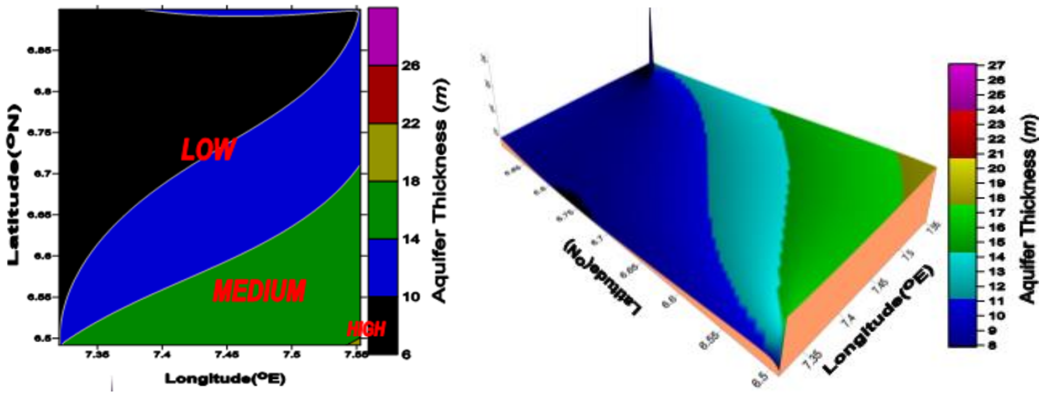

Figure 8. Aquifer thickness 2D and 3D contour map

The variation in the longitudinal conductance values range from 0.0024 to 0.0623 Ω^{-1} with an average value of 0.0324 Ω^{-1} which was used to classify the area into its protective capacity rating indicates that the aquifer protection is poor. The areas with low longitudinal conductance values are considered to be highly vulnerable to pollution from infiltration of contaminants from dumpsite leachate and/or leakage from buried underground storage facilities. The variation in longitudinal conductance across the study area is shown in the contour map presented in Figure 9. Here the longitudinal conductance increases from NE to SW direction showing that vulnerability of protective layers increases from the northeastern part to southwestern part of the study. Generally, it can be inferred that aquifers in this zone are prone to contamination as a result of the high porosity and permeability rate of geomaterial present which might be sandy.

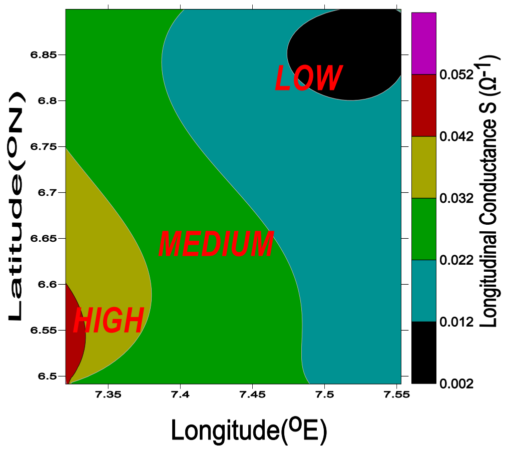

Figure 9. Contour map of longitudinal conductance

The transverse resistance values vary from 698.94 to 27178.7 Ωm^2 with an average of 13938.82 Ωm^2. It was observed from the contour map in Figure 10 that high transverse resistance values are in the northern parts of the study area which corresponds with areas of high aquifer resistivity which can be delineated as zones with low transmissivity, low aquifer conductivity, and low yield.

The aquifer conductivity ranges from 0·0003 to 0·0094 $\Omega^{-1}m^{-1}$ with an average of 0.0049 $\Omega^{-1}m^{-1}$ which increases in the EW direction as observed from the contour map in Figure 11. It was also observed from the contour map that it varies inversely to aquifer resistivity and transverse resistance but directly to longitudinal conductance. The NE and SE areas have very low aquifer conductivity while NW and SW part is associated with medium to high aquifer conductivity which implies that there is a chance for downward transmission of leachate to the groundwater in the weak zone where resistivity of the overlying layer is higher than the resistivity of underlying layers [24]. The lateral and vertical flow of contaminants in the subsurface of the study area is taking the direction of elevation, which shows a direct flow from a region of higher elevation to a region of low elevation as shown in Figure 12. The vector flow direction of groundwater in the study area as shown in Figure 13 trending SW to NE.

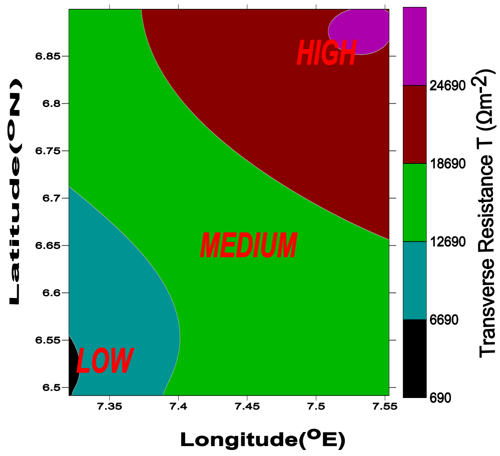

Figure 10. Contour map of transverse resistance

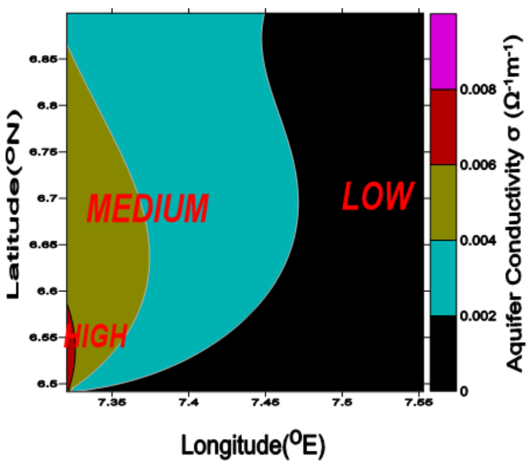

Figure 11. Aquifer conductivity contour map

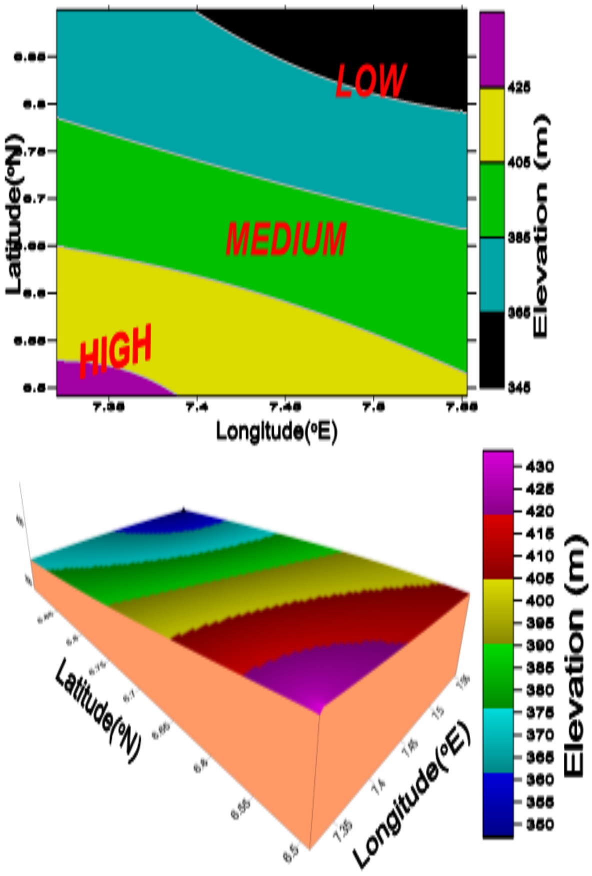

Figure 12. Elevation contour map of the study area

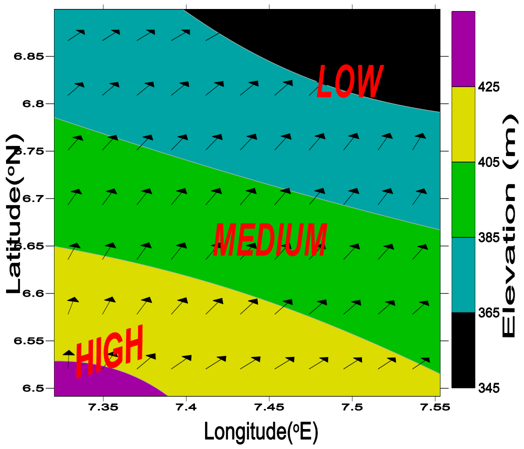

Figure 13. Elevation vector contour map

The field measured ERT data was analyzed using RES2DINV software and model results of the four profiles are shown in Figure 14 and Figure 15 as inverted models of the subsurface resistivity. The variation in the subsurface resistivity can be observed clearly, and the zones with high and low resistivity values are delineated. The two profiles (ERT 1 and 2) were taken close to VES 1 and 2, respectively. ERT profile 1 shown in Figure 14 was conducted on the decomposed heap of waste; it shows low resistivity in the eastern part down to a depth of 18.0 m between lateral positions of 80 to 100 m. The areas with extremely low resistivity values are attributed to areas with high leachate contamination, indicating that the eastern part of the dumpsite has a high concentration of leachate which might spread to the surrounding aquifer in the area [25], [26].

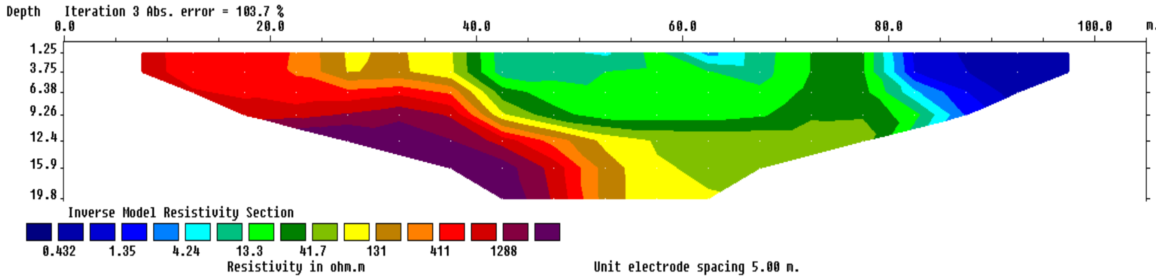

Figure 14. Inverted model of ERT profile 1

In Figure 15, profile 2 was conducted along the edge of a major road accessing the dumpsite which shows a lateral spread of low resistivity value down to a depth of 6.38 m the leachate concentration is low in this layer. The leachate contamination was higher in the eastern region (blue-green color indicator) than in the western part of the dumpsite (red-purple color indicator). This observation shows that leachate flow within the dumpsite is extending gradually to its aquifer at depth of 17.7 m extending downwards at the lateral position between 40 to 60 m and gradually moving away from the dumpsite to its outside environment between the lateral position of 95 and 100 m eastwards.

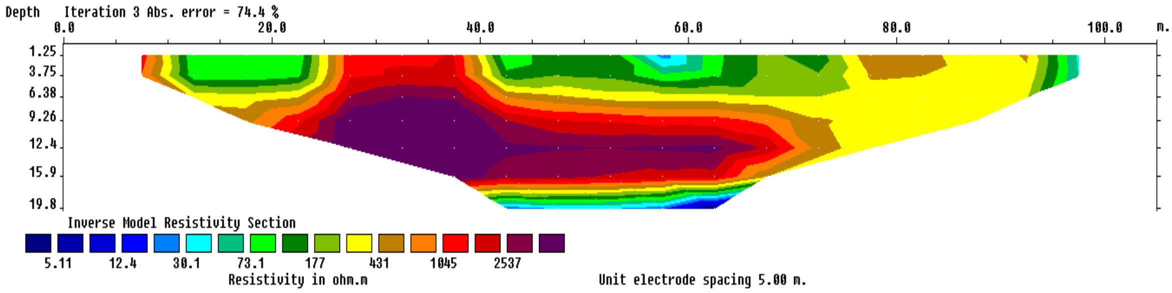

Figure 15. Inverted model of ERT profile 2

4. CONCLUSION

This research aimed to determine the effect of leachate on groundwater at the Ezeani-Obimo community using the geophysical survey method. This was achieved using an integration of vertical electric sounding and electrical resistivity tomography carried out within and outside the dumpsite which showed the aquifer potentials, it's protective rating, also delineating the high and low resistive zone. From the results obtained, low resistivity values exist in the earth subsurface within the eastern part of the dumpsite which might be due to the amount of leachate that accumulate on the surface and eventual percolation into the groundwater table during the recharge process as a result of poor aquifer protective capacity in the area. This study has shown that dumpsite leachate has a significant effect on groundwater repositories because it contains organic and inorganic substances which contaminate the earth's surface and subsurface reducing the quality of groundwater. This study will help waste managers to take mitigation measures on the dumpsite to avoid the risk of total contamination of the groundwater in the area in the nearest future.

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