Hydro-Geophysical Assessment of Soil and Groundwater Near Active Dumpsites in Gusau Metroplis, Zamfara State, Nigeria

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Abstract

Soil and groundwater pollutions are worldwide phenomena which result from both natural and anthropogenic sources. In this research, geophysical investigations involving geoelectric survey using ABEM SAS 300 Terrameter was carried out around three active dumpsites in Gusau, Northwestern, Nigeria for hydro-geophysical assessment of the contamination of soil and groundwater. Vertical electrical Soundings (VES) were conducted on the dumpsites by 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 has been analyzed using WinGlink software which gives an automatic interpretation of apparent resistivity. The VES results revealed three subsurface layers. The geologic sequence beneath the study area is composed of topsoil (clay to sandy-clay, sandy-lateritic), weathered basement, fractured basement and fresh basement. The topsoil has resistivity ranging from 1.5 Ω m to 48.2 Ω m while the thickness vary from 0.47 m to 3.37 m across the profiles. The second layer's resistivity vary from 5.4 Ω m to 144.35 Ω m and their thickness ranges from 1.36 m to 16.93 m. The third geoelectric layer has resistivity from 70.0 Ω m to 6003.0 Ω m. The results revealed that the top soils in all the dumpsites were characterized by very low resistivity depicting possible pollution and contamination at all dumpsites. The dumpsites are depicted by differential decomposition of waste as zones of advanced decomposition and fresh waste are reflected by low and high resistivity respectively. The second and third layers show moderate to high resistivity values which are indicative of leachate absence. These areas are suitable for groundwater exploration. Findings from the study indicate 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.

Introduction

The environment has over the years faced adverse natural and anthropological challenges including over population, rapid loss of biodiversity, global warming and waste management.

Solid wastes are produced on daily basis as a result of direct consequence of inevitable human activities. Refuse contents consist of various kinds of materials like metallic, organic and non-biodegradable materials [1]. The intensity of the human activities has led to increasing volume of solid

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Accepted: November 18, 2019; **Published:** November 20, 2019

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Murana et al. *Int J Earth Sci Geophys* 2019, 5:028

ISSN 2631-5033

9 772631 503007

Citation: Murana KA, Shuaibu AM, Ajibade II (2019) Hydro-Geophysical Assessment of Soil and Groundwater Near Active Dumpsites in Gusau Metroplis, Zamfara State, Nigeria. *Int J Earth Sci Geophys* 5:028

waste worldwide despite the current level of global technological advancement and industrialization [2-4]. Poor management of solid waste has resulted to a lot of disastrous effects such as aesthetics, environmental hazard and pollution. Arbitrary refuse dumping pose a serious threat of polluting soil, groundwater and downstream surface water. Pollution of soil by leachate from surrounding municipal waste dumps has been recognised for a long time [5-8].

The waste disposal sites in Gusau are uncontrolled open dumps, thus creating serious health and environmental threats. Studies have shown that soil and groundwater systems can be polluted due to poorly designed waste disposal facilities, leakage from underground storage tanks and agricultural waste. Soil and groundwater acidification and nitrification have been linked to waste dumps [9] as well as microbial contamination of soil and groundwater system [10,11] attributed cancer, heart diseases and teratogenic abnormalities to groundwater contamination via leachate from waste dumps.

The management of solid waste landfills has been a major problem in Nigeria as well as other developing nations worldwide. Solid waste managements in Nigeria is characterized by inefficient collection methods, insufficient coverage of the collection system and improper disposal of solid waste [12,13]. Wastes are generated daily and disposed indiscriminately in land and rivers without recourse to the underground environment, local geology and proximity to the residential houses.

Gusau, being the state capital is characterized by beehive of activities as a result of farming activities, banking and communication sectors, and other economic activities. Gusau has witnessed an upsurge in population over the years [14], this has led to generation of huge masses of diverse wastes. As a result, wastes are dumped on open ground which may constitute environmental and health problems. Consequently, Gusau metropolis may face critical problem pertaining to its groundwater resources if the problem of waste disposal which litters the town is not adequately addressed.

In this study, resistivity survey using Schlumberger array was carried out at three dumpsites in Gusau to assess the impact of leachate on the environment, soil and estimate the harm done to the soil as well as ascertaining the groundwater quality

in the area. Earth materials are either resistive or conductive. Materials found at dumpsites which have been infiltrated by chemical from biodegradable wastes have resistivities or conductivities greatly altered by the migrating chemicals. Since direct resistivity method of electrical prospecting exploits the resistivity of the earth materials, as an anomaly, it is therefore one of the most suitable geophysical methods for the intended study.

Description of the study areas

Three dump sites within Gusau were selected for the study. The first dumpsite was Hiran DeKodi, Church pan which is located within latitude 12°09'57.7"N to 12°09'59.4"N and longitude 6°41'9.2"E to 6°41'11.5"E. The second site was Gangare Yarima close to Bye-pass which is located within latitude 12°10'50.5"N to 12°10'51.9"N and longitude 6°41'1.1"E to 6°41'2.1"E. The third site was Ahmadu Bello way Near Bebeji area which is located within latitude 12°10'11.5"N to 12°10'514.1"N and longitude 6°39'51.7"E to 6°39'53.8"E. The elevation in the study areas varies between 451 m to 454 m above mean sea level.

The area is within the tropical Savannah climate with distinct dry and wet seasons. The hottest months in Gusau are March and April, which is just before the first rainfall (the highest temperature is about 41 °C). The lowest temperature of 25 °C is in January, at the peak of Harmattan or in August during rainy season. The mean annual rainfall in Gusau is between 850-1350 mm. The onset of the rain on the average is between mid-April and May, lasting for about six months till the end of October [15].

The study areas are underlain by different lithological units which are crystalline in nature and belong to the Basement complex rock suites, mostly the oldest being Pre-cambrian in age. From the field mapping exercise Migmatite, Banded gneiss, Quartzite, Mica schists, Phyllites, Granites and minor intrusion of pegmatites were the rock types found underlain the study area (Figure 1).

Theories of Electrical Resistivity Survey

The D.C. resistivity method is based on the fact that when current (I) is driven into the earth, any variation of the subsurface resistivity will alter the current flow which will in turn affect the distribution of the electric potential. The measurement of the electric potential and the current especially on

Figure 1: Map of the study area.

Figure 2: Schematic diagram of Schlumberger array.

the earth surface makes it to obtain information about the resistivity variation of the subsurface in the area concerned [16].

In the Schlumberger array employed, the four electrodes are 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 [17] and the boundary planes between subsequent layers are assumed to be horizontal. Figure 2 is a schematic illustration of the Schlumberger array which is used for the survey.

Where A and B are electrodes through which current is driven into the ground while M and N are 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:

$$V = I R \quad (1)$$

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 , is considered. A potential gradient is measured between M and N when current I is 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 are as shown in Figure 3.

Absolute potentials are difficult to measure [18] so the potential difference ΔV between M and N

Figure 3: Shows the typical sounding curve.

is 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),

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

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

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,

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

Materials and Methods

Two dimensional (2D) electrical resistivity surveys were carried out on the dumpsites using ABEM

SAS 300 systems in December, 2018. 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 involves 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 [16,18]. The VES was conducted by using the Schlumberger array with a maximum current electrode spacing (AB) of 180 m.

The widest current electrode spacing used was 180 m, that is, $\frac{1}{2} AB = 90$ m. According to [19], 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 [20].

Table 1: Resistivity values adopted for this work [29].

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 [24].

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

Measurements were taken at expanding current electrodes 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 [17] with the help of master curves [15,21]. From the preliminary interpretation, initial estimates of 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 gotten from the sounding curves were discussed based 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).

Data processing

Geoelectric data acquired were processed to remove noise arising from instrumentation and environmental influence. The apparent resistivity data were presented as sounding curves. The curves were obtained by plotting the apparent re-

sistivity 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 type in each VES station depends on the subsurface layers sequence. The main purpose of processing the VES data displayed as curves is to determine the subsurface layers, their resistivities, as well as their 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.

Results and Discussion

From the 1D-resistivity curves, the interpreted layer parameters for each dumpsite are summarized below. For better understanding, the results of investigation are presented in form of geoelectric sections. However, the top soil and weathered basement are regarded as the overburden while the bedrock consists of the fracture and the fresh basement rocks [22]. The modelling of VES measurements carried out at the fifteen (15) stations has been used to derive geoelectric sections for the profiles (Figure 4, Figure 5 and Figure 6). The interpreted layer parameters for the three dumpsites are presented in Table 3, Table 4 and Table 5 below. The geoelectric and geologic sections were

Geological and Geoelectrical Sections

Gangeren Yerima

Figure 5: Geoelectric section at Gangeren Terima Dumpsite, Gusau.

Geological and Geoelectrical Sections

Bebeji Area

Figure 6: Geoelectric section at Bebeji Area Dumpsite, Gusau.

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.

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 has

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	1.50	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		

Table 4: Interpreted layer parameter for Gangare Yarima 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		

three subsurface layers as depicted in Figure 4. The first layer is the top soil which is characterized by very low resistivity values ranging from 1.5 Ωm to 6.5 Ωm across the profile (Table 3). The thicknesses of this layer range between 0.68 m to 2.29 m. The topsoil might be polluted due to low resistivity values whose lithology according to Table 2 above is leachate. The second layer has resistivity ranging from 5.4 Ωm to 144.35 Ωm with thicknesses from

1.36 m to 14.2 m. The lithology of this layer as evidenced on Table 1 above might range from 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 was due to the high porosity and permeability that characterizes the soil present in the study area. The third subsurface layer has resistivities that range from 70 Ωm -6003 Ωm . So, based on the porosity

Table 5: Interpreted layer parameter for Bebeji dumpsite.

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		

and permeability conditions of the observed geologic materials in the area, the result shows that VES 2-5 of the Hiran Decodi dumpsite has been polluted by leachate. The extremely low resistivity values in this layer suggest the contamination plume zone in the area [23]. It is interesting to note that at VES 1, fresh basement was encountered from depth of about 16 m. The results of this investigations show that both the soil and groundwater at this dumpsite have been contaminated.

Discussion of findings at Gangeren Yerima Dumpsite

The results of the investigation show that three subsurface layers exist in this site. The dumpsite consists of VES 6 to 10. The top soil resistivity values ranging from 5.0 Ωm to about 72 Ωm and thicknesses varying from 0.47 m to 1.64 m. The lithology of the first layer is majorly clay. The low resistivity values at the top soil is an indication of leachate at the layer. The second subsurface layer delineated has resistivity and thickness values varying from 44 Ωm to 180 Ωm and 1.58 m to 16.47 m respectively. The third subsurface layer's resistivity ranges from 292 Ωm to 1932 Ωm . The results of this investigation show that at Gangeren Yerima dumpsite site, apart from topsoil at VES 6 (Table 4) which has low resistivity of 5.0 Ωm indicating leachate, there is absence of leachate contamination from this dumpsite. The high resistivity response in this zone

is evident that the soil and groundwater are safe for exploitation.

Discussion of findings at Bebeji Dumpsite

This geoelectric section consists of VES from point 11 to 15. Three subsurface layers are delineated. The resistivity of the first layer across the VES points are generally low ranging 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 has resistivity values and thicknesses that varies from 65.50 Ωm to 142.50 Ωm and 3.42 m to 4.32 m respectively (Table 5). The third geoelectric layer has resistivity ranging from 315.5 Ωm to 986.0 Ωm . The lithology at this dumpsite ranges from clay, sandy soil, weathered basement, fractured basement up to fresh basement. At VES 11, the bedrock is encountered from depth of 7.18 m. At other sounding points around this dumpsite, the high resistivity response of this zone is an indication that the area is free from leachate contamination and hence suggestive that the area is safe for groundwater development [24-31].

Conclusion

The study revealed that the dumpsites consist of topsoil, clayey soil, sandy clay, weathered basement, fractured basement, fresh basement which are indications that the dumpsites are located on the aquiferous zones. Results from the

analysis of data revealed that leachate generated by surface water percolating through the waste has polluted and contaminated the topsoil in all the dumpsites as depicted by low resistivity values. Apart from Hiran Decodi dumpsite where there is strong evidence of contamination due to low resistivity response, the other two dumpsites showed high resistivity response in many VES points which implied that the areas are free from leachate contamination and hence suitable for groundwater development. The survey has successfully mapped the contaminant leachate plume and characterized the dumpsite in terms of subsurface resistivity distribution of leachate. The heterogeneous nature of the dumpsites and the complexity of its subsurface condition require that effective remediation measures be put in place to reduce environmental hazards from dumpsite. There may also be possible contamination of shallow groundwater within the dumpsites in years to come due to porous geologic materials.

Recommendations

It is recommended that leachate samples be collected to really ascertain its composition. Physical, Chemical and microbiological assessment can be done to test for quality of the groundwater in comparison to WHO standard.

Acknowledgement

The research team wishes to express their gratitude to the Tertiary Institution Fund (TetFund), Nigeria for the sponsorship of this ongoing work under the subheading. "TETFUND/DESS/UNI/GUSAU/2017/RP/VOL.1".

Conflict of Interest

There is no conflict of interest associated with this research.

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