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2D electrical resistivity imaging and induced polarization monitoring for groundwater contamination in an uncontrolled landfill. Case study: Gyadi-Gyadi Tarauni LGA, Kano, Nigeria



Farouq Mohammed Jibril^{1*}, Ismaila Adenoyi Sule², Abulrahim Ali Bunawa², Nura Muhammad Nagoda², and Ahmed Abubakar Sarki³

¹ Division of Agricultural Colleges, Ahmadu Bello University, Zaria, Nigeria

² Department of Physics, Bayero University, Kano, Nigeria

³ Department of Geology, Faculty of Earth and Environmental Sciences, Bayero University, Kano, Nigeria

ABSTRACT

This study investigated the impact of the Gyadi-Gyadi dumpsite on groundwater quality using Geophysical and Physicochemical methods. The area is located between latitudes 11°58'15"N to 12°02'22"N and longitudes 08°32'55"E to 08°38'50"E. Data were collected at a length of 150 m to four profiles using Advance Geoscience Imaging (AGI) SuperSting R1/ induced polarization (IP) resistivity meter. Results from the resistivity model showed that the profiles were underlain by four lithologic layers which involved lateritic soil, clay sand, highly weathered basement complex, and partially weathered basement complex rocks, respectively. The possible water bearing identified zones existed between the horizontal distance of 40 to 150 m at depth of 15 m in Profile 1; 25 to 45 m depth of 15 m in Profile 2; 35 to 50 m and 75 to 90 m, depth of 13 m in Profile 3; and 40 to 70 m, depth of 16 m in Profile 4, respectively. The IP result revealed that the waste in the dumpsite was buried to a depth of over 16 m along the profiles. The physicochemical results when compared with the WHO standard and Nigerian Standard for Drinking Water show that the pH of the water samples and Zn (0.121 to 0.975 mg/l) were within the permissible limit. Parameters such as the electrical conductivity (16.5 to 99.3 dS/m), Pb (0.142 to 0.602 mg/l), Cu (1.765 to 0.188 mg/l), and Cd (0.020 to 0.083 mg/l) were above the permissible limit. The results of this study identified the presence of conductive zones around the profiles, thus, indicating the surrounding underground water around the dumpsite may have been contaminated, especially in Profile 2 and Profile 3 having low resistivity values of 12 and 17 Ω m, which were indicative of highly conductive area as a result of leachate migration.

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1. Introduction

For decades, the investigation and monitoring of landfill sites are of major concern to environmental scientists. The dumping of a large amount of waste materials in sites without adequate soil protection measures

results in soil surface and groundwater pollution (Eikelboom et al., 2001). Furthermore, most of the waste disposal sites especially the older ones, are illegal landfills in unknown locations which lack containment objectives (Signh et al., 2011). The diffusion of landfill leachate is extensive and occurs quickly owing

* Corresponding author Farouq Mohammed Jibril ✉ farooqjibrin@gmail.com ✉ Division of Agricultural Colleges, Ahmadu Bello University, Zaria, Nigeria

to an increase in groundwater flux following heavy rain. The study area (Gyadi-Gyadi dumpsite Kano state Northern, Nigeria) was not initially set up based on scientific and health hazard considerations, the dumpsite is located within residential areas, hospitals, and markets. This unguarded refuse dumping in an environment not appropriate for that purpose could be a time bomb. This can be seen as even the quality of underground water in some areas around the site may have been grossly affected. Therefore, in order to address this problem there is a need to understand the interaction between the surrounding aquifer and the contaminant plume leaching from the landfill.

Geological and hydrogeological characterization of aquifer properties using borehole information and water sampling are the most common techniques used for this purpose but, do not give precise information with regard to the contaminants present and the spatial information (Maurya et al., 2016). Geophysical measurement gives precise information about the contaminant present as well as subsurface information of the earth. These methods, when combined with the chemical analysis of the earth portions of the investigation sites, will enable one to develop a detailed understanding of the subsurface and thus guide decision-making regarding the condition of the region. Two-dimensional geoelectrical imaging has frequently been used in subsurface pollution studies. The method not only maps the distribution of resistivity of subsurface materials but also provides general information on the subsurface stratification of buried waste and contaminated soil (Hakan et al., 2015).

Karlik and Kaya (2001) investigated groundwater contamination using electric and electromagnetic methods at an open waste disposal site. The result of the study showed a good correlation between the Direct Current (DC) resistivity and Very Low Frequency Electromagnetic Method (VLF-EM) methods, where contaminated zones were reflected by low resistivity and negative values of electromagnetic field components.

Ntarlagiannis et al. (2016) showed that Electrical Resistivity Imaging (ERI) and IP can be successfully utilized for temporal leachate monitoring; they monitored an olive oil mill waste deposition pit for 15 months showing that conductive leachate is leaking from the pit at times of high waste load.

This study combines 2D resistivity and induced polarization (IP) methods together with the water samples collected from boreholes to investigate the effect of the Gyadi-Gyadi dumpsite on groundwater quality. The objectives of this study are to determine the subsurface geologic formations and also to detect and map contaminated zones in the study area.

1.1 Location and geology of the study area

The study area is located in Tarauni local government area along Court road of Kano state, in Northern Nigeria, and lies between latitudes $11^{\circ}58'15''\text{N}$ to $12^{\circ}02'22''\text{N}$ and longitudes $08^{\circ}32'55''\text{E}$ to $08^{\circ}38'50''\text{E}$, which covers an area of about $5,600 \text{ m}^2$. The study area has the same geology as that of Kano State in general having a basement complex mainly. The rock types in the area are older granite sediments and older basement. The older basement is composed of



Figure 1. Map showing the study area.

migmatite, biotite gneiss, and blended gneiss. Joints and fractures in the basement complex rocks are better developed in the granites and quartzite and less in the gneisses and migmatite. (www.kanostate.net, 2019).

2. Methodology

2.1 Electrical resistivity and IP methods

The investigation points were laid out in four profiles which lie within the co-ordinates of longitudes 11.96847°N to 11.9674°N and latitudes 8.54362°E to 8.54398°E for the first profile, longitudes 11.96602°N to 11.96628°N and latitudes 8.54227°E to 8.54337°E for the second profile, longitudes 11.96623°N to 11.9658°N and latitudes 8.54117°E to 8.54195°E for the third profile, and longitudes 11.7120°N to 11.97071°N latitudes 8.54077°E to 8.53975°E for the fourth profile, respectively. The electrical resistivity and IP data were acquired using the SuperSting R1/IP resistivity meter by employing the Wenner configuration array. The device was positioned in line with the current and potential electrodes along a straight line at minimum electrode spacing of 5 m and maximum electrode spacing of 30 m. The field data was carried out by moving the four electrodes (i.e. two potential and two current electrodes) between each measurement. The device automatically calculates the apparent resistivity and IP values. The resistivity and IP data set collected in the field were converted into resistivity and IP models for geological interpretation using the

RES2DINV software. The data were imported to Surfer 9.0 to give geological layers of the various profiles.

2.2 Groundwater sample analysis

A total of five water samples were collected from Boreholes along the profiles and at the dumpsite (Control). The coordinates of the sample points are as follows: Sample 1(11.96877°N and 8.54263°E), Sample 2 (11.96632°N and 8.54246°E), Sample 3 (11.9653°N and 8.54186°E), Sample 4 (11.7128°N and 8.54073°E), and Sample 5 which is the Dumpsite is 11.5825°N and 8.3243°E. The water samples were taken for lab analysis at the soil science laboratory, Bayero University Kano, for various elements and heavy metals to ascertain the water quality of the area. The water quality analysis involves the pH, electrical conductivity (EC), and some heavy metals which involve Cu, Pb, Zn, and Cd, respectively.

3. Results and Discussion

3.1 Resistivity results

Figures 2 and 3 showed the inverse resistivity model and geologic section of Profile1 collected with a minimum electrode spacing of 5 m. The length of the profile is 150 m having the coordinates of longitude 11.96847°N and latitude 8.54362°E respectively. The inverted resistivity values range from 9.62 to 100 Ω m, 100 to 183 Ω m, 183 to 330 Ω m, and 330 to 595 Ω m, respectively. The area was underlain by four geological layers which involve the laterite soil consisting

Table 1. Result of the physicochemical analysis compared with WHO NSDQW standard values.

Sampling locations	Coordinates		pH	EC (dS/m)	Pb (mg/l)	Cd (mg/l)	Cu (mg/l)	Zn (mg/l)
Sample 1 (Babbau Layi Road)	11.96877°N	8.54263°E	6.860	45.700	0.602	0.020	0.749	0.162
Sample 1 (Babbau Layi Road)	11.96632°N	8.54246°E	6.070	50.700	0.308	0.066	0.886	0.220
Sample 3 (Hausawa Road)	11.9653°N	8.54186°E	6.830	98.200	0.509	0.044	0.832	0.121
Sample 4 (Bawo Road)	11.7128°N	8.54073°E	6.320	16.500	0.142	0.036	0.851	0.248
Dumped Site	11.5825°N	8.3243°E	7.010	99.300	0.599	0.083	1.765	0.975

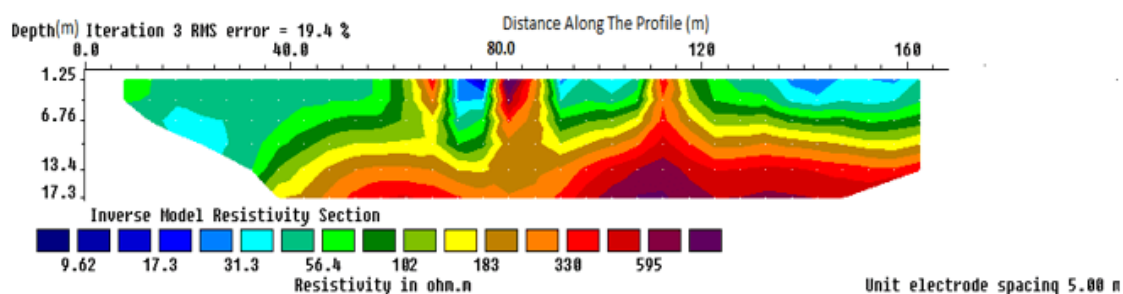


Figure 2. Inverse resistivity model of profile1.

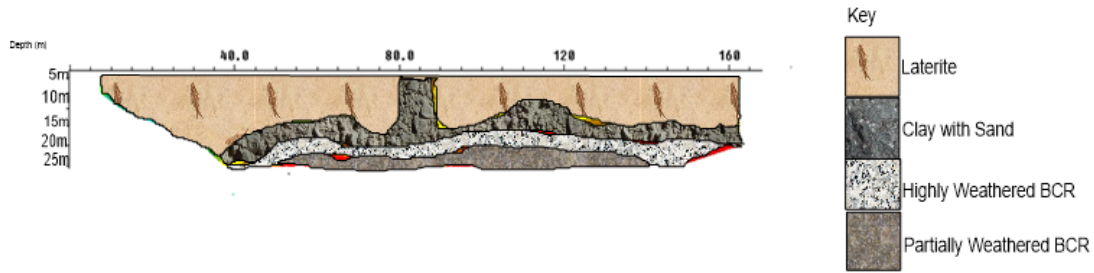


Figure 3. Geological section of profile 1.

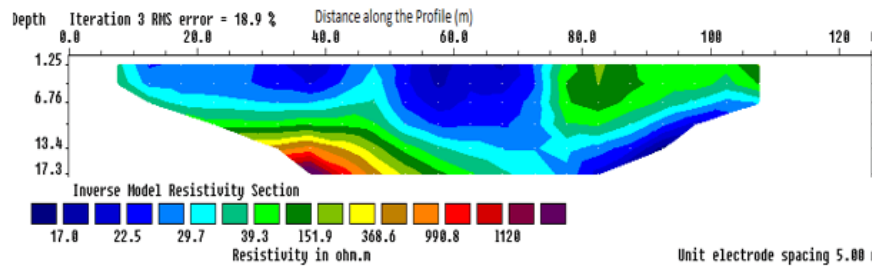


Figure 4. Inverse resistivity model of profile 2.

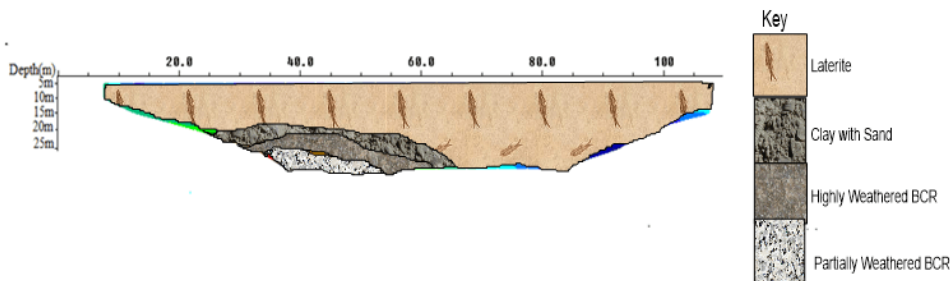


Figure 5. Geological section of profile 2.

of clay, clay with sand, a highly weathered basement, and partially weathered basement complex rock. The water-bearing zone exists between the horizontal distance ranging from 40 to 150 m at the depth of 15 m. The result showed that the profile was dominated by medium and high resistivity marked areas with a handful of conductive structures with low resistivity anomalies which exist between the distance of 75 to 80 m, 90 to 110 m, and 140 to 150 m at the depth of 7 m within the profile. The low resistivity marked areas may be evidence of leachate plume accumulation. This pocket of conductive structures may extend beneath the surface to form a conductive flow path which will contaminate the fresh water.

Figures 4 and 5 showed the inverse resistivity model and geological section of Profile 2 collected

with a minimum electrode spacing of 5 m. The maximum electrode spacing used was 30 m over a survey line of 100 m with the coordinates of longitudes 11.96602°N to 11.96628°N and latitudes 8.54227°E to 8.54398°E respectively. The inverted resistivity values range from 17.0 to 151.9 Ωm , 151.9 to 368.6 Ωm , 368.6 to 990 Ωm and 990 to 1120 Ωm respectively. According to Table 2, the low resistivity values ranging from 17.0 to 151.9 Ωm was interpreted as laterite, followed by a layer of resistivity values ranging from 151.9 to 368.6 Ωm which was interpreted as clay with sand, the third layer having the resistivity values ranging from 368.6 to 990 Ωm was interpreted as highly weathered basement, while the fourth layer having the range of resistivity values from 990 to 1120 Ωm was interpreted as partially

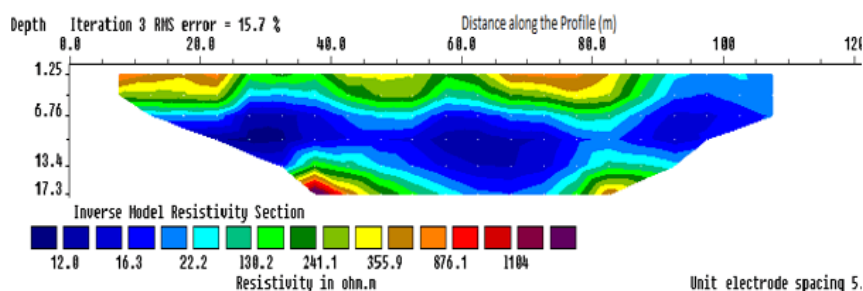


Figure 6. Inverse resistivity model of profile 3.

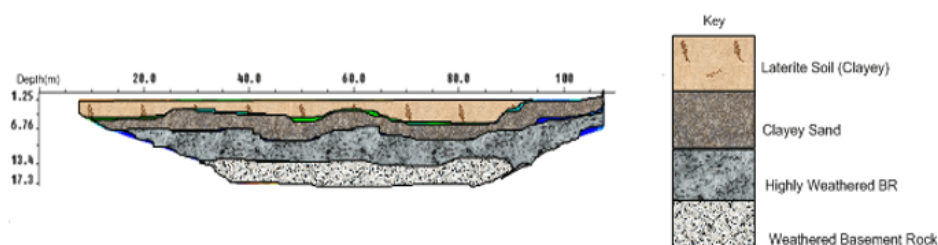


Figure 7. Geological section of profile 3.

weathered basement complex rock. The water-bearing zone exists between the distance of 25 to 45 m at the depth of 15 m. Results from this profile showed a continuous spread of low resistivity values from a horizontal distance of 10 to 75 m. This low resistivity marked area tends to extend beneath the surface to form a conductive flow path which indicates an area of leachate migration as a result of fracture or cracks. This conductive flow path may also serve as a formal fluid conduit that enables the movement of a contaminant into the freshwater.

Figures 6 and 7 showed the inverse resistivity model and geological section of location 3 collected with a minimum electrode spacing of 5 m. The length of the third profile is 100 m having the coordinate of longitude 11.96623°N and latitude 8.54117°E, respectively. The inverted resistivity model showed rocks of varying resistivity along the profile. The resistivity values range from 12.0 to 130.2 Ωm , 130.2 to 241.1 Ωm , 241.1 to 355.9 Ωm , and 355.9 to 1104 Ωm respectively. This shows regions from low to medium, medium to high, and high along the profile. The water-bearing zones exist between the distance of 35 to 50 m and 75 to 90 m at the depth of 13 m. The result from this profile showed a spurious conductive structure ranging from the right side of the profile which extends beneath the surface to the left at depth of 17 m. The conductive area with a range of low resistivity values

Table 2 Typical Resistivity values for Some Rock Materials (Telford, et. al, 1990)

Rock Type	Resistivity Range (Ωm)
Top Soil/Clay	1-100
Lateritic Soil	30-500
Highly Weathered Bedrock	100-1000
Fractured Basement Complex Rock	40-10000
Fresh Basement Complex Rock	300-1000000

may be attributed to contaminants that could have migrated into the area to form a block of a plume.

Figures 8 and 9 showed the inverse resistivity model of profile 4 located at latitude 11.7120°N and longitude 8.54077°E, respectively. The inverted resistivity model showed rocks of varying resistivity along the profile. The resistivity values range from 37.9 to 43.3 Ωm , 43.3 to 49.4 Ωm , 49.4 to 56.3 Ωm , 56.3 to 164.2 Ωm , 164.2 to 273.3 Ωm , 273.3 to 483.6 Ωm , and 483.6 to 795.4 Ωm , respectively. This shows that the profile is underlain by four geological layers which consist of the laterite soil, clay with sand, a highly weathered basement, and a partially weathered basement complex rock. The water-bearing zone exists between the distance of 40 to 70 m at the depth of 16 m. The results showed that the profile was dominated by medium and high resistivity marked areas. These zones of medium and high resistivity values

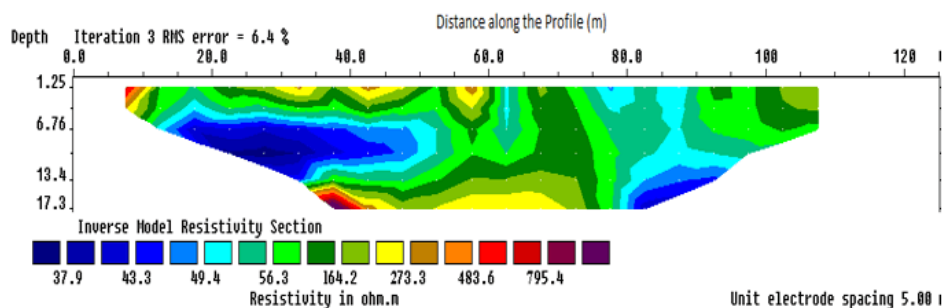


Figure 8. Inverse resistivity model of profile 4.

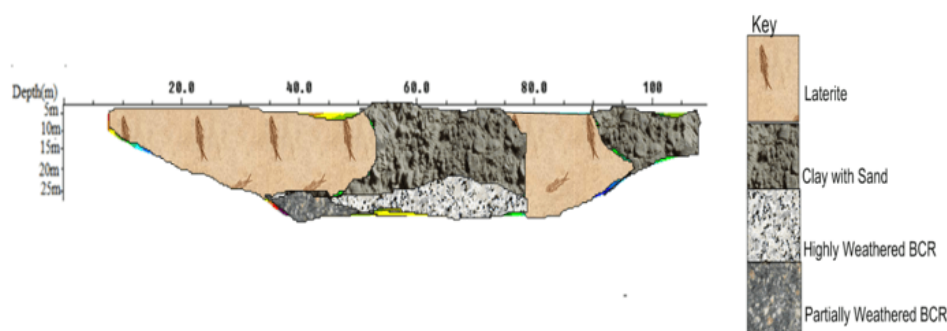


Figure 9. Geological section of profile 4.

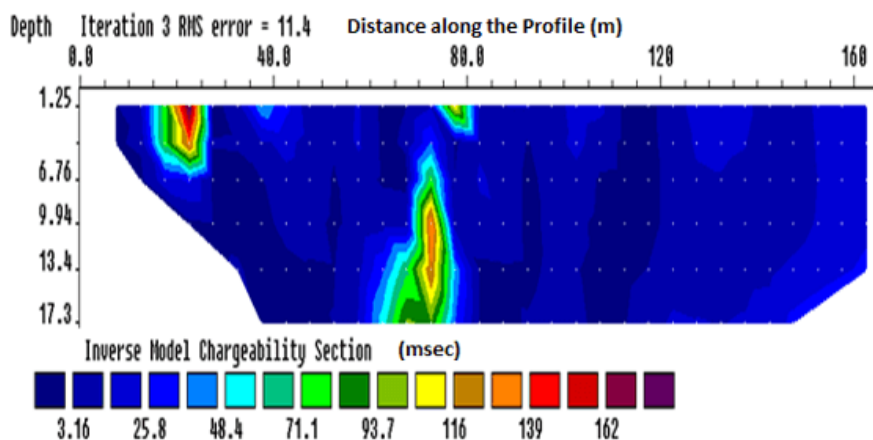


Figure 10. Chargeability model of profile 1.

could be an indication that the zones are free or safe from contaminants. While the low resistivity anomalies which exist between the distance of 10 to 55 m and 80 to 95 m may be susceptible to movement of contaminant coming from the dump site.

IP Results

Figure 10 shows the chargeability model of Profile1 ranging from 3.16 to 162 m second, respectively. The profile is underlain by three anomalies which reveal the presence of buried materials from the surface to

the maximum depth of 17 m at a horizontal distance ranging from 15 to 25 m at depth of 5 m, 55 to 70 m at depth of 17 m, and 75 to 80 m at depth of 3 m respectively, with high chargeability values greater than 25.8 m second indicating the presence of buried waste along the points. The chargeability values ranging from 3.16 to 25.8 m second is an indication of alluvium material consisting of clay minerals.

Figure 11 is an IP model showing the chargeability values ranging from low to medium, medium to high, and high along the profile point. The values ranging

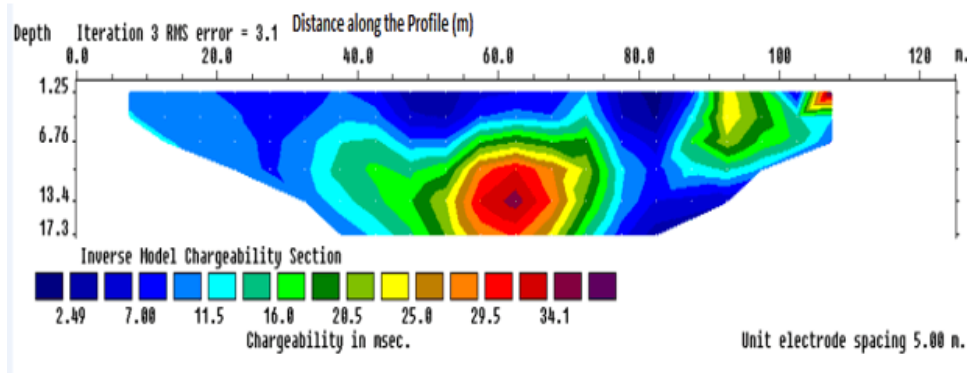


Figure 11. Chargeability model of profile 2.

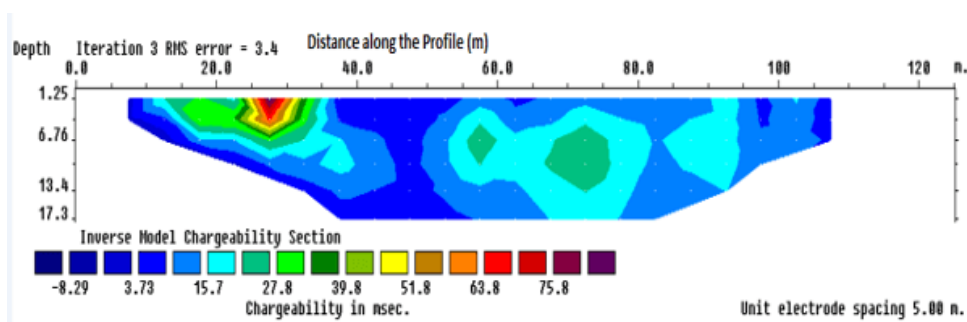


Figure 12. Chargeability model of profile 3.

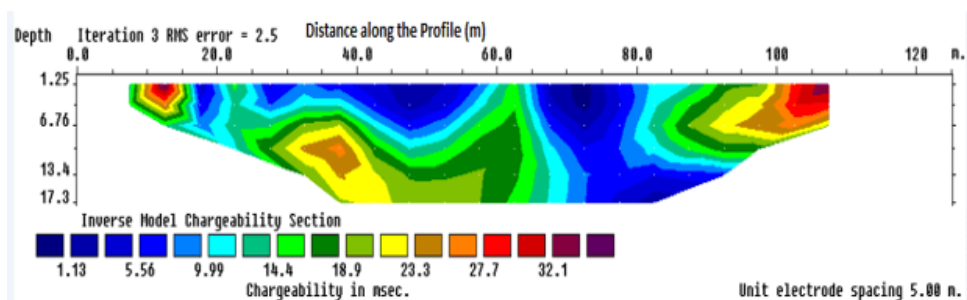


Figure 13. Chargeability model of profile 4.

from 2.49 to 16 m second indicate the presence of alluvium material which consists of clay, at a horizontal distance ranging from 10 to 90 m. While the high chargeability values above 20.5 m second which exist between the horizontal distances ranging from 50 to 75 m at depth of 17 m and 90 to 100 m at depth of 7 m indicate the presence of buried organic waste along the profile. The chargeability increases as the salinity of groundwater increase up to 500 mg/l.

Figure 12 is an IP model of Profile 3, the chargeability values range from -8.29 to 75.8 m second. The results of the model showed high chargeability anomalies at a distance of 10 to 35 m which extend beneath the surface to a depth of 7 m. These high chargeability values may be an indication of buried organic waste along the profile.

Figure 13 showed the IP model of Profile 4 with chargeability values ranging from 1.13 to 32.1 m second, respectively. The profile is underlain by high chargeability anomalies which exist between the horizontal distance of 6 to 15 m at the depth of 6 m, 25 to 40 m at the depth of 17 m, and 85 to 100 m at the depth of 12 m, respectively.

3.2. Physicochemical results

3.2.1. pH

The pH levels for water samples from different selected sampling locations showed little variation as presented in Table 1. The highest value was recorded at the dumped site (7.01) while the least value (6.07)

was obtained at profile 2 with an average value of 6.62 across the location. The high pH value obtained at the dumped site could be attributed to high carbon dioxides and dissolved minerals that normally affect the pH. From the rating developed by WHO (2004) and Nigerian Standard for Drinking Water (2007), the pH from this study was within the normal range for drinking of 6.5 to 8.5.

3.2.2. Electrical conductivity

The EC values vary among the profiles as presented in Table 1. The highest EC value was obtained at the dumpsite then followed by Sample 3; while the lowest value was obtained at Sample 4. The highest EC value observed at the dumpsite might be due to the presence of different forms of soluble salts which may explain the reason for having low resistivity across the profiles from the geophysical studies. Although, all the samples were above the permissible limit of 4 dS/m for water as documented by WHO (2004) and Nigerian Standard for Drinking Water (2007).

3.2.3. Lead (Pb)

As presented in Table 1, the highest value of Pb content was recorded in Sample 1 (0.602 mg/l) which was found to be closer to the value obtained at the dumpsite while the lowest value was obtained in Sample 4 (0.142 mg/l). The varying concentration levels of the Pb contents observed between the sampling locations might be due to the differences in underground seepage of the contaminants from the dumpsite to the other part of the sampling location. According to the WHO (2004) and Nigerian Standard for Drinking Water (2007) guidelines, the Pb concentrations recorded from this study were generally above the maximum permissible Pb concentrations limits of 0.10 mg/l.

3.2.4. Cadmium (Cd)

The Cd concentration in the water samples ranged from 0.020 to 0.083 with an average value of 0.050 mg/l in Table 1. The highest value was obtained at the dumpsite followed by Sample 2. According to the WHO (2004) and Nigerian Standard for Drinking Water (2007), the Cd concentrations recorded from this study were generally above the maximum permissible Cd concentrations limits of 0.01 mg/l and 0.03 mg/l, respectively. The level of Cd in the water samples may have come from the burning of the plastics to recover the metals and also from the Ni/Cd batteries dumped in the area which confirmed the finding of Hardy et al. (2008). High concentrations of Cd above the threshold

level in all the water samples have a detrimental effect on the people who use the water for drinking.

3.2.5. Copper (Cu)

The result in Table 1 indicates that the maximum concentration of Cu was obtained at the dumpsite (1.765 mg/l) and the minimum value was at Sample 1 (0.749 mg/l) with a mean value of 1.045 mg/l across the locations. The levels of Cu obtained from this study were above the permissible limit of the Nigerian Standard for Drinking Water (2007). The highest Cu levels at dumpsites could be attributed to the intensive dismantling and burning activities to recover the metal. Air deposition and runoff could also be a factor.

3.2.6. Zinc (Zn)

The Zn concentration in the water samples varied with a maximum value of 0.917 mg/l at the dumpsite and a minimum of 0.121 mg/l at Sample 3 which was found to be close to other values observed in other samples. The varying concentration of Zn observed between the sampling locations might be due to the differences in the burning activities of plastic materials at the sites. This agrees with the result obtained by Hardy et al. (2008) who reported that high levels of Zn could Pb to the high burning of electronic waste and the dismantling activities to recover various metals which can influence the activity of microorganisms and earthworms thereby retarding the breakdown of organic matter (Bala et al., 2008). According to the WHO (2004), the average Zn concentrations recorded from this study were generally below the maximum permissible Zn concentrations limits of 15.0 mg/l as reported by WHO (2004).

4. Conclusion

The study investigated the impact of the Gyadi-Gyadi dumpsite on groundwater quality using the combined geophysical and physicochemical methods. From the study, the following conclusions were drawn.

Four geological layers were identified along the profiles which involve the laterite, clay sand, highly weathered basement complex rock, and partially weathered basement complex rock, respectively. The resistivity values range from 9.62 to 595 Ω m in Profile 1, 17.0 to 1120 Ω m in Profile 2, 12.0 to 1104 Ω m in Profile 3, and 37.9 to 795.4 Ω m in Profile 4, respectively. The IP result reveals that the waste in the dumpsite was buried to a depth of over 16 m along the profiles. The physicochemical results when compared with the WHO and Nigerian Standard For Drinking Water show that the pH and Zn (0.121 to

0.975 mg/l) of the water samples were within the permissible limit. Parameters such as the EC (16.5 to 99.3 dS/m), Pb (0.142 to 0.602 mg/l), Cu (1.765 to 0.188 mg/l), and Cd (0.020 to 0.083 mg/l) were above the permissible limit. The results of this study suggest that conductive zones were identified around the profiles, indicating the surrounding groundwater around the dumpsite may have been contaminated, especially in profile 2 and profile 3 having water-bearing zones existing at a distance of 25 to 45 m depth of 15 m and 35 to 50 m and 75 to 90 m at depth 13 m, which were indicated as highly conductive areas as a result of leachate migration. The highest EC value was obtained at the dumpsite, followed by Sample 3 and Sample 2 of 99.300 dS/m, 98.200 dS/m, and 50.700 dS/m, respectively. This is due to the presence of different forms of soluble salts which explains the reasons for having low resistivity values across the profiles from the geophysical studies.

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