

**ASSESSMENT OF THE PROBLEMS AND MANAGEMENT OF DUMPSITE  
LEACHATE: IMPLICATIONS FOR SUSTAINABLE LEACHATE MANAGEMENT  
AT LEMNA DUMPSITE CALABAR, NIGERIA**

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**ABSTRACT**

Dumpsite leachate remains one of the most critical environmental challenges in rapidly urbanizing cities, particularly in developing countries where open dumping persists as a major solid waste disposal method. This study investigated the assessment of the problems and management of dumpsite leachate as an implication for sustainable leachate management at Lemna Dumpsite Calabar, Nigeria. An integrated approach was adopted, combining geophysical surveys, air quality monitoring, and laboratory treatment trials. Electrical resistivity imaging and vertical electrical sounding (VES) were employed to delineate leachate plume migration and assess subsurface contamination. Air quality was monitored over morning, afternoon, and evening periods, focusing on temperature, relative humidity, particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>), formaldehyde, total volatile organic compounds (TVOCs), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), and hydrogen sulfide (H<sub>2</sub>S), benchmarked against World Health Organization (WHO) and Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA) guidelines. Laboratory experiments tested the effectiveness of alum and ferric chloride, with granular biochar, at varying doses to evaluate removal efficiency (RE%) of turbidity, chemical oxygen demand (COD), biochemical oxygen demand (BOD), H<sub>2</sub>S, and total coliforms. Geophysical results revealed that the leachate plume extended laterally from 30 m to 70 m and vertically down to 8–12 m, with resistivity values as low as 1.14 Ωm, indicating significant leachate infiltration into both shallow and deep subsurface zones. Air quality analysis showed severe exceedances of safety standards, with PM<sub>2.5</sub> (126.11 µg/m<sup>3</sup>) and PM<sub>10</sub> (187.60 µg/m<sup>3</sup>) exceeding WHO limits fivefold and threefold, respectively. Carbon dioxide concentrations (3570.10 ppm) were more than three times the acceptable limit, while H<sub>2</sub>S levels (45.35 mg/m<sup>3</sup>) far exceeded both WHO and NESREA standards, indicating high-risk gaseous emissions from the dumpsite. The Air Quality Level (AQL) classified the site as “very serious” throughout the monitoring period. Treatment trials demonstrated that biochar significantly enhanced the coagulation efficiency of alum and ferric chloride. The optimal performance was recorded at 120 mg/L of either alum or ferric chloride combined with 30 mg/L biochar, achieving maximum removal efficiencies across all tested parameters. Aeration further improved reductions in volatile compounds and microbial contaminants. The findings indicate that biochar-enhanced coagulation be adopted as a cost-effective and sustainable treatment option prior to leachate discharge and on the dumpsite to eliminate odor nuisance in surrounding environments.

## 1. INTRODUCTION

Open dumpsites remain one of the most pressing environmental challenges facing many developing countries, particularly in Sub-Saharan Africa. In Nigeria, the indiscriminate disposal of municipal solid waste in unmanaged or poorly managed dumpsites has resulted in a myriad of environmental and public health problems. Among the most serious consequences of this practice is the generation of dumpsite leachate a highly contaminated liquid that results from the percolation of water through decomposing waste materials. The Lemna dumpsite, located in Calabar, Cross River State, exemplifies the typical open dumpsite scenario where inadequate waste handling and the absence of modern engineering designs for leachate containment have led to widespread environmental degradation and potential threats to human health.

The Lemna dumpsite was established over a decade ago as a temporary waste disposal site for Calabar metropolis, but it has since evolved into the primary receptacle for both domestic and commercial solid waste without any major infrastructural upgrades. With the growing urban population and increasing consumption patterns in Calabar, the volume and heterogeneity of waste entering the dumpsite have risen significantly. Plastic materials, household refuse, food remnants, industrial waste, and even biomedical discards are now common at the site, intensifying the complexity of leachate composition and treatment.

Leachate is a toxic effluent rich in organic and inorganic compounds, heavy metals, pathogenic microorganisms, and other pollutants that pose significant risks to the environment (Igelle, et al., 2024; Igelle, et al., 2024; Igelle, et al., 2024). Once generated, leachate migrates into surrounding soils, surface water bodies, and groundwater aquifers, thereby contaminating critical environmental media

and threatening ecological balance. In the Lemna dumpsite, situated within a peri-urban setting, the proximity to residential neighborhoods, farmlands, and surface water sources raises major concerns regarding air pollution by Sulphide ( $S^{2-}$ ), water, and soil pollution, especially during the rainy season when leachate production intensifies due to increased percolation.

Sulphide ( $S^{2-}$ ) refers to a chemical ion or compound in which sulphur exists in the minus two oxidation state. Sulphide ions often arise from the anaerobic decomposition of sulphate containing wastes by sulphate-reducing bacteria. A notable property of sulphides is their reaction with acids, which leads to the release of hydrogen sulphide ( $H_2S$ ) gas. This gas is easily recognized by its characteristic foul odor, often described as resembling rotten eggs, and it is also highly toxic even at relatively low concentrations. Therefore, the presence of sulphide in leachate not only indicates ongoing biochemical activity but also poses potential risks of toxicity and odor nuisance in surrounding environments (Greenwood & Earnshaw, 2012).

Residents living near the Lemna dumpsite have often complained of unbearable odors resembling rotten eggs a likely indication of the presence of hydrogen sulfide and other volatile organic compounds emitted from anaerobic decomposition and leachate volatilization. In addition to the foul odor, the leachate seeps into open drains, stagnant water bodies, and sometimes agricultural plots, posing direct and indirect threats to human and ecosystem health (Igelle, *et al.*, 2024; Igelle, *et al.*, 2024; Igelle, *et al.*, 2024). This condition is further exacerbated by the absence of a leachate treatment facility at the dumpsite, as well as inadequate policy enforcement and limited environmental monitoring.

The environmental implications of leachate are multifaceted. In soils, leachate causes acidification, alters nutrient dynamics, and accumulates heavy metals

that can reduce soil fertility and crop productivity. In water bodies, it promotes eutrophication, depletes dissolved oxygen, and introduces microbial pathogens that endanger aquatic life and public health. Furthermore, airborne pollutants emanating from leachate and the decomposing waste mass contribute to atmospheric pollution and respiratory ailments among nearby populations. These intersecting pathways of pollution underline the importance of an integrated assessment that considers the air, soil, groundwater and leachate treatment.

Sustainable leachate management requires adoption of cost effective, eco-friendly, and socially acceptable treatment method that are suitable for the local context. Globally, advanced leachate treatment methods such as activated carbon adsorption, membrane filtration, constructed wetlands, and anaerobic biological treatments, aerobic biological treatments have been widely employed with considerable success. However, these technologies are rarely deployed in Nigerian dumpsites due to high capital and operational costs, lack of technical expertise, and limited political will to deal with the effects and management of dumpsite leachate.

Nevertheless, there are few studies on the issues of leachate pollution and treatment in Calabar dumpsite. Eni, Obiefuna and Oko (2011), assess the impact of urbanization on subsurface water quality in Calabar municipality. The study assessed the vulnerability of borehole located close to Lemna dumpsite in Calabar Municipality. Borehole water samples were collected from ten designated boreholes and their physicochemical parameters were analyzed. The length, breadth and depth of the landfill were measured with a tape and meter rule. The length of the landfill was 960m, the width 430m and the depth 180m. Geographical positioning system (GPS) was used to obtain the static water level from where the groundwater flow map was

deduced. Parameters such as BOD, DO, Fe<sup>2+</sup>, Ni<sup>2+</sup>, Zn<sup>2+</sup>, faecal and total coliform count values when compared with world health organization standard (WHO) were seen to exceed the recommended value. The research revealed that groundwater flow from the North to South, carrying along with it dissolved waste materials and leachates which infiltrates into the borehole water and contaminates it, thereby rendering it unsuitable for drinking and domestic use. Inah, Obiefuna, Etuk, and Iwuanyanwu (2023) investigated the effects of leachate on both surface and groundwater quality in the Lemna District of Calabar Municipality, Cross River State, Nigeria. Water samples were obtained from surface and groundwater sources and subjected to physico-chemical and bacteriological analyses. The average values of the analyzed parameters were: pH = 6.2, electrical conductivity = 63.38, temperature = 24.43°C, BOD = 1.08 mg/L, DO = 5.35 mg/L, and zinc = 0.08 mg/L. Additional results included coliform count = 166.00, turbidity = 24.50 NTU, lead = 0.097 mg/L, and total hardness = 30.73 mg/L. Statistical evaluation showed significant differences between the observed values of BOD, DO, coliform, zinc, iron, turbidity, potassium, nitrate, copper, total hardness, and sodium when compared to the WHO's recommended limits. The study concluded that leachate has had a considerable impact on both surface and groundwater in the area. It recommended that open dumpsites should be located at a safe distance from water bodies and aquifers used for domestic purposes. It also emphasizes the need for proper treatment of dumpsite leachate, to prevent environmental contamination and protect public health (Inah, Obiefuna, Etuk, & Iwuanyanwu, 2023).

However, this study focuses on the assessment of the problems and management of dumpsite leachate as an implication for sustainable leachate management at Lemna Dumpsite Calabar, Nigeria, and advance in knowledge on leachate treatment to

eliminate odor nuisance. The treatment of sulphide ( $S^{2-}$ ) in environmental systems is highly significant because uncontrolled sulphide accumulation poses serious ecological and public health risks. In waste disposal sites, dumpsite leachates, sulphide ions can react with acids to release hydrogen sulphide ( $H_2S$ ) gas, which is toxic, corrosive, and has a characteristic rotten egg odor.  $H_2S$  is not only harmful to human health, even at low concentrations, but also contributes to air pollution and odor nuisance in surrounding environments.

## 2. STUDY AREA

The Calabar dumpsite is situated at latitude  $5^{\circ}2'1.040928''$  N and longitude  $8^{\circ}21'55.727856''$  E. The dumpsite spans a surface area of approximately  $37,943$  m<sup>2</sup> (Fig 1) and lies at an elevation of around 24 m above sea level (Igelle *et al.*, 2024). The geology of the study site is dominated by an aquifer system that is recharged by high rainfall. The aquifer is confined with a few aquicludes and contains two principal water-bearing zones. The upper aquifer, which is more prone to contamination from surface activities, and the lower aquifer, which is relatively better protected. While the lithological profile of the dumpsite comprises top-soil, coarse sand and medium sand within the subsurface layers.

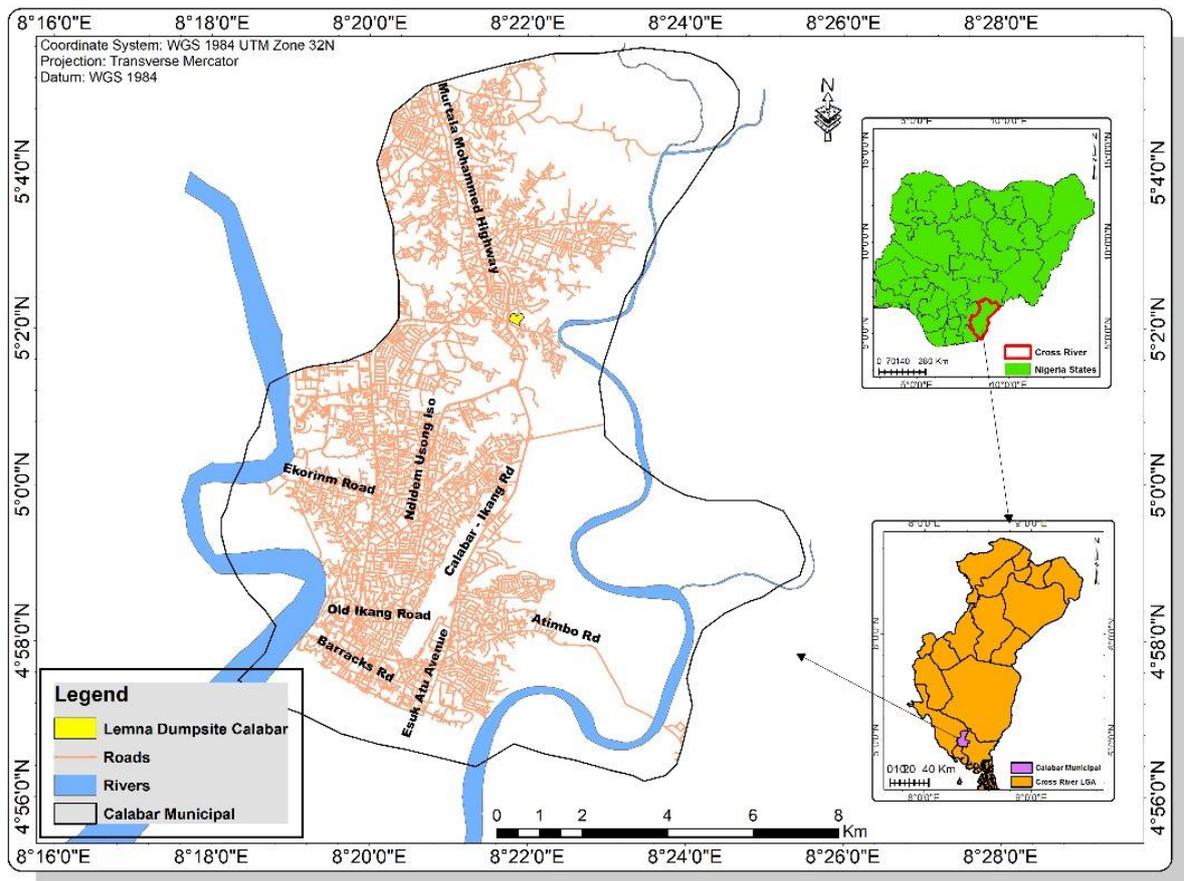


FIG 1: Cross River State showing location of dumpsites in the study area

Source: Author's Analysis (2025).

## 3. METHODOLOGY

### 3.1 Soil sample collection

Geographical Positioning System (GPS) was used to locate sampling points. Samples were collected using a hand-held auger. Soil samples were collected at a depth ranging from 0 cm to 30 cm. Soil samples were collected between 1m and 50m from the dumpsite. The three points at each sampling position were as follows: entry point within 5 m from the dumpsite, middle point (25 m away from the dumpsite), and exit point (50 m away from the dumpsite). About nine soil samples were collected randomly in and around the dumpsite. Control soil samples were collected about 1 km away from the experimental dumpsite. The soil samples were transferred from the auger to sampling bags, which were sealed and marked. The samples were stored in a cold box at 4°C and taken to the laboratory for physicochemical parameter analysis.

### 3.2 Water sampling collection

The water sample area was within a 300-500 meter buffer zone. Control water samples were collected from about 1 km away from the experimental borehole, where there was no dumpsite. Water samples were purposively selected from five boreholes close to Calabar and one control point, within 300-500m and outside the buffer zone. The water sources were purposively selected because they were close to the dumpsites and served as the major water supply sources for the inhabitants around the study area. The inhabitants of the study area carried out their daily activities using these water sources.

Before sample collection, all plastic bottles were washed with dilute nitric acid, followed by distilled water, and rinsed. Then, dried containers were rinsed with the water to be collected (borehole water) before the respective water samples were collected.

After the collection of water samples at each sampling point, the plastic containers were properly labelled with the dates accordingly. The collected samples were stored in a cold box at 4°C and taken to the laboratory for analysis.

### 3.3 Electrical Resistivity Tomography of the soil

The Wenner array, one of the most widely used configurations (Wenner, 1916), will be employed in this study. The array will consist of four electrodes (C1, P1, P2, C2), which will be placed along a straight line symmetrically at point 'O' on the ground surface. The electrodes will include two current electrodes and two potential electrodes. Electrical resistivity measurements will be taken at 5-unit increments of electrode spacing, and measurements will be conducted across the dumpsites at low elevations. The use of 2D ERT was selected for its ability to generate horizontally extensive subsurface images (>100 m) with high resolution (Chambers et al., 2011). These images will provide visual insights into resistivity variations within the shallow subsurface, assisting in the interpretation of geological structures and patterns. The configuration is given as follows;

$$2 \pi a \times R = \rho_{aw} \dots\dots\dots(1)$$

Where:

$\rho_{aw}$  = Apparent resistivity ( $\rho_{aw}$ )

2 Current electrodes A-B=C1-C2

2 Potential currents M-N=P1-P2

R = Apparent Resistance) (ohms)

$\pi = 3.14$

a = The distance between the source and the point (pair of electrodes)



# Electrical Resistivity Methods

## Part 1: The Wenner Array

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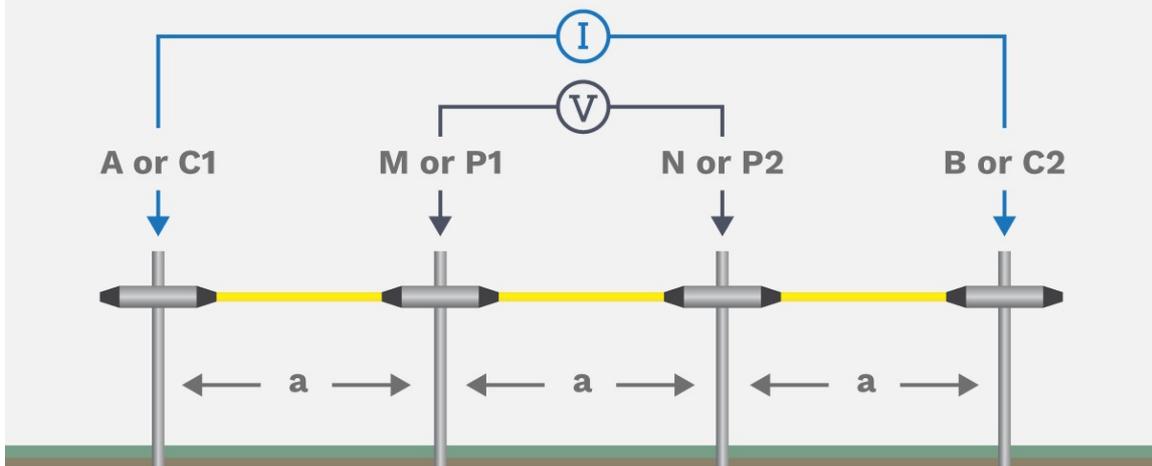


FIG 2: WENNER ELECTRICAL RESISTIVITY PROFILLING Source: (AGI, 2025a, AGI, 2025b).

### 3.4 Vertical Electric Sounding of the soil

VES, using the Schlumberger method, will be conducted to investigate vertical changes in resistivity. The Schlumberger method is sensitive to vertical variations and offers a reliable resolution at greater depths (Loke, 2003). In this method, four electrodes (A, M, N, B) will be arranged along a line with the Center fixed, while electrode spacing will be gradually increased from 5 meters to several tens of meters (Badrinarayanan, Sundara Moorthy, & Jawahar, 2022). Current will be passed through the outer electrodes (A, B), and the potential difference will be measured across the inner electrodes (M, N). The

configuration factor for Schlumberger array is given as;

$$K = \frac{\pi}{4} \frac{L^2 - a^2}{2} \dots\dots\dots(2)$$

The apparent resistivity calculated formula is given as:

Where:

a = The distance between the potential electrodes (M, N)

L = The distance between the current electrodes (A, B)

$\pi = 3.14$

$\rho = K \cdot R$

K = Configuration factor for Schlumberger array

R = Resistance (ohms)

$\rho$  = Apparent Resistivity (ohm-m)



# Electrical Resistivity Methods

## Part 2: The Schlumberger Array

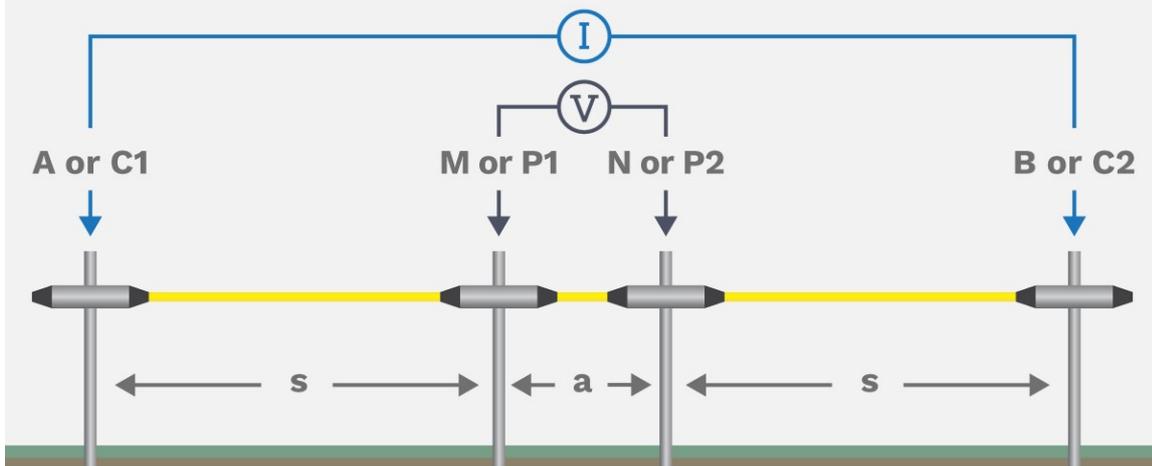


FIG 3: SCHLUMBERGER VERTICAL ELECTRIC SOUNDING (VES) (source: AGI, 2025a, AGI, 2025b).

### 3.5 Longitudinal Conductance

Longitudinal conductance was used to evaluate the VES data. It rates the vulnerability of the aquifer to pollution. First-order geo-electric parameters obtained from the iteration are used to develop the second-order geo-electric parameters or the Dar Zarrouk parameters (Aladesanmi, Mohammed, Ayinuola & Okunade, 2014). The second-order parameter of interest is the longitudinal unit conductance (Si). Longitudinal conductance Si, is derived by hi, the thickness of the aquifer; pi, apparent resistivity and n, the number of layers. The longitudinal conductance is used to predict the protective capacity of the aquifer in an area. It is rated from excellent to poor capacity. Longitudinal conductance is rated as excellent >10, very good 5-10, good 0.8-4.9, moderate 0.2-0.79, weak 0.0-0.19 and poor <0.1 (Akiang, Emujakporue & Nwosu, 2023). Longitudinal conductance was used to predict the aquifer protective capacity rating. The formula is given as follows;

$$S = \frac{h_1}{p_1} + \frac{h_2}{p_2} + \frac{h_3}{p_3} + \frac{h_4}{p_4} + \frac{h_5}{p_5} + \dots + \frac{h_n}{p_n} = \sum_{n=1}^n \left( \frac{h_i}{p_i} \right) \dots \dots \dots (3)$$

S= Longitudinal conductance  
 hi= Thickness of the aquifer  
 pi= Apparent resistivity  
 n= layers

### 3.6 Air quality sampling

The air quality of the dumpsite was measure using a portable air quality sensor 1 in 9AQM. The Air quality parameters includes Carbon monoxide, Volatile Organic Compound (VOC), Temperature, Relative Humidity, Particulate matter PM 2.5, Particulate matter PM10, HCHO, and Hydrogen sulfide (H<sub>2</sub>S). Air quality data readings were taken in the morning, afternoon and evening for 5days at 10 am, 1p m and 6 pm. Each parameter was measured three (3) times a day for 5days. This is to get a representative of the day air quality of the dumpsite.

### 3.7 Leachate samples collection

Leachate samples were collected directly from the discharge points of the

dumpsite using a grab sampling technique, following the procedures outlined in Standard Methods for the Examination of Water and Wastewater (American Public Health Association APHA, 2017). Prior to sampling, 1-Litter high-density polyethylene (HDPE) bottles were washed with detergent, rinsed with distilled water, and soaked in nitric acid for 24 hours to avoid contamination. Each bottle was finally rinsed three times with the leachate to be sampled before collection. Samples were collected at different points within the dumpsite drainage to obtain representative leachate characteristics. The bottles were filled without leaving headspace to minimize oxidation and volatilization. Immediately after collection, the samples were stored in ice-packed coolers at approximately 4 °C and transported to the laboratory for physicochemical and bacteriological analysis within 24 hours.

### **3.8 Laboratory Analysis of Heavy Metals in Soil and Borehole Water**

The laboratory analysis of heavy metals in soil and borehole water samples was conducted using an Atomic Absorption Spectrometer (AAS). Soil samples were first dried in an electric oven at 100°C for two hours, ground with a hand mill, and sieved using a 75 µm mesh to ensure homogenization. A 1 g portion of the dried soil was digested by adding 150 ml of hydrochloric acid (HCl) and 5 ml of nitric acid (HNO<sub>3</sub>), followed by heating in a sandy bath for 60 minutes. After cooling, 5 ml of HCl and 50 ml of distilled water were added to wash the sides of the container. The sample was heated to boiling for 3 minutes, filtered, and collected in a 100 ml container for further analysis.

For water samples, 1 ml of nitric acid was added to 100 ml of water, filtered, and stored at 4°C until analysis. Concentrations of heavy metals, including Ar, Hg, Pb, Cd, Cr, and Ni, in both soil and water samples, were measured using AAS, with a calibration procedure conducted beforehand

using multi-elemental standard solutions at a concentration of 100 mg/l.

### **3.9 Laboratory Analysis of BTEX in Soil and Borehole Water**

In the analysis of BTEX (Benzene, Toluene, Ethylbenzene, and Xylene) in soil and borehole water, 5 g of soil was mixed with 2 g of anhydrous sodium sulfate (Na<sub>2</sub>SO<sub>4</sub>), and 50 ml of methanol was added and stirred for 20-30 minutes for extraction. A syringe cartridge, conditioned with 5 g of silica gel and rinsed with methanol, was used for silica gel clean-up, and the eluent was collected in a 25 ml volumetric flask. An additional 5 ml of methanol was used to remove any remaining BTEX, and the final extract was transferred to autosampler vials.

For water samples, 50 ml of methanol was added to 100 ml of water, stirred for 20-30 minutes, and prepared for analysis. Calibration was performed using standard solutions diluted to 100 mg/l, following established methods (Biose & Ogbewi, 2017; USEPA, 2017).

### **3.10 Laboratory Analysis of Physicochemical and Bacteriological**

The laboratory analysis measured several key physicochemical and bacteriological parameters. To determine turbidity, a turbidity meter was used, which measured the cloudiness of water caused by suspended particles, providing results in Nephelometric Turbidity Units (NTU) (American Public Health Association APHA, 2017). The Kobold Turbidity Probe ATL-F is a high-precision, single channel absorption probe. The probe uses the light in the visible (VIS) range at a selected wavelength of 430 nm. An optical filter on the lamp side adapts the wavelength for specific applications and allows colour measurements with great accuracy.

For Chemical Oxygen Demand (COD), a COD thermoreactor CR 2200 and colorimeter YSI 910 COD colorimeter were employed to measure the intensity of colour formed after the digestion of organic matter

with potassium dichromate, a strong oxidizing agent, following standard protocols (ASTM 2015). In the experimental procedure, the digestion of the leachate samples for Chemical Oxygen Demand (COD) analysis was carried out using potassium dichromate ( $K_2Cr_2O_7$ ) as the strong oxidizing agent, in accordance with standard methods (American Society for Testing and Materials ASTM, 2015). The concentration of potassium dichromate used during the digestion process was 1,500 mg/L. In addition to potassium dichromate, sulfuric acid ( $H_2SO_4$ ) was used to provide the necessary acidic conditions for the oxidation of organic matter in the sample. The typical concentration of sulfuric acid used was 1:1 (v/v) for the digestion process.

Biochemical Oxygen Demand (BOD) was determined using a BOD incubator, which maintained the sample at a controlled temperature of 20°C for 5 days, and a BOD meter OxiDirect RS 232, which measured the oxygen consumed during microbial degradation of organic materials (APHA, 2017; ASTM, 2015; Eni, & Igelle, 2019).

Sulfide ( $S^{-2}$ ) concentrations were analyzed using a gas chromatograph GC-7860D, which separated and quantified the concentration (ASTM 2015; Parham, 2013).

The Total Coliform Bacteria concentration was measured using a membrane filtration system, which filtered a (100 mL) volume of water, trapping bacteria that were then cultured on selective agar and counted as Colony Forming Units (CFU/mL) (APHA, 2017; International Standard Organization ISO, 2014). For the membrane filtration, a specific volume of the leachate sample (100 mL) was filtered through a 0.45  $\mu m$  membrane filter, which was then placed on a Agar Medium. The samples were incubated at 35°C for 24-48 hours to allow bacteria to grow, and the colonies formed were counted and converted to Colony Forming Units (CFU/mL). pH levels were assessed using a pH meter PHM-

W-301, which measured the acidity or alkalinity of the leachate (APHA, 2017), while the temperature was monitored using a digital thermometer to maintain the desired experimental conditions (APHA, 2017).

### 3.11 Experimental Design for Dumpsite Leachate Treatment

The experimental design is expected to adopt coagulant method using aluminium sulphate (alum) and ferric chloride (chlorine) with accelerator substance granular biochar. Granular biochar is a reliable Sulphide ( $S^{-2}$ ) adsorbents which can adsorb high capacity Sulphide (Schlumberger, 2016). Sulphide ions can be immobilized on the biochar surface, reducing their solubility and preventing the release of hydrogen sulphide ( $H_2S$ ) gas, which is toxic and malodorous. The experiment will examine the optimum doses for granular biochar as accelerating substances for Aluminium sulphates (alum) and ferric chloride (chlorine) in 1 litter dumpsite leachate sample. The measurement parameter for detecting the removal of pollutants is the physicochemical and bacteriological parameters. These parameters help in indicating the presence of impurities in water. The experimental design are as follows,

#### First experiment doses

- i. Leachate sample will be kept between 28-30 °C for 4days in aerobic condition
- ii. A rapid mixing rate of 350 rapid mixing (rpm) for 3min and followed by 3hrs settling time and filtration.
- iii. Adding alum doses of 40, 90,100 and 120 mg/l to the sample and maintaining a temperature of 28-30 °C and maintain pH at 5-7.
- iv. Filtration
- v. Adding granular biochar doses of 5, 10, 20 and 30mg/l to the sample allowed for 4 hours
- vi. Allow aeration to take place

### Second experiment doses

- i. Leachate sample will be kept between 28-30 °C for 4 days in aerobic condition
- ii. A rapid mixing rate of 350 rapid mixing (rpm) for 3 min and followed by 3 hrs settling time and filtration.
- vii. Adding ferric chloride (chlorine) doses of 40, 90, 100 and 120 mg/l to the sample and maintaining a temperature of 28-30 °C and maintain pH at 5-7.
- iii. Filtration
- iv. Adding granular biochar doses of 5, 10, 20 and 30 mg/l to the sample and allowed for 4 hours
- v. Allow aeration to take place

$$RE = \frac{C_{Lb} - C_{La}}{C_{Lb}} \times 100 \dots \dots \dots (4)$$

RE = Removal efficiency percentage of dumpsite leachate constituent  
C<sub>Lb</sub> = Concentration of dumpsite leachate constituent before treatment  
C<sub>La</sub> = Concentration of dumpsite leachate constituent after treatment

### 3.12 Sampling Size

The population sample comprised people living close to dumpsites in Calabar. The formula was used to determine the sample size (Yamane, 1967). The formula is given as:

$$n = \frac{N}{1 + N(e)^2} \dots \dots \dots (5)$$

Where:

n = Sample Size

N = Population

e = Margin of Error (0.05)

The sampled population and the dumpsite location were purposively selected. The population sample size was 399 people living very close to refuse dumpsites in the study area. A total sample size of 392 was returned and used for the study.

### 3.13 Instrument for Data Collection

The study utilized the questionnaire as its research instrument. The questionnaire was divided into sections A, B and C section. Section A comprised of the demographic characteristics; section B comprised of the problems of dumpsite leachate; and section C comprised of dumpsite leachate management strategies. The respondents are required to indicate their opinion on each item of the question based on a five-point Likert scale of Strongly Agree (SA) 1, Agree (A) 2, undecided (U) 3, Disagree (D) 4, Strongly Disagree (SA) 5. The Likert scaling means value within ( $\bar{x}=1$ ) indicates that the respondents strongly agreed, within ( $\bar{x}=2$ ) agreed, within ( $\bar{x}=3$ ) undecided, within ( $\bar{x}=4$ ) disagreed and within ( $\bar{x}=5$ ) strongly disagreed respectively. The researcher with the help of three (3) research assistants administered the questionnaire.

The instruments used for soil samples collection include an Auger and sampling bags, a cooler with ice blocks at 4°C. Allied Associates Geophysical Ltd Ohmega 0191 equipment was used to determine the resistivity and Global Positioning System (GPS). Instruments used for borehole water sample collection and analysis include plastic containers, a cooler with ice blocks at 4°C.

### 3.14 Validation

The questionnaire was distributed to professionals in waste management and geology for review and validation. Two experts in Environmental Management and one expert in geology validated the questionnaire. A total of 14 questions were validated. The reliability test was used to validate the instrument. The Cronbach's alpha was used to test the instrument by comparing the amount of shared variance, among the items making up an instrument to the amount of overall variance. This means testing the reliability of the cell's mean and the total observations in the cells. Cronbach's alpha was used to test the internal

consistency of the items. It shows how closely related a set of items are as a group. It is considered to be a measure of scale reliability. If the instrument is reliable, there

will be a great deal of correlation among the items and the level of significance will be  $<0.05$  at a 95% confidence level.

## 4 RESULTS

### 4.1 Delineate and identify the dumpsite locations

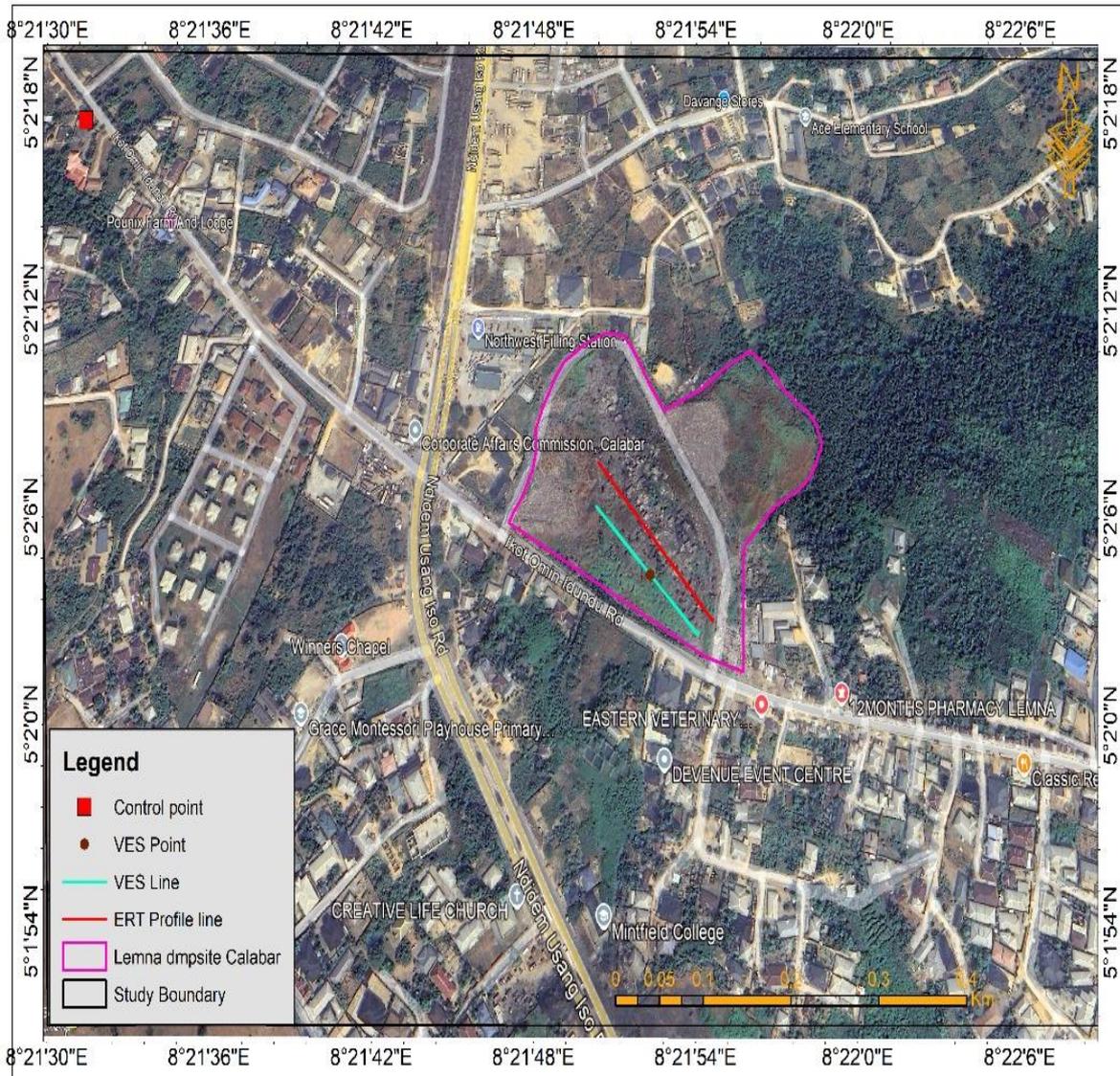


FIG 4: Aerial Photo of the Dumpsite  
Source: Author's Analysis (2025).

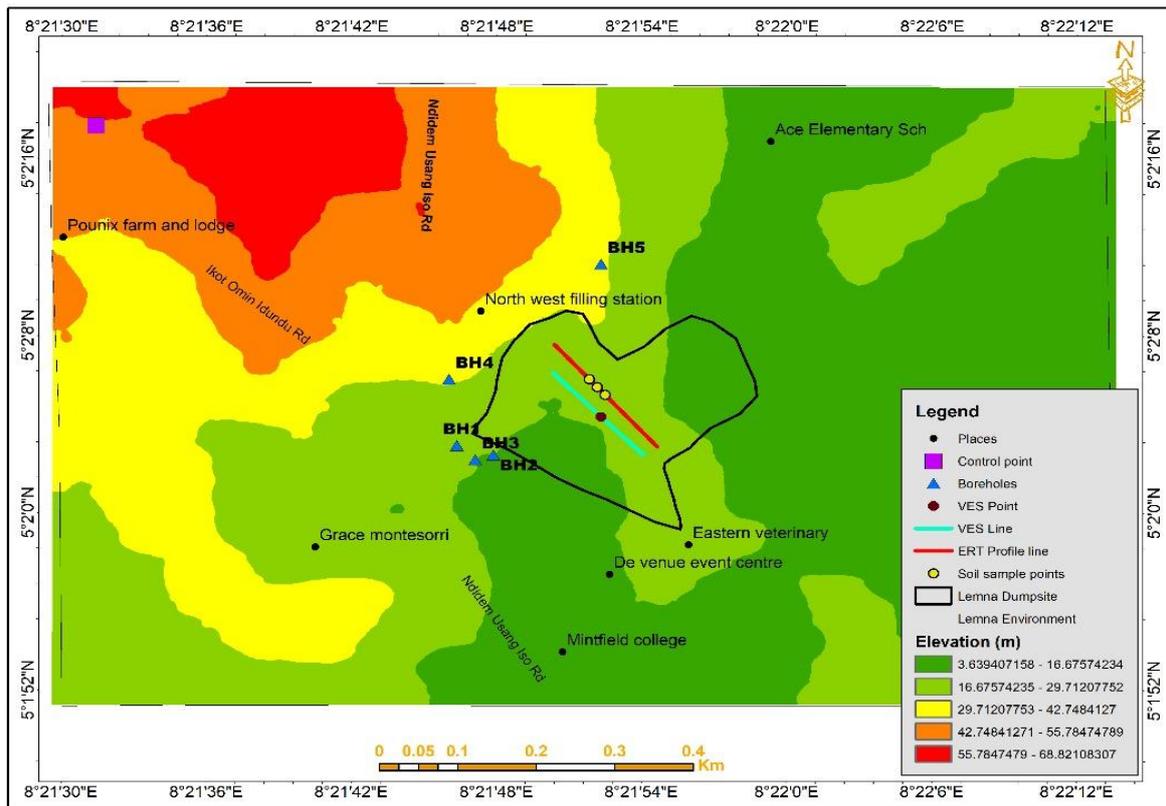


FIG 5: ERT and VES points of the dumpsite in the study area  
Source: Author’s Analysis (2025).

Analysis of the dumpsite characteristics in Calabar Municipal shows that the dumpsite is located at an elevation of 24 meters above sea level. The dumpsite has an estimated surface area of 37,943 m<sup>2</sup>, indicating a large and potentially unmanaged waste accumulation zone. The proximity assessment reveals that the dumpsite is located approximately 42.82 meters from the nearest borehole.

The dumpsite is located 881.3 meters away from the nearest water body, placing it within the moderately suitable range and reducing the immediate risk of surface water pollution. The site has a slope range between 5° and 8°, which falls within the moderately suitable category, suggesting minimal risk of erosion or waste wash-off. However, the

dumpsite is situated only 5.66 meters from the nearest road, which is considered unsuitable due to potential hazards such as odor, litter dispersion, and traffic safety issues. Distance to the nearest residential area is 17.88 meters, also unsuitable according to standard environmental guidelines, as it exposes residents to health risks from air pollution, insects, vectors, and noise. Soil type is alluvial, which is highly permeable and therefore unsuitable for waste disposal due to a high risk of leachate percolation into groundwater. The site is underlain by siltstone geology, classified as unsuitable because it has low permeability but poor structural stability, increasing the likelihood of contamination retention.

Table 1: Characteristics of the location of dumpsites environment of the study location

Dumpsites	Type of Environment	Description	Suitability classes
Calabar	Distance to Water Body	881.3m	Moderately suitable
	Slope	5 <sup>0</sup> - 8 <sup>0</sup>	Moderately suitable
	Distance to Road	5.66m	Unsuitable
	Distance to residential Area	17.88m	Unsuitable
	Soil types	Alluvial soil	Unsuitable
	Geology	Siltstone	Unsuitable

\*=Exceeded NESREA guideline limit; ND=Note Detected;  
Source: Researcher's Analysis (2025).

#### 4.1 Soil vulnerability to leachate contamination of the study location

The results of the laboratory analysis of soil heavy metals and BTEX in Calabar dumpsite is presented in (Table 2). The soil indices tested include Arsenic, Lead, Cadmium, Chromium, Nickel, Mercury, Benzene, Toluene, Ethylbenzene and Xylene for all the soil locations. Lead, Arsenic, Cadmium, Benzene and Ethylbenzene concentrations at all three distances (5m, 25m, and 50m) are extremely

high, significantly exceeding the values recommended in NESREA guideline limits. While Toluene at 25m and 50m distances were higher than the NESREA. Xylene, Mercury, Nickel and Chromium were below NESREA limit (Table 2). The contamination of the soil with heavy metals and BTEX may be due to the type of waste at the dumpsite which may comprise of substances and typical pollutants in dumpsite. The contamination may also be due to the soil porosity.

Table 2: Results of soil heavy metals and BTEX around Calabar dumpsite

	Unit	5m	25m	50m	NESREA
Parameters					
Lead	(mg/kg)	688.23*	684.16*	682.42*	164
Mercury	(mg/kg)	0.074	0.081	0.075	4
Arsenic	(mg/kg)	45*	44*	42*	20
Cadmium	(mg/kg)	15.82*	15.64*	15.37*	3
Chromium	(mg/kg)	94.62	98.31	96.72	100
Nickel	(mg/kg)	27.74	25.69	24.82	70
BTEX					
Benzene	(mg/kg)	1.36*	1.34*	1.32*	0.1
Toluene	(mg/kg)	0.017	1.019*	1.016*	0.1
Ethylbenzene	(mg/kg)	1.28*	1.25*	1.26*	0.1
Xylene	(mg/kg)	0.018	0.016	0.014	0.1

\*=Exceeded NESREA guideline limit; ND=Note Detected;  
Source: Researcher's Analysis (2025).



#### 4.2 Quality of borehole water in proximity to dumpsite of the study location

The result of the laboratory water quality analysis of the Borehole (BH) water around Calabar dumpsite is presented in (Table 3). The water quality indices tested were Arsenic, Lead, Cadmium, Chromium, Nickel, Mercury, Benzene, Toluene, Ethylbenzene and Xylene for all the boreholes. The water quality analyses of BH2, BH3 BH5 and BH6 around the Calabar Dumpsite revealed elevated concentrations

of Arsenic, Lead, Cadmium, Nickel and Benzene exceeding the established limits of the World Health Organization (WHO). Additionally, the presence of Ethylbenzene in BH2 was found to surpass the regulatory limits set by WHO. Although, the concentrations of heavy metals in BH 4 were lower than the guideline limit of WHO. The contamination of the boreholes may be due to the unsuitability of the soil porosity and unsuitable geology in the dumpsite.

Table 3: Results of heavy metals and BTEX for boreholes around Calabar dumpsite

Parameter	Unit	Sample codes					
		BH2	BH3	BH4	BH5	BH6	WHO
Arsenic	(mg/l)	0.074*	0.062*	0.0032	0.048*	0.039*	0.01
Lead	(mg/l)	0.991*	0.832*	0.0006	0.21*	0.28*	0.01
Cadmium	(mg/l)	0.0082*	0.0079*	0.00013	0.0048*	0.0047*	0.003
Chromium	(mg/l)	0.0085	0.0063	0.0004	0.0037	0.0051	0.05
Nickel	(mg/l)	0.097*	0.078*	0.0002	0.024*	0.026*	0.07
Mercury	(mg/l)	0.00031	0.000023	0.00001	0.00016	0.000018	0.006
Benzene	(mg/l)	0.0998*	0.0783*	ND	0.012*	0.013*	0.010
Toluene	(mg/l)	0.0086	0.0072	ND	0.0028	0.0018	0.700
Ethylbenzene	(mg/l)	0.53*	0.048	ND	0.063	0.0056	0.300
Xylene	(mg/l)	0.0083	0.0062	ND	0.0018	0.0017	0.500

\*=Exceeded WHO Standard; ND=Note Detected;  
Source: Researcher's Analysis (2025).

#### 4.3 Spatial Analysis of leachate infiltration and its pollution impact on the subsurface environment of the study location

The Measured Apparent Resistivity Pseudosection (top panel) represents the raw field data collected during the survey, with resistivity values plotted based on readings obtained from the electrodes. Variations in resistivity suggest subsurface heterogeneity,

likely due to leachate infiltration and differences in soil composition. The Calculated Apparent Resistivity Pseudosection (middle panel) is a model-based representation of the measured data after inversion, providing an estimate of how resistivity should appear according to the inversion model. Finally, the Inverse Model Resistivity Section (bottom panel) is the



processed resistivity model that visualizes the subsurface resistivity distribution. The resistivity values are color-coded, ranging from low (blue) to high (red/purple). Low-resistivity zones (dark blue to purple) indicate areas with high moisture content, likely due to leachate accumulation from the dumpsite. The leachate plume extends laterally from approximately 30m to 70m and vertically down to about 8m, indicating significant infiltration into the subsurface. The surrounding higher resistivity areas (green to red) represent relatively drier and less contaminated zones.

extends down to 8m to 12m, as indicated by the depth scale on the left. The most intense blue areas, which correspond to the lowest resistivity zones, are concentrated in the central part of the section, confirming significant leachate infiltration. The leachate plume extends laterally from 30m to 70m and vertically down to around 8 to 12m in some areas. The deepest contamination is observed in the central zone, where resistivity values drop as low as 1.14 ohm.m, indicating a high concentration of leachate (Fig 6). This confirms that the dumpsite leachate has migrated both laterally and vertically, posing a potential risk of groundwater contamination.

The shallow blue region appears near the surface at approximately 1.25m depth in some areas, while the deepest blue region

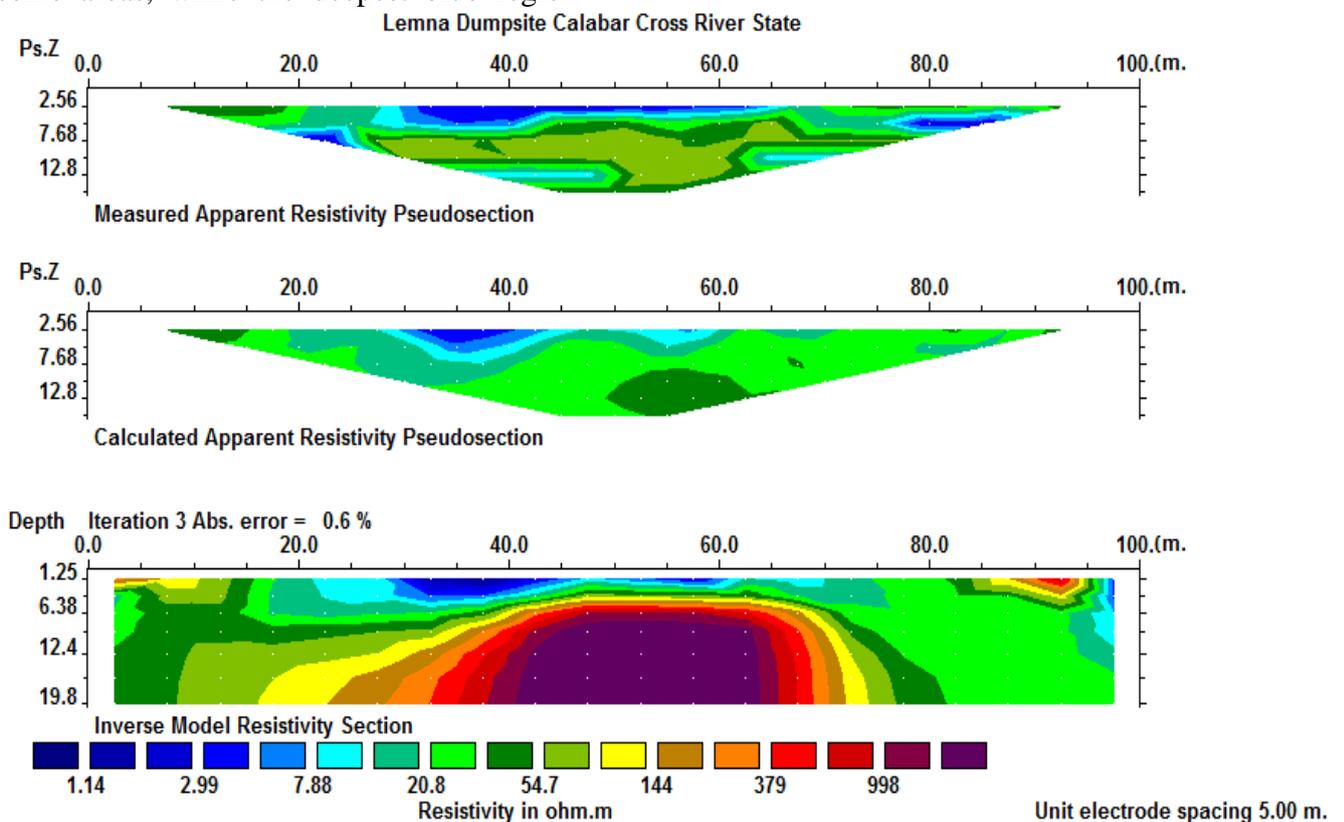


FIG 6: Pseudo-section showing vertical and lateral variation of apparent resistivity within the dumpsite area

Source: Author's Analysis (2025).

Meanwhile the measured and calculated apparent resistivity correlation plot showed a linear straight line, indicating a strong correlation of the resistivity in all the

ERT model of the dumpsites. The resistivity inverse model was obtained after 4 iterations with a low Root Mean Square (RMS)

maximum error of 3.1 %, at 5 meters' unit electrode spacing in the study areas (Fig 7).

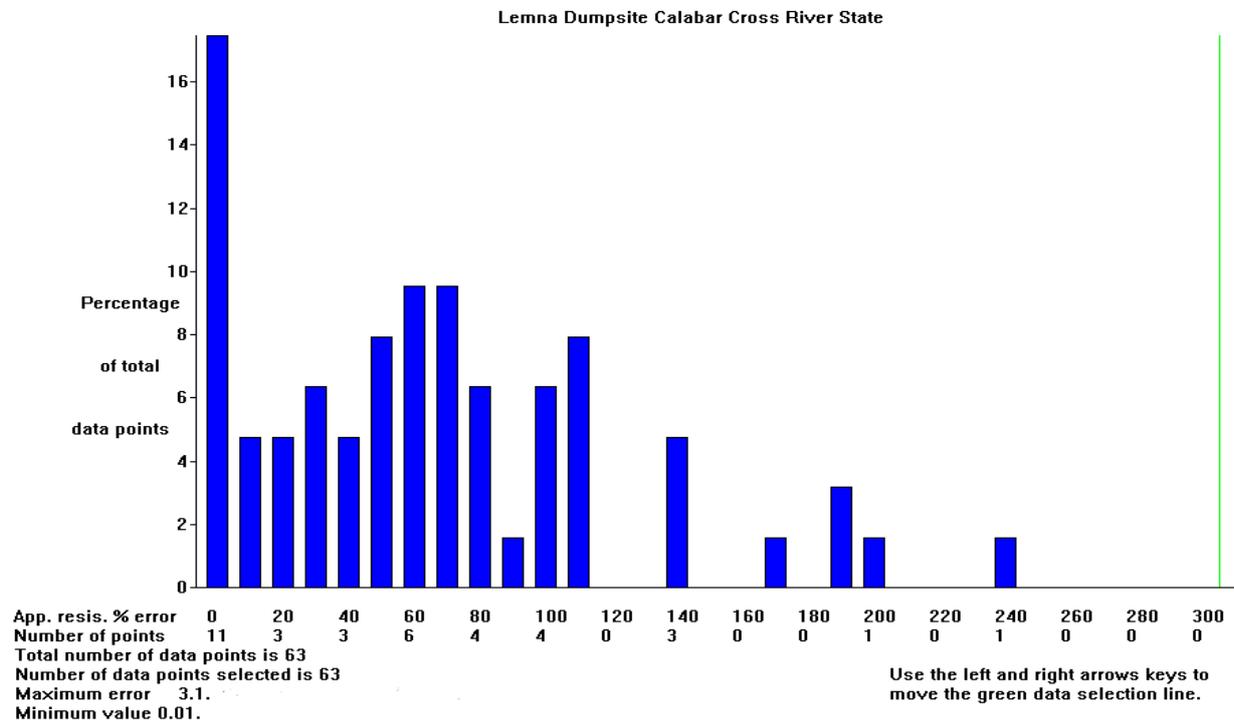


FIG 7: Root Mean Square Error  
 Source: Author's Analysis (2025).

### 4.3.1 Leachate percolation and groundwater contamination

The VES curve reveals key subsurface characteristics related to groundwater potential. The shallow zone (0–2 m depth) exhibits low resistivity values (10–100  $\Omega\text{m}$ ), indicating a conductive layer likely composed of leachate-contaminated soil, which has minimal groundwater storage potential. Between 2–10 m depth, resistivity increases to above 1000  $\Omega\text{m}$ , suggesting a more resistive layer, possibly compacted lateritic soil or solid waste material, which

may act as a semi-permeable barrier. Beyond 22 m depth, resistivity declines again to below 100  $\Omega\text{m}$ , indicating a highly conductive zone that suggests the presence of a saturated layer or water-bearing formation. However, the low resistivity values in this deeper zone imply leachate percolation and possible groundwater contamination, making it unsuitable for direct use without proper treatment. Thus, while groundwater may be present at depths greater than 22 m, its quality is likely compromised due to dumpsite leachate infiltration.

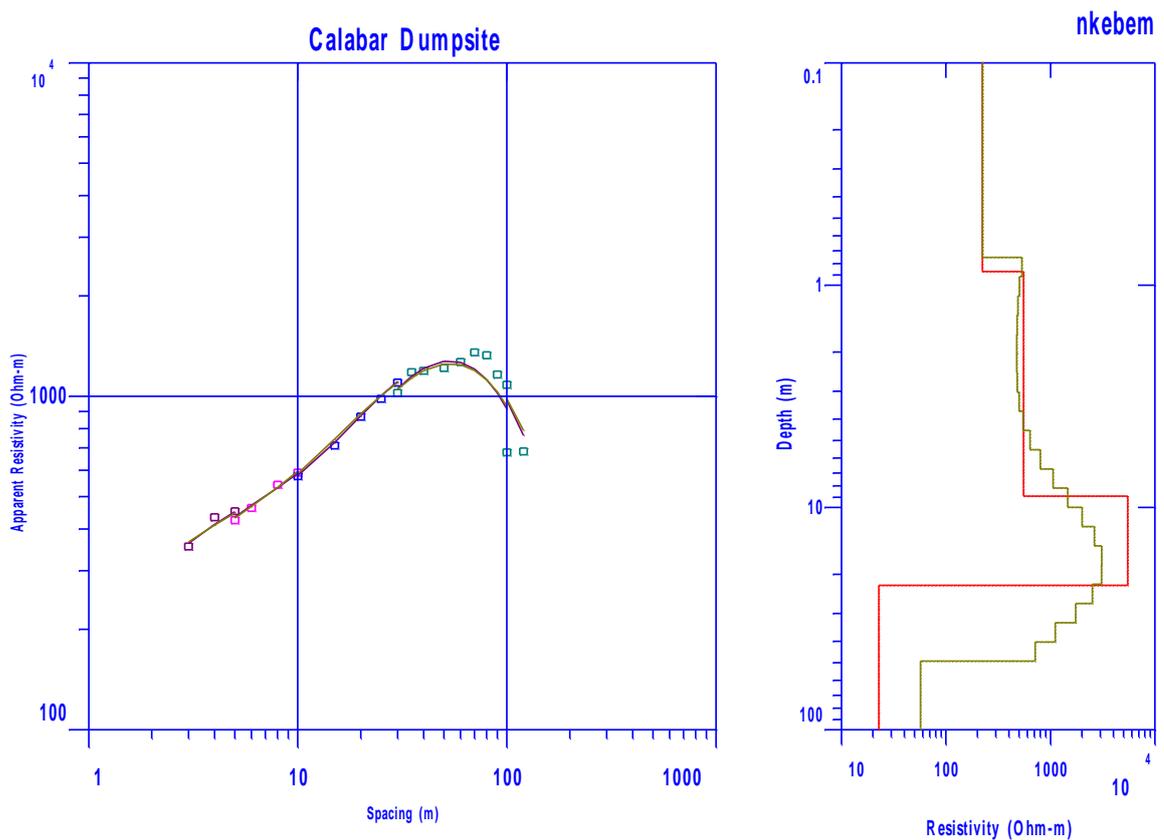


FIG 8: Resistivity curve showing vertical variation of apparent resistivity at the dumpsite  
Source: Author’s Analysis (2025).

Table 1 and Table 2 outlines the longitudinal conductance of various layers within an aquifer, with each layer exhibiting distinct properties in terms of apparent resistivity, thickness, and calculated conductance. The Topsoil layer, with moderate resistivity (222.93  $\Omega\text{m}$ ) and a thin thickness (0.86819 m), contributes minimally to the overall conductance (0.0039 Siemens), indicating poor protective capacity. The Medium Sand 1 layer, while thicker (8.0185 m) and having a moderate resistivity (551.16  $\Omega\text{m}$ ), provides a slightly higher conductance (0.0146 Siemens), suggesting a poor level of protection. The Coarse Sand layer, despite being quite thick (13.538 m), has a very high resistivity (5486.1  $\Omega\text{m}$ ), resulting in a low conductance value (0.0025 Siemens), indicating poor protection. Lastly, the Medium Sand 2 layer, with a very low

resistivity (22.786  $\Omega\text{m}$ ) and a substantial thickness (8.8867 m), exhibits the highest conductance (0.3903 Siemens), indicating moderate protection against contamination. In summary, the coarse sand layer offers the best protection, while the second medium sand layer provides the least, allowing contaminants to flow more freely through it.

Table 4 and Table 5 shows the apparent resistivity, thickness, and the individual conductance for each layer, with the total conductance value being 0.411 Siemens. With a calculated longitudinal conductance of 0.4110 Siemens, the aquifer's protective capacity is rated as Moderate, meaning it has a moderate ability to resist contamination or protect the groundwater from pollutants. This indicates that the aquifer is somewhat effective in preventing the migration of contaminants, but additional

protective measures may be needed depending on the type of contaminants and other environmental factors.

TABLE 4: Apparent resistivity, thickness and depth of apparent resistivity variation with depth within the dumpsite

Apparent resistivity ( $\Omega\text{m}$ )	Thickness (m)	Depth (m)	Probable lithology
222.93	0.86819	0.86819	Topsoil
551.16	8.0185	8.8867	Medium sand
5486.1	13.538	22.425	Coarse sand
22.786	$\alpha$	$\alpha$	Medium sand

Source: Fieldwork (2025)

TABLE 5: Longitudinal conductance

Layer	Apparent Resistivity ( $\rho_i$ ) [ $\Omega\text{m}$ ]	Thickness ( $h_i$ ) [m]	Conductance ( $h_i/\rho_i$ ) [Siemens]
Topsoil	222.93	0.86819	0.0039
Medium Sand 1	551.16	8.0185	0.0146
Coarse Sand	5486.1	13.538	0.0025
Medium Sand 2	22.786	8.8867	0.3903
Total			0.4110

Source: Fieldwork (2025).

TABLE 6: Longitudinal conductance of Aquifer Source: Olusegun, Adeolu & Dolapo (2016); Akiang, Emujakporue & Nwosu (2023).

Longitudinal conductance (mhos)	Protective Capacity rating
> 10	Excellent
5-10	Very Good
0.8-4.9	Good
0.2-0.79	Moderate
0.1-0.19	Weak
<0.1	Poor

#### 4.4 Ambient Air Quality of the Study Location

The analysis of air quality parameters measured across morning, afternoon, and evening periods reveals significant exceedances above established health and environmental safety limits as set by the World Health Organization (WHO) and Nigeria's National Environmental

Standards and Regulations Enforcement Agency (NESREA). The average ambient temperature recorded was 29.86°C, far above the WHO guideline of 24°C and NESREA's recommended limit of 25.5°C, indicating a trend toward thermal stress that could exacerbate pollutant impacts and discomfort.



Particulate matter concentrations showed particularly critical values. PM2.5 averaged 126.11  $\mu\text{g}/\text{m}^3$ , exceeding WHO's guideline of 25  $\mu\text{g}/\text{m}^3$  by more than fivefold, and NESREA's limit of 40  $\mu\text{g}/\text{m}^3$  by over three times. PM10 concentrations averaged 187.60  $\mu\text{g}/\text{m}^3$ , also drastically surpassing the WHO (50  $\mu\text{g}/\text{m}^3$ ) and NESREA (150  $\mu\text{g}/\text{m}^3$ ) limits. These elevated particulate levels suggest a hazardous air quality condition that poses serious respiratory health risks.

Relative Humidity (RH) was also excessively high, averaging 93.73%, well beyond the comfortable indoor air standard of 60% and NESREA's guideline of 70%. Such high humidity may contribute to microbial growth and enhance pollutant absorption by the respiratory tract.

Formaldehyde (HCHO) concentrations averaged 0.0291  $\text{mg}/\text{m}^3$ , which, while below WHO's threshold of 0.1  $\text{mg}/\text{m}^3$ , is marginally above NESREA's standard of 0.02 ppmv (approx. 0.024  $\text{mg}/\text{m}^3$ ), suggesting mild chemical pollution likely from vehicular emissions or industrial activities. Total Volatile Organic Compounds (TVOC) were within permissible limits (0.072  $\text{mg}/\text{m}^3$  and

NESREA's approximate limit of 4  $\text{mg}/\text{m}^3$ ), indicating relatively moderate emissions from the dumpsite.

Carbon monoxide (CO) levels averaged 8.72  $\text{mg}/\text{m}^3$ , dangerously close to WHO's limit of 10  $\text{mg}/\text{m}^3$  and significantly higher than NESREA's stricter 5  $\text{mg}/\text{m}^3$  threshold, indicating substantial exposure risks, especially during the afternoon and evening. Carbon dioxide ( $\text{CO}_2$ ) concentrations were extremely high at 3570.10 ppm more than three times the acceptable limit of 1000 ppm signifying inadequate ventilation and elevated dumpsite emissions.

Hydrogen sulfide ( $\text{H}_2\text{S}$ ) levels were alarmingly high, averaging 45.35  $\text{mg}/\text{m}^3$ , massively exceeding WHO's limit of 0.1  $\text{mg}/\text{m}^3$  and NESREA's 5 ppmv ( $\sim 7 \text{ mg}/\text{m}^3$ ), potentially indicating emissions from dumpsite leachate.

The Air Quality Level (AQL) remarks marked the entire monitoring period as "very serious," with the highest index value reaching 358.57 in the afternoon (Table 7).

TABLE 7: Air quality analysis of the study location

Parameters	Morning	Afternoon	Evening	Average	WHO Limit	NESREA
Temperature	28.07	31.5714	29.96	29.86 <sup>0</sup> C	24 <sup>0</sup> C	25.5 <sup>0</sup> C
PM2.5	120.78	130.96	126.60	126.11 $\mu\text{g}/\text{m}^3$	25 $\mu\text{g}/\text{m}^3$	40 $\mu\text{g}/\text{m}^3$
PM10	170.71	199.96	192.14	187.60 $\mu\text{g}/\text{m}^3$	50 $\mu\text{g}/\text{m}^3$	150 $\mu\text{g}/\text{m}^3$
RH	91.96	97.32	91.92	93.73%	60%	70%
HCHO	0.0164	0.0351	0.0358	0.0291 $\text{mg}/\text{m}^3$	0.1 $\text{mg}/\text{m}^3$	0.02 ppmv
TVOC	0.044	0.086	0.086	0.072 $\text{mg}/\text{m}^3$	-	1.9 ppm (around 4 $\text{mg}/\text{m}^3$ )
CO	2.85	12.25	11.07	8.72 $\text{mg}/\text{m}^3$	10 $\text{mg}/\text{m}^3$	5.0 $\text{mg}/\text{m}^3$
CO2	2468.75	4531.35	3710.21	3570.10 ppm	1000ppm	1000 ppm

Hydrogen Sulphide	27.57	68.07	40.42	45.35	0.1 mg/m <sup>3</sup>	5 ppmv
AQL REMARK Very serious	192.14	358.57	203.42	251.38	Very serious	Very serious

Source: Fieldwork (2025).

#### 4.5 Concentration of Hydrogen Sulfide (H<sub>2</sub>S) in leachate and Treatment of dumpsite Leachate

The treatment of dumpsite leachate using increasing doses of alum in combination with granular biochar significantly improved the removal efficiency (RE%) of all measured parameters, including turbidity, chemical oxygen demand (COD), biochemical oxygen demand (BOD), sulphide (S<sup>2-</sup>) and total coliform bacteria.

The addition of biochar enhanced the coagulation performance of alum, resulting in better pollutant removal compared with alum

alone. This effect was more pronounced at higher biochar doses, particularly 20 mg/L and 30 mg/L, which provided greater adsorption capacity and surface interaction for contaminants.

Removal efficiency increased consistently with rising alum doses. The combination of 120 mg/L alum and 30 mg/L biochar demonstrated the highest removal efficiencies across all measured parameters, indicating that this dosage ratio represents the optimal treatment condition for maximum contaminant reduction in the studied leachate samples (Table 8).

TABLE 8: Removal Efficiency (RE%) of alum dose with biochar

Parameter	Alum Dose (mg/L)	Biochar Dose (mg/L)	Initial Concentration (CLb)	Final Concentration (CLa)	Removal Efficiency (RE%)
Turbidity	40	5	250 NTU	95 NTU	62%
	40	10	250 NTU	80 NTU	68%
	40	20	250 NTU	62 NTU	75%
	40	30	250 NTU	45 NTU	82%
	90	5	250 NTU	85 NTU	66%
	90	10	250 NTU	74 NTU	72%
	90	20	250 NTU	55 NTU	78%
	90	30	250 NTU	38 NTU	85%
	100	5	250 NTU	75 NTU	70%
	100	10	250 NTU	60 NTU	76%
	100	20	250 NTU	45 NTU	82%
	100	30	250 NTU	30 NTU	88%
COD	120	5	250 NTU	70 NTU	72%
	120	10	250 NTU	55 NTU	78%
	120	20	250 NTU	40 NTU	84%
	120	30	250 NTU	25 NTU	90%
	40	5	1200 mg/L	540 mg/L	55%
	40	10	1200 mg/L	480 mg/L	60%
	40	20	1200 mg/L	420 mg/L	65%

	40	30	1200 mg/L	360 mg/L	70%
	90	5	1200 mg/L	504 mg/L	58%
	90	10	1200 mg/L	444 mg/L	63%
	90	20	1200 mg/L	384 mg/L	68%
	90	30	1200 mg/L	324 mg/L	73%
	100	5	1200 mg/L	456 mg/L	62%
	100	10	1200 mg/L	408 mg/L	67%
	100	20	1200 mg/L	360 mg/L	70%
	100	30	1200 mg/L	312 mg/L	74%
	120	5	1200 mg/L	432 mg/L	64%
	120	10	1200 mg/L	384 mg/L	69%
	120	20	1200 mg/L	336 mg/L	74%
	120	30	1200 mg/L	288 mg/L	80%
BOD	40	5	600 mg/L	288 mg/L	52%
	40	10	600 mg/L	252 mg/L	58%
	40	20	600 mg/L	222 mg/L	63%
	40	30	600 mg/L	192 mg/L	68%
	90	5	600 mg/L	276 mg/L	54%
	90	10	600 mg/L	240 mg/L	60%
	90	20	600 mg/L	210 mg/L	65%
	90	30	600 mg/L	180 mg/L	70%
	100	5	600 mg/L	258 mg/L	57%
	100	10	600 mg/L	216 mg/L	63%
	100	20	600 mg/L	180 mg/L	70%
	100	30	600 mg/L	144 mg/L	74%
	120	5	600 mg/L	252 mg/L	59%
	120	10	600 mg/L	216 mg/L	64%
	120	20	600 mg/L	180 mg/L	70%
	120	30	600 mg/L	144 mg/L	76%
Sulphide (S <sup>2-</sup> )	40	5	50 mg/L	20 mg/L	60%
	40	10	50 mg/L	17.5 mg/L	65%
	40	20	50 mg/L	14 mg/L	72%
	40	30	50 mg/L	11 mg/L	78%
	90	5	50 mg/L	18.5 mg/L	63%
	90	10	50 mg/L	16 mg/L	68%
	90	20	50 mg/L	13 mg/L	75%
	90	30	50 mg/L	10 mg/L	81%
	100	5	50 mg/L	16 mg/L	66%
	100	10	50 mg/L	14 mg/L	72%
	100	20	50 mg/L	12 mg/L	78%
	100	30	50 mg/L	9 mg/L	84%
	120	5	50 mg/L	15 mg/L	69%
	120	10	50 mg/L	13 mg/L	75%
	120	20	50 mg/L	11 mg/L	81%
	120	30	50 mg/L	8 mg/L	87%
Total Coliform	40	5	1.2 × 10 <sup>6</sup> CFU/mL	4.2 × 10 <sup>5</sup> CFU/mL	65%

	40	10	$1.2 \times 10^6$ CFU/mL	$3.6 \times 10^5$ CFU/mL	70%
	40	20	$1.2 \times 10^6$ CFU/mL	$2.6 \times 10^5$ CFU/mL	78%
	40	30	$1.2 \times 10^6$ CFU/mL	$1.8 \times 10^5$ CFU/mL	85%
	90	5	$1.2 \times 10^6$ CFU/mL	$3.8 \times 10^5$ CFU/mL	68%
	90	10	$1.2 \times 10^6$ CFU/mL	$3.0 \times 10^5$ CFU/mL	74%
	90	20	$1.2 \times 10^6$ CFU/mL	$2.4 \times 10^5$ CFU/mL	80%
	90	30	$1.2 \times 10^6$ CFU/mL	$1.2 \times 10^5$ CFU/mL	90%
	100	5	$1.2 \times 10^6$ CFU/mL	$3.6 \times 10^5$ CFU/mL	70%
	100	10	$1.2 \times 10^6$ CFU/mL	$2.8 \times 10^5$ CFU/mL	74%
	100	20	$1.2 \times 10^6$ CFU/mL	$2.0 \times 10^5$ CFU/mL	80%
	100	30	$1.2 \times 10^6$ CFU/mL	$1.0 \times 10^5$ CFU/mL	91%
	120	5	$1.2 \times 10^6$ CFU/mL	$3.4 \times 10^5$ CFU/mL	72%
	120	10	$1.2 \times 10^6$ CFU/mL	$2.6 \times 10^5$ CFU/mL	78%
	120	20	$1.2 \times 10^6$ CFU/mL	$1.8 \times 10^5$ CFU/mL	85%
	120	30	$1.2 \times 10^6$ CFU/mL	$9.0 \times 10^4$ CFU/mL	94%

Source: Fieldwork (2025).

The treatment of dumpsite leachate using ferric chloride in combination with granular biochar demonstrated significant removal efficiencies across all measured physicochemical and bacteriological parameters. The combined process proved effective in reducing turbidity, chemical oxygen demand (COD), sulphide ( $S^{2-}$ ) and microbial loads.

The highest removal efficiencies (RE%) were observed at a ferric chloride dose of 120 mg/L coupled with a biochar dose of 30 mg/L. Under these optimized conditions, notable reductions were achieved for  $H_2S$  and total coliform bacteria, indicating strong performance of the treatment process in addressing both volatile pollutants and microbial contaminants (Table 9).

TABLE 9: Removal Efficiency (RE%) of Ferric Chloride dose with biochar

Parameter	Ferric Chloride Dose (mg/L)	Biochar Dose (mg/L)	Initial Concentration (CLb)	Final Concentration (CLa)	Removal Efficiency (RE%)
Turbidity	40	5	250 NTU	90 NTU	64%
	40	10	250 NTU	80 NTU	68%
	40	20	250 NTU	65 NTU	74%
	40	30	250 NTU	50 NTU	80%
	90	5	250 NTU	85 NTU	66%
	90	10	250 NTU	75 NTU	70%
	90	20	250 NTU	60 NTU	76%
	90	30	250 NTU	45 NTU	82%
	100	5	250 NTU	80 NTU	68%
	100	10	250 NTU	70 NTU	72%

	100	20	250 NTU	55 NTU	78%
	100	30	250 NTU	40 NTU	84%
	120	5	250 NTU	75 NTU	70%
	120	10	250 NTU	65 NTU	74%
	120	20	250 NTU	50 NTU	80%
	120	30	250 NTU	35 NTU	86%
COD	40	5	1200 mg/L	530 mg/L	56%
	40	10	1200 mg/L	480 mg/L	60%
	40	20	1200 mg/L	430 mg/L	64%
	40	30	1200 mg/L	370 mg/L	69%
	90	5	1200 mg/L	500 mg/L	58%
	90	10	1200 mg/L	450 mg/L	62%
	90	20	1200 mg/L	400 mg/L	67%
	90	30	1200 mg/L	350 mg/L	71%
	100	5	1200 mg/L	470 mg/L	61%
	100	10	1200 mg/L	420 mg/L	65%
	100	20	1200 mg/L	370 mg/L	69%
	100	30	1200 mg/L	320 mg/L	73%
	120	5	1200 mg/L	450 mg/L	62%
	120	10	1200 mg/L	400 mg/L	67%
	120	20	1200 mg/L	350 mg/L	71%
	120	30	1200 mg/L	300 mg/L	75%
BOD	40	5	600 mg/L	270 mg/L	55%
	40	10	600 mg/L	240 mg/L	60%
	40	20	600 mg/L	210 mg/L	65%
	40	30	600 mg/L	180 mg/L	70%
	90	5	600 mg/L	260 mg/L	57%
	90	10	600 mg/L	230 mg/L	61%
	90	20	600 mg/L	200 mg/L	67%
	90	30	600 mg/L	170 mg/L	72%
	100	5	600 mg/L	240 mg/L	60%
	100	10	600 mg/L	210 mg/L	65%
	100	20	600 mg/L	180 mg/L	70%
	100	30	600 mg/L	150 mg/L	75%
	120	5	600 mg/L	220 mg/L	63%
	120	10	600 mg/L	190 mg/L	68%
	120	20	600 mg/L	160 mg/L	73%
	120	30	600 mg/L	130 mg/L	78%
Sulphide (S <sup>2-</sup> )	40	5	1.8 mg/L	0.8 mg/L	56%
	40	10	1.8 mg/L	0.7 mg/L	61%
	40	20	1.8 mg/L	0.6 mg/L	67%
	40	30	1.8 mg/L	0.5 mg/L	72%
	90	5	1.8 mg/L	0.7 mg/L	61%
	90	10	1.8 mg/L	0.6 mg/L	67%

	90	20	1.8 mg/L	0.5 mg/L	72%
	90	30	1.8 mg/L	0.4 mg/L	78%
	100	5	1.8 mg/L	0.6 mg/L	67%
	100	10	1.8 mg/L	0.5 mg/L	72%
	100	20	1.8 mg/L	0.4 mg/L	78%
	100	30	1.8 mg/L	0.3 mg/L	83%
	120	5	1.8 mg/L	0.5 mg/L	72%
	120	10	1.8 mg/L	0.4 mg/L	78%
	120	20	1.8 mg/L	0.3 mg/L	83%
	120	30	1.8 mg/L	0.2 mg/L	89%
Total Coliform (CFU/mL)	40	5	1000 CFU/mL	400 CFU/mL	60%
	40	10	1000 CFU/mL	350 CFU/mL	65%
	40	20	1000 CFU/mL	300 CFU/mL	70%
	40	30	1000 CFU/mL	250 CFU/mL	75%
	90	5	1000 CFU/mL	380 CFU/mL	62%
	90	10	1000 CFU/mL	330 CFU/mL	67%
	90	20	1000 CFU/mL	280 CFU/mL	72%
	90	30	1000 CFU/mL	230 CFU/mL	77%
	100	5	1000 CFU/mL	350 CFU/mL	65%
	100	10	1000 CFU/mL	300 CFU/mL	70%
	100	20	1000 CFU/mL	250 CFU/mL	75%
	100	30	1000 CFU/mL	200 CFU/mL	80%
	120	5	1000 CFU/mL	320 CFU/mL	68%
	120	10	1000 CFU/mL	270 CFU/mL	73%
	120	20	1000 CFU/mL	220 CFU/mL	78%
	120	30	1000 CFU/mL	180 CFU/mL	82%

Source: Fieldwork (2025).

#### 4.6 Public Perception of the Problems and Management Related to Dumpsite Leachate in the Study Locations

##### 4.6.1 Demographic Characteristics around Calabar Dumpsite

The demographic characteristics of respondents in Calabar, as presented in Table 10, depict a varied distribution across different categories. In terms of sex, the data shows that there were 167 male respondents, constituting 42.6% of the total, while there were 225 female respondents, accounting for 57.4%. Regarding age groups, the highest proportion falls within the 31-40 years category, with 148 respondents (37.8%),

followed by the 15-30 years category with 120 respondents (30.6%). The lowest representation is observed in the 61 years and above category, with only 10 respondents (2.6%). Marital status exhibits diversity, with the majority being married, comprising 159 respondents (40.6%), followed by single individuals with 126 respondents (32.1%). Divorced, separated, and widow/widower categories exhibit lower numbers, with 37 (9.4%), 46 (11.7%), and 24 (6.1%) respondents, respectively. Educational qualification distribution shows a dominance of OND/NCE with 187 respondents (47.7%), followed by HND/BSc with 95 respondents (24.2%). Non-formal education and

FSLC/SSCE categories show lower representation, with 34 (8.7%) and 76 (19.4%) respondents, respectively. Occupationally, unemployed individuals represent the largest group with 175 respondents (44.6%), followed by traders/transporters with 66 respondents (16.8%). Borehole owners exhibit the lowest representation, with only 9 respondents

(2.3%). Regarding length of residence, the distribution across categories varies, with the majority falling within the 5-9 years and 10-14 years categories, each comprising 120 respondents (30.6%) and 112 respondents (28.6%), respectively. The lowest representation is observed in the <1 year category, with only 8 respondents (2%).

Table 10: Demographic characteristics of respondents at Calabar

Calabar	Section A Distribution of demographic characteristics of respondents		
Variable	Category	Frequency	Total %
Sex	Male	167	42.6
	Female	225	57.4
Age (years)	15-30	120	30.6
	31-40	148	37.8
	41-50	83	21.2
	51-60	31	7.9
	61yrs& above	10	2.6
Marital status	Single	126	32.1
	Married	159	40.6
	Divorced	37	9.4
	Separated	46	11.7
	Widow/widower	24	6.1
Educational Qualification	Non-formal education	34	8.7
	FSLC/SSCE	76	19.4
	OND/NCE	187	47.7
	HND/B.Sc	95	24.2
Occupation	Civil servant	46	11.7
	Farmer	10	2.6
	Trader/ transporter	66	16.8
	Artisan	20	5.1
	Unemployed	175	44.6
	Student	29	7.4
	Staff of Urban Development Authority	26	6.6
	House/Borehole owners	20	5.1
Length of stay in the area	<1	8	2.0
	1-4	40	10.2
	5-9	120	30.6
	10-14	112	28.6

Source: Researcher's Analysis (2025).

**4.6.2 Problems Associated with Dumpsite Leachate at Calabar dumpsite**

The result of the problems associated with dumpsite leachate in Calabar is presented in (Table 11). The study on the problems and management of dumpsite leachate in Calabar provides detailed responses from the research questionnaire, summarising the combined agreement (SA+A) and disagreement (SD+D) values, as well as the standalone undecided (UN) values for each item. All types of waste are dumped in the dumpsite indicates a total of 334 respondents (85.2%) agree, 45 respondents (11.5%) disagree, and 13 respondents (3.3%) are undecided (UN). There are no underlying liners in the dumpsite illustrate a total of 324 respondents (82.7%) agree, 34 respondents (8.7%) are undecided (UN), and 34 respondents (8.7%) disagree. There are no leachate collection systems such as pumps, pipes/drainage, leachate well to siphon leachate for treatment illustrate a total of 329 respondents

(83.9%) agree, 37 respondents (9.5%) disagree, and 26 respondents (6.6%) are undecided (UN). Poor site design to contain dumpsite leachate scored a total of 341 respondents (87.0%) agree, 37 respondents (9.5%) disagree, and 14 respondents (3.6%) are undecided (UN). The dumpsite is an open dumpsite and contaminated air from dumpsite leachate conveys odour which may result in diseases scored a total of 330 respondents (84.2%) agree, 47 respondents (12.0%) disagree, and 15 respondents (3.8%) are undecided (UN). Perceived seepage of leachate into the ground contaminating soil and drinking water illustrate a total of 319 respondents (81.4%) agree, 56 respondents (14.3%) disagree, and 17 respondents (4.3%) are undecided (UN). Lack of solution to the problems of dumpsite leachate can result in anger and disappointment illustrate a total of 303 respondents (77.3%) agree, 62 respondents (15.8%) disagree, and 27 respondents (6.9%) are undecided (UN).

Table 11: Problems associated with dumpsite leachate at Calabar dumpsite

Research questionnaire of the study							
The problems of dumpsite leachate at Calabar							
Item	Section B: Problems of dumpsite Leachate	SA (1)	A (2)	UN (3)	D (4)	SD (5)	Total
1	All types of waste are dumped in the Dumpsite	95 24.2%	239 61.0%	13 3.3%	31 7.9%	14 3.6%	392 100%
2	There are no underlying liners in the dumpsite	103 26.3%	221 56.4%	34 8.7%	13 3.3%	21 5.4%	392 100%
3	There are no leachate collection system such as pumps, pipes/drainage, leachat well to siphon leachate for treatment	93 23.7%	236 60.2%	26 6.6%	16 4.1%	21 5.4%	392 100%
4	Poor site design to contain dumpsite leachate	112 28.6%	229 58.4%	14 3.6%	25 6.4%	12 3.1%	392 100%
5	The dumpsite is an open dumpsite and contaminated air from dumpsite leachate conveys odour which may result in diseases.	111 28.3%	219 55.9%	15 3.8%	31 7.9%	16 4.1%	392 100%



6	Perceived seepage of leachate into the ground contaminating soil and drinking water	96 24.5%	223 56.9%	17 4.3%	22 5.6%	34 8.7%	392 100%
7	Lack of solution to the problems of dumpsite leachate can result to anger and disappointment	91 23.2%	212 54.1%	27 6.9%	31 7.9%	31 7.9%	392 100%

Source: Researcher's Analysis (2025).

#### 4.6.3 Dumpsite leachate Management at Calabar dumpsite

The result of dumpsite leachate management in Calabar is presented in (Table 12). There is no regulatory check on how dumpsite leachate is being discharged illustrate a total of 195 respondents (49.7%) agree, 162 respondents (41.3%) disagree, and 35 respondents (8.9%) are undecided (UN). Waste compacted, use of chlorine and charcoal (activated carbon) indicate a total of 268 respondents (68.4%) agree, 85 respondents (21.7%) disagree, and 39 respondents (9.9%) are undecided (UN). There is no source zone removal (excavation of soil & sediment for treatment) at the dumpsite indicate a total of 260 respondents (66.3%) agree, 86 respondents (21.9%) disagree, and 46 respondents (11.7%) are undecided (UN). There is no source zone containment (use of capping, slurry walls, sheet piling, and in situ stabilization as a remedial option to limit future migration of contaminants) indicate a total of 338 respondents (86.3%) agree, 33 respondents (8.4%) disagree, and 21 respondents (5.4%) are undecided (UN). There is no biodegradation of source zone contaminated area indicate a total of 344 respondents (87.7%) agree, 20 respondents (5.1%) disagree, and 28 respondents (7.1%) are undecided (UN). There is no contaminants flow path monitoring control plan around the dumpsite indicate a total of 297 respondents (75.7%) agree, 65 respondents (16.6%) disagree, and 30 respondents (7.7%) are undecided (UN). Government does not care about public attitudes and opinions when making decisions concerning dumpsite

leachate indicate a total of 316 respondents (80.6%) agree, 66 respondents (16.8%) disagree, and 10 respondents (2.6%) are undecided (UN).

Table 12: Dumpsite leachate Management at Calabar dumpsite

Item	Section C: Dumpsite Leachate management	SA (1)	A (2)	UN (3)	D (4)	SD (5)	Total
1	There is no regulatory check on how dumpsite leachate is been discharged	93 23.7%	102 26.0%	35 8.9%	66 16.8%	96 24.5%	392 100%
2	Waste compacted, use of chlorine and charcoal ( <i>activated carb</i>	97 24.7%	171 43.6%	39 9.9%	25 6.4%	60 15.3%	392 100%
3	There is no source zone removal (excavation of soil & sediment for treatment) at the dumpsite	102 26.0%	158 40.3%	46 11.7%	26 6.6%	60 15.3%	392 100%
4	There is no source zone containment (use of capping, slurry walls, sheet pili and in situ stabilization as a remedial option to limit future migration of contaminants)	108 27.6%	230 58.7%	21 5.4%	24 6.1%	9 2.3%	392 100%
5	There is no biodegradation of source zone contaminated area	117 29.8%	227 57.9%	28 7.1%	13 3.3%	7 1.8%	392 100%
6	There is no contaminants flow path monitoring control plan around the dumpsite	95 24.2%	202 51.5%	30 7.7%	35 8.9%	30 7.7%	392 100%
7	Government does not care about public attitudes and opinions when making decisions concerning dumpsite leachate	111 28.3%	205 52.3%	10 2.6%	29 7.4%	37 9.4%	392 100%

Source: Researcher's Analysis (2025).

#### 4.6.4 Analysis of the Problems Associated with Dumpsite Leachate Management of the study area

The result of the correlation of the problems associated with dumpsite leachate management in Calabar is presented in (Table 13). Dumping all types of waste at the dumpsite is significantly associated with several infrastructure deficiencies, including the absence of underlying liners ( $\rho = 0.480$ ,  $p < 0.001$ ) and leachate collection systems ( $\rho = 0.420$ ,  $p < 0.001$ ). This suggests that poor waste management practices coincide with inadequate infrastructure, exacerbating environmental concerns. Poor site design to contain dumpsite leachate shows significant positive associations with

various environmental impacts, such as the presence of open dumpsites and contaminated air ( $\rho = 0.610$ ,  $p < 0.001$ ). This indicates that ineffective site design contributes to environmental degradation. Perceived seepage of leachate into the ground correlates positively with actual remediation efforts ( $\rho = 0.630$ ,  $p < 0.001$ ). This suggests that public perception may drive actions towards mitigating environmental issues. Government attitudes towards public opinions exhibit significant negative correlations with various environmental factors, including infrastructure deficiencies and

environmental impacts ( $\rho = -0.202$ ,  $p < 0.001$ ). This indicates that government responsiveness to public concerns may influence environmental management practices. The absence of regulatory measures, such as regulation for the discharge of leachate, shows significant positive associations with the lack of specific remediation efforts ( $\rho = 0.149$ ,  $p = 0.003$ ). This suggests that regulatory gaps may contribute to inactive remediation practices. Certain infrastructure deficiencies, like the absence of contaminants plume remediation and source zone removal, exhibit strong positive correlations with each other ( $\rho = 0.890$ ,  $p < 0.001$ ). This highlights the interconnectedness between inadequate infrastructure and ineffective remediation strategies. Lack of contaminants flow path monitoring control plans around the

dumpsite is significantly associated with various environmental factors, including poor site design and infrastructure deficiencies ( $\rho = -0.159$ ,  $p = 0.002$ ). This suggests that inadequate monitoring exacerbates environmental problems. Lack of biodegradation of source zone contaminated areas shows significant negative correlations with contaminants flow path monitoring ( $\rho = -0.389$ ,  $p < 0.001$ ). This implies that the absence of biodegradation efforts may lead to increased reliance on monitoring control plans. Government attitudes towards public opinions exhibit significant negative associations with various environmental factors, indicating the potential influence of governmental actions on addressing environmental concerns ( $\rho = -0.766$ ,  $p < 0.001$ ) (Table 13).

Table 13: Spearman correlation of the problems associated with dumpsite leachate management at Calabar

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Spearman's rho	All types of waste are dump in the dumpsites	Correlation Coefficient	1.000	.480**	.420**	.610**	.701**	.630**	.554**	.149**	.045	.046	-.035	-.042	-.159**	-.202**
		Sig. (2-tailed)	.	.000	.000	.000	.000	.000	.000	.003	.376	.366	.494	.409	.002	.000
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392
	There are no underlying liners in the dumpsite	Correlation Coefficient	.480**	1.000	.901**	.609**	.544**	.524**	.521**	.191**	-.008	-.004	-.071	-.146**	-.254**	-.238**
		Sig. (2-tailed)	.000	.	.000	.000	.000	.000	.000	.871	.931	.159	.004	.000	.000	.000
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392
	There are no leachate collection systems such as pumps,	Correlation Coefficient	.420**	.901**	1.000	.698**	.553**	.578**	.521**	.180**	.004	.019	-.059	-.122*	-.240**	-.230**
		Sig. (2-tailed)	.000	.000	.	.000	.000	.000	.000	.934	.711	.242	.016	.000	.000	.000
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392
	Poor site design to contain dumpsite leachate	Correlation Coefficient	.610**	.609**	.698**	1.000	.708**	.730**	.638**	.184**	.043	.057	-.052	-.096	-.212**	-.250**
		Sig. (2-tailed)	.000	.000	.000	.	.000	.000	.000	.000	.396	.264	.308	.056	.000	.000
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392
	The dumpsite is an open dumpsite and contaminated air	Correlation Coefficient	.701**	.544**	.553**	.708**	1.000	.707**	.575**	.186**	-.051	-.022	-.137**	-.154**	-.218**	-.246**
		Sig. (2-tailed)	.000	.000	.000	.000	.	.000	.000	.000	.314	.658	.007	.002	.000	.000
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392
	Perceived seepage of leachate into the ground	Correlation Coefficient	.630**	.524**	.578**	.730**	.707**	1.000	.741**	.208**	-.003	-.002	-.037	-.096	-.266**	-.260**
		Sig. (2-tailed)	.000	.000	.000	.000	.000	.	.000	.000	.948	.972	.470	.058	.000	.000
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392
	Lack of solution to the problems of dumpsite leachate can result	Correlation Coefficient	.554**	.521**	.521**	.638**	.575**	.741**	1.000	.219**	.032	.034	-.029	-.136**	-.236**	-.238**
		Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.	.000	.523	.507	.562	.007	.000	.000
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392
	No regulation for the discharge of leachate	Correlation Coefficient	.149**	.191**	.180**	.184**	.186**	.208**	.219**	1.000	.443**	.463**	.107*	.088	-.044	-.007
		Sig. (2-tailed)	.003	.000	.000	.000	.000	.000	.000	.000	.000	.000	.035	.082	.390	.897
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392
	No contaminants plume remediation of the dumpsite area	Correlation Coefficient	.045	-.008	.004	.043	-.051	-.003	.032	.443**	1.000	.890**	.248**	.289**	-.005	.027
		Sig. (2-tailed)	.376	.871	.934	.396	.314	.948	.523	.000	.	.000	.000	.000	.926	.594
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392
	No source zone removal (excavation of soil & sediment for treatment)	Correlation Coefficient	.046	-.004	.019	.057	-.022	-.002	.034	.463**	.890**	1.000	.351**	.325**	.055	.082
		Sig. (2-tailed)	.366	.931	.711	.264	.658	.972	.507	.000	.000	.	.000	.000	.275	.104
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392
	No source zone containment (use of capping, slurry walls, sheet piling, and	Correlation Coefficient	-.035	-.071	-.059	-.052	-.137**	-.037	-.029	.107*	.248**	.351**	1.000	.584**	.131**	.243**
		Sig. (2-tailed)	.494	.159	.242	.308	.007	.470	.562	.035	.000	.000	.	.000	.010	.000
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392
	No biodegradation of source zone contaminated area	Correlation Coefficient	-.042	-.146**	-.122*	-.096	-.154**	-.096	-.136**	.088	.289**	.325**	.584**	1.000	.389**	.322**
		Sig. (2-tailed)	.409	.004	.016	.056	.002	.058	.007	.082	.000	.000	.000	.	.000	.000
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392
	No contaminants flow path monitoring control plan around the dumpsite	Correlation Coefficient	-.159**	-.254**	-.240**	-.212**	-.218**	-.266**	-.236**	-.044	-.005	.055	.131**	.389**	1.000	.766**
		Sig. (2-tailed)	.002	.000	.000	.000	.000	.000	.000	.390	.926	.275	.010	.000	.	.000
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392
	Government cares about public attitudes and opinions	Correlation Coefficient	-.202**	-.238**	-.230**	-.250**	-.246**	-.260**	-.238**	-.007	.027	.082	.243**	.322**	.766**	1.000
		Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.897	.594	.104	.000	.000	.000	.
		N	392	392	392	392	392	392	392	392	392	392	392	392	392	392



## 5. DISCUSSION

The geophysical and environmental analyses highlight the extent and severity of leachate migration and its associated impacts on groundwater and air quality. The resistivity imaging revealed a distinct leachate plume extending laterally from 30 to 70 m and vertically down to approximately 8–12 m, with resistivity values as low as 1.14  $\Omega\text{m}$  in the central section, confirming significant infiltration. Such low resistivity values are consistent with the presence of highly conductive leachate, which has been shown in similar studies to percolate into subsurface layers and increase the risk of groundwater contamination (Olayinka & Olayiwola, 2001; Oyeyemi et al., 2019; Igelle et al., 2024). The shallow conductive zones (0–2 m) suggest contamination of the surface soil, while deeper conductive layers (>22 m) point toward possible leachate penetration into groundwater-bearing formations. This aligns with previous findings that open dumpsites often contribute to subsurface pollution, rendering groundwater unsuitable without treatment (Akpan et al., 2021; Igelle et al., 2024).

The air quality results further confirm the environmental risks associated with the dumpsite. Elevated particulate matter concentrations ( $\text{PM}_{2.5} = 126.11 \mu\text{g}/\text{m}^3$ ;  $\text{PM}_{10} = 187.60 \mu\text{g}/\text{m}^3$ ) exceeded both WHO (2006) and NESREA (2011) standards, presenting serious respiratory health hazards. High concentrations of  $\text{CO}_2$  (3570.10 ppm) and  $\text{H}_2\text{S}$  ( $45.35 \text{ mg}/\text{m}^3$ ) were particularly alarming, indicating significant emissions from the decomposition of organic waste and leachate volatilization. Similar studies have linked dumpsite emissions to elevated toxic gases and respiratory ailments in nearby communities (Ugbogu et al., 2019; Singh et al., 2020). The “very serious” Air Quality Level (AQL) recorded suggests chronic exposure risks and underscores the need for mitigation measures.

Treatment trials using chemical coagulants and biochar demonstrated promising results in improving leachate quality and odor nuisance. The combination of alum with granular biochar significantly enhanced the removal efficiency of turbidity, COD, BOD, sulphide ( $\text{S}^{2-}$ ), and coliform bacteria. Biochar’s porous structure and adsorption capacity complemented alum’s coagulation ability, and improves pollutant capture in water treatment (Tan et al., 2015; Yin et al., 2020). The highest efficiencies were recorded at 120 mg/L alum and 30 mg/L biochar, indicating an optimal synergistic effect.

Similarly, ferric chloride combined with biochar showed strong performance, particularly in removing volatile pollutants and microbial contaminants. This agrees with prior studies noting that ferric salts provide more effective coagulation for leachate treatment due to their higher charge density, while biochar enhances adsorption of organic and microbial pollutants (Tchobanoglous et al., 2002; Ren et al., 2021). The aeration step after biochar addition further improved removal of sulphide ( $\text{S}^{2-}$ ), in line with aeration that promotes oxidation and enhances treatment efficiency.

The results demonstrate that combining coagulants with biochar provides a sustainable and effective treatment approach for dumpsite leachate. However, the extent of subsurface infiltration and the dangerously high air pollutant concentrations observed emphasize the need for integrated waste management strategies to prevent further environmental and public health impacts.

## 6. CONCLUSION

The study revealed that dumpsite leachate has significantly infiltrated the subsurface, with the plume extending laterally up to 70 m and vertically to depths of 8–12 m, indicating a substantial risk of groundwater contamination. The low resistivity zones



confirmed the presence of highly conductive leachate, while the VES results highlighted leachate penetration into both shallow and deeper groundwater-bearing formations. Air quality monitoring further emphasized the environmental impact of the dumpsite, with particulate matter, CO<sub>2</sub>, CO, and H<sub>2</sub>S levels far exceeding both WHO and NESREA standards, thereby posing severe risks to human health and ecological stability.

Treatment experiments demonstrated that combining coagulants (alum or ferric chloride) with granular biochar significantly enhanced removal efficiencies across all measured parameters, including turbidity, COD, BOD, (S<sup>2-</sup>) and total coliform bacteria. Optimal results were obtained with doses of 120 mg/L coagulant and 30 mg/L biochar, indicating the effectiveness of biochar in improving pollutant removal through adsorption and synergistic interaction with coagulants. The additional aeration step further improved the reduction of volatile and microbial contaminants.

The findings highlight the urgent need for proper dumpsite management, groundwater protection, and air quality monitoring in the affected area. The findings indicate that biochar-enhanced coagulation be adopted as a cost-effective and sustainable treatment option prior to leachate discharge and on the dumpsite to eliminate odor nuisance in surrounding environment.



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- Fieldwork (2025) TABLE 2: Longitudinal conductance.
- Fieldwork (2025) TABLE 4: Air quality analysis of the study location.
- Fieldwork (2025) TABLE 5: Removal Efficiency (RE%) of alum dose with biochar.
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