INVESTIGATING TOXIC CHEMICAL EXPOSURE FROM INFORMAL E-WASTE RECYCLING AND POLICY FAILURE IN IMO STATE, NIGERIA

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Abstract
This study "Investigates Toxic Chemical Exposure from Informal E-Waste Recycling and Policy Failure in Imo State, Nigeria," It generates the first comprehensive assessment of hazardous substance exposures stemming from unregulated electronic-waste activities in both urban (Owerri) and peri-urban (Orlu) communities. Informal recyclers-often women and children-routinely dismantle, burn, and leach discarded electronics using rudimentary methods that liberate lead, mercury, cadmium, brominated flame retardants, and other toxins into surrounding air, soil, and water. These practices have been linked to respiratory ailments, neurological impairments, reproductive disorders, and elevated blood-lead levels among nearby residents. Using a mixed-methods design, the project surveyed 200 adult respondents (100 from recycler households; 100 from non-recycler households) via a rigorously pre-tested, bilingual (English/Igbo) questionnaire covering demographics, exposure behaviors, health symptoms, knowledge of hazards, safety practices, and policy awareness. Deliverables include geo- referenced exposure maps; detailed profiles of recyclers' Knowledge-Attitude-Practice (KAP) patterns; a policy gap analysis report; peer reviewed journal articles; targeted policy briefs for NESREA and the Imo State Environmental Protection Agency; and community outreach materials. Based on the findings, the study recommends that rapid risk communication and training programme among other things.

Keywords: Toxic Chemical Exposure, Informal E-Waste Recycling, Policy Failure.

Introduction

The exponential growth in the production and consumption of electronic devices has led to a corresponding surge in electronic waste (e-waste), posing significant environmental and public health challenges globally. Audu et al.(2024) stated that in Nigeria, the situation is particularly dire, with an estimated 60,000 tones of second-hand electronics entering the country annually, often under the guise of reusable or refurbished items, many of which are non-functional and quickly become waste. The informal sector dominates e-waste recycling in Nigeria, employing rudimentary methods such as open burning and manual dismantling to recover valuable materials, practices that release hazardous substances into the environment (Audu et al., 2024).

These informal recycling activities are typically conducted without protective equipment or awareness of the associated health risks, leading to significant exposure to toxic substances like lead, mercury, cadmium, and brominated flame retardants. Such exposure has been linked to a range of health issues, including respiratory problems, neurological disorders, and adverse reproductive outcomes. Parvez et al. (2021) reported that children and women, who constitute a substantial portion of the informal recycling workforce, are particularly vulnerable, with studies reporting elevated blood lead levels and associated cognitive impairments among children living near e-waste sites.

Despite the existence of regulatory frameworks like the National Environmental (Electrical/Electronic Sector) Regulations and the Extended Producer Responsibility (EPR) program, enforcement remains weak, allowing informal recycling practices to persist unchecked. In Imo State, Nigeria, informal e-waste recycling is a growing concern, with activities often taking place in residential areas, thereby increasing the risk of exposure to toxic chemicals for the local population. The state's regulatory framework has been insufficient in addressing the challenges posed by informal e-waste recycling, leading to environmental degradation and health hazards (Ajania & Kunlerea, 2019).

This research aims to investigate toxic chemical exposure resulting from informal e-waste recycling practices in Imo State and to assess the effectiveness of existing policies in mitigating these risks. By identifying gaps in policy implementation and enforcement, the study seeks to inform the development of effective strategies to address the environmental and health challenges posed by informal e-waste recycling in the region.

Statement of the Problem

The proliferation of informal electronic waste (e-waste) recycling activities in Imo State, Nigeria, has precipitated a significant public health and environmental crisis. Informal recyclers employ rudimentary techniques such as open burning, manual dismantling, and acid leaching to extract valuable materials from discarded electronics. These methods release hazardous substances—including heavy metals like lead, mercury, cadmium, and arsenic, as well as persistent organic pollutants such as poly-chlorinated biphenyls (PCBs) and poly-brominated diphenyl ethers (PBDEs)-into the environment. Consequently, communities situated near these informal recycling sites are exposed to contaminated air, soil, and water, leading to a spectrum of health issues.

Vulnerable populations, particularly women and children, bear the brunt of these health hazards. Exposure to toxic chemicals from e-waste recycling has been linked to adverse health outcomes such as spontaneous abortions, cancers, neurological impairments, and developmental disorders in children. Despite the existence of national regulations and Nigeria's commitment to international treaties like the Basel Convention, enforcement remains weak. This regulatory lapse has allowed unsafe recycling practices to persist, exacerbating the public health crisis.

In Imo State, the absence of comprehensive data on the extent of toxic chemical exposure resulting from informal e-waste recycling impedes the development of effective policy interventions. This research is imperative to elucidate the magnitude of the problem, assess the effectiveness of existing policies, and inform the formulation of robust strategies to mitigate health risks and environmental degradation associated with informal e-waste recycling.

Objectives of the Study

To assess the extent of toxic chemical exposures resulting from informal e-waste recycling and to critically examine the policy failures contributing to this environmental and public health issue in Imo State, Nigeria. Specifically, the study sought:

1. To investigate the perspective of residents of Imo state on the level of toxic chemical exposure among individuals living or working in proximity to informal e-waste recycling sites, with particular attention to children and women.
2. To evaluate the awareness, practices, and safety measures among informal e-waste recyclers regarding health risks and environmental impacts.
3. To examine the effectiveness of existing environmental and health-related policies and regulations on e-waste management in Imo State, and identify key gaps in enforcement and implementation.

Research Question

Below are questions which guided the study.

1. How do residents of Imo State perceive as

the level and nature of toxic chemical exposure experienced by children and women living or working near informal e-waste recycling sites?

2. How aware are informal e-waste recyclers in Imo State of the health and environmental hazards associated with their work, and what safety practices do they observe?
3. How effective are the current environmental and health policies regulating e-waste management in Imo State, and what enforcement and implementation gaps exist?

Conceptual Framework

This study investigates the interplay between informal electronic waste (e-waste) recycling practices, toxic chemical exposure, and policy failures in Imo State, Nigeria. The conceptual framework integrates environmental health, occupational safety, and governance perspectives to elucidate the multifaceted challenges inherent in informal e-waste recycling practices.

1. Informal E-Waste Recycling Practices

In Nigeria, a significant portion of e-waste is processed through informal channels employing rudimentary methods such as open burning, manual dismantling, and acid leaching. These practices release hazardous substances, including heavy metals like lead, mercury, and cadmium, as well as persistent organic pollutants, into the environment. Workers often operate without personal protective equipment, exacerbating their exposure to these toxins (Ibifunmilola, 2024).

2. Toxic Chemical Exposure

The hazardous substances released during informal recycling contaminate air, soil, and water, leading to direct and indirect human exposure. Exposure routes include inhalation of fumes, dermal contact, and ingestion of contaminated food or water. Health impacts range from neurological disorders and respiratory issues to reproductive health problems and developmental delays in children (Perkins et al., 2014).

3. Policy and Regulatory Framework

Nigeria has established regulations such as the National Environmental (Electrical/Electronic Sector) Regulations and is a signatory to international treaties like the Basel Convention. However, enforcement remains weak due to factors like inadequate infrastructure, limited funding, and lack of political will. This regulatory gap allows informal recycling practices to persist unchecked, perpetuating environmental and health hazards (**Barnabas,** 2025).

4. Socioeconomic and Institutional Factors

Poverty, unemployment, and lack of education drive individuals to participate in informal recycling despite the associated risks. Institutional weaknesses, including fragmented responsibilities among agencies and lack of coordination, hinder effective policy implementation and public awareness campaigns (Zisopoulos et al., 2023; Solaja et al., 2024).

4. Health Outcomes and Environmental Degradation

The cumulative effect of toxic exposures and weak policy enforcement leads to significant public health crises and environmental degradation. Communities near informal recycling sites experience higher incidences of health issues, and ecosystems suffer from contamination, affecting biodiversity and agricultural productivity (Tulchinsky et al., 2014; Shetty et al., 2023; Alabi et al., 2024).

This conceptual framework underscores the interconnectedness of informal recycling practices, toxic exposures, policy failures, and socioeconomic factors. Addressing the e-waste challenge in Imo State requires a holistic approach that combines stringent policy enforcement, public education, socioeconomic interventions, and infrastructure development to mitigate health risks and environmental harm.

Empirical Literature Review

The proliferation of electronic waste (e-waste) has emerged as a significant environmental and public health concern globally, with developing countries like Nigeria facing acute challenges

due to informal recycling practices. In regions such as Imo State, the absences of formal recycling infrastructure and inadequate policy enforcement have led to the dominance of informal e-waste recycling methods. These practices often involve rudimentary techniques like open-air burning and manual dismantling, which release hazardous substances into the environment, posing severe health risks to workers and nearby communities. This literature review synthesizes empirical studies on the health impacts of informal e-waste recycling, the awareness and safety practices among recyclers, and the effectiveness of existing regulatory frameworks in Nigeria, with a particular focus on Imo State.

Health Impacts of Informal E-Waste Recycling

Informal e-waste recycling exposes individuals to a myriad of toxic substances, including heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), and persistent organic pollutants (POPs). These substances are released during processes like open-air burning and acid leaching, commonly employed in informal recycling. Studies have documented elevated levels of these toxins in the blood and tissues of individuals involved in e-waste recycling, leading to adverse health outcomes. For instance, exposure to lead has been associated with neuro-developmental deficits in children, including reduced cognitive function and behavioral issues. Similarly, cadmium exposure has been linked to kidney dysfunction and bone demineralization (Grant et al., 2013, Perkinset al., 2014, WHO, 2021, Eckhardt & Kaifie, 2024).

Children and women are particularly vulnerable to the health effects of e-waste exposure. Children's developing systems are more susceptible to toxic insults, and studies have shown that prenatal exposure to e-waste-related toxins can result in low birth weight, preterm birth, and developmental delays (WHO, 2021).Women, especially those of reproductive age, face increased risks of reproductive health issues, including spontaneous abortions and menstrual irregularities, due to exposure to hazardous substances during recycling activities (Grant et al., 2013, Perkinset al., 2014, Eckhardt & Kaifie, 2024, Odeyingbo et al., 2025).

Awareness and Safety Practices Among Informal Recyclers

The informal nature of e-waste recycling in Nigeria often means that workers lack awareness of the health risks associated with their activities. Studies by Perkins et al. (2014) and Eckhardt & Kaifie (2024) highlighted that many informal recyclers are unaware of the toxic substances they are exposed to and do not use personal protective equipment (PPE).This lack of awareness and safety measures exacerbates the health risks for these workers and their communities. Furthermore, economic pressures and lack of alternative employment opportunities compel individuals to continue engaging in hazardous recycling practices despite the known risks.

Regulatory Frameworks and Policy Effectiveness in Nigeria

Nigeria has established several regulatory frameworks aimed at managing e-waste, including the National Environmental (Electrical/Electronic Sector) Regulations of 2011, enforced by the National Environmental Standards and Regulations Enforcement Agency (NESREA). However, the effectiveness of these regulations is hindered by challenges such as inadequate enforcement, lack of awareness, and insufficient infrastructure for proper e-waste collection and recycling ().Studies have pointed out that the absence of a cohesive national policy and the failure to domesticate international conventions like the Basel Convention contribute to the persistence of informal and hazardous e-waste recycling practices in the country Okposin, 2019, Odeyingbo et al., 2025.

In Imo State, similar challenges persist, with limited implementation of existing regulations and a lack of formal e-waste management systems. The state's regulatory bodies often face resource constraints, limiting their capacity to monitor and enforce compliance with environmental standards. This regulatory gap allows informal recycling activities to thrive, perpetuating environmental degradation and public health risks (Barnabas, 2025).

Empirical evidence underscores the significant health risks posed by informal e-waste recycling, particularly for vulnerable populations such as children and women. The lack of awareness among recyclers and inadequate safety practices exacerbate these risks. While Nigeria has established regulatory frameworks to address e-waste management, their effectiveness is compromised by enforcement challenges and infrastructural deficits. In Imo State, these issues are pronounced, necessitating targeted interventions to enhance policy implementation, raise awareness, and develop sustainable e-waste management systems.

Research Methodology

This study adopts a descriptive survey design, because it is appropriate to generate data and explain the Toxic Chemical Exposure from Informal E-Waste Recycling and Policy Failure in Imo State.

Study Area

The study was conducted across two strategically selected zones in Imo State-urban Owerri (including areas such as Otamiri and Relief Market) and peri-urban Orlu (focusing on informal recycling clusters and scrap yards). These zones are chosen to capture contrasting exposure patterns and regulatory contexts, enabling the research to encompass diverse environmental scenarios across Imo State.

Population of the Study.

The population of the study was 200 households (with one adult each) yielding 200 respondents. The number was drawn first by site zones-urban (Owerri) and peri-urban (Orlu)-to account for geographical variability; then by household involvement, with two strata per zone (households with at least one e-waste recycler versus those situated near recycling sites but without recyclers); and finally by individual selection, where one adult (18 years or older) from each selected household is purposefully chosen based on their ability to provide informed responses.

Sample and Sampling and Procedure

The sample of the study was the two hundred (200) household, using stratified random sampling-50 involved and 50 non-involved households per zone (total N = 200 households). Also three major steps were involved. First, local partners and informants helped map informal e-waste hot spots, from which we identified geographically coherent clusters (e.g., neighborhoods) within each zone. Clusters were randomly selected proportional to observed recycling intensity. Second, within each selected cluster, all households within a 500 m buffer of recycling activity were listed, and the two household strata sampled using stratified random sampling—50 involved and 50 non-involved households per zone (total N = 200 households).

Data Collection Instruments

A structured questionnaire-translated and back-translated in English and Igbo-were administered face-to-face. It is pre-tested for cultural and linguistic clarity and consists of sections covering demographics, exposure behaviors (e.g., PPE use, proximity to sites), self-reported health symptoms, knowledge/awareness of chemical hazards, safety practices, and policy enforcement experiences.

Method of data analysis

Statistical analysis was done using Statistical Package for Social Sciences (SPSS) for descriptive (e.g. frequencies, means) and inferential statistics (e.g. chi-square, t-tests, ANOVA, and logistic regression), disaggregated by age and gender.

Objective 1: Investigate the perspective of residents on toxic chemical exposure near informal e-waste sites, with attention to children and women

Activities:

- Develop and validate a structured questionnaire focused on perceived exposure risks and health symptoms related to e-waste.
- Conduct household surveys targeting residents living near informal recycling sites, with disaggregation by age and gender.

Expected Outputs:

- A validated and context-specific questionnaire instrument.
- A geo-referenced data set of residents' responses, highlighting gender- and age-specific exposure concerns.
- A technical report detailing residents' perceptions and the levels of heavy metals and persistent organic pollutants (POPs) in environmental samples, consistent with literature reporting high contamination near such sites.

Objective 2: Evaluate the awareness, practices, and safety measures among informal e-waste recyclers

Activities:

- Design and deploy a Knowledge, Attitude, and Practice (KAP) survey tailored to informal recyclers.
- Conduct in-depth interviews and site observations to assess real-time safety behaviors and informal dismantling practices.

Expected Outputs:

- A comprehensive KAP data set reflecting recyclers' knowledge and behavioral patterns.
- A field report on occupational exposures and risky practices, especially open burning and lack of protective gear-common across informal recycling hubs.
- A gap analysis report with policy and educational recommendations for improving awareness and safety compliance.

Objective 3: Examine the effectiveness of environmental and health-related policies and identify enforcement gaps

Activities:

- Review national and state policies on e-waste, health, and environmental regulation.
- Conduct interviews with regulatory agencies, health officers, and NGOs involved in waste management.
- Compare policy provisions with field realities to identify enforcement barriers and structural weaknesses.

Expected Outputs:

- A synthesized inventory of relevant environmental and health policies, highlighting their strengths and limitations.
- A policy gap analysis report showing the disconnect between legislative intent and ground-level implementation, reflecting findings from related contexts.
- A policy brief with actionable recommendations for strengthening Imo State's e-waste governance framework.

Cross-Cutting Outputs:

- Peer-reviewed journal article(s) and conference paper(s) based on findings.
- A final comprehensive project report incorporating exposure data, public perception, safety practices, and policy analysis.
- Stakeholder dissemination workshop involving community members, recyclers, regulators, and academics.

Results

Demographic Profile

Out of the 200 respondents (100 from recycler households and 100 from non-recycler households), recyclers were more frequently female (62%) and younger, with half of them aged 18–30. In contrast, non-recycler households had fewer women (43%) and fewer young adults (33% aged 18–30). Education levels also differed sharply: 42% of recyclers had only primary or no formal education, compared to just 14% in non-recyclers. Most non-recyclers (60%) had tertiary education, while only 24% of recyclers attained the same level (Table 1). These findings reflect the concentration of less-educated women and youth in informal recycling work.

Table 1: Demographic Profile

Characteristic	Recyclers (n=100)	Non – Recyclers (n=100)
Female	62 (62%)	43 (43%)
Male	38 (38%)	57 (57%)
Age 18 – 30	50 (50%)	33 (33%)
Age 31 – 50	30 (30%)	41 (41%)
Age 51+	20 (20%)	26 (26%)
Primary or less	42 (42%)	14 (14%)
Secondary	34 (34%)	26 (26%)
Tertiary	24 (24%)	60 (60%)

Knowledge and Protective Practices

Overall awareness of health hazards from e-waste was limited, but recyclers demonstrated significantly lower knowledge. Only 27% of recyclers had heard of health dangers associated with e-waste compared to 59% of non-recyclers. Use of protective equipment was also uncommon: just 5% of recyclers consistently used any form of PPE, while nearly one-third of non-recyclers reported doing so. Alarmingly, more than three-quarters (76%) of recyclers admitted they never used PPE, compared with 38% of non-recyclers (Table 2).

Table 2: Knowledge and Protective Practices

Indicator	Recyclers (%)	Non - Recyclers (%)
Always use PPE	5	31
Never use PPE	76	38
Aware of health hazards	27	59
Aware of regulations	21	22

Health Outcomes and Perceived Risks

Self-reported health complaints were more widespread among recyclers. About 61% of them reported experiencing at least one health problem (such as cough, breathing difficulty, or skin irritation), compared to only 30% among non-recyclers. The difference was statistically significant (p<0.001). Cough or breathing issues (35%) and skin irritation (28%) were the leading symptoms among recyclers, while the rates in non-recyclers were lower (12% and 10%, respectively). Importantly, recyclers were more likely to believe that women and children face serious risks from toxic exposure around recycling sites-46% expressed high concern, compared to 25% of non-recyclers (Table 3).

Table 3: Health Outcomes and Perceived Risks

Indicator	Recyclers (%)	Non-Recyclers (%)
Any health symptom reported	61	30
High risk perception for women/children	46	25

Awareness of Policy and Regulation

Both groups had very limited knowledge of existing e-waste policies or agencies tasked with enforcement. Only about one in five

respondents-21% of recyclers and 22% of non-recyclers-had ever heard of any regulation. This highlights a major information and enforcement gap, despite national e-waste regulations having been introduced over a decade ago.

The analysis reveals sharp contrasts between recyclers and non-recyclers in education, awareness, and health experiences. Recyclers are younger, less educated, and much less likely to use protective equipment, while also reporting more frequent health problems. Both groups, however, show very poor awareness of official e-waste policies. These findings point to weak policy enforcement and the urgent need for interventions-such as awareness campaigns, safety training, and provision of protective gear-to reduce toxic exposure risks in affected communities.

Discussion

Demographic profile and vulnerability

This study results on demography shows a clear socio-demographic pattern: respondents from recycler households were disproportionately female (62%) and skewed younger (50% aged 18–30) compared with non-recycler households (43% female; 33% aged 18–30). Educational attainment diverged sharply: 42% of recyclers had primary-level education or less versus only 14% in non-recycler households, while 60% of non-recyclers had tertiary qualifications compared with 24% of recyclers.

These differences matter for exposure and intervention design. Lower formal education and younger age among recyclers are likely to limit access to technical information about chemical hazards, reduce bargaining power to demand safer working conditions, and constrain livelihood choices factors that perpetuate engagement in hazardous informal recycling. The gender imbalance more women in recycler households raises additional concerns because women may combine recycling with domestic roles, increasing the potential for take-home contamination and exposure of dependents (e.g., children). In short, the demographic profile identifies both who is at greatest risk and which subgroups should be prioritized for protective interventions(Farzana Sathar et al., 2016; Papadopoli et al., 2020).

Awareness of hazards and safety practices

Knowledge and protective behaviours were alarmingly low among recyclers. Only 27% of recyclers reported any awareness of health risks from e-waste (versus 59% among non-recyclers). Regular PPE use was rare: just 5% of recyclers reported always using PPE, while 76% reported never using PPE; in non-recyclers these figures were 31% always and 38% never, respectively.

From a public-health perspective, this combination of low hazard awareness and minimal PPE use is critical. It suggests that routine recycling activities manual dismantling, open burning, acid leaching is being carried out with little to no protection against inhalation of fumes, dermal contact with toxic residues, or ingestion via contaminated hands and food. The low policy awareness (≈21–22% across groups) compounds the problem because regulations cannot protect communities if they are unknown and unenforced at the grassroots level (Annamalai, 2015; Abogunrin-Olafisoye & Adeyi, 2025).

Health complaints and perceived risk

Self-reported symptom burden was substantially higher among recyclers: 61% reported at least one health symptom (respiratory complaints, skin irritation, etc.) compared with 30% of non-recyclers. Respiratory issues and skin problems were the most frequently reported symptoms among recyclers. Recyclers were also more likely to report that children and women face high exposure risk (46% vs 25% among non-recyclers).

These findings indicate both objective and perceived harms. The higher prevalence of symptoms among recyclers is consistent with direct occupational exposure to airborne particulates, acid fumes and heavy-metal dust. The elevated perception of risk for children and women signals community recognition of the potential inter-generational impact-an important motivator for community action and behaviour change. Statistically, the difference in symptom prevalence between recyclers and non-recyclers

was robust, indicating that observed differences are unlikely due to chance (Poole & Basu, 2017; Wang et al., 2024)

Environmental-policy awareness and enforcement gaps

Only one in five respondents knew about applicable e-waste regulations or enforcement agencies. This low policy penetration points to a disconnect between formal regulatory frameworks and local realities. In practice, weak outreach, limited inspection capacity, and fragmented institutional responsibilities mean that laws exist on paper but do not translate to safer practices or enforcement on the ground.

This implementation gap is consequential. Without active enforcement and community outreach, informal recyclers will continue operating in hazardous ways and vulnerable groups particularly women and children will remain exposed. The data therefore support a shift in emphasis from purely legislative change to operational measures: resourcing local enforcement, integrating policy with community education, and establishing clear, accountable roles for state and federal agencies (Solaja et al., 2024)

Based on the findings, the following priorities are recommended:

1. **Rapid risk communication and training:** implement targeted, bilingual (English/Igbo) hazard-awareness and hands-on PPE training for recycler communities, prioritizing women and youth. Training should be pragmatic (how to use locally available Personal Protective Equipment (PPE), safe dismantling techniques) and include practical demonstrations.
2. **PPE provisioning and behaviour support:** subsidize or distribute basic PPE kits (gloves, respirators/masks, eye protection) and teach safe storage/sanitation to reduce take-home contamination. Behavioral nudges (removal of work clothing before entering living quarters, hand-washing stations) can meaningfully reduce household exposure.
3. **Task shifting and safe-technology pilots:** introduce low-cost, low-smoke dismantling methods and centralized, supervised processing points to reduce open burning. Pilot demonstration sites linked to incentives can demonstrate feasibility and create demonstration effects.
4. **Strengthen enforcement & interagency coordination:** NESREA and Imo State Environmental Protection Agency (ISEPA) should co-design local enforcement plans that include regular inspections, clear penalties, and formal referral pathways for assisted closure or formalization of hazardous yards.
5. **Formalization & economic alternatives:** support the transition of informal recyclers into regulated recycling cooperatives or collection/repair centres with revenue-sharing models and safer working conditions. Such pathways reduce exposure while preserving livelihoods.
6. **Health surveillance & bio-monitoring:** establish routine bio-monitoring (e.g., blood lead levels) and basic health screening (respiratory testing) for workers and exposed children, accompanied by referral networks for medical care.
7. **Community-based monitoring and GIS mapping:** expand geo-referenced exposure mapping to identify hotspots, prioritize interventions, and monitor change over time.
8. **Public policy translation and outreach:** domesticate international commitments (e.g., EPR schemes) into concrete local actions producer take-back, collection points, and financing mechanisms to support safe recycling systems.

Conclusion

The evidence points to a high-risk scenario in which less-educated, predominantly female and

young informal recyclers operate with limited awareness and protection, suffer higher symptom burdens, and remain disconnected from formal e-waste policies. Addressing this situation requires coordinated, multi-pronged action: immediate community risk-reduction (training, PPE, safe technology pilots), medium-term systems change (formalization, EPR implementation, enforcement capacity), and longer-term monitoring and research (bio-monitoring, environmental sampling, longitudinal evaluation). Prioritizing women and children both vulnerable and central to household livelihoods will maximize the health and equity impact of any intervention.

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