

Physicochemical Properties of Gosa Dumpsite Soil and Their Potential Influence on the Bioavailability and Retention of Polycyclic Aromatic Hydrocarbons (PAHs)

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Abstract: This study investigated the physicochemical properties of soils within and around the Gosa dumpsite, Abuja, Nigeria, and evaluated their potential implications for the retention, mobility and bioavailability of polycyclic aromatic hydrocarbons (PAHs). Seventy-four soil samples were collected from the 0–20 cm depth, comprising 10 samples within the fenced dumpsite and 64 samples from four directional zones outside the dumpsite. The samples were analysed for pH, temperature, electrical conductivity (EC), cation exchange capacity (CEC), soil organic carbon (SOC), soil organic matter (SOM), and particle-size distribution. Soil pH ranged from 7.46 ± 0.05 to 8.25 ± 0.01 , indicating neutral to moderately alkaline conditions, while temperature varied narrowly from 29.5 ± 0.01 to 29.7 ± 0.01 °C. EC ranged from 130 ± 1.15 to 494 ± 0.50 $\mu\text{S cm}^{-1}$, with the highest value recorded at SC, suggesting greater accumulation of soluble ionic constituents and possible influence of waste-derived leachate. SOC varied from 1.21 ± 0.13 to $2.02 \pm 0.13\%$, while SOM ranged from 2.36 ± 0.23 to $4.00 \pm 0.26\%$, with the highest concentrations observed at SC. CEC ranged from 16.54 ± 0.01 to 20.17 ± 0.01 [unit], indicating relatively moderate spatial variation in exchange capacity. The soils were predominantly sandy, with sand contents reaching 82.47% at SS and 83.00% at SW, whereas SE exhibited a comparatively high clay fraction of approximately 33.19%. The observed heterogeneity suggests that soil physicochemical properties may collectively influence the environmental behaviour of

PAHs. Higher SOC and SOM at SC may favour the partitioning and retention of hydrophobic PAHs, potentially reducing their freely dissolved fraction while increasing persistence. Conversely, the predominantly sandy texture at SS and SW may favour infiltration and downward transport of weakly sorbed contaminants during rainfall. Overall, the findings demonstrate that site-specific variations in soil properties are important considerations when assessing the potential mobility, retention and bioavailability of PAHs at dumpsites. Direct measurement of PAH concentrations and bioavailable fractions is recommended to quantitatively establish these relationships.

Keywords: Cation exchange capacity (CEC), Electrical conductivity (EC), Soil pH, Bioavailability, Sorption and retention

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1.0 Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a diverse group of persistent organic contaminants consisting of two or more fused aromatic rings that are widely distributed in environmental compartments as a result of natural and anthropogenic processes (Kim *et al.*, 2013; Nguyen *et al.*, 2014). (Kim *et al.*, 2013; Nguyen *et al.*, 2014). In soils, PAHs originate primarily from incomplete combustion of fossil fuels and biomass, petroleum-related activities, industrial emissions, vehicular exhaust, waste burning and other activities involving contaminated materials (Abdel-Shafy and Mansour, 2016; Cheruiyot *et al.*, 2015; Ravindran *et al.*, 2020). (Abdel-Shafy and Mansour, 2016; Cheruiyot *et al.*, 2015; Ravindran *et al.*, 2020). Once released into the environment, PAHs can accumulate in soil and undergo a range of processes, including adsorption, desorption, volatilization, dissolution, degradation, and transport (Ukalska-Jaruga *et al.*, 2020). The behaviour and environmental persistence of PAHs in soil are therefore strongly influenced by the physicochemical characteristics of the soil matrix (Ukalska-Jaruga *et al.*, 2020; Yu *et al.*, 2018). Municipal waste disposal sites are of particular environmental concern because the accumulation, decomposition and burning of

heterogeneous waste materials can introduce PAHs into soils and facilitate their redistribution through particulate deposition, leachate infiltration and surface runoff. The occurrence and persistence of PAHs in dumpsite soils therefore depend not only on contaminant inputs but also on the physicochemical characteristics of the receiving soil.

The Gosa dumpsite, located in Abuja, Federal Capital Territory (FCT), Nigeria, represents a heterogeneous waste-disposal environment in which the accumulation and decomposition of municipal wastes may alter the physicochemical characteristics of the underlying and surrounding soils. The presence of organic wastes, combustion residues and potentially petroleum-derived materials may provide sources of PAHs, while leachate infiltration may facilitate their redistribution within the soil environment. Consequently, spatial variations in the physicochemical properties of Gosa dumpsite soils may influence the partitioning, retention, mobility and potential bioavailability of PAHs.

Soil physicochemical properties play a major role in determining the distribution, retention, mobility and potential bioavailability of PAHs within contaminated soils.. Properties such as soil organic matter (SOM), soil organic carbon (SOC), soil texture, clay content, pH, electrical conductivity (EC) and cation exchange capacity (CEC) influence the interactions between PAHs and soil particles and consequently affect their environmental fate (Ukalska-Jaruga *et al.*, 2020; Beljin *et al.*, 2024; Gupta *et al.*, 2024; Kim *et al.*, 2023; Zhao *et al.*, 2023; Esfandiar *et al.*, 2022). In particular, soil organic matter is one of the most important factors controlling the retention of PAHs because many PAHs are hydrophobic and have a strong affinity for organic phases (Ukalska-Jaruga *et al.*, 2020).

The combined effects of these physicochemical properties are particularly important in



heterogeneous dumpsite soils, where organic matter accumulation, mineral composition, particle-size distribution, soluble salts and leachate inputs may vary considerably over short distances. Consequently, differences in pH, EC, SOC, SOM, CEC and particle-size distribution may create localized conditions that either favour PAH retention or enhance contaminant mobility and potential bioavailability. Assessing these parameters collectively is therefore more informative than interpreting any single physicochemical property in isolation.

Soils with relatively high organic carbon and organic matter contents generally provide more sorption domains for hydrophobic PAHs, thereby enhancing their retention and potentially reducing their immediate mobility.. Soil texture can also influence PAH retention because fine-textured soils containing greater proportions of clay and silt generally provide larger specific surface areas and more potential sorption sites than coarse-textured sandy soils (Li *et al.*, 2023). Conversely, highly sandy soils may facilitate infiltration and downward transport of weakly sorbed contaminants, particularly under conditions of high rainfall and leachate generation.(Li *et al.*, 2023).

The bioavailability and degradability of PAHs are also strongly influenced by their interactions with soil constituents.. Although a substantial proportion of soil-associated PAHs may be retained within the soil matrix, total PAH concentration does not necessarily represent the fraction available for biological uptake or microbial degradation. Strong sorption to soil organic matter and condensed carbonaceous materials, such as black carbon, can reduce the freely dissolved and readily bioavailable fractions of PAHs, whereas weakly sorbed fractions may remain more accessible to microorganisms, plants and transport processes.

Soil pH may also influence PAH behaviour, although this effect is generally indirect

because most parent PAHs are non-ionizable under typical environmental conditions.. Changes in pH can modify soil organic matter characteristics, microbial activity and community composition, nutrient availability and mineral surface properties, thereby indirectly affecting PAH sorption, transformation and degradation (Hu *et al.*, 2025). Similarly, CEC and clay mineralogy may influence PAH retention indirectly by reflecting the abundance and characteristics of reactive mineral and organic surfaces capable of interacting with hydrophobic contaminants (Muller *et al.*, 2007; Zhao *et al.*, 2023).. These interactions demonstrate that the fate of PAHs cannot be attributed to a single soil property but rather results from the combined effects of several physicochemical characteristics.

The environmental fate of PAHs in soil reflects the balance among sorption, desorption, dissolution, volatilization, degradation and transport processes.. PAHs with strong sorption to soil organic matter and carbon tend to exhibit reduced mobility and longer residence times, whereas less strongly sorbed compounds may be more readily transported through leaching, runoff, volatilization, or erosion. Their persistence is also influenced by molecular characteristics such as molecular weight and number of aromatic rings. Low-molecular-weight PAHs generally exhibit greater volatility and water solubility and may therefore be relatively more mobile, whereas high-molecular-weight PAHs generally have lower volatility and solubility but stronger associations with soil organic matter and carbonaceous phases, resulting in greater persistence in soil (Berríos-Rolón *et al.*, 2025; Ukalska-Jaruga *et al.*, 2020).Despite the extensive literature on soil-PAH interactions, site-specific information remains limited on how variations in physicochemical properties influence the potential environmental behaviour of PAHs in heterogeneous municipal dumpsite soils. In particular, there is



insufficient information on the spatial variability of pH, EC, SOC, SOM, CEC and particle-size distribution in Gosa dumpsite soils and the implications of these characteristics for PAH retention, mobility and potential bioavailability. This knowledge gap limits the interpretation of contaminant behaviour and the development of appropriate environmental management strategies for the site.

Characterizing the physicochemical properties of Gosa dumpsite soils is therefore important for establishing the environmental conditions that may govern PAH partitioning, retention, mobility and persistence. The findings can provide site-specific baseline information for environmental risk assessment, contaminant monitoring and remediation planning, while contributing to the broader understanding of PAH behaviour in heterogeneous waste-disposal environments. Such information is particularly relevant for assessing the potential movement of contaminants from dumpsite soils into surrounding terrestrial and aquatic environments.

Therefore, this study aims to characterize the physicochemical properties of soils within and around the Gosa dumpsite, Abuja, Nigeria, and evaluate their potential implications for the retention, mobility and bioavailability of PAHs in the soil environment.

Specifically, the study determines the pH, temperature, electrical conductivity, cation exchange capacity, soil organic carbon, soil organic matter and particle-size distribution of soils collected from selected locations within and around the dumpsite, and examines the potential implications of their spatial variability for PAH retention, mobility and bioavailability.

2.0 Materials and Methods

2.1 Materials

Barium chloride dihydrate ($\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$), magnesium sulphate (MgSO_4), potassium

dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$), sulphuric acid (H_2SO_4), sodium fluoride (NaF), phosphoric acid (H_3PO_4), ferroin solution, ferrous ammonium sulphate ($\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$) and sodium hexametaphosphate ($\text{Na}_6(\text{PO}_3)_6$) (AR/ACS) were purchased from LOBA Chemie Laboratory and Fine Chemicals, Palghar, India.

2.2 Study Area

The Gosa dumpsite is an open waste-disposal facility covering approximately **90 ha** and is located near Idu Train Station along the Nnamdi Azikiwe International Airport Road, Abuja, Nigeria. The study area lies between approximately $09^\circ 01' .270''$ N, $07^\circ 19' .590''$ E and $09^\circ 01' .173''$ N, $07^\circ 20' .510''$ E. The dumpsite has reportedly been in operation for approximately two decades and constitutes one of the major waste-disposal sites serving Abuja. Solid wastes deposited at the site comprise both biodegradable and non-biodegradable materials.

The soils within and around the dumpsite are predominantly sandy loam and clayey in texture. The study area experiences a tropical seasonal climate characterized by distinct rainy and dry seasons. The rainy season generally extends from April to October, whereas the dry season occurs from November to March. Mean annual precipitation is approximately 1,100–1,600 mm, while mean monthly temperatures generally range from 25 to 30 °C. These climatic conditions may influence waste decomposition, leachate generation, contaminant transport and the physicochemical characteristics of the surrounding soils.

The location of the Gosa dumpsite and the sampling area are presented in Fig. 1.

2.3 Soil Sampling and Pretreatment

A total of 74 soil samples were collected from locations within and around the fenced Gosa dumpsite. Soil samples were collected from the 0–20 cm surface-soil layer using a stainless-steel soil auger. Before each



sampling operation, grasses, surface litter, debris and other foreign materials were carefully removed from the sampling point using a hand trowel. The sampling equipment was cleaned between sampling locations to minimize cross-contamination.

Ten soil samples were collected randomly from different locations within the fenced dumpsite. For sampling outside the dumpsite, the surrounding area was divided into four cardinal directions: North, South, East and West. Four transects, separated by 30 m, were

established perpendicular to the dumpsite boundary in each direction. Each transect extended outward from the dumpsite fence, with sampling points established at 10-m intervals from the fence to a maximum distance of 40 m. Thus, 16 sampling points were established in each direction, giving a total of 64 exterior sampling points. Combined with the 10 samples collected within the dumpsite, a total of 74 soil samples were obtained.

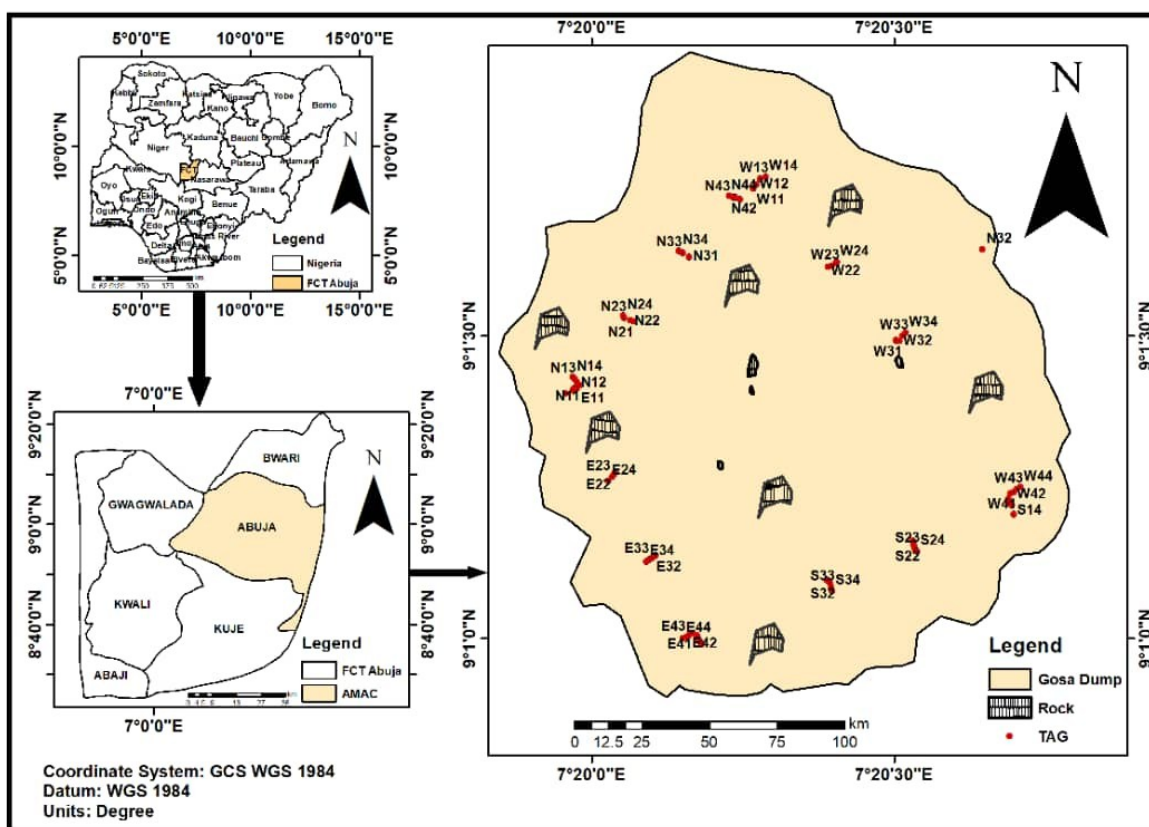


Fig. 1: Map of Gosa dumpsite (Source Omada *et al*, 2024)

Each sample was transferred into a clean, labelled polyethylene bag and transported to the laboratory immediately after collection. The samples were stored under cool, dark conditions prior to laboratory processing. In the laboratory, samples were manually homogenized, and visible stones, plant residues, plastics and other foreign materials

were removed. The samples were passed through a 2-mm stainless-steel sieve to remove coarse materials and subsequently air-dried at room temperature in a cool, well-ventilated environment. The dried samples were gently pulverized and passed through a 1-mm sieve before analysis. The processed samples were stored in clean, labelled polyethylene bags



until physicochemical analysis.

2.4 Determination of Physico-chemical characteristics of Soil

The physicochemical properties determined for the soil samples included pH, temperature, electrical conductivity (EC), cation exchange capacity (CEC), soil organic carbon (SOC), soil organic matter (SOM), and particle-size distribution (soil texture). The analytical procedures used for each parameter are described below..

2.4.1 Soil pH and Temperature

Soil pH and temperature were determined using standard procedures. Soil temperature was measured in situ at each sampling location using a calibrated soil thermometer. For laboratory determination of pH, a soil–water suspension was prepared by mixing the soil sample with deionized water at a 1:2.5 soil-to-water ratio (w/v). The suspension was thoroughly mixed and allowed to equilibrate before the pH was measured using a previously calibrated pH meter following the procedure described by FAO (2021a). The pH meter was calibrated using appropriate standard buffer solutions before measurements.

2.4.2 Electrical Conductivity

Electrical conductivity (EC) was determined using a calibrated conductivity meter following the procedure described by FAO (2021b). A soil–water suspension was prepared by mixing the soil sample with deionized water at a 1:5 soil-to-water ratio (w/v). The suspension was thoroughly mixed and allowed to equilibrate, after which the electrical conductivity of the supernatant was measured. The EC values were recorded in the appropriate conductivity units, preferably dS m^{-1} or $\mu\text{S cm}^{-1}$, depending on the instrument used.

2.4.3 Cation Exchange Capacity

Cation exchange capacity (CEC) was determined using the modified compulsive exchange method described by Gilman and

Sumpter (1986). Briefly, 2.0 g of prepared soil was weighed into a 30-mL centrifuge tube, after which 20 mL of 0.1 M $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ was added. The mixture was shaken for 2 h and subsequently centrifuged at 10,000 rpm. The supernatant was carefully separated from the soil residue by decantation.

A further 20 mL of 0.002 M $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ was added to the soil residue, followed by shaking and centrifugation under the same conditions. The supernatant was separated by decantation, and the washing procedure was repeated twice to remove residual exchangeable ions.

Thereafter, 10 mL of 0.005 M MgSO_4 solution was added to the soil residue and the mixture was shaken for 1 h. The resulting solution was separated, and its conductivity and pH were measured. The concentration of Mg^{2+} remaining in the final solution was determined according to the adopted method, and the CEC was calculated from the difference between the amount of Mg^{2+} initially added and that remaining in the final solution.

$\text{CEC (meq/100g)} = \text{Total Mg added} - \text{Mg in final solution} \times \text{dilution factor}$ (1)

$\text{Mg added (meq)} = \text{Volume of MgSO}_4 \text{ solution (mL)} \times \text{concentration of MgSO}_4 \text{ (meq mL}^{-1}\text{)}$;

$\text{Mg remaining (meq)} = \text{Volume of final supernatant (mL)} \times \text{concentration of Mg}^{2+} \text{ in the supernatant (meq mL}^{-1}\text{)}$;

Dilution factor was calculated according to the dilution procedure used in the adopted analytical method.

2.4.4 Soil Organic Carbon and Organic Matter

Soil organic carbon (SOC) was determined using the Walkley–Black wet oxidation method described by Walkley and Black (1934). Briefly, 2.0 g of air-dried, sieved soil was weighed into a 500-mL Erlenmeyer flask. Ten millilitres of potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) solution and 20 mL of concentrated H_2SO_4 were added successively. The contents were gently swirled to ensure thorough mixing



and allowed to stand for 30 min to complete the oxidation reaction.

Subsequently, 200 mL of distilled water, 10 mL of 85% H_3PO_4 , 0.2 g of NaF and a few drops of ferroin indicator were added. The remaining dichromate was titrated with 0.5 M ferrous ammonium sulfate solution. A reagent blank containing all reagents except the soil sample was prepared and titrated under identical conditions.

The percentage of organic carbon was calculated using equation 2

$$\%SOC = \frac{[(X-Y)] \times M \times 0.003 \times 100}{W} \quad (2)$$

where X = Vol of ferrous ammonium sulphate used to titrate blank, Y = Vol of ferrous ammonium sulphate used to titrate sample and $12/4000$ = milliequivalent weight of C in g

$$\% OM = \frac{\% Total C \times 1.72}{0.58} \quad (3)$$

$$\% total C = \frac{\% C}{0.77} \quad (4)$$

Soil texture was determined using the hydrometer method as described by Beretta *et al.* (2014). Air-dried soil samples were gently

disaggregated and passed through a 2-mm sieve. The soil samples were dispersed using a 5% sodium hexametaphosphate (Calgon) solution. The resulting suspension was thoroughly mixed and transferred into a 1-L sedimentation cylinder. Hydrometer readings were taken at specified settling times, with appropriate corrections made for temperature and the reagent blank. The proportions of sand, silt, and clay were calculated from the hydrometer readings, and the textural class of each soil sample was determined using the USDA soil-texture classification system (Beretta *et al.*, 2014).

3.0 Results and Discussion

The physicochemical characteristics of soils collected within and around the Gosa dumpsite are presented in Table 1. The parameters evaluated included soil pH, temperature, electrical conductivity (EC), soil organic carbon (SOC), soil organic matter (SOM), cation exchange capacity (CEC), and particle-size distribution.

Table 1: Physicochemical Properties of Soils from Within and Around Gosa Dumpsite

Parameter	SC	SN	SS	SE	SW
pH	8.19 ± 0.01	7.88 ± 0.09	8.25 ± 0.01	7.46 ± 0.05	7.53 ± 0.14
Temperature (°C)	29.70 ± 0.01	29.70 ± 0.01	29.50 ± 0.01	29.60 ± 0.01	29.70 ± 0.01
EC ($\mu S\ cm^{-1}$)	494.00 ± 0.50	133.00 ± 0.01	187.00 ± 0.01	130.00 ± 1.15	212.00 ± 1.52
SOC (%)	2.02 ± 0.13	1.46 ± 0.05	1.62 ± 0.09	1.21 ± 0.13	1.62 ± 0.18
SOM (%)	4.00 ± 0.26	3.08 ± 0.15	3.24 ± 0.18	2.36 ± 0.23	3.20 ± 0.40
CEC	17.18 ± 0.01	18.82 ± 0.02	19.08 ± 0.01	20.17 ± 0.01	16.54 ± 0.01
Soil texture (%)					
Sand	Verify	36.30 ± 0.02*	82.47 ± 0.32	61.00 ± 0.03	83.00 ± 0.15
Silt	40.00 ± 0.29*	38.33 ± 0.60	8.33 ± 1.88	6.66 ± 1.80	6.64 ± 0.13
Clay	Verify	10.35 ± 0.07	14.11 ± 0.01	33.19 ± 0.11	11.20 ± 0.14

Note: SC = soil collected within the dumpsite; SN = soil collected north of the fenced dumpsite; SS = soil collected south of the fenced dumpsite; SE = soil collected east of the fenced dumpsite; SW = soil collected west of the fenced dumpsite. Values are presented as mean ± standard deviation.

The results showed spatial variability in several physicochemical properties, reflecting

differences in soil composition and potentially variations in waste deposition, decomposition



processes, leachate distribution and the inherent characteristics of the underlying soils. These physicochemical characteristics are relevant to the environmental behaviour of organic contaminants because they can influence contaminant partitioning, sorption, mobility and potential bioavailability.

3.1 Soil pH

Soil pH ranged from 7.46 ± 0.05 at SE to 8.25 ± 0.01 at SS, indicating that the soils were generally neutral to moderately alkaline. The relatively alkaline conditions may be associated with the heterogeneous composition of the deposited wastes, including ash, construction-derived materials, concrete residues and other alkaline components. The decomposition of organic wastes and associated geochemical reactions may also contribute to changes in soil pH through the release and transformation of dissolved chemical constituents.

The pH of dumpsite soils may vary with the age and stage of waste decomposition. During the early stages of waste degradation, the production of organic acids can result in acidic leachate and relatively low pH. As decomposition progresses, the consumption and transformation of readily degradable organic acids, together with the maturation of the waste matrix, may result in relatively neutral or alkaline conditions (Podlasek *et al.*, 2023; Benaddi *et al.*, 2022). The relatively neutral to alkaline conditions observed at Gosa may therefore be consistent with the reported prolonged operation of the dumpsite. However, the present study did not establish a direct causal relationship between dumpsite age and soil pH.

The observed pH values are comparable with those reported for other Nigerian dumpsites. Agibe (2014) reported soil pH values of 7.84–8.26 in selected dumpsites in Kano, which are comparable with the Gosa values. Similarly, soils from Saje dumpsite in Abeokuta were

reported to be moderately alkaline, with pH values of 7.95–8.53 (Ojekunle *et al.*, 2018). Sawyerr *et al.* (2017) reported pH values of 7.1–7.8 in dumpsites located in satellite towns of the Federal Capital Territory. The relatively similar pH ranges among these sites suggest that neutral to alkaline conditions can occur commonly in Nigerian dumpsite soils. Differences among individual sites may reflect variations in waste composition, degree of decomposition, soil parent material, mineral composition and the quantity and composition of leachate reaching the soil.

Because most parent PAHs are non-ionizable under typical environmental conditions, soil pH is unlikely to control their sorption through direct ionization mechanisms. Nevertheless, pH can indirectly influence PAH behaviour by modifying the characteristics of soil organic matter, dissolved organic matter, microbial communities and mineral surfaces. Thus, the neutral to moderately alkaline conditions at Gosa may contribute indirectly to the partitioning and degradation of PAHs, although pH alone cannot be regarded as a direct indicator of PAH retention or bioavailability.

3.2 Soil temperature

Soil temperature varied only slightly among the sampling locations, ranging from 29.5 ± 0.01 to 29.7 ± 0.01 °C. The narrow range indicates relatively uniform thermal conditions across the sampling locations at the time of sampling. Soil temperature in waste-disposal environments can be influenced by ambient temperature, solar radiation, microbial activity and heat generated during the decomposition of organic wastes.

The observed temperatures are consistent with the warm climatic conditions prevailing in Abuja and fall within the range commonly reported for surface soils in tropical waste-impacted environments. The relatively warm conditions may support microbial decomposition of biodegradable materials;



however, microbial activity is also controlled by moisture availability, oxygen supply, substrate quality and nutrient conditions. Consequently, temperature should not be considered independently when interpreting decomposition processes at the dumpsite.

The limited spatial variation in temperature suggests that temperature was unlikely to be a major factor responsible for differences in the physicochemical characteristics among the sampling locations. It may nevertheless influence contaminant processes at the site because temperature can affect molecular diffusion, desorption and microbial degradation. Given the narrow temperature range observed in the present study, variations in SOC, SOM, texture and other soil characteristics are likely to be more important in explaining potential differences in contaminant behaviour.

3.3 Electrical Conductivity

Electrical conductivity (EC) showed considerable spatial variation, ranging from $130 \pm 1.15 \mu\text{S cm}^{-1}$ at SE to $494 \pm 0.50 \mu\text{S cm}^{-1}$ at SC. The highest EC at SC indicates a relatively greater concentration of soluble ionic constituents in the soil solution at this location. Such constituents may originate from decomposing organic wastes, household refuse, ash, dissolved salts and weathering materials.

The EC values obtained in the present study are broadly comparable with values reported for other Nigerian dumpsites. Agibe (2014) reported EC values of $171.3\text{--}286.1 \mu\text{S cm}^{-1}$ for selected dumpsites in Kano. Thus, some Gosa sampling locations had EC values within this range, whereas SC exhibited a higher value. Sawyerr et al. (2017) reported conductivity values of $81\text{--}137 \mu\text{S cm}^{-1}$ in dumpsites located in satellite towns of Abuja. The higher EC observed at some Gosa locations may reflect differences in waste composition,

decomposition processes and soluble material accumulation.

The elevated EC at SC may indicate greater accumulation of soluble materials and possible influence of leachate. However, EC alone cannot confirm leachate contamination or identify the specific ions responsible for the observed conductivity. Rather, spatial differences in EC provide evidence of variation in the ionic environment of the soil and may reflect differences in waste deposition and leachate distribution.

Although EC is not a direct measure of PAH contamination, variations in ionic strength may influence interactions among dissolved organic matter, mineral surfaces and hydrophobic contaminants under some soil conditions. Therefore, the relatively high EC at SC, when considered together with its elevated SOC and SOM, suggests that this location has a distinct chemical environment that could influence the partitioning and mobility of organic contaminants.

3.4 Soil Organic Carbon and Organic Matter

SOC concentrations ranged from $1.21 \pm 0.13\%$ at SE to $2.02 \pm 0.13\%$ at SC, whereas SOM ranged from $2.36 \pm 0.23\%$ to $4.00 \pm 0.26\%$. SC recorded the highest SOC and SOM concentrations, while SE recorded the lowest. The parallel variation in SOC and SOM is expected because organic carbon constitutes a major component of soil organic matter.

The relatively high SOC and SOM at SC may reflect greater accumulation and decomposition of biodegradable waste within the fenced disposal area. Municipal dumpsites commonly contain food residues, plant materials, paper and other organic materials that can contribute to soil organic matter during decomposition. Ideriah et al. (2006), for example, reported mean soil organic matter values of approximately $5.28\text{--}5.46\%$ in a solid-waste dumpsite in Port Harcourt, which were higher than the values observed at Gosa. Conversely, the SOC values obtained at Gosa



are broadly comparable with the 1.35–1.86% reported by Agibe (2014) for selected dumpsites in Kano, although the value recorded at SC was slightly higher.

Considerably higher SOC and SOM values were reported for an e-waste dumpsite in Alaba, Lagos, where SOC ranged from 13.75–20.25% and SOM from 17.88–26.32% (Okushemiya, 2023). The substantially lower values at Gosa may reflect differences in waste composition, soil type, degree of decomposition and the amount of organic material accumulated at individual sampling locations.

The variation in SOC and SOM is environmentally important because organic matter contributes to soil structure, nutrient retention and contaminant sorption. Organic-rich zones may act as sinks for hydrophobic contaminants while simultaneously serving as sources of dissolved organic constituents during decomposition and leaching. In particular, soil organic matter represents an important sorption domain for hydrophobic organic contaminants such as PAHs.

3.5 Cation Exchange Capacity

CEC values ranged from 16.54 ± 0.01 to 20.17 ± 0.01 [insert appropriate unit], with the highest value recorded at SE and the lowest at SW. The relatively narrow range suggests comparatively limited spatial variability in the capacity of the soils to retain exchangeable cations.

CEC is strongly influenced by clay minerals and soil organic matter. The relatively high CEC at SE may therefore be associated with its comparatively high clay content, as indicated by the particle-size data. The CEC values obtained at Gosa were generally higher than those reported by Agibe (2014) for selected dumpsites in Kano, where values ranged from 8.22 to 14.96 cmol kg⁻¹. Similarly, Oyeyiola (2017) reported a CEC of 7.38 cmol kg⁻¹ for dumpsite soil in Lagos. Differences among sites may be associated with variations in clay

mineralogy, organic matter content, soil parent material and waste-derived inputs.

The relatively high CEC at Gosa may enhance the retention of exchangeable nutrient and metal cations. However, high CEC does not indicate an absence of contamination because retained contaminants can become mobile when soil conditions change, including changes in pH, ionic strength and organic-matter decomposition.

CEC should not, however, be interpreted as a direct measure of PAH sorption. Parent PAHs are predominantly neutral, hydrophobic compounds and are not retained through conventional cation-exchange mechanisms in the same manner as positively charged metal ions. Instead, CEC provides indirect information about the abundance and characteristics of clay minerals and organic matter, which may contribute to contaminant retention through surface adsorption and hydrophobic partitioning. Thus, the relatively high CEC at SE, together with its relatively high clay content, may indicate a soil matrix with greater potential for contaminant retention than predominantly sandy locations, although direct PAH sorption measurements would be required to confirm this relationship.

3.6 Soil Texture and Particle-Size Distribution

The particle-size distribution showed spatial differences in the proportions of sand, silt and clay among the sampling locations. The soils were generally dominated by sand, particularly at SS and SW, where sand accounted for approximately 82.47% and 83.00%, respectively. SC contained a relatively greater proportion of silt, whereas SE had a comparatively high clay fraction of approximately 33.19%. These differences indicate spatial heterogeneity in the physical characteristics of the Gosa soil.

The predominance of sand at several sampling locations indicates relatively coarse-textured soils with potentially greater permeability. Such characteristics may facilitate infiltration



and downward movement of water and dissolved constituents through the soil profile. This is environmentally important in a dumpsite because rainfall infiltration may promote the movement of leachate and dissolved contaminants toward deeper soil layers and potentially groundwater. However, actual contaminant transport depends on additional factors, including soil moisture, hydraulic conductivity, organic carbon content, contaminant properties and the intensity of rainfall.

The predominance of sand at Gosa is consistent with observations from several Nigerian dumpsites. Amos-Tautua et al. (2014) reported 87.40–91.42% sand in dumpsite soils from Yenagoa, Nigeria, with the soils classified as loamy sand to sandy. Similarly, an e-waste dumpsite study in Lagos reported sand contents ranging from 58.56 to 87.52%. Ideriah et al. (2014) also described the main dumpsite soil in Port Harcourt as loamy sand and noted that its coarse texture could increase susceptibility to downward movement of surface-derived pollutants.

The relatively high sand content at several Gosa locations may therefore favour contaminant mobility, particularly where the soil contains relatively low amounts of organic carbon and fine particles. Conversely, locations containing greater proportions of clay and silt may have greater surface area and more potential sorption sites. However, the influence of texture should be interpreted together with SOC and SOM because organic carbon can provide an important sorption domain for hydrophobic organic contaminants.

The spatial heterogeneity in particle-size distribution is therefore important for understanding the potential environmental behaviour of contaminants at Gosa. During rainfall events, sandy zones may permit relatively rapid infiltration, whereas clay-rich zones may provide greater resistance to water movement and potentially enhance

contaminant retention. Nevertheless, direct measurements of hydraulic properties and contaminant concentrations would be required to quantify these processes.

3.7 Implications of Soil Physicochemical Properties for PAH Retention and Potential Bioavailability

The physicochemical characteristics observed at Gosa provide a basis for evaluating the potential influence of soil conditions on PAH behaviour. Because PAH concentrations, freely dissolved fractions, bioavailable fractions and PAH-specific sorption coefficients were not directly determined in the present study, the following interpretation represents an assessment of the potential implications of the measured soil properties rather than a direct measurement of PAH retention or bioavailability.

PAHs are predominantly hydrophobic organic compounds whose distribution in soil is strongly influenced by interactions with soil organic matter, organic carbon and mineral surfaces. Consequently, spatial differences in SOC, SOM and particle-size distribution may affect the extent to which PAHs partition into the soil matrix. The relatively high SOC and SOM concentrations at SC suggest greater potential for partitioning and retention of hydrophobic organic compounds at this location than at locations with lower organic matter contents. Strong association with soil organic matter can reduce the freely dissolved fraction of PAHs and may consequently reduce their immediate accessibility to microorganisms and other receptors (Yu et al., 2018; Lamichhane et al., 2016; Ukalska-Jaruga et al., 2020; Riding et al., 2013; Ren et al., 2017).

The relationship between soil organic matter and PAH availability is, however, complex. Stable and hydrophobic organic fractions may promote PAH sequestration, whereas relatively labile or dissolved organic matter may facilitate desorption and increase the apparent



availability of some PAHs. Previous studies have shown that the composition, stability and physicochemical characteristics of soil organic matter can therefore determine whether organic matter acts primarily as a contaminant sink or contributes to contaminant mobilization (Yu et al., 2018; Lamichhane et al., 2016; Ukalska-Jaruga et al., 2020). Thus, the relatively high SOC and SOM at SC may favour PAH retention, but this cannot be interpreted as evidence that PAHs at SC are necessarily unavailable or environmentally harmless.

Particle-size distribution provides an additional control on potential PAH mobility. The high sand content observed at SS and SW indicates relatively coarse-textured soils that may allow greater water infiltration and movement of weakly sorbed contaminants. During rainfall events, infiltration may facilitate the downward movement of dissolved or colloid-associated contaminants, particularly where organic-carbon content and sorption capacity are relatively low. Conversely, the greater clay fraction observed at SE may provide additional mineral surfaces capable of interacting with contaminants and may reduce their immediate mobility. The effect of texture should nevertheless be considered together with SOC and SOM because mineral surfaces alone may have a weaker influence on hydrophobic PAH partitioning than organic-carbon-rich phases.

The CEC results provide additional information about the mineral and organic characteristics of the soil matrix. Although CEC is not a direct mechanism for retaining neutral PAHs, relatively high CEC can be associated with greater proportions of clay minerals and organic matter. These constituents may contribute indirectly to contaminant retention through surface adsorption and hydrophobic partitioning. The relatively high CEC at SE, together with its comparatively high clay fraction, therefore suggests potentially greater capacity for contaminant retention than the more sandy

locations. Direct PAH sorption measurements would nevertheless be required to establish the magnitude of this effect.

The pH values of 7.46–8.25 indicate neutral to moderately alkaline conditions throughout the sampling area. Because most parent PAHs are non-ionizable under normal environmental pH conditions, pH is unlikely to exert a strong direct influence on their sorption through ionization. Nevertheless, pH may indirectly influence PAH behaviour by modifying the chemical characteristics of soil organic matter and dissolved organic matter, mineral surface properties and microbial activity. The observed pH conditions may therefore contribute to differences in PAH partitioning and degradation, although the present study did not directly measure microbial activity or PAH degradation rates.

EC ranged from 130 ± 1.15 to $494 \pm 0.50 \mu\text{S cm}^{-1}$, with the highest value at SC. The elevated EC indicates a greater concentration of soluble ionic constituents at this location and may reflect differences in waste decomposition and leachate influence. EC is not a direct indicator of PAH contamination; however, variations in the ionic environment may modify interactions among dissolved organic matter, mineral surfaces and hydrophobic contaminants. The combination of relatively high EC, SOC and SOM at SC is consistent with greater accumulation of soluble and organic constituents and may indicate stronger influence from waste decomposition and leachate processes.

Soil temperature varied only slightly, from 29.5 to 29.7 °C, indicating relatively uniform thermal conditions across the study area. Although temperature can influence contaminant diffusion, desorption and microbial degradation, the narrow range observed suggests that temperature was unlikely to be a major factor responsible for spatial differences in potential PAH behaviour at the time of sampling. Differences in SOC,



SOM, texture, CEC and leachate-related conditions are more likely to contribute to spatial variability in the potential retention and mobility of PAHs.

Overall, the results indicate that the physicochemical characteristics of Gosa dumpsite soils vary spatially and may create different conditions for contaminant retention and mobility. The relatively high SOC and SOM at SC may favour retention of hydrophobic PAHs, whereas the predominantly sandy texture at SS and SW may provide conditions conducive to infiltration and movement of weakly sorbed contaminants. The comparatively high clay content and CEC at SE may favour greater interaction with the soil matrix. These interpretations are consistent with previous studies identifying soil composition, organic matter, contaminant properties and environmental conditions as important controls of PAH partitioning and potential bioavailability (Yu et al., 2018; Lamichhane et al., 2016; Ukalska-Jaruga et al., 2020; Riding et al., 2013; Ren et al., 2017). However, direct determination of PAH concentrations, chemical profiles, freely dissolved fractions, bioavailable fractions and sorption characteristics would be necessary to quantitatively establish the relationship between the observed soil properties and PAH behaviour at Gosa.

4.0 Conclusion

This study determined the physicochemical properties of soil within and around Gosa dumpsite. The study demonstrated that the soils of the Gosa dumpsite exhibit considerable spatial variation in their physicochemical characteristics, reflecting differences in waste composition, decomposition processes, leachate influence and inherent soil properties. The soils were predominantly neutral to moderately alkaline, with pH values ranging from 7.46 to 8.25, while soil temperature

remained relatively uniform (29.5–29.7 °C). Electrical conductivity varied considerably among sampling locations, with the highest value recorded at SC, suggesting spatial differences in the accumulation of soluble constituents and possible leachate influence. Soil organic carbon and organic matter ranged from 1.21–2.02% and 2.36–4.00%, respectively, with the highest concentrations occurring at SC. The CEC values (16.54–20.17) and the predominantly sandy texture further demonstrate heterogeneity in the soil's capacity to retain contaminants and regulate their movement.

The physicochemical characteristics of the Gosa soils have important implications for the environmental fate of polycyclic aromatic hydrocarbons (PAHs). The relatively high organic carbon and organic matter contents, particularly at SC, provide important sorption domains for hydrophobic PAHs and may promote their retention within the soil matrix. Such retention can reduce the freely dissolved fraction of PAHs and consequently their immediate bioavailability, although strongly sorbed PAHs may persist in the soil for prolonged periods. The predominantly sandy texture observed at several sampling locations, particularly SS and SW, may conversely facilitate infiltration and downward movement of weakly sorbed PAHs through the soil profile, especially during the rainy season. The relatively higher clay fraction at some locations may increase sorption capacity through greater mineral surface area. These observations are consistent with established evidence that soil organic matter, mineral surfaces and contaminant–soil interactions are important controls of PAH sorption, desorption and bioavailability (Lamichhane *et al.*, 2016; Yu *et al.*, 2018).

The neutral to moderately alkaline pH conditions and relatively warm soil temperatures may also influence PAH fate indirectly by affecting microbial activity,



organic-matter characteristics and contaminant desorption. However, because most parent PAHs are non-ionizable under environmentally relevant pH conditions, pH should not be considered a primary determinant of their sorption in the same way as it is for ionizable contaminants. Similarly, CEC is not a direct measure of PAH sorption because PAHs are predominantly neutral compounds; rather, CEC provides an indication of the clay and organic-matter characteristics that can contribute indirectly to contaminant retention. Consequently, the observed PAH behaviour at Gosa is likely to result from the combined effects of organic carbon, organic matter, soil texture, mineral surfaces, temperature, pH and leachate processes rather than from any single physicochemical parameter.

The findings further indicate that total PAH concentration alone may not adequately represent the potential environmental risk associated with the Gosa dumpsite. PAHs retained strongly within organic matter or carbonaceous materials may have lower immediate bioavailability while remaining environmentally persistent. Conversely, weakly sorbed PAHs in sandy, organic-carbon-poor portions of the dumpsite may be more susceptible to desorption, transport and biological uptake. The distinction between total concentration and bioavailability is therefore important in assessing the environmental significance of PAHs at the site.

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Declaration

Conflict of Interest

The authors declare that there is no known conflict of interest or personal relationships that have influence the work reported in this paper.

Ethical Consideration

Not applicable

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Author Contributions

Henrietta Ijeoma Kelle conceived the study, designed the methodology, coordinated sampling, data analysis, and manuscript preparation. Joseph Itah Omada and Adebisi A. Fagbohun contributed to sample collection, laboratory analysis, interpretation, and manuscript review. Emeka Chima Ogoko supported environmental assessment, data interpretation, and editing. Yomi Barnabas Gideon contributed to geological and groundwater assessment. Bethel Onyeka Ekute supported laboratory analysis, data interpretation, and critical manuscript review. All authors approved the final manuscript.

