

**INTERNATIONAL JOURNAL OF SCIENCE FOR GLOBAL SUSTAINABILITY****Electrical Resistivity Investigation of Dumpsites in Gusau
Metropolis, Zamfara State, Nigeria**

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Received on: August, 2023

Revised and Accepted on: September, 2023

Published on: October, 2023

ABSTRACT

Electric resistivity survey was carried out in three selected dumpsites in Gusau metropolis for groundwater contamination. The dumpsites were investigated by conducting Vertical Electrical Soundings (VES) using Schlumberger array with maximum current electrode separations of 180 m. Five VES were conducted on each dumpsite making a total of fifteen VES along three profiles. The field data obtained from VES were analyzed using WinGlink software. The VES results revealed three subsurface layers. The topsoil had resistivity ranging from 1.45 Ω m to 48.2 Ω m while the thicknesses varied from 0.47 m to 3.37m across the profiles. The second layer's resistivities varied from 5.4 Ω m to 144.35 Ω m and their thicknesses' ranges from 1.36 m to 16.93 m. The third geoelectric layer had resistivity from 70.0 Ω m to 6003.0 Ω m. The results indicated that the top soils in all the dumpsites were characterized by very low resistivity depicting possible pollution and contamination. Findings from this study indicated that there may be possible contamination of shallow groundwater system in the nearest future if proper mitigation measures are not taken into consideration at the dumpsites.

Keywords: Electrical resistivity, Groundwater, Geoelectric layer, Dumpsites, Hydro-chemical**1.0 INTRODUCTION**

Wastes are produced on daily basis as a result of direct consequences of human activities (Ameh, 2022). Refuse consist of various kinds of materials like metallic, organic and non-biodegradable materials (Sunmonu, *et al.*, 2012). The intensity of human's activities has led to increasing volume of solid waste worldwide despite the level of global technological advancement and industrialization (Ganiyu *et al.*, 2015; Abdullahi *et al.*, 2011; Akankpo and Igboekwe 2011, Murana, *et al.*, 2019). Poor management of solid waste has resulted to lot of disastrous effects such as: aesthetics, odour, environmental hazard and pollution. These has attracted insects, rodents and various disease vectors (Olayinka and Olayiwola, 2001, Adeyemi *et al.*, 2007). Arbitrary refuse dumping poses a serious threat to soil, groundwater and downstream surface water pollutions.

Pollution of groundwater occurs mostly due to percolation of fluvial water and the infiltration of contaminants through the soil beneath the dumpsite. Contamination takes place when this leaking aqueous liquid, called leachate, reaches the groundwater table, thus affecting the quality of the groundwater.

Environmental pollution is one of the concerns of earth Scientists. Fast industrial development and the uncontrolled growth of urban population result in the production of massive toxic waste residues. Urban waste materials, mainly domestic garbage, are usually disposed inappropriately on land surface, shallow excavation, stream and river channels which place the ground water at high risk of being polluted.

Gusau, being the state capital has witnessed increase in population over the years. This has led to increment in wastes which litter many places. The waste disposal sites are in most cases uncontrolled open dumps, thus creating serious threats to public health (Murana, *et al.*, 2019). Consequently, Gusau metropolis may face critical groundwater pollution if the problem of waste disposal sites is not adequately addressed.

In this study, electrical resistivity survey was carried out at three dumpsites in Gusau to investigate the effects of leachate on groundwater quality and contamination. Fifteen points were sounded using Schlumberger array.

2.0 DESCRIPTION OF THE STUDY AREA

Three dumpsites were surveyed. Three waste dumpsites studied were located at Hira Dekodi (12° 10'10"N, 06°39'48"E), Low Cost Area (12°10'21" N, 06°41'15 " E) and Behind Total Filing Station (12°9'57 " N, 06°41'10"E), all in Gusau metropolis (see figure 1).

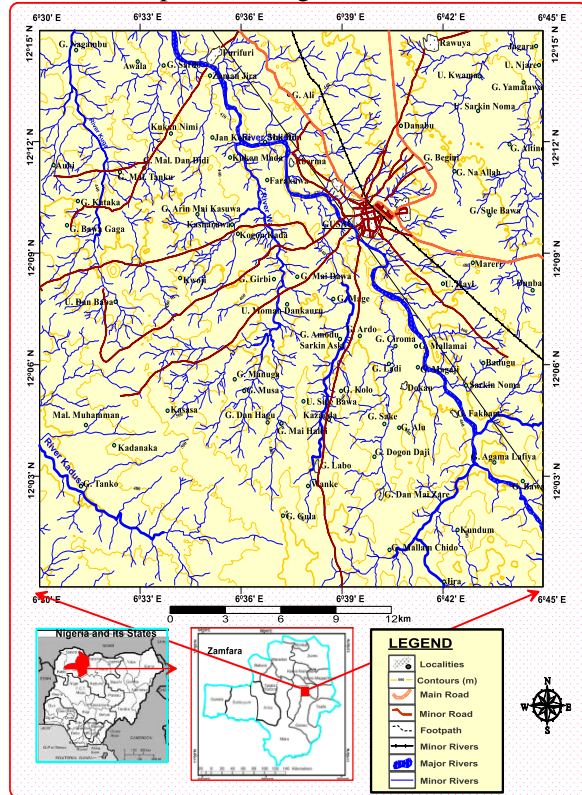


Figure 1: Map of Gusau

The study area was characterized by two distinct seasons, the dry and rainy seasons. The mean annual rainfall in the area is 800 mm while the minimum and maximum temperatures were 24°C and 40°C respectively. The dry season is between the month of October and May of the year while the rainy season commence from June to September and sometimes reaches October. In addition, the temperature condition of the study area falls within the temperature region (Sahelian Savanah) with temperature rising up to 40°C and above (Zamfara State Government, 2001).

The vegetation of the study area is that of the Sahelian Savanah with a variety of short grasses, thorns, shrubs and scattered trees which can resist long dry season.

The study area is underlain by different lithological units made up of the Basement complex rock suites, the oldest being Pre-

cambrian in age. From the field mapping exercise, migmatite, banded gneiss, quartzite, mica schists, phyllites, granites and minor intrusions of pegmatites were the rock types that underlined the study area (figure 1).

3.0 THEORIES OF ELECTRICAL RESISTIVITY SURVEY

In the resistivity method, artificially generated electric currents (I) were driven into the earth, and the resulting potential difference (V) were measured at the surface. The measurement of the electric potential and the current were used to obtain information about the resistivity variation of the subsurface in the area surveyed (Telford *et al.*, 1976).

In the Schlumberger array employed, the four electrodes were positioned on a straight line, with the two current electrodes on the outside of the potential measuring electrodes. The interpretation of the vertical electrical sounding (VES) data is based on the assumption that the subsurface consists of a sequence of distinct layers of finite thickness and each of these layers is assumed to be electrically homogenous and isotropic (Koefoed, 1971) and the boundary planes between subsequent layers are assumed to be horizontal. Figure 2 is an illustration of the Schlumberger array which was used for the survey.

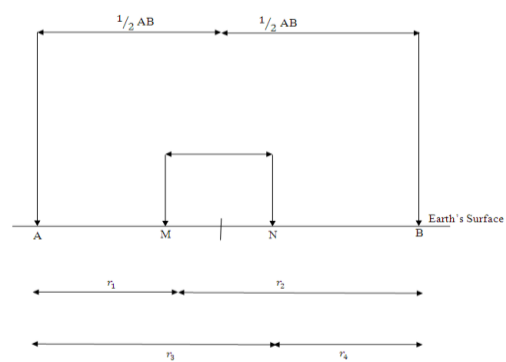


Figure 2: Schlumberger array

where A and B are electrodes through which currents were driven into the ground while M and N were two potential electrodes (to record the potential distribution in the subsurface). The principle underlying the resistivity method is embodied in Ohm's law. From Ohm's law, the current I and potential difference V in a metallic conductor at constant temperature are related as follows:

$$V = IR \quad (1)$$

R is the constant of proportionality termed resistance measured in ohms. The resistance R of a conductor is related to its length L and cross sectional area A by:

$$R = \frac{\rho L}{A} \quad (2)$$

where ρ is the resistivity and it is the property of the material considered.

From equations (1) and (2),

$$V = \frac{I\rho L}{A} \quad (3)$$

For simple treatment, a semi-infinite solid with uniform resistivity, ρ , was considered. A potential gradient was measured between M and N when current I was introduced into the material through A and B on the surface. The surface area is $2\pi L^2$. Thus equation (3) becomes:

$$V = \frac{I\rho}{2\pi L} \quad (4)$$

By deduction then, the potential at M (V_M), due to the two current electrodes is:

$$V_M = \frac{I\rho}{2\pi} \left(\frac{1}{r_1} - \frac{1}{r_2} \right) \quad (5)$$

Similarly, the potential at electrode N (V_N) is given by:

$$V_N = \frac{I\rho}{2\pi} \left(\frac{1}{r_3} - \frac{1}{r_4} \right) \quad (6)$$

where r_1, r_2, r_3 and r_4 were as shown in Figure 2. Absolute potentials are difficult to measure (Kearey, *et al.*, 2002) so the potential difference ΔV between M and N was measured. When the subsurface is inhomogeneous, apparent resistivity ρ_a is considered.

Thus:

$$\Delta V = (V_M - V_N) = \frac{I\rho_a}{2\pi} \left\{ \left(\frac{1}{r_1} - \frac{1}{r_2} \right) - \left(\frac{1}{r_3} - \frac{1}{r_4} \right) \right\} \quad (7)$$

Then,

$$\rho_a = \frac{2\pi\Delta V}{I \left\{ \left(\frac{1}{r_1} - \frac{1}{r_2} \right) - \left(\frac{1}{r_3} - \frac{1}{r_4} \right) \right\}} \quad (8)$$

where ρ_a is apparent resistivity in ohm-metre. From equation (8),

$$\rho_a = K \left(\frac{\Delta V}{I} \right) \quad (9)$$

i.e.

$$K = 2\pi \left[\left(\frac{1}{r_1} - \frac{1}{r_2} \right) - \left(\frac{1}{r_3} - \frac{1}{r_4} \right) \right]^{-1}$$

where K is the geometric factor in metre which depends on the electrode array used.

For Schlumberger array, if $MN=b$ and $\frac{1}{2} AB = a$ then,

$$K = \pi \left(\frac{a^2}{b} - \frac{b}{4} \right) \quad (10)$$

4.0 MATERIALS AND METHODS

Two dimensional (2D) electrical resistivity surveys were carried out in some selected dumpsites in Gusau, Zamfara State using ABEM SAS 300 systems in May, 2023. The resistivity survey was completed with 15 sounding stations. Either N-S or E-W profile was taken at each single vertical electrical sounding (VES) point. The VES involved injecting an artificially generated direct current or very low frequency alternating current into the ground through two electrodes. The resulting potential difference is measured by another pair of potential electrodes in the vicinity of the current flow. The field data acquisition was carried out by moving two or four of the electrodes used, between each measurement, following the technique outlined by (Kearey *et al.*, 2002) and (Telford, *et al.*, 1976). The VES was conducted by using the Schlumberger array with a maximum current electrode spacing (AB) of 180m.

The widest current electrode spacing used was 180m, that is, $\frac{1}{2} AB = 90m$. According to (Barker, 1989), the maximum depth of penetration in Schlumberger array is 0.19 AB. The potential electrode separation, MN, was also increased intermittently in order to maintain a measurable potential, but it did not exceed one-fifth of the half-current electrode separation, $\frac{1}{2} AB$, as suggested by (Dobrin and Savit, 1988).

Measurements were taken at expanding current electrode distances such that in theory, the

injected electrical current should be penetrating at greater depth. The Terrameter gave values of resistance (ohms) from where the values of apparent resistivity were calculated using equation 9 above. The field data was interpreted by applying partial curve matching technique (Koefoed, 1971) with the help of master curves (Mussett and Khan, 2000) and (Zohdy, 1975). From the preliminary interpretation, the resistivity and thickness of the various geoelectric layers at each VES locations were determined. These geoelectric parameters were then employed as starting models for the computer-aided iteration using WinGlink software.

In the interpretation stage, resistivity values obtained from the sounding curves were discussed base on the resistivity values of rock types similar to the study area (table 1) and compared to resistivity values obtained from laboratory measurements for landfill and other earth materials (table 2).

Table 1: Resistivity Values Adopted for this Work (Adeoti *et al.*, Murana, 2011)

Sampled Materials	Resistivity range (Ωm)
Clay	1-20
Clayey Sand and Sandy Clay	30 -100
Weathered Basement	100- 300
Fractured Basement	300-900
Fresh Basement	>1000

Table 2: Resistivity Values (Adeoti *et al.*, 2011)

Sampled Materials	Resistivity (Ωm)
Leachate only	2.994
Sand saturated with leachate	4.97 – 5.04
Fresh water (plant materials, rubber strans) with saturated with leachate	6.03 - 7.16
Soil saturated with leachate	3.15 – 4.00
Rain water only	73.88
Sand saturated with rain water	14.36 – 17.50
Fresh waste (plant materials, rubber strands) saturated with rain water	9.30 – 10.57
Clay saturated with rain water	9.30 – 10.57

Clay saturated with brackish water	0.12 – 0.20
Clean sand saturated with sea water	1.5 – 3.5
Fresh sand stone	600
Phyllite	300
Hard rock	> 600

4.1 Data Processing

The data acquired were processed to remove noise arising from instrumentation. The apparent resistivity data were presented as sounding curves. The curves were obtained by plotting the apparent resistivity values against half of the current electrode separations (AB/2) on log-log graphs that have the same modulus as that of the 2-layer master curves. The curve in each VES station depends on the subsurface layer sequence (Murana *et al.*, 2019; Murana, *et al.*, 2014). The main purpose of processing the VES data displayed as curves were to determine the subsurface layers, their resistivities as well as the thicknesses. These were achieved through utilization of WinGlink software for processing the acquired data. The processed data were presented as 1-D iteration models and geoelectric sections.

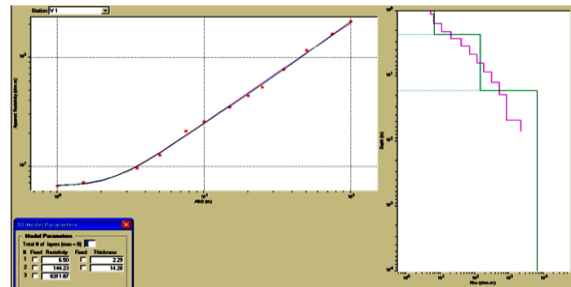


Figure 2: Typical sounding curve

5.0 RESULTS AND DISCUSSION

From the 1D-resistivity curves, the interpreted layer for each dumpsites were summarized below. The results of the investigations were presented in form of geoelectric sections. However, the top soil and weathered Basement were regarded as the overburden while the bedrock consists of the fracture and the fresh Basement rocks (Oladapo, 2013). The modelling of VES measurements carried out at the fifteen (15) stations has been used to derive geoelectric sections for the profiles (figures 4-6). The interpreted layer for the three dumpsites are presented in tables 1-3 below. The geoelectric

and geologic sections were plotted with the aid of Autocard. The geoelectric sections of the study area were generated to show the vertical variation of the material in relation to their resistivities values.

Table 3: Interpreted Layer Parameter for Hiran Decode Dumpsite, Church Pan Area.

VES Station	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)
1	1	6.50	2.29	2.29
	2	144.35	14.2	16.49
	3	6003.00		
2	1	4.50	1.58	1.58
	2	31.40	8.78	10.36
	3	309.10		
3	1	2.50	1.29	1.29
	2	14.00	4.52	5.81
	3	198.00		
4	1	1.35	0.68	0.68
	2	5.40	7.96	8.64
	3	70.0		
5	1	3.70	0.74	0.74
	2	17.50	1.36	2.10
	3	95.50		

which is characterized by very low resistivity values ranging from $1.5\Omega m$ to $6.5\Omega m$ across the profile (table 3). The thicknesses of this layer ranged between $0.68m$ to $2.29m$. The topsoil low resistivity values suggested pollution from leachates (table 2 above). The second layer has resistivity ranging from $5.4\Omega m$ to $144.35\Omega m$ with thicknesses from $1.36m$ to $14.2m$. The lithology of this layer as evidenced from table 1 above suggested clay to sandy clay. However, no such thickness of clay has been reported in the area from the available borehole data. The infiltration of contamination plumes maybe due to the high porosity and permeability that characterizes the soil present in the study area. The third subsurface layer has resistivity that range from $70\Omega m - 6003\Omega m$. So, based on the porosity and permeability conditions of the observed geologic materials in the area, the result showed that VES 2-5 of the Hiran Decodi dumpsite has been polluted by leachates. The extremely low resistivity values in this layer also suggested contamination plume in the area (Okpoli, 2013). It is interesting to note that at VES 1, fresh Basement rocks were encountered from depths of about $16m$. The results of this investigations showed that both the soil and groundwater at this dumpsite have been contaminated.

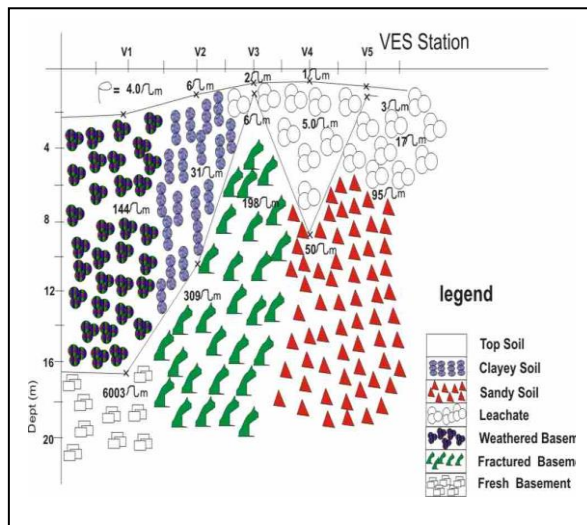


Figure 4: Geoelectric Section at Hiran Decodi, Church Kwanu Dumpsite, Gusau

5.1 Discussion of findings at Hiran Decode Dumpsite

The geoelectric sections of this dumpsite consist of five VES points from VES 1 to 5. The area was underlain by three subsurface layers as depicted in figure 4. The first layer is the top soil

5.2 Discussion of findings at Low Cost Dumpsite

The results of the investigation showed that three subsurface layers exist in this site. The dumpsite consists of VES 6 to 10. The top soil resistivity values varied from $5.0\Omega m$ to about $72\Omega m$ and thicknesses varied from $0.47m$ to $1.64m$. The lithology of the first layer was mostly clay. The low resistivity value at the top soil is an indication of leachate at that layer. The second subsurface layer delineated has resistivity and thickness values of $44\Omega m$ to $180\Omega m$ and $1.58m$ to $16.47m$ respectively. The third subsurface layer's resistivity ranged from $292\Omega m$ to $1932\Omega m$. The results of this investigation revealed that at Low Cost dumpsite, apart from the topsoil at VES 6 (table 4) which has low resistivity of $5.0\Omega m$ indicating leachate, there was absence of leachate contamination from this dumpsite. The high resistivity response in this zone was an evidence that the soil and groundwater are safe for exploitation.

Table 4: Interpreted Layer Parameter for Low Cost Dumpsite.

VES Station	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)
6	1	5.00	0.47	0.47
	2	120.00	2.62	3.09
	3	586.00		
7	1	72.00	0.58	0.58
	2	180.00	1.68	2.26
	3	1932.10		
8	1	48.20	1.28	1.28
	2	98.14	16.93	18.21
	3	1200.00		
9	1	9.57	1.64	1.64
	2	73.40	16.47	18.11
	3	530.0		
10	1	18.40	1.25	1.25
	2	44.50	6.14	7.39
	3	292.60		

Figure 5: Geoelectric Section at Low Cost Dumpsite, Gusau.

5.3 Discussion of findings at Dumpsite behind Total Filling Station

Three subsurface layers were delineated. It consists of VES from points 11 to 15. The resistivity of the first layer across the VES points were from 3.4 Ωm to 5.0 Ωm which is an indication of leachate contamination (table 2) at topsoil across this profile. The second layer had resistivity values and thicknesses that varied from 65.50 Ωm to 142.50 Ωm and 3.42m to 4.32m respectively (table 5). The third geoelectric layer had resistivity values from 315.5 Ωm to 986.0 Ωm . The lithology at this dumpsite ranged from clay, sandy soil, weathered Basement, fractured Basement up to fresh Basement. At VES 11, the bedrock encountered was at the depth of 7.18m. At other sounding points around this dumpsite, the high resistivity response of this zone was an indication that the area is free from leachate contamination and hence suggestive that the area is safe for groundwater development.

Table 5: Interpreted Layer Parameter of Dumpsite behind Total Filling Station.

VES Station	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)
11	1	3.40	3.38	3.38
	2	80.00	3.80	7.18
	3	986.00		

12	1	5.00	0.58	0.58
	2	85.00	1.68	2.26
	3	572.10		
13	1	4.72	1.28	1.28
	2	132.14	16.93	18.21
	3	975.00		
14	1	3.8	1.64	1.64
	2	65.50	16.47	18.11
	3	315.50		
15	1	4.15	1.25	1.25
	2	142.50	6.14	7.39
	3	522.50		

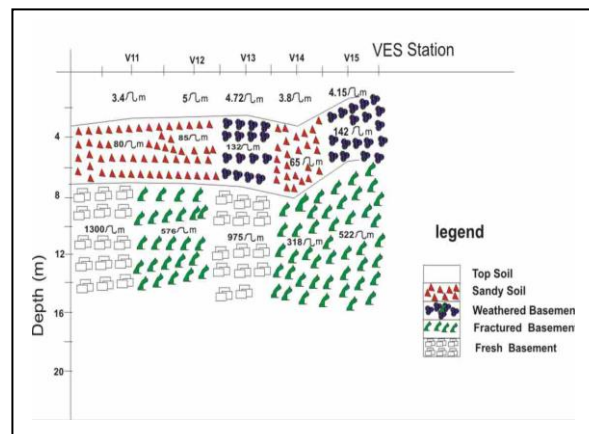


Figure 6: Geoelectric Section of Dumpsite behind Total Filling Station

6.0 CONCLUSION

The electrical resistivity survey was successfully used in mapping the contaminant leachate plume and characterization of the dumpsites in term of subsurface resistivity distribution of leachate, waste material and soil condition beneath the dumpsites. The results indicated that the topsoil in all the dumpsites were polluted and contaminated as depicted by low resistivity values. The infiltration of contaminated plumes was due to the high porosity and permeability that characterized the rocks and soils of the study area. The layered parameters together with geoelectric and geologic sections confirmed that the Hiran Decodi dumpsite display strong evidence of contamination as revealed by very low resistivity at almost all the VES points. At both Low-Cost and behind Total Filling Station dumpsites, the top soils were polluted but the results at some points signified high resistivity values, which is an indication of leachates free zone. Based on this study therefore, there could be possible contamination of shallow water within the dumpsites in the years to come due to migration of leachate plume. The top weathered

layers stand the greater risk of contamination by leachate accumulation.

7.0 RECOMMENDATIONS

It is recommended that leachate samples from the dumpsites be collected to really ascertain its composition. Physical, chemical and microbiological assessment should also be carried out to test the quality of the groundwater in comparison to WHO standard.

8.0 ACKNOWLEDGEMENT

The research team wishes to express their profound gratitude to Federal University Gusau, Zamfara State and the Tertiary Institution Fund (TetFund), Nigeria for the sponsorship of this work under the subheading. "TETF/DR&D/CE/UNI/GUSAU/IBR/2021/VO L.1"

Conflict of Interest

There is no conflict of interest associated with this research.

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