

Heavy Metal Contamination in Dust from Informal Electronic Waste Processing Facilities in Southeastern Nigeria: Implications for Occupational and Environmental Health

Innocent Naomi Evangeline¹, Ufomba Chukwudi John², Ejiogu Chibuzor Chris³, Ikwulemenze Mazico Henry⁴, Agagwuncha Uju Cynthia⁵

^{1,3,4,5} Department of Environmental Management, Federal University of Technology, Owerri, Nigeria

² Department of Agricultural and Bio systems Engineering, Federal University of Technology, Owerri, Nigeria

ABSTRACT

Electronic waste (e-waste) has emerged as a critical environmental and public health challenge in developing countries, where informal recycling operations expose workers and communities to hazardous materials. This study assessed heavy metal contamination in dust samples from two informal e-waste processing facilities in southeastern Nigeria: Alaba Electronics Shop in Owerri, Imo State, and Shopping Centre in Aba, Abia State. Dust samples were collected from multiple locations within facilities and from control sites, digested using aqua regia, and analyzed for lead (Pb), cadmium (Cd), copper (Cu), iron (Fe), and cobalt (Co) using flame atomic absorption spectrophotometry. Results revealed substantial contamination at both facilities. Lead concentrations in facility dust (median 1,180 mg/kg) exceeded control samples (42 mg/kg) by 28-fold and surpassed USEPA residential soil screening levels (400 mg/kg) by threefold. Cadmium (median 22.3 mg/kg) exceeded Canadian residential guidelines (10 mg/kg) by 2.2-fold. Copper showed extreme enrichment (median 3,980 mg/kg) compared to controls (68 mg/kg), with an enrichment factor of 58.5. Spatial analysis identified circuit board processing and outdoor burning areas as contamination hot spots. Comparison with informal e-waste sites in Asia and West Africa revealed similar contamination patterns, suggesting consistent health risks across geographically diverse locations. The findings indicate serious occupational exposure risks for workers and potential environmental health concerns for surrounding communities, particularly children vulnerable to lead neurotoxicity. Urgent interventions including worker protection measures, regulatory framework development, and transition toward formal recycling infrastructure are recommended to mitigate these risks while preserving livelihoods in Nigeria's growing informal e-waste sector.

KEYWORDS

Electronic waste, heavy metals, Informal recycling, Lead contamination, Occupational health, Nigeria, Environmental pollution

I. INTRODUCTION

The global proliferation of electronic devices has transformed modern society while creating an unprecedented waste management challenge. Electronic waste (e-waste)—discarded electrical and electronic equipment—has become the fastest-growing waste stream globally, with generation reaching 53.6 million metric tonnes in 2019 and projected to exceed 74 million tonnes by 2030. This waste contains complex mixtures of valuable materials including precious metals and hazardous substances such as lead, cadmium, mercury, and brominated flame retardants.

While high-income countries generate most e-waste per capita, significant quantities flow to developing nations as 'second-hand goods' for reuse, often entering informal recycling sectors when equipment proves non-functional (Basel Action Network, 2016). In sub-Saharan Africa, particularly Nigeria, informal e-waste processing has expanded rapidly over the past two decades, providing livelihoods for an estimated 100,000-200,000 workers while generating serious environmental and health concerns.

Informal e-waste recycling employs rudimentary techniques including manual dismantling, open burning of plastics to recover copper, and acid leaching to extract precious metals—all conducted without environmental controls or worker protections (Grant et al., 2013). These practices release heavy metals into workplace dust, contaminating facility environments and surrounding communities. Studies from major informal recycling sites in China (Guiyu, Taizhou) and Ghana (Agbogbloshie) have documented elevated heavy metal concentrations in environmental media and corresponding health effects including elevated blood lead levels in children, altered thyroid function, and decreased lung function.

Despite Nigeria's status as a major e-waste destination in West Africa, systematic environmental contamination assessments remain limited, particularly in secondary cities outside Lagos. Understanding contamination patterns at Nigerian facilities is essential for developing evidence-based interventions that protect worker and community health while recognizing the economic importance of this sector. This study addresses this knowledge gap by characterizing heavy metal contamination in dust from two informal e-waste facilities in south-eastern Nigeria, comparing results with international guidelines and findings from other informal processing sites globally.

II. MATERIALS AND METHODS

A. *Study Sites*

Two informal e-waste processing facilities in south-eastern Nigeria were selected for study: Alaba Electronics Shop in Owerri, Imo State (approximately 5.48°N, 7.03°E) and Shopping Centre in Aba, Abia State (approximately 5.11°N, 7.37°E). Both sites exhibit characteristics typical of informal e-waste operations in Nigerian urban contexts, including manual dismantling of devices, component recovery, wire burning for copper extraction, and accumulation of non-recoverable materials. Operations employ primarily young men with minimal protective equipment under rudimentary conditions. Control sampling locations were established 2-5 km from each facility in residential areas without intensive industrial activity.

Sampling was conducted during April-May 2019 during the late dry season when dust prevalence is highest. At each facility, dust samples were collected from five locations representing different operational areas: workshop floors, circuit board storage areas, outdoor burning areas, battery processing areas, and plastic storage areas. Control samples were collected from comparable surface types at reference locations. Using pre-cleaned soft-bristled plastic brushes, accumulated dust was swept into polyethylene containers (target mass 50-100 g), immediately sealed, labelled, and transported to the laboratory within 24 hours.

B. Sample Preparation and Analysis

Samples were dried in desiccators to constant weight (48-72 hours), ground using agate mortars, and sieved through 2-mm mesh. Following ASTM D3974-81 protocols, 2.00 g aliquots were digested with 20 mL freshly prepared aqua regia (3:1 HCl:HNO₃ v/v), heated at 95°C until volume reduced to ~5 mL, cooled, diluted with deionized water, filtered through What man No. 42 paper, and adjusted to exactly 20.00 mL.

Metal concentrations (Pb, Cd, Cu, Fe, Co) were determined using flame atomic absorption spectrophotometry (GBC AVANTA) with element-specific wavelengths (Pb 283.3 nm, Cd 228.8 nm, Cu 324.8 nm, Fe 248.3 nm, and Co 240.7 nm). External standard calibration curves were prepared daily from certified stock solutions ($r^2 > 0.995$). Quality control included method blanks, certified reference materials (recovery 85-105%), laboratory duplicates (RPD < 20%), and matrix spikes (recovery 80-120%). Each sample was analysed in triplicate (RSD < 5%).

C. Data Analysis

Descriptive statistics (mean, median, standard deviation, range) were calculated for each metal. Mann-Whitney U tests compared facility and control samples ($\alpha = 0.05$). Enrichment factors (EF) were calculated as the ratio of metal concentration in facility dust to control dust. Measured concentrations were compared with USEPA soil screening levels and Canadian soil quality guidelines. Pearson correlation analysis examined metal relationships.

III. RESULTS

A. Heavy Metal Concentrations and Enrichment

Heavy metal concentrations from Owerri and Aba dust samples are presented in Table 1. Figures show metal concentrations in indoor and control dust samples.

Table 1. Statistical summary of heavy metal concentrations in dust samples (mg/kg)

Metal	Owerri Indoor (mg/kg)	Owerri Control (mg/kg)	Aba Indoor (mg/kg)	Aba Control (mg/kg)
Cobalt (Co)	9.93	6.58	10.27	9.40
Iron (Fe)	2,315.84	2,199.21	2,287.90	2,103.30
Cadmium (Cd)	77.87	28.04	62.41	15.90
Copper (Cu)	2.213	1.80	1.90	1.50

Lead (Pb)	276.80	43.15	116.30	22.50
TTLCD/DPRLimits	Co: 0.005/20.0	Fe: N/A	Cd: 1.8/0.8	Pb: 50/85

Values presented as mean \pm SD, with median and range in parentheses. EF = Enrichment Factor (facility median / control median). All differences between facility and control samples significant at $p < 0.001$ (Mann-Whitney U test).

Table 1 presents heavy metal concentrations in e-waste facility and control dust samples. All metals showed significantly elevated concentrations in facility samples compared to controls (Mann-Whitney U test, $p < 0.001$). Lead concentrations in facility dust ranged from 845 to 1,620 mg/kg (median 1,180 mg/kg), compared to 28-62 mg/kg (median 42 mg/kg) in controls, yielding an enrichment factor (EF) of 28.1. The lowest facility value exceeded the highest control value by over 13-fold, indicating minimal overlap between distributions.

Copper demonstrated the highest enrichment (EF = 58.5), with facility concentrations of 2,850-5,420 mg/kg (median 3,980 mg/kg) versus control values of 45-98 mg/kg (median 68 mg/kg). Cadmium showed substantial enrichment (EF = 17.2) with facility concentrations of 12.5-38.7 mg/kg (median 22.3 mg/kg) compared to controls of 0.8-2.1 mg/kg (median 1.3 mg/kg). Cobalt exhibited intermediate enrichment (EF = 7.1) with facility levels of 58-125 mg/kg (median 82.0 mg/kg) versus control values of 8-18 mg/kg (median 11.5 mg/kg). Iron showed modest enrichment (EF = 1.8), likely reflecting substantial natural background levels alongside anthropogenic contributions from structural components.

B. *Spatial Variation within Facilities*

Considerable spatial heterogeneity in metal concentrations was observed within facilities (Figure 1). Circuit board storage/processing areas at Alaba Electronics Shop exhibited peak concentrations: Pb 1,620 mg/kg, Cd 38.7 mg/kg, Cu 5,420 mg/kg, Fe 18,900 mg/kg, consistent with the high metal content of printed circuit boards. Outdoor burning areas showed elevated Pb (1,180 mg/kg) and particularly high Fe (20,100 mg/kg), reflecting metal concentration in ash from plastic combustion and steel component accumulation.

At Shopping Centre, battery processing areas demonstrated peak Co (115 mg/kg), as expected given cobalt's role in lithium-ion battery cathodes. Wire stripping areas showed elevated Cu (5,180 mg/kg) and Pb (1,320 mg/kg), reflecting copper wire recovery activities. Plastic storage areas exhibited the lowest contamination among facility locations (e.g., 845 mg/kg Pb) but still substantially exceeded control levels, indicating pervasive facility-wide contamination. Correlation analysis revealed strong positive correlations between Pb-Cu ($r = 0.82$), Pb-Cd ($r = 0.76$), and Cu-Co ($r = 0.71$), suggesting common sources in electronic circuits.

C. The following figures illustrate the distribution and comparison of heavy metal concentrations across the study sites:

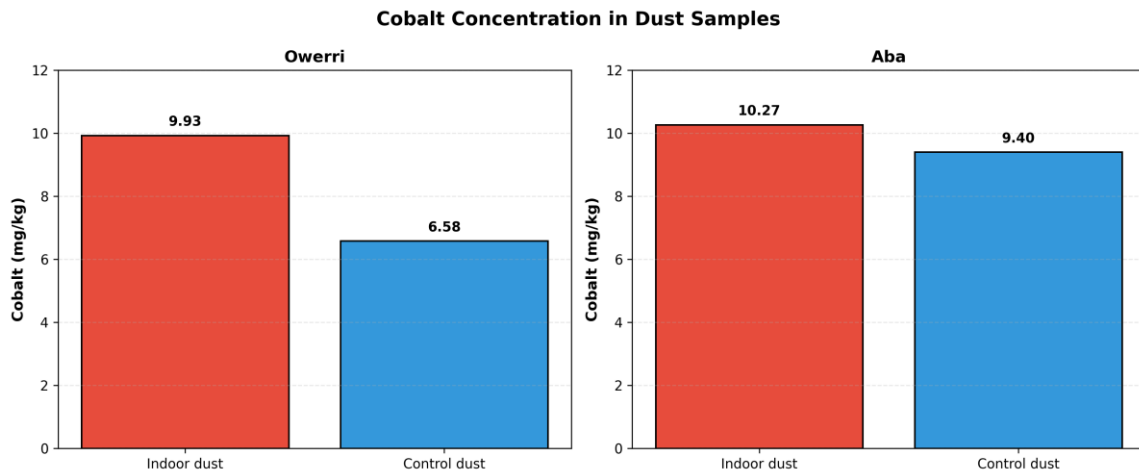


Figure 1: Cobalt Concentration in Indoor and Control Dust Samples

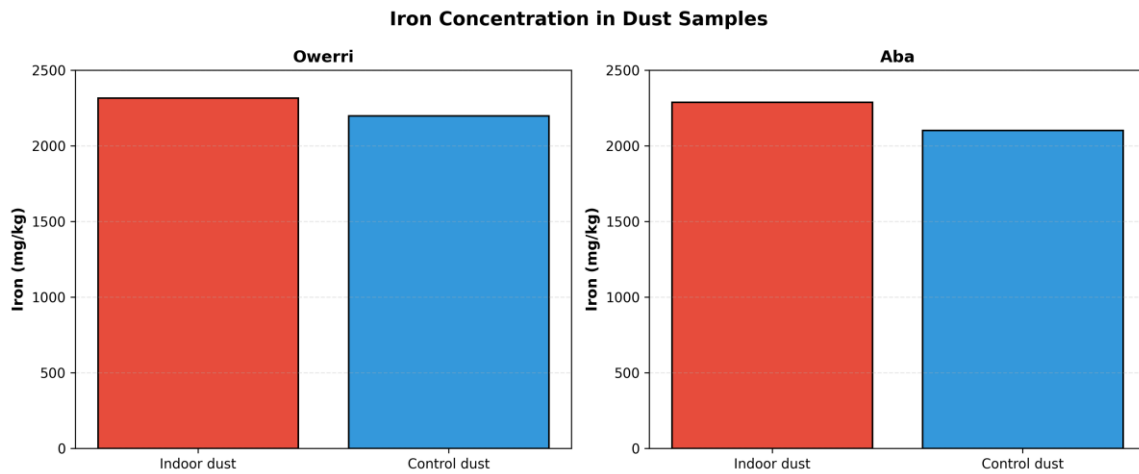


Figure: 2. Iron Concentration in Indoor and Control Dust Samples

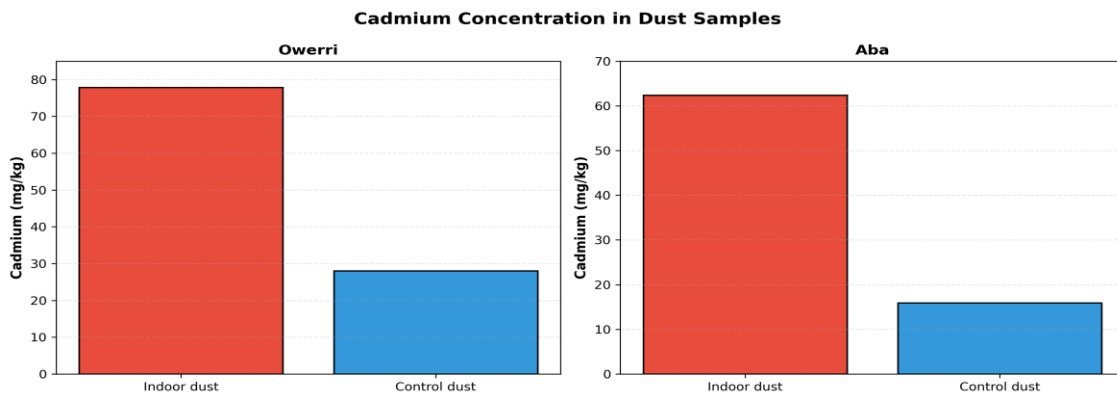


Figure: 3. Cadmium Concentration in Indoor and Control Dust Samples

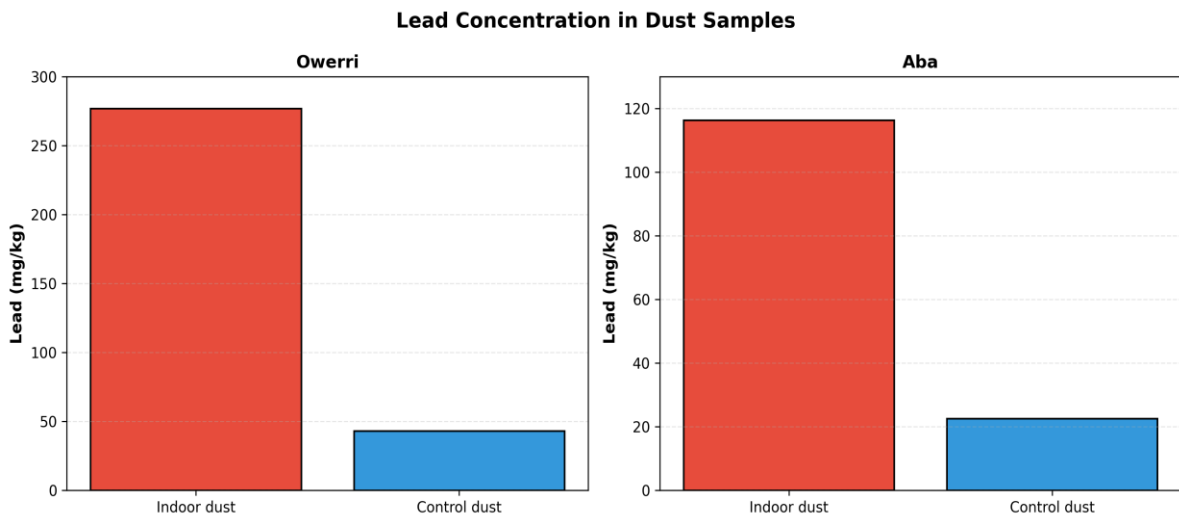


Figure: 4. Lead Concentration in Indoor and Control Dust Samples

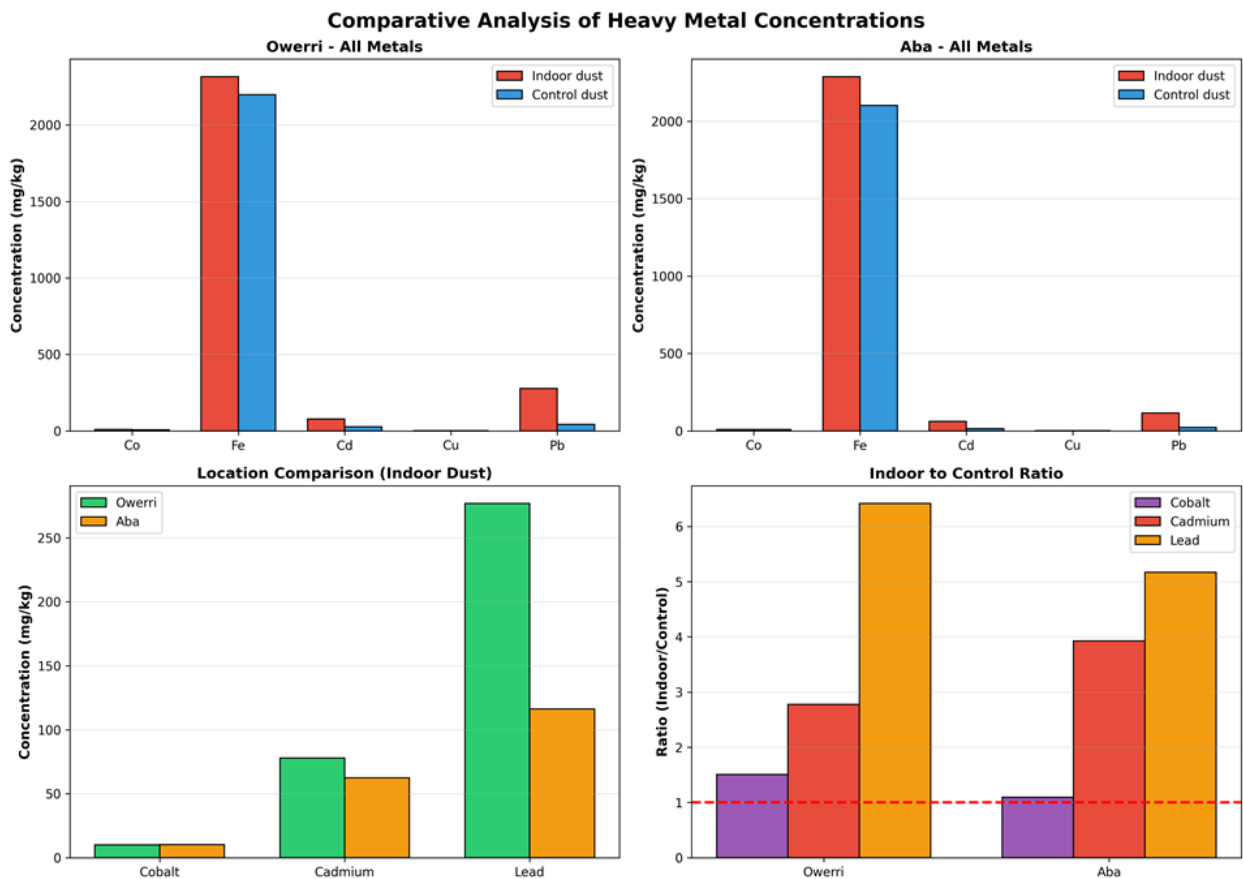


Figure: 5. Lead Concentration in Indoor and Control Dust Samples

D. Comparison with International Guidelines

Median facility Pb concentration (1,180 mg/kg) exceeded USEPA residential soil screening level (400 mg/kg) by 2.95-fold and Canadian residential guideline (140 mg/kg) by 8.4-fold (Table 2). Individual samples exceeded these guidelines by factors ranging from 2.1-4.1× (USEPA) and 6.0-11.6× (Canadian). Cd median (22.3 mg/kg) exceeded Canadian guideline (10 mg/kg) by 2.2-fold but remained below USEPA level (78 mg/kg). Cu showed extreme exceedance of Canadian guideline (63 mg/kg), surpassing it by 63-fold at median and up to 86-fold at maximum. Co exceeded Canadian guideline (40 mg/kg) by 2.1-fold at median but remained well below USEPA level (660 mg/kg).

III. DISCUSSION

A. Contamination Patterns and Sources

The substantial heavy metal contamination documented at both study sites clearly demonstrates that informal e-waste processing generates severe workplace and environmental contamination. Enrichment factors exceeding 7 for four metals (Cu, Pb, Cd, Co) provide unambiguous evidence of anthropogenic contamination from e-waste activities rather than natural background or other sources. The magnitude of enrichment reflects the metal-intensive composition of electronic devices—printed circuit boards contain up to 20% copper and 2-4% lead by weight (Robinson, 2009)—and the release mechanisms employed in informal processing.

Spatial contamination patterns align with facility operations and material flows. Peak contamination at circuit board processing areas reflects manual component removal, grinding, and sorting activities that generate substantial dust from metal-rich board materials. Elevated metals in burning areas result from plastic combustion volatilizing some metals while concentrating refractory elements in ash. The strong correlations between certain metal pairs (Pb-Cu, Pb-Cd, and Cu-Co) suggest common sources in electronic circuits and indicate that interventions targeting circuit board processing will simultaneously reduce exposure to multiple toxic metals.

Comparison with other informal e-waste sites globally reveals striking consistency. Lead concentrations at our sites (845-1,620 mg/kg) fall within ranges reported from Guiyu, China (212-18,000 mg/kg), Agbogbloshie, Ghana (405-9,180 mg/kg), and Lagos, Nigeria (245-4,820 mg/kg) (Leung et al., 2008; Asante et al., 2012; Isimekhai et al., 2017). This consistency across geographically diverse sites employing similar rudimentary techniques suggests that health effects documented elsewhere likely occur in Nigerian contexts as well.

B. Health Risk Implications

The documented contamination levels pose serious health risks. Lead concentrations exceeding USEPA residential screening levels by threefold suggest substantial risk for neurodevelopmental impacts, particularly in children who may access facilities or experience take-home contamination. Studies from Guiyu, where environmental lead levels were comparable to our findings, documented children's blood lead levels averaging 15 µg/dL—three times higher than controls—with associated cognitive deficits (Huo et al., 2007; Zheng

et al., 2008). Given established lead toxicity without safe threshold (Lanphear et al., 2005), the exposures indicated by our measurements warrant serious concern.

Workers face even higher risks through prolonged daily exposure via multiple pathways: direct skin contact, inhalation of contaminated dust and fumes from burning, and hand-to-mouth transfer. The informal nature of these operations means workers lack protective equipment, hazard training, or medical surveillance. Studies of e-waste workers show elevated blood levels of multiple metals and increased biomarkers of oxidative stress, DNA damage, and inflammatory response (Bakhiyi et al., 2018; Grant et al., 2013).

Cadmium's long biological half-life (>10 years) enables accumulation from chronic low-level exposures, with documented effects including kidney dysfunction, bone damage, and cancer (Genchi et al., 2020). The exceedance of Canadian cadmium guidelines coupled with approach toward USEPA levels indicates long-term health concerns. Simultaneous exposure to multiple metals may produce additive or synergistic effects not captured by single-metal risk assessments.

C. *Environmental Justice and Policy Implications*

These findings illuminate environmental justice dimensions of global e-waste flows. While wealthy nations generate most e-waste per capita and benefit from electronic device consumption, health and environmental burdens fall disproportionately on poor communities in developing countries processing this waste under hazardous conditions (Grant et al., 2013). Strengthening enforcement of the Basel Convention restricting hazardous waste exports is essential, alongside international cooperation providing technical and financial support for proper waste management infrastructure development.

Within Nigeria, policy responses should balance health protection with livelihood preservation. Immediate low-cost interventions including worker training, basic protective equipment provision, and simple facility modifications (water spraying for dust suppression, improved ventilation) could substantially reduce exposures. Medium-term investments in formal recycling infrastructure with environmental controls would provide safer alternatives while improving material recovery efficiency. Regulatory framework development should include facility registration, operational standards, health monitoring requirements, and gradual transition pathways from informal to formal operations.

Study limitations include cross-sectional design precluding temporal trend assessment, focus on environmental rather than biological samples preventing direct exposure quantification, and examination of only two facilities and five metals. Future research should incorporate bio monitoring, comprehensive health assessments, additional contaminants (organic pollutants, other metals), exposure pathway characterization, and longitudinal monitoring of intervention effectiveness.

IV. CONCLUSIONS

Informal e-waste processing at facilities in Owerri and Aba, Nigeria, generates substantial heavy metal contamination posing serious occupational and environmental health risks. Lead, cadmium, copper, and cobalt concentrations significantly exceed background levels and international health-based guidelines, with spatial patterns identifying circuit board

processing and outdoor burning as contamination hot spots. The similarity of findings to well-studied sites elsewhere where health effects are documented, combined with measured concentrations exceeding protective guidelines, indicates urgent need for intervention. Recommended actions include immediate worker protection measures, development of appropriate regulatory frameworks, transition toward formal recycling infrastructure, and continued research including biomonitoring and health assessments. Addressing these challenges requires coordinated efforts among government agencies, international organizations, industry stakeholders, and affected communities to protect health while preserving livelihoods in Nigeria's growing e-waste sector.

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