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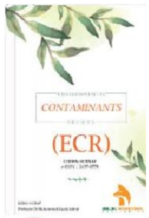

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RESEARCH ARTICLE

APPLICATION OF INDUCED POLARIZATION IMAGING FOR SPATIAL MAPPING OF LEACHATE PLUME IN A MUNICIPAL WASTE DUMPSITE IN KANO, NIGERIA

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ABSTRACT

This study investigates the Application of Induced Polarization Imaging for Spatial Mapping of Leachate Plume in a Municipal Waste Dumpsite in Kano, Nigeria, using 2D Induced Polarization (IP) imaging and physicochemical groundwater analysis. The primary objective is to assess subsurface contamination and its impact on groundwater quality. The research employs two-dimensional geoelectrical imaging to map subsurface resistivity variations and identify buried waste materials. Groundwater samples were collected from five boreholes along the study profiles and analyzed for pH, electrical conductivity (EC), and heavy metal concentrations, including lead (Pb), cadmium (Cd), copper (Cu), and zinc (Zn). The IP results reveal high chargeability anomalies indicative of buried waste, particularly at depths of up to 17 meters. The chargeability values correlate with areas of significant contamination, suggesting extensive leachate migration. The physicochemical analysis of groundwater samples indicates variations in water quality across the study area. The pH values range from 6.07 to 7.01, within acceptable drinking water limits. However, EC values exceed the permissible threshold, indicating high dissolved ion content. Heavy metal analysis reveals Pb and Cd concentrations above World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDQW) limits, suggesting contamination from landfill leachates. Elevated Cu and Zn levels, particularly at the dumpsite, further confirm anthropogenic pollution, likely from the burning and dismantling of electronic waste. The findings highlight the necessity for continuous environmental monitoring and the implementation of containment measures to mitigate leachate migration.

KEYWORDS

Induced Polarization, Chargeability, Landfill, Leachate, Contamination.

1. INTRODUCTION

The growing of global population has increased the demand for proper supervision of landfill sites, especially in the developing countries. Most of the landfills in developing countries lack containment objectives (Singh et al., 2011). Leaching of organic and inorganic contamination from these landfills is a serious environmental problem as surface water and aquifers are affected. However, the characterization and monitoring of these landfills is necessary to risk assessment and management of the overall environment. Geophysical surveys serve as complementary tools for monitoring wells, as well as evaluation of landfill sites and their surrounding environments (Dagwar and Dutta, 2024).

Induced Polarization (IP) imaging has emerged as a valuable geophysical technique for characterizing leachate plumes at landfill sites. This non-invasive method offers high spatial resolution and sensitivity to changes in subsurface properties, making it particularly useful for delineating contamination zones (Abdulrahman et al., 2016). At landfills, leachate plumes typically exhibit low resistivity (<10 Ωm) and weak chargeability (<20 ms), allowing for their differentiation from surrounding materials (Abdulrahman et al., 2016).

The application of IP imaging, often in conjunction with other geophysical and geochemical methods, provides a comprehensive approach to understanding the spatial distribution and behavior of leachate plumes. This integrated methodology has been successfully employed at various landfill sites worldwide, offering insights into plume migration pathways, extent of contamination, and potential environmental impacts (Bjerg et al., 2009; Soupios and Ntarlagiannis, 2017).

While IP imaging presents a promising tool for leachate plume characterization, it is important to note that careful interpretation and validation through direct sampling methods are necessary for accurate results. The technique's effectiveness can vary depending on site-specific conditions, such as geological setting and leachate composition (Abdulrahman et al., 2016; Ntarlagiannis et al., 2016; Soupios and Ntarlagiannis, 2017). Overall, IP imaging contributes significantly to the spatial characterization of leachate plumes, supporting informed decision-making in landfill management and remediation efforts.

Geophysical measurement gives precise information of 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 develop detailed understanding of the subsurface and thus guide in 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 subsurface stratification of buried waste and contaminated soil (Hakan et., 2015).

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2. MATERIAL AND METHODS

2.1 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^{0}58''15N to 12^{0}02'22''N and longitudes 08^{0}32'55''E to 08^{0}38'50''E, which covers an area of about 5600m^{2}. The study area has the same geology as that of Kano State in general having basement complex mainly. The rock types in the area are older granites sediments and older basement. The older basement is composed of 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).

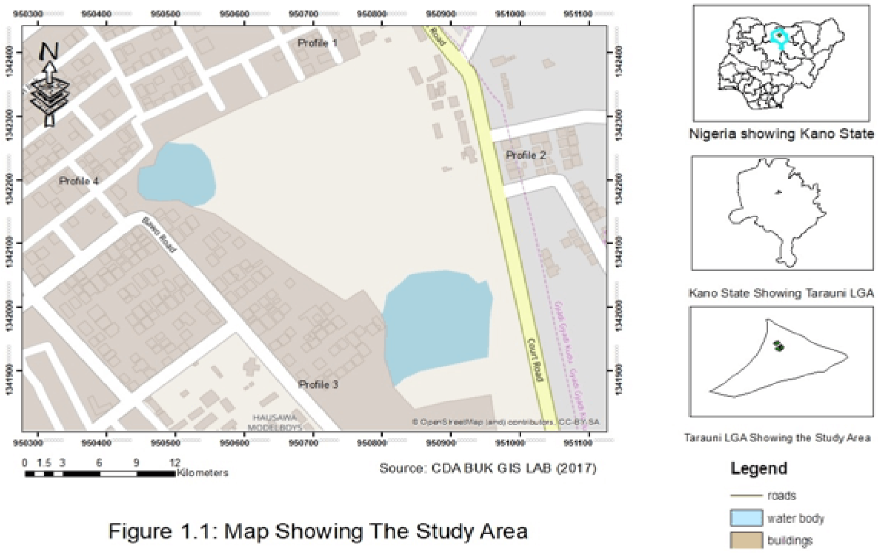

Figure 1.1: Map Showing The Study Area

2.2 Induced Polarization Method

The induced polarization (IP) method is based on a current-stimulated electrical phenomenon observed as a delayed voltage response in earth materials. The IP effect is observed as a residual voltage decay after the current flow is interrupted (time domain IP) or as a frequency-dependent resistivity (frequency domain). In the time domain, the voltage decay is recorded during a time interval $\Delta t = t2 - t1$(ms) after the current flow is interrupted. The calculated parameter is the chargeability, given by $M = 1/Vp \int V(t)dt$ where V(t) (V) is the residual voltage at time t after the current interruption, Vp (V) is the primary voltage recorded during the current flow.

2.3 Electrical resistivity and Induced Polarization Methods

The investigation points were laid out in four profiles which lies within the co-ordinates of longitudes 11.96847^{0}N to 11.9674^{0}N and latitudes 8.54362^{0}E to 8.54398^{0}E for the first profile, longitudes 11.96602^{0}N to 11.96628^{0}N and latitudes 8.54227^{0}E to 8.54337^{0}E for the second profile, longitudes 11.96623^{0}N to11.9658^{0}N and latitudes 8.54117^{0}E to 8.54195^{0}E for the third profile and longitudes 11.7120^{0}N to 11.97071^{0}N latitudes 8.54077^{0}E to 8.53975^{0}E for the fourth profile respectively. The electrical resistivity and induced polarization data were acquired using Super Sting 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 5m and maximum electrode spacing of 30m. 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 calculate the apparent resistivity and induced polarization values. The resistivity and induced polarization (IP) data sets collected in the field were converted into resistivity and induced polarization (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.

2.4 Groundwater sample analysis

Total of five (5) water samples were collected from Boreholes along the profiles and at the dumpsite (Control). The coordinates of the sample points are as follow: Sample 1(11.96877^{0}N and 8.54263^{0}E), Sample 2 (11.96632^{0}N and 8.54246^{0}E), Sample 3 (11.9653^{0}N and 8.54186^{0}E), Sample 4 (11.7128^{0}N and 8.54073^{0}E) and the 5th Sample which is the Dumpsite is 11.5825^{0}N and 8.3243^{0}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 involve that of the pH, electrical conductivity and some heavy metals which involve Cu, Pb, Zn and Cd respectively.

3. RESULTS AND DISCUSSIONS

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^{0}N	8.54263^{0}E	6.860	45.700	0.602	0.020	0.749	0.162
Sample 1 (Babbau Layi Road)	11.96632^{0}N	8.54246^{0}E	6.070	50.700	0.308	0.066	0.886	0.220
Sample 3 (Hausawa Road)	11.9653 ^{0}N	8.54186^{0}E	6.830	98.200	0.509	0.044	0.832	0.121
Sample 4 (Bawo Road)	11.7128 ^{0}N	8.54073^{0}E	6.320	16.500	0.142	0.036	0.851	0.248
Dumped Site	11.5825 ^{0}N	8.3243 ^{0}E	7.010	99.300	0.599	0.083	1.765	0.975

3.1 Induced Polarization (IP) Results

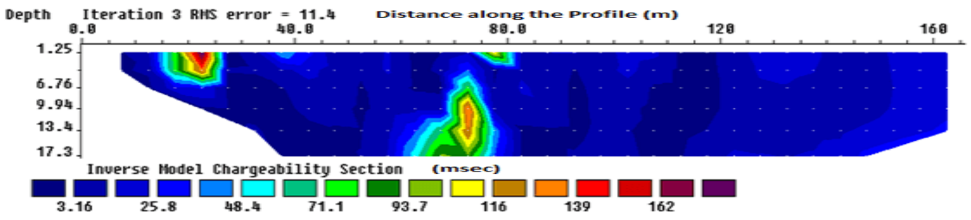

Figure 2: Chargeability model of profile 1

Figure 2 showed the chargeability model of Profile1 ranging from 3.16 msec to 162 msec respectively. The profile is underlain by three anomalies which reveals the presence of buried materials from the surface to the maximum depth of 17m at horizontal distance ranging from 15m to 25m at depth of 5m, 55m to 70m at depth of 17m and 75m to 80m at depth of 3m respectively, with high chargeability values greater than 25.8 msec indicating the presence of buried waste along the points. The chargeability values ranging from 3.16 msec to 25.8 msec is an indication of alluvium material consisting of clay minerals.

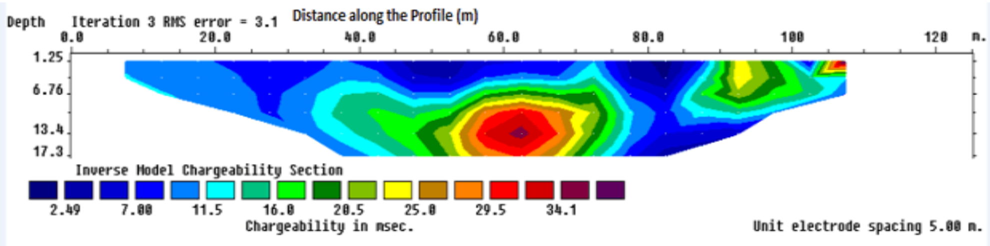

Figure 3: Chargeability model of profile 2

Figure 3 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 from 2.49 msec to 16 msec indicates the presence of alluvium material which consisting of clay, at horizontal distance ranging from 10m to 90m. While the high chargeability values above 20.5 msec which exist between the horizontal distances ranging from 50m to 75m at depth of 17m and 90m to 100m at depth of 7m indicates the presence of buried organic waste along the profile. The chargeability increases as the salinity of ground water increase up to 500mg/L .

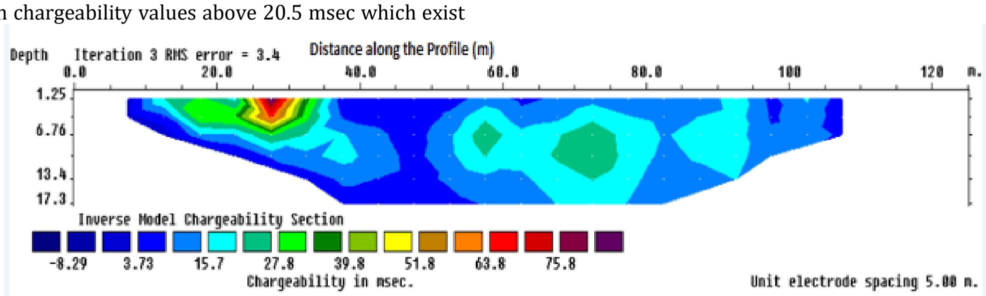

Figure 4: Chargeability model of profile 3

Figure 4 is an IP model of Profile 3, the chargeability values ranges from -8.29 msec to 75.8 msec . The results of the model showed a high chargeability anomalies at distance of 10m to 35m which extend beneath the surface to the depth of 7m. These high chargeability values may be an indication of buried organic waste along the profile.

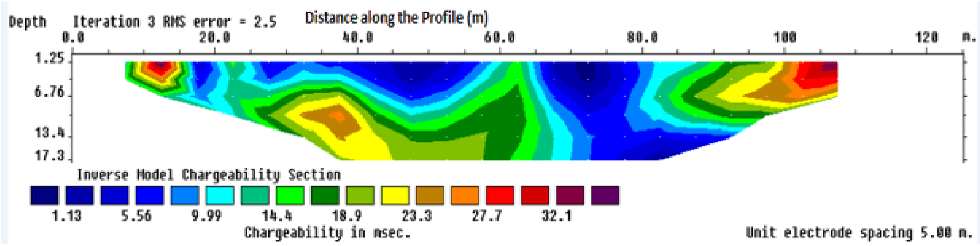

Figure 5: Chargeability model of profile 4

Figure 5 showed the IP model of Profile 4 with Chargeability values ranging from 1.13 msec to 32.1 msec respectively. The Profile is underlain by high chargeability anomalies which exist between the horizontal distance of 6m to 15m at the depth of 6m, 25m to 40m at the depth of 17m and 85m to 100m at the depth of 12m respectively.

3.2 Physicochemical Results

3.2.1 pH

The pH levels for water samples from different selected sampling location showed little variation as presented in Table 1. Highest value was recorded at the dumped site (7.01) while the least value (6.07) was obtained at profile 2 with average value across the location of 6.62. 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 were within the normal range for drinking of 6.5 to 8.5.

3.3 Electrical Conductivity (EC)

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

3.3.1 Lead (Pb)

As presented in Table 1 the highest value of Pb content was recorded at the 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 at Sample 4 (0.142mg/l). The varying concentration levels of the lead 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 study guidelines, the Pb concentrations recorded from this study were generally above the maximum permissible Pb concentrations limits of 0.10mg/l (WHO, 2004; Nigerian Standard for Drinking Water, 2007).

3.3.2 Cadmium (Cd)

The cadmium concentration in the water samples ranged from 0.020 to 0.083 with average value of 0.050mg/l in Table 1. Highest value was obtained at the dumpsite followed by Sample 2. According to the study; the cadmium concentrations recorded from this study were generally above the maximum permissible cadmium concentrations limits of 0.01mg/l and 0.03mg/l respectively (WHO, 2004; Nigerian Standard for Drinking Water, 2007). The level of the cadmium 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 cadmium above the threshold level in all the water samples have detrimental effect to the people who uses the water for drinking.

3.3.3 Copper (Cu)

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

3.3.4 Zinc (Zn)

The zinc concentration in the water samples were varies with maximum value of 0.917 mg/l at the dumpsite and the minimum of 0.121mg/l at Sample 3 which was found to be close to other value observed at other Samples. The varying concentration of zinc observed between the sampling locations might be due to the differences in burning activities of plastic materials at the sites. This agree with the result obtained who reported that high levels of zinc (Zn) could lead to the high burning of the 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; Hardy et al., 2008). According to the study, the average zinc concentrations recorded from this study were generally below the maximum permissible zinc concentrations limits of 15.0mg/l as reported by WHO (2004).

4. Conclusion

This study applied two-dimensional Induced Polarization (IP) imaging in conjunction with physicochemical analysis to spatially characterize leachate contamination from the Gyadi-Gyadi municipal dumpsite in Kano, Nigeria. The IP imaging technique proved effective in detecting high-chargeability anomalies associated with buried organic waste and leachate migration, with notable subsurface contamination observed up to depths of 17 meters across all four geophysical profiles. These findings were corroborated by groundwater analysis, which revealed elevated levels of electrical conductivity and heavy metals particularly lead (Pb), cadmium (Cd), copper (Cu), and zinc (Zn) in most samples, exceeding the WHO and Nigerian Standard for Drinking Water Quality limits. The spatial variability in pollutant concentrations suggests that subsurface leachate movement is influenced by both geological structures and anthropogenic activities, such as waste burning and electronic waste dismantling. The combination of geophysical and hydrochemical methods provided a comprehensive understanding of contamination distribution and intensity, emphasizing the potential health and environmental risks to nearby communities. These results highlight the urgent need for continuous environmental monitoring, proper landfill containment measures, and remediation strategies to prevent further degradation of groundwater quality.

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