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Soil Quality and Heavy Metal Contamination Around Informal Electronic Waste Disposal Sites in Aba Metropolis, Southeastern Nigeria

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Abstract: This study assessed soil quality and heavy metal contamination around informal e-waste disposal sites in Aba to establish baseline data for environmental monitoring and sustainable waste management. Surface soil samples (0–15 cm) were collected from three major e-waste disposal locations, composited, and analyzed for physicochemical properties and selected heavy metals using standard APHA procedures and Atomic Absorption Spectrophotometry. Spatial variations were evaluated using one-way analysis of variance (ANOVA). The soils were acidic (pH 4.67–5.85), with relatively high organic matter (10.46–11.68%) and moisture content (25.62–27.86%). Cadmium concentrations (0.24–0.33 mg/L) exceeded the NESREA permissible limit by 24–110 times, whereas lead, mercury, chromium, copper, cobalt, and nickel remained within regulatory limits or below detection thresholds. Significant spatial differences in soil quality were observed among the sampling sites ($F = 242.87$, $p < 0.001$), indicating localized contamination associated with informal e-waste disposal. The combined occurrence of soil acidification and elevated cadmium concentrations highlights the risk of contaminant mobility and potential groundwater pollution. These findings provide critical baseline information for environmental regulators, public health agencies, and urban planners to strengthen e-waste management policies, prioritize remediation of contaminated sites, and protect vulnerable communities from long-term ecological and human health risks.

Keywords: *Electronic waste, Soil quality, Heavy metal, Cadmium pollution, Aba Metropolis.*

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I. INTRODUCTION

The rapid growth of electronic waste (e-waste) has become a major environmental challenge worldwide, particularly in developing countries where informal recycling and disposal dominate waste management practices. In Nigeria, crude recycling methods such as manual dismantling, open burning, and indiscriminate dumping release hazardous substances, including potentially toxic metals, into surrounding soils, thereby threatening ecosystem integrity and public health (Ohajinwa et al., 2018; Moeckel et al., 2020; Andeobu et al., 2023). These activities have intensified concerns over soil contamination because heavy metals are persistent, non-biodegradable, and capable of accumulating in the food chain through plant uptake and groundwater migration.

Studies across Nigeria and other African countries have consistently reported elevated concentrations of heavy metals, including Lead (Pb), Cadmium (Cd), Copper (Cu), Zinc (Zn), Nickel (Ni), and Mercury (Hg), in soils surrounding informal e-waste recycling sites (Olafisoye et al., 2013; Isimekhai et al., 2017; Anselm et al., 2021). Cadmium has been identified as one of the most critical contaminants because of its high ecological risk and toxicity, while contamination is generally greatest in active dismantling and open-burning areas and decreases with increasing distance from disposal sites (Adenuga et al., 2022; Owusu-Sekyere, & Aladago 2024). Soil physicochemical properties, particularly pH and organic matter, further influence metal mobility, bioavailability, and leaching potential, thereby determining the extent of environmental contamination (Adeyi et al., 2020).

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Although Aba Metropolis is recognized as one of Nigeria's major informal e-waste recycling centres, detailed investigations of soil quality remain limited. Existing studies have largely examined Aba alongside other cities or focused primarily on groundwater vulnerability and hydrogeophysical characteristics rather than providing a comprehensive assessment of soil physicochemical properties and heavy metal contamination around local e-waste disposal sites (Ohajinwa et al., 2018; Oluwagbemi et al., 2023). This limitation restricts understanding of the spatial distribution of contaminants and the environmental processes controlling their persistence and movement within Aba's soils. Considering that the city is characterized by permeable soils and shallow groundwater, localized contamination may readily migrate beyond disposal sites, posing risks to surrounding residential communities and agricultural land (Kyere et al., 2016; Oluwagbemi et al., 2023).

This study addresses these knowledge gaps by providing a site-specific assessment of soil quality and heavy metal contamination around informal e-waste disposal locations in Aba Metropolis, Southeastern Nigeria. Unlike previous multi-city investigations, the study integrates soil physicochemical characteristics with heavy metal concentrations to evaluate contamination patterns and identify potential environmental risks. The findings will provide baseline information for monitoring soil quality, identifying priority contaminants, and supporting evidence-based environmental management, remediation strategies, and regulatory interventions aimed at reducing the ecological and human health impacts of informal e-waste disposal in Aba and similar urban centres in developing countries (Adenuga et al., 2022; Okeke et al., 2024; Ahanor et al., 2025).

II. MATERIALS AND METHODS

Study Area

The study was conducted in Aba Metropolis, Abia State, southeastern Nigeria, one of the country's major commercial and industrial centres where informal electronic waste (e-waste) collection, dismantling, repair, and disposal are widely practiced. Aba lies between latitudes 5.05°–5.13°N and longitudes 7.30°–7.40°E and covers approximately 72 km². The metropolis comprises Aba North, Aba South, and parts of Obingwa Local Government Areas. The area experiences a tropical monsoon climate with annual rainfall ranging from approximately 2,160 to 2,400 mm and a mean annual temperature of about 29 °C. The underlying geology consists predominantly of sedimentary formations with porous sandy soils that favour infiltration, making the area particularly susceptible to contaminant migration into shallow groundwater. Boreholes constitute the major domestic water supply, further increasing the environmental significance of soil contamination around e-waste disposal sites.

Study Design

A field-based environmental assessment employing an experimental research design was adopted to evaluate soil quality and heavy metal contamination associated with informal e-waste disposal. The investigation focused exclusively on soils collected from active e-waste dumpsites and surrounding locations within Aba Metropolis. The design enabled comparative evaluation of soil physicochemical characteristics and heavy metal concentrations across sampling locations to determine the influence of informal e-waste activities on soil quality.

Soil Sampling

Surface soil samples were collected from major informal e-waste disposal sites distributed across Aba Metropolis using a purposive sampling approach based on the intensity of e-waste accumulation and recycling activities. Sampling locations included active dumpsites and areas characterized by frequent dismantling, repair, burning, and disposal of obsolete electrical and electronic equipment. At each sampling location, surface soils (0–15 cm) were collected using a stainless-steel hand auger after removing surface debris. Multiple subsamples were collected within each site and composited to obtain representative samples. Approximately 1 kg of soil was collected into clean polyethylene bags, labelled, transported to the laboratory, and stored under appropriate conditions prior to analysis. The samples were air-dried at room temperature, gently crushed, homogenized, and sieved through a 2-mm stainless-steel sieve before physicochemical and heavy metal analyses. This procedure minimized sample heterogeneity and ensured analytical consistency.

Laboratory Analysis

Prepared soil samples were analysed for selected physicochemical properties and heavy metal concentrations following Standard Methods for the Examination of Water and Wastewater (APHA, 2017). Soil pH was determined using a calibrated digital pH meter, while moisture content and loss on ignition were determined gravimetrically using standard laboratory procedures. Heavy metal concentrations, including lead (Pb), cadmium (Cd), copper (Cu), chromium (Cr), nickel (Ni), and other selected elements, were quantified using a UNICAM Atomic Absorption Spectrophotometer (AAS) after appropriate acid digestion. Instrument calibration was performed using certified standard solutions before sample analysis, and all analyses were conducted in triplicate to improve analytical precision.

Quality Assurance and Quality Control

Quality assurance procedures included the use of acid-washed sampling equipment and laboratory glassware to minimize contamination. Analytical instruments were calibrated using certified reference standards before each analytical session. Procedural blanks and duplicate analyses were incorporated during laboratory measurements to evaluate analytical accuracy and precision. All laboratory

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determinations followed APHA (2017) quality assurance recommendations, and concentrations were reported on a dry-weight basis.

➤ *Statistical Analysis*

Descriptive statistics were used to summarize soil physicochemical properties and heavy metal concentrations across sampling locations. One-way analysis of variance (ANOVA) was employed to evaluate spatial differences among sampling sites at a 95% confidence level ($p < 0.05$). Statistical analyses were performed and significant differences were identified where p-values were less than 0.05.

III. RESULTS AND DISCUSSION

➤ *Soil Physicochemical Characteristics*

Table 1: Soil Sample Analysis.

Parameters	Shopping Centre	Ogbor Dumpsite	Obingwa Dumpsite	NESREA LIMIT
Temperature	27	27.3	27	<30
pH	5.85	4.67	5.60	6.5 - 8.5
Loss on Ignition (%)	10.91	10.46	11.68	NS
Moisture (%)	25.62	27.86	25.83	NS
Calcium (mg/L)	49.61	52.05	60.4	NS
Magnesium (mg/L)	19.31	21.93	20.72	NS
Lead (mg/L)	0.02	0.02	0.03	0.01 - 0.1
Mercury (mg/L)	<0.001	<0.001	<0.001	0.001 - 0.003
Cobalt (mg/L)	<0.001	<0.001	<0.001	0.05 - 0.10
Cadmium (mg/L)	0.24	0.26	0.33	0.003 - 0.01
Chromium (mg/L)	0.001	0.001	0.001	0.05 - 0.10
Copper (mg/L)	<0.001	<0.001	<0.001	0.05 - 1.5
Nickel (mg/L)	0.001	0.001	0.002	0.01 - 0.05

Source: Field Survey 2024.
NS = No Specific Limit

The physicochemical properties of soils collected from the Shopping Centre, Ogbor Dumpsite, and Obingwa Dumpsite are presented in Table 1. Soil temperatures ranged from 27.0 to 27.3 °C, remaining below the NESREA permissible limit (<30 °C), indicating that thermal conditions were unlikely to significantly influence contaminant behaviour across the sampling sites. In contrast, soil pH values ranged from 4.67 to 5.85, which are substantially lower than the recommended NESREA range (6.5–8.5), demonstrating that soils surrounding the informal e-waste disposal sites are acidic. The Ogbor Dumpsite exhibited the highest degree of acidity (pH 4.67), suggesting more intensive waste decomposition or prolonged disposal activities than the other locations.

The acidic soil conditions observed in this study agree with findings reported by Ohajinwa et al. (2018) at informal e-waste recycling sites in Aba, Lagos, and Ibadan, where continuous dismantling and open burning contributed to declining soil pH. Similarly, Nwachukwu et al. (2019) reported acidic soils (pH 4.8–6.1) around municipal dumpsites in southeastern Nigeria, attributing the low pH to organic waste decomposition and the production of acidic leachates. Acidic environments enhance the dissolution, mobility, and bioavailability of heavy metals, thereby increasing their ecological and human health risks (Adeyi et al., 2020). Conversely, studies from controlled electronic recycling facilities in Europe have reported near-neutral soil pH because engineered containment systems minimize leachate formation and contaminant migration, highlighting the environmental consequences of informal recycling practices.

Loss on ignition (10.46–11.68%) and moisture content (25.62–27.86%) indicated relatively high organic matter accumulation within the sampled soils. These values are comparable to those reported by Ighodaro and Edem (2020) and Osuagwu and Ezeh (2022) for municipal dumpsites in southern Nigeria, where continuous deposition of biodegradable refuse increased soil organic content. Elevated organic matter can enhance the adsorption of heavy metals through complexation with humic substances, although decomposition under acidic conditions may also increase metal mobility.

➤ *Heavy Metal Contamination*

Heavy metal analysis showed marked differences among the investigated elements (Table 1). Lead concentrations ranged from 0.02 to 0.03 mg/L, remaining within the NESREA permissible range, while mercury, cobalt, chromium, copper, and nickel were either below analytical detection limits or substantially lower than regulatory thresholds.

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Cadmium was the only heavy metal that exceeded the permissible limit, with concentrations ranging from 0.24 to 0.33 mg/L, exceeding the NESREA standard (0.003–0.01 mg/L) by approximately 24 to 110 times. The highest concentration occurred at Obingwa Dumpsite, suggesting localized accumulation associated with intensive informal e-waste disposal activities.

This finding agrees with previous Nigerian studies that identified cadmium as one of the dominant contaminants associated with informal e-waste recycling. Olafisoye et al. (2013) reported elevated cadmium concentrations around electronic waste recycling sites in southwestern Nigeria, while Isimekhai et al. (2017) found cadmium to contribute the greatest ecological risk among several heavy metals because of its persistence and high toxicity. Similarly, Adenuga et al. (2022) demonstrated that cadmium was the principal contributor to ecological risk indices at informal recycling locations in Lagos. The elevated cadmium concentrations observed in Aba may originate from discarded rechargeable batteries, semiconductors, printed circuit boards, pigments, and plastic stabilizers commonly found in obsolete electronic equipment.

In contrast, the relatively low concentrations of lead, chromium, nickel, copper, and mercury differ from studies conducted at Agbogbloshie, Ghana, where Kyere et al. (2016) and Owusu-Sekyere, and Aladago (2024) reported substantial enrichment of lead, copper, zinc, and chromium resulting from intensive open burning and dismantling operations. The comparatively lower concentrations observed in Aba may reflect differences in waste composition, recycling intensity, disposal duration, sampling depth, or environmental conditions influencing contaminant accumulation. It is also possible that informal recycling activities within Aba are less intensive than those occurring at internationally recognized e-waste recycling hotspots.

Despite the generally low concentrations of most heavy metals, the elevated cadmium levels remain environmentally significant because cadmium is highly mobile under acidic soil conditions and readily accumulates in agricultural crops, posing long-term ecological and public health risks.

➢ *Soil Sample Analysis*

The analysis assessed whether e-waste significantly affects soil quality by comparing multiple soil samples collected from different locations around the e-waste disposal site in Aba. The results are summarized in the ANOVA table below.

Table 2: One-Way Anova Table on Soil Sample Analysis

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	7786.235	8	973.2794	242.8739	9.93E-17	2.510158
Within Groups	72.1322	18	4.007344			
Total	7858.367	26				

➢ *Statistical Decision:*

Since the F-statistic = 242.87 is much greater than the F critical value = 2.51, and the p-value < 0.001 (which is less than 0.05), we reject the null hypothesis.

One-way ANOVA revealed statistically significant differences among the measured soil quality parameters ($F = 242.87$; $p < 0.001$), with the calculated F-value substantially exceeding the critical value ($F_{crit} = 2.51$). The null hypothesis was therefore rejected, confirming significant spatial variability in soil characteristics among the sampling locations.

The observed spatial variability suggests that contamination is strongly influenced by local site conditions rather than regional environmental factors alone. Ogbor Dumpsite exhibited the lowest soil pH, whereas Obingwa Dumpsite recorded the highest cadmium concentration, indicating differences in waste composition, disposal duration, and recycling activities among the sites. Similar spatial heterogeneity has been reported by Anselm et al. (2021) and Ohajinwa et al. (2018), who observed substantial differences in heavy metal accumulation among Nigerian informal e-waste recycling centres due to variations in waste handling practices and burning intensity.

➢ *Environmental Implications*

The combined occurrence of acidic soils and elevated Cadmium concentrations indicates that informal e-waste disposal has begun to alter soil quality within Aba Metropolis. Soil acidification increases the solubility of Cadmium, thereby enhancing its transport into groundwater and its uptake by vegetation. Given that Aba is characterized by permeable sandy soils and shallow groundwater systems, continued informal e-waste disposal could facilitate contaminant migration beyond disposal sites, increasing the risk of exposure among nearby communities.

Although most heavy metals remained below NESREA guideline values, the elevated cadmium concentrations alone warrant environmental concern because cadmium is classified among the most hazardous trace metals owing to its persistence, bioaccumulative nature, and toxicity. Similar conclusions were reached by Andeobu et al. (2023) and Owusu-Sekyere, and Aladago (2024), who emphasized that Cadmium frequently represents the greatest ecological threat at informal e-waste

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recycling sites despite relatively low concentrations of other metals.

The study findings indicate that the environmental impacts of informal e-waste disposal in Aba are currently characterized more by soil acidification and localized Cadmium enrichment than by widespread heavy metal contamination. These results provide an important baseline for environmental monitoring and support the implementation of sustainable e-waste management strategies, including formalized recycling systems, routine soil quality surveillance, and remediation of contaminated sites. Such interventions are essential for minimizing future contaminant accumulation and protecting soil resources, groundwater quality, and public health.

IV. CONCLUSION

This study demonstrates that informal electronic waste disposal has begun to degrade soil quality in Aba Metropolis, primarily through soil acidification and localized cadmium contamination. Although most investigated heavy metals remained within permissible limits, cadmium concentrations substantially exceeded the NESREA guideline, while significant spatial differences in soil quality confirmed that contamination varies with disposal intensity and site characteristics. These findings highlight the environmental vulnerability of Aba's permeable soils and the potential for contaminant migration into shallow groundwater and surrounding ecosystems. The study provides one of the first site-specific baseline assessments integrating soil physicochemical properties with heavy metal contamination around informal e-waste disposal sites in Aba, thereby contributing valuable evidence for environmental monitoring and risk management. Future research should incorporate seasonal sampling, contamination and ecological risk indices, and human health risk assessments to better characterize long-term impacts. Immediate action by environmental regulators, local authorities, and waste management agencies is needed to strengthen e-waste collection, formalize recycling practices, implement routine soil monitoring, and remediate contaminated sites to safeguard environmental quality and public health.

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