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# Electronic wastes in sub-Saharan Africa: A critical review of environmental and health impacts, regulatory responses, and future perspectives

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ABSTRACT

Recent technological advancements coupled with lax policy regulations have caused increased electronic waste (e-waste) burden in the Sub-Saharan Africa (SSA), thereby exacerbating the environmental signatures of hazardous substances including contaminants of emerging concern (CECs), endocrine-disrupting chemicals (EDCs), persistent organic pollutants (POPs), and toxic metals such as lead (Pb), mercury (Hg), and cadmium (Cd), among others. This review synthesized 62 studies published between 2008 and 2025 to assess the environmental and health risks associated with e-waste disposal in SSA. Pb, Hg, Cd, and brominated flame retardants were the most detected hazardous substances. Near e-waste sites, Pb levels in soil ranged from 120 to 14,000 mg/kg, while Cd reached 6.8 mg/kg in topsoil. Water contamination by Hg near informal processing sites ranged from 0.3 to 2.8 μg/L, exceeding the U.S Centers for Disease Control and Prevention (CDC) safety thresholds. Air pollution from open burning releases polycyclic aromatic hydrocarbons (400–1800 ng/m$^3$), dioxins (3.5–19.2 ng/m$^3$), and volatile metals, worsening the environmental health crisis. Informal recycling practices were the primary source of these pollutants, exposing workers and nearby communities to these toxic substances. This review highlighted significantly elevated health risks, with widespread exceedance of safety thresholds (e.g., blood Pb levels up to 309 μg/dL, compared to CDC reference: 5 μg/dL; Cd up to 8.5 μg/L), leading to cognitive deficits, neurological damage, cancer, and respiratory and reproductive disorders, particularly for the vulnerable populations. Observed trends, gaps in recycling infrastructure and policy underscore the urgent need for improved legislation, formal recycling systems, and public awareness to mitigate health risks in the SSA.

## 1. Introduction

Electronic waste (e-waste), which includes used electrical and electronic devices such as mobile phones, computers, televisions, and household appliances, is one of the fastest-growing waste streams globally (Asante et al., 2019). In 2019, approximately 53.6 million metric tonnes of e-waste were generated worldwide, a figure projected to rise due to rapid technological advancements, increased consumer demand, and shorter product lifespans (Baldé et al., 2024). Africa generated about 2.9 million metric tonnes of e-waste in 2019, with a per capita generation rate of 2.5 kg, significantly lower than Europe's 16.2 kg per capita or the America's 13.3 kg per capita (Forti et al., 2020). However, this lower per capita generation rate masks the severe challenges related to e-waste imports, informal recycling, and inadequate

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waste management infrastructure across the continent (Awere et al., 2020). While developed countries maintain relatively robust waste management systems and enforce bans or restrictions on the export of hazardous e-waste, weak institutional capacity and fragmented enforcement structures in many African countries have made it difficult to intercept non-functional imports, which often enter as "usable" electronics (McMahon et al., 2021). These systemic gaps, alongside infrastructural and policy limitations, have been documented across the continent (Lawhon, 2013; Maphosa and Maphosa, 2020). These operational challenges in implementing transboundary waste controls could exacerbate e-waste pollution.

Among the regions in Africa, Sub-Saharan Africa (SSA), marked by limited infrastructural development and heightened ecological vulnerability, has emerged as a key destination for e-waste disposal (Fatema et al., 2025; Skrdlik, 2023). This trend is driven by the demand for affordable electronics and a steady influx of second-hand imports from developed nations (Lambrechts and Hector, 2016; Schluep et al., 2012). A substantial proportion of these imports comprise of obsolete or non-repairable devices that often enter informal recycling streams (Baldé et al., 2024). Moreover, with an extensive network of water bodies supporting diverse ecosystems, SSA still faces significant vulnerability due to the increasing e-waste importation and/or mis-management. Informal recycling practices including open burning, manual dismantling, and acid leaching to recover valuable metals such as gold, copper, and aluminium release hazardous substances like lead, cadmium, mercury, and brominated flame retardants (BFRs) into the environment, posing severe risks to both human health and ecological systems (Daum et al., 2017; Ongondo et al., 2011). Studies from Ghana, Nigeria, and South Africa have reported elevated levels of heavy metals such as Pb (up to 100 mg/kg), Cd (4.2 mg/kg), and Hg (1.3 mg/kg) in soils near informal e-waste recycling sites (Asante et al., 2019; Akortia et al., 2017). These contaminants usually leach into surface and groundwater, thereby affecting food security and community water access.

These findings underscore the need to comprehensively assess e-waste impacts and inform evidence-based interventions since the environmental and health consequences of e-waste mis-management are severe. Scientific studies have linked chronic exposure to these toxins to a wide range of adverse health effects. For example, Cd levels in human blood ranging from 1.2 to 6.4 μg/dL have been linked to kidney damage, while elevated Pb levels have been associated with cognitive decline, neurological disorders, and reduced IQ in exposed children (Sindiku et al., 2015; Srigboh et al., 2016). Hg bioaccumulation in fish poses neurodevelopmental risks to the communities reliant on fish-based diets (Asante et al., 2016; Tokumaru et al., 2017). Other pollutants such as polybrominated diphenyl ethers (PBDEs) and polychlorinated dibenzo p-dioxins and/or furans (PCDD/Fs) measured in the environmental and biological matrices contribute to endocrine disruption, respiratory illnesses, and increased cancer risks in humans (Amankwaa et al., 2017; Tue et al., 2019).

This review, therefore, examined the environmental and human health impacts associated with e-waste disposal in the SSA. The review also consolidated quantitative data on the contaminant levels in the various matrices by synthesizing national and international regulatory responses. It highlights institutional and policy gaps that shape current waste flows, and community-level exposure risks. In doing so, this review provided a consolidated platform for informing sustainable waste management strategies, and guiding future research and policymaking on e-waste in SSA.

## 2. Materials and methods

This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure rigor in data collection, screening, and synthesis (Page et al., 2021). A comprehensive literature search was conducted across six major scholarly databases: Wiley Online Library, Scopus, ScienceDirect®, PubMed, and Web of Science. To ensure a thorough examination of all available data and to capture potentially underreported findings, the review also included reports and documents from Google Scholar, and from reputable organizations and ministry websites, such as United Nations and national environmental agencies, recognizing that such sources often complement academic publications with field-based or policy-relevant data.

Keywords and Boolean combinations included "e-waste AND Sub-Saharan Africa," "e-waste AND environmental impacts," "e-waste AND health risks," "informal e-waste recycling AND Africa," and "toxic pollutants AND e-waste." Additional terms like "WEEE" and "heavy metals AND e-waste" were used to address hazardous components of e-waste. Broader terms such as "developing countries AND e-waste management" or "informal waste recycling AND health impacts" supplemented the search. Country-specific searches used terms like "e-waste impacts AND Ghana," or "informal recycling AND Nigeria," or "heavy metals AND South Africa." The review included studies published in English between 2008 and 2025—a period marked by rapid population growth, increased importation of second-hand electronics, and rising consumption of digital and computing technologies across the SSA (Baldé et al., 2024; Fatema et al., 2025; Maphosa and Maphosa, 2020).

Fig. 1 shows the screening and selection process, including exclusions at each stage. From a total of 310 articles that were identified through the database search, 62 unique studies were retained for full analysis. Inclusion criteria included a focus on e-waste and its regulation, or impacts, or assessment in the SSA. Studies that had methodological limitations including those with undefined sampling strategies, absence of empirical data, or lack of analytical procedures were also excluded (**Table S1** in Supplementary Material).

### 2.1. Overview of research studies on e-waste in sub-Saharan Africa

Of the 62 studies identified in this review, 28 were experimental, 21 were case studies while 13 were research reports (**Table S1,** Supplementary Material). Experimental studies primarily concentrated on laboratory analyses of hazardous e-waste components and/or their environmental and health implications. Case studies employed qualitative and quantitative methods such as field observations and interviews, to investigate occupational health risks and social behaviours associated with informal e-waste collection and recycling, while developing intervention strategies, often in collaboration with organizations like the Blacksmith Institute. Given the complex and informal nature of many e-waste sites in Africa, where data collection and regulation are often limited, selected studies by Machete (2017), and Lambrechts and Hector (2016) underscored the value of incorporating contextual and sociological perspectives into scientific assessments. In this regard, this current review included experimental studies, case studies, and integrated research reports.

The reviewed literature encompassed studies conducted in 13 countries across the SSA, with predominant contributions from Ghana (29 studies, 54 %), Nigeria (11 studies, 17 %), and South Africa (4 studies, 7 %) as visualized in **Figure S1.** Seven studies addressed multiple SSA countries (Amera and Edwards, 2013; Baldé et al., 2017, 2024; Forti et al., 2020; ITU, 2023; Perkins et al., 2014; Traverso et al., 2024). Ghana's prominence could be largely attributed to Agbogbloshie, recognized as Africa's most hazardous e-waste hotspot and among the world's largest dumping sites (Itai et al., 2014; Kaifie et al., 2020; Lebbie et al., 2021; Srigboh et al., 2016; Tetteh and Lengel, 2017; Tokumaru et al., 2017; Traverso et al., 2024; Tue et al., 2016, 2019; Wittsiepe et al., 2015).

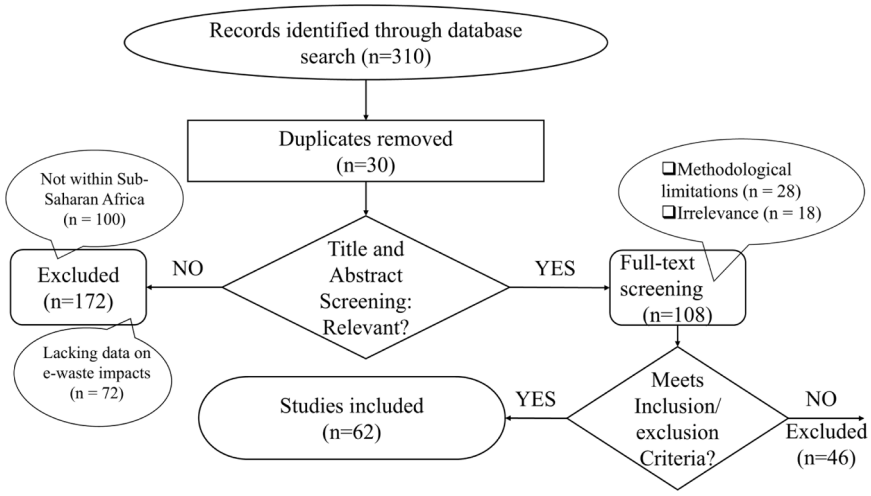



**Fig. 1.** PRISMA flow diagram illustrating the systematic article selection process.

## 3. Results: E-waste in sub-Saharan Africa

### 3.1. E-waste generation and management in sub-Saharan Africa

#### 3.1.1. E-waste generation

In 2019, approximately 546,000,000 kg of e-waste were imported into the SSA, with about (~) 19,000,000 kg under controlled conditions, and the remaining ~527,000,000 kg arriving as uncontrolled shipments. Countries such as Ghana, Nigeria, and South Africa act as the primary entry points, largely due to their established ports and informal recycling industries. Ghana's Agbogbloshie, one of the world's largest e-waste dumping sites processes ~215,000 tonnes of e-waste annually, much of which is imported (Adanu et al., 2020). Despite contributing minimally to the global e-waste generation, as illustrated in **Fig. S2**, SSA disproportionately bears the burden of imported e-waste. Out of Africa's estimated population of 1.55 billion in 2025, ~1.2 billion people reside in the SSA, a region that continues to experience the most significant challenges in e-waste management (World Population Review, 2025). Table 1 presents the current general e-waste statistics of the 11 SSA countries that have implemented national policies on the e-waste management. Nigeria generates ~500,000 tonnes of the e-waste annually, followed by South Africa at ~530,000 tonnes (Baldé et al., 2024). Other contributors included Angola (~150,000,000 kg), Ethiopia (~88,000,000 kg), and DRC (~56,000,000 kg) (Table 1), highlighting the scale of e-waste challenges across the region. South Africa, with a per capita e-waste generation rate of ~9 kg, ranks among the highest in the SSA, while Libya and Seychelles lead the continent at ~14 kg per capita (Baldé et al., 2024; Luyeye, 2023).

Severe challenges of e-waste mismanagement have been reported. For instance, in 2019, e-waste generated in Africa was linked to the release of ~12.4 billion (in kg) of $CO_2$ equivalents, ~6000 kg of Hg emissions, and unmanaged disposal of ~3000,000 kg of plastics containing BFRs (Awere et al., 2020). E-waste generation in SSA originates from two dominant pathways: domestic consumption and imports from high-income countries (Fig. 2). Domestic sources are primarily driven by the rapid uptake of mobile phones, computers, and small IT equipment, especially in South Africa, Kenya, and Nigeria, which have been linked to the economic growth and increasing access to digital infrastructure (Kyere et al., 2017; Lebbie et al., 2021). Significant volumes of e-waste estimated at over 5000 tonnes annually from illegal shipments alone arrive in the SSA through second-hand electronics imports, often labelled as donations or affordable technology to bridge the digital divide. This trend, which was documented in a study by Skrdlik (2023), underscores the ongoing challenge of regulating transboundary e-waste flows disguised as reuse (Moletsane and Venter, 2018). However, a large proportion of these imports, often >70 % are obsolete, non-functional, or irreparable upon arrival, transforming into waste immediately after entry (Amoabeng Nti et al., 2020; Manhart et al., 2013).

**Table 1**
E-waste statistics for Sub-Saharan African countries with national e-waste policies.

| Country | E-waste generation per capita[1] (kg/person) | Total e-waste generation (tonnes/year)[1] | Highest e-waste generation (million kg)[2] | Formally collected & recycled (tonnes/year) |
|---|---|---|---|---|
| Cameroon | NA | ~33,000 | 33 | NA |
| Côte d'Ivoire | ~0.3 | ~42,000 | 42 | NA |
| Ghana | 0.4–0.8 | ~215,000 | NA | <5000 |
| Kenya | ~0.45 | ~51,300 | 88 | <5000 |
| Madagascar | NA | NA | NA | NA |
| Nigeria | ~2.0 | ~500,000 | 500 | <10,000 |
| Rwanda | ~0.2–0.3 | ~10,000 | NA | ~1000[3] |
| South Africa | ~5.7–11 | ~415,000 | 530 | ~25,000 |
| Tanzania | ~0.4 | NA | 61 | NA |
| Uganda | ~0.18 | ~22,000 | NA | NA |
| Zambia | ~0.4 | ~10,000 | NA | NA |

Sources Baldé et al. (2024)[1]; Lebbie et al. (2021)[2]; Enviroserve Rwanda Green Park (2025)[3]; NA=data not available.

#### 3.1.2. E-waste management: informal sector involvement

In the SSA, the recycling and disposal of e-waste are primarily managed by the informal sector. Agbogbloshie, for instance, processes ~215,000 tonnes of e-waste annually, and employs thousands of informal recyclers, including the vulnerable groups such as children and women (Abubakar et al., 2022; Yu et al., 2017). The recycling is characterized by unregulated practices and a lack of protective measures. Workers, including children, employ rudimentary/crude techniques such as open burning, acid baths, and manual dismantling to recover valuable materials (Adanu et al., 2020; Peluola, 2016). These methods are not only inefficient (i.e., recovering minimal fractions of valuable metals), but also release hazardous pollutants like heavy metals (e.g., Pb, Cd, Hg), and POPs into the environment (Ouabo et al., 2019; Amoabeng Nti et al., 2020). Consequently, these practices pose severe environmental risks and expose workers to significant health hazards (Kyere et al., 2017; Awere et al., 2020). Informal recyclers, driven by economic necessity, often resist formalization efforts due to fears of income loss and high compliance costs. However, integrating informal workers into formalized systems has shown promise in improving safety, efficiency, and environmental outcomes (Baldé et al., 2024). For

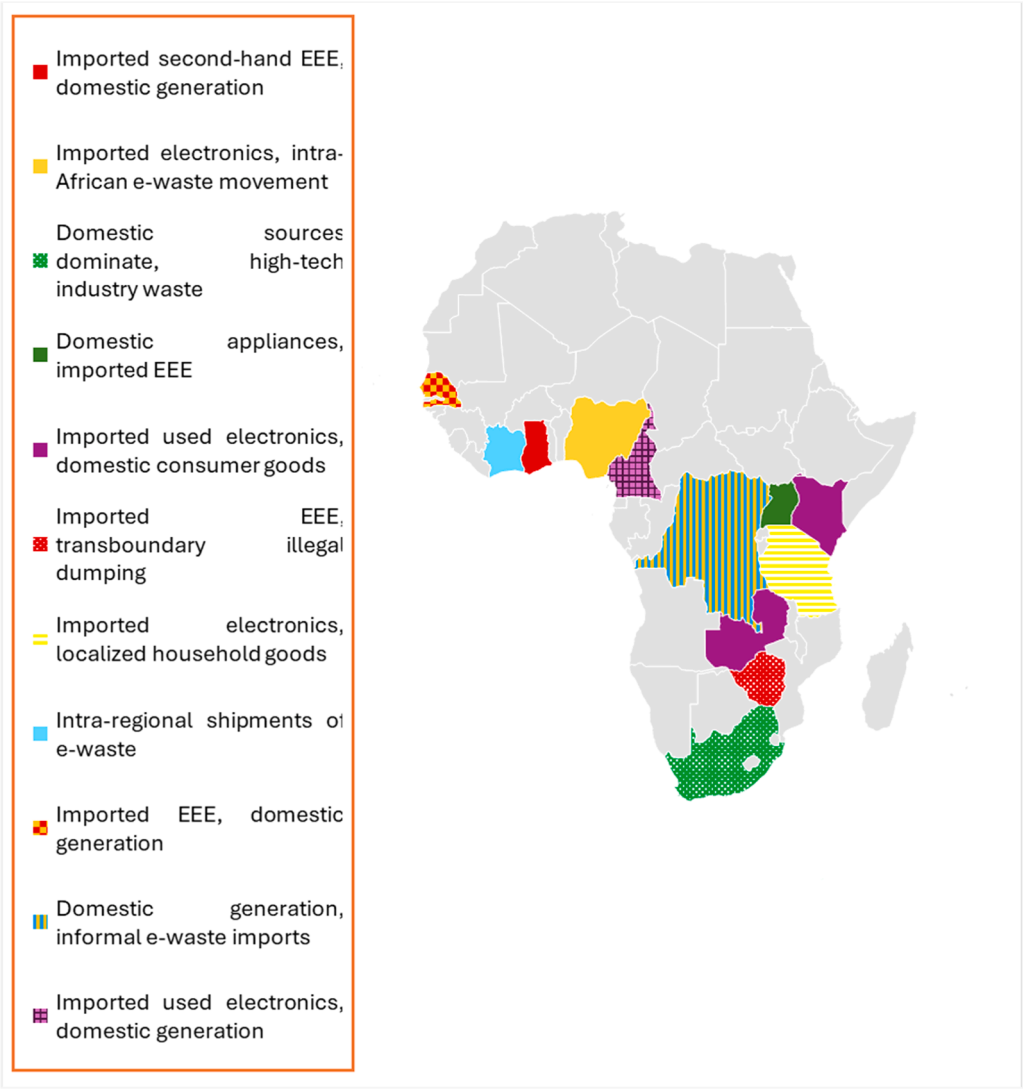



**Fig. 2.** Major sources of e-waste across the Sub-Sahara Africa.

**Table 2**
E-waste contamination and associated environmental risks in Sub-Saharan Africa.

| Contaminants | Matrix | Levels (Min – Max) | Environmental risks | Potential sources of pollutants | Study |
|---|---|---|---|---|---|
| Lead, cadmium, mercury, arsenic | Soil, water | Lead: 260–8100 mg/kg; Mercury: 0.5–1.2 μg/L | Heavy metal accumulation in soil and water; toxicity to aquatic ecosystems; reduced soil productivity. | E-waste dumping and runoff | Srigboh et al. (2016) |
| PAHs, PCDD/Fs, lead, cadmium | Air, soil | Lead: 120–14,000 mg/kg; PAHs: 500–1200 ng/m$^3$ | Atmospheric pollution; soil contamination; bioaccumulation in terrestrial food chains. | Open burning and dumping | Amoabeng Nti et al. (2020) |
| PCDD/Fs, PCBs | Soil, water, air | PCDD/Fs: 2.1–42.7 pg/g (lipid base); PCBs: 0.011–0.62 μg/L | Persistent organic pollutants in air, water, and soil; disruption of aquatic and terrestrial ecosystems; long-term toxicity risks. | E-waste dismantling and combustion | Wittsiepe et al. (2015) |
| Lead, cadmium, mercury, chromium | Soil, water | Lead: 530–6700 mg/kg; Cadmium: 0.8–6.8 mg/kg | Soil and water contamination; bioaccumulation in fish and crops; reduced agricultural productivity. | Leachate runoff and informal recycling | Tue et al. (2016) |
| PAHs, PCDD/Fs | Air, soil | PAHs: 400–1100 ng/m$^3$; PCDD/Fs: 3.5–19.2 ng/m$^3$ | Airborne pollutants causing atmospheric degradation; contamination of nearby soils. | Open burning of plastics and cables | Feldt et al. (2014) |
| Mercury, PBDEs | Water, aquatic biota | Mercury: 0.3–2.8 μg/L; PBDEs: 0.15–2.5 mg/kg (fish) | Mercury bioaccumulation in fish; toxic effects on aquatic ecosystems; long-term contamination of water sources. | E-waste runoff into rivers | Asante et al. (2012) |
| Lead, cadmium, PAHs | Air, soil | PAHs: 1000–1800 ng/m$^3$; Lead: 600–8500 mg/kg | Airborne PAHs causing respiratory risks; lead accumulation in agricultural soils reducing crop viability. | Burning and dismantling of e-waste | Kyere et al. (2017) |
| Lead, cadmium, arsenic | Water, soil | Cadmium: 0.7–5.3 mg/kg (soil); Lead: 3.4–6100 mg/kg | Contamination of water bodies and agricultural soils; health risks through water and food chain exposure. | Leachate from informal recycling zones | Awere et al. (2020) |

example, in Ghana, pilot programs have fostered partnerships with informal recyclers, providing training, access to safer equipment, and incentives to participate in regulated processes (Lebbie et al., 2021). These initiatives demonstrate the potential for scalable solutions that balance economic livelihoods with environmental sustainability.

### 3.2. Environmental impacts of e-waste in sub-Saharan Africa

Out of 28 experimental studies reviewed, 19 focused on the environmental levels of pollutants associated with e-waste recycling and disposal. The studies generally examined contamination across soil, water, and air matrices (Ackah, 2019; Amoabeng Nti et al., 2020; Asante et al., 2012; Itai et al., 2014; Srigboh et al., 2016; Tokumaru et al., 2017; Tue et al., 2016) (**Table S2**, Supplementary Material). Hazardous substances frequently identified included heavy metals (Pb, Cd, Hg, Cr, As), and POPs; polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), PCDD/Fs, and BFRs like PBDEs and phthalates (Tables 2 and **S2**).

#### 3.2.1. Soil contamination

Thirteen of the reviewed studies focused on soil contamination linked to the e-waste activities (Kyere et al., 2017; Asante et al., 2012; Cao et al., 2020; Fujimori et al., 2016; Ouabo et al., 2019; Tue et al., 2019) (see Tables 2 and **S2**). Studies from West Africa (Isimekhai et al., 2017; Moeckel et al., 2020) more broadly underlined the spatial variability and ecological risks from soil-borne toxicants. For instance, Pb (120–14,000 mg/kg), Cd (0.7–6.8 mg/kg), and As (up to 30 mg/kg) have been reported in soils near the informal e-waste hubs, notably Agbogbloshie (Amoabeng Nti et al., 2020; Tue et al., 2016; Awere et al., 2020; Ackah, 2019). PAHs (500–1800 ng/$m^3$) and PCDD/Fs (3.5–19.2 ng/$m^3$) were also detected in adjacent soils from open burning activities (Feldt et al., 2014; Kyere et al., 2017). Complementary data revealed PBDEs up to 320 ng/g in soils and dust (Akortia et al., 2017), and spatially heterogeneous metal distribution linked to proximity to combustion zones (Itai et al., 2014). A significant fraction of Cd was found in bioavailable forms (Tokumaru et al., 2017), which highlighted the risks of trophic transfer and ecological harm. Occurrence of dioxins and PCBs (Wittsiepe et al., 2015) further confirmed persistent contamination from dismantling and combustion residues. Overall, heavy metals and POPs accumulate in e-waste-affected soils, posing long-term risks to both ecosystems and human health.

#### 3.2.2. Water pollution

E-waste activities contribute to water pollution primarily via leachate runoff into nearby surface and groundwater systems. Informal recycling zones in Ghana and Nigeria have reported elevated levels of Hg (0.3–2.8 μg/L in water), Cd (0.8–5.3 mg/kg in sediment), and Pb (3.4–6100 mg/kg in soil), with values surpassing WHO drinking water standards (Asante et al., 2012; Isimekhai et al., 2017; Awere et al., 2020). Bioaccumulation in aquatic species has also been documented, with PBDEs in fish tissues ranging from 0.15 to 2.5 mg/kg, posing dietary exposure risks to local populations (Asante et al., 2012). PCBs (0.011–0.62 μg/L) have been detected in surface waters near dismantling sites, contributing to long-term contamination and endocrine-disrupting effects (Wittsiepe et al., 2015). Inadequate containment and infrastructural deficiencies facilitate toxicant infiltration into aquifers and surface water sources (Olafisoye et al., 2013; Nwagwu and Okuneye, 2016). These findings underscore the transboundary and persistent nature of e-waste contaminants in aquatic systems.

#### 3.2.3. Air pollution

Airborne emissions from e-waste recycling primarily result from open burning and thermal dismantling of cables and plastics to extract metals like copper. Near major recycling hubs such as Agbogbloshie, atmospheric levels of PAHs (400–1800 ng/$m^3$), PCDD/Fs (3.5–19.2 ng/$m^3$), and Pb in dust (up to 14,000 mg/kg) have been reported, highlighting intense exposure zones (Feldt et al., 2014; Kyere et al., 2017; Amoabeng Nti et al., 2020). Such emissions contribute to poor air quality, with children and informal workers exhibiting increased respiratory symptoms, and toxic metal accumulation (Amoabeng Nti et al., 2020; Yu et al., 2017; Coker and Kizito, 2018). Volatile organic compounds (VOCs) including benzene, toluene, and xylene, have also been identified as significant urban pollutants from these sites (Orisakwe et al., 2019). The high mobility of these airborne contaminants means exposure extends beyond immediate recycling locations, with implications for broader urban public health.

### 3.3. Health impacts of e-waste

E-waste recycling and (mis)management in the SSA poses significant occupational and public health risks, largely due to the direct exposure to these hazardous substances released during dismantling, open burning, and chemical treatment processes. Twelve studies have reported health risks linked to e-waste related substances such as PBDEs, PCDD/Fs, PBDD/Fs, PCBs, As, Cd, and Pb (Ackah, 2019; Akortia et al., 2017; Amankwaa et al., 2017; Feldt et al., 2014; Sindiku et al., 2015; Srigboh et al., 2016; Tokumaru et al., 2017; Tue et al., 2016, 2019; Wittsiepe et al., 2015). The health impacts and interventions identified to address these health issues are presented in Table 3. In major e-waste hubs in West Africa, e-waste recycling workers and the environment are chronically exposed to toxicants. In Agbogbloshie (Ghana), blood Pb levels among e-waste recycling workers reached 15 μg/dL (range: 8.7–309 μg/dL), while soil samples from informal recycling zones have recorded Pb levels up to 460 mg/kg. Similarly, Cd levels among workers ranged from 1.2 to 8.5 μg/L in blood (Srigboh et al., 2016; Sindiku et al., 2015). These levels exceeded the CDC safety thresholds and were likely to contribute to cognitive deficits, neurodevelopmental delays, and kidney dysfunction (Sindiku et al., 2015), as well as increased risk of skeletal damage (Tue et al., 2016; Amoabeng Nti et al., 2020). Exposure to Cd posed health risks including chronic respiratory illnesses and renal damage (Srigboh et al., 2016; Tokumaru et al., 2017). The levels of Hg in ambient air at informal recycling sites in Ghana ranged from 0.012 to 0.045 μg/$m^3$, while local water sources recorded levels up to 3.8 μg/L, exceeding WHO drinking water guidelines and posing risks of neurotoxicity and cardiovascular effects (Asante et al., 2012; Feldt et al., 2014).

The health risks are compounded by exposure to organic pollutants produced during e-waste recycling. For instance, PBDEs in e-waste dust (2.5 to 320 ng/g) were reported in soil and dust samples from Agbogbloshie, Ghana (Akortia et al., 2017), and have been linked to thyroid dysfunction, developmental neurotoxicity, and potential carcinogenicity. Moreover, exposure to elevated PCBs and PBDD/Fs levels poses long-term risks of endocrine disruption, cancer, and immune suppression (Tue et al., 2019; Issah et al., 2022). Exposed workers also reported frequent respiratory conditions including chronic bronchitis and asthma, due to prolonged inhalation of particulate matter from open e-waste burning (Amoabeng Nti et al., 2020), as well as dermatological conditions including chronic wounds, and skin irritation from the handling of corrosive substances without protective equipment (Kyere et al., 2017).

#### 3.3.1. Public health concerns

The public health burden of e-waste extends beyond workers to include nearby communities, especially children and pregnant women. Toxicants from e-waste infiltrate air, water, and soil, creating chronic exposure pathways. A notable case from Alaba Market in Lagos, Nigeria, revealed emissions of dioxins, furans, chromium, and nickel from informal recycling into the surrounding ecosystems, causing soil and water contamination, thereby affecting agricultural productivity, and aquatic food safety (Zeng et al., 2016; Odeyingbo et al., 2017). In Ghana (Agbogbloshie), investigated soil samples recorded Pb levels as high as

**Table 3**
Human exposure, contaminant levels, and associated health outcomes linked to e-waste activities in Sub-Saharan Africa.

| Contaminants | Matrices | Levels (Min - Max) | Health risks | Suggested interventions | Study |
|---|---|---|---|---|---|
| PBDEs, PCBs, heavy metals (As, Cd, Pb, Hg) | Soil, dust, blood | PBDEs: 2.5–320 ng/g; Cd: 1.2–6.4 μg/dL | Elevated blood Pb and Cd linked to cognitive deficits and kidney damage | Improved site management, protective equipment for workers | Sindiku et al. (2015); Ohajinwa et al. (2019) |
| As, Cd, Pb, Ni, Hg, Mn, Zn | Blood, urine | Blood Cd: 1.2 μg/L; Pb: 6.4 μg/dL (67 % above CDC threshold) | Neurotoxicity, renal dysfunction, and arsenicosis in workers | Occupational safety measures and public awareness programs | Srigboh et al. (2016) |
| Zn, Cd, Pb, Sb, Mo | Soil, sediment, human hair | Cd: 58.9 % in exchangeable fraction; Pb in hair: 0.011–0.037 mg/kg | Chronic exposure to toxic metals causing neurological and reproductive disorders | Soil remediation and stricter e-waste policies | Tokumaru et al. (2017) |
| PCDD/Fs, PBDD/Fs, PXDD/Fs, DL-PCBs | Soil | PBDD/Fs: 83–3800 ng/g; TEQ: 7x U.S. action level | Cancer risk and endocrine disruption from dioxin exposure | Controlled burning and alternative recycling methods | Tue et al. (2016) |
| PBDEs, PCDEs, PXDFs | Soil | PBDEs: 1.3–380 ng/g; TEQ: 7.9–5400 pg/g | Increased cancer risk due to elevated dioxin-like compounds | Emission control measures and worker health monitoring | Tue et al. (2019) |
| PCDD/Fs, PCBs | Blood | PCDD/Fs: 6.18 pg/g lipid (exposed group); PCBs: 0.011–0.019 μg/L | Higher dioxin exposure linked to immune suppression and hormonal disruption | Health monitoring for exposed populations and better waste handling practices | Wittsiepe et al. (2015) |
| PBDEs, PCBs, heavy metals | Air, dust, soil, blood | PBDEs: 3.7–130 ng/g; PCBs: 2.6–35.2 ng/g | Respiratory illnesses and long-term carcinogenic risks | Air quality control and protective measures for workers | Akortia et al. (2017) |
| Pb, Cd, Hg | Soil, blood | Pb in soil: 10–460 mg/kg; blood Pb: 15 μg/dL | Neurological impairments in children exposed to Pb | Site cleanup and relocation of vulnerable populations | Ackah, A. (2019) |
| Heavy metals (As, Cd, Pb) | Blood, soil, hair | Hair Pb: 0.015–0.045 mg/kg; soil As: 4.5–20.8 mg/kg | Developmental delays and cancer risks | Educational programs and stricter enforcement of e-waste laws | Amankwaa et al. (2017) |
| PAHs, heavy metals | Air, blood | PAHs: 0.5–12.4 μg/m$^3$; blood Pb: 7.5 μg/dL | Respiratory illnesses and oxidative stress | Air quality improvement measures and worker health programs | Burns et al. (2019); Feldt et al. (2014). |

See **Table S3** for list of abbreviations and full names.

14,000 mg/kg, and was associated with developmental delays, behavioural disorders, and neurotoxicity in the exposed children, usually through direct contact with the contaminated soil during play, hand-to-mouth activity, and by inhalation or ingestion of Pb-laden dust (Ackah, 2019; Ahirwar and Tripathi, 2021). Hg, which is often released during informal treatment of e-waste components bioaccumulates in aquatic ecosystems, thereby contaminating fish that serve as a primary food source for local communities. Consumption of Hg-laden fish is associated with neurological impairments, motor skill dysfunction, and cognitive deficits, particularly in children and pregnant women (Asante et al., 2012; Feldt et al., 2014).

Airborne pollutants such as PAHs, dioxins, and furans released during open burning contribute to the respiratory complications, oxidative stress, cardiovascular disease, and cancer in local populations (Fasinu and Orisakwe, 2013; Kyere et al., 2017). Children living near e-waste sites often exhibit elevated blood Pb levels and other biomarkers of toxic exposure, far exceeding the internationally accepted thresholds (Srigboh et al., 2016). Empirical case studies from Ghana, Nigeria, and Kenya where e-waste recycling is prevalent further illustrate the severity of these exposures. In Ghana's Agbogbloshie, over 67 % of the individuals tested had blood Pb levels exceeding the CDC and National Institute for Occupational Safety and Health (NIOSH) reference threshold of 5 μg/dL. The levels of Cd ranged between 1.2–8.5 μg/L, correlating with respiratory and renal symptoms (Srigboh et al., 2016; Wittsiepe et al., 2015). Individuals involved in dismantling and burning activities consistently showed highest biomarker levels (Tue et al., 2016; Amoabeng Nti et al., 2020). In Nigeria, workers faced musculoskeletal injuries from repetitive and unergonomic work, alongside exposure to heavy metals (Ouabo et al., 2019). In Kenya, Hg and Cd contamination in water sources near recycling zones has been linked to liver and kidney dysfunction in local communities (Feldt et al., 2014). Hair samples from e-waste workers in multiple countries revealed high concentrations of PBDEs, reinforcing concerns about chronic endocrine disruption (Asante et al., 2012; Tue et al., 2019).

In general, these studies underscore the urgent need for interventions aimed at reducing health risks associated with informal e-waste recycling in SSA. Regulatory reforms to establish safer recycling protocols, public health education to raise awareness of e-waste hazards, and investments in environmentally sound recycling infrastructure are essential in mitigating long-term health impacts, and fostering sustainable e-waste management practices (ITU, 2023; Magoum, 2022; Umesi and Onyia, 2008).

## 4. Regulatory and institutional responses to e-waste pollution

### *4.1. Existing regulations on e-waste management and/or recycling in sub-Saharan Africa*

Our literature review showed that 12 reports existed on national and international laws governing e-waste management in the SSA (Amera and Edwards, 2013; Baldé et al., 2017, 2024; Forti, Baldé, Kuehr, and Bel, 2020; ITU, 2023; Nasasira, 2016; National Bureau of Statistics and United Nations University, 2019; Odeyingbo et al., 2017; Perkins et al., 2014; Prakash et al., 2010; Skrdlik, 2023; Tetteh and Lengel, 2017; Wasswa and Schluep, 2008; Table 4), which encompass regional, national, and global perspectives. These reports highlighted the various regulatory efforts, enforcement challenges, and recycling initiatives across the region. National and international frameworks for e-waste management exist across the SSA, but there is still weak implementation. Of the 13 countries highlighted in recent studies, only eight (Cameroon, Ghana, Kenya, Nigeria, South Africa, Tanzania, Uganda, and Zambia) have enacted dedicated e-waste legislation, but they also still lack explicit recycling-rate targets. Extended Producer Responsibility (EPR) provisions appear on paper in Ghana and Nigeria, yet limited oversight keeps enforcement weak (Baldé et al., 2017; Baldé et al., 2024; Perkins et al., 2014).

At the multilateral level, nearly all States are parties to the Basel, Rotterdam, and Stockholm Conventions, while the Bamako Convention bans hazardous-waste imports outright. However, funding gaps, technical shortfalls, governance problems–corruption, poor accountability, and a dominant informal sector undermine the impact of these agreements (Babayemi et al., 2015; Prakash et al., 2010; Skrdlik, 2023). Ghana's Hazardous and Electronic Waste Control Act and Nigeria's sector-specific regulations, for example have not stemmed illegal imports or informal processing (Odeyingbo et al., 2017; Nasasira, 2016). Regional initiatives offer promising, but nascent solutions. The African Circular Economy Alliance, East Africa Communications Organization, Ghana's bilateral programme with Germany on safe recycling, and

**Table 4**
Selected e-waste management reports across the Sub-Saharan Africa.

| Report title | Authors (Year) | Region covered | Key results/outcomes |
|---|---|---|---|
| E-Waste in sub-Saharan Africa: Challenges and Opportunities | Amera and Edwards (2013) | sub-Saharan Africa | Highlights rapid increase in e-waste generation, underdeveloped recycling infrastructure, and lack of regulatory frameworks to manage e-waste effectively. |
| The Global E-Waste Monitor | Baldé et al. (2017) | Global, with focus on Africa | Stresses the dominance of the informal recycling sector, the inadequacy of e-waste management policies, and the lack of awareness of environmental and health impacts in SSA. |
| The Global E-Waste Monitor: 2024 | Baldé et al. (2024) | Global, with focus on Africa | Provides updated statistics on e-waste generation, underlines insufficient formal recycling systems in SSA, and emphasizes the need for improved policies and regulatory enforcement. |
| The Global E-Waste Statistics Partnership Report | Forti et al. (2020) | Global, with focus on Africa | Emphasizes the global increase in e-waste generation, highlights the urgent need for more formal recycling systems in Africa, and calls for comprehensive e-waste management strategies. |
| E-Waste and ICT: A Situation Analysis | ITU (2023) | Global, with focus on Africa | Explores the exponential growth of ICT devices contributing to e-waste and identifies challenges in managing e-waste due to poor infrastructure and lack of enforcement in SSA. |
| E-Waste Management in Uganda | Nasasira (2016) | Uganda | Focuses on the limited capacity for e-waste management in Uganda, where informal recycling dominates, and regulatory measures are underdeveloped, leading to health and environmental risks. |
| E-Waste in Sub-Saharan Africa: Facts and Figures | National Bureau of Statistics & United Nations University. (2019) | Sub-Saharan Africa | Examines e-waste generation patterns in SSA, revealing a high dependency on the informal recycling sector and a severe lack of formal recycling systems, which exacerbates environmental and health challenges. |
| Environmental Impacts of E-Waste in West Africa | Odeyingbo et al. (2017) | West Africa | Investigates the environmental contamination caused by improper e-waste disposal, particularly the leaching of hazardous materials like lead, mercury, and cadmium into soil and water resources. |
| The Health Impacts of E-Waste Exposure in Sub-Saharan Africa | Perkins et al. (2014) | Sub-Saharan Africa | Discusses the serious health risks of e-waste exposure, especially to toxic substances such as mercury, lead, and cadmium, which affect vulnerable populations engaged in informal recycling activities. |
| E-Waste and Sustainability in India | Prakash et al. (2010) | India, with parallels to Africa | Highlights parallels between e-waste management issues in India and SSA, particularly the unregulated informal recycling sector and its environmental and health risks. |
| Europe-Africa Electronic Waste Smuggling | Skrdlik (2023) | Europe, Africa | Reports on the smuggling of e-waste from Europe to Africa, exposing Africa to hazardous substances like mercury, lead, and cadmium, and underlining the lack of enforcement and weak regulation in the affected African countries. |
| Proposing a Transdisciplinary Approach to the E-Waste Crisis in Sub-Saharan Africa | Tetteh and Lengel (2017) | Sub-Saharan Africa | Advocates for the integration of Health Impact Assessment (HIA) into e-waste management policies, stressing the importance of transdisciplinary approaches to address health, environmental, and social impacts. |
| E-Waste Recycling Practices and Challenges in East Africa | Wasswa and Schluep (20080 | East Africa | Analyses the challenges faced by East African countries in managing e-waste, focusing on the dominance of informal recycling practices, poor infrastructure, and lack of effective regulatory mechanisms. |

Rwanda's Enviroserve Green Park have demonstrated how targeted partnerships, and harmonised standards could close enforcement gaps and build the infrastructure needed for responsible e-waste management (ITU, 2023; Wasswa and Schluep, 2008).

Despite broad subscription to the Basel Convention, translation of international commitments into effective action remains uneven across the SSA. Eleven countries (Cameroon, Côte d'Ivoire, Ghana, Kenya, Madagascar, Nigeria, Rwanda, South Africa, Tanzania, Uganda, and Zambia) have adopted national e-waste statutes, yet most lack the infrastructure, financing, and public awareness needed to enforce them. Several countries in the continent including Angola, Benin, Botswana, Burkina Faso, report little or no progress toward domestic policymaking, while countries like the Democratic Republic of Congo, Equatorial Guinea, Liberia, Somalia, and South Sudan have not reported any e-

waste measures. This patchwork hampers regional cooperation and obscures performance comparisons, underscoring the need for shared bench-marks, stronger regulatory enforcement, and capacity-building via public–private partnerships if the Basel principles are to be implemented (Ilankoon et al., 2018; Lebbie et al., 2021; Mmereki et al., 2015).

E-waste regulation enforcement in the SSA is undermined by corruption, weak infrastructure, and limited institutional capacity. At Lagos's Tin Can Island, over 70 % of imported electronics were found to be non-functional, entering the country under the guise of second-hand goods (Nduneseokwu et al., 2017; Odeyingbo et al., 2017). High-profile incidents such as the Probo Koala disaster in Côte d'Ivoire (2006), where 500 tonnes of hazardous waste were illicitly dumped near Abidjan, and the toxic dumping in Koko, Nigeria (1987), highlight systemic regulatory failures (Lambrechts and Hector 2016; Abdelbasir et al., 2018). In Somalia, post-tsunami assessments revealed hazardous waste buried along the coastline, linked to cancer and birth defects (Adeniran et al., 2022; Nour and Olusegun, 2024). These cases demonstrate persistent non-compliance with international conventions like Basel and Bamako (Skrdlik, 2023). Moreover, while countries like Nigeria and Ghana have introduced regulations incorporating EPR such as Nigeria's 2022 EEE regulations and Ghana's Act 917 (2016), enforcement remains weak, with data limitations hindering oversight (Maphosa and Maphosa, 2020). Informal recycling remains dominant due to the absence of standardized recycling targets. Even recent efforts to improve compliance, such as the 2023 interception of 331 illegal e-waste containers route from Europe to West Africa, reveal the scale of enforcement challenges (Okeke et al., 2024).

### 4.2. Recycling programs and formal solutions

Despite the widespread enforcement gaps, some SSA countries have piloted effective formal recycling initiatives. In South Africa, the e-Waste Association of South Africa (eWASA) has developed a coordinated system for e-waste collection, treatment, and public education, improving compliance with the environmental standards (Bob et al., 2017; Baldé et al., 2024). Kenya's National Environment Management Authority (NEMA), in partnership with NGOs, supports the Nairobi WEEE Centre, which offers safe recycling services while generating employment (Nwagwu and Okuneye, 2016). Ghana and Nigeria have adopted scalable recycling models through projects such as Global Electronic Management (GEM) programme backed by Global Environment Facility (GEF) and United Nations Industrial Development Organization (UNIDO) (Nasasira, 2016; Baldé et al., 2024). Uganda's national e-waste guidelines detail the protocols for decontamination, dismantling, and separation of valuable materials with attention to hazardous components such as Hg and Chlorofluorocarbons (CFCs) (Nasasira, 2016). Some pilot technologies like hydrokinetic electricity solutions in Kenya, and automated dismantling lines in South Africa, show potential but remain in early stages (Bob et al., 2017).

Our review identified 21 investigative case studies and three recent experimental studies which highlighted a diverse set of technological and sociological solutions for e-waste management in the SSA (e.g., Acquah et al., 2019; Adanu et al., 2020; Awandu et al., 2025; Ledwaba and Sosibo, 2017; Magoum, 2022; Nwagwu and Okuneye, 2016; Oteng-Ababio et al., 2020; Okorhi et al., 2019; Sanana and Mwanza, 2024; Traverso et al., 2024).

Table 5

#### 4.2.1. Technological solutions

Critical technological innovations for e-waste management include efficient recycling techniques, structured collection systems, and sustainable processing methods (Table 6). Sustainable Recycling Technologies (SRTs) offer a transformative opportunity to address e-waste challenges in the SSA by minimizing environmental and health impacts. In South Africa, closed-loop material recovery systems and automated disassembly lines have been developed, significantly reducing landfill use while enhancing resource recovery (Ledwaba and Sosibo, 2017). In Kenya, low-cost hydrokinetic technologies constructed from e-waste components have achieved 99 % efficiency rate in delivering sustainable energy solutions to the off-grid communities (Awandu et al., 2025).

**Table 5**
E-waste legislation and policy regulations in the Sub-Saharan African countries.

| Region | Country | NP | EPR | CR | NP | Region | Country | NP | EPR | CR |
|---|---|---|---|---|---|---|---|---|---|---|
| Central Africa | Central African Republic | × | × | × | × | South Africa | Angola | × | × | × |
| | Cameroon | ✓ | ✓ | × | ✓ | | Botswana | × | × | × |
| | Chad | × | × | × | × | | Lesotho | × | × | × |
| | Congo B | × | × | × | × | | Madagascar | ✓ | NA | × |
| | DR-Congo | NA | × | × | NA | | Malawi | × | × | × |
| | Equatorial Guinea | NA | × | × | NA | | Mauritius | × | × | × |
| | Gabon | × | × | × | × | | Mozambique | × | × | × |
| | South Sudan | NA | × | × | NA | | Namibia | × | × | × |
| | São Tomé and Príncipe | ✓ | × | × | ✓ | | South Africa | ✓ | × | × |
| East Africa | Burundi | × | × | × | × | | Swaziland | × | × | × |
| | Comoros | × | × | × | × | | Zambia | ✓ | ✓ | × |
| | Djibouti | × | × | × | × | | Zimbabwe | × | × | × |
| | Ethiopia | × | × | × | × | West Africa | Benin | × | × | × |
| | Kenya | ✓ | × | × | ✓ | | Burkina Faso | × | × | × |
| | Rwanda | ✓ | ✓ | ✓ | ✓ | | Cabo Verde | × | × | × |
| | Seychelles | × | × | × | × | | Cote d'Ivoire | ✓ | ✓ | × |
| | Somalia | NA | × | × | NA | | Gambia | × | × | × |
| | Tanzania | ✓ | ✓ | × | ✓ | | Ghana | ✓ | ✓ | × |
| | Uganda | ✓ | NA | × | ✓ | | Guinea | × | × | × |
| | | | | | | | Guinea Bissau | × | × | × |
| | | | | | | | Liberia | NA | × | × |
| | | | | | | | Mali | × | × | × |
| | | | | | | | Niger | × | × | × |
| | | | | | | | Nigeria | ✓ | ✓ | × |
| | | | | | | | Senegal | × | × | × |
| | | | | | | | Sierra Leone | × | × | × |
| | | | | | | | Togo | × | × | × |

NP: National e-waste policy, legislation, or regulation in place, EPR: environmental policy principle of extended producer responsibility, CR: has collection targets in place. ✓: Has e-waste legislation/policy regulations, ×: Does not appear to have e-waste legislation/policy regulations, NA: Data unavailable or uncertain, all countries have no recycling targets in place. Sources: EPR, CP – Baldé et al. (2017, 2024); NP – Lebbie et al. (2021); CR – Enviroserve Rwanda Green Park (2025).

**Table 6**
E-waste management in Sub-Saharan Africa.

| Key focus | Methodology | Findings | Recommendations | Study |
|---|---|---|---|---|
| E-waste recycling in Ghana | Qualitative case study | Identified barriers to e-waste recycling in informal sectors. | Strengthen awareness, enforce regulations. | Acquah et al. (2019) |
| E-waste management policies in Africa | Policy review | Highlighted gaps in policy enforcement across SSA. | Strengthening policy frameworks and enforcement. | Adanu et al. (2020) |
| E-waste management in Ghana | Descriptive study | Noted growing e-waste issues in Accra. | Establish formal recycling systems and community education. | Agyei-Mensah and Oteng-Ababio (2012) |
| E-waste and health risks | Survey and interviews | Found high health risks among informal recyclers. | Train workers on safety protocols. | Asante et al. (2016) |
| E-waste management technologies | Technical analysis | Identified advanced recycling technologies with potential to reduce environmental pollution and human health risks. | Adopt appropriate technologies and training for workers. | Asante et al. (2019) |
| Impact of informal e-waste recycling | Case study | Highlighted social impacts on vulnerable groups. | Develop formal sector capacity and regulations. | Bergeron (2021) |
| E-waste management strategies | Literature review | Identified successful recycling models in other countries. | Transfer technology and build local capacity. | Boaten (2011) |
| E-waste and informal recycling in Nigeria | Fieldwork | Documented e-waste recycling practices and associated health risks. | Promote safe recycling practices and PPE use. | Bob et al. (2017) |
| Circular economy and e-waste | Comparative analysis | Found challenges in transitioning to a circular economy. | Strengthening public-private partnerships for circular models. | Ghosh et al. (2016) |
| Public awareness in Ghana | Survey and interviews | Found low public awareness of e-waste hazards. | Increase educational campaigns targeting informal recyclers. | Grant and Oteng-Ababio (2016) |
| Technological solutions for e-waste | Field study | Proposed sustainable technology alternatives for e-waste management. | Implement low-cost technologies suitable for local contexts. | Luyeye, 2023 |
| Informal e-waste management | Case study | Identified health and environmental risks of informal practices. | Develop alternative livelihoods and formalize the sector. | Machete (2017) |
| E-waste and socio-economic development | Policy analysis | Found that e-waste can drive economic growth if managed well. | Promote formal e-waste recycling to harness economic potential. | Magoum (2022) |
| E-waste management in Nigeria | Survey | Identified knowledge gaps among small-scale operators. | Implement training and awareness programs. | Nwagwu and Okuneye (2016) |
| E-waste management in Accra | Case study | Found informal recycling widespread in Accra. | Implement government regulations and awareness campaigns. | Oteng-Ababio et al. (2020) |
| E-waste and environmental impact | Environmental study | Noted severe environmental impacts from improper e-waste handling. | Strengthening enforcement of environmental laws. | Okorhi et al. (2019) |
| E-waste management challenges in Zambia | Quantitative study | Identified lack of investment and recycling technologies. | Develop infrastructure and public-private collaborations. | Sanana and Mwanza (2024) |
| Social impacts of e-waste in Africa | Social impact analysis | Found high social vulnerability in informal recycling sectors. | Develop social support programs and regulatory reforms. | Traverso et al. (2024) |
| E-waste management in Nigeria | Policy review | Identified gaps in Nigerian policy and enforcement. | Strengthening policy and enforcement mechanisms. | Umesi and Onyia (2008) |
| Health hazards in e-waste recycling | Qualitative study | Found poor knowledge of health risks among workers. | Increase education on health risks and protective practices. | Yu et al. (2017) |
| Hydrokinetic technology in Kenya | Experimental study | Developed low-cost, efficient technology for energy generation. | Promote local use of sustainable energy solutions. | Awandu et al. (2025) |
| Iron-based leaching for copper recovery | Experimental study | Achieved high recovery rates without toxic chemicals. | Expand the use of non-toxic recovery technologies. | Fatema et al. (2025) |
| E-waste recycling in South Africa | Case study | Analysed automated disassembly and material recovery systems | Invest in automated recycling systems and education. | Ledwaba and Sosibo (2017) |
| E-waste recycling challenges | Literature review | Identified regulatory and infrastructure challenges | Improve regulatory frameworks and infrastructure. | Ilankoon et al. (2018) |

Furthermore, innovative iron-based leaching techniques have enabled copper recovery from printed circuit boards at rates as high as 72.69 %, without reliance on toxic solvents like aqua regia (Fatema et al., 2025).

Despite these advancements, several systemic challenges remain. Stakeholder awareness of e-waste hazards remains limited, particularly among informal operators in countries like Nigeria (Nwagwu and Okuneye, 2016). The absence of standardized policies, poor enforcement of international conventions (e.g., the Basel Convention), and limited investment in infrastructure continue to hinder broader adoption of SRTs (Ilankoon et al., 2018). In order to address these limitations, a multi-pronged strategy that includes targeted awareness programmes, capacity-building initiatives and partnerships with international actors like GEF is crucial. Strengthening domestic recycling infrastructure through public-private investments can further catalyze the transition toward sustainable e-waste management.

#### *4.2.2. Social solutions*

Social solutions emphasize awareness creation, education, alternative livelihoods, behavioral changes, and capacity building around e-waste management practices. These efforts include integrated stakeholder engagement involving governments, NGOs, international development agencies, academia, and informal sector actors. In Ghana, collaboration with the German Development Bank has supported outreach programmes that educate informal recyclers and communities on environmental and health hazards associated with improper e-waste handling (Oteng-Ababio et al., 2020). NGOs like the Environmental Justice Foundation have initiated successful awareness campaigns targeting schools and urban areas, promoting safe disposal methods and economic benefits of formal recycling (Grant and Oteng-Ababio, 2016). Capacity-building is pivotal to stronger e-waste governance in the SSA. Community-led campaigns in Kenya, for example, have raised regulatory compliance and reduced reliance on informal recyclers (Nwagwu and Okuneye, 2016). Training programmes for informal recyclers in Ghana and Nigeria covering safe dismantling techniques and Personal Protective Equipment (PPE) have already demonstrated a reduction in health risks and improved environmental practices (Agyei-Mensah and Oteng-Ababio, 2012; Asante et al., 2019), while certification schemes reward compliance and drive best practice (Traverso et al., 2024). International backing has established specialist training centres such as the UNIDO-supported facilities in South Africa that supply technical

skills and jobs (Magoum, 2022). As second-hand phones and computers flood the regional markets, scaling these initiatives and replacing open burning or dumping with certified recovery systems will curb pollution and improve livelihoods. Therefore, sustained investment in training, infrastructure, and public outreach is essential for lasting impact.

In general, available literature suggests that inclusive multi-stakeholder engagement is pivotal for shifting e-waste practices in SSA. Pilot projects in Kenya, Ivory Coast, and South Africa show that sustainable recycling technologies; closed-loop processing, automated disassembly, and non-toxic leaching, succeed when integrated with social innovations such as community sensitisation, inclusive training, and formalisation of the informal sector (Awandu et al., 2025; Bergeron, 2021; Ghosh et al., 2016). Aligning these measures with the Basel and Bamako Convention obligations and embedding them in the public-private partnerships helps curb illicit trade and sectoral fragmentation. Persistent barriers – policy incoherence, limited infrastructure and finance, and weak politics will underscore the need for a coordinated, systems-based approach that integrates technological feasibility with social inclusion to deliver sustainable e-waste governance across the region.

## 5. Conclusions and future perspectives

This review synthesised literature on the management of and risks posed by e-waste in the SSA. Hazardous substances commonly found in e-waste such as heavy metals (Pb, Hg and Cd), and toxic flame retardants have been shown to contaminate soil, water, and air. Soils at Ghana's Agbogbloshie e-scrap yard contained Pb with levels up to ~10,280 mg/kg (mean: ~953 mg/kg), and Cd levels ~0.4–26.5 mg/kg (mean: ~6.6 mg/kg), far above typical rural soil (usually ≪ 100 mg/kg Pb, ≪ 0.5 mg/kg Cd) (Ackah, 2019). Hg in these soils reached a few mg/kg (up to ~4.4 mg/kg at Ghana sites), versus ~0.02–0.17 mg/kg in nearby control soils (Amponsah et al., 2023). By contrast, non–e-waste SSA soils (urban or agricultural) had only low μg-levels of Hg and Pb, well below WHO/FAO thresholds (Amponsah et al., 2023). Similarly, PBDE flame retardants were dozens or hundreds of times higher in e-waste dust/soil: Ghanaian e-scrap soils showed ΣPBDEs ~15–97 ng/g (mean: ~55 ng/g), whereas background soils have near-zero PBDEs (Abafe and Martincigh, 2015). In Nigeria, informal e-waste sites recorded ΣPBDEs up to $\sim 1.5 \times 10^5$ ng/g (Sindiku et al., 2015). These SSA e-waste levels are comparable to many global hotspots. For instance, Guiyu (China) "burning" site soils showed ΣPBDEs levels $\sim 3.9 \times 10^5$ ng/g and Pb ~449 mg/kg, nearly 2.3 times higher than the local reference areas (Wang et al., 2025), and Bangladesh e-scrap soils had Pb levels ~ 587 mg/kg (Rahman et al., 2014). Air and dust at Asian sites also carry elevated metals, with Zn and Ni reaching ~2000 mg/kg in the Bangladeshi e-waste dust (Rahman et al., 2014). Occupationally, these environmental loads translate into elevated exposures: at Agbogbloshie, ~78 % of the workers had pathologic blood-Pb levels (BLLs), and ~6 % exceeded 15 μg/dL (Srigboh et al., 2016), compared to BLL of ~9.9 μg/dL in a non-e-waste Chinese village where Guiyu children averaged 15.3 μg/dL (Zheng et al., 2008). These e-scrap areas showed heavy-metal and PBDE burdens orders of magnitude above local background and in the same range or somewhat lower than the worst Asian scrap sites. This data underscores that informal e-scrap recycling yields severe contamination of soils (and linked water/air), far above non-recycling areas and rivalling global hotspots. These pollutants contribute to long-term ecosystem damage, including soil infertility, water contamination, and the disruption of the aquatic life.

The findings of the review also underscore severe environmental and health risks stemming from improper e-waste disposal in the SSA. In terms of health risks, vulnerable populations, especially the children and informal sector workers are at heightened risk due to their exposure to these toxic e-waste components. Respiratory illnesses, skin conditions, neurological disorders, and an increased incidence of cancers are some of the major health impacts associated with exposure to these hazardous substances. For example, inhalation of smoke from open burning of e-waste has been linked to respiratory problems (Amoabeng Nti et al., 2020; Tue et al., 2016), while direct skin contact with toxic materials can cause dermatological issues and increased risk of systemic diseases (Burns et al., 2019; Alabi et al., 2012, Alabi et al., 2021; Ackah, 2019). Detailed risk information is presented in **Tables S4** and **S5**.

Despite these risks, the review found that the region faces significant challenges in managing both domestically generated and imported e-waste, which is exacerbated by weak regulatory frameworks, inadequate recycling infrastructure, and the heavy reliance on informal recycling practices. The dual challenges of domestic and imported e-waste necessitate:

- Urgent and coordinated actions at all governance levels to protect both the environment and public health in the SSA.
- A multi-pronged approach involving legislative action, international cooperation, and public engagement.
- International cooperation is crucial in addressing the illegal importation of hazardous e-waste. International agreements should foster partnerships between African countries and industrialized nations to support technology transfer, capacity building, and investment in sustainable recycling infrastructure.
- Policymakers to prioritize the creation and enforcement of tailored e-waste legislation that ensures environmentally sound disposal practices, thus mitigating the associated environmental and health risks of improper management. Enhancing port inspections and imposing stringent penalties for non-compliance can reduce the influx of non-functional and hazardous electronics into SSA.
- The formalization of recycling systems, alongside the integration of EPR. This would help shift the management burden to manufacturers, incentivizing the design of more durable, recyclable, and environmentally friendly electronics.
- Raising awareness about the environmental and health dangers of informal recycling practices. This will empower local communities to demand better waste management solutions, and cultivate collective responsibility, aiding the transition to legally compliant and sustainable systems.
- Incentivize the development of context-specific, affordable, and safe recycling technologies that align with the continent's socio-economic realities to ensure better adoption and accessibility.

Furthermore, the findings highlight that beyond heavy metals, this review underscores the presence of other hazardous constituents including phthalates, BFRs, and PCBs. Their diverse toxicological profiles form a complex mixture with significant implications for human health and the environment. Few published studies regarding these overlooked contaminants presents a major data gap that warrants urgent policy attention, and targeted regulatory interventions in future studies.

This review also found that, despite substantial evidence of e-waste risks across SSA, research on the issue remains insufficient. Current research is largely focused on Western contexts (Nigeria and Ghana), highlighting the need for other country-specific studies. Longitudinal studies are also necessary to evaluate the long-term health impacts of e-waste exposure to humans, particularly on vulnerable populations such as children and pregnant women (Zeng et al., 2016). Moreover, studies on the economic feasibility of formal recycling systems and the potential market for recycled materials would help attract investment and support sustainable practices. In-depth research into the socio-economic dynamics of informal recycling is also needed, as the sector is intricately linked with informal networks, thus complicating regulatory enforcement. Interdisciplinary approaches that combine environmental science, public health, and economics can significantly enhance our understanding of the e-waste crisis. Integrating quantitative environmental monitoring with epidemiological and economic analyses will enable the development of holistic strategies that address both the ecological contamination and socio-economic vulnerability (Baldé et al., 2017;

Zeng et al., 2016; ITU, 2023). In addition, more studies need to develop robust tracking and monitoring systems for the lifecycle of imported electronics. These research initiatives are vital in laying a foundation for sustainable and equitable e-waste management, ensuring that both environmental and health concerns are adequately addressed.

In conclusion, the e-waste crisis in the SSA presents significant environmental and health challenges that demand urgent and coordinated efforts across governments, international organizations, and local communities. While progress is being made in some countries, widespread informal recycling and inadequate regulatory frameworks continue to exacerbate the risks. Continued research and investment in safer recycling technologies will play a pivotal role in mitigating the adverse impacts of e-waste and promoting a healthier and more sustainable future for the region.

## CRediT authorship contribution statement

**Patrick Ssebugere:** Writing – original draft, Funding acquisition, Conceptualization. **Ashirafu Miiro:** Writing – review & editing, Methodology, Investigation, Formal analysis, Conceptualization. **Henry Matovu:** Writing – review & editing, Methodology. **Silver Odongo:** Writing – review & editing, Methodology. **Charles Drago Kato:** Writing – review & editing, Conceptualization. **Prudence Mary Babirye:** Writing – review & editing. **Josephine Nabuuma:** Writing – review & editing. **Mika Sillanpaä:** Writing – review & editing, Conceptualization. **Douglas Sifuna:** Writing – review & editing. **George William Nyakairu:** Writing – review & editing, Funding acquisition, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.hazadv.2025.100873.

## Data availability

No data was used for the research described in the article.

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