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Geophysical and Geotechnical Assessment of the Effects of Barikin-Sale Dumpsite on Groundwater Quality, Minna, North-Central Nigeria

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Abstract

Discharge of leachate from refuse dumpsites is a source of groundwater pollution within its immediate environment of location. Geophysical investigation of an uncontrolled open solid waste dumpsite located at Barikin-Sale area of Minna was carried out for possible contamination of groundwater. The investigation is aimed at delineating groundwater contamination due to leachate percolation thereby assessing the quality of groundwater from hand dug wells and boreholes within the dumpsite and the surrounding environment. A total of ten (10) Vertical Electrical Sounding (VES) points with maximum current electrode spacing of 20m and two (2) 2D Subsurface Electrical Imaging were investigated within and outside the dumpsite to assess possible movement of leachate to the area. Schlumberger configuration was used for the VES while the Wenner configuration was used for the subsurface imaging. The VES data were analysed and a maximum of three (3) geoelectric sections were identified; the top soil, weathered basement and the fractured/fresh basement. The obtained apparent resistivity for those layers were between 19.4Ωm and 122.6Ωm for the first layer, 18.2Ωm and 33.4Ωm for the second layer and 93.5Ωm and 166.4Ωm for the third layer respectively. The range of thickness for the first layer is 0.9m and 1.8m and for the second layer are 4.0m and 5.3m respectively. The 2D resistivity data were processed and inverted using the RES2DINV software. The inverse resistivity models of the subsurface from the 2D electrical imaging revealed low resistivity value <20Ωm which is taken to be leachate derived from decomposed waste while these wastes that cannot decompose are occurring as isolated parts with slightly higher resistivity value of >20Ωm. The areas with the highest resistivity value of >100Ωm were further interpreted to be chemical weathering product of crystalline bedrock considered to be regolith. From the estimated hydraulic conductivity (K) from the sieve analysis, the values range between 1.97×10^{-4} and 2.52×10^{-5} m/s. These values are high and they correspond to leachate movement through the interconnected pore spaces of the soil underlying the waste dumpsite. This further clarifies the geophysical investigation results. From the results, it could be concluded that leachates are concentrated within the lower part of the dumpsite; therefore the surrounding environment groundwater sources are vulnerable to leachate contamination from the dumpsite.

***Keywords**: Resistivity, Dumpsite, Leachate, Contamination, Groundwater*

Introduction

Disposal of solid waste on land is the most common waste disposal method across Nigeria. Groundwater forms an important part of the water resources across the world particularly in the arid regions. It is used for domestic purposes because it is of high quality and required slight or no treatment before usage. According to Sampat (2001), bacteria, fungi and other biological pollutants are naturally filtered and diluted as the water infiltrate or permeate through the soil. The lackadaisical management and/or disposal of hazardous materials, fresh groundwater supplies are decreased greatly. The problem of environmental contaminations is one of the concerns of earth scientists today, and researchers from other related fields across the world. Indiscriminate disposal of organic waste is detrimental to health because it creates unsanitary environment that have adverse effects for urban residents. Where sanitary facilities are scarce, household solid wastes also tend to be mixed with fecal matter, further compounding the health hazards (Kiellen, 2011). Most of these waste disposal sites are located in open spaces within the vicinity of human settlements where several wells and boreholes are found. Indiscrimate disposal and improper management of domestic and industrial wastes will impact negatively on the environment and health of the inhabitants. Infectious diseases associated with poor environmental conditions kill one out of every five children in Africa, with diarrhoea and acute respiratory infections being the two major killers (WHO, 1979). Diseases such as cholera, typhoid, guinea worm, trachoma, bilharzias, polio, hookworm, and tapeworm are related to drinking of poor quality water and sanitation (Boadi and Kuitunen, 2005). As a result of industrial advancement and urbanization in recent time, there is tremendous increase in the population of people living in Barikin-Sale, and this has led to exceptional increased in the waste generation, therefore refuse dumpsites become a common feature in the city.

Groundwater contamination within a waste disposal site results from the infiltration of leachates through the soil. The leachates are formed when rain falls on the dump, sinks into the waste and picks up contaminants as it seeps downwards (Egbai et al., 2015). The frequent shallow aquifer found in the basement complex terrains is typically exposed to surface and near-surface contamination (Aweto, 2011). It has been affirmed that once an aquifer is extremely exhausted or contaminated, the damage is basically unending and efforts to reduce the contamination are exceptionally expensive (Jegede et al., 2013). In the study area and the surrounding environs, groundwater is tapped from hand-dug wells and boreholes at depths that are sometimes as shallow as 5 m as the main source of water used for domestic purposes in the area. The contamination becomes obvious resulting from the hydraulic contact between the hazardous contents of the leachate plumes and groundwater (Nasir et al., 2010).

Basically, two distinctive methods can be used in investigating the level of contaminants in groundwater. Firstly, the destructive method which involves taking samples using soil auger/core sampler in which case the geology of the area is continually disturbed. Secondly, the non-destructive method which makes use of geophysical method where the geology of the area is not disturbed (Oyedele, 2009). One of the recognized geophysical methods is the electrical resistivity method which provides beneficial and non-destructive means to identify, delineate and map the sub-surface defining leachate contaminant plumes from dumpsites. This method is based on electrical conductivity of leachate which tends to be above that of groundwater (Cristina et al., 2012). Researches have also proven that resistivity method is a tool for identifying, delineating and mapping of leachate contaminant plumes (Porsani et al., 2004).

Direct Current (DC) electrical resistivity methods of geophysical exploration are popular and have proven to be successful and dependable in the fields of geo-environment, hydrogeology, engineering and contaminant hydrology. Recently, one of the new developments is in the application of 2-D electrical imaging techniques to map areas with moderate to complex geology (Griffths and Barker, 1993). Also, mapping of changes in the recorded resistivity in the vertical as well as the horizontal direction, gives a more accurate model of the subsurface in two-dimension (2-D). Electrical resistivity methods for contaminant studies have a wide range of application on shallow groundwater resources, and the advantages include the reduction in the need for intrusive techniques and direct sampling, produces intrinsic properties (electrical conductivity/resistivity) of groundwater chemistry that gives information on contamination, reasonably economical, and optimization of the requisite number of observation wells (Ebraheem et al., 1997 and El-Mahmoudi, 1999). The objective of the study is to apply geoelectric technique implementing the vertical electrical sounding and the 2-D subsurface electrical imaging (2D resistivity tomography), employing the Wenner techniques to detect and delineate leachate plume from an uncontrolled solid waste disposal site in Barikin-Sale Minna, North-central Nigeria.

Location of the Study Area

The dumpsite is located within the Barikin-Sale area and it is accessible through the Minna Western bye-pass within longitudes 6° 31′E and 6° 33′E of the Greenwich Meridian and latitudes 9° 34′N and 9° 36′N of the Equator (Figure 1). It covers an area extent of about 150 by 100 m with the present dump height of about 5 m. The system of waste disposal at Barikin-Sale is open dumping, consequently the widespread indiscriminate dumping of solid waste at the dumpsite. The increasing population of Minna has made Barikin-Sale a significant settlement for the middle class and low income earners working and living in the capital city of Niger State. Most of the inhabitants of the area embark on the development of hand-dug wells and private boreholes to supplement the insufficient public water supplies.

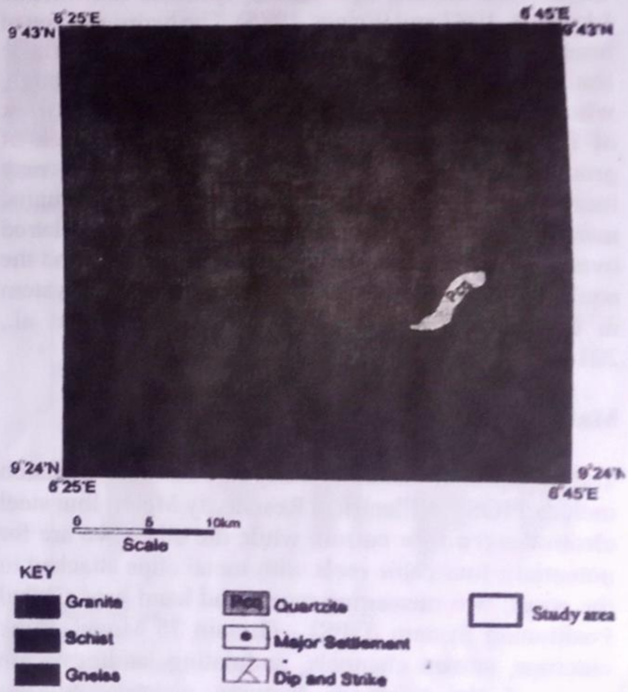

Fig. 1: Geological map of Minna showing the study area (adapted from Nigerian Geological Survey Agency, 2009)

Geology of the Study Area

The study area lies within the Nigerian Basement Complex terrain. This terrain is characterized by three lithofacies: i. the migmatite gneiss complex, ii. the low metasedimentary schist and iii. the older granites (Oyawoye, 1972 and Rahaman, 1976). Important to the area is the granite, granite-gneiss and schist with relics of quartz veins and pegmatite's as minor intrusions underlying the area. Granitic rock occupies about 95% of the area under study. They are mostly exposed on the western part of Minna town. They form high batholiths that are extensive in size. The granitic outcrops are fractured, jointed and foliated.

The rocks are made up of light and dark coloured minerals; quartz and feldspar and biotite-mica respectively. The alteration in the mineral colour defines the gneissose banding. In some cases the rocks are fractured and weathered. The pegmatites and quartzitic veins which appear as minor mineral intrusive rock also form part of the area. The granitic and gneisses rock most times serve as the host rock on which the pegmatetic and quarzitic mineral veins fined expression. They are defined by coarse textures. Minerologically, they are composed of quartz, feldspars and some precious minerals of high quality which include tourmaline, aquamarine, epidotite and emerald (Ajibade, 1982 and Wright, 1985). The hydrogeology of basement areas is simple since there is an intrinsic limitation to groundwater occurrences. Although, where there is thick regolith and there is a dense network of fractures, the posibilities for the accumulation of groundwater in the basement complex rocks may increase. Ideally, the area can be divided into two units, namely, the aquiferous zone within the weathered overburden overlying the fresh basement rocks and the aquiferous zone within the intense fracture joint system in the partially weathered basement (Omale et al., 2016).

Materials and Methods

The equipment used in carrying out this research include PIOS O1 Electrical Resistivity Meter; four steel electrodes (two for current while the other two are for potential); four cable reels with metal clips attached to the wires; two measuring tapes; and hand held Global Positioning System (GPS) - Garmin 75 Model. Rock outcrops, stream channels, undulating landforms are some of the geologic features observed during reconnaissance visits to the site. The information obtained during the reconnaissance was used in carrying out the fieldwork.

Electrical resisfivity method which employs the Schlumberger electrode configuration with maximum current electrode separation (AB/2) of 20 m was used in acquiring VES data at the site. A total of ten (10) VES points were established. Electrical resistivity surveys are usually designed to measure the electrical resistivity of subsurface materials by making measurements at the earth surface (Abdel-Azim et al., 1996). Vertical Electrical Sounding (VES) works on the principle of electrical resistivity which involves injecting a specified amount of electric current into the ground through a pair of current electrodes and then with the aid of potential electrodes, measures the potential difference between two points at the surface caused by the flow of the electric current in the subsurface. From the measured current (I) and the voltage (V) values, the ensuing resistivity is determined. The sounding curves produced were interpreted qualitatively through visual inspection and then subjected to the technique of partial curve matching and iteration with the WinResist software for interpretation quantitatively to generate the layered apparent resistivity and thickness. Figure 2 shows a simplified diagram of the Schlumberger array.

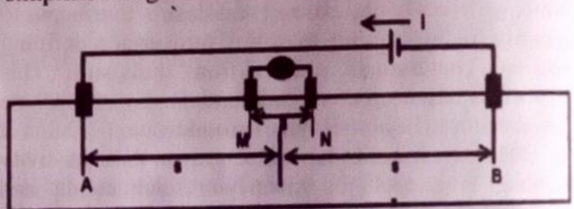

Fig. 2: Simplified diagram of the Schlumberger array

In addition, the 2D subsurface electrical imagings employing the Wenner array were carried out with electrode separation of 5m to map the possible migration of leachate from the dumpsite to the aquifer. The Wenner resistivity data were imputed into the RES2DINV software, which converts the result to a 2D resistivity model (Pseudosection). The generated pseudosection gives the variation of resistivity in both the vertical and horizontal direction with respect to depth.

The VES data were processed to determine the geoelectric parameters (overburden units, thickness and resistivity) as well as the hydrogeological characteristics of the subsurface (Sikandar et al., 2010). The apparent resistivity values calculated for each geoelectric layer were plotted on a log-log graph against the half current electrode separation AB/2. From the qualitative values, geoelectric parameters such as the resistivity of the top (first) layer as well as the thickness/depth of each layer were determined. The first quantitative interpretations were carried out using partial curve matching method which revealed the layers of the VES points, the apparent resistivity, of each layer, the thickness (h) of each layer (Table 1). These parameters were again iterated with WinResist software with a minimized root mean square error to get the sounding curves, the true resistivity of the layers, their real saturated aquifer thickness (h).

Results

The result of the geoelectric parameters obtained from the VES is presented on Table 1. Figure 3 is a representative of the interpreted VES data. Figure 4 and 5 are the geoelectric sections obtained from the study area while Figure 6 and 7 are the 2D inverse reisitivity models for profiles 1 and 2 respectively. Furthermore, the result of the calculated hydraulic conductivity (K) from sieve analysis is presented on Table 2. The interpreted VES curves (Figure 3) reveals three major lithologic layers with the topmost layer being the top soil with a depth range of 0.90m and 1.80m, the second layer being the weathered basement with depth range of 4.0m and 5.3m and the third being the fractured/fresh basement which is the main aquifer unit.

Table 1: Geoelectrical parameters and lithologic delineation of the study area

VES No.	Coordinates	Layer	Resistivity, ρ(Ωm)	Thickness (m)
1	9° 35′ 10.2″ N	1	71.7	1.0
	6° 32′ 04.7″ E	2	33.4	5.0
		3	137.8	
2	9° 35′ 10.2″ N	1	27.9	1.1
	6° 32′ 04.4″ E	2	25.1	4.6
		3	106.8	
3	9° 35′ 10.2″ N	1	65.3	1.6
	6° 32′ 04.0″ E	2	23.9	4.6
		3	134.4	
4	9° 35′ 09.9″ N	1	52.9	1.8
	6° 32′ 03.6″ E	2	23.3	4.3
		3	166.4	
5	9° 35′ 09.3″ N	1	19.4	1.1
	6° 32′ 03.3″ E	2	30.3	4.1
		3	93.5	
6	9° 35′ 09.1″ N	1	34.7	1.5
	6° 32′ 02.7″ E	2	25.5	5.0
		3	113.3	
7	9° 35′ 10.2″ N	1	27.0	1.3
	6° 32′ 04.7″ E	2	18.2	4.1
		3	166.1	
8	9° 35′ 08.0″ N	1	76.0	0.9
	6° 32′ 02.7″ E	2	29.7	4.8
		3	124.4	
9	9° 35′ 08.4″ N	1	122.6	0.9
	6° 32′ 03.1″ E	2	22.0	5.3
		3	120.5	
10	9° 35′ 08.8″ N	1	102.4	1.6
	6° 32′ 03.5″ E	2	21.7	4.3
		3	166.3	

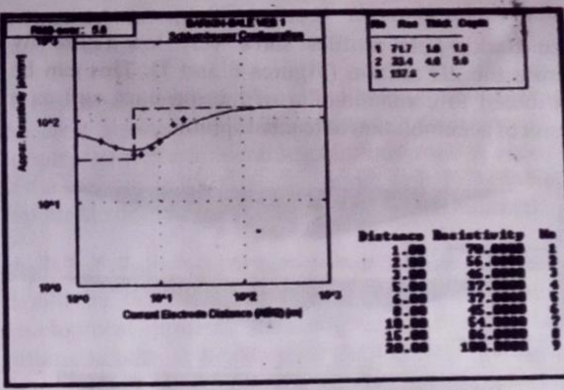
Fig. 3: VES Curve Representative of VES graphs obtained from the Study Area

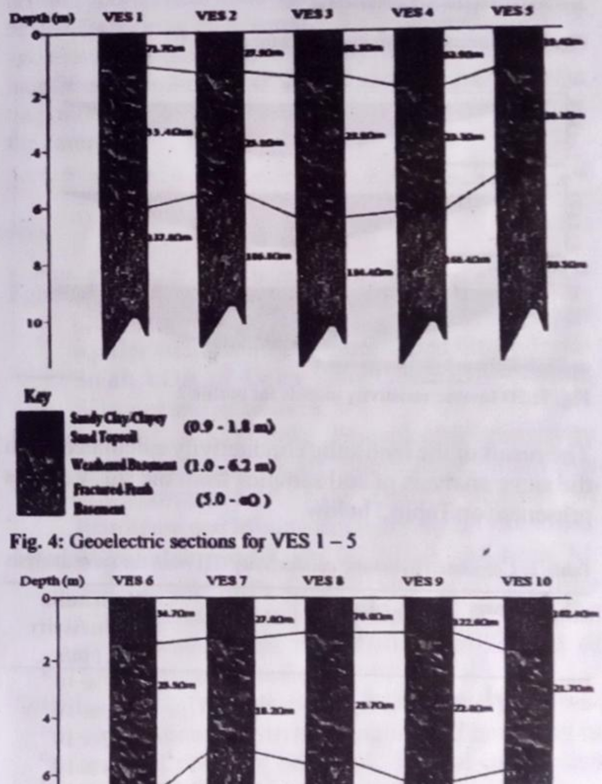

Fig. 4: Geoelectric sections for VES 1 – 5

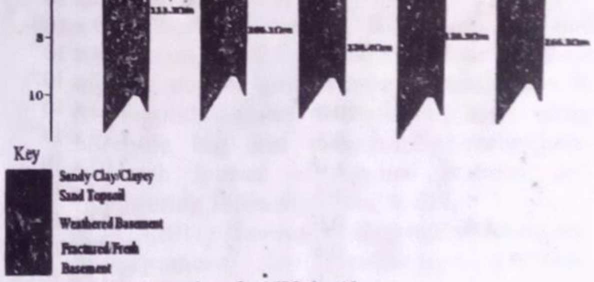

Fig. 5: Geoelectric sections for VES 6 – 10

The Barkin-Sale profiles show very low resistivity across the 2D section (Figures 6 and 7). This can be attributed to contamination of the top-most soil as a result of accumulation of leachate plume.

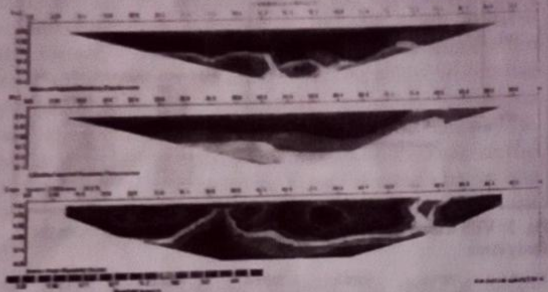

Fig. 6: 2D Inverse resistivity models for profile 1

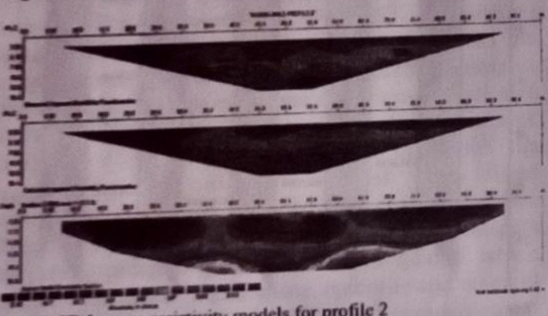

Fig. 7: 2D Inverse resistivity models for profile 2

The result of the hydraulic conductivity calculated from the sieve analysis of soil samples from the study area is presented on Table 2 below.

Table 2: Calculated hydraulic conductivity (K) from the sieve analysis

Locations	Depth (m)	Hydraulic Conductivity (K) m/s
L1	0.0	6.57×10^{-5}
	0.5	8.90×10^{-5}
	1.0	1.42×10^{-4}
	1.5	5.41×10^{-5}
L2	0.0	8.90×10^{-5}
	0.5	7.69×10^{-5}
	1.0	9.74×10^{-5}
	1.5	1.97×10^{-4}
L3	0.0	5.63×10^{-5}
	0.5	1.20×10^{-4}
	1.0	5.63×10^{-5}
	1.5	1.27×10^{-4}
L4	0.0	2.52×10^{-5}
	0.5	1.00×10^{-4}
	1.0	1.15×10^{-4}
	1.5	6.43×10^{-5}

Discussion

The VES results shows that the area is characterized by three (3) layers which are the top soil of 19.4Ωm to 112.6Ωm and the weathered basement of 18.2Ωm to 33.4Ωm and the fractured/fresh basement of 93.5Ωm to 166Ωm with corresponding thickness of 0.9m to 1.8m and 4.0m to 5.3m for the first and second layers respectively. These zones are also indication of solid wastes dumped in the area. Geoelectric sections generated for the overburden units show that the topmost layers at all the VES points are mostly sandy, while the second layer are occupied by clayey sand. The second layer is generally thin at all the VES points, therefore providing slight or no protection at all to the aquifer beneath it. Clayey overburden is characterized by area of relatively high longitudinal unit conductance which offers protection to the underlying aquifer. It has been reported that materials such as sand and gravel have low longitudinal conductance resulting from their higher resistivity values as a result of having low aquifer protective capacity (Farid et al., 2017)..This prevailing condition in the study area enhances the percolation of possible contaminants into the aquifer. From the abovementioned, it is seen that the aquifer in the dumpsite area is prone to contamination (Egbai et al., 2015). Obviously, the shallow aquifer in the area can be easily polluted by contaminated surface runoff water in the area (Odong, 2013).

The 2D inverted resistivity models were generated from measurements along the two perpendicular traverses across the dumpsite area (Figuress 6 and 7). This is to identify and map possible migration of the leachate across the dumpsite area. The 2D inverted resistivity sections image the subsurface geologic sequence and the structural disposition of the layer. The sections reveal basically a maximum of three subsurface layers, which is in agreement with the results of the VES geoelectric section. The resistivity of the various layers ranges from 35.7 to 2860Ωm. However, a low resistivity structure is found at a depth of about 3.75m with resistivity ranging from 3.91 to 42.3Ωm which is indicative of the presence of leachate from the dumpsite.

The calculated hydraulic conductivity (K) from the sieve analysis ranges between 1.97×10^{-4} and 2.52×10^{-5} m/s. Table 2 shows that the hydraulic conductivity ranges between 1.97×10^{-4} and 2.52×10^{-5} m/s. According to Macauley (2008), these values are high implying that the leachate can move downward to the aquifer. These values are high and they correspond to leachate movement through the interconnected pore spaces of the soil underlying the waste dumpsite. This indicates that the leachate can move gradually through the soil and if the dumpsite is not relocated or completely evacuated from the area, the adjoining aquifer and surrounding are susceptible to contamination. The dumpsite has to be properly designed in order for it to serve as a dumpsite.

Conclusion

The vertical electrical sounding, 2D subsurface electrical imaging and geotechnical studies have been applied in the mapping of in a public waste disposal site in Barikin-Sale Minna, Nigeria. This was with a view to unravel potential groundwater pollution that could arise from leachate associated with the dumpsite. The outcome of the research revealed that the open dumpsite in area is underlain by materials of poor protective capacity for the aquifers. This indicates that as time goes on, the aquifer in the area will continue to receive loads of contaminants. Therefore, the aquifer systems in the area are extremely susceptible to contamination from infiltration of leachate from decomposed wastes dumped at the site.

To ensure safe consumption of potable groundwater in the area, wastes should be evacuated from the area because the area is vulnerable to pollution and as a result of the shallow depth of the aquiferous unit, It is advised that further dumping of waste should be discontinued.

Also, the results and data generated from this study should be taken into consideration when planning development projects that engages the subsurface within and outside the dumpsite such as water borehole, farms, health facilities, residential and commercial facilities etc. Specifically, it is recommended that pre-drilling geophysical investigations should be carried out before embarking on any water borehole project within and around the dumpsite. Certainly, modern engineered landfills with bottom liner for safe and sustainable waste disposal and management should be introduced across the country.

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