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 controlled station located about 200m away from the dumpsite to assess the vertical extent of leachate contamination of the dumpsite and its impact on the soil and groundwater resources. Subsurface resistivity of the dumpsite and the controlled stations were examined, which reflects the subsurface soil tolerance and the impact of the vertical extent of leachate contamination on the subsurface. The leachate infiltration may reflect the state and the quality of the groundwater. This implies that leachates from the dumpsite must have also migrated into the aquifer system, thereby contaminating the water-bearing unit.

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

1. Introduction

The rapid increase of active open dumpsites across the world, especially in Africa is becoming more worrisome because all dumpsites are usually associated with environmental and water pollution as well as health hazards [1,2]. All open dumpsites 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 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 function of hydraulic conductivity at waste dumpsites. Recent studies have shown that the deposited wastes on landfills undergo a 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 migrate to the water-bearing unit. This is because groundwater pollution usually happens as a result of the percolation of fluvial contaminants 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 the subsoil. While [7] is of the view that, natural and man-made factors are usually the cause the events that lead to soil and environmental pollution, others believe, that soil pollutants are dependent on the soil resistivity and conductivity, because the soil resistivity and conductivity are influenced by various geological factors such as 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 Cities and are situated at residential areas, markets and roadsides. According to [1, 8, 10], groundwater in cracks and fractured rocks have proven to be favourable zone for groundwater accumulation, 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, recent studies have shown that the dumpsite leachate can weaken a resistive soil, thereby paving way for contaminants to penetrate the ground easily [9, 10, 13]. Based on this fact, the vertical electrical sounding (VES) was chosen as a robust technique suitable for determining the vertical extent of leachate contamination of open dumpsites. This is because the geophysical investigation is a non-destructive means of delineating the contaminant plumes from landfills and open dumpsites. This paper assesses the effect of uncontrolled open dumpsites on soil and groundwater resources.

2. Site and Geology Description

Fig 1 shows a typical uncontrolled and active open dumpsite located at Goni-Gora, Kaduna, in the basement complex of Nigeria. The dumpsite lies on the geographical coordinates of Latitudes and longitudes 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 has been in operation for more than two decades. The landfill is an undersigned sanitary landfill that is predominant in most parts of the country. The dumpsite is estimated to contain about 56,250 m^3 of municipal solid wastes. The open dumpsite contains various wasters 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 of the Active Open Dumpsite Showing all the VES Points

2.1 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 [14 – 16]. African countries are generally hot, especially Nigeria, sitting close to the equator with temperatures varying between 24℃ - 38℃ because it directly relates 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 release of odour into the environment. Therefore, the dumpsites that are often located in complex terrain 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 to the 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.

2.2 Climatic Conditions

The hydrogeology factor plays an important role in the open dumpsites because it can influence the dumpsite leachate. Leachate influx can be influenced by the drainage system of any terrain [22]. Though, the noticeable streams around the study area all drain into the famous river

Kaduna, while the surface waters are drained directly by evaporation, infiltration, and run-off. However, 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 1500mm, and the maximum temperatures, on the other hand, varies between 24°C - 38°C, 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 have 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].

3. Dumpsite Leachate

Leachate is formed 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 tropical 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]. Landfill leachate is characterized by high biological oxygen demand (BOD) and chemical oxygen demand (BOD), which mostly consists of high concentrations of organic contaminants heavy toxic materials, ammonia and inorganic materials, metallic materials, and refractory compounds, like humic substances [14, 15, 16, 20], are contaminants of emerging concern. 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 contaminants that can be classified into four major groups, these include; 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 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.

4. Technique

An Electrical Resistivity Meter was used to acquire a total of fifteen (15) vertical electrical soundings (VES) data set using a Schlumberger array to determine the subsurface resistivity and map the vertical extent of leachate plumes contamination of a dumpsite. Another four (4) VES stations about 200 m away from the open dumpsite were investigated to serve as ~~a~~ control station for this research. Fig 2 shows the Schlumberger arrangement of the four electrodes. The electrical resistivity method works on the principle of Ohm's [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:

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

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:

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

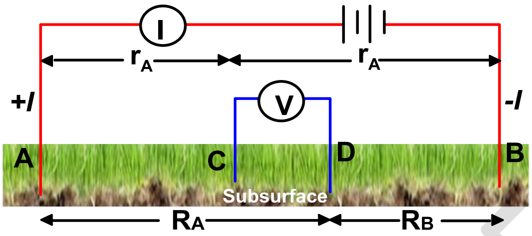

Fig. 2: Schlumberger Configuration

5. Data Processing

The first stage in the interpretation of apparent resistivity sounding curves is to note the curve type before applying *Res ID version 1.00.07* Beta software [22, 24, 30, 31]. The Micro-soft excel was used to initiate the rough idea of the expected curve after the data collected was reduced and computed. The subsurface geo-electrical data obtained from Res 1D were utilized to generate the depth sections. Fig 3 shows the resultant curve for the VES station A2 along with profile A (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].

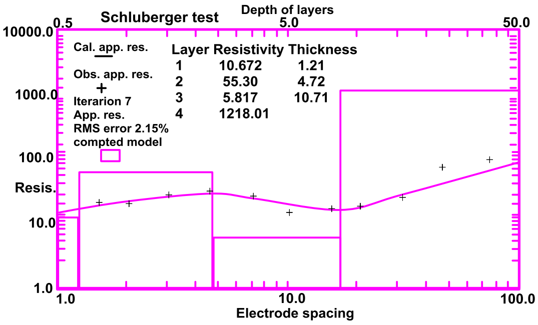

Fig. 3: Typical resistivity curves of VES **A2**

6. Results and Discussion

The model parameters obtained from *Res ID* after quantitative interpretation were further processed to generate the geo-electric/geologic profiles or soil depth sections for the study area presented in Figures 4–7. These sections according to [9, 10, 11, 25], describe the subsurface electrical properties, and the sequence of layered rocks. The geo-electrical sections are 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 200 m away from the open dumpsite. This was established to compare the results of the dumpsite with the controlled (sample) station as a means of evaluating 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 resistivity and the thickness values ranging from 674 Ωm – 1241 Ωm and 1.1 m – 2.4 m respectively. The next highly resistive indurated laterite/sand layer was found the resistivity value ranging from 2510 Ωm – 5102 Ωm. The third layer which also represents the water-bearing unit has resistivity and thickness values between 69 Ωm – 103 Ωm and 9 m – 16 m respectively. However, [8, 29, 31], noted that the regions with overburden thickness (> 12m) may likely be considered as an area with high groundwater potential, and is highly protective from the near-surface contamination. This implies that a deeper aquifer, with a highly compacted, resistive, indurate laterite and impermeable clay topsoil could be significantly protected. The bedrock is highly resistive and impermeable.

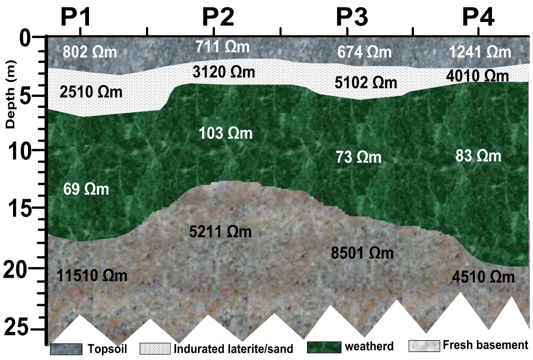

Fig 4: Geoelectric/geologic section along control Profile P (about 200 m away from the dumpsite)

b. Geoelectric/geology Section of the Dumpsite

Figures 5-7 show all the profiles taken across ~~in~~ the dumpsite. The first layer has an average resistivity and thickness values of 17 Ωm and 1.9 m respectively (Table 1), while the 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 13 m. However, the aquifer unit of the dumpsite has a very low resistivity value with ~~on~~ an average of 17 Ωm and a thickness of 15 m approximately. These resistivity values suggest leachate plumes 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 have 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.

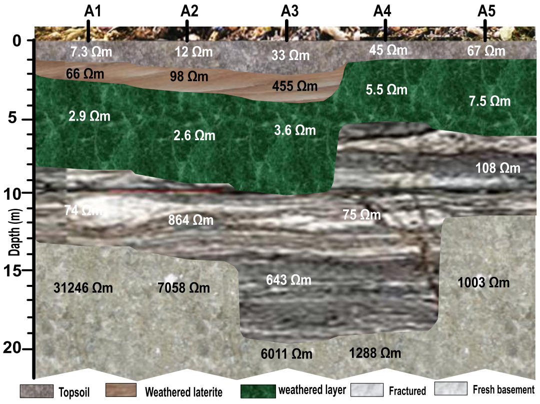

Fig 5: Geoelectric section along Profile A

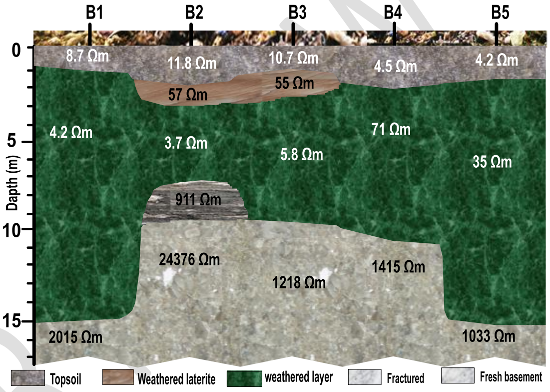

Fig 6: Geoelectric section along Profile B

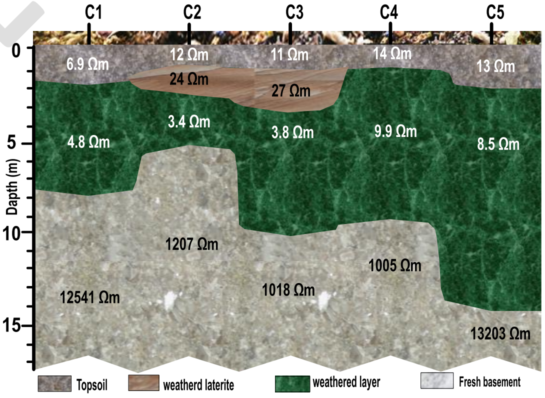

Fig 7: Geoelectric section along Profile C

c. Percentage of Leachate Leach Estimation

The percentage of the leachate leach (leached percentage) was estimated using percentage error or defect. We consider the values of the subsurface layered resistivity obtained from the controlled station as an ideal/true value, while the one obtained at the dumpsite was considered an observed value. The magnitude of the difference between the true and observed values is called the defect value. Thus, the leached percentage can be expressed by equation (iv):

$$\%leached = \frac{V_T - V_O}{V_T} \times 100 \qquad \text{(iv)}$$

Where:
V_0 = Resistivity value at the dumpsite
V_T = Resistivity value at controlled station

d. 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 may have severely contaminated the soil and groundwater resources. Table 2 shows a comparative assessment between the active open 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 at the dumpsite have leached down to at least 14 m depth. This implies that; the soil and groundwater resources of the active open dumpsite must have undergone severe impact. 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].

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

Layers	**Soil Profile**	**Average Parameters**	**Control Station**	**Dumpsite**	**% leachate Leached**	**Observations**
1	Topsoil	Resistivity Thickness	857Ωm 1.8 m	17 Ωm 1.9m	98%	Topsoil has been extremely leached, and thus contaminated
2	Indurated laterite	Resistivity Thickness	3686 Ωm 1.5 m	126 Ωm 1.6 m	97%	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	86%	The weathered layer is heavily leached; and contaminated and the groundwater resources are seriously impacted
4	Fractured layer	Resistivity Thickness	Not exists -	353 Ωm 6.5 m		The fracture layer which is the water house has been impacted
5	Fresh basement	Resistivity Overburden	7433 Ωm 15 m	7272 Ωm 16 m	2%	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 controlled stations for analysis and validation

7. 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 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. Therefore, the groundwater within the dumpsite much have migrated into the surrounding aquifer system, thereby contaminating it. The dug wells around the dumpsite fell within a depth of 5 m to 9 m. This implies that all the dug wells close to the dumpsite (between 0 m – 50) much have been impacted, contaminated and may be 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, the leachate from the open dumpsite has impacted the groundwater of the study based on the geophysical investigation. Therefore, further geochemical studies within and around the study area should be carried out to evaluate the level of the groundwater resource to minimize the environmental and human health risks associated with open dumpsites across the world. Hence, proper treatment and planning of dumpsites should be taken as a serious concern for the government and individuals.

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