# The effect of e-waste in urban health: a systematic review

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## Abstract

**Purpose:** E-waste is among the most rapidly increasing types of waste worldwide. This paper aims to systematise the existing literature and explore future research prospects on the effect of e-waste on urban health. **Methods:** This systematic review follows the Preferred Reporting Items for Systematic Reviews (PRISMA) guidelines. This literature search utilized articles available in the ScienceDirect, PubMed, and Google Scholar databases, published within the last ten years (2014-2024), to explore the relationship between e-waste and urban health. **Results:** E-Waste poses serious environmental and health risks, especially in areas with weak regulations and poor waste management. Exposure to hazardous substances through air, soil, and water, such as lead, mercury, and polycyclic aromatic hydrocarbons (PAHs), can lead to respiratory, cardiovascular, and neurodevelopmental issues. Informal recycling worsens these risks, particularly for workers and nearby communities. Weak enforcement, economic barriers, and low public awareness further exacerbate the problem. Effective mitigation includes extended producer responsibility (EPR), formal recycling systems, and a circular economy. Urgent action is needed through stronger policies, enforcement, and awareness; future research should focus on developing sustainable e-waste solutions. **Conclusion:** Our findings underscore the urgent need for integrated e-waste management policies and practices to safeguard urban public health and mitigate the adverse effects of e-waste exposure. This review lays the groundwork for future research aimed at understanding and addressing the complex health challenges posed by e-waste in urban environments.

**Keywords:** e-waste; health and well-being; urban health; waste management

## INTRODUCTION

The rapid growth of urban populations and technological advancements has led to an exponential increase in electronic waste (e-waste) [1]. E-waste is a major byproduct of modern consumption, including discarded electronic products such as smartphones, computers, televisions, and other electrical appliances [2]. The improper disposal and recycling of e-waste pose significant environmental and health risks, particularly in urban settings where large quantities of e-waste accumulate [3,4]. In recent years, concerns have been rising about the impact of e-waste on public health, with studies suggesting potential links to respiratory, neurological, and cardiovascular diseases [5,6].

In 2022, a record 62 million metric tons of e-waste were generated, marking an 82% increase from 2010 levels [7–9]. This figure is projected to rise by 32% to reach 82 million metric tons by 2030, translating to an annual increase of approximately 2.6 million tons [8, 9]. According to the Global E-Waste Monitor 2020, only 17.4% of e-waste generated globally is officially recycled, while the rest is either informally recycled or ends up in landfills [8]. The trend indicates that e-waste will continue to grow rapidly, with estimates suggesting it could reach up to 120 million metric tons annually by 2050 if current consumption patterns persist [8–10]. This growth is driven by ongoing urbanization, technological innovation, and shorter product life cycles [11].

In cities, informal e-waste recycling practices, which often involve open burning and hazardous chemical processes, can release toxic substances such as lead, mercury, and cadmium into the environment, further exacerbating the health risks [12]. The effects of exposure to these toxic substances, particularly in densely populated urban areas, are becoming a critical public health issue [13]. Urban populations are often at higher risk due to the proximity to e-waste disposal sites and informal recycling activities [12]. Vulnerable groups, such as children and low-income communities, face increased risks due to limited access to healthcare and protective measures [14].

This systematic review aims to consolidate existing research on the effects of e-waste on urban health. It explores the specific health outcomes associated with e-waste exposure. The findings will inform future research directions and provide evidence for policymakers to address public health challenges in urban areas.

## METHODS

This systematic review consists of three main steps: (1) search strategy, (2) selection criteria, and (3) data extraction and quality assessment.

**Step 1: Search strategy**

This study uses the PICO (Population, Intervention, Comparison, and Outcome) framework. The three research questions in this study are: 1) What are the impacts of e-waste on urban public health?; 2) What factors exacerbate or mitigate the impact of e-waste on urban health?; 3) How does e-waste management in urban areas affect public health?. Data search sources include ScienceDirect, PubMed, and Google Scholar. The search strategy based on the PICO framework are detailed in Tables 1, 2, and 3.

**Table 1. PICO framework for research question 1**

| PICO Framework | Description | Keywords |
|---|---|---|
| P (Population/Problem) | Urban communities exposed to e-waste | *city population, urban health, urban pollution* |
| I (Intervention/Exposure) | Exposure to electronic waste and toxic materials | *e-waste* , *electronic waste* , *electronic disposal* |
| C (Comparison) | No specific comparison | - |
| O (Outcome) | Health problems caused by e-waste | *respiratory diseases* , *health risks, toxic exposure, heavy metals* |

The search keywords to answer research question 1 based on the PICO framework in table 1 are: (*“electronic waste” OR “e-waste”* OR *“electronic disposal”)* **AND** *(“urban health”* OR *“city population”* OR *“urban pollution”)* **AND** *(“respiratory diseases”* OR *“health risks”* OR *“toxic exposure”* OR *“heavy metals”*).

**Table 2. PICO framework for research question 2**

| PICO Framework | Description | Keywords |
|---|---|---|
| P (Population/Problem) | Urban communities affected by e-waste | urban population |
| I (Intervention/Exposure) | Factors that exacerbate or mitigate the impact of e-waste on health, including the environment, policies, and waste management. | “e-waste disposal” OR “informal e-waste recycling” OR “hazardous waste exposure” OR “waste management in urban areas” |
| C (Comparison) | No specific comparison | - |
| O (Outcome) | The health impacts of e-waste, and how certain factors worsen or reduce their impacts | health impact |

The search keywords to answer research question 2 based on the PICO framework in Table 2 are: ("urban population") AND ("e-waste disposal" OR "informal e-waste recycling" OR "hazardous waste exposure" OR "waste management in urban areas") AND ("health impact").

**Table 3. PICO framework for research question 3**

| PICO Framework | Description | Keywords |
|---|---|---|
| P (Population/Problem) | Urban communities exposed to e-waste | *city population, urban health, urban pollution* |
| I (Intervention/Exposure) | Efforts to reduce the impact of e-waste through regulation, recycling technology, education, and environmentally friendly design. | "Extended Producer Responsibility" OR "Basel Convention" OR "waste management policies" OR "advanced recycling technologies" OR "public awareness campaigns" OR "eco-friendly electronics") |
| C (Comparison) | No specific comparison | - |
| O (Outcome) | Effectiveness of strategies in reducing pollution, increasing recycling, and protecting public health | ("waste reduction" OR "resource recovery" OR "public health impact" OR "circular economy" OR "pollution control") |

The search keywords to answer research question 3 based on the PICO framework in table 3 are: ("e-waste pollution" OR "electronic waste management" OR "hazardous waste control") AND ("Extended Producer Responsibility" OR "Basel Convention" OR "waste management policies" OR "advanced recycling technologies" OR "public awareness campaigns" OR "eco-friendly electronics") AND ("waste reduction" OR "resource recovery" OR OR "circular economy" OR "pollution control").

**Step 2: Selection criteria**

Inclusion criteria: 1) Studies on the impact of e-waste on urban health; 2) Articles in English or Indonesian; 3) Publications in the last 10 years (2014–2024); 4) Epidemiological studies, case studies, or reviews. Original research on the themes raised in this systematic review is limited, both in terms of the number and variety of methodologies used. Therefore, review articles serve as an essential complement to the synthesis of evidence, providing a broader and deeper perspective and supporting a more comprehensive understanding of the topic under study. Exclusion criteria: 1) Articles that are not peer-reviewed and 2) Theses and dissertations.

**Step 3: Data extraction and quality assessment**

Data extraction was carried out using a matrix consisting of title, method, focus of research questions (health impact, e-waste exposure, e-waste management, Factors Increasing E-Waste Risk Impact, Factors Reducing E-Waste Risk Impact), results, conclusions and recommendations. To assess the quality of the research used in this study, the selected articles were evaluated using the Joanna Briggs Institute (JBI) critical appraisal tool and the PRISMA-SR 2020 framework as a guide in the literature review.

## RESULTS

A total of 2,733 articles were retrieved from the database using several keywords, comprising 19 articles from ScienceDirect, 8 articles from PubMed, and 2,706 articles from Google Scholar. All articles were imported into Mendeley, and 2,648 articles were removed; however, a duplication check was still conducted. The titles and abstracts of 85 research articles were manually screened, and 52 articles were eliminated for not aligning with the study's title and topic. A total of 33 articles were considered eligible, but 4 articles were further excluded for not meeting the inclusion criteria, leaving 29 articles that met the inclusion criteria (Figure 1).

Table 4 shows the results obtained to answer research question 1 related to the impact of e-waste on urban public health. There were four articles obtained from PubMed, zero articles from Science Direct, and 790 articles from Google Scholar. Based on the title, 6 articles were selected, then after reading the abstract, 4 articles were selected, which will be reviewed by reading the entire article. Table 4 show several findings related to the impact of e-waste on urban public health. Studies in South China found that indoor dust in e-waste recycling sites contains high levels of organic contaminants and heavy metals, increasing the risk of respiratory and neurological disorders through inhalation, ingestion, and skin contact [15]. Similarly, research in Ghana revealed excessive PM levels in e-waste sites, exceeding air quality standards and leading to respiratory and cardiovascular diseases among workers and nearby residents [14]. Biomonitoring studies on e-waste workers demonstrated elevated levels of PAHs in hair and fingernails, highlighting occupational exposure with potential carcinogenic effects [17,18].

Table 5 presents the results obtained to answer research question 2, which relates to e-waste management in urban areas and its impact on public health. There were 0 articles obtained from PubMed, 19 articles from Science Direct, and 117 articles from Google Scholar. Based on the title, 24 articles were selected, then after reading the abstract, 15 articles were selected, and finally 11 were reviewed by reading the entire article.

It shows several findings related to e-waste management and public health implications. Studies from various regions, including Nigeria, Ghana, India, and Bangladesh, highlight the hazardous exposure of workers and nearby communities to heavy metals such as mercury, lead, and cadmium [19,20,26,27]. These toxic substances, found in contaminated soil, dust, and air, contribute to neurological disorders, respiratory illnesses, and heavy metal poisoning [19,27]. The lack of formal e-waste management infrastructure exacerbates these risks, with improper disposal and unregulated scavenging further endangering both human health and the environment [21,22,24,25,30]. Researchers emphasize the need for stronger regulations, improved recycling infrastructure, and protective measures for workers [21,22,31]. Integrating formal and informal recycling, adopting a circular economy approach, and increasing public awareness are crucial steps toward mitigating the adverse health effects of e-waste in urban settings [21,23,29].

Table 6 presents the results obtained to answer research question 3, which relates to factors that exacerbate or mitigate the impact of e-waste on urban health. There were 4 articles obtained from PubMed, 0 articles from Science Direct, and 1,820 articles from Google Scholar. Based on the title, 57 articles were selected. After reading the abstract, 14 articles were selected and will be reviewed by reading the entire article.

It presents several findings related to factors that exacerbate and mitigate the health impacts of e-waste. Weak enforcement of e-waste regulations, inadequate infrastructure, financial constraints, and a lack of public awareness contribute to increased health risks, particularly in regions where informal recycling practices prevail [32,33,36,39,44,45]. Studies have shown that unregulated e-waste processing leads to severe environmental pollution and direct exposure to

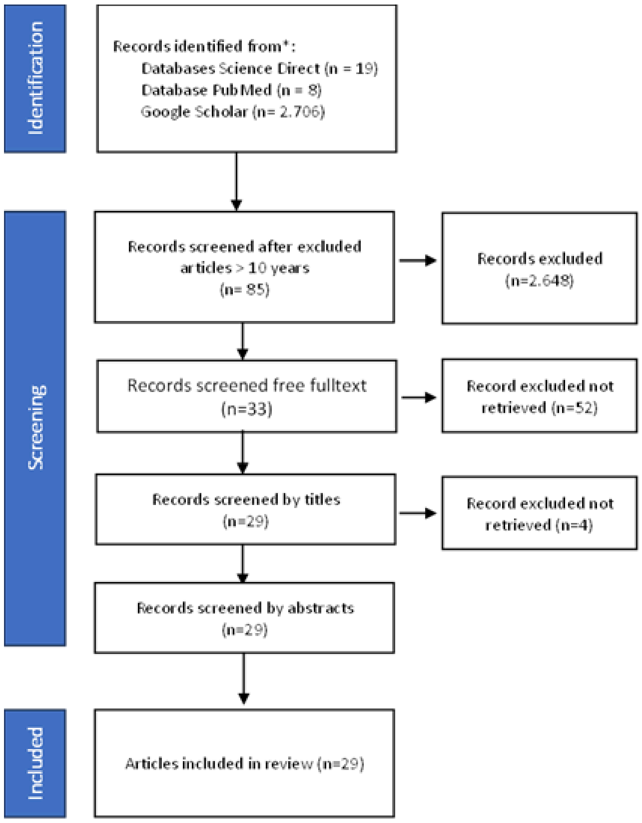


**Figure 1. PRISMA flow chart**

hazardous substances such as PBDEs and heavy metals, which pose significant health threats to both workers and nearby residents [41,42]. Additionally, economic and technological barriers hinder the adoption of safer recycling methods, further exacerbating the issue [34,37,43].

On the other hand, several measures have been identified to mitigate the health risks associated with e-waste. Effective policy frameworks, such as Extended Producer Responsibility (EPR), investment in advanced recycling technologies, and the promotion of circular economy principles, can significantly improve e-waste management [32,34,38]. Strengthening regulatory enforcement, implementing centralized recycling hubs, and fostering international cooperation are also crucial in reducing environmental and health impacts [35,39,40,44]. Moreover, structured and legally enforced recycling systems, along with financial and technical support, can help developing countries transition towards safer e-waste management practices [35,45].

**Table 4. Extraction table of research question 1 (impact of e-waste on urban public health)**

| No | Title, Year | Method | Results | Conclusion & Recommendation |
|---|---|---|---|---|
| 1 | Organic contaminants and heavy metals in indoor dust from e-waste recycling, rural, and urban areas in South China: Spatial characteristics and implications for human exposure, 2017<br><br>[15] | Measurement of organic contaminants and heavy metal concentrations in indoor dust from e-waste recycling, rural, and urban areas in South China. | • Indoor dust in e-waste recycling areas contains elevated levels of organic pollutants and heavy metals.<br>• Potential health risks due to chronic exposure to toxic substances, including respiratory and neurological effects.<br>• Higher levels of organic contaminants and heavy metals in e-waste sites compared to rural and urban areas.<br>• The median concentrations of PCB, PBDE, DBDPE, and DP were 38.6–3560, 2360–30100, 665–2720, and 19.5–1860 ng/g, respectively; while Cd, Pb, Cu, Cr, and Zn were 2.46–40.4, 206–1380, 217–1200, 25.3–134 μg/g, respectively. | **Conclusion:**<br>E-waste recycling sites had significantly higher levels of organic contaminants and heavy metals in indoor dust, posing a risk of human exposure through inhalation, ingestion, and dermal contact.<br><br>**Recommendation:**<br>Strengthen indoor pollution control and waste management strategies |
| 2 | Air Quality Impacts at an E-Waste Site in Ghana Using Flexible, Moderate-Cost and Quality-Assured Measurements, 2020<br><br>[16] | Application of moderate-cost approaches to provide spatial and temporal information on concentrations of particulate matter (PM) at an e-waste site in Ghana. | • Elevated PM levels at e-waste sites due to activities like open burning.<br>• Increased risk of respiratory and cardiovascular diseases due to high PM exposure<br>• High levels of particulate matter and hazardous air pollutants detected.<br>• 24-hour PM2.5 levels averaged 31, 88, and 57 μg/m³ at upwind, e-waste, and downwind sites, respectively, and PM10 averaged 145, 214, and 190 μg/m³, considerably exceeding air quality standards. Exceptionally high concentrations (e.g., 1-hour average PM10 exceeding 2000 μg/m³) were sometimes encountered near combustion sources, including open fires at the e-waste site and spoil piles. | **Conclusion:**<br>E-waste activities significantly contribute to elevated PM levels, posing health risks to workers and nearby residents.<br><br>**Recommendation:**<br>Implement pollution control measures and provide alternative recycling methods |
| 3 | Insights into biomonitoring of human exposure to polycyclic aromatic hydrocarbons with hair analysis: A case study in e-waste recycling area, 2020<br><br>[17] | Collection and analysis of 96 pairs of hair and urine samples from e-waste dismantling workers and residents living in surrounding areas to measure concentrations of polycyclic aromatic hydrocarbons (PAHs) and hydroxylated PAH metabolites (OH-PAHs). | • Occupational exposure to PAHs among e-waste dismantling workers.<br>• Potential health risks including carcinogenic effects due to PAH exposure.<br>• Elevated levels of PAHs in individuals from e-waste recycling areas.<br>• Higher concentrations of PAHs and OH-PAHs were found in samples from e-waste workers compared to residents, indicating occupational exposure. | **Conclusion:**<br>Hair analysis is effective for biomonitoring human exposure to PAHs in e-waste recycling areas.<br><br>**Recommendation:**<br>Promote personal protective equipment and awareness programs |
| 4 | PAHs and their hydroxylated metabolites in the human fingernails from e-waste dismantlers: Implications for human non-invasive biomonitoring and exposure, 2021<br><br>[18] | Collection and analysis of 72 human fingernail samples from workers and nearby residents at an e-waste dismantling site to measure PAHs and their mono-hydroxyl metabolites (OH-PAHs). | • Occupational exposure to PAHs among e-waste dismantlers.<br>• Potential health risks including carcinogenic effects due to PAH exposure.<br>• Presence of PAHs and their metabolites in fingernails of e-waste workers.<br>• Higher levels of PAHs and OH-PAHs were detected in fingernails of e-waste workers compared to nearby residents. | **Conclusion:**<br>Fingernail analysis is a useful non-invasive method for assessing human exposure to PAHs in e-waste dismantling areas.<br><br>**Recommendation:**<br>Encourage better workplace safety practices |

**Table 5. Extraction table of research question 2 (e-waste management and public health implications)**

| No | Title, Year | Method | Results | Conclusion & Recommendation |
|---|---|---|---|---|
| 1 | Mobility, spatial variation and human health risk assessment of mercury in soil from an informal e-waste recycling site, Lagos, Nigeria, 2021<br><br>[19] | Soil sampling and mercury concentration analysis; human health risk assessment | • High mercury concentration found at informal e-waste recycling sites<br>• Workers and nearby residents exposed to mercury through contaminated soil<br>• Informal e-waste recycling practices without proper waste management<br>• Health risks due to mercury exposure, including potential nervous system damage | **Conclusion:**<br>Intervention is needed to reduce mercury exposure and related health risks<br><br>**Recommendation:**<br>Implementation of safe recycling practices and proper waste management; regular soil quality monitoring |
| 2 | Exploring the Dynamics of E-waste Disposal Strategies in Tamale, Ghana, 2018<br><br>[20] | Interviews and surveys with local residents; descriptive data analysis | • Large amounts of e-waste disposed of without proper management<br>• Communities exposed to e-waste through improper disposal methods<br>• Lack of adequate e-waste management facilities; indiscriminate disposal of e-waste<br>• Potential health impacts due to exposure to hazardous materials from e-waste | **Conclusion:**<br>Public awareness of e-waste hazards is still low<br><br>**Recommendation:**<br>Public education on e-waste hazards; development of e-waste management infrastructure |
| 3 | The recycling of e-waste in the Industrialised Global South: the case of Sao Paulo Macrometropolis, 2021<br><br>[21] | Case study with policy and e-waste recycling practice analysis | • Identifies challenges in integrating formal and informal recycling practices<br>• Recycling workers exposed to hazardous materials during recycling processes<br>• Combination of formal and informal e-waste recycling practices<br>• Health risks for workers due to exposure to hazardous material | **Conclusion:**<br>Better regulations are needed to integrate recycling practices<br><br>**Recommendation:**<br>Policy development supporting formal-informal recycling integration; improved working conditions for recycling workers |
| 4 | Assessment of Micronutrient Status of Electronic Waste (E-waste) Recyclers at Agbogbloshie (Ghana) Using Dietary Information and Biomarker Data, 2020<br><br>[22] | Survey on dietary intake and biomarker analysis of 151 participants (100 e-waste workers and 51 controls) | • Heavy metal exposure may affect micronutrient status in e-waste workers<br>• E-waste workers exposed to heavy metals that may affect micronutrient status<br>• Informal e-waste recycling practices without adequate protection<br>• Micronutrient deficiencies such as calcium, copper, selenium, and magnesium in e-waste workers | **Conclusion:**<br>Interventions are needed to improve micronutrient status among e-waste workers<br><br>**Recommendation:**<br>Provision of micronutrient supplements and nutritional education for e-waste workers |
| 5 | The future of e-waste in the circular economy of Ghana; implications for urban planning, environmental and human health risks, 2023<br><br>[23] | Literature review and policy analysis | • Increased health risks due to exposure to hazardous materials from e-waste<br>• Increased exposure to e-waste due to informal recycling practices Informal recycling practices dominate, with weak regulations<br>• Exposure to hazardous substances such as heavy metals affecting human health | **Conclusion:**<br>A circular economy approach is needed for e-waste management<br><br>**Recommendation:**<br>Encourage circular economy implementation and stricter regulations to reduce health and environmental risks |
| 6 | The local contours of scavenging for e-waste and higher-valued constituent parts in Accra, Ghana, 2014<br><br>[24] | Field observations and interviews with e-waste scavengers | • Scavengers face poor working conditions with no health protection<br>• Scavengers are directly exposed while collecting and processing e-waste<br>• No formal system; e-waste management is done individually by scavengers collecting high-value components | **Conclusion:**<br>A safer approach is needed for e-waste management<br><br>**Recommendation:**<br>Strengthening regulations and providing health protection for e-waste scavengers |

| No | Title, Year | Method | Results | Conclusion & Recommendation |
|---|---|---|---|---|
| | | | • Health risks due to direct contact with hazardous materials in e-waste | |
| 7 | WEEE generation and the consequences of its improper disposal, 2018<br><br>[25] | Literature review on the impact of improper e-waste disposal | • Improper e-waste disposal causes environmental pollution and health issues<br>• Increasing volume of WEEE (waste electrical and electronic equipment) that is not properly managed<br>• Lack of effective regulations for WEEE management<br>• Exposure to toxic substances such as lead, mercury, and cadmium | **Conclusion:**<br>A better WEEE management system is needed to mitigate its impact<br><br>**Recommendation:**<br>Strengthening policies and sustainable e-waste management |
| 8 | Electronic waste (E-waste) generation and management scenario of India, and ARIMA forecasting of E-waste processing capacity of Maharashtra state till 2030, 2024<br><br>[26] | ARIMA forecasting analysis for e-waste processing capacity in Maharashtra, India | • Forecasts indicate that Maharashtra's e-waste processing capacity will be insufficient by 2030<br>• Significant increase in e-waste volume in India<br>• E-waste management is still suboptimal with limited processing capacity<br>• Health risks due to exposure to unmanaged electronic waste | **Conclusion:**<br>Expansion of e-waste processing capacity is urgently needed<br><br>**Recommendation:**<br>Investment in infrastructure and technology for e-waste management |
| 9 | Blood lead, cadmium and hair mercury concentrations and association with soil, dust and occupational factors in e-waste recycling workers in Bangladesh, 2024<br><br>[27] | Measurement of heavy metal concentrations in blood and hair of e-waste recycling workers | • Heavy metal levels in workers are higher compared to the general population<br>• Workers exposed to heavy metals from e-waste, including lead, cadmium, and mercury<br>• Recycling is conducted informally without adequate protection<br>• Health risks such as heavy metal poisoning and nervous system disorders | **Conclusion:**<br>Worker protection must be a top priority<br><br>**Recommendation:**<br>Implementation of strict regulations and provision of personal protective equipment for e-waste workers |
| 10 | Toxic transitions in the lifecycle externalities of a digital society: The complex afterlives of electronic waste in Ghana, 2019<br><br>[28] | Case study on the externalities of e-waste in Ghana | • Negative impact of e-waste on both the environment and workers' health<br>• Increasing volume of e-waste from discarded electronics<br>• E-waste management is unstructured, largely conducted informally<br>• Health risks from exposure to hazardous chemicals in e-waste | **Conclusion:**<br>More sustainable solutions are needed for e-waste management in Ghana<br><br>**Recommendation:**<br>Strengthening regulations and infrastructure for e-waste management |
| 11 | A preliminary assessment of physical work exposures among electronic waste workers at Agbogbloshie, Accra Ghana, 2021<br><br>[29] | Survey and observation of physical work exposure among e-waste workers in Agbogbloshie | • Many workers experience excessive physical exposure without protection<br>• Workers are directly exposed to hazardous materials and poor working conditions<br>• No clear occupational safety standards in e-waste recycling<br>• Health risks from poor working conditions | **Conclusion:**<br>Improved worker protection in the e-waste industry is urgently needed<br><br>**Recommendation:**<br>Strict regulations and provision of personal protective equipment for e-waste workers |

**Table 6. Extraction table of research question 3 (factors exacerbating and mitigating e-waste health impacts)**

| No | Title, Year | Method | Results | Conclusion & Recommendation |
|---|---|---|---|---|
| 1 | Extended producer responsibility's (EPR) effect on producers' electronic waste management practices in Japan and Canada, 2023 [30] | Comparative analysis of EPR policies in Japan and Canada | • EPR is effective but requires stronger enforcement<br>• EPR policies in both countries promote e-waste recycling and producer responsibility<br>• Lack of enforcement and financial constraints increase e-waste risk impact<br>• Stronger regulations and incentives for producers reduce e-waste risk impact | **Conclusion:** Better enforcement of EPR policies is needed<br>**Recommendation:** Strengthen policy enforcement and financial support for producers |
| 2 | E-waste it wisely: lessons from Africa, 2022 [31] | Case studies and policy review | • Africa faces significant e-waste challenges due to lack of formal management<br>• Predominantly informal recycling with minimal regulations<br>• Poor infrastructure, lack of awareness increase e-waste risk impact<br>• Government intervention, public-private partnerships reduce e-waste risk impact | **Conclusion:** Stronger governance is required<br>**Recommendation:** Implement structured e-waste policies and awareness programs |
| 3 | Environmental and economic impacts of e-waste recycling: A systematic review, 2024 [32] | Systematic literature review | • Recycling reduces environmental impact but requires higher investment<br>• Evaluates the balance between environmental benefits and economic feasibility of recycling<br>• High costs of recycling, lack of proper technology increase e-waste risk impact<br>• Investment in advanced recycling technologies, regulatory incentives reduce e-waste risk impact | **Conclusion:** Circular economy approaches are necessary<br>**Recommendation:** Increase funding for e-waste recycling technologies |
| 4 | Hub-driven policy packages as a basis for e-waste reform, 2023 [33] | Policy analysis and case study | • Hub-based models can enhance e-waste management efficiency<br>• Centralized hubs for managing e-waste effectively<br>• Lack of coordination among stakeholders increase e-waste risk impact<br>• Improved governance through centralized policies reduce e-waste risk impact | **Conclusion:** A coordinated approach improves outcomes<br>**Recommendation:** Implement hub-based e-waste policy packages |
| 5 | Environmental pollution of E-waste in Mexico, 2020 [34] | Case study and policy analysis | • E-waste contributes significantly to pollution in Mexico<br>• Weak enforcement of e-waste laws leads to pollution<br>• Poor waste collection systems, inadequate regulations increase e-waste risk impact<br>• Stricter enforcement of recycling laws reduce e-waste risk impact | **Conclusion:** Improved regulation can mitigate environmental risks<br>**Recommendation:** Strengthen legislation and increase recycling incentives |
| 6 | e-Waste Management: A Transition Towards a Circular Economy, 2022 [35] | Literature review and framework development | • Circular economy approach can improve sustainability<br>• Proposes a shift to a circular economy for e-waste<br>• Resistance to change, lack of technology increase e-waste risk impact<br>• Circular economy principles, producer responsibility reduce e-waste risk impact | **Conclusion:** Transition to circular economy is essential<br>**Recommendation:** Promote circular economy in e-waste policies |
| 7 | A global perspective on e-waste recycling, 2023 [36] | Global data analysis and policy review | • Some regions excel in recycling while others lag<br>• Compares e-waste recycling practices globally<br>• Economic constraints, lack of harmonized regulations increase e-waste risk impact | **Conclusion:** Global collaboration can improve e-waste management |

| No | Title, Year | Method | Results | Conclusion & Recommendation |
|---|---|---|---|---|
| | | | • International cooperation and standardization reduce e-waste risk impact | **Recommendation:** Promote standardized e-waste regulations across countries |
| 8 | Understanding Environmental Pollutions of Informal E-Waste Clustering in Guiyu, China, 2020 [37] | Case study | • Informal recycling leads to severe pollution<br>• Examines pollution from informal e-waste recycling<br>• Unregulated processing, lack of waste management infrastructure increase e-waste risk impact<br>• Regulatory frameworks, stricter environmental policies reduce e-waste risk impact | **Conclusion:** Regulations are needed to control informal recycling<br><br>**Recommendation:** Strengthen environmental laws and alternative job opportunities |
| 9 | Global E-waste management: Can WEEE make a difference? 2021 [38] | Policy review and trend analysis | • Effective WEEE management requires coordinated efforts<br>• Analyzes global trends and regulatory frameworks for WEEE<br>• Fragmented policies, lack of enforcement increase e-waste risk impact<br>• Harmonized global policies, stricter regulations reduce e-waste risk impact | **Conclusion:** Strengthening WEEE policies is critical<br><br>**Recommendation:** Establish a global standard for e-waste regulations |
| 10 | Occurrence and ecotoxicological impacts of PBDEs in e-waste in Africa, 2024 [39] | Environmental impact assessment | • PBDE contamination poses serious environmental risks<br>• Focus on PBDE contamination from e-waste<br>• High PBDE levels due to improper disposal increase e-waste risk impact<br>• Eco-friendly disposal methods reduce e-waste risk impact | **Conclusion:** Need for sustainable disposal strategies<br><br>**Recommendation:** Implement eco-friendly e-waste disposal technologies |
| 11 | Informal E-waste recycling practices and environmental pollution in Africa, 2023 [40] | Field study and environmental sampling | • Informal practices cause severe environmental degradation<br>• Examines pollution from informal e-waste recycling in Africa<br>• Lack of formal disposal systems increase e-waste risk impact<br>• Formal recycling systems, enforcement of regulations reduce e-waste risk impact | **Conclusion:** Formalization of e-waste recycling is needed<br><br>**Recommendation:** Develop structured and legally enforced recycling systems |
| 12 | Modeling the e-waste mitigation strategies using grey-theory and DEMATEL framework, 2021 [41] | Quantitative modeling | • Identifies key mitigation strategies for e-waste management<br>• Analyzes risk factors and mitigation strategies<br>• Complex e-waste streams, economic barriers increase e-waste risk impact<br>• Strategic planning, investment in research reduce e-waste risk impact | **Conclusion:** Strategic frameworks improve decision-making<br><br>**Recommendation:** Apply data-driven decision-making for e-waste policies |
| 13 | An overview of electronic waste laws in developing countries, 2024 [42] | Legal review and case study | • Many developing countries lack effective e-waste laws<br>• Evaluates e-waste legislation in various developing countries<br>• Weak enforcement, inadequate legal frameworks increase e-waste risk impact<br>• Strengthening of regulatory mechanisms reduce e-waste risk impact | **Conclusion:** Stronger legal frameworks are necessary<br><br>**Recommendation:** Develop and enforce comprehensive e-waste laws |
| 14 | Policy issues for efficient management of E-waste in developing countries, 2020 [43] | Policy review and analysis | • Developing countries struggle with inefficient policies<br>• Examines policy gaps and challenges in e-waste management<br>• Lack of financial and technical resources increase e-waste risk impact<br>• International support, funding for waste management reduce e-waste risk impact | **Conclusion:** Financial and technical support can improve outcomes<br><br>**Recommendation:** Foster international cooperation for e-waste management |

# DISCUSSION

**Impact of e-waste on urban public health**

E-waste poses significant health risks to urban populations due to exposure to hazardous materials, including heavy metals and polycyclic aromatic hydrocarbons (PAHs). Studies have shown elevated levels of contaminants in indoor dust at e-waste recycling sites compared to rural and urban areas, which can lead to potential chronic health issues, including respiratory and neurological disorders [15]. Additionally, air quality assessments in Ghana highlight increased levels of particulate matter due to e-waste burning, which contributes to respiratory and cardiovascular diseases among workers and nearby residents [16]. Biomonitoring studies indicate that workers at e-waste dismantling sites have higher concentrations of PAHs and their metabolites in hair and fingernail samples, suggesting occupational exposure and increased cancer risks [17,18]. A 2024 study in Bangladesh also linked increased levels of lead, cadmium, and mercury in blood and hair samples to direct environmental and occupational factors related to e-waste processing [27].

Numerous studies have reported elevated concentrations of toxic elements in individuals working at or living near e-waste sites. In a 2024 study of e-waste workers in Bangladesh, 92.5% of participants had blood lead levels exceeding the U.S. CDC's safety threshold of 5 μg/dL, with 38% surpassing 10 μg/dL—levels associated with cognitive and neurological impairment [27,46]. Additionally, 71% of these workers had cadmium levels exceeding WHO-recommended occupational exposure limits, contributing to renal dysfunction and bone demineralization risks. Hair mercury levels were also significantly elevated: e-waste workers averaged 4.6 μg/g—nearly five times higher than the general urban population (0.9 μg/g), exceeding the U.S. EPA reference level of 1 μg/g for non-fish-consuming populations [27,46].

PAH exposure is a major concern in informal e-waste recycling, particularly due to the open burning of plastics and insulation. A study conducted at an e-waste site in South China found that 80% of dismantlers had detectable levels of hydroxylated polycyclic aromatic hydrocarbon (PAH) metabolites (OH-PAHs) in their hair and nails, with concentrations several times higher than those in control groups [17,18]. The estimated lifetime cancer risk (LCR) from PAH exposure among these workers was calculated at $>1\times10^{-4}$—exceeding the U.S. EPA acceptable risk threshold ($1\times10^{-6}$), signaling significant carcinogenic potential [17,18]. Moreover, in a hair biomonitoring study, e-waste dismantlers had average ∑OH-PAH concentrations of 1,200 ng/g in hair samples compared to 310 ng/g in non-occupationally exposed individuals, showing a nearly 4-fold increase in internal PAH burden [17].

Air quality assessments at Agbogbloshie in Ghana found average $PM_{2.5}$ concentrations reaching 170 μg/m³ during burning activities—6.8 times higher than the WHO recommended 24-hour limit of 25 μg/m³ [16]. Such exposures are linked with significantly higher rates of chronic bronchitis and cardiovascular morbidity. A study conducted among 160 workers at this site found that 57% reported chronic respiratory symptoms, including persistent cough and shortness of breath. Lung function tests revealed that 34% had abnormal spirometry indicative of restrictive or obstructive pulmonary conditions [47].

In Lagos, mercury levels in surface soils around informal e-waste sites ranged from 0.41–12.5 mg/kg—exceeding the Canadian environmental quality guideline of 6.6 mg/kg [19]. Chronic exposure to such levels is linked with tremors, memory loss, and neurodevelopmental issues, particularly in children. Longitudinal assessments of children living near e-waste sites in China have shown lower scores in neurobehavioral testing and reduced attention spans compared to age-matched peers [46]. Although full-scale cohort studies are limited, initial findings suggest that long-term cognitive and endocrine disruption may result from ongoing low-dose exposure.

A 2020 study in Ghana analyzed 82 e-waste recyclers and found that 61% had iron-deficiency anemia, attributed to both poor dietary intake and the oxidative stress induced by heavy metal exposure [47]. Zinc and selenium deficiencies—critical for immune function—were also prevalent in over half of the participants, suggesting synergistic health risks from toxicant-nutrient interactions. Moreover, 42% of workers reported chronic fatigue, and 25% experienced frequent dizziness—symptoms consistent with chronic exposure to multiple neurotoxicants and micronutrient imbalances [47].

**E-waste management and public health implications**

The effectiveness of e-waste management has a direct impact on public health outcomes. Informal e-waste recycling, commonly practiced in urban areas, results in uncontrolled exposure to toxic elements. For instance, studies in Lagos, Nigeria, found high mercury concentrations in soil near informal recycling sites, posing severe neurological health risks to workers and nearby residents [19].

Similarly, in Accra, Ghana, the absence of formal infrastructure forces many to engage in unsafe scavenging practices, exacerbating exposure to toxicants [24]. Case studies demonstrate that poor infrastructure and fragmented policy enforcement persist as significant problems. Despite global awareness, e-waste continues to be handled unsafely in many parts of the Global South due to weak institutional capacity and economic dependency on informal recycling [42,49].

**Factors exacerbating and mitigating e-waste health impacts**

Several factors contribute to the severity of e-waste-related health risks in urban areas. Weak enforcement of policies, lack of financial resources, and informal recycling practices exacerbate public health threats [32,33]. In contrast, structured policy frameworks such as EPR have demonstrated potential in mitigating health risks by incentivizing producers to manage e-waste sustainably [34].

Investment in circular economy strategies, improved recycling technologies, and public awareness campaigns can significantly reduce e-waste-related health risks. For instance, centralized e-waste management hubs have been proposed as an effective solution to streamline waste collection and processing, thereby minimizing occupational exposure and environmental contamination [35]. Strengthening international cooperation and harmonizing e-waste policies can further enhance urban public health outcomes [40].

Moreover, research has shown that e-waste scavengers in Accra, Ghana, face direct exposure to hazardous materials due to the lack of formal recycling infrastructure, increasing their vulnerability to health risks [24]. The lack of effective WEEE (Waste Electrical and Electronic Equipment) management systems exacerbates environmental pollution and human health risks, highlighting the need for comprehensive policies [25].

**Unique challenges of e-waste management in developing countries**

Developing countries face a distinctive set of challenges in managing e-waste, often shaped by rapid urbanization, weak regulatory frameworks, economic dependency on informal labor, and limited technological infrastructure. These factors converge to create a cycle of inadequate disposal practices and severe public health consequences.

*1.Dominance of informal recycling and lack of regulation*

One of the most pressing challenges is the predominance of informal recycling practices. In countries such as Ghana and Nigeria, large informal sectors operate without adequate regulation, health standards, or waste management technologies. At Agbogbloshie in Accra, one of the world's most studied e-waste sites, scavengers dismantle electronic devices using rudimentary tools and open burning, exposing themselves to lead, mercury, PAHs, and other toxicants [24,47]. A study in Lagos reported alarmingly high concentrations of mercury in soil samples near informal waste sites, indicating widespread environmental contamination and potential long-term health threats [19]. Regulatory efforts are frequently undermined by institutional weaknesses. Despite the existence of policies like EPR in some countries, enforcement is often inconsistent due to bureaucratic inefficiencies, lack of monitoring systems, and limited inter-agency coordination [20,42].

*2. Economic dependency on the informal sector*

For many urban poor, informal e-waste recycling is a critical source of income. As noted in Ghana and India, the absence of formal employment opportunities forces individuals to rely on hazardous recycling work, even when they are aware of the health risks involved [47]. This economic dependency complicates the implementation of safer alternatives. Interventions that aim to shut down informal operations without offering viable economic substitutes risk exacerbating poverty and social unrest.

*3. Lack of infrastructure and safe technologies*

Developing countries often lack basic e-waste management infrastructure, including safe collection points, certified recycling facilities, and disposal systems. In India, for example, the majority of e-waste is processed without proper segregation or safety measures, and urban authorities struggle to forecast e-waste generation [26] accurately. Even in cities where e-waste collection is improving, downstream processing remains rudimentary and hazardous.

Moreover, the high cost of advanced recycling technologies and the absence of investment incentives restrict the modernization of existing facilities. Attempts to introduce centralized recycling hubs, as seen in parts of Ghana, face hurdles in integrating informal workers and sustaining financial viability [14,49].

*4. Environmental justice and health inequities*

E-waste dumping disproportionately affects marginalized communities. Urban peripheries—where informal recycling often takes place—experience higher levels of air and soil pollution. These areas frequently lack healthcare infrastructure, compounding the impact of toxic exposures. Biomonitoring studies in South Asia and West Africa have demonstrated that workers and nearby residents exhibit elevated levels of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in their biological samples, underscoring systemic environmental injustice [17,18,27].

*5. Limited public awareness and educational gaps*

A recurring issue in many developing contexts is the lack of public knowledge regarding the risks associated with e-waste. Awareness campaigns are often fragmented or nonexistent, especially in areas with high illiteracy rates or limited access to digital media. Without strong community education programs, households and small businesses frequently dispose of e-waste alongside regular garbage, contributing to uncontrolled contamination [47].

*6. Global waste trade and policy disparities*

Developing countries often bear the brunt of global e-waste flows, either through legal imports of second-hand electronics or illegal dumping disguised as donations. Policy asymmetries between high-income and low-income countries facilitate these transboundary movements, despite international agreements such as the Basel Convention [14,20]. This creates a situation where countries least equipped to manage toxic waste become primary recipients, deepening their environmental and health burdens.

**Research gaps and future directions**

Despite the comprehensive analysis of e-waste impacts on urban health, this study has several limitations. First, the available literature on e-waste health effects is limited in scope, with most studies focusing on specific geographic regions, particularly in developing countries. This geographic bias may limit the generalizability of the findings to other urban settings. Second, variations in study methodologies and data collection approaches among the reviewed studies pose challenges in drawing direct comparisons and establishing universal trends. Third, the long-term health effects of e-waste exposure remain underexplored due to the lack of longitudinal studies. Future research should prioritize longitudinal investigations and standardized methodologies to provide more definitive conclusions on the impact of e-waste on urban health.

## CONCLUSION

The study highlights the severe health risks associated with e-waste exposure in urban areas, particularly in regions with weak regulatory frameworks. Informal recycling methods, improper disposal, and inadequate pollution control contribute to increased risks of respiratory, neurological, and carcinogenic diseases. Strengthening e-waste management policies, promoting formal recycling infrastructure, and enforcing stricter regulations can mitigate these health risks. Future research should focus on developing sustainable and scalable solutions for safe e-waste management in urban environments.

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