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Physicochemical, Heavy Metal and Microbial Concentrations in the Soil around the Idu Dumpsite, Abuja, Nigeria

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Abstract

Various human activities having influence on the environment, dumpsite remains one of the major point of references in assessing such influence. The study assessed the physicochemical, heavy metal and microbial concentrations in the soil sourced around the Idu Dumpsite, Abuja, Nigeria. Groundwater samples (3) were collected around the dumpsite and analysed through laboratory procedure and standard of American Public Health Association (APHA-2012). The finding revealed that The groundwater samples showed pH values of 6.83 –6.97, conductivity (103 – 105 µs/cm), Cation Exchange Cation (CEC) between 7.518 – 7.566 mg/kg, and total alkalinity levels of 40– 43.0 mg/kg. The nutrients concentration of the soil showed that Nitrate range from 1.054 – 1.123 mg/kg and Nitrite concentration range from 0.049 – 0.053 mg/kg. The mean concentration of heavy metals showed that Fe (6.92 mg/kg), Cu (2.0 mg/kg), Pb (0.97 mg/kg), Cd (2.27 mg/kg) and Cr (1.24 mg/kg) exceeded World Health Organization limits. The Total Heterotrophic bacterial (THB) of the soil sample ranged from 21×10^5 cfu/g to 53×10^5 cfu/g. Conclusively, the soils samples are characterized by elevated salinity, organic enrichment, nutrient loading, and heavy metal accumulation, with cadmium emerging as the principal ecological risk. There is need to establish a long-term monitoring program for the surrounding soil to ensure environmental sustainability practices.

Keywords: Environmental Pollution, Dumpsite, Physicochemical, Heavy Metal, Microbial Parameters, Cadmium

Introduction

The proportion of waste collected in developing countries averages 50%–80% of generated waste (Wilson et al., 2006). In several Nigerian cities, the rate of waste generation often exceeds the rate of waste collection (Akindutire and Alebiosu, 2013; Oloruntade et al., 2013; Omole et al., 2016). This ultimately results in a net accumulation of wastes (Omole et al., 2016). A rapid change occurred during the oil boom of the 1970s in the Nigerian urban environment with regard to the large amount of waste generated. State capital cities, along with other large cities in the country, were overtaken with all waste types, even though there were state and local government agencies in place for waste collection and disposal. These waste collection agencies were inefficient and lacked modern technology for the waste management (Omole et al., 2016).

Anthropogenic activities are the major source of contaminants to the soils. Major anthropogenic activities include the dumpsite, use of pesticides, herbicides, and fertilizers in agriculture; mining and smelting activities; leather tanning industries and heavy mechanical industries. These activities add various organic and inorganic contaminants to the soils which make the soil unsafe for humans, animals, plants, and microbes (Murtaza et al., 2014). Waste disposal through landfilling remains the most common method of solid waste management in many developing cities and poses a potential threat to various environmental components (Afolabi and Eludoyin, 2021; Aja et al., 2021).

Ingestion of heavy metals through food and drinking water is a major exposure source for the general human population. Industrialization, urbanization and the rapid economic development around the globe have led to intensification in industrial and agricultural activities (Ali et al., 2019). Such activities may cause contamination of water, air and soils with toxic heavy metals. Growing human foods in heavy metal-contaminated media lead to bioaccumulation of these elements in the human food chains from where these elements ultimately reach the human body (Ali et al., 2019). Soil enrichment with heavy metals could reflect historical human activities (Mazurek et al. 2017; Kowalska et al., 2018).

The improper management of landfill/dumpsites and generated leachate can cause a significant impact on the surrounding environmental media (Ololade et al., 2019; Jablonska-Trypuc et al., 2021; Vaverkováet al., 2020). Similarly, leachate from dumpsites is known to reduce soil quality due to various contaminants such as heavy metal which poses a risk to human health and the environment due to their toxicity (Afolabi et al., 2023). According to Afolabi & Adesope (2021), quantifying various contaminants in the environmental medium around and within the anthropogenically impacted area is essential and can help provide appropriate remedial measures and enhance sustainability practices. The aim of the study was to assessed the physicochemical, heavy metal and microbial concentrations in the soil around the Idu Dumpsite, Abuja, Nigeria.

Material and Methods

Study Area

The study area was the Idu Dumpsite, located within the Idu Industrial Area of the Abuja Municipal Area Council (AMAC) in Nigeria's Federal Capital Territory (FCT). Geographically, the Idu area lies between latitudes 9°03′44″ N and longitude 7°20′32″ E (Figure 1) in the northeastern part of Abuja. The site is accessible through the Idu Industrial Road, adjoining major transport and industrial corridors that support manufacturing, metal works, and automobile activities (Enitan et al., 2018).

The Idu dumpsite serves as one of the main solid waste disposal points for Abuja, receiving a mixture of municipal, industrial, and construction wastes. Its proximity to residential settlements, small-scale industries, and surface drainage channels increases the potential for environmental contamination and human exposure (Enitan et al., 2018). The surrounding environment falls within the Guinea Savannah ecological zone, characterised by moderate relief, tropical climate, and an annual rainfall of about 1,500 mm between April and November. Soils in the area are typically ferruginous tropical soils prone to leaching and metal accumulation, while drainage patterns flow toward low-lying wetlands and streams (Enitan et al., 2018).

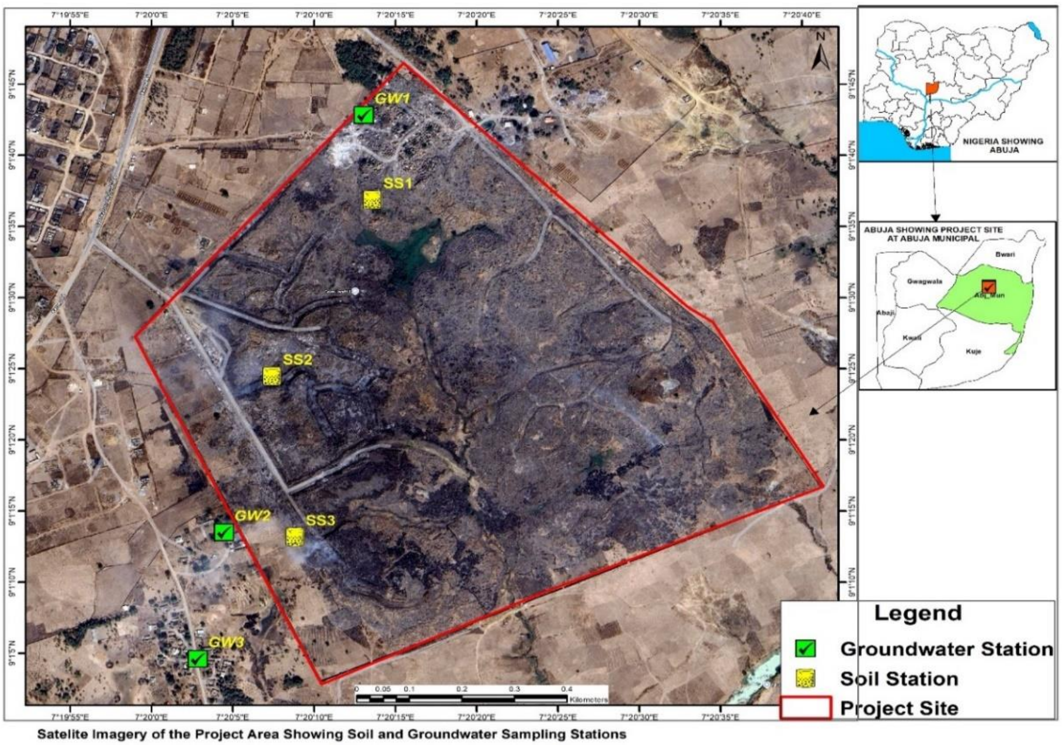

Figure 1: Overview of the Idu dumbsite and sampling points for groundwater and soil samples

Sample Collection Procedure

The samples for the study were collected on the 2nd of May, 2025, using standard procedure and required apparatus such as bottles, icebox, gloves, marker, handheld global positioning system (GPS) and zip-lock bags.

Soil samples (3-composite samples) were collected at three designated points within the dumpsite area at a distance of 100-150m away from each point. At each point, a radius of about 5-10 m was made around the point, and 5 random soil samples were collected around the radius into a collection pan at a depth of about 0-15 cm and mixed to form a composite sample for the designated point. The process was repeated for each point. All samples were collected while wearing gloves to prevent contamination, and the collected samples were instantly placed in an icebox and appropriately labelled and taken to the laboratory (Myrtle Analytical Laboratory and Innovation Limited) for analysis.

The geographical coordinates of each sampling point were recorded using a handheld global positioning system (GPS), and detailed geographical information for the sampling points is presented in Table 1 and Figure 1.

Table 1: Sampling Points Details and Geographical Information

Description	Code	Latitude	Longitude
Soil Point 1	SS1	9.026913	7.337109
Spoil Point 2	SS2	9.023466	7.335393
Soil Point 3	SS3	9.020329	7.335788

Data Analysis

Laboratory Analysis

Based on the American Public Health Association (APHA) 3030E, the sample was digested ~1 g with HNO_3, covered and heated to near-boiling (about 95°C) for ~15 minutes and cooled. 5 mL of HNO_3 was added and heated again to near-boiling for 15 min and then cooled. Slowly, 3–5 mL 30% H_2O_2 was added in small portions, allowing the reaction to subside before heating to ~95°C, then cooled.

The prepared soil sample was analysed for relevant physicochemical, anions, inorganic, heavy metals and microbial parameters following the standard methods of the APHA (2012), similar to those described by Afolagboye et al. (2020) and Afolabi et al. (2023). The summary of the analytical method used in analysing the sample parameters was presented in Table 2. The acidified water samples were filtered using Whatman ashless filter paper and thereafter analysed with an Atomic Absorption Spectrophotometer (Shimadzu AA-6650) using a standard method (ASTM 4691) to determine the level of heavy metals in the sample (Sokpuwu, 2017).

Table 2: Analytical method for sample parameters

Parameters	Analytical Method
pH	4500H+
Total Dissolved Solids (TDS), Total Suspend Solid (TSS), Total Solid (TS), Total Hardness (TH)	APHA 2540 C, APHA 2540 D, APHA 2540 B, APHA 2340 C
Electrical Conductivity (EC), Total Alkalinity, Bicarbonate/Carbonate, Chloride	APHA 2510, APHA 2320 B, APHA (4500-HCO_3^-/2320B, APHA 4500-Cl^- B/C,
Nitrite, Nitrate, Oil and Grease, Salinity, Chemical oxygen demand (COD), Biological oxygen demand (BOD)	APHA4500-NO_3, APHA 4500-NO_3^- E/B, APHA 5520 B/C, APHA 2520 B, APHA 5220 B, APHA 5210 B
Sulphate (SO_4^2), Ammonium, Phosphorus	APHA 4500-SO_4^{2-}E, APHA 4500-NH_3 G, APHA 4500-P E,
Lead (Pb), Iron (Fe), Chromium (Cr), Copper (Cu), Manganese (Mn), Zinc (Zn), Arsenic (As)	ASTMD 4691
Total Coliforms (TC), Heterotrophic Plate Count	APHA 9222B & 9222D, APHA 9215B

Result and Discussion

The physicochemical, heavy metals and microbial parameters of soil samples around the Idu dumpsite were analysed, and the outcome was presented in Table 3 and 4.

Physicochemical Parameters

pH: The pH value of the soil sample ranged from 6.830 at SS3, 6.963 at SS2 to 6.97 at SS1, with a mean pH value of 6.92 and 6.67 at the control point, while all the values are within the WHO permitted limit of 8.5. The pH of soils within the study area was near neutral at 6.92, reflecting a balance between acidic decomposition products and alkaline residues from ash and mineral wastes. This pH range favours the mobility of certain metals such as cadmium and lead, while also supporting active microbial populations. Similar neutral to slightly acidic soil conditions have been reported in Nigerian dumpsites, such as those in Lagos and Port Harcourt, where refuse decomposition creates fluctuating pH conditions that influence metal mobility (Afolabi & Eludoyin, 2021; Ejimofor et al., 2023). Globally, comparable near-neutral soils are observed at landfill sites in Spain and India, confirming that such pH is typical of mixed municipal waste environments (Monroy et al., 2019).

Electrical Conductivity (EC): The EC of the soil samples ranged from 103 µs/cm at SS2, 104.05 µs/cm at SS3 to 105.70 µs/cm at SS1 µs/cm with a mean concentration of 104.25 and a control point concentration of 81.1 µs/cm. All the reported EC concentrations are within the WHO allowable limit of 1000 µs/cm. EC was moderately elevated, indicating soluble salts from decomposing organic matter and household waste. Similar findings were documented in soils of south-eastern Nigerian dumpsites where ionic concentrations reflect leachate infiltration (Ibe et al., 2021). Elevated EC is also widely reported in international studies, where chloride-rich leachates increase soil salinity and compromise soil productivity (Kay et al., 2017).

Moisture Content (MC), Total Organic Carbon (TOC), Total Organic Matter (TOM) and Total Organic Nitrogen (TON): The MC concentration ranged from 3.115% at SS2 to 3.129% at SS1, with a mean concentration of 3.12 and a control point concentration of 0.15%. The TOC of the sample was 1.832% across all sample points with a control point concentration of 2.35%. The TOM of the soil sample ranged from 1.05% at SS3 to 1.063% at SS1, with a mean concentration of 1.06 and a control point concentration of 2.61%. The TON of the soil sample ranges from 0.048% at SS2 to 0.054% at SS3, with a mean concentration of 0.05 and a control point concentration of 0.54%. The soils contained appreciable organic fractions, reflecting municipal waste deposition and active decomposition. Elevated TOC and TOM enhance microbial proliferation and influence metal complexation, either stabilising or mobilising trace metals depending on redox conditions. Nigerian case studies in Aba and Enugu reported similar organic-rich profiles in dumpsite soils, highlighting their role in microbial enrichment and pollutant binding (Chiroma et al., 2020). Comparable organic matter enrichment has been described in European landfill soils (Naveedullah et al., 2019).

Exchangeable Cations and Cation Exchange Capacity (CEC)

The concentration of exchangeable potassium in the soil sample ranged from 0.292 Cmol/kg at SS2 to 0.298 Cmol/kg at SS1, with a mean concentration of 0.30. The concentration of exchangeable calcium in the soil sample ranged from 0.039 Cmol/kg at SS2 to 0.053 Cmol/kg at SS3, with a mean concentration of 0.05. The concentration of exchangeable magnesium in the soil sample ranged from 0.913 Cmol/kg at SS3 to 0.938 Cmol/kg at SS1, with a mean concentration of 0.93. The CEC of the soil sample ranged from 7.518 mg/kg at SS2 to 7.566 mg/kg at SS1 and SS3, with a mean concentration of 7.55 and a control point concentration of 1.12 mg/kg. Exchangeable sodium, calcium, magnesium, and potassium, along with moderate CEC values, suggest soils have some capacity to retain cationic metals. However, leachate saturation may overwhelm this buffering potential. This observation agrees with results from Onifade et al. (2018), who reported similar CEC levels in southeastern Nigeria dumpsites, attributing them to mineral-rich ash and clay fractions.

Nutrients (Nitrate, Nitrite, and Phosphate)

The concentration of NO_{3^-} in the soil sample ranges from 1.054 mg/k at SS2 to 1.123 mg/kg at SS3, with a mean concentration of 1.08 and a control point concentration of 0.21 mg/kg. The concentration of NO_2 in the soil sample ranges from 0.049 mg/k at SS3 to 0.053 mg/kg at SS1, with a mean concentration of 0.05 and a control point concentration of 0.25 mg/kg. The PO_3 concentration in the soil sample ranges from 1.827 mg/k at SS3 to 1.832 mg/kg at SS1, with a mean concentration of 1.83 and a control point concentration of 0.51 mg/kg. The soils contained measurable nutrient anions, consistent with waste-derived organic decomposition. Nigerian studies have frequently associated high nitrate and phosphate levels with refuse dumps and their potential to cause eutrophication in nearby water bodies (Ejimofor et al., 2022). Similarly, international findings highlight nitrates and phosphates as common landfill tracers impacting both soils and aquifers (Kay et al., 2017).

Table 3: Physicochemical Concentrations in the Soil Samples

S/N	Parameters	SS1	SS2	SS3	Control	Mean	SD	WHO
Physicochemical								
1	pH	6.970	6.963	6.830	6.67	6.92	1.36	8.5
2	EC	105.70	103.00	104.05	81.1	104.25	0.08	1000
3	Moisture Content (%)	3.129	3.115	3.124	0.15	3.12	0.01	-
4	Total Alkalinity	40.00	43.000	41.000	25	41.33	1.53	
5	Salinity	55.963	56.261	52.537	-	54.92	2.07	
6	Ammonium	0.296	0.290	0.293	-	0.29	0.003	
7	Ammonia	0.269	0.248	0.251	-	0.26	0.01	
8	*Exchangeable sodium	0.047	0.044	0.045	-	0.05	0.002	-
9	*Exchangeable potassium	0.298	0.292	0.297	-	0.30	0.003	-
10	*Exchangeable Calcium	0.042	0.039	0.053	-	0.05	0.01	-
11	*Exchangeable Magnesium	0.938	0.925	0.913	-	0.93	0.01	-
12	*Exchangeable Acidity	6.241	6.237	6.245	-	6.24	0.004	-
13	*Exchangeable Bases	1.325	1.313	1.322	-	1.32	0.01	-
14	CEC	7.566	7.518	7.566	1.12	7.55	0.03	-
15	Base Saturation (%)	17.514	17.514	17.514	11.41	17.51	0	-
16	SAR	0.067	0.063	0.065	0.01	0.07	0.002	-
17	ESP (%)	3.537	3.520	3.532	1.1	3.53	0.01	-
Macro Nutrients								
18	Total Nitrogen	13.310	13.305	13.323	18.51	13.31	0.01	-
19	Available Phosphorus	1.819	1.815	1.811	1.25	1.82	0.004	-
20	Total Potassium	116.131	116.243	116.135	-	116.17	0.06354	-
Organics								
21	TOC (%)	1.832	1.832	1.832	2.35	1.83	0	-
22	TOM (%)	1.063	1.060	1.050	2.61	1.06	0.01	-
23	TON (%)	0.053	0.048	0.054	0.54	0.05	0.003	-
Anions and Inorganic Elements								
24	Chloride	1.832	1.830	1.828	0.51	1.83	0.002	
25	Nitrite	1.063	1.054	1.123	0.21	1.08	0.04	-
26	Nitrate	0.053	0.051	0.049	0.25	0.05	0.002	40
27	Phosphate	1.832	1.827	1.831	0.51	1.83	0.003	40
28	Sulphate	1.063	1.055	1.060	1.11	1.06	0.004	250
29	Calcium	8.410	8.400	8.378	3.21	8.40	0.02	
30	Magnesium	112.610	112.600	112.590	10.3	112.6	0.01	
31	Sodium	10.780	10.773	10.776	2.46	10.78	0.004	

*unit in Cmol/Kg, All other parameters reported in mg/kg or indicated.

EC: Electrical Conductivity, TOC: Total Organic carbon, TOM: Total Organic Matter, TON: Total Organic Nitrogen, SAR: Sodium Adsorption Ratio, ESP: Exchangeable Sodium Potassium, CEC: Cation Exchange Cation

Table 4: Heavy Metals and Microbial Concentrations of the Soil Samples

S/N	Parameters	SS1	SS2	SS3	Control	Mean	SD	WHO
Heavy Metals (mg/kg)								
1	Iron (Fe)	3.280	3.281	3.282	<0.001	3.281	0.001	0.05
2	Copper (Cu)	2.000	2.341	2.256	<0.001	2.20	0.18	2.0
3	Lead (Pb)	0.966	0.968	0.963	<0.001	0.97	0.003	0.01
4	Zinc (Zn)	1.982	1.980	1.975	<0.001	1.98	0.004	3.0
5	Arsenic (As)	0.012	0.010	0.010	<0.001	0.010	0.001	
6	Mercury (Hg)	0.000	0.000	0.000	-	0	0	
7	Cadmium (Cd)	2.286	2.245	2.280	-	2.27	0.02	0.003
8	Chromium (Cr)	1.244	1.243	1.229	-	1.24	0.01	
Microbial Parameters (cfu/g)								
9	THB (10^5)	21	42	53	-	38.67	16.23	
10	THF (10^4)	10	10	10	-	10	0	
11	TC (10^5)	9	18	27	-	18	9	

THB: Total Heterotrophic Bacteria, THF: Total Heterotrophic Fungi, TC: Total Coliform

Anion (Chloride and Sulphate)

The sulphate concentration in the soil sample ranges from 1.055 mg/k at SS2 to 1.063 mg/kg at SS1, with a mean concentration of 1.06 and a control point concentration of 1.11 mg/kg. The Cl^- concentration in the soil sample ranges from 1.828 mg/k at SS3 to 1.832 mg/kg at SS1, with a mean concentration of 1.83 and a control point concentration of 0.51 mg/kg. Chloride and sulphate enrichment reflect decomposition of organic and inorganic refuse. Elevated chloride in dumpsite soils has been documented in Port Harcourt and Abuja, while global landfill studies consistently identify chloride as a leachate migration indicator (Abiye & Raimi, 2025).

Heavy Metals and Microbial Concentrations

Iron (Fe): the concentration of Fe in the soil sample ranged from 3.28 mg/kg at SS1 to 3.281 mg/kg at SS2, with a mean concentration of 6.92 and a control point concentration of <0.001 mg/kg. All the reported concentrations are above the WHO allowable limit for Fe at 0.05 mg/kg. Iron was enriched in soils and exceeded the WHO limit, consistent with corrosion products and ferrous waste. Similar enrichments are reported in Nigerian dumpsites such as Lagos and Port Harcourt (Afolabi & Eludoyin, 2021). Globally, Fe is consistently elevated in landfill soils but is considered less toxicologically significant compared to other metals.

Copper (Cu): The concentration of Cu in the soil sample ranged from 2.0 mg/kg at SS1 to 2.341 mg/kg at SS2, with a mean concentration of 2.20 and a control point concentration of <0.001 mg/kg. All the reported concentrations are above the WHO allowable limit for Cu at 2.0 mg/kg except SS1. Cu enrichment was moderate, originating from electronic waste and industrial refuse. Comparable results were reported in Ibadan and southeastern Nigeria, where Cu contamination was attributed to e-waste (Ibe et al., 2021).

Lead (Pb): The concentration of Pb in the soil sample ranged from 0.963 mg/kg at SS3 to 0.968 mg/kg at SS2, with a mean concentration of 0.97 and a control point concentration of <0.001 mg/kg. All the reported concentrations are above the WHO allowable limit for Pb at 0.01 mg/kg. The Pb contamination was evident as all the reported samples exceeded the WHO limits, consistent with disposal of batteries, paints, and vehicular residues. Pb exceedances are a recurring issue in Nigerian dumpsites (Onifade et al., 2018) and international studies, where their persistence poses significant public health risks.

Zinc (Zn): The concentration of Zn in the soil sample ranged from 1.975 mg/kg at SS3 to 1.982 mg/kg at SS1, with a mean concentration of 1.98 and a control point concentration of <0.001 mg/kg. All the reported concentrations are below the WHO allowable limit for Zn at 3.0 mg/kg. The zinc levels were moderate and concentrations were below the WHO standard, often linked to galvanised materials and batteries. Similar patterns have been reported globally, with Zn rarely being the dominant ecological risk driver but still capable of phytotoxicity under prolonged accumulation (Kay et al., 2017).

Arsenic (As): The concentration of As in the soil sample ranged from 0.010 mg/kg at SS2 and SS3 to 0.012 mg/kg at SS1, with a mean concentration of 0.01 and a control point concentration of <0.001 mg/kg. The As occurred at low levels, while mercury was minimal or absent, which aligns with Nigerian dumpsites that primarily receive household rather than industrial/healthcare wastes. Globally, Hg contamination is more associated with specific industrial landfills than municipal sites (WHO, 2021).

Cadmium (Cd): The concentration of Cd in the soil sample ranged from 2.245 mg/kg at SS2 to 2.286 mg/kg at SS1, with a mean concentration of 2.27. All the reported concentrations are above the WHO allowable limit for Cd at 0.003 mg/kg. The Cd was identified as the dominant ecological risk driver in this study. Its enrichment factor and ecological risk index far exceeded other metals, a finding consistent with Nigerian and global literature. Afolabi and Eludoyin (2021) and Monroy et al. (2019) similarly found Cd disproportionately influencing ecological risk at dumpsites due to its mobility and toxicity.

Chromium (Cr): The concentration of Cr in the soil sample ranged from 1.229 mg/kg at SS3 to 1.244 mg/kg at SS1, with a mean concentration of 1.24 and a control point concentration of <0.001 mg/kg. The Cr contamination was present at moderate levels, consistent with industrial and metallurgical waste inputs. Chromium enrichment in dumpsites is variably reported in Nigeria, with higher concentrations usually tied to industrial co-disposal (Ejimofor et al., 2023).

Microbial Parameters

The Total Heterotrophic bacteria (THB) of the soil sample ranged from 21x 10^5 cfu/g SS1 to 53x 10^5 cfu/g at SS3, with a mean concentration of 38.68x 10^5. The total heterotrophic fungi (THF) of the soil sample was 10x 10^4 cfu/g across all the sampling points. The TC of the soil samples ranged from 9x 10^5 cfu/g at SS1 to 27x 10^5 cfu/g at SS3, with a mean concentration of 18x 10^5. The soils harboured abundant heterotrophic bacteria and detectable coliforms, indicating active biodegradation and potential faecal contamination. Such microbial richness is widely documented in Nigerian dumpsites, including those in Abuja and Port Harcourt (Abubakar et al., 2020). Similar microbial activity is observed internationally, where waste-rich soils sustain high microbial loads that can pose sanitary risks.

Conclusion and Recommendations

Various human activities have an influence on the environment, dumpsite remains one of the major points of reference in assessing such influence. With consideration for environmental media such as soil from the Idu dumpsite, the study combined field sampling, laboratory analyses, and comparative evaluation against national and international standards to examine the physicochemical, nutrient, heavy metal, and microbial parameters in soil. Conclusively, the soil samples are characterised by elevated salinity, organic enrichment, nutrient loading, and heavy metal accumulation, with cadmium emerging as the principal ecological risk. Microbial proliferation further reflects sanitary and public health concerns. There is a need to initiate soil remediation measures such as phytoremediation or chemical stabilisation, targeting cadmium. Also, the waste management board should establish a long-term monitoring program for the surrounding soil, with periodic testing of physicochemical, microbial, and heavy metal parameters.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Credit Authorship Contribution Statement

Otu, M. A.: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Visualization, Project administration, Writing - original draft. **Woke, G. N. and Edwin-Wosu, N. L.:** Supervision, Methodology, Validation, Formal analysis, Data curation, Visualization, Review & Editing.

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