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WASTE-INDUCED SOIL DEGRADATION AT UNN: PHYSICO-CHEMICAL AND HEAVY METAL ASSESSMENT

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Abstract:
Improper waste disposal on land can alter soil physico-chemical properties and increase heavy metal accumulation. This study assessed soil characteristics and heavy metal concentrations at two dumpsites and nearby control sites at Odim-gate and the Faculty of Engineering (FOE), University of Nigeria, Nsukka. Soil samples were collected at 0–20 cm and 20–40 cm depths and analyzed using a 2 × 2 × 2 factorial design. Soils were predominantly sandy loam, ranging from slightly acidic to slightly alkaline, with high available phosphorus but low organic carbon (OC), total nitrogen, exchangeable bases (Ca^{2+}, Na^{+}, K^{+}), and effective cation exchange capacity. Dumpsites exhibited higher total porosity, pH, OC, Ca^{2+}, and Na^{+} concentrations but lower bulk density and exchangeable acidity (Al^{3+} and H^{+}) compared to control soils. OC and macronutrient concentrations were significantly greater in the topsoil. Heavy metals Fe and Pb were present at low concentrations overall, though Fe was significantly higher at Odim-gate and control sites. However, elevated Zn levels, particularly in the 0–20 cm layer of the FOE dumpsite, may pose environmental and health risks due to potential toxicity.

Keywords: *Soil contamination, Heavy metals, Dumpsite impact, Zinc accumulation*

INTRODUCTION

In general, the amount of waste generated in a municipality is directly proportional to population growth (Singh *et al.*, 2011). According to Kadafa (2017), solid municipal waste is generated daily, on average 0.5-1.5 kg day^{-1} per household. In southeastern Nigeria, particularly in Enugu State, waste management is increasingly becoming a complex task as millions of tons of solid waste from various sources (industrial, domestic and agricultural) are disposed in the soil. Soil is a complex and dynamic natural system that provides important services to humans and the environment, including transforming and recycling of raw materials by microorganisms. However, there is evidence of spatial contamination of soil *in-situ* at landfills and similar waste disposal sites (Aja *et al.*, 2021). Food waste, for example, is a common source of solid waste found in landfills and other disposal sites. The decomposition of organic food waste releases methane, a potent greenhouse gas that contributes to climate change and whose flammability can pose a danger to local residents (Rong *et al.*, 2015). Solid wastes such as construction waste, industrial waste and sludge from water treatment plants and air purification plants can contain various pollutants, including heavy metals, organic chemicals and pathogens. Over time, the accumulation of pollutants can lead to soil degradation, groundwater contamination and potential exposure of humans and wildlife to toxins (Aja *et al.*, 2021; Okebalama *et al.*, 2024).

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Open dumping of waste especially household waste is a common practice among low- and middle-income people in many developing countries (Salami *et al*., 2014). Such uncontrolled waste disposal can damage the environment, pollute soil and water resources and pose a potential health risk to plants, animals and humans (Baderna *et al*., 2011). Landfills can be a significant source of air pollution due to various factors such as unpleasant odours, methane leaks and fires, dust and windblown waste, and pests such as worms and flies. Solid waste also causes nuisance and significant pollution through the production of biogas and leachate due to the decomposition of organic matter (Aronsson *et al*., 2010). Such leachates contain a range of pollutants and can contaminate the surrounding soil and groundwater with heavy metals. Heavy metals in soil can alter soil chemistry and affect soil microorganisms and some plant species that depend on soil for nutrition (Nganje *et al*., 2007). Ideriah *et al*. (2005) found that heavy metal concentrations in soil near dumpsites are influenced by the type of waste, topography, runoff and the degree of heavy metal uptake by plants and other organisms.

On the other hand, studies have shown that soils from dumpsites are rich in soil nutrients (nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S), which are released into the soil during the decomposition of organic material (Ogbonna *et al*., 2009; Agbeshie *et al*., 2020). Municipal solid waste landfills are designed for the disposal of household and commercial waste within a specific jurisdiction, however, the decay and burning of certain hazardous and nonhazardous waste materials produce toxic substances such as heavy metals (Sari *et al.,* 2019). Soils from dumpsite in Nsukka metropolis have a heavy metal profile of iron (Fe) > zinc (Zn) > manganese (Mn) > copper (Cu) > chromium (Cr) > lead (Pb) > cadmium (Cd) (Ohanu *et al*., 2020).

As the first indigenous university in Nigeria, the University of Nigeria Nsukka (UNN), Nigeria, founded in 1955, generates a significant amount of solid and liquid waste on a daily basis due to the large number of students, staff and visitors. According to Ugwu *et al*. (2020), the University had a per capita solid waste generation rate of about of 0.06 kg day^{-1}. The waste generated is often disposed of by open dumping, incineration and burial in pits. The university had improved its waste management practices years ago by establishing a waste management committee and building a waste transfer station for sorting and collecting waste. However, the waste management strategies in the UNN hostels, for example, have proved ineffective (Nweke and Ajibo, 2022), as waste is currently dumped indiscriminately in open areas such as Odim Street, Awolowo Hostel, Student Union Building (SUB), etc. As a result, the waste and its unpleasant odours are blown by the wind and pollute the surrounding areas up to 20 m away from the site. Although consequences such as environmental pollution and health risks have been associated with major operational failures at the University (Nwachukwu and Adighije, 2017), waste dumpsites are a source of heavy metals in the ecosystem (Ohanu *et al*., 2020). Given their mobility, non-degradability and potential to cause adverse effects at toxic levels in soils, it is important to assess the heavy metal loads in the soil environment around the university dumpsites.

Solid waste disposal in soil is an important environmental and health issue that requires proper management and disposal practices to minimize the negative impact on soil quality and human health (Agbeshie *et al*., 2020; Aja *et al*., 2021). A more comprehensive analysis of the impacts of open dumping of waste on soil will lead to a better understanding of the mechanisms surrounding the retention, exposure and toxicity of heavy metals accumulation in dumpsite soils. The study is expected to provide reliable and useful baseline information necessary for establishing effective procedures for regulating, controlling and monitoring the environmental impacts of improper waste disposal. This study could help identify dumpsites where heavy metal reduction is urgently needed and thus contribute to the protection of the environment and human health within and around the University community. The information would also be useful to the University governing council in establishing policies to ensure sustainable land use planning and combat harmful disposal practices at the University. The aim of the study was to assess some soil physical and chemical properties including concentration of heavy metals in dumpsites at UNN, Nigeria. Assessing the pattern of heavy metal pollution and associated risks to the environment and human health lies outside the structured framework of our quantitative research.

MATERIALS AND METHODS

Study Area

Field reconnaissance was carried out in UNN, to select representative dumpsites and non-dumpsites (control). Two locations including the Odim-gate and the Faculty of Engineering were selected. The vegetation of the UNN consists mainly of derived savannah. The climate is tropical with rainy and dry seasons. The dry season last from November to March, while the rainy season occurs between April and October with very high intensity. The location has an average annual rainfall of around 1500-1600 mm and minimum and maximum average temperatures of 26 and 31 ^{0}C, respectively. Nsukka is 400 m asl and the soil at the study location originated from weathered Sandstone (Nwadialo, 1989).

The Odim-gate dumpsite is located after EniNjoku hostel and has been used as a dumping ground for over 10 years according to residents living around the area. The location lies within geographical coordinates of latitude 6°52' N and longitude 7°24' E at an altitude of 400 m, while the control site adjacent to the dumpsite is 50 m away. The waste generated from Odim inhabitants, and building sites around Odim, which includes some discarded metallic and plastic materials, farm residues etc., is usually dumped on the site and burned in the dry seasons (Plate 1).

The Faculty of Engineering dumpsite is located behind UNN Chitis restaurant, next to the Abuja building. The site has been used for refuse dump for over six years and the waste from Engineering Faculty canteens, chemistry, and physics laboratories are dumped and burned on the site during the dry seasons (Plate 2). The area is located at latitude 6°52' N and longitude 7°24' E at an altitude of 419

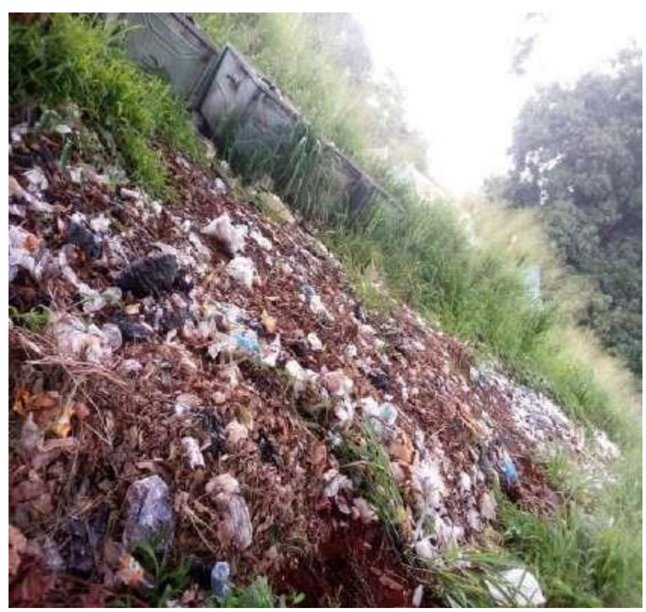

Plate 2: Cross-section of the

Plate 1: Cross-section of the Odim-gate dumpsite Engineering dumpsite

Collection of Soil Sample

Disturbed (auger) and undisturbed (core) soil samples were collected at two depths; 0-20 cm (topsoil) and 20-40 cm (subsoil) from the waste disposal sites and the adjacent control sites of the Odim-gate and the Faculty of Engineering locations. At each site, three experimental plots (replicates) were selected along an established transect and soil samples were collected at each depth within each replicate plot. Three auger and three core samples were collected, resulting in three sampling points per soil depth and six samples per study site. A total of 24 loose and 24 core samples (two locations, two study sites, two sampling depths, and three replicates) were taken and labelled accordingly. The soil samples were taken to the Department of Soil Science Uundergraduate Laboratory for sample preparation and analysis. The disturbed soil samples were air-dried, crushed and sieved through a 2.00mm mesh and used for particle size and chemical analyses (including heavy metal concentration) of the soils. The soil cores were trimmed and saturated for 48 h and used to determine bulk density and saturated hydraulic conductivity of the soils.

Soil Physical and Chemical Analysis

Particle size analysis was done by the Bouyoucous hydrometer method using sodium hexametaphosphate as dispersant (Gee and Bauder, 1986). Saturated hydraulic conductivity (K_{sat}) was by the constant head method and was calculated using Darcy's equation:

$$\text{Ksat (cm h}^{-1}) = \frac{Q * L}{AT\,\Delta H} \text{ .... (1);}$$

where Q is steady-state volume of flow (cm), A is cross sectional area (cm^3), L is length of core sample (cm), T is change in time interval (h), and ΔH is hydraulic head change (cm).

The bulk density was determined as described by Blake and Hartage (1986). The total soil porosity was calculated as the function of the total volume not occupied by soil solid assuming a particle density of 2.65 Mg m^{-3}, using the formula
below (Danielson and Sutherland, 1986).

$$\text{Porosity (\%)} = \left(1 - \frac{D}{D\,p}\right) * 100 \text{ .... (2);}$$

where Dp is particle density, assumed to be 2.65 Mg m^{-3}, and Db is bulk density. Soil pH was determined in water and in 0.1N KCl solution at a soil-liquid ratio of 1:2.5 and the pH values were measured with a glass electrode pH meter (McLean, 1982). Soil organic carbon (OC) was determined using the modified wet digestion and oxidation method of Walkey and Black (Nelson and Sommers, 1996). Total nitrogen (TN) was determined using the Micro-Kjeldahl distillation method as described by Bremner (1982). Available phosphorus (Av. P) was extracted using Bray-II (Olsen and Sommers, 1982). Soil exchangeable bases were extracted with 1N NH_4OAc pH 7 solution. Exchangeable calcium and magnesium were determined from the extract by EDTA titration, while exchangeable sodium and potassium were determined using a flame photometer (Van Reeuwijk, 2002). Exchangeable acidity (hydrogen and aluminium) was determined by the titration method with 1N KCl extract (McLean, 1982). The effective cation exchange capacity (ECEC) was determined by the summation of exchangeable bases and exchangeable acids. The concentrations of heavy metals iron (Fe), zinc (Zn), and lead (Pd) were extracted with 1N NH_4OAc pH 4.8 (Minkina *et al.* (2018) and measured using a UV/VIS spectrophotometer Single Beam VT-LI295 model (wavelength range, 190-1000 nm). Data Analysis

The study was laid out as a 2 x 2 x 2 factorial experiment. The factor A consists of the two locations (Odim-gate and Faculty of Engineering); Factor B consists of the dumpsite and the control site, and factor C includes the two soil depths (0-20 and 20-40 cm). Analysis of variance (ANOVA) using GenStat statistical package for windows was used to analyze the collected data on soil parameters. Mean separation was performed using the least significant differences (LSD) of means at 5% probability level. To assess the heavy metals concentration status of the soils studied, the permissible limit values for heavy metals in agricultural soil recommended by the United States Environmental Protection Agency (US EPA, 2003), and the WHO (1996) were used.

RESULTS

Some Physical Properties of the Studied Soils

The results on the particle size distribution of the soils at the Odim-gate and Faculty of Engineering locations (Table 1) showed that the sand content was predominant with mean values of 80.17% and 77.58%, respectively, while the silt content was lowest with mean values of 3.67% and 5.83%, respectively. The soils at both locations had a similar average clay content of about 16%. The sand and clay contents did not vary appreciably (CV < 19%) between the study locations, the study sites (control and dumpsite) and the soil depths (0-20 and 20-40 cm), whereas the silt content showed a higher variability (CV = 41.76%). Accordingly, the textural class of the soils was sandy loam (SL) at both locations, in both study sites and at both soil depths, with the exception of the sandy clay loam (SCL) texture at 20-40 cm depth at the Faculty of Engineering dumpsite.

The bulk density, hydraulic conductivity and total porosity of the soils at the Odim-gate and Faculty of Engineering locations ranged between

1.46 and 1.70 g cm^{-3}, 12.80 to 21.72 cm h^{-1}, and 35.97% to 44.91%, respectively (Table 2). In general, the soil bulk density was significantly higher in the control (1.65 g cm^{-3}) than the dumpsite (1.54 g cm^{-3}); the opposite was true for the total porosity of the soils (control, 37.45%; dumpsite, 41.92%). Significant differences in the interaction between location and soil depth also showed a higher bulk density at 0-20 cm than at 20-40 cm depth at the Odim-gate dumpsite, while the opposite was found at the Faculty of Engineering dumpsite. Saturated hydraulic conductivity was significantly higher at the Odimgate (17.49 cm h^{-1}) than at the Faculty of Engineering (14.28 cm h^{-1}) location, and also in the control soil compared to the dumpsite at Odim-gate.

Table 1: Particle size distribution and textural class of the studied soils

Location/Site		Soil depth (cm)	% Sand	% Silt	% Clay	Textural class
Odim-gate	Control	0 - 20	82.66	3.67	13.67 16.33	Sandy loam
		20 - 40 0 -	79.33	4.33	15.67 19.00	Sandy loam
	Dumpsite	20	81.33	3.00	16.17	Sandy loam
		20 - 40 Mean	77.33	3.67		Sandy loam
			80.17	3.67	15.00 13.00	
		0 - 20			16.33 21.67	
Engineering	Faculty	20 - 40 0 -	77.33	7.67	16.50	Sandy loam
	Control	20	83.00	3.67	18.99	Sandy loam
		20 - 40 Mean	78.00	5.67		Sandy loam
	Dumpsite	% CV	72.00	6.33		Sandy clay loam
			77.58	5.83		

	5.22	41.76

CV - Coefficient of variation

Table 2: Some physical properties of the studied soils

Location	Study site	Soil depth (cm)	Bulk density (g cm^{-3})	Ksat (cm h^{-1})	% Total porosity
Odim-gate	Control	0 - 20	1.65	17.68	37.11
		20 - 40	1.70	21.72	35.97
		Mean	1.67	19.70	36.54
	Dumpsite	0 - 20	1.64	12.80	40.50
		20 - 40	1.48	17.78	42.14
		Mean	1.56	15.29	41.32
		Grand mean	1.61	17.49	38.93
Engineering Faculty	Control	0 - 20	1.60	14.32	39.12
		20 - 40	1.65	14.01	37.61
		Mean	1.63	14.17	38.37
	Dumpsite	0 - 20	1.46	13.64	44.91
		20 - 40	1.60	15.15	40.13
		Mean	1.53	14.39	42.52
		Grand mean	1.59	14.28	40.44
$LSD_{0.05}$ Location			NS	2.24	NS
$LSD_{0.05}$ Study site			0.05	NS	2.55
$LSD_{0.05}$ Soil depth			NS	NS	NS
$LSD_{0.05}$ Location x Study site			NS	3.17	NS
$LSD_{0.05}$ Location x Soil depth			0.07	NS	NS
$LSD_{0.05}$ Study site x Soil depth			NS	NS	NS
$LSD_{0.05}$ Location x Study site x Soil depth			NS	NS	NS

K_{sat} - saturated hydraulic conductivity, $LSD_{0.05}$ - least significant difference at 5 % probability level, NS - not significant.

Table 3: Some chemical properties of the studied soils at Odim-gate and Faculty of Engineering locations

Location	Study site	Soil depth (cm)	pH-H_2O	OC (g kg^{-1})	% TN	Av. P (mg kg^{-1})	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Al^{3+}	H^{+}	ECEC
							---------------------------- cmol$_c$ kg^{-1} --------------------------						
Odim-gate	Control	0 - 20	6.73	0.98	0.04	28.60	0.80	0.73	0.03	0.07	0.20	2.27	4.10
		20 - 40	6.50	1.02	0.04	26.74	0.67	1.00	0.01	0.03	0.47	2.07	4.24

		Mean	6.62	1.00	0.04	27.70	0.73	0.87	0.02	0.05	0.33	2.17	4.17
	Dumpsite	0 - 20	7.77	1.88	0.05	27.67	2.27	1.07	0.07	0.13	0.20	1.60	5.34
		20 - 40	7.83	1.09	0.05	28.60	1.53	1.13	0.04	0.10	0.27	1.60	5.14
		Mean	7.80	1.49	0.05	28.10	1.90	1.10	0.06	0.12	0.23	1.60	5.24
		Grand mean	7.21	1.42	0.05	26.23	1.50	1.03	0.05	0.10	0.28	1.88	4.70
Engineering Faculty	Control	0 - 20	7.47	1.36	0.06	28.91	1.60	1.33	0.06	0.12	0.20	2.00	5.31
		20 - 40	7.50	0.84	0.05	32.02	1.20	0.80	0.03	0.07	0.20	1.40	3.70
		Mean	7.48	1.10	0.05	30.50	1.40	1.07	0.04	0.10	0.20	1.70	4.51
	Dumpsite	0 - 20	8.23	1.51	0.04	33.27	2.53	0.87	0.05	0.10	0.20	1.47	5.22
		20 - 40	8.00	0.23	0.07	33.26	1.00	0.67	0.01	0.04	0.20	1.33	3.25
		Mean	8.12	0.87	0.05	33.30	1.77	0.77	0.03	0.07	0.20	1.40	4.24
		Grand mean	7.80	0.96	0.05	31.87	1.48	1.01	0.04	0.08	0.20	1.55	4.37
$LSD_{0.05}$ Location			0.32	0.28	NS	4.48	NS	NS	NS	NS	0.05	0.33	NS
$LSD_{0.05}$ Study site			0.32	0.28	NS	NS	0.30	NS	0.01	0.02	0.05	0.33	NS
$LSD_{0.05}$ Soil depth			NS	0.28	NS	NS	0.30	NS	0.01	0.02	0.05	NS	NS
$LSD_{0.05}$ Location × Study site			NS	0.40	NS	NS	0.42	0.44	0.02	0.03	0.07	NS	NS
$LSD_{0.05}$ Location × Soil depth			NS	NS	NS	NS	NS	0.44	NS	NS	0.07	NS	NS
$LSD_{0.05}$ Study site × Soil depth			NS	0.40	0.01	NS	0.42	NS	0.02	NS	0.07	NS	NS
$LSD_{0.05}$ Location × Study site × Soil depth			NS	NS	NS	NS	NS	NS	NS	NS	0.09	NS	NS

OC - organic carbon; TN - total nitrogen; Av. P - available phosphorus; Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Al^{3+} and H^{+} - exchangeable calcium, magnesium, sodium, potassium, aluminium and hydrogen, respectively; ECEC - effective cation exchange capacity; $LSD_{0.05}$ - least significant difference at 5 % probability level; NS - not significant

Some Chemical Properties of the Studied Soils

The chemical properties of the soils (Table 3) showed that the pH of the soils ranged from 6.50 to 8.23. However, the soil pH at the Faculty of Engineering location (7.80) was significantly higher than that of Odim-gate location (7.21), and also higher in the dumpsite soil (7.96) than in the control soil (7.05). The OC content of the soils ranged from 0.23 to 1.51 g kg^{-1} and was significantly higher at the Odim-gate than at the Faculty of Engineering location, higher in the dumpsite than in the control soil and higher at 0.20 cm than at 20-40 cm depth. The interaction between location and study site showed that the SOC was higher in the control than the dumpsite at Faculty of Engineering, while the reverse was the case at the Odim-gate location. The TN of the soils was between 0.04 and 0.07%. Differences in TN content was only found in the interaction between study site and soil depth, while the available P content was statistically higher at the Faculty of Engineering (31.87 mg kg^{-1}) than at the Odim-gate location (26.23 mg kg^{-1}).

The mean concentrations of the exchangeable bases namely Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} of the soils, in the ranges of 0.67-2.53, 0.67-1.33, 0.01-0.07, and 0.03-0.13 $cmol_c$ kg^{-1}, respectively, were similar at the two locations of the study. Significant differences in the concentrations of exchangeable bases were found between study sites, soil depths, location × study site, location × soil depth and the study site ×

soil depth. The Al^{3+} content differed significantly among the different sources of variations, with the Al^{3+} and H^{+} concentrations being significantly higher at the Odim-gate than at the Faculty of Engineering location, and higher in the control than in the dumpsite soil. The differences in ECEC between the locations, study sites and soils depths were not significant.

Concentration of Some Heavy Metals in the Soils The heavy metal concentrations in the soils (Table 4) showed that the Fe concentration was higher at the Odim-gate than at the Faculty of Engineering location, and was also higher in the control than in the dumpsite soils. Zinc concentration ranged from 1.22 to 4.60 mg kg^{-1} across locations, study sites and soil depths, and was significantly higher at the 0-20 cm than at the 20-40 cm depth. Significant differences were also due to the three factors studied and their interactions. The effects of these factors (sources of variations) on Pb concentrations in the soils were not analysed statistically because Pb was not detected in some replicates of the soil samples. Nonetheless, the results showed similar mean values (0.04 mg kg^{-1}) for both study sites and locations.

Table 4: Some heavy metal concentration in the soils at Odim-gate and Faculty of Engineering locations

Location	Study site	Soil depth (cm)	Iron	Zinc	Lead
			--------mg kg^{-1}	--------	
Odim-gate	Control	0 - 20	4.72	2.13	0.03
		20 - 40	3.79	2.73	0.04
		Mean	4.35	2.43	0.04
	Dump-site	0 - 20	2.85	4.00	nd
		20 - 40	3.79	3.47	0.04
		Mean	3.32	3.73	0.04
		Grand mean	3.83	3.08	0.04
Engineering Faculty	Control	0 - 20	3.23	3.33	0.05
		20 - 40	2.67	3.33	0.03
		Mean	2.95	3.33	0.04
	Dump-site	0 - 20	2.11	4.60	0.04 nd
		20 - 40	2.29	1.22	
		Mean	2.20	2.91	0.04
		Grand mean	2.57	3.12	0.04
$LSD_{0.05}$ Location			0.74	NS	-
$LSD_{0.05}$ Study site			0.74	NS	-
$LSD_{0.05}$ Soil depth			NS	0.65	-
$LSD_{0.05}$ Location × Study site			NS	0.92	-
$LSD_{0.05}$ Location × Soil depth			NS	0.92	-
$LSD_{0.05}$ Study site × Soil depth			NS	0.92	-
$LSD_{0.05}$ Location × Study site × Soil depth			NS	NS	-

$LSD_{0.05}$ - least significant difference at 5 % probability level,
NS - not significant, nd - not detected

DISCUSSION

Some Physical Properties of the Studied Soils In general, the soils at both locations are coarse textured, as the sand content predominates over clay and silt. The high sand content could be due to the similar parent material (weathered sandstone from sedimentary geological deposits) of the soils. The > 20% clay content of the Faculty of Engineering dumpsite at 20-40 cm depth contributed to the sandy clay loam texture in the soil. This slight difference in clay content could provide some colloidal advantage in terms of moisture holding capacity and cation exchange capacity over the sandy loam textured soils as supported by Patnaik *et al.* (2013).

The average bulk density of the soils (about 1.60 g cm^{-3}) is moderately low and typical of soils with a sandy loam texture as documented in NRCS (2001). The overall porosity of the soils was moderately high and within the range for coarse soils. The location, soil depth and location x study site interaction, which did not affect the bulk density and total porosity of the soils, can be attributed to the dominant sand content of the soils (CV = 5.22%), which primarily determines soil physical properties. However, the two dumpsites had similar bulk density and total porosity, which were significantly lower and higher, respectively, than at their controls. The study finding share similarity with that of Agbeshie et al. (2020) and these could be related to the organic matter (OM) content of the decomposable waste, which aggregates the soil particles and promotes good drainage and rapid water permeability through the soil. It is to be expected that the different porosity of the study sites influences the leaching of cations and thus the pH value of the soils, which according to Król *et al*. (2020), determines the concentration of heavy metals. Nonetheless, the higher Ksat for the Odim-gate location compared to the Faculty of Engineering location could be related to the differences in OC content. Hüseyin (2017) found a positive relationship between hydraulic conductivity and OM content of the soil. This indicates that the former location has a better water permeability at saturation than the latter location.

Some Chemical Properties of the Studied Soils

In general, the pH of the soils was slightly acidic to slightly alkaline. In particular, the soil pH at the Faculty of Engineering location (7.80) and in the dumpsite (7.96) was in the slightly alkaline range, while the pH at the Odim-gate location (7.21) and in the control soil (7.05) was close to neutral. These pH values of the Faculty of Engineering location and the dumpsite could be due to the higher concentrations of Ca^{2+} and Na^{+} that contribute to the alkaline pH. The elevated pH of the dumpsite's soils, as similarly reported by Onwukeme and Eze
(2021) at pH value 7.60, is due to the various biochemical reactions that play an important role in the decomposition of wastes and the release of pollutants. Consequently, the pH of the dumpsites can affect the availability of nutrients for plant uptake and the concentration and leachability of heavy metals in the soil (Marschner, 1995; Król *et al*., 2020). On the other hand, the near neutral pH of the control soil is remarkable considering the high rainfall and associated heavy leaching, erosion and runoff characteristic of the humid tropics.

The OC content of the studied soils was in the low range (< 0.20%). It was relatively higher at the Odim-gate than at the Faculty of Engineering location. This disparity may be due to the different composition and number of decomposable wastes and decomposition rate as well as differences in the Ksat of the soils at each location. The higher OC in the dumpsite compared to the control soil, especially at the Odim-gate (location × study site), is expected given the higher organic waste content and associated elevated soil microbial activities at the site. The OC content of between 0.02 and 0.19% at 0-40 cm depth in the dumpsites falls within the low range compared to the range of 4.50 to 12.60% at 0-30 cm depth reported for four active dumpsites in southeastern Nigeria (Onwukeme and Eze, 2021). The higher OC content in the topsoil (0-20 cm) than in the subsoil (20-40 cm) could be attributed to greater accumulation and a higher mineralization rate of organic waste deposited on the soil surface. Decomposition is facilitated in the presence of O_2 and is mostly limited by O_2 concentration at high moisture content (Sierra *et al.*, 2017). Thus, the reduced decomposition rate accounts for the decrease in OC content in the subsoil. Okebalama *et al.* (2017) observed a similar OC trend with soil depth in some soils of southeastern Nigeria. The significantly higher OC content in the dumpsites topsoil (study site × soil depth interaction) may favour sorption and desorption of heavy metals in the soils (Catlett *et al.*, 2002).

The low TN concentration, which is similar in both locations, study sites and soil depths is inconsistent with the reported higher TN concentration in uncultivated soils within the University community (Okebalama *et al.*, 2022a).

This indicates a loss of N in the soil, implying that N should be supplied for crop growth in the control soil. Similarly low and contradictorily higher TN concentrations were also found in dumpsites (Ogbonna *et al.*, 2009). The low TN concentration of the soils could be related to their sandy texture (72-83% sand content) and the moderately high porosity, which promotes drainage and nutrient leaching due to the heavy rainfall that is prevalent in the area. Available P concentrations in the studied soils were high, although higher at the Faculty of Engineering than at the Odim-gate location. High available P concentration have been reported in coarse-textured surface soils (0-20 cm depth) of municipal dumpsite (Amos-Tautua *et al.*, 2014). In contrast, low available P concentrations were recorded in a similar sandy loam Ultisols with permeable and well-drained structure within the UNN community (Okebalama *et al.*, 2022b). The high and sufficient available P concentrations in the studied soils are remarkable given the high P fixation potential due to reactions such as soil adsorption, immobilization, or precipitation in Ultisols (Mora *et al.*, 2017).

The concentrations of exchangeable bases in the soils were low, with the exception of Mg^{2+}, which is in the optimum range. The low base cations could be due to the parent material of the soils (Tomašić *et al.,* 2013) and to heavy leaching, erosion and runoff due to heavy rainfall, which contribute to nutrient losses. The higher Ca^{2+} and Na^{+} concentrations in the dumpsite compared to the control and in the topsoil compared to the subsoil could be due to increased recycling of organic waste, as evidenced by their corresponding OC contents. The observed waste from cements, which has a high proportion of Ca compounds, may have contributed to the higher Ca concentration in the dumpsite. The concentrations of Ca^{2+}, Mg^{2+} and H^{+} are relatively higher than the Na^{+}, K^{+} and Al^{3+} concentrations. Even so, the higher Al^{3+} and H^{+} concentrations at the Odim-gate location and in the control, site compared to their corresponding counterparts indicate the contribution of Al^{3+} and H^{+} to the acidic status of these soils. Likewise, the contribution of the higher Ca^{2+}, Na^{+}, K^{+} concentrations to the alkaline pH of the soil in the dumpsite is also evident. The greater retention of these cations in the topsoil compared to the subsoil could be due to the direct accumulation and decomposition of organic materials in the topsoil. More so, the higher OM content in the topsoil and its net negative charges attract and retain these cations from leaching losses. The burning of waste at the dumpsite, is also responsible for the higher K^{+} concentration in these soils, and at 0-20 cm depth. The ECEC values of the studied soils were low, which is in contrast to the reported moderate to high ECEC range in soils from open dumpsite (Amos-Tautua *et al.*, 2014). The generally low OC content of the soils could partly explain the low ECEC, as soil OM content is directly proportional to the ECEC of the soil (Nwachukwu *et al.*, 2021).

Concentration of Some Heavy Metals in Soils the Fe concentration across the locations, study sites and soil depths was < 4.50 mg kg^{-1}, indicating low concentrations as shown in Table 5. High Fe concentrations ranging from 14.05 to 21.08 mg kg^{-1} in public refuse dumpsites in Nsukka metropolis, Nigeria were reported by Ohanu *et al.* (2020). In our study, the higher Fe concentration at the Odimgate location than at the Faculty of Engineering could be partly due to the dumped Fe-bearing waste at the dumpsite as well as the inherent Fe metallic substance in the soil. Nevertheless, the concentration of Fe in the soils is within the acceptable limits as described by WHO (1996).

Iron is a common metallic element in weathered soils of the humid tropics and is easily recognized by its red colour. The Fe concentration in the control soil confirms the report of Ezeaku (2000) that Nsukka soils are well-drained ferallitic soils. The higher Fe concentration in the control soil than in the dumpsite could be related to the different porosity of the soils. The higher porosity of the dumpsites promotes drainage and leaching process. Leaching process leads to an increase in soil pH, which in turn leads to a decrease in the amount and form of available Fe (Payne *et al.*, 2007). Soil redox potential and pH are key factors that determine Fe availability and the form of Fe present in the soil; with ferrous Fe available in acidic soil and ferric Fe available in alkaline soils. Thus, as soil pH increases, ferrous iron (Fe^{2+}) is readily oxidized to insoluble ferric iron (Fe^{3+}), which unlike the ferrous form, cannot be absorbed by plant roots (Payne *et al.*, 2007; Morrissey and Guerinot, 2009). Considering the high rainfall in the study region and the high mobility of Fe in soils (Osae *et al.*, 2022), this finding suggests that the refuse dumpsites in UNN could reduce Fe content and availability in the surrounding soils, which has implications for plant nutrition due to its importance in chlorophyll formation and hence for photosynthesis process (Rout and Sahoo, 2015). Thus, the increased porosity and pH of the soils at the dumpsites therefore determine the lower insoluble ferric Fe content in the soil.

The low concentration range of Pb (0.00 to 0.05 mg kg^{-1}) in the soils is attributed to leaching losses as influenced by the moderate porosity of the soils (Król *et al.*, 2020), given the high rainfall regime in the study area. Medium Pb concentrations of between 0.40 and 0.54 mg kg^{-1} have been recorded in waste dumpsite and surrounding down-site (Agbeshie *et al.*, 2020). Ukpong *et al.* (2013) found that the waste dumpsite had higher Pb concentrations than the control site, and the concentration was higher in the surface soil than in the subsurface soil. Increases in Pb concentrations in soils are mainly due to industrial wastes, mining, smelting works, sludge, waste-water irrigation, chemical fertilizer, and pesticides (Rani *et al.*, 2024). Other Pb-containing wastes and activities that release Pb include paints, lead wastes, cell batteries, lead solders, auto-mechanic wastes, print materials, and wielding (Abadin *et al.*, 2007; Ohanu *et al.*, 2020).

Table 5: Ratings of some heavy metals in the soil

Heavy metal	Low	Medium	High
Zn	< 0.8	0.8 - 2.0	> 2.0
Pb	< 0.4	-	> 2.0
Fe	< 4.5	4.5 - 10.0	> 10.0

Source: Lindsay and Norvell (1978) and FAO (1979)

Sources of Pb in the dumpsites may be from the disposal of cell batteries and cosmetics, which necessitates responsible disposal, given that Pb is potentially more mobile and bioavailable in waste dumpsite soils (Uba *et al*., 2007). Moreso, Pb is a harmful heavy metal that is highly toxic to humans and the environment (McQueen, 2017).

As shown in Table 5, the Zn concentration in the soils (about 3.10 mg kg^{-1}) is in the high concentration range. This is lower than the values of 9.10 to 19.33 mg kg^{-1} reported by Ohanu *et al.* (2020), which were attributed to the dumping of old dry batteries, rubber products, paint containers, and incineration of waste in public dumpsites in Nsukka, Nigeria. Although Zn occurs naturally, the elevated Zn concentration at the 0-20 cm than at the 20-40 cm depth is an indication of anthropogenic sources and a reduced mobility of Zn in the topsoil. The immobilization and insolubility of Zn contribute to binding (adsorption) of Zn to the soil constituents (e.g., clay, OM, metal oxides), which is influenced by various factors mainly pH, temperature, clay content and OM content (Shukla, 1971; Cakmak, 2008).

Accordingly, the solubility and mobility of Zn in water decreases with high pH, high clay content and low OM content, as found in this study. The observed high Zn concentration in the topsoil at the Faculty of Engineering (location × soil depth), and in the dumpsite (study site × soil depth) is thus consistent with what is already known. The OC concentrations in the soils were fairly high (1.61 g kg^{-1}), while the Zn concentrations were high. Soil pH and OM content have been identified in many studies as factors affecting Zn mobility and sorption in soils (Catlett *et al.* 2002; Rutkowska *et al*., 2015). Interestingly, we now better understand why the pH of the dumpsite was higher than that of the control soil, confirming that a small change in pH leads to a significant change in Zn concentration (Król *et al*., 2020).

The higher Zn concentration in the dumpsite than the control soil suggests that the dumpsites in the UNN can increase Zn content in the environment by entering the water via erosion, runoff and flooding. In surface and groundwater, Zn enters the environment primarily through the erosion of soil particles containing Zn (Noulas *et al*., 2018). Given the hilly topography of study region, this implies that the surrounding agricultural fields and areas with lower slopes (offices and residential areas) are indirectly inclined to Zn accumulation and possible entry into the food chain via Zn uptake by plants. Zinc plays a vital role in various plant physiological functions including membrane structure, photosynthesis, protein synthesis, and tolerance to drought and disease (Noulas *et al*., 2018). Although Zn is an essential microelement, cases of contamination of soil, water and food chains has been documented (Alloway, 2008; Noulas *et al*., 2018).

Zinc becomes toxic at high concentrations, and exposure to excess Zn increases the risk of Zn toxicity, which impairs crop productivity and jeopardises food security and human health worldwide (Meng *et al*., 2023). Due to Zn induced changes in enzyme activity, disruption of cytostructural and N metabolism, excess Zn in soil is phytotoxic and causes various structural and functional abnormalities that impair plant growth and development, including seed germination and elongation of roots and stems, eventually leading to weakened plant performance and even death (Broadley *et al*., 2007; Kaur and Garg, 2021). According to Marschner (2012), between 30 and 200 µg Zn g^{-1} dry weight (DW) is required for the well-being of most crops. A zinc content of > 500 mg kg^{-1} in the soil disturbs specific plant physiological balance and the uptake of other essential metals such as Mg, Mn, Cu and Fe by the plant (Emsley, 2011; Tewari *et al*., 2008). Therefore, the yield potential of several important food crops (beans, citrus, fruit trees, maize, etc.) and the quality of crop produce can be affected under conditions of Zn toxicity.

Part of the exposure medium for Zn toxicity is commonly through inhalation, consumption of food/water, excessive use of nutritional supplements, use of denture cream, and ingestion of soil contaminated with Zn (Agnew and Slesinger, 2020). Excessive exposure and ingestion of Zn above the Recommended Dietary Allowance (RDA) of 100300 mg day^{-1} could result in nausea, dizziness, headache, abdominal pain, diarrhoea, drowsiness, hallucination, vomiting, loss of appetite, epigastric pain, and lethargy fatigue (Fosmire, 1990; Rahman *et al*., 2011). Yokoyama *et al*. (1986) showed that a short 15 min exposure to 300–600 µM Zn is toxic to cortical neurons and can result in extensive neuronal death. Furthermore, excessive Zn intake has been linked to a higher risk of prostate cancer in men (Jarrard, 2005; Rahman *et al*., 2011).

In this study, there was no contamination of the soils with Fe, Pb and Zn from dumpsites at both locations. In general, the soil concentration of these heavy metals in both dumpsites were far below the permissible limits for standard soils according to the US EPA (2003) and the WHO (1996). Thus, the dumpsites and surrounding soils do not require remediation or soil reclamation as they are not considered polluted at the time of this study. However, given the current high Zn concentration in the soils, the accumulation of these metals could later become a serious threat to human health and the environment. This implies that the surrounding agricultural farms and people working or living nearby are predispose to the possible occurrence of Zn toxicity through direct exposure to contaminated soil, and indirectly through entry into water and food chain due to flooding, erosion, runoff and absorption by plants. Therefore, proactive measures for proper disposal practices in UNN community are encouraged to prevent heavy metal Fe, Zn and Pb contamination. For example, the University management should ensure that the various wastes are segregated and disposed of according to putrescible, recyclable and non-recyclable wastes to prevent indiscriminate pollution of the ecosystem.

CONCLUSIONS

The two studied soils were generally sandy loam and exhibited favourable soil physical properties with moderately low bulk density, moderately high porosity and better water permeability, indicating better drainage. The soils were slightly acidic to slightly alkaline with high available P, but low OC, total N and exchangeable base cations. Waste disposal on soil surface altered the soil physicochemical properties, including bulk density, total porosity, soil pH, OC, and all the exchangeable cation concentrations except Mg^{2+}, increasing the soil nutrient reserves at 0-20 cm depth. However, the concentration of heavy metal Fe was reduced, while the Zn concentration at 0-20 cm depth was high. Nevertheless, the concentrations of the heavy metals Fe, Zn and Pb in the soils were below the permissible limits for standard soils. Due to the high concentration of Zn, further studies on the ecological risk assessment of this heavy metal, which is important for environmental safety and human health, would be necessary considering the adverse effects of excessive Zn accumulation in soils. The assessment of the potential risk of Zn to the environment and human health is beyond the structured scope of our quantitative research. Despite all limitations, this study provides a reference for the high Zn > Fe > Pb concentration at both locations and study sites. The Odim-gate and Faculty of Engineering dumpsites pose a potential ecological risk and therefore require a responsible disposal plan given the high rainfall and the hilly topography of study region.

RECOMMENDATIONS

Based on the results of the study, the following recommendations are emphasized:

i. There is a need to create awareness of the current status of heavy metal concentrations and their environmental and health consequences, as well as the achievement of heavy metal reduction targets.

ii. It is important to introduce heavy metals reduction targets through proper waste disposal/ waste management and to take pro-active measures to protect the environment of the University community and its surroundings.

iii. It is strongly recommended to provide different waste bins for putrescible, recyclable and non-recyclable waste and to educate the populace on the appropriate use of the bins. iv. In addition, regular monitoring of dumpsites is necessary to ensure strict enforcement of regulations for responsible waste disposal.

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