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Investigation of Groundwater Contamination from the Use of Fertilizers, Pesticides and Herbicides on Agricultural Lands in Parts of Kaduna State Using Electrical Resistivity Imaging Technique

Afuwai G Cyril[1] and Ema Abraham[2]

[1] Department of Physics, Kaduna State University, Kaduna, Kaduna State, Nigeria
[2] Department of Physics, Alex Ekweme Federal University, Ndufu-Alike, Ebonyi State, Nigeria

Corresponding E-mail: cyril.afuwai@kasu.edu.ng

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Abstract

Fertilizers, pesticides and herbicides contain toxic chemicals which leach into groundwater bodies resulting in the generation of high Biological Oxygen Demand (BOD), and thus contaminating the groundwater system. In order to save the environment from further degradation, a geophysical investigation was carried out across agricultural lands at Kaura Local Government Area (LGA) of Kaduna State, Nigeria where prevalent use of fertilizer, pesticides and herbicides is a norm. The research aims to delineate areas of possible contamination plumes and their migration path. For this purpose, Electrical Resistivity Tomography (ERT) data were acquired along six (6) Traverses and the results were inverted using the RES2DINV Software. Distinct low-resistivity zones adjudged to represent the contamination plumes were obtained from the ERT results. Water samples collected from boreholes, hand-dug wells and river channels were also analyzed. The analyzed water samples results revealed that the total dissolved solids (TDS) ranged between ($2.30\text{x}10^1$ - $8.20\text{x}10^1$) μScm^{-1} as against the Nigerian Standard for Water Quality (NSDWQ) value of $1\text{x}10^3$ μScm^{-1}. Biochemical Oxygen Demand (BOD), chemical oxygen demand (COD) and dissolved oxygen (DO) values ranged between 1-10, <2 - <98 and 0.01 - 0.12 mg/L respectively. The water samples had detectable levels of Cu, Cd, Ni, Mn, Pb and Zn contents which were below the permissible limits, and microbiologically revealed the presence of faecal contamination with bacteria pathogens such as Coliform and Escherichia coli, whose levels were above the acceptable limit while the mould yeast and total aerobic were below the permissible limit. Ultimately, the results obtained showed that the agricultural land constitutes a serious threat to groundwater bodies in the area.

Keywords: Groundwater Contamination; Fertilizers; Pesticides; Herbicides; Electrical Resistivity Tomography (ERT).

I. INTRODUCTION

The United Nations (UN) ardently promotes the application of sustainable development principles in the management of the soil-water environment, highlighting the necessity of reconciling present demands with the conservation of resources for future generations, guaranteeing equitable water access, and mitigating environmental impacts through practices such as water conservation and pollution control [1].

Water pollution may result from anthropogenic activities, including inappropriate agricultural practices, waste disposal, industrial effluents, and leaking subterranean tanks, as well as from natural sources [2]. Agricultural practices such as the use of fertilizers, pesticides, and irrigation water, have been one of the major sources of water pollution around the world; it is the top source of contamination in rivers and streams, the second-biggest source in wetlands, the third main source in lakes, and a major contributor of contamination to estuaries and groundwater in the United States of America (USA) [3].

With the increase in food insecurity in Nigeria due to poverty, climate change, conflict, banditry etc., the Nigerian Government has been encouraging its citizens to go into farming and has taken steps to improve food production and reduce dependence on imports through programmes such as school/graduate agricultural support programmes, agricultural promotion policy, smart agricultural subsidy etc. [4-5]. This has led to increased farming activities such as increased land cultivation and the associated use of chemical fertilizers, pesticides and herbicides. The indiscriminate use of these fertilizers particularly the NPK (nitrogen, phosphorus and potassium) and a significant rise in the application of herbicides and pesticides such as atrazine, glyphosate, paraquat, and s-metolachlor [6] on agricultural lands within Kaduna and its environs, has necessitated this research.

Research has shown that pesticides are appearing in groundwater with an unanticipated frequency with possible chronic effects, and herbicides can destroy soil and even non-targeted plants and may also seep into the ground contaminating wells and any available municipal water systems [7].

A study by [8] on the effects of pesticides and fertilizers on groundwater in Oko-Efo, LASU, identified probable geoelectric layers, such as topsoil, clayey sand, sand, and saturated sand, that are presumed to be contaminated. The findings indicate that the indiscriminate use of pesticides and fertilizers leads to soil degradation and nutritional imbalances, and advocate for regulating these chemicals to prevent groundwater pollution. A comparable study, on groundwater investigation, assessment and borehole design in the basement complex area of Kaduna sheet 123SE, was conducted by [9]. Reference [10] conducted an Electrical resistivity survey at a shallow hydrocarbon contamination site in Ahoada, Nigeria, three years after a post-spill clean-up. The geophysical investigation used Vertical Electrical Sounding and horizontal profiling methods, and the results showed moderate to high resistivity values ($> 200\,\Omega m$) up to $49\,m$, potentially affecting crops and groundwater development, with the probability of obtaining a good aquifer at depths $\geq 30\,m$, while [11] conducted a geophysical assessment of groundwater vulnerability to diesel contamination at a telecommunication mast in Adebayo area, Ado-Ekiti, Southwestern Nigeria.

In this study, geophysical methods for obtaining topsoil and aquifer conductivity measurements will be applied with the aim of identifying contaminated zones within the study area. The objectives of this study include detecting and mapping areas of possible migration and accumulation of leachate from dissolved solids (fertilizers) and pesticides and herbicides, comparing areas of high and low conductivity with quality of crop yield, determining the conductivity variation of the topsoil, the aquifer thickness and depth, and the subsurface layers with relatively high contamination.

II. MATERIALS AND METHODS

A. *Location Description and Geological Setting*

Kaura area lies between latitudes 9°30'N and 9°45'N and longitudes $8^0 20' E$ and $8^0 35' E$ in the southern part of Kaduna state Nigeria. This work focuses on Kaura because of the indiscriminate use of fertilizers, pesticides and herbicides on agricultural lands. The area is geologically rugged and punctuated by many low hills here and there (Fig. 1). However, the relief is exaggerated by hills like the Kagoro Younger Granite Complex, which rises to about 2500 m above sea level [12].

The study area comprises the rocks of the Migmatite-Gneiss Complex, Older Granites, Younger Granites and Newer Basalts. The distribution of the various rock types is shown on the geological map of the area in Fig. 1. The basement rocks that occur in the study area could be classified into: Newer Basalts, Younger Granites, Older Granites, Undifferentiated Schists and Migmatites-Gneiss Complex.

B. *Materials*

Materials used for this study are an Ohmega Resistivity Meter, a Global Positioning System, Electrical cables and reels, and Copper electrodes.

C. *Data Description, Acquisition and Processing*

Electrical resistivity methods were adopted using Electrical Resistivity Tomography (ERT) which is very successful in delineating vertical and lateral variations of subsurface structures. Comprehensive Geophysical studies using electrical resistivity were conducted with a DC resistivity meter (Omega Allied). Omega Allied is an improved Digital resistivity meter with multiple ingenious functional attributes built into its design and is known for its high-quality data acquisition capability and fieldworthiness. It is a very close-packed, sophisticated, and well-grounded piece of equipment that is used for resistivity investigations**.** Omega Allied resistivity meter is made up of two units (i) Current unit (C unit), and (ii) Potential unit (P unit). This unit has the provision for measuring the potential difference across the potential electrode as well as the resistance values which provide direct display over digital panel metre. The current units provide the purpose of sending the required output of constant current, whereas the potential unit provides an accurate measurement and display.

The depth of penetration is dependent on the increase of electrode spacing so that apparent resistivity measured at various depths is used to construct a vertically contoured section, displaying the resistivity contrast both laterally and vertically over the section. The 2D electrical resistivity pseudosection study was used in different locations to characterise the geology of various subsurface lithological, structural and hydrological conditions [13].

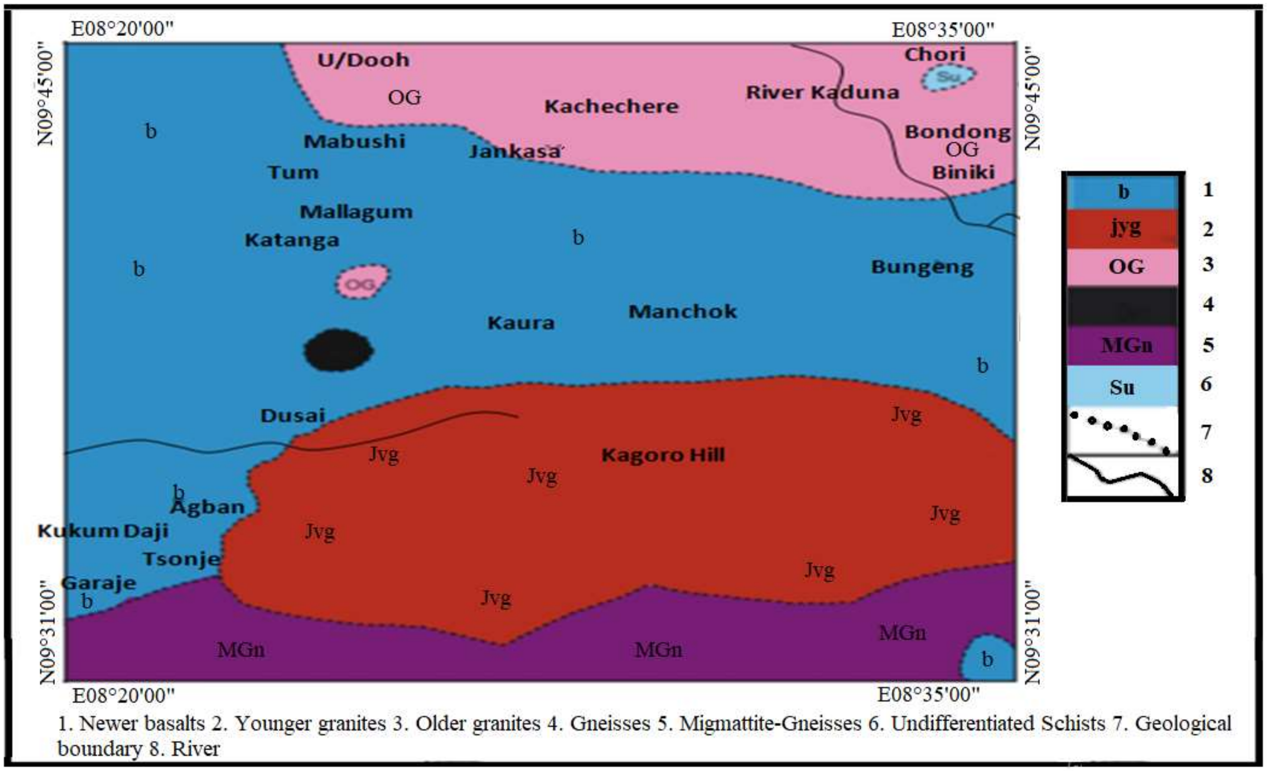

Fig. 1. Geological Map of the Kaura Area [14].

1) Wenner arrangement

A simple method of determining the resistivity of the ground using four electrodes discussed in [15], otherwise called Horizontal Profiling (HP), where four electrodes are placed in a traverse line, and a known current is injected through the two extreme electrodes, and the potential difference measured between the two inner electrodes gives a measure of the resistivity of the ground was used. The value of resistivity (ρ) is computed using (1).

$$\rho_a = \left(\frac{V}{I}\right) 2\pi a \quad (1)$$

Where V is the potential in volts (V) measured between the two inner electrodes, and I is the current in amperes (A) passed into the ground, (a) is the distance between the successive electrodes in meters (m) and $2\pi, a$ constant. Since $^{V}/_{I} = R$, the resistance measures in ohms (Ω), (1) may be expressed as:

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

In the electrode arrangement, the two current electrodes are usually designated as C_1 and C_2, while the two inner electrodes, which pick up the potentials in the ground, are designated as P_1 and P_2, known as the potential electrodes or the measuring electrodes.

2) Schlumberger array

In the Schlumberger array, letters A and B denote the current electrodes while M and N represent the potential electrodes. The distance between M and N may be represented by l, while the distance AB/2 is represented by L. During the field layout, the current electrodes AB are placed as outer electrodes, while the two potential electrodes M and N as inner electrodes as shown in Fig. 2. The Schlumberger array has a major advantage in depth soundings in that, long current carrying cables may not be necessary. However, if the ground consists of two or more layers with different resistivity contrast, and if the electrode separation 'a' is less than the thickness of the first layer, then the measured resistivity value (ρ_1) will pertain to the first layer; on increasing the separation to, say (2a), the second layer having a different resistivity will make itself felt in the apparent resistivity measured. Therefore, by successively increasing the electrode separation about a central point, a deeper depth of investigations of the earth may be measured. The apparent resistivity values obtained by expanding the electrode intervals are plotted against the respective electrode separations.

The Schlumberger array's potential electrodes, M and N, remain stationary while employing in-depth soundings, but current electrodes A and B are positioned further apart on each side., i.e., increasing the distance L, i.e. (AB/2) in successive steps and obtaining the resistivity values for a series of such increases for one setting of MN with an interval of l. With this arrangement, deep investigation can be made in two or more settings, increasing the spacing of the potential electrodes and then moving out the current electrodes. When the readings are completed for a particular spacing of the potential electrodes MN, the spacing of the latter is increased; whenever such a shift of MN is made, a duplicate reading is obtained while the current electrodes are still in the old setting; this serves as to validate the integrity of the acquired data. Thereafter, only the current electrodes are shifted for the next set of observations. The resistivity curves obtained from in-depth soundings indicate the number of layers involved in the sounding depending on AB/2 spread length and the number of geologic layers in the study area.

However, if the ground under investigation is homogeneous and isotropic, the generated values of ρ will be the true resistivity. Such ideal conditions rarely exist in the ground since the earth is inhomogeneous, and the value of ρ is usually affected by the variations in the lateral and vertical dimensions, particularly layered medium. Several electrode arrays for measuring the ground's resistivity will be examined in this work.

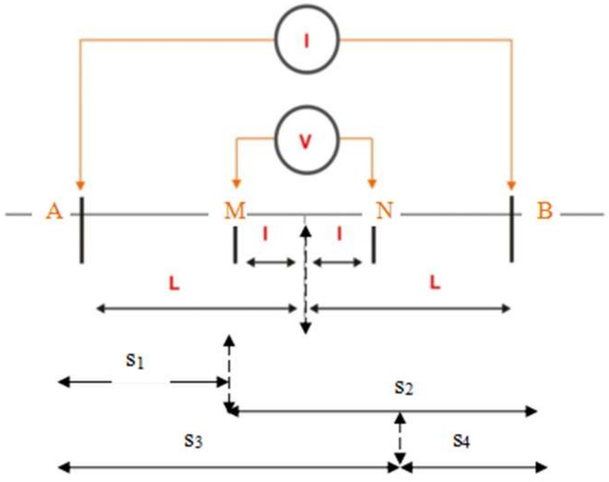

Fig. 2. Schlumberger Array Layout.

III. RESULTS AND DISCUSSION

A. Data Presentation and Interpretations

The generated 2D pseudosections of the subsurface resistivity arrangement obtained from the 2D inversion process are shown in Fig. 3-10 produced from the acquired Wenner data. These resistivity peudosections along traverses 1-6 reveal the distributional extend over the leachate plume across a horizontal direction with a distance of 7.5-9.0 m in the East-West direction with a resistivity reading of about 3.09 Ωm, which is attributed to the presence of leachate plume summing up to 22 m depth below the earth surface and supposed to have infiltrated into the groundwater table thereby polluting it. This was measured to be within the range of 10-15 m as confirmed by the observable in-situ samples from the borehole and open well, due to joints, cracks and faulting system as a result of deformations that the subsurface rocks could have suffered, thus making the weathered and fractured basement below the basin-like structure leach easily.

Infiltration of contaminant plumes within some of the traverse lines originates from the western end of the traverse where it infiltrates the subsurface. Fig. 6 shows the pseudosection model along the third traverse with low resistivity contrasts below 17.6 Ωm attributed to leachate or contaminant plume's migration at horizontal distances 7.5-45.0 and 50-75.0 m along the traverse. Traverse 4 shown in Fig. 7 indicates that the leachate, vadose zone and contaminant plumes region fall within the resistivity range of 10.5-120 Ωm and with an estimated depth of 1.25-7.6 m with overlaid fractured and fresh basement which have resistivity range of 125-6552 Ωm. Fig. 7 shows the psudosection model along traverse 5, showing resistivity anomalies as low as 20 Ωm and below. These low resistivity values further indicate the presence of leachate across the horizontal distance of 10.0–50.0 m and 55.0 -82.0 m. The general resistivity values across the study area as shown in the 2D pseudosections were mostly less than 100.0 Ωm which coincides with the leachate, vadose zones and contaminant plume regions at the surface.

Traverse 6 pseudosection which shows low resistivity values ranging from 10.9-60 Ωm is attributed to the leachate portion along traverse 6, which covered a distance of 30-70 m and has a depth of 9.26 m. The traverse 7 pseudosection model in Fig. 9 shows a resistivity anomaly of 14.1-82.1 Ωm which is interpreted as leachate, vadose zone and contaminant plume region which covered a distance of 7.5-95 m and a depth of 9 m deep. Traverses 7 and 8 run North-South perpendicular to traverses 2-6 while traverse 1 was used as a control since it was located some distance from the dump site. Contaminant plumes thus infiltrated the weathered layer at a depth of 10-17 m with resistivity values ranging from 12-100 Ωm showing characteristics of possible infiltration of leachate thereby contaminating the groundwater at greater depth at the under-study dumpsite. Relatively low resistivity anomaly of resistivity values 3.05-12.3 Ωm to a depth of about 7.26 m occurs at the near-surface indicating the presence of sandy clay mixed with indestructible garbage.

The resistivity pseudosection results along traverses 7 and 8 depict a general trend of uniform spreading of the contaminant plume from a horizontal distance of 8-82 m along the North-South direction with resistivity values of 10 Ωm and below; an indication of leachate plume building up to the depth of about 12.4 m at the subsurface. The 2D pseudosections show that leachate plume formation migrates uniformly along horizontal and vertical directions within the study area. The low resistivity contrast of the upper stratum indicates that the underlying layer has higher resistivity values ranging between 140 and 300 Ωm indicating a weathered or fractured basement across traverse 1-8 in the study area.

In the central part of traverses shown in Fig. 3-9 the 2D pseudosection models with characteristics of low resistivity anomaly were observed between the positions 10-60 m with resistivity values ranges between 14 and 60 Ωm, this is indicative of contaminant plumes at depth of about 12.4 m below the surface. The subsurface low resistivity was not obvious between 7.5 and 22 m along the traverse 1. Relatively high resistivity anomalies with resistivity values between 100 and 1097 Ωm attributed to fractured basements were observed at depths above 12.4 m. The last layer of the pseudosections reveals an undulating fresh basement across traverses 1-8 with relatively high resistivity values between 1097 and 14173 Ωm.

The 2D pseudosection models of traverses 3-8 in Fig. 6-10 show two major low resistivity anomalies situated at 7.5-90 m in the eastern and central portion across the traverses respectively, with resistivity values below 50 Ωm, which further characterize the dumpsite into leachate, vadose zones and contaminant plume.

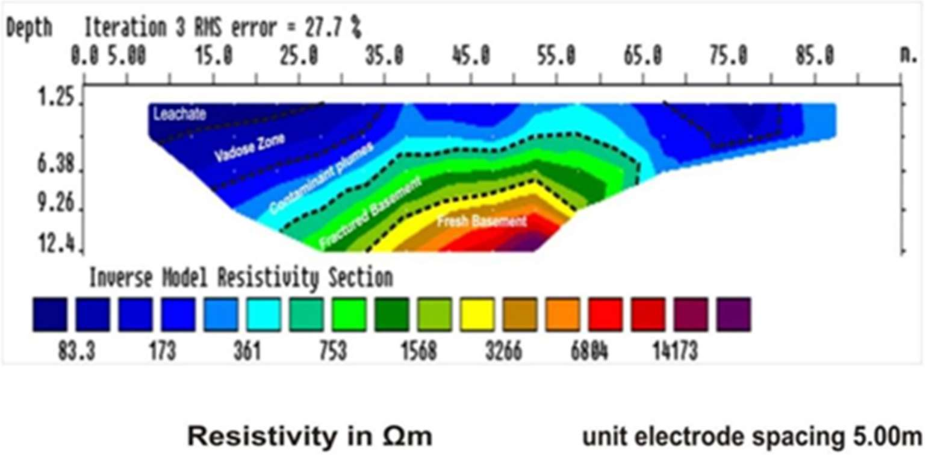

Fig. 3. 2D Resistivity Pseudosection Model for Traverse 1.

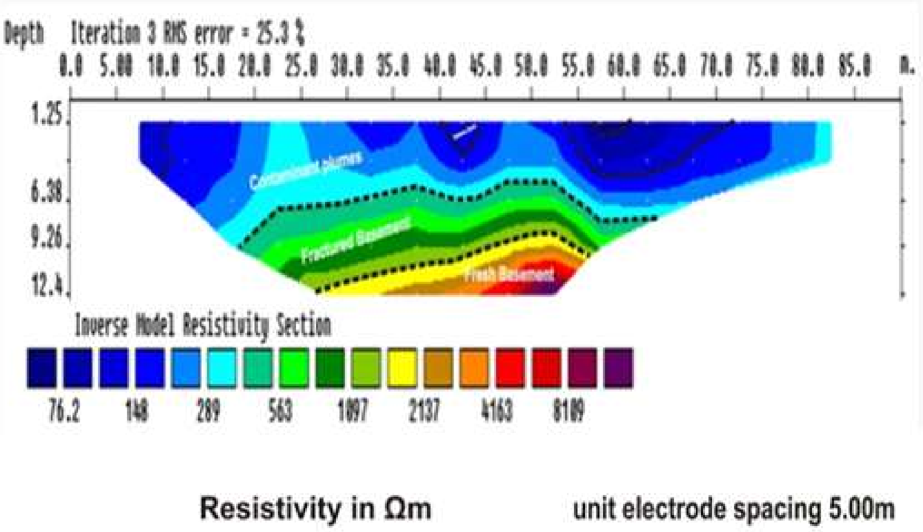

Fig. 4. 2D Resistivity Pseudosection Model for Traverse 2.

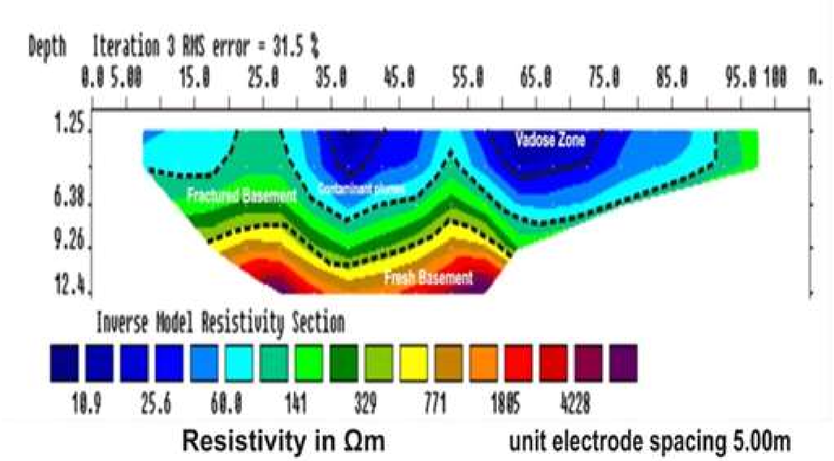

Fig. 5. 2D Resistivity Pseudosection Model for traverse 3.

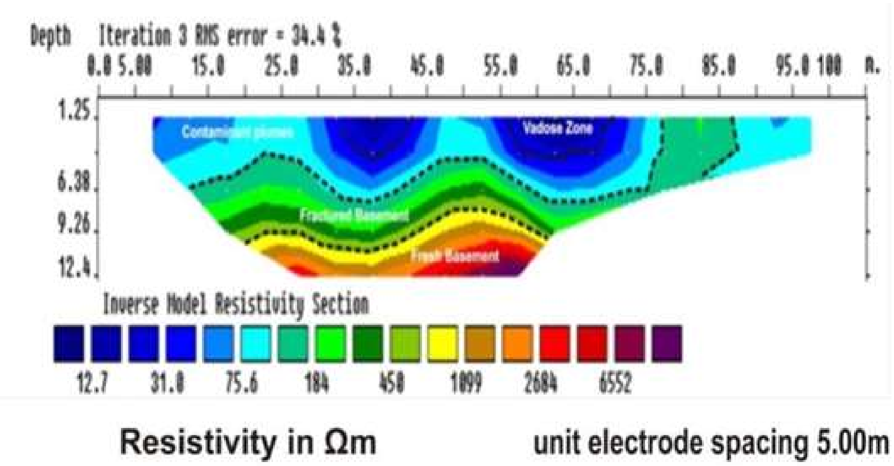

Fig. 6. 2D Resistivity Pseudosection Model for Traverse 4.

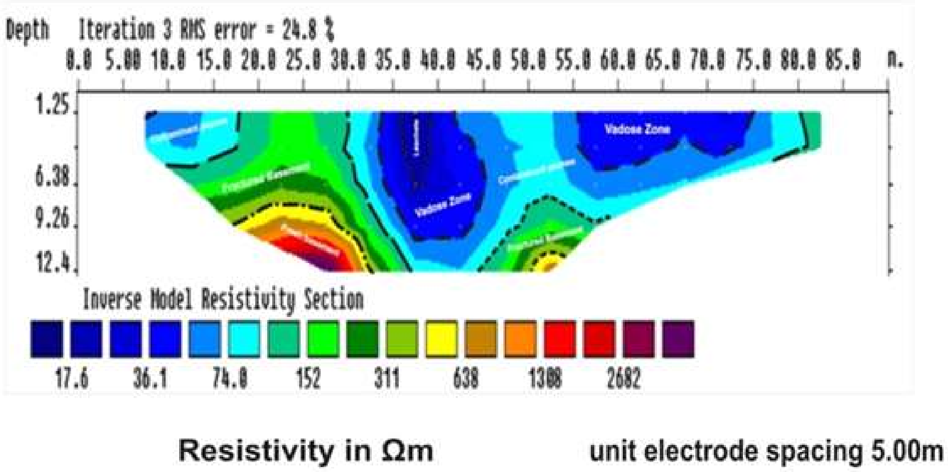

Fig. 7. 2D Resistivity Pseudosection Model for Traverse 5.

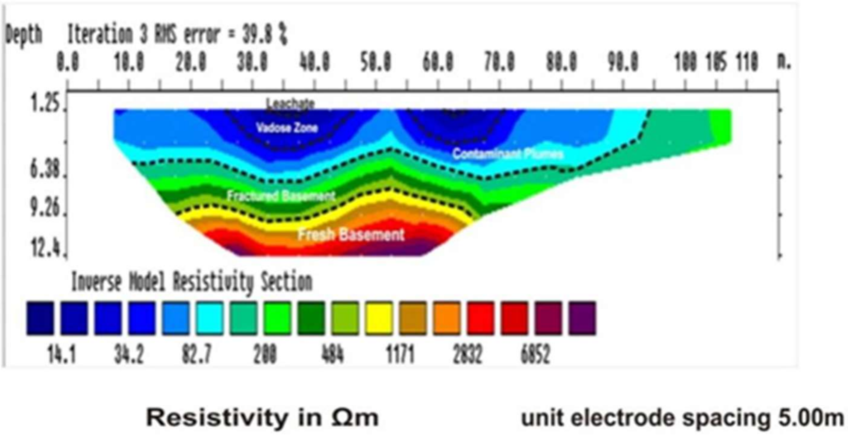

Fig. 8. 2D Resistivity Pseudosection Model for Traverse 6.

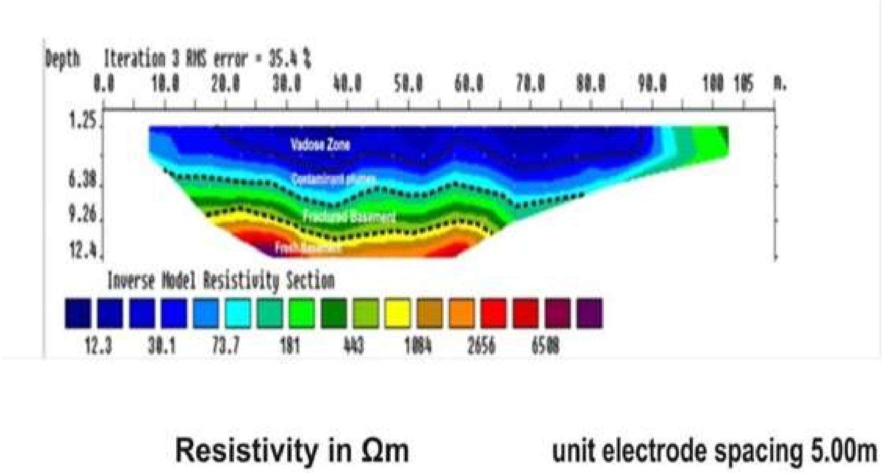

Fig. 9. 2D Resistivity Pseudosection Model for Traverse 7.

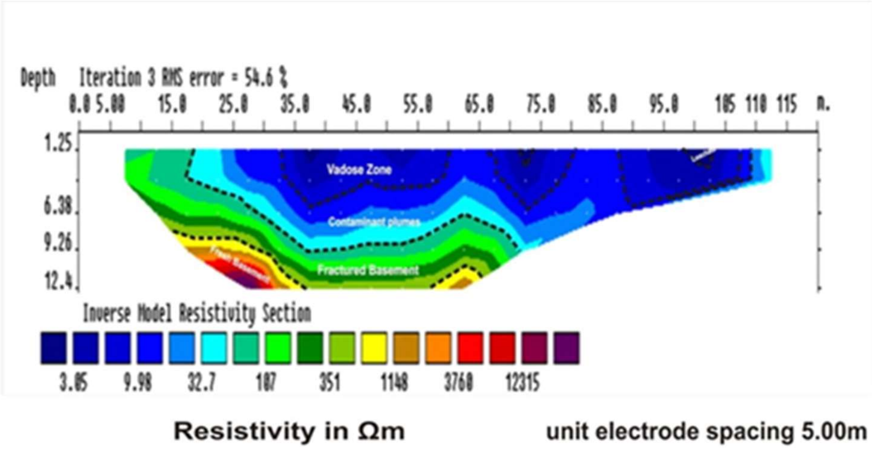

Fig. 10. 2D Resistivity Pseudosection Model for Traverse 8.

B. *Interpreted Results of Water samples from Borehole, open Well and River Channel.*

The low Electrical Conductivity (EC) measurement values in the water samples near the study area indicate its effect on groundwater. The EC values in the study area were below the NSDWQ suggested levels (1000 µs.cm^{-1}). According to [12, 16] water conductivity within 1000 µs.cm^{-1} is suitable for irrigation. It is important to note that the electric conductivity of the groundwater under Kagoro-Garaje Fadama is lower than the water conductivity of (230-460 µs.cm^{-1}) as shown in Tables I and II.

The major anions tested are Chloride (Cl^-), Nitrate (NO_3^{-2}) and sulphate (SO_4^{-2}). Reference [17] asserted that chloride is not detrimental at reasonable concentrations. However, it induces corrosion at concentrations exceeding 250 mg/L and a salty taste in water at 400 mg/L, with increased Cl^- levels harmful to those with kidney or cardiac conditions. Chloride concentration was measured, and the range was not acceptable according to those permissible by the Nigerian Industrial Standard (NIS) [18-19] for potable water as shown in Tables II. According to the values indicated in Tables I and II, obtained from the physicochemical analysis, the geochemical investigation concludes the water samples are both physico-chemically and microbiologically unsatisfactory, which supports the geophysical results. Physicochemical analysis revealed possible elemental contaminants within the groundwater system. Leachate from dumpsite is a major pollutant contaminating groundwater bodies, and because there are dumpsites around the study area, the situation is currently bad and is expected to become worse in the future [20].

The analysed results of the physicochemical parameters of the water samples corroborate the georesistivity interpretations, and the physicochemical results revealed that the analysed sample falls below NSDWQ [18-19] as shown in Table I specification limits for potable water purposes. Therefore, the effect of leachate infiltrating the agricultural land through run-off and fertilizer application might have raised the ion concentrations in open wells, and river channels respectively. A significant indication of leachate mobility and the degree of soil infiltration due to potential structural geologic deformations could result in adulteration of shallow groundwater bodies within the study area.

Table I. Physicochemical Analysis For Borehole Sample

Physio-Chemical parameter	Result of Sample	NSDWQ
pH	7.10	6.5 – 8.5
Conductivity, µs cm^{-1}	2.30×10^2	1×10^3
Total alkalinity, mg L^{-1}	57	100
P. Alkalinity, mg L^{-1}	Nill	100
M. Alkalinity, mg L^{-1}	57	100
TDS, ppm	115	500
Free Chlorine	Nill	0.1
Freely dissolved CO_2, mg L^{-1}	21	50
Total Chloride, mg L^{-1}	18	200
Total Hardness, mg L^{-1}	73	150
Nitrite, mg L^{-1}	0.00	0.02
Nitrate, mg L^{-1}	0.00	10
Lead, mg L^{-1}	0.00	0.01
Cadmium, mg L^{-1}	0.00	0.003
Chromium, mg L^{-1}	0.00	0.01
Arsenic, mg L^{-1}	0.00	0.01
BOD, mg L^{-1}	1	1-3
COD, mg L^{-1}	<2	-
TOC, mg L^{-1}	0.01	0.5
Iron, mg L^{-1}	0.01	0.3
Sulphate, mg L^{-1}	0	200

Table II. Microbiological Analysis for Borehole Samples

Test	Count	Limit
Total aerobic bacteria plate count cfu/ml	1.1x10^1	1 x 10^2
Mould/Yeast, cfu/ml	2.0x10^1	1 x 10^2
Coliform, MPN/100ml	11	0
E.coli, MPN/100ml	0	0

IV. CONCLUSION

The electrical resistivity tomography (ERT) method and Physico-chemical analysis approach were employed to investigate the impacts of fertilizers, pesticides and herbicides on agricultural lands in the Kaura area of Kaduna State Nigeria. The 2D resistivity image of subsurface structures delineated the contaminant plume, and leachate and thus further characterise the study area based on subsurface resistivity apportionment of vadose zones, contaminant plumes and the hydrogeological conditions underneath the study area. The analysed results of the physicochemical parameters of the water samples corroborate the georesistivity interpretations, thus the physicochemical results revealed that the analysed sample falls below NSDWQ specification limits for potable water purposes. Therefore, the effect of leachate infiltrating the agricultural land through run-off and fertilizer application might have raised the ion concentrations in open wells, and river channels respectively. There is a potential adulteration of shallow groundwater bodies around the study area resulting from a strong manifestation of leachate movement and degree of soil infiltration due to possible structural geologic deformations of the region.

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