Original Research Article

Effect of an Active Open Dumpsite on the Earth's Subsurface and Groundwater Resource

ABSTRACT

An electrical resistivity survey was carried out at a dumpsite and at a sample station (about 200 m) away from the dumpsite to serve as the controlled station, to compare and evaluate the vertical extent of leachate contamination of the dumpsite and its impact on the soil and groundwater resources. The results show that the dumpsite has been heavily leached and contaminated compared to the same station. The subsurface resistivity values reveal that the leachate plume has heavily leached and infiltrated the soil to the water table and its surroundings. This implies that the surrounding soil and groundwater of the dumpsite must have migrated into the aquifer system of the terrain, thereby contaminating the water-bearing unit to a depth extent of 14 m after 21 years of existence. Interestingly, the Leachate usually associated with the high ion concentrations has weakened a highly resistive soil as revealed by the sample station; and provides an easy flow path for the dumpsite leachates to penetrate the ground.

Keywords: dumpsite, controlled station, impact, groundwater, vertical extent, leachate contamination,

Introduction

The rapid increase of active open dumpsites across the world, especially in Africa is becoming more worrisome to geoscientists and researchers because all dumpsites are usually associated with environmental and water pollution as well as health hazards [1,2]. All open dumpsites, large or small are usually associated with leachate, whether the leachate contaminates groundwater or not, depends on how the landfill is constructed [3]. The characteristics of active open dumpsite leachate may be differed, depending on the degradation procedure, hydrological nature, climate conditions and the age of the dumpsite. Many researchers are of the view that the environmental pollution and health issues are usually connected to the inadequate treatment of dumpsite leachate [3-5], while [6-8], believe that the degree of groundwater pollution is a measurement of hydraulic conductivity value at waste dumpsites, but the recent studies have shown that the deposited wastes on landfill undergo series of chemical reactions and changes and the shallow sediments above the water-bearing unit (water table) can get contaminated through leaching of leachates thereby contaminating usable surface water and groundwater resources [1], [8-10]. However, contaminants or pollutants released into the environment hardly remain at the surface but usually discharge and infiltrate the ground down to the water-bearing unit, this is because groundwater pollution usually happens as a result of infiltration and percolation of fluvial contaminants water through the soil in landfill sites [1, 9, 11]. However, the effect of open dumpsite leachate is not limited to the groundwater resources, but it also affects ground soil. While [7] is of the view that, natural and man-made factors are usually the cause of the events that lead to soil and environmental pollution, which degenerated into diverse calamitous and disastrous, others believe, that soil pollutants are dependent on the soil resistivity and conductivity, because the soil resistivity and conductivity are the measurements of the degree of various geological factors such as the porosity, soil mineral, soil water content & [8, 12]. However, the views of these studies are not contradicting because natural and man-made factors are responsible for the degree of soil resistivity and conductivity. Most open dumpsites across the world, especially in Africa are usually located in the City such as residential areas, markets, roadsides, and others, where the wastes are not properly discharged, and this

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could threaten the groundwater resources, even structures like buildings and road facilities are not speared. According to [1, 8, 10], groundwater found in the cracks and fractured rock has proven to be a favourable zone accumulation groundwater, since their hydrological characteristics like porosity and hydraulic conductivity are enhanced. Therefore, the presence of fractures in or around dumpsites could increase hydraulic contact between the groundwater and leachate thereby increasing the risk of environment and water contamination since dumpsites constitute an integral part of the soil hydrological system [1, 10, 12]. However, studies have shown that the leachates are associated with high ion concentrations that weaken a highly resistive soil, and provide an easy flow path for contaminants and electric current to penetrate the ground [9, 10, 13]. Based on this fact, vertical electrical resistivity is chosen as a robust technique suitable and adequate for determining the vertical extent of leachate contamination of open dumpsites, this is because the geophysical investigation provides us with robust economics and nondestructive means of delineating and identifying the contaminant plumes from landfills and open dumpsites. This paper presents the results obtained through geophysical investigation to create awareness and adequately advice the government and the general public on the negative impact of the uncontrolled open dumpsites, which may lead to complex situations.

1. Site and Geology Description

Fig 1 shows a typical uncontrolled and active open dumpsite located at Goni-Gora, Kaduna, in the complex basement of Nigeria. The dumpsite lies on the geographical coordinate of Latitude and longitude of 10° 24.393' N to 10° 24.351' N, and 007° 23.955' E to 007° 23.926' E respectively with a total landmass of 24,500 square metres. The open dumpsite consists of heterogeneous waste materials that have been in operation for more than two decades. The landfill is an unstandardized sanitary landfill that is predominant in most parts of the country. The dumpsite is estimated to have contained about 56,250 m^3 of municipal solid wastes. The open dumpsite contains all forms of waste such as sewage (human and animal Excretion), municipal wastes, medical wastes, agricultural wastes, industrial wastes, and other hazardous wastes

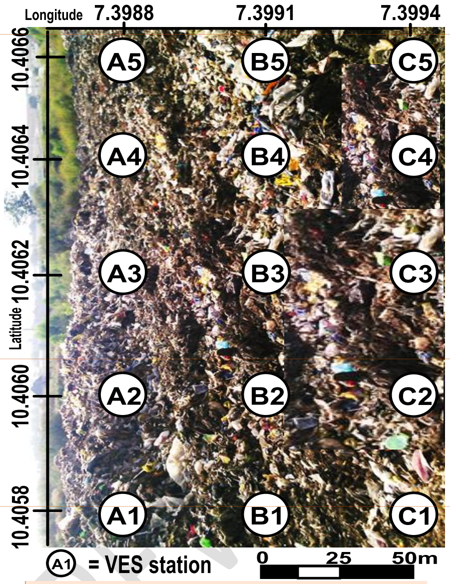

Fig. 1: Image of the Case Study Active Open Dumpsite Showing all the VES Points

2. Dumpsite Leachate and Its Challenges

Leachate usually forms when water infiltrates the waste in an active open dumpsite, which is then transferred in the form of contaminants [3]. Leachate is a liquid that leaches from dumpsites. It usually contains suspended and dissolved materials; and is considered one of the most common liquids that seep into our groundwater resources and contaminate them [3, 14, 15, 16]. The increase in landfill gas emission rates across the world has generated a lot of complaints, especially in tropic countries [17-19]. The waste materials placed in an active dumpsite for many years will naturally decompose and sweat. Dumpsite leachates are usually characterized by high biological oxygen demand (BOD) and chemical oxygen demand (COD), and they occasionally consist of high concentrations of organic pollutants and contaminants [14, 15, 20]. Heavy toxic materials, metallic materials, inorganic, and ammonia materials as well as refractory compounds, like humic substances as well as contaminants of emerging concern [14, 15, 16, 20]. Though, the characteristics of dumpsite leachate may vary depending on the degradation process, hydrology, climate conditions, and age of a dumpsite. According to [3, 16], municipal dumpsite leachate contains

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contaminants that can be classified into four major groups, this includes; the organic contaminants and substrates, the heavy metals, and the inorganic compounds, the total dissolved solids and colour. The age of dumpsite leachate may be classified into three main groups as shown in Table 1, and this includes; the young (the acid phase), the intermediate and the old [3-5]. Table 1 shows that the leachate is dominated by low pH levels, high volatile acids and highly degraded organic matter.

Table 1: Leachate characteristics and treatability based on landfill age [3, 21].

Age	**Young [0 – 5]**	**Intermediate [5 – 10]**	**Old [> 10]**
PH	< 6.5	6.5 – 7.5	>7.5
COD(Mg/L)	>10000	5000 – 10000	<5000
BOD_5/COD	0.5 – 10	0.1 – 0.5	>0.1
NH_3-N(Mg/L)	< 400	–	>400
H.M	Medium-low	Low	Low
VFA/HFA	VFA (80%)	VFA (5–30%)	HFA (80%)
Biodegradability	High	Medium	Low

Where HM is heavy metals; VFH is volatile fatty acids; HFA is humic and fluvic acids.

3. Hydrogeological and Climatic Conditions

There may be a slight difference in some other studies across the world; because the waste characteristics, most times depend on the nature of the countries concerned. African countries are generally hot, especially Nigeria, sitting close to the equator with temperatures varying between 24℃ - 38℃ because it directly relate to the meteorological conditions on the site [1, 17]. The low wind speed or low mixing height of the atmospheric weather conditions could severely affect the rapid expansion and releasing of odour into the environment. Therefore, the dumpsites that are often located in complex terrain area are mostly affected by the meteorological conditions Of the terrain and the effects are difficult to predict [19-21]. According to [2, 3], heat is a major factor that spread gas and leachate due to high pressure created and helps in the decomposition of biodegraded material which could lead wide and fast spread of contaminants both on the surface and subsurface [21]. Therefore, the climatic conditions of an environment can reflect and influence the character of open dumpsite leachate. On the other hand, many researchers are of the view that geological factors such as topography, rain, and erosion can increase the rate at which a dumpsite leaches down the soil to contaminate groundwater [3, 4, 7, 8, 16, 21]. The tropical region like Nigeria where the annual rainfall ranges from 1000 to 1500 mm, and the maximum temperatures, on the other hand, varies between 24℃ - 38℃, reflects the influences the character of an active open dumpsite leachates in the tropical continental and equatorial maritime air masses [22]. Nigerian landmass is characterized by various crystalline Basement Complex rocks of Precambrian to early Paleozoic which has been subjected to different deformations over the year in the folding and fracturing of the rocks [1, 2]. Finally, the hydrogeological characteristics of such terrains must have been enhanced due to fracturing, since the present dumpsites constitute an integral part of the soil hydrological system [1, 9, 10, 22].

4. Geophysics Technique

An electrical Resistivity was used to acquire a total of fifteen (15) vertical electrical soundings (VES) using a Schlumberger array to determine the subsurface resistivity and conductivity, as well as the vertical extent of leachate plumes contamination of a dumpsite. Another four (4) VES sample stations were taken, which are about 200m away from the open dumpsite to serve as a controlled station for this research. Fig. 2 shows the Schlumberger arrangement of the four

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electrodes. Schlumberger array works on the principle of Ohm's law [23-30]. That is:

$$V = IR \qquad \text{(i)}$$

The soil's resistive response to the flow of current through the ground can be expressed as:

$$\Rightarrow \rho_a = RK \qquad \text{(ii)}$$

Where R is resistivity, and K is a geometrical factor that depends on the arrangement of the four electrodes as shown in Fig. 2 and can be expressed as:

$$K = \frac{2\pi}{\left[\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \left(\frac{1}{R_A} - \frac{1}{R_B}\right)\right]} \qquad \text{(iii)}$$

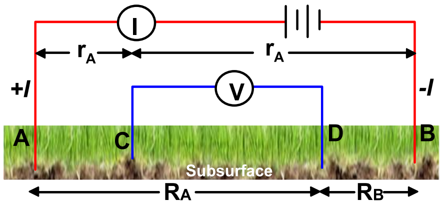

Fig. 2: Schlumberger Configuration

5. Data Processing

The first stage in any interpretation of apparent resistivity sounding curves is to note the curve shape before applying a more complicated method of interpretation [22, 30]. The Micro-soft excel to initiate the rough idea of the expected curve after the data collected was reduced and computed. Consequently, the subsurface geo-electrical data collected was interpreted utilizing the computer software called *Res ID version 1.00.07* Beta. Fig 3 shows one of the resultant curves for the VES station **B3** along with profile **B** (Fig. 3). However, the measurement of resistivity is based on the difference in the subsurface resistivity values of the model blocks between the measured and calculated apparent resistivity values from the field. Consequently, the accuracy of fit is expressed in terms of the root mean square (RMS) error [12, 13, 22, 23, 26].

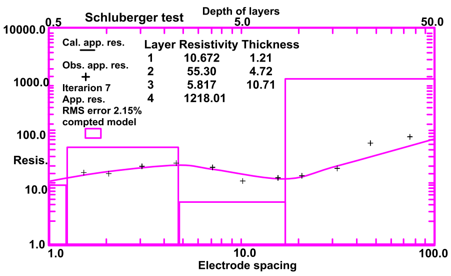

Fig. 3: Typical resistivity curves of VES **A2**

6. Results and Discussion

The model parameters obtained from *Res ID* after quantitative and qualitative interpretation were further processed to generate the geo-electric/geologic profile or soil depth section of the study area presented in Figures 4–7. This section according to [9, 10, 11, 25], describes the subsurface of the earth's electrical and conductivity properties, and the soil profile of the sequence of layered rocks. The geo-electrical information is characterized by the values of layer resistivities and their thicknesses.

a. Geoelectric Section for the Controlled Station

Fig 4 shows the Geoelectric/geologic profile of the controlled (sample) station which is about 200m away from the open dumpsite. This was established to compare the results of the dumpsite to the controlled (sample) station to evaluate the vertical extent and the degree of the dumpsite impact on the ground conductivity and the groundwater resources of the study area. From the four (4) investigated VES stations, the results show that the topsoil is highly resistive with an average resistivity and the thickness values of 857 Ωm and 1.8 m respectively. The preceding highly resistive indurated laterite/sand layer was found with an average resistivity value of 3686 Ωm. The third layer which also represents the water-bearing unit has an average resistivity and thickness value of 82 Ωm and 12 m respectively. However, [8, 29], noted that the regions with overburden thickness (> 12m) may likely consider an area with high groundwater potential, and is highly protective from the near-surface contamination. This implies a deeper aquifer, with a highly compacted, resistive, indurate laterite and impermeable clay topsoil could provide an additional protective cover for any region's groundwater. The bedrock is highly resistive, which indicates that there is no or little action of leachate plumes contamination on the basement rocks

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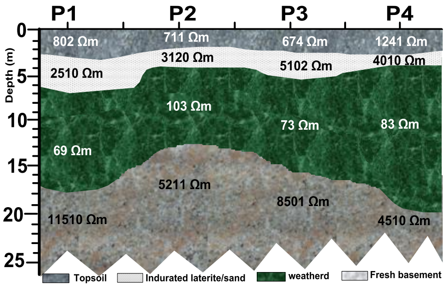

Fig 4: Geoelectric/geologic profile of the sample station (about 200 m away from the dumpsite)

b. Geoelectric/geology Section of the Dumpsite

Figures 5-7 show all the profiles taken in the dumpsite. The results show that the dumpsite is highly conductive to the current flowing into the ground. This suggests that the leachate plumes contamination at the dumpsite has infiltrated the subsurface according to its resistivity layered values. The first layer has an average resistivity and thickness values of 17 Ωm and 1.9 m respectively (table 1), while the preceding (second) layers of resistive laterite as observed in the controlled station has been weathered (table 1). The aquifer unit as observed in the controlled station has an average resistivity of 82 Ωm and thickness of 13m. However, the aquifer unit of the dumpsite has a very low resistivity value on an average of 17 Ωm and a thickness of 15m approximately. These resistivity values suggest one thing, that is, the leachate plumes contaminations have highly penetrated the soil down to the water-bearing unit. The second layer which is believed to have been made up of compacted laterite and impermeable clay, also indicates that the leachate plumes contamination has deeply penetrated the soil. A fractured basement was encountered with an average resistivity value of 353 Ωm is also threatened. The bedrock of the dumpsite and the sample station were found with average resistivity values of 7433 Ωm and 7042 Ωm respectively. This suggests fresh basement rock has not been affected by the leachate plumes contamination.

[8, 13], are of the view that any terrains with the bedrock resistivity ≥2000Ωm, are undoubtedly considered unfractured. Based on the variation in the resistivity values of the dumpsite, the leachate contamination has little or no effect on the fresh basement rock.

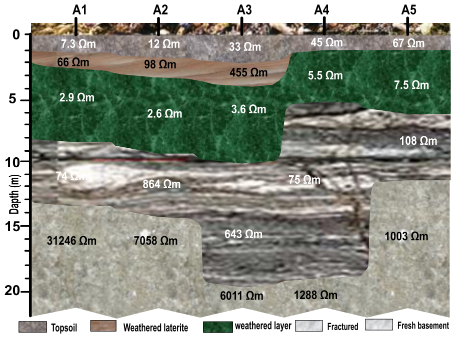

Fig 5: Geoelectric Profiles of the Terrain

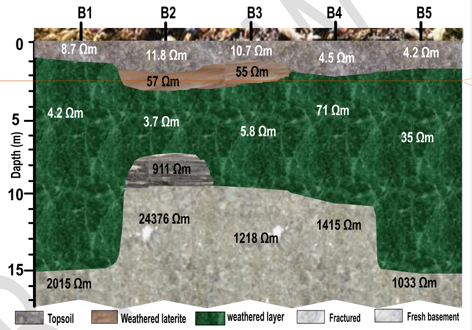

Fig 6: Geoelectric Profiles of the Terrain

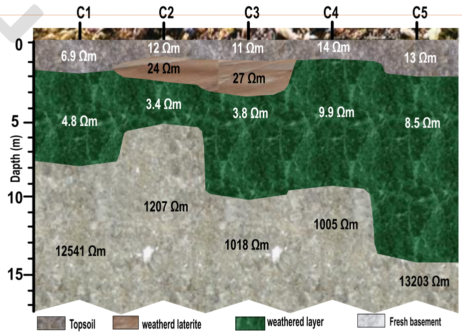

Fig 7: Geoelectric Profiles of the Terrain

c. Statistical Comparison between the Open Dumpsite and Sample Station Parameters

According to [7], terrain with a very low topsoil resistivity may be considered highly porous, weathered and leached as the case may be. Based on this fact, coupled with the topsoil resistivity values obtained from the dumpsite (17 Ωm on average), the leachate of the dumpsite has grossly and severely contaminated the soil and groundwater resources. Table 2 shows a comparative assessment between the active open

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dumpsite and sample stations (which serve as the controlled station). From the reliable source, it was discovered that; the case study active open dumpsite has been in existence for the past 21 years, and the results presented in table 2, show that the leachate plumes contamination in dumpsite has leached down the soil to at least 14 m depth. This implies that; the soil and groundwater resources of those active open dumpsites that have been in existence for over 21 years must have undergone severe damage, which could be very hazardous to human health. It is however noted that the leachate plumes also can expand horizontally; since the liquid movement under the ground is not limited to vertical movement [18, 19, 20, 24].

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Table 2: The Statistics of the Controlled Station (sample station about 200 m away) and the Open Dumpsite

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Layers	Soil Profile	Average Parameters	Control Station	Dumpsite	Percentage of Leachate Leach	Observations
1	Topsoil	Resistivity Thickness	857Ωm 1.8 m	17 Ωm 1.9m	98%	Topsoil has been extremely leached, thus, water/soil is contaminated
2	Indurated laterite	Resistivity Thickness	3686 Ωm 1.5 m	126 Ωm 1.6 m	96%	This layer is critically leached, allowing easy flow and infiltration of contaminants down the water table
3	Weathered Layer	Resistivity Thickness	82 Ωm 13 m	11.5 Ωm 13.5 m	85%	The weathered layer is heavily leached; and contaminated and the groundwater resources are seriously under attack.
4	Fractured layer	Resistivity Thickness	- -	353 Ωm 6.5 m		The fracture layer is the water house, which is leached and, the water found here is undoubtedly contaminated.
5	Fresh basement	Resistivity Overburden	7433 Ωm 15 m	7142 Ωm 16 m	4%	The contaminant plumes from the dumpsite have little or no effect on the fresh basement rock
Number of VES in Sample point			4	15		The 4 VES stations serve as sample or controlled stations for analysis and validation

Conclusion and Recommendation

DC electrical resistivity has been successfully used to delineate the vertical extent of leachate contamination in dumpsite zones as well as fractures and subsurface contaminant pathways at the dumpsite. The Geoelectric/geologic soil profile derived suggests that the weathered basement layer which is presumably clay/silt/sand as well as the fractured basement constituted the area aquifer units. The results of the soil resistivity delineated indicate a very low resistivity across all the layers. The results have helped in the characterization of the dumpsite subsurface, which includes the dumpsite geometry, leachate plumes, and disposal trenches at the dumpsite. Consequently, the ecological and environmental contamination, and pollution, coupled with the health challenges are commonly connected to the inadequate treatment of landfill leachate. Therefore, the soil and groundwater within and around any dumpsite can migrate into the surrounding aquifer system, thereby contaminating it to a depth extent of 14 m on an average down the soil. Interestingly, the dug wells around the dumpsite fall within a depth of 5 m to 9 m. This implies that all the dug wells close to the dumpsite (between 0 m – 50) are certainly affected and are considered contaminated and declared unfit for consumption. Based on this research and the data available, the study, therefore; recommended the following:

- Active open dumpsites should be passionately discouraged
- Landfills should be discouraged in the residential area
- Landfills should be properly constructed, well piped and concreted
- Landfills should be treated regularly

- Existing open dumpsite should be evacuated
- Further geochemical tests and analysis of the soil/water of the area within and around the existing dumpsite should be done to ascertain the level of contamination and thus, treated.

Finally, while the government of every nation across the world are largely responsible to protect the properties and the lives of her citizenry, this work can help us to understand the negative impact of an active open dumpsite in any terrain, and hence adequately advise the government and the public the environmental impact of open dumpsite for proper planning in order avert likely future disasters. Minimizing the environment and human health risks that; are associated with open dumpsites across the world, proper treatment and planning of dumpsites should be taken as a serious concern for the government and individuals.

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