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Assessment of micronutrient and heavy metal contamination in soils near refuse dumpsites in Ughelli North, Delta State, Nigeria

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Abstract
Soil quality plays a critical role in sustaining agro-ecosystems, particularly in areas adjacent to refuse dumpsites where contamination risks are high. This study investigates the levels of micronutrients and heavy metals in soils near a refuse dumpsite in Ughelli North Local Government Area, Delta State, Nigeria, comparing them to a control site with neutral soil. Soil samples were collected at varying depths (0-15 cm, 15-30 cm, and 30-45 cm) and analyzed using standard laboratory procedures, including the Double Acid Extraction Method and Flame Atomic Absorption Spectrophotometry (FAAS). Results revealed that soils from the dumpsite exhibited lower levels of essential micronutrients such as iron (Fe), manganese (Mn), and zinc (Zn), while showing elevated levels of heavy metals like nickel (Ni) and mercury (Hg) compared to the control site. The control site, by contrast, demonstrated better soil quality, with higher organic carbon content, total nitrogen, and a more neutral pH. The findings indicate significant soil degradation and potential environmental risks associated with refuse dumpsites, emphasizing the need for proper waste management and soil remediation strategies to safeguard agricultural productivity and environmental health in the region.
Keywords
Heavy metal, Micronutrients, Soil properties, Dumpsite, Ughelli

Introduction

Soil is a critical component in sustaining the productivity of an agro-ecosystem, as its capacity to provide essential nutrients directly influences plant growth. However, field studies have increasingly identified micronutrient deficiencies in soils as a significant barrier to maintaining soil productivity and sustainability (Jiang et al., 2009). The sustainable use of soil resources is essential for successful agriculture, as soil quality and quantity can rapidly decline due to factors like intensive farming, leaching, and erosion (Kiflu and Beyene, 2013). Heavy metals are notable environmental pollutants, and their toxicity is becoming an increasingly important concern for ecological, nutri-

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tional, and environmental health (Jaishankar et al., 2013). In the natural environment, heavy metals exist in various chemical forms, each with distinct behaviors in terms of interactions, mobility, bioavailability, and toxicity (Osu et al., 2014). These metals are crucial in plant physiology, participating in redox reactions and serving as core components of many enzymatic processes (Nagajyoti et al., 2010). Refuse dumpsites are significant sources of heavy metal pollution, where leachate from landfills can contaminate surrounding soil and groundwater, posing health risks to nearby communities (Saheed et al., 2020). Unauthorized and illegal mining of gold ores, apparently containing high levels of Pb, caused widespread contamination of soil and drinking water sources with Pb. High concentration of Pb was detected in the blood of children, many of whom had suffered from headaches, vomiting, abdominal pains, seizures and death (Orisakwe et al., 2017). More recently, artisanal mining operations, similar to that in Zamfara state have been spreading across the country, and a recent investigation suggests that about two million people in Southwestern Nigeria may be at risk of Pb and Hg poisoning (Vanguard, 2021). The availability of micronutrients in soils, on the other hand, is influenced by several factors, including soil pH, organic matter content, and the physical, chemical, and biological conditions of the rhizosphere (Yadav, 2011). Hence, this study examines the levels of micronutrients and heavy metals contamination in soils near refuse dumpsites compared to a control site in Ughelli metropolis. By assessing these concentrations, the research aims to understand the extent of contamination and the potential risks to agricultural practices in the surrounding areas.

Materials and Methods

Description of the study area

This research was conducted in Ughelli North Local Government Area, located in Delta State, Nigeria. Ughelli is one of the major urban areas in Delta state, which is located between the latitude 5.500187°N and longitude 5.993834°E. According to USDA Taxonomy, the soil found in Ughelli is Ultisol ((Soil Survey Staff, 1998). These soils are usually acidic, low in natural fertility, and found in areas with significant leaching due to high rainfall. They often require soil management practices, such as fertilization and liming, to improve productivity. Also, the area is riddled with an intricate system of natural water channels and valleys, culminating in poorly drained landscape (Udo, 1976). It covers an area of 818km^2 and a population of 321,028 (National Population Commission, 2006). The area is made up of the Urhobo ethnic group and comprises of 6 Clans (Agboje et al., 2023). The climate in Ughelli North L.G.A is typically tropical, characterized by two distinct seasons: the rainy season and the dry season. The rainy season usually spans from April to October, providing ample rainfall to support crop growth. The dry season, from November to March, is characterized by lower precipitation and higher temperatures, necessitating irrigation for some crops. Agriculture is predominantly small-scale and subsistence-based, with farmers cultivating crops such as cassava, yam, maize, and vegetables like okra and tomatoes. Traditional farming methods are common, livestock farming, including poultry and small ruminants, also plays a role in the local agricultural system.

Sample collection

Soil samples were collected from two distinct sites: Ughelli Main Market Area (dumpsite, treatment site) and an agricultural farm at Omotor Street (control site), located off Ughelli Main Market. The geographical coordinates of the treatment site were Latitude 5.4989° N, Longitude 5.9886° E, and those of the control site were Latitude 5.498575° N, Longitude 5.985040° E. At each site, soil samples were taken from three different points, evenly spaced across the area. For each point, samples were collected at three depths (0–15 cm, 15–30 cm, and 30–45 cm) and bulked together to make a single sample for each depth using a soil auger (Wilding, 1985). The soil samples from the three points at each depth were composited to create a single representative sample for each depth interval, both at the treatment and control sites. This composite sampling approach was used to ensure representative soil characterization at each location.

Soil laboratory analysis

Soils collected from each depth were air-dried, crushed and passed through a 2mm sieve. The sieved samples were analyzed for some physical and chemical properties using standard laboratory procedures. The pH level of the air-dried soil was measured using a glass electrode pH meter with a 1:1 ratio, following the procedure outlined by Mclean (1982). Prior to the pH measurement, calibration of the pH meter was performed using buffer pH 4.0 and 9.0. The electrode was immersed in the liquid portion of the mixture to

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obtain the reading, which was then recorded. Soil organic carbon was determined by the Walkley-Black method procedure by wet oxidation using chromic acid digestion (Nelson and Sommer, 1996). Particle size was determined by the hydrometer method (Gee and Or, 2002). Soil organic carbon was determined by the Walkley-Black method (Nelson and Sommer, 1996). The available phosphorus was determined by colorimetric method after extracting with Bray 1solution (Murphy and Riley 1962).

Micronutrient and heavy metal analysis

The soil samples were analyzed in the laboratory for both micronutrients and heavy metals using the Double Acid Extraction Method and Flame Atomic Absorption Spectrophotometry (FAAS). The microntrients and heavy metals tested included Zinc (Zn), Chromium (Cr), Iron (Fe), Manganese (Mn), Cadmium (Cd), Lead (Pb), Nickel (Ni), Mercury (Hg), and Copper (Cu) (Udo et al., 2009). To prepare the samples, one gram (1.0 g) of soil was accurately weighed and digested with 15 mL of a double acid solution composed of 0.05N Hydrochloric Acid (HCl) and 0.125N Sulfuric Acid (H_2SO_4). This extraction method is effective in dissolving both exchangeable and acid-soluble fractions of heavy metals from the soil matrix. After digestion, the mixture was filtered using Whatman No. 1 filter paper to remove solid residues, leaving a clear extract containing the solubilized metals. The filtered extract was then analyzed using FAAS, which detects the concentration of metals based on the absorption of light by free atoms vaporized in a flame (Udo et al., 2009).

Statistical analysis

The data obtained were analyzed by Genstat computer package. The difference between the means were separated using Duncan multiple range test at 5% level of probability.

Results

Soil physical properties

The table compares the physical and chemical properties of soils from a control site and a dumpsite (farmland) across three different depths (0-15 cm, 15-30 cm, and 30-45 cm).

Clay content. At the farm site (control), clay content increases with depth, ranging from 116.70 g/kg at 0-15 cm to 135.30 g/kg at 30-45 cm, with a mean of 125.11 g/kg. The dumpsite site also shows an increasing trend, from 116.30 g/kg at 0-15 cm to 139.30 g/kg at 30-45 cm, with a higher mean of 128.3 g/kg. This indicates that both sites have a significant amount of clay, with the control site showing slightly higher values.

Silt content. The silt content at the control site decreases with depth, from 47.00 g/kg at 0-15 cm to 37.00 g/kg at 30-45 cm, with a mean of 42.2 g/kg. Similarly, the dumpsite site shows a decrease in silt content with depth, from 42.33 g/kg at 0-15 cm to 28.33 g/kg at 30-45 cm, with a mean of 34.6 g/kg. The farm area has higher silt content overall, suggesting finer soil particles compared to the dumpsite site.

Sand content. Sand content is high in both locations but shows a slight decrease with depth. At the control site, it ranges from 836.30 g/kg at 0-15 cm to 827.70 g/kg at 30-45 cm, with a mean of 832.7 g/kg. The dumpsite has a higher sand content, ranging from 841.30 g/kg at 0-15 cm to 832.30 g/kg at 30-45 cm, with a mean of 837.1 g/kg.

Soil chemical properties

pH. Soil pH at the dumpsite is slightly acidic, ranging from 4.46 at 0-15 cm to 4.10 at 30-45 cm, with a mean of 4.35. The control site has a more neutral pH, ranging from 6.13 at 0-15 cm to 5.04 at 30-45 cm, with a mean of 5.6.

Electrical Conductivity (EC). EC, which measures soil salinity, decreases with depth at the dumpsite, from 85.70 μS/cm at 0-15 cm to 50.75 μS/cm at 30-45 cm, with a mean of 68 μS/cm. The control site shows significantly higher EC values, ranging from 341.80 μS/cm at 0-15 cm to 203.60 μS/cm at 30-45 cm, with a mean of 253.3 μS/cm. Higher EC in the control site suggests more soluble salts, which may affect plant growth if excessively high.

Organic Carbon (C org). Organic carbon content, crucial for soil fertility, decreases with depth at the dumpsite, from 8.00 g/kg at 0-15 cm to 6.10 g/kg at 30-45 cm, with a mean of 6.74 g/kg. The control site has higher organic carbon content, from 9.12 g/kg at 0-15 cm to 4.750 g/kg at 30-45 cm, with a mean of 22.25 g/kg. The control site's higher organic carbon suggests better soil fertility and microbial activity.

Available Phosphorus (Av.P). Available phosphorrus at the dumpsite decreases significantly with depth, from 28.40 mg/kg at 0-15 cm to 14.70 mg/kg at 30-45 cm, with a mean of 20.04 mg/kg. The control site has lower phosphorus content overall, ranging from

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10.98 mg/kg at 0-15 cm to 8.35 mg/kg at 30-45 cm, with a mean of 9.94 mg/kg. Higher phosphorus levels in the dumpsite might be due to waste decomposition, although they could also be a sign of potential pollution.

Total Nitrogen (TN). Total nitrogen content at the dumpsite decreases with depth, from 0.66 g/kg at 0-15 cm to 0.30 g/kg at 30-45 cm, with a mean of 0.48 g/kg. The control site has higher total nitrogen levels, ranging from 2.73 g/kg at 0-15 cm to 1.43 g/kg at 30-45 cm, with a mean of 2.05 g/kg. The higher nitrogen content in the control site indicates more fertile soil, which is likely to support better crop yields.

Table 1. *Soil physico-chemical properties of control site and dumpsite*

Sites	Depth	Clay	Silt	Sand	pH	Org. C	Total N	EC	Av. P
	cm	g/kg						µS/cm	mg/kg
Control	0-15	116.70c	47.00a	836.30a	6.13a	8.00a	0.66a	85.70a	28.40a
	15-30	123.30b	42.67b	834.00b	5.63b	6.13b	0.50b	67.59b	17.02b
	30-45	135.30a	37.00c	827.70c	5.04c	6.10b	0.30c	50.75c	14.70c
	Mean	125.11	42.20	832.70	5.60	6.74	0.48	68.00	20.04
Dumpsite	0-15	116.30c	42.33a	841.30a	4.46a	9.12a	2.73a	341.80a	10.98a
	15-30	129.30b	33.00ab	837.70b	4.50a	7.04b	2.00b	215.20b	10.49a
	30-45	139.30a	28.33b	832.30c	4.10b	4.75c	1.43b	203.60c	8.35b
	Mean	128.30	34.60	837.10	4.35	7.09	2.05	253.3	9.94

Mean value(s) with the same letters(s) in the column are not significantly different from one another at 5% level of probability.

Micronutrients and heavy metals in dumpsite and control site

In the context of your study, the following micronutrients were analyzed: Iron (Fe), Manganese (Mn), Zinc (Zn). However. heavy metals are metallic elements that have high atomic weights and densities and can be toxic to the environment and living organisms at elevated levels. The heavy metals analyzed in your study include Copper (Cu), and Chromium (Cr), Nickel (Ni) and Mercury (Hg).

Iron (Fe). At the dumpsite, the iron content ranged from 103.40 mg/kg at 30-45 cm depth to 146.00 mg/kg at 0-15 cm depth, with a mean value of 121.1 mg/kg. In contrast, the control site had significantly higher iron levels, ranging from 176.10 mg/kg at 30-45 cm depth to 203.20 mg/kg at 0-15 cm depth, with a mean of 187.78 mg/kg.

Manganese (Mn). Manganese levels at the dumpsite ranged from 42.07 mg/kg at 30-45 cm depth to 62.92 mg/kg at 0-15 cm depth, with a mean of 51.4 mg/kg. The control site exhibited higher manganese content,. ranging from 55.97 mg/kg at 30-45 cm depth to 94.09 mg/kg at 0-15 cm depth, with a mean of 71.75 mg/kg. This pattern is similar to that observed for iron, suggesting possible micronutrient depletion in the dumpsite area.

Zinc (Zn). Zinc concentration in the dumpsite ranged from 55.67 mg/kg at 30-45 cm depth to 105.77 mg/kg at 0-15 cm depth, with a mean of 79.7 mg/kg. The control site had higher zinc levels, from 102.90 mg/kg at 30-45 cm depth to 185.60 mg/kg at 0-15 cm depth, with a mean of 134.4 mg/kg.

Copper (Cu). The dumpsite soil contained copper levels ranging from 20.92 mg/kg at 30-45 cm depth to 34.25 mg/kg at 0-15 cm depth, with a mean of 28.54 mg/kg. Copper levels were higher in the control site, ranging from 42.86 mg/kg at 30-45 cm depth to 56.98 mg/kg at 0-15 cm depth, with a mean of 40 mg/kg.

Chromium (Cr). Chromium levels in the dumpsite soil ranged from 9.80 mg/kg at 30-45 cm depth to

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20.55 mg/kg at 0-15 cm depth, with a mean of 15.87 mg/kg. The control site had higher chromium concentrations, from 19.93 mg/kg at 30-45 cm depth to 36.78 mg/kg at 0-15 cm depth, with a mean of 26.59 mg/kg. Chromium, being both a micronutrient and a heavy metal, shows lower concentrations in the dumpsite compared to the control site.

Nickel (Ni). In the dumpsite area, nickel levels decreased with soil depth, ranging from 11.44 mg/kg at 0-15 cm depth to 7.73 mg/kg at 30-45 cm depth, with a mean of 9.52 mg/kg. At the control site, nickel concentrations were significantly lower, ranging from 3.35 mg/kg at 0-15 cm depth to 1.51 mg/kg at 30-45 cm depth, with a mean of 2.42 mg/kg. The higher nickel content in the dumpsite suggests contamination, likely due to anthropogenic activities.

Mercury (Hg). Mercury concentrations at the dumpsite also decreased with depth, from 18.05 mg/kg at 0-15 cm to 14.82 mg/kg at 30-45 cm, with a mean of 16.52 mg/kg. The control site exhibited much lower mercury levels, from 1.42 mg/kg at 0-15 cm to 0.77 mg/kg at 30-45 cm, with a mean of 1.07 mg/kg. The elevated mercury levels in the dumpsite area are indicative of significant environmental contamination, posing potential risks to the ecosystem.

Lead (Pb). At the Control Site, Pb concentrations are highest in the topsoil (0-15 cm) and lowest at 15-30 cm, with a slight increase at 30-45 cm. The average concentration is 0.80 mg/kg. At the Dumpsite, Pb concentrations are consistently higher than at the Control Site, with the highest level at 0-15 cm and a similar pattern of decrease and then increase with depth. The average concentration is significantly higher at 1.16 mg/kg, indicating greater Pb contamination at the Dumpsite.

Cadmium (Cd). At the Control Site, Cd follows a similar pattern to Pb, with the highest concentration at 0-15 cm, a sharp decrease at 15-30 cm, and a slight increase at 30-45 cm. The average Cd concentration is 0.25 mg/kg. At the Dumpsite, Cd levels are much higher, particularly at 0-15 cm (1.42 mg/kg), and again, there's a notable decrease at 15-30 cm, followed by an increase at 30-45 cm. The average concentration is 1.0 mg/kg, suggesting significant Cd contamination at the Dumpsite.

Table 2. *Micronutrients and heavy metal properties of dumpsite and control site*

Sites	Depth	Fe	Mn	Zn	Cu	Cr	Ni	Hg	Pb	Cd
	cm	mg/kg								
Control Site	0-15 cm	146.00a	62.92a	105.77a	34.25a	20.55a	3.35a	1.42a	1.05a	0.44a
	15-30cm	113.90b	49.14b	77.54b	30.45b	17.26b	2.37b	0.98b	0.51b	0.10b
	30-45cm	103.40c	42.07c	55.67c	20.92b	9.80c	1.51c	0.77c	0.83c	0.22c
	Mean	121.10	51.40	79.70	28.54	15.87	2.42	1.07	0.80	0.25
Dumpsite	0-15cm	203.20a	94.09a	185.60a	56.98a	36.78a	11.44a	18.05a	1.66a	1.42a
	15-30cm	184.00b	65.19b	114.80b	44.16b	23.06b	9.39b	16.69b	0.67b	0.12b
	30-45cm	176.10c	55.97c	102.90c	42.86c	19.93c	7.73c	14.82c	1.15c	0.45c
	Mean	187.78	71.75	134.40	40.0	26.59	9.52	16.52	1.16	1.00

Mean value(s) with the same letters(s) in the column are not significantly different from one another at 5% level of probability.

Discussion

The control site generally exhibits better soil quality, likely due to its use for agricultural purposes and lack of exposure to external contaminants. The higher levels of organic carbon, total nitrogen, and a more neutral pH, which ranges from 5.04 to 6.13, support sustainable agricultural productivity. In contrast, the dumpsite soil shows significant signs of degradation and contamination, evidenced by stronger acidity, lower organic carbon, and elevated phosphorus levels. The causes of this degradation are likely linked to the accumulation of various waste materials deposited at the dumpsite, which introduce pollutants and alter the natural properties of the soil (Chude et al., 2011; Enwezor et al., 1989). The acidic conditions at the dumpsite, with pH values ranging from 4.10 to 4.46, are likely a result of waste decomposition and the release of acid-forming compounds, including organic

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acids. The accumulation of industrial and household wastes in the dumpsite likely contributes to the increased soil acidity, which enhances the solubility of heavy metals such as iron (Fe) and mercury (Hg). According to Tandon (1995), the dissolution of iron minerals is promoted under acidic conditions, and this aligns with the elevated iron concentrations at the dumpsite (187.78 mg/kg) compared to the control site (121.1 mg/kg). Furthermore, the control site's more neutral pH prevents excessive solubilization of toxic metals, supporting a healthier environment for plant growth (FDALR, 1990; Pam, 1990). Mercury (Hg) levels at the dumpsite (14.82 to 18.05 mg/kg) are particularly concerning, as they are significantly higher than those at the control site (0.77 to 1.42 mg/kg). The elevated Hg levels are likely linked to contamination from industrial or electronic waste, which commonly contains mercury. Such high concentrations pose serious environmental and public health risks, as they exceed the critical limits for mercury contamination, which are set at 0.1 mg/kg by the Department of Petroleum Resources (DPR, 2002) and 0.3 mg/kg by the World Health Organization (WHO, 1996). The presence of mercury in the dumpsite soil could be related to improper waste disposal practices, highlighting a pressing need for better waste management strategies (Weggler, 2004; Akhilesh et al., 2009). The control site exhibits higher levels of essential micronutrients like manganese (Mn) and zinc (Zn), which are necessary for plant growth and soil health, while the dumpsite soil shows deficiencies in these micronutrients. The average manganese concentrations at the dumpsite (51.4 mg/kg) are lower than those at the control site (71.74 mg/kg), and zinc levels follow a similar trend, with dumpsite concentrations at 79.7 mg/kg compared to 134.4 mg/kg at the control site (Tisdale 1985). Despite the lower levels of these micronutrients at the dumpsite, both sites have sufficient levels of zinc and manganese based on critical thresholds reported by Pam (1990), suggesting that these soils can still support plant growth, albeit at a reduced capacity. Lead (Pb) and cadmium (Cd) concentrations are higher in the dumpsite across all depths, with significant differences observed in the topsoil (0-15 cm). Elevated lead levels at the dumpsite may be attributed to waste materials containing lead, such as batteries and paints, which are commonly found in open dumps (Akhilesh et al., 2009). Cadmium contamination could be due to the disposal of industrial waste and the accumulation of biosolids such as sewage sludge, which has been noted to increase cadmium concentrations in soils (Weggler, 2004). The movement of these metals through the soil profile, influenced by factors such as pH and soil composition, may explain the observed trend of decreasing concentrations with depth followed by a slight increase at certain depths. In general, the dumpsite exhibits signs of significant environmental contamination, with elevated levels of heavy metals like mercury (Hg) and lead (Pb), and deficiencies in key micronutrients such as manganese (Mn) and zinc (Zn). The contamination at the dumpsite can be attributed to various waste materials, including industrial by-products and electronic waste, which have altered the natural properties of the soil and pose risks to environmental and human health. Effective waste management practices are crucial to mitigate further contamination and restore soil quality in affected areas (Raymond & Felix, 2011; Kabata-Pendias, 2010; Orhue et al., 2015; Olowolafe, 1995).

Conclusions

The study's findings highlight a marked difference in soil quality between the refuse dumpsite and the control site. The dumpsite soils, characterized by lower levels of essential micronutrients and higher concentrations of toxic heavy metals, indicate significant environmental contamination that could adversely affect soil health, plant growth, and overall agricultural productivity. The control site, with its higher organic carbon content, total nitrogen, and relatively neutral pH, suggests a more conducive environment for sustainable agricultural practices. The elevated levels of nickel (Ni), mercury (Hg), lead (Pb) and cadmium (Cd) at the dumpsite pose a serious risk to environmental safety, necessitating immediate intervention through improved waste management and soil remediation efforts to mitigate the impact of such contaminants on the ecosystem and surrounding communities. These findings underline the importance of regular monitoring and proactive measures to preserve soil health and ensure the long-term sustainability of agricultural practices in areas vulnerable to pollution from refuse dumpsites.

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