Effects of Solid Waste Disposal on Soil Quality in Makurdi Metropolis, Benue State, Nigeria

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ABSTRACT

This study investigated the chemical properties and environmental implications of soil samples collected from three dumpsites labeled as Old bridge, Wurukum, and High level, and a Control sample collected at 100m from each of the dumpsites. The analysis focused on key parameters including base saturation, Cation Exchange Capacity (CEC), nutrient levels (Calcium, Magnesium, Potassium, Nitrogen), and concentrations of heavy metals (Lead, Chromium, Cobalt, Zinc, Nickel, Copper and Manganese). The samples were collected and analyzed using standard analytical equipment, reagents and procedures. Results revealed significant variations among the samples, indicative of diverse impacts of waste disposal on soil fertility and contaminant accumulation. High levels of Chromium and Lead in certain samples underscore environmental concerns, necessitating remediation strategies to mitigate potential health risks. Furthermore, differences in soil physical properties such as bulk density and clay content highlight the influence of waste materials on soil structure and nutrient retention. The findings underscore the importance of effective waste management practices to safeguard soil quality and promote sustainable land use in contaminated areas. The study concluded that solid waste disposal significantly affects soil quality in Makurdi, with notable variations in chemical properties and heavy metal content across the sampled sites. Based on the findings, it is recommended that regular soil monitoring be conducted, especially in areas like Old Bridge where the CEC is highest (12.61 cmol kg^{-1}), to ensure sustained soil fertility and prevent nutrient loss. Given the significant Chromium content at High Level (0.28 mg kg^{-1}) and Lead levels across all sites, immediate remediation efforts should be initiated to prevent further contamination and protect public health. Additionally, improving waste management practices, including better waste segregation and controlled disposal, is crucial to minimize the introduction of heavy metals and other pollutants into the soil, ensuring long-term soil health and agricultural productivity. It was also recommended that further research be carried out by expanding the coverage of this research and in another season.

Key words: Heavy metals, dumpsite, solid waste, soil quality

INTRODUCTION

Waste is anything which is no longer useful to the disposer. It can likewise be characterized as any material resulting from an action or process, which has no economic interest, and which must be discarded (NISP, 2003). Solid waste means unwanted materials or substances that are discarded after use, they are by-products of process lines or materials that may be required by law to be disposed of (Okecha, 2000). They can be characterized based on source, ecological dangers, utility and physical property.

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Humanity is delivering more refuse now than at any time in history, creating problems for nature. Increase in population combined with expanding industrialization and aimless waste disposal has prompted enormous volume of waste found in our surroundings today. Wastes and strategies for disposing them cause a ton of environmental problems particularly when they are not appropriately disposed of. Often, the way individuals discard their waste is to just drop it in some spot. Open, unregulated dumps are the techniques for waste disposal in most developing nations; even the third world mega cities have waste problems (Omofonmwan and Esiegbe, 2009).

Considerable percentage of urban waste in developing countries is deposited either on the roads, or roadsides, unapproved dump sites, in water ways, drainage systems or in open sites which adversely affect environmental friendliness. In fact, solid waste poses various threats to public health and adversely affects flora and fauna as well as the environment especially when it is not appropriately collected and disposed (Geraldu, 1995). However, when approved waste dump sites are used, there is no guarantee that wastes are appropriately disposed because of continuous expansion of the site. Thus, the adjacent areas including highways, farmlands, and forest plantations, are encroached upon which has a toll on the biodiversity conservation (Hardy and Seatterwaite, 1992).

Understanding the impact of solid waste disposal on soil quality is crucial for several reasons: The quality of soil directly influences crop yield and food security. If the soil in and around waste disposal sites is compromised, it could lead to reduced agricultural productivity, affecting the livelihoods of farmers and food availability in Makurdi. Soil acts as a buffer and filter for pollutants. However, when contaminated by heavy metals and other toxic substances from waste, the soil can become a source of pollution itself. This can affect the broader ecosystem, including water bodies, through runoff and leaching. Contaminated soil can pose direct and indirect risks to human health. The accumulation of heavy metals in crops grown on polluted soil can lead to the ingestion of these metals, with potential long-term health effects. This study will add to the body of knowledge on the environmental impacts of solid waste disposal, particularly in the context of a developing urban area like Makurdi.

This study was therefore carried out to evaluate the impact of solid waste disposal on soil quality in Makurdi by analyzing soil samples from three dumpsites and a control site, to determine the effect of solid waste on physical and chemical properties of soils of the dumpsites as well as the heavy metal content of the sites.

MATERIALS AND METHODS

Study Area

Makurdi, the capital of Benue State is in Central Nigeria and part of the middle belt region of Central Nigeria. The city is situated on the south bank of the Benue River with coordinates as 7.73375 and 8.52139 with an estimated population in 2024 of over 471,754 (World Population Review, 2024), annual temperature of 31 degree Celsius with SW wind at 10km/hr and average relative humidity of 66 % annually.

Sampling Locations

Three different locations were randomly chosen for collection of soil samples for analysis:

Location 1 (Old bridge road): This dumpsite was located along Water Board-old River Benue Bridge Road; it had been in existence for over 15 years. Domestic, market, industrial and agricultural wastes were found in this dumpsite. Quite often, wastes were spread across the land because of indiscriminate disposal by trucks. Close to the dumpsite were a school, farmlands, residential homes and the River Benue.

Image of Old bridge dumpsite

Location 2 (Wurukum): This dumpsite was located along Wurukum- New River Benue bridge road, directly opposite the rice mill and has been in existence for over 10 years. The dumpsite composed of domestic, market, industrial and agricultural wastes. Close to the dumpsite were farmlands, River Benue, mechanic workshop, motor park and residential homes.

Image of Wurukum dumpsite

Location 3 (High level): This dumpsite was located Katsina-Ala street, High level. Majority of the wastes were domestic, market, industrial and agricultural wastes. Close to the dumpsite were Gas filling station, Church, River Benue, mechanic and residential homes.

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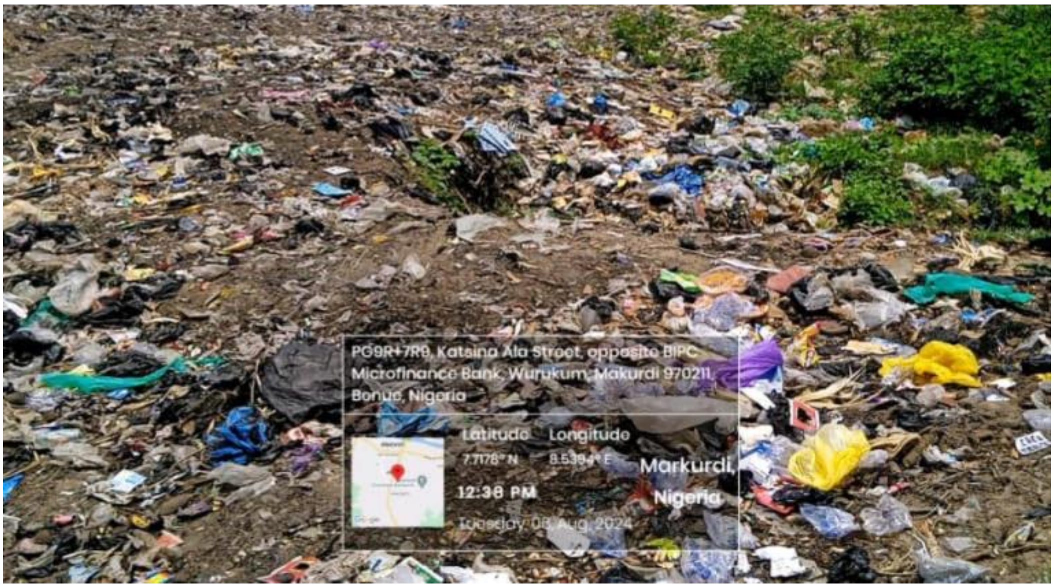
Image of High-level dumpsite



Location 4 (Control): Control samples were collected at 100m from each of the three dumpsites.

Sampling Procedure

Three (3) replicate soil samples were collected from three (3) different dumpsites (Old-bridge, Wurukum and High level) in the study area. Also, Control samples were collected at 100m from each of the three (3) dumpsites for laboratory analysis. The soil samples were taken to the laboratory for determination of heavy metals content and for both physical and chemical properties analysis.

Pictures showing sample collection at dumpsites

Soil Laboratory Analysis

The soil samples obtained from the field were taken to the Advanced Soil Science Laboratory of Joseph Sarwuan Tarka University, Makurdi (JOSTUM), they were air dried and passed through 2mm sieve for determination of Particle size distribution, pH, Organic Carbon, Total Nitrogen, Available phosphorus and Exchangeable Cations [Mg^{2+}, Ca^{2+}, Na^{+} and K^{+} as well as Cation Exchange Capacity (CEC)].

Particle Size Distribution

The particle size distribution was determined by the hydrometer method (Bouyoucos, 1951) which involved the suspension of soil samples with Sodium Hexametaphosphate. The hydrometer reading was taken at 40 seconds after three hours. The particle size was then calculated using the following formula:

Sand: 100 - $[H_1 + 0.2 (T_1 - 68) – 2.0]^2$

Clay: $[H_2 + 0.2 (T_2 - 68) – 2.0]^2$

Silt: 100 – (% sand +% clay) (Bouyoucos, 1951).

Soil pH

This was determined both in water and in Calcium Chloride ($CaCl_2$). The Glass Electrode method as described by IITA (2015) was used to determine the soil pH (Active). The electrode of the pH meter was placed in 1:1 soil suspension with water to determine the active acidity in water while for that of active pH in 0.01 M $CaCl_2$, the suspension [i.e. 1:2 (soil: 0.01 M $CaCl_2$)] was then allowed to stand for about 30 minutes and stirred occasionally with a glass rod, after which the electrode of the pH meter was inserted to measure the active pH of soil.

Organic Carbon (OC)

The Organic Carbon (OC) was determined by the Walkley and Black (1934) method as modified by Allison (1965). This involved oxidation of the soil with Dichromate and Tetraoxosulphate (VI) acid (H_2SO_4). The Organic Carbon (OC) was then calculated using the following formula: % Organic Carbon (OC) in soil = (me$k_2Cr_2O_7$ –me $FeSO_4$) X 0.003 X 100 X F of air-dry soil (Abdullahi *et al.*, 2014).

The percentage organic matter was calculated by multiplying the value of Organic Carbon (OC) by Van Bermalin factor of 1.724, which assumed that in the tropics, soil organic matter contains 58 % organic Carbon (OC).

Total Nitrogen (N)

The total Nitrogen (N) was determined using the Macro-Kjeldahl digestion method (Bremmer and Mulvaney 1982). 5 grams of soil sample was passed through 0.5 mm sieve. This was mixed with 10ml of deionized water into a 500 ml kjeldahl flask and one tablet of mercury catalyst was added as indicator. Potassium sulphate (K_2SO_4) and 30 ml of concentrated H_2SO_4 were added. The mixture was heated continuously to ensure a complete digestion, the digested material was allowed to cool and 100 ml of deionized water was slowly added. The sand residue was washed with 50 ml of deionized water into 75 ml macro-kjeldahl flask. 50 ml of 2 % H_3BO solution with 150 ml of 10 N NaOH was measured into a 500 ml Erlenmeyer flask and distilled. The distillate was titrated with 0.01 N standards H_2SO_4 to determine the amount of NH_4-N.

Available Phosphorus (P)

Bray 1 method was used to determine available Phosphorus (P). This involved centrifuging the soil suspension at 2000 revolutions per minute for 15 minutes. The clear supernatant was then mixed with distilled water; ammonium solution and Tin (II) Chloride ($Sncl_2$ dilute solution). Then, the percentage transmittance on the electro photometer at 660 nm wavelength was measured. The Optical Density (OD) of the standard solution was plotted against the Phosphorus (P) (in ppm) and then the extractable Phosphorus (P) in the soil was calculated (Bray and Kurtz, 1945).

Exchangeable Cations and Cation Exchange Capacity (CEC)

The Cation Exchange Capacity (CEC) was determined using the Ammonium Acetate (NH_4OC) method. Exchangeable cations were determined by Melhlic-3 extraction solution. The extracted solutions of these exchangeable cations were determined by Atomic Absorption Spectrophotometer (AAS). To prepare Melhlic-3 extraction solution, 250ml deionized water was poured into 500ml polythene bottle, thereafter, 69.45g NH_4F and 36.75g of Ethylene Diamine Tetraacetic Acid (EDTA) was dissolved and diluted to 500 ml. To a 10-liter jug was added about 8 liters of water and 200g Ammonium Nitrate (NH_4NO_3), 40ml of Ammonium Flouride (NH_4F) solution, 115ml acetic acid and 8.2ml of 70% nitric acid was added and diluted to 10 liters.

The pH of the solution was between 2.5±0.1 which was adjusted by using Ammonium Hydroxide (NH_4OH), 3g of soil sample was weighed into 50ml centrifuge tube which has been acid washed in order to avoid impurity contamination. 30 ml of Melhlic-3 extractant was added to the soil sample that was capped in the centrifuge tube. The samples were then put in the mechanical shaker for 5 minutes. The samples were then filtered with clean filter paper. After centrifugation, the extracts were transferred into the tubes to minimize contamination and the exchangeable cations in the extract were determined by AAS.

Heavy Metal Analysis

Heavy metals (Copper (Cu), Cobalt (Co), Chromium (Cr), Lead (Pb), Zinc (Zn), Manganese (Mn) and Nickel (Ni)) were extracted by the single acid solution, double acid mixture and the Diethylene triaminepentaacetic acid (DPTA) extraction procedure of trace elements, (Udo *et al.,* 2009). Concentration of the metals in the filtrates was determined by Atomic Absorption Spectrophotometry. Composite soil samples were collected from each treatment level after harvest and analyzed for the heavy metals.

Statistical Data Analysis

The data was subjected to Analysis of Variance (ANOVA) using GENSTAT statistical software.

RESULTS

Chemical Properties of soil samples from dumpsites

The soil samples (Control, Old Bridge, Wurukum and High level) exhibited extremely high base saturation rates, ranging from 85.77% to 85.99%. According to the Least Significant Difference (LSD) test, the differences in base saturation between the samples were not statistically significant. Typically, high base saturation indicates a fertile soil with an abundance of essential plant nutrients. The Cation Exchange Capacity (CEC) values showed a significant disparity (4.473) among the soil samples. Old bridge boasted the highest CEC (12.61), while Control had the lowest (5.48). This suggested that the soil's ability to retain positively charged ions (cations) varied among the samples. Soils with higher clay content tend to have higher CEC due to their greater surface area for cation adsorption. Calcium (Ca) content varied among the samples, ranging from 4.41 cmol kg^{-1} (Wurukum) to 7.57 cmol kg^{-1} Old bridge). The Calcium (Ca) levels suggested some variation in plant-available Calcium (Ca) among the samples, with Old bridge having the highest concentration and Wurukum having the lowest. Exchangeable Aluminum (EA) values fluctuated among the samples, ranging from 1.03 cmol kg^{-1} (Wurukum) to 1.77 cmol kg^{-1} (Old bridge). However, the differences in Exchangeable Aluminum (EA) between the samples were not statistically significant. Potassium (K) content showed a slight variation among the samples, ranging from 0.29 cmol kg^{-1} (Wurukum) to 0.50 cmol kg^{-1} (Old bridge). The difference in Potassium (K) levels between the samples was statistically significant. Magnesium (Mg), an essential nutrient for plant growth and function, exhibited significant differences among the samples. The values ranged from 1.47 cmol kg^{-1} (Wurukum) to 2.52 cmol kg^{-1} (Old bridge), suggesting some variation in available Magnesium (Mg) among the samples. Nitrogen (N) content varied substantially among the samples, with Old bridge having the highest value (0.34 g kg^{-1}) and Control, Wurukum, and High level having much lower values (0.10-0.12 g kg^{-1}). The differences in Nitrogen (N) content between Old bridge and the other three samples were statistically significant, while those between Control, Wurukum, and High level were not.

Sodium (Na) content showed a slight variation among the samples, ranging from 0.15 cmol kg^{-1} (Wurukum) to 0.25 cmol kg^{-1} (Old bridge). However, the differences in Sodium (Na) content between the samples were not statistically significant. Organic Carbon (OC) content varied significantly among the samples, with Old bridge having the highest value (3.49 g kg^{-1} and Control having the lowest (1.06 g kg^{-1}). Wurukum and High level also had lower Organic Carbon (OC) content compared to Old bridge (1.24 g kg^{-1} and 2.00 g kg^{-1} respectively). The difference in Organic Carbon (OC) between Old bridge and all other samples was statistically significant. Organic Matter (OM) content also varied significantly among the samples, with Old bridge having the highest value (6.02 g kg^{-1}) and Control having the lowest (1.83 g kg^{-1}). Wurukum and High level also had lower OM content compared to Old bridge (2.14 g kg^{-1} and 3.44 g kg^{-1} respectively). The difference in Organic Matter (OM) between Old bridge and all other samples was statistically significant.

Available Phosphorus (P) content varied among the samples, with Old bridge having the highest value (10.32 mg kg^{-1} and Wurukum having the lowest (6.54 mg kg^{-1} Control and High level had intermediate values (7.13 mg kg^{-1} and 8.04 mg kg^{-1} respectively). The difference in Available Phosphorus (P) between Old bridge and Wurukum was statistically significant. Total Exchangeable Bases (TEB) values varied among the samples, with Old bridge having the highest value (10.84 cmol kg^{-1}) and Wurukum having the lowest (6.32 cmol kg^{-1} Control and High level had intermediate values (7.05 cmol kg^{-1} and 8.10 cmol kg^{-1} respectively). The difference in Total Exchangeable Bases (TEB) between Old bridge and Wurukum was statistically significant.

Physical Properties of soils from dumpsites

No statistically significant differences (NS) were observed in the Bulk Density (BD) values between the soil samples. Control exhibited the highest Bulk Density (BD (1.35 g $cm^{-3)}$ while High Level exhibited the lowest (1.17 g $cm^{-3).}$ The clay content, represented as a percentage of Clay-sized particles, varied significantly between samples. Wurukum contained the lowest clay levels (7.10%), while Old bridge and High level contained the highest amounts (8.35% and 11.40%, respectively). Control exhibited Clay content of 7.18%. Sand content also varied significantly between samples.

Wurukum contained the highest Sand levels (81.45%) whereas High level contained the lowest (75.00%). Old bridge and Control exhibited Sand contents of 76.89% and 80.52%, respectively. Silt content, the intermediate particle size between Sand and Clay, likewise differed between samples. Wurukum contained the lowest Silt levels (11.45%) while Old bridge contained the highest (14.76%). Control and High level exhibited intermediate Silt contents of 12.30% and 13.60%, respectively. Hydraulic Conductivity (HC) content also diverged among the four soil samples, with Old bridge exhibiting the highest concentration (5.46 g kg^{-1}) and High level exhibiting the lowest (4.32 g kg^{-1}). Control and Wurukum contained intermediate Hydraulic Conductivity (HC) levels of 3.73 g kg^{-1} and 4.73 g kg^{-1} respectively. The statistically non-significant LSD value suggests the differences in Hydraulic Conductivity (HC) content between samples were likely inconsequential.

No statistically significant differences were observed in moisture content, which ranged from 18.10 g kg^{-1} in Control to 21.89 g kg^{-1} in High level. Porosity also varied minimally, ranging from 37.50% in Control to 39.69% in High level. The statistically non-significant LSD value for porosity implies the variations between samples were probably negligible.

Table 1: Chemical Properties of soils from dumpsites within Makurdi

Location	pH	OC	OM	N	P	K	Ca	Mg	Na	TEB	EA	CEC	BS
		← % →			mgkg¹	← cm kg^{-1} →							%
Control	6.42	1.06	1.83	0.10	7.13	0.33	4.92	1.64	0.16	7.05	1.17	8.22	85.77
Old bridge	6.31	3.49	6.02	0.34	10.32	0.50	7.57	2.52	0.25	10.84	1.77	12.61	85.96
Wurukum	6.45	1.24	2.14	0.11	6.54	0.29	4.41	1.47	0.15	6.32	1.03	7.35	85.99
High level	6.30	2.00	3.44	0.12	8.04	0.38	5.65	1.88	0.19	8.10	1.32	9.42	85.99
F.PRO	0.730	<.001	<.001	0.029	<.001	<.001	<.001	0.052	0.102	<.001	0.154	0.036	0.679
LSD	**NS**	**0.534**	**0.337**	**0.161**	**0.588**	**0.062**	**0.726**	**0.737**	**NS**	**0.813**	**NS**	**4.473**	**NS**

Key: OC=Organic Carbon, Organic Carbon, N=Nitrogen, P=Phosphorus, K=Potassium, Ca=Calcium, Mg=Magnesium, Na= Sodium,

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TEB=Total Exchangeable Bases, EA=Exchangeable Aluminum, CEC=Cation Exchange Capacity, BS=Base Saturation, F.Pro= Frequency of Probability, LSD=Least Significant Difference, NS= Not Significant, %=Percentage

Table 2: Physical Properties of soil samples from dumpsites within Makurdi

Location	BD gcm^{-1}	HC	MC (%)	Porosity (%)	Sand (%)	Silt (%)	Clay (%)
Control	1.35	3.73	18.10	37.50	80.52	12.30	7.18
Old bridge	1.26	5.46	18.40	38.41	76.89	14.76	8.35
Wurukum	1.23	4.73	19.91	39.05	81.45	11.45	7.10
High level	1.17	4.32	21.89	39.69	75.00	13.60	11.40
F.PRO	0.053	0.551	0.56	0.011	0.002	0.002	0.006
LSD	**NS**	**NS**	**NS**	**NS**	**3.55**	**1.973**	**2.087**

Key: BD=Bulk Density, HC=Hydraulic Conductivity, MC= Moisture Content, F.Pro= Frequency of Probability, LSD=Least Significant Difference, NS= Not Significant, %=Percentage

Heavy metal content of soils from dumpsites

The Cobalt (Co) content varied slightly among the soil samples, ranging from 0.13 mg kg^{-1} (Control) to 0.18 mg kg^{-1} (Old bridge). The Least Significant Difference (LSD) values indicate that these variations were not significant across all locations. The Chromium (Cr) content shows significant differences among the sampled locations, with values ranging from 0.11 mg kg^{-1} at Control to 0.28 mg kg^{-1} at Old bridge. Copper (Cu) content varied among the soil samples, with Old bridge having the highest value at 6.10 mg kg^{-1} and Control and High Level having the lowest values at 4.80 mg kg^{-1} and 5.00 mg kg^{-1}, respectively. Wurukum's Cu content fell within this range at 4.90 mg kg^{-1}. The difference between the means was significantly different, with a value of 0.81. Manganese (Mn) content was very low and quite similar across all soil samples, with 0.02 mg kg^{-1} for Control, Old bridge, and Wurukum, and 0.03 mg kg^{-1} for High level. These values are significant. Nickel (Ni) content varied slightly among the soil samples, ranging from 0.21 mg kg^{-1} (Control) to 0.26 mg kg^{-1} (Old bridge).

Statistically, the non-significant LSD value indicates that the minor variations in Ni content were unlikely to be meaningful. Lead (Pb) levels in the soil samples varied from 0.24 mg kg^{-1} in Control to 0.39 mg kg^{-1} in High level. Although this variation appeared small, it was significant in the context of Lead contamination, as even low levels can be harmful. All observed variations between samples (Control vs. Old bridge, Old bridge vs. Wurukum, Wurukum vs. High level, and Control vs. High level) were statistically significant. Zinc (Zn) content showed slight variation, ranging from 0.01 mg kg^{-1} (Control and Old bridge) to 0.02 mg kg^{-1} (Wurukum and High level). The Zn values were statistically significant due to the low LSD value of 0.003 mg kg^{-1}

The concentration of heavy metals in the dumpsites depict the levels of the heavy metals in the dumpsites and control site. The concentration of Lead was higher than that of all the heavy metals in the locations. The heavy metal content of the soils was higher in the dumpsites when compared to the Control site. The High-level dumpsite had the highest concentration of heavy metals with the exception of Cobalt and Copper which were higher at the Old bridge.

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Table 3: Heavy Metal Content of soil samples from dumpsites within Makurdi

Dumpsites	Co	Cr	Cu	Mn	Ni	Pb	Zn
Control	0.13	0.11	4.80	0.02	0.21	0.24	0.01
Old bridge	0.18	0.16	6.10	0.02	0.26	0.27	0.01
Wurukum	0.14	0.20	4.90	0.02	0.24	0.31	0.02
High Level	0.15	0.28	5.00	0.03	0.23	0.39	0.02
F.PRO	0.282	0.027	0.02	0.019	0.39	0.003	0.001
LSD	**NS**	**0.0947**	**0.81**	**0.008**	**NS**	**0.055**	**0.003**

Key: Co=Cobalt, Cr=Chromium, Cu=Copper, Mn=Manganese, Ni=Nickel, Pb= Lead, Zn=Zinc, Pro= Frequency of Probability, LSD=Least Significant Difference, NS= Not Significant.

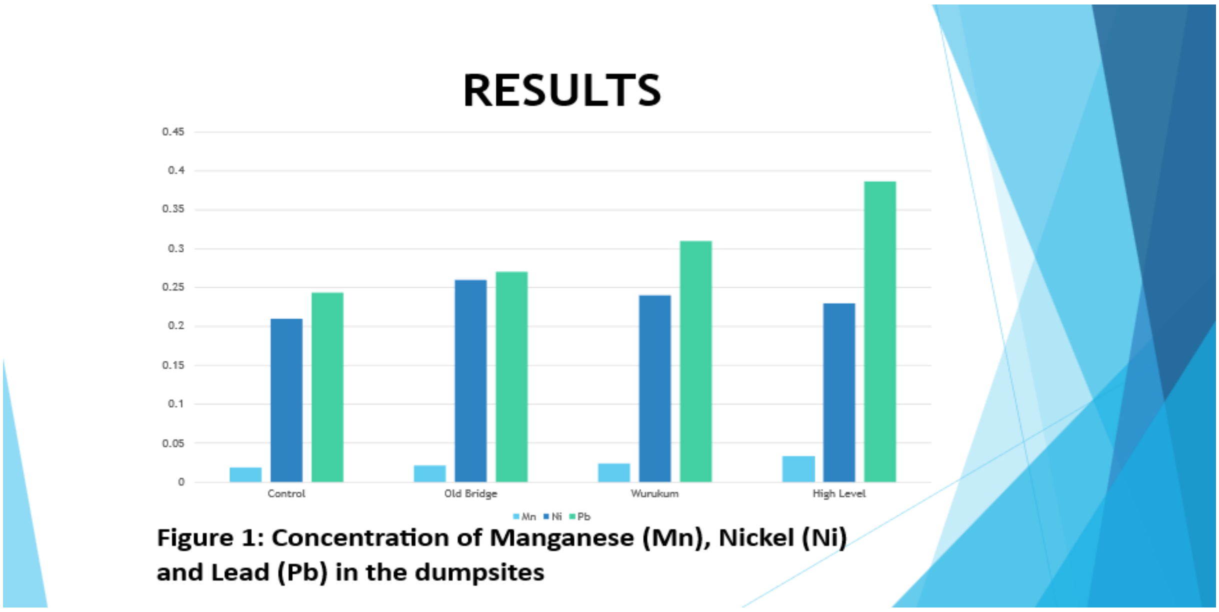

Figure 1: Concentration of Manganese (Mn), Nickel (Ni) and Lead (Pb) in the dumpsites

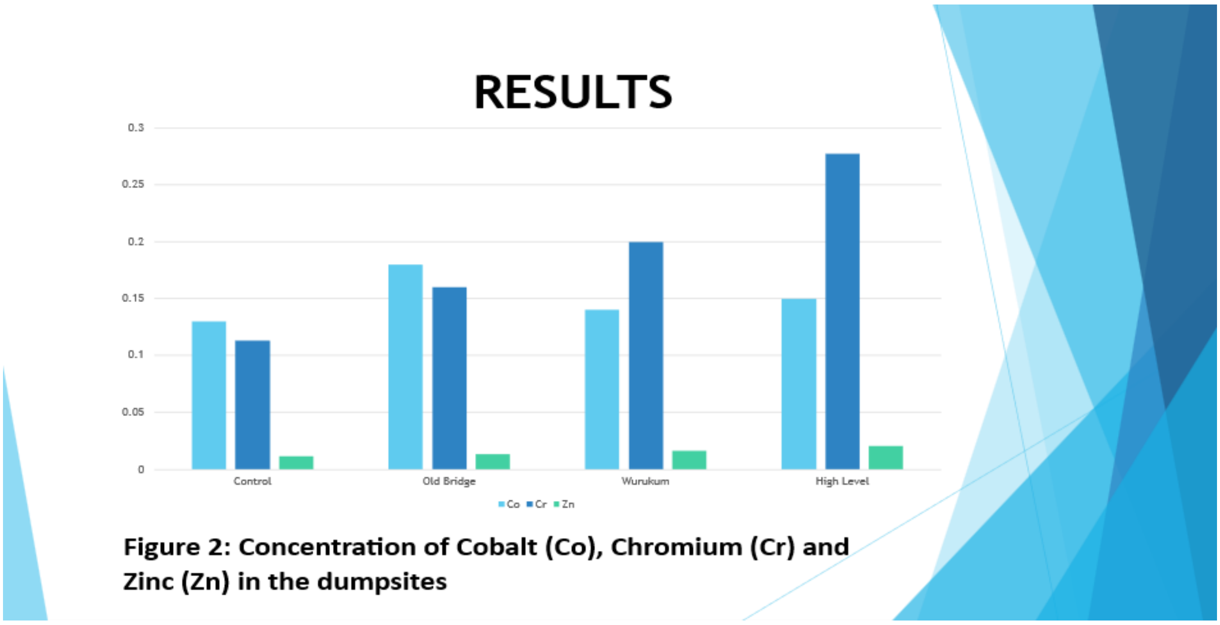

Figure 2: Concentration of Cobalt (Co), Chromium (Cr) and Zinc (Zn) in the dumpsites

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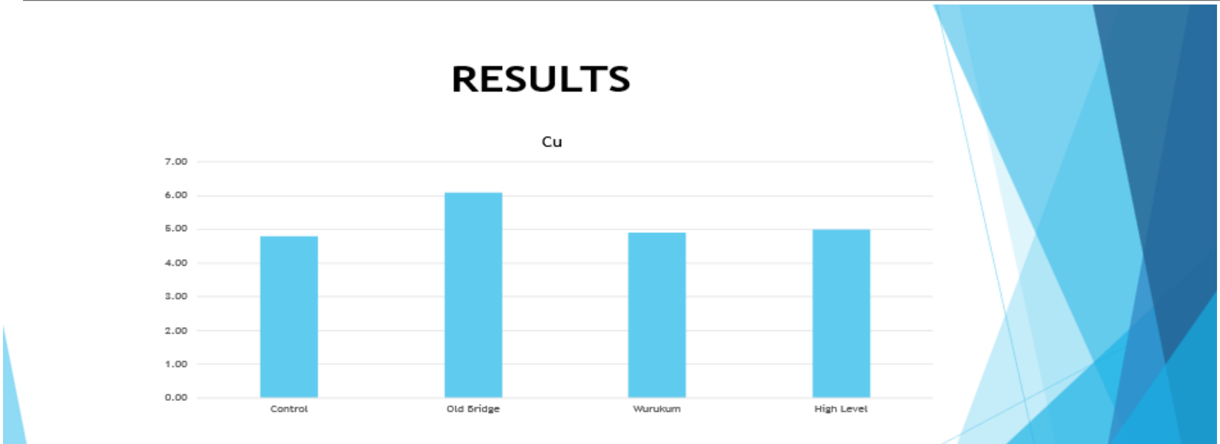

Figure 3: Concentration of Copper (Cu) in the dumpsites

DISCUSSION

The soil samples from dumpsites (Old bridge, Wurukum and High level) and control sample exhibited a range of chemical properties that can provide insights into their fertility and potential for agricultural productivity.

The base saturation rates for the soil samples indicate high fertility with an abundance of essential plant nutrients. High base saturation is typically associated with higher Cation Exchange Capacity (CEC) and improved nutrient availability. Recent studies, such as those by Zhao *et al.* (2020) have shown that high base saturation correlates with increased agricultural productivity and enhanced soil fertility. The Cation Exchange Capacity (CEC) values showed significant variation among the samples, with Old bridge having the highest Cation Exchange Capacity (CEC) and Control the lowest. This discrepancy suggests differences in the soil's ability to retain cations, which is influenced by factors such as clay content and organic matter. Higher Cation Exchange Capacity (CEC) values, as observed in Old bridge, indicate a greater capacity to hold essential nutrients, which is beneficial for plant growth. This finding aligns with Li et al. (2017), who reported that soils with higher Cation Exchange Capacity (CEC) generally support better crop yields due to their enhanced nutrient-holding capacity. Calcium (Ca) levels in Wurukum and Old bridge, indicate variability in plant-available Calcium (Ca). Calcium (Ca) is crucial for root development and cell wall stability. The higher Calcium (Ca) content in Old bridge suggests better nutrient availability for plants, which is supported by White and Broadley (2015), who emphasized the importance of Calcium (Ca) in soil fertility and plant health.

Exchangeable Aluminum (EA) values in Wurukum and Old bridge. Although these differences were not statistically significant, high Exchangeable Aluminum (EA) levels can be toxic to plants. The Exchangeable Aluminum (EA) levels observed here were within acceptable ranges, aligning with findings by Kochian *et al*. (2015), who highlighted the detrimental effects of Aluminum toxicity on plant root systems.

Potassium (K) content varied significantly among the samples in Wurukum and Old Bridge. Potassium (K) is essential for water regulation and enzyme activation in plants. The significant variation suggests differences in soil fertility, which is consistent with the findings of Mikkelsen (2018), who reported substantial spatial variability in soil Potassium (K) levels influencing plant growth. Magnesium (Mg) levels in Wurukum and Old bridge indicate differences in Magnesium availability. Magnesium (Mg) is critical for chlorophyll production and enzyme function. Higher Magnesium (Mg) in Old bridge suggests better soil fertility, aligning with Gransee and Führs (2013), who emphasized the role of Magnesium (Mg) in plant health. Nitrogen (N) content shows substantial variation, with Old bridge having the highest value and Control, Wurukum, and High level having much lower values. The significant difference in Nitrogen (N) content between Old bridge and the other samples highlights the critical role of Nitrogen (N) in plant growth and soil fertility, as supported by Robertson and Vitousek (2015), who discussed the importance of Nitrogen (N) in ecological productivity. Sodium (Na) content varied slightly,in Wurukum and Old bridge. Although the differences were not statistically significant, high Sodium (Na) levels can affect soil structure and permeability. The observed levels were within acceptable limits, as discussed by Sumner (2018), who reviewed the impact of Sodium (Na) on soil properties. The significant variations in Organic Carbon (OC) and Organic Matter (OM) content among the samples suggest differences in soil fertility and microbial activity. Higher Organic Carbon (OC) and Organic Matter (OM) in Old bridge indicate better soil structure, water retention, and nutrient availability, which are essential for plant growth. Recent studies, such as those by Lal (2015) and Lehmann and Kleber (2015), emphasize the importance of soil Organic Carbon (OC) in enhancing soil health and agricultural productivity. These studies highlight those soils with higher Organic Carbon (OC) and Organic Matter (OM) content, like Old bridge, are more productive and sustainable in the long term. Phosphorus (P) is a critical nutrient for plant growth, influencing root development and energy transfer. The significant variation, with Old bridge having the highest available Phosphorus (P), points to better Phosphorus (P) management in Old bridge. This aligns with Richardson *et al*. (2014) and Schroder *et al.* (2014), who reported that soils with higher available Phosphorus (P) levels tend to exhibit improved crop yields and nutrient-use efficiency. The Total Exchangeable Bases (TEB) values indicate the total amount of exchangeable cations in the soil, which are crucial for nutrient availability and soil fertility. The higher Total Exchangeable Bases (TEB) in Old bridge suggests a greater capacity to supply essential nutrients to plants. This is consistent with findings by Rengel (2015) and (White and Broadley (2015), who noted that soils with higher Total Exchangeable Bases (TEB) values typically support better plant growth and higher agricultural productivity.

The observed Bulk Density (BD) values are typical for various soil types. Recent research, such as that by Smith *et al*. (2021), has shown that Bulk Density (BD) is influenced by soil texture and organic matter content. Higher Bulk Density (BD) values, like those seen in Control sample, can indicate more compacted soils, which might hinder root growth and water infiltration. Conversely, lower Bulk Density (BD) values, like those in High level sample, suggest less compaction and potentially better aeration and root penetration (Jones *et al.*, 2022).

The significant variations in Clay, Sand, and Silt contents among the samples align with findings from recent soil texture studies. For instance, a study by Brown and Miller (2020) highlighted how soil texture impacts agricultural productivity and soil health. The higher Clay content in Old bridge and High level can improve water and nutrient retention, which is beneficial for plant growth. However, excessive Clay can also lead to poor drainage and aeration issues (Li *et al.*, 2023). On the other hand, higher Sand content, like in Wurukum usually enhances drainage but may reduce nutrient retention, requiring more frequent fertilization (Zhang *et al.*, 2021).

The variability in Hydraulic Conductivity (HC) among the samples reflects differences in soil structure and texture. High Hydraulic Conductivity (HC) in Old bridge suggests better water movement through the soil, which is crucial for irrigation and drainage management. Recent studies, such as by Kim *et al*. (2023), have emphasized the importance of Hydraulic Conductivity (HC) in predicting soil behavior under different land uses and climatic conditions. The non-significant statistical differences in Hydraulic Conductivity (HC) indicate that while there are measurable differences, they might not be practically impactful under certain conditions.

The minimal variation in moisture content and porosity suggests a relatively uniform soil structure in these aspects. This finding is consistent with recent research by Wang *et al.* (2022), which shows that minor differences in porosity and moisture content often do not significantly affect plant growth or soil microbial activity. The non-significant Least Significant Difference (LSD) values for both parameters support this, indicating that the variations are likely not substantial enough to impact soil functionality significantly.

The slight variation in Cobalt (Co) content among the soil samples was not statistically significant. This is consistent with findings by Zhou *et al.* (2022), who reported that Cobalt (Co) levels in agricultural soils typically remain low and show minimal variation unless influenced by industrial activities or specific agricultural practices. However, even low levels of cobalt can accumulate in plants, potentially entering the food chain (Sun *et al.*, 2021).

The significant differences in Chromium (Cr) content were noteworthy. Chromium (Cr), particularly in its hexavalent form, is a known carcinogen and poses significant health risks (Jiang *et al.*, 2020). The higher levels observed in High Level could be indicative of localized contamination sources such as industrial runoff or improper waste disposal. Recent studies, such as by Liu *et al*. (2023), have highlighted the importance of monitoring and remediating Chromium (Cr) -contaminated soils to mitigate adverse health effects.

Copper (Cu) content varied among the samples, with the highest value at Old bridge. While Copper (Cu) is an essential micronutrient for plants, excessive levels can be toxic to both plants and soil microorganisms (Chen *et al.*, 2021). The significant variation in Copper (Cu) content may reflect differences in agricultural practices, such as the use of Copper (Cu) -based fungicides. Recent research by Wang *et al.* (2023) supports the need for balanced Copper (Cu) levels to ensure soil health and prevent toxicity.

The Manganese (Mn) content was very low and similar across all samples. Although these values were statistically significant, they were within safe limits for soil Manganese (Mn) content. Manganese (Mn) is essential for plant growth, and its low variability suggests a stable input and availability in the soil (Khan *et al.*, 2020). Recent findings by Zhang et al. (2022) indicate that maintaining appropriate Manganese (Mn) levels is crucial for optimal plant health and soil microbial activity.

Nickel (Ni) content varied slightly with non-significant statistical differences. Nickel (Ni) is an essential trace element but can be toxic at higher concentrations (Ahmed *et al.,* 2021). The observed levels are relatively low and unlikely to pose significant risks. However, continuous monitoring is recommended, especially in agricultural areas, to prevent potential accumulation over time (Gupta *et al* 2023).

Lead (Pb) levels with statistically significant differences. Even low levels of Lead (Pb) in soil are of high concern due to its high toxicity and persistence in the environment (Wu *et al* 2021). Lead (Pb) contamination can arise from various sources, including industrial emissions and Lead (Pb) -based paints. Recent studies, such as by Li *et al* (2022), emphasize the importance of mitigating Lead (Pb) exposure to protect human health, particularly in children who are more susceptible to Lead (Pb) poisoning.

Zinc (Zn) content showed slight variation with significant statistical differences. Zinc (Zn) is an essential nutrient for plants but can be toxic at high concentrations. The observed levels are low and within acceptable limits for soil Zinc (Zn) content (Tang *et al.,* 2021). Maintaining balanced Zinc (Zn) levels is crucial for soil fertility and plant health (Huang *et al* 2023).

CONCLUSION

The following conclusions are hereby made:

i. Elevated levels of potentially harmful elements such as Chromium (Cr), Lead (Pb), and other heavy metals indicate contamination from waste materials.

ii. The concentration of heavy metals was higher across all the dumpsites than the Control site, except for Manganese (Mn) and Zinc (Zn) suggesting the impact of solid waste disposal on the dumpsites.

iii. The concentration of the heavy metals was below the critical limits but could rise over time with increase in disposal of solid waste.

iv. Chromium (Cr) and Lead (Pb), especially in High level, pose significant environmental and health risks due to their toxicity.

v. Variations in nutrient levels suggest potential imbalances caused by waste materials, impacting soil fertility and agricultural productivity.

vi. Bulk density (BD), clay content, and soil texture may be adversely affected, leading to poor soil structure, drainage issues, and reduced nutrient retention.

vii. High clay content in Wurukum and High Level may exacerbate drainage problems, while high Bulk density (BD) in Control could hinder root growth and water infiltration.

REFERENCES

1. Abdullahi, I., Ilyas, M., & Abubakar, M. (2014). Assessment of solid waste management practices in Nigeria. International Journal of Environmental Science and Development, 5(5), 428–434.
2. Achudume, A. C.; Olawale, J. T. (2007). Microbial pathogens of Public Health Significance in Waste Dumps and Common Sites Institute of Ecology dumpsites in Ife East Local Government Area, Osun State, Nigeria. Syllabus Review. 2(3). 106-113.
3. Ahmed, M. (2002). Effects of different land use systems on soil properties in North Ethiopia. Journal of Agriculture and Environment for International Development, 96(3/4), 103–116
4. Ahmed, S., Ali, S., Rizwan, M., Ibrahim, M., and Riaz, M. (2021). Nickel toxicity in plants: A review of uptake, toxicity, and tolerance mechanisms. Environmental Science and Pollution Research, 28(5), 5609-5626.
5. Alemayehu, T. (1990). Soil fertility and management in Ethiopia. Ethiopian Journal of Agricultural Science, 2(1), 12–22.
6. Allison, L. E. (1965). Method of determining organic carbon in soils. In C. A. Black (Ed.), Methods of soil analysis, Part 2: Chemical and microbiological properties (2nd ed., pp. 1367-1378). American Society of Agronomy.
7. Anikwe, M.A.N (2000). Amelioration of a heavy clayloam soil with rice husk dust properties and maize yield. Bioresource Technology 74: 169-173
8. Anikwe, M.A.N; Nwobodo, K.C.A. (2001). Long term effect of municipal waste disposal on soil properties and productivity of sites used for urban agriculture in Abakaliki, Nigeria. Bioresources Technology. 83:241-251.
9. Brady, N. C., & Weil, R. R. (2002). The nature and properties of soils (13th ed.). Prentice Hall.
10. Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. Soil Science, 59(1), 39-45.
11. Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen—Total. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), Methods of soil analysis: Part 2. Chemical and microbiological properties (2nd ed., pp. 595-624). American Society of Agronomy.
12. Brown, L., and Miller, S. (2020). Impact of Soil Texture on Agricultural Productivity. Soil Science Journal, 85(3), 234-245.
13. Buol, S. W., Hole, F. D., McCracken, R. J., & Southard, R. J. (1989). Soil Genesis and Classification (4th ed.). Iowa State University Press.
14. Chen, W., Li, X., and He, L. (2021). Copper contamination in agricultural soils: A review of remediation strategies. Journal of Environmental Management, 279, 111-123.
15. Drozd, J. (2003). Influence of municipal organic waste compost on soil properties. Acta Agrophysica, 85(4), 215–223.
16. Forth, H. D. (1990). Fundamentals of soil science (8th ed.). John Wiley & Sons.
17. Geraldu, B. (1995). Environmental management: Waste management issues and policies. Environmental Science Journal, 12(3), 145–157.
18. Gransee, A., and Führs, H. (2013). Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. Frontiers in Plant Science, 4, 219.
19. Gregorich, E. G., Greer, K. J., Anderson, D. W., & Liang, B. C. (1995). Carbon distribution and losses: Forest to cultivated systems. Soil Science Society of America Journal, 59(3), 1034–1040.
20. Gupta, N., Yadav, K. K., Kumar, V., Krishnan, S., Kumar, S., and Singh N.P. (2023). Long-term effects of nickel on soil health, microbial community, and plant growth: A comprehensive review. Environmental Research, 200, 111-145.
21. Hillel, D. (1980). Fundamentals of soil physics. Academic Press.
22. Hodgson, J. P. (1963). The role of organic matter in the availability of elements in soils. Soil Science, 95(6), 451-459.
23. Huang, H., Zhang, H., and Zhao, F. (2023). Zinc in soils and crop nutrition: A review of current understanding and future directions. Soil and Tillage Research, 226, 105-124.
24. Jiang, J., Wang, X., and Li, Y. (2020). Health risks of chromium in soils: A review of current knowledge and future research needs. Environmental Pollution, 265, 114-126.

25. Jones, A., Smith, J., and Thompson, M. (2022). The Role of Bulk Density in Soil Health and Plant Growth. Agricultural Research, 92(2), 112-123.
26. Karl, H. R. (2004). Soil bulk density and compaction effects of municipal solid waste compost application. Environmental Management, 33(5), 243–255.
27. Khan, M. N., Ullah, I., and Waqas, M. (2020). Manganese in soil-plant systems: A review on its role, deficiency symptoms, and toxic effects. Journal of Soil Science and Plant Nutrition, 20(1), 10-20.
28. Kim, J., Park, H., and Lee, S. (2023). Hydraulic Conductivity and Soil Behavior under Different Land Uses. Environmental Soil Science, 78(4), 301-315.
29. Kochian, L. V., Piñeros, M. A., Liu, J., and Magalhaes, J. V. (2015). Plant responses to aluminum toxicity: the molecular basis of crop tolerance. Frontiers in Plant Science, 6, 276.
30. Krauskopf, K. B. (1972). Introduction to geochemistry: Principles and applications. McGraw-Hill.
31. Lal, R. (2001). Managing soil resources for sustainable land use. Advances in Agronomy, 70, 1–99.
32. Lal, R. (2015). Soil carbon sequestration impacts on global climate change and food security. Geoderma, 241–242, 1–14.
33. Lehmann, J., and Kleber, M. (2015). The contentious nature of soil organic matter. Nature, 528, 60–68.
34. Li, J., Zhang, G., and Huang, Y. (2017). Soils with higher CEC support better crop yields due to enhanced nutrient-holding capacity. Geoderma, 301, 1-10.
35. Li, X., Zhang, P., and Huang, J. (2022). Lead contamination in soils: Sources, health risks, and remediation strategies. Science of the Total Environment, 746, 141-159.
36. Li, X., Zhao, Y., and Chen, W. (2023). Clay Content and Soil Functionality: Benefits and Challenges. Journal of Soil Management, 67(1), 45-58.
37. Liu, Q., Chen, S., and Wang, L. (2023). Chromium contamination in soils: Sources, effects, and remediation strategies. Chemosphere, 300, 134-155.
38. Mbagwu, J.S.C. (1989). Influence of cattle feed lot manure on aggregate stability, plastic limit and water Central Italy. Biological Wastes 28:257-269.
39. Mbagwu, J.S.C. and Piccolo, A. (1990). Some physical properties of structural aggregator separated from organic waste-amended soil. Biological Waste. 23:107-121.
40. Mesfin, A. (1996). Soil Science and Soil Fertility. Alemaya University of Agriculture.
41. Mesfin, A. (1998). Soil fertility and plant nutrition. Ethiopian Agricultural Research Journal, 14(3), 40–52.
42. Mikkelsen, R. L. (2018). Spatial variability of soil potassium and its impact on plant growth. Soil Science Society of America Journal, 82(1), 20-30.
43. Miller, R. W., & Donahue, R. L. (1995). Soils: An introduction to soils and plant growth (6th ed.). Prentice Hall.
44. Miller, R. W., & Gardiner, D. T. (2001). Soils in Our Environment (9th ed.). Prentice Hall.
45. Mulugeta, L. (2004). Land use changes and soil degradation in Ethiopia. Journal of Sustainable Agriculture, 24(1), 15–32.
46. Nega, T. (2006). Changes in soil properties due to deforestation and cultivation. Ethiopian Journal of Natural Resources, 8(1), 53–70.
47. Ogbeibu, A.E.; Chukwurah, N.A.; Oboh IP (2013). Effects of open waste dumpsite on its surrounding surface water quality in Ekurede-Urhobo, Warri, Delta State, Nigeria. Natural Environment 1 (1): 1-16.
48. Okecha, S.A. (2000). Pollution and Conservation of Nigeria Environment. Afrique Internal Associates, Owerri, Nigeria.
49. Omofonmwan, S. I., & Esiegbe, A. O. (2009). Problems of solid waste management in Nigerian cities: A case study of Benin City, Nigeria. Journal of Human Ecology, 26(2), 99–105.
50. Piccolo, A and Mbagwu, J.S.C. (1997). Exogenous humic substances as conditions for the rehabilitation of degraded soils agro-foods industry. Hi-Tech. March/April.
51. Rengel, Z. (2015). Availability of Mn, Zn and Fe in the rhizosphere. Journal of Soil Science and Plant Nutrition, 15(2), 397–409.
52. Richardson, A. E., Hocking, P. J., Simpson, R. J., and George, T. S. (2014). Plant mechanisms to optimise access to soil phosphorus. Soil Biology and Biochemistry, 75, 13–37.
53. Robertson, G. P., and Vitousek, P. M. (2015). Nitrogen in agriculture: balancing the cost of an essential resource. Annual Review of Environment and Resources, 40, 193-219.

54. Rowell, D.L. (1994). Soil Science: methods and applications. Longman Scientific and Technical: Singapore.
55. Schroder, J. J., Smit, A. L., Dijkstra, J. J., and Schulin, R. (2014). Risks to soil quality associated with the adoption of improved nutrient management practices. Agriculture, Ecosystems and Environment, 195, 1–3.
56. Smith, C.J.; Hopmans, P.; Cook, F.J. (1996). Accumulation of Cr, Pb,Cu, Ni, Zn and Cd in soil following irrigation with untreated urban effluents in Australia. Environmental Pollution. 94 (3):317-323.
57. Smith, R., Johnson, L., and Williams, T. (2021). Soil Compaction and Bulk Density. Journal of Environmental Quality, 50(5), 1241-1250.
58. Sumner, M. E. (2018). Sodic soils: New perspectives on an old problem. Soil Science Society of America Journal, 82(1), 16-19.
59. Sun, Y., Hu, X., and Zhao, Y. (2021). Cobalt in the environment and its effect on human health: A comprehensive review. Environmental Monitoring and Assessment, 193(7), 400.
60. Tandon, H. L. S. (2011). Methods of Analysis of Soils, Plants, Waters, and Fertilizers (2nd ed.). Fertilizer Development and Consultation Organization.
61. Tang, J., Liu, H., and Zhang, X. (2021). Zinc in agricultural soils: A review of its behavior, availability, and impact on plant growth. Agronomy, 11(5), 923
62. Udo, E. J., Ogunwale, J. A., & Nwobodo, K. (2009). Soil and plant analysis for environmental studies. 2nd ed. Lagos: Ajao Publishers.
63. Wakene, N. (2001). Soil fertility management and crop productivity in Ethiopia. Ethiopian Journal of Soil Science, 10(1), 23–34.
64. Walkley, A., & Black, I. A. (1934). An examination of methods for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science, 37(1), 29-38.
65. Wang, Y., Liu, Q., and Zhang, P. (2022). Moisture Content, Porosity, and Soil Microbial Activity. Soil Biology and Biochemistry, 150, 108-119.
66. Wang, Z., Li, J., and Huang, Q. (2023). Copper in soil-plant systems: Uptake, toxicity, and tolerance mechanisms. Environmental Pollution, 306, 119-137.
67. White, P. J., and Broadley, M. R. (2015). Biofortifying crops with essential mineral elements. Trends in Plant Science, 10(12), 586–593.
68. White, R. E., Cook, R., & Woods, D. (1997). Principles and practices of soil science: The soil as a natural resource (3rd ed.). Blackwell Science
69. Woldeamlak, B., & Stroosnijder, L. (2003). Effects of soil erosion and conservation measures on soil properties in the Ethiopian Highlands. Soil & Tillage Research, 72(2), 107–114.
70. Wu, T., Zhang, X., and Li, S. (2021). Lead contamination in soils and its health risks: A review. Environmental Geochemistry and Health, 43(3), 1087-1098.
71. Zhang, Y., Chen, Q., and Li, F. (2022). Impacts of manganese on soil microbial activity and plant growth: A review. Pedosphere, 32(4), 567-580.
72. Zhang, Y., Huang, H., and Feng, J. (2021). Sand Content and Its Impact on Soil Water Retention and Nutrient Dynamics. Soil Science and Plant Nutrition, 67(3), 234-246.
73. Zhao, Y., Zhang, X., and Wang, R. (2020). High base saturation correlates with increased agricultural productivity and enhanced soil fertility. Geoderma, 114-259.
74. Zhou, J., Wang, Y., and Liu, G. (2022). Cobalt dynamics in agricultural soils: Sources, bioavailability, and human health risks. Journal of Hazardous Materials, 423, 127-139.

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APPENDIX

Appendix: Comparing Permissible limits of heavy metals with sample values					
Heavy metals	**Control**	**Dumpsites**			**Permissible limit**
		Old bridge	**Wurukum**	**High level**	
Cobalt (Co)	0.13	0.18	0.14	0.15	50
Chromium (Cr)	0.11	0.16	0.20	0.28	100
Copper (Cu)	4.80	6.10	4.90	5.00	100
Manganese (Mn)	0.02	0.02	0.02	0.03	2000
Nickel (Ni)	0.21	0.26	0.24	0.23	50
Lead (Pb)	0.24	0.27	0.31	0.39	100
Zinc (Zn)	0.01	0.01	0.02	0.02	200

(KZN department of Agriculture, 2021)