# E-Waste in Africa

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Waste electronic and electrical equipment (e-waste) consists of used and discarded electrical and electronic items ranging from refrigerators to cell phones and printed circuit boards.

e-waste children Africa air pollution cognitive function

## 1. Introduction

How to safely dispose of waste products coming from human activity is a global problem. Often in countries without adequate regulation, wastes are simply discarded. Most countries put wastes into landfills, but without adequate control landfills stink, leachate coming from the landfill can contaminate water and methane escaping from degradation of organic material contributes to climate change. In addition, landfills often attract vermin than can cause and spread disease. In many poor countries, people—including children—scavenge landfills for items of value, increasing risk of injury, infection and exposure to dangerous substances. Incineration is an alternative to landfills, but if incinerators are not operated with appropriate controls, they release toxic metals and dioxins that have the potential to cause significant harm to human health [1][2].

The harm to the environment is made worse when the discarded material is not readily degradable, as is the case with plastics that now contaminate land, lakes, streams and even the ocean. About eight million metric tons of plastics enter the oceans each year [3]. Hazardous wastes, defined as wastes that are ignitable, corrosive, reactive or toxic, add to the problem and are often intermixed with non-hazardous solid wastes. Hazardous wastes can cause significant harm to human health if not properly contained and disposed, including neuropsychological harm to children [4] and elevations in cancer and birth defects [5].

The term electronic and electrical waste (e-waste) refers to “electrical or electronic equipment, which is waste, including all components, subassemblies, and consumables, which are part of the equipment at the time the equipment becomes waste [6]”. E-waste includes large, discarded appliances, such as refrigerators, air conditioners and washing machines, as well as small personal items, including computers, televisions, mobile phones, and many other devices that are operated by electrical currents or batteries [7][8]. E-waste contains plastics, ceramics, metals, glass, toxic chemicals, such as organic flame retardants and polychlorinated biphenyls (PCBs), and various other potentially hazardous compounds [9][10].

In 2019, the world generated an estimated 53.6 million metric tons (Mt) of e-waste, or an average of 7.3 kg per person [11]. Furthermore, only 17.4% of this was officially documented as properly collected and recycled. Africa generated a total of 2.9 Mt of e-waste in 2019, or 2.5 kg per capita, the lowest regional rate in the world.

The value of the raw materials in global e-waste is estimated to be 57 billion USD, with iron, copper and gold contributing the most [11]. In some African countries, recycling and dismantling electronic devices has become a major source of employment and income. For example, in Ghana in 2010, an estimated 10,000 to 15,000 people were involved in refurbishing old and second-hand computers while another 20,300 to 33,600 were estimated to be working in recycling and e-waste management [12]. More recently this number has been estimated at more than 40,000 [13]. In 2010, an estimated 201,600 people across Ghana, including families and children, were dependent on e-waste recycling and management for support [12]. This number has almost certainly grown over time.

E-waste includes many substances that are dangerous to the health of humans and the environment if released in an unsound manner. E-waste recorded in 2019 contained as much as 50 tons of mercury and 71 kt of brominated flame retardants [11]. The improper dumping and recycling of e-waste in several African countries serves as a major source for the release of harmful substances. These harmful substances can pollute soil, water, air, dust, and food sources [14][15]. Numerous

studies have reported contamination of e-waste workers and local residents with toxic metals, dioxins and furans, brominated flame retardants (BFRs), PCBs, polyaromatic hydrocarbons (PAHs), per- and polyfluoroalkyl substances (PFAS), particulate matter and other air pollutants, phthalates and other chemicals in plastics, and the chemical mixtures at these sites [16][17][18][19][20][21][22]. There are other chemicals present in e-waste for which little information is available. Growing research has found associations between e-waste recycling and a range of adverse health effects, including negative birth outcomes, impaired neurological and behavioral development, impaired thyroid function, and increased risk of chronic diseases later in life [23].

While there is significant exposure risk to all individuals who are involved in informal e-waste recycling [24] children are particularly vulnerable to exposure from hazardous chemicals released during informal or unregulated e-waste recycling activities due to their developing organs and immune system, rapid growth, and developmental vulnerabilities. Child labor has been documented at informal e-waste recycling areas across the world. Children as young as five years of age have been observed engaging in e-waste activities in Ghana [12]. Children breathe more air and ingest more food and water relative to their size than adults. As a result, children have higher intakes of pollutants relative to their size than adults. In addition, children's bodies metabolize and eliminate toxic substances differently compared to adults, making them less able to break down and eliminate some hazardous substances. Children are also closer to the ground, where some toxicants may be at their highest concentration, and are more likely to put their hands, objects, and soil into their mouths, increasing their risk of ingesting contaminants [25][26][27]. Steps taken to protect children will also serve to protect adults.

## 2. What Chemicals Are Present in E-Waste?

Tsydenova and Bengtsson [28] reviewed the distribution of toxic chemicals in different items commonly found in e-waste. Their research indicated that common electronic items and their components, such as batteries, switches, relays, and printed circuit boards, may contain antimony, barium, beryllium, cadmium, copper, gold, lead, lithium, mercury, nickel, silver, palladium, and zinc. Items are also known to contain a variety of organic chemicals and rare earth metals, many of which have not been studied for health effects. Plastics may constitute as much as 30% of e-waste by weight [29] and BFRs are added to most plastics to reduce flammability. BFRs are often found in computers and other electronics for the same reason. As many plastics contain chlorine, combustion of plastic results in the formation of both chlorinated and brominated dioxins and furans. **Figure 1** shows the sources of some of these chemicals.

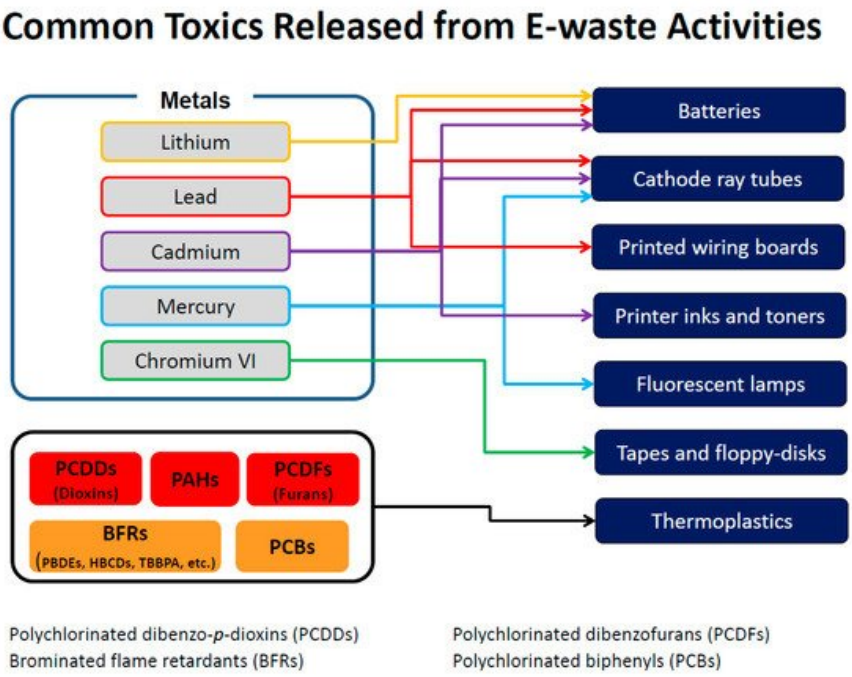


**Figure 1.** Sources and chemicals released from some specific e-waste sites. Adapted from: Frazzoli, et al. [30].

Landfills in African countries containing e-waste have shown elevations of many different potentially hazardous metals [31]. Soils around an informal e-waste recycling site in Nigeria have displayed elevated levels of copper, lead, zinc, manganese, nickel, antimony, chromium, cadmium [32]. Alabi et al. [33] compared levels of metals in soils and plants at e-waste sites in China and Nigeria and found that both sites had significant elevations of lead, copper, chromium, nickel, cadmium, and manganese relative to Dutch and Chinese standards. Several reports have investigated blood concentrations of metals in the blood of residents living near e-waste recycling sites as compared to control areas. Li et al. [34] reported that residents living near Taizhou, when studied two years after the site was closed, had elevated levels of chromium, arsenic, cobalt, nickel, silver, tin, mercury, lanthanum, and cerium as compared to residents at a control site. In Ghana, workers at an e-waste recycling site displayed significantly higher concentrations of blood lead, cadmium, chromium, and urinary nickel when compared to non-e-waste workers [35]. Many of these metals are toxic, especially to children.

## 3. How Does E-Waste Pollute the Environment?

E-waste is recognized as a resource as it contains valuable materials [18]. However, in developing countries many e-waste recyclers use primitive methods, such as mechanical shredding, manual dismantling and sorting and open burning, to isolate these valuable materials [16][36]. Plastics are burned, often at low temperatures, to dispose of computer casings and to retrieve metals from electronic chips and other components leading to the formation of dioxins [37]. Old tires may be burned to generate the heat to melt wires and incineration is used to extract valuable materials [38]. Since there are often inadequate stack emission controls, incineration can also release harmful heavy metals into the environment [37]. Strong acids are used to extract metals from printed circuit boards [39].

These methods result in severe air pollution containing many toxic substances around e-waste recycling areas. Particulates and other air pollutants are inhaled by workers and nearby residents. In addition, chemicals escape and may contaminate dust, soil, and water in communities around dump sites leading to additional routes of exposure, such as dermal contact and consumption of contaminated food and water [40]. E-waste contains as many as 1000 different harmful substances that have been identified as either components of e-waste or involved in the processing systems engaged by informal recyclers [41]. Fetuses, infants and children are at particular risk as their bodies are undergoing vital development. Exposure to such toxicants results in the disruption of these development processes and may result in long-term health impacts. Physical injuries, including burns, cuts and scrapes and musculoskeletal injuries, are also a major problem among e-waste workers in African countries, due to lack of safety measures, training, and education [42]. Some of the hazardous substances found in e-waste and their associated health effects are discussed in detail below. As very few health effects studies have been completed at African sites, the findings are supported by additional research completed at other international e-waste sites.

## 4. Health Effects Associated with Chemicals Found in E-Waste

**Lead:** Lead is a well-known neurotoxin [43]. Even relatively low lead exposure in children can result in a reduction in total intelligence quotient (IQ) and several behavioral abnormalities, including decrease in attention span and increase in frustration and disruptive behavior. At higher exposures, lead can cause anemia, coma and even death. There is no concentration of lead that does not have adverse effects on neurobehavior [44]. Lead exposure at e-waste recycling sites has been associated with altered physical development, increased bone resorption and childhood temperament abnormalities [45][46]. The chain of activities at e-waste sites and the long duration of exposures to lead are major contributing factors to the elevated blood lead levels in African countries [47].

**Manganese:** Manganese is an essential nutrient, but both deficiency and excessive exposure can cause disease. Excessive prenatal manganese levels may result in lower birth weight [48] and adverse effects on child neurodevelopment [49]. Rodriquez-Barranco et al. [50], in a meta-analysis of 17 publications, concluded that a 50% increase in manganese concentrations in hair was associated with a 0.7 IQ deficit in children between 6–13 years of age. Manganese exposure from e-waste has been associated with reduced lung function and elevations in levels of malondialdehyde and superoxide dismutase in children aged 8–13 years [51].

**Mercury:** E-waste workers are at risk from exposure to both mercury and methylmercury. Methylmercury is formed when elemental or inorganic mercury is deposited in the environment. Methylmercury is a potent neurotoxicant and the major route of exposure is consumption of contaminated fish. The release of mercury compounds near e-waste sites can result in serious contamination of an important food source. Sensitive populations, such as pregnant women and children, are at high risk of severe health effects of mercury inhalation due to its impact on the renal and central nervous systems [52]. Metal artisans, who are at risk of chronic mercury exposure, have displayed prevalence of cough, chest pain, dyspnea, interstitial pneumonitis, and impaired pulmonary function [53]. High blood mercury levels in children aged 3–6 years were associated with elevated 8-hydroxydeoxyguanosine (8-OHdG), an indication of oxidative DNA damage at an e-waste site [54].

**Nickel:** Nickel is a neurotoxic, immunotoxic, nephrotoxic, and genotoxic agent [55]. Some nickel compounds are known human carcinogens while metallic nickel is listed as a possible human carcinogen [56]. Allergic reactions are common effects of nickel exposure, such as skin rashes, dermatitis, and hand eczema. Inhalation of nickel exposure can trigger asthma attacks. Occupational exposure to dust containing nickel has been linked to reduced lung function, nasal sinus, chronic bronchitis, and lung cancer [56]. E-waste workers are vulnerable to these health outcomes. Ni et al. [57] suggested a positive association between nickel and neonatal umbilical cord blood plasma 8-OHdG concentrations. School children residing in an e-waste recycling area have shown significant body accumulation of nickel. Lower forced vital capacity, decrease in catalase activities and significant increase in superoxide dismutase activities and malondialdehyde levels has been associated with nickel exposure in boys aged 8–9 years at an e-waste site [51].

**Arsenic:** Arsenic is highly toxic to humans. Studies of children in China have found that elevated arsenic in drinking water is associated with a reduction in childhood IQ [58][59]. Parajuli et al. [60] found that cord blood levels of arsenic were associated with reduced neurodevelopmental indicators in newborns. Liu et al. [61] reported that women exposed to elevated arsenic levels in soil during pregnancy were associated with elevated rates of developmental delays in their children. High urinary arsenic has been associated with decrease in IQ in children between 6–13 years of age [62]. Arsenic is also a potent carcinogen [63] and a major cause of cardiovascular disease [64]. While these diseases may not appear during childhood, exposure during childhood may increase risk of disease later in life. Very little research on arsenic has been conducted at e-waste sites.

**Cadmium:** Cadmium is a known human carcinogen and can have adverse effects on cognitive function. Cadmium has been associated with adverse birth outcomes, reduced cognitive development and IQ and elevated withdrawal, social and attention problems in children [65][66][67][68]. Cadmium exposure in adults is associated with elevated risk of peripheral artery disease [64], but this has not been studied in children. At e-waste sites in China, cadmium exposure has been linked to increased risk of sex-specific adverse birth outcomes and altered mitochondrial respiration [69][70].

**Chromium:** Chromium (VI) is a genotoxic carcinogen, whereas chromium (III) is an essential micronutrient [71]. Children exposed to chromium at e-waste sites have shown lymphocyte DNA damage [72] and reduced weight and chest circumference as compared to unexposed children [73]. Preschool age children from an e-waste site have shown reduced lung function and lower concentrations of hemoglobin in comparison to unexposed children [74].

**Polybrominated diphenyl ethers (PBDEs):** PBDEs are a group of BFRs. BFRs can be detected at elevated levels in humans and the environment in areas far away from the points of production, are resistant to degradation and can bioaccumulate [75]. Studies of the health effects of PBDEs on humans have shown significant change in thyroid stimulating hormone in children [76], decrease in full-scale IQ following prenatal exposure [77] and changes in childhood body mass index (BMI) [78] Animal studies indicate that early life exposure to PBDEs promotes obesity later in life [79], and human studies support this conclusion [80]. Elevated concentrations of PBDEs have been found in breastmilk, soil, plants and animals at e-waste sites in China [81][82]. Workers at e-waste sites have shown altered thyroid function associated with elevated serum PBDE levels [82]. Exposure to PBDEs at e-waste sites has also been correlated with reduced head circumference and neonatal BMI, decrease in Apgar1 score, changes to human semen quality and thyroid and endocrine system function [83][84][85][86][87].

**Dioxins, furans, PCBs:** Dioxins, furans, and PCBs are known human carcinogens [88][89] Dioxins and furans at e-waste sites are primarily products of combustion. Dioxins, furans and PCBs have been found at elevated levels in soil and air at e-waste sites [90]. There is strong evidence that individuals working at e-waste sites and their children have elevated blood, hair, serum and tissue levels of dioxins, furans, polybrominated biphenyls (PBBs) and PCBs associated with e-waste recycling activities in Ghana [22][91] and China [92][93][94]. PCBs can cause adverse alterations to the nervous system, skin, thyroid and sex steroid hormonal systems, liver, kidney, cardiovascular system, and pancreas [95][96][97]. Children exposed to dioxins, furans and PCBs are at significant risk of respiratory infections and decrease in lung function [98][99]. Exposure to dioxins, furans and PCBs at e-waste sites has been linked to changes in immune system function and significant changes to thyroid and endocrine system function [84][100][101][102].

**Perfluoroalkyl substances (PFAS):** There are more than 5000 PFAS widely used as stain resistant and water repellent chemicals on fabrics, household products and as fire-fighting foam [103]. These chemicals have been found in drinking water, food, and indoor and outdoor air [104]. Exposure can result in elevated rates of some cancers [105], altered immune function with a reduced response to immunization [106] and disruption of thyroid hormone function [107]. There is little available research on PFAS compounds at e-waste sites [108] reported that mothers from an e-waste site were exposed to higher levels of perfluorooctanoic acid (PFOA), a common PFAS, and that prenatal exposure was associated with adverse birth outcomes and decreased physical development in children.

**Polycyclic aromatic hydrocarbons (PAHs):** PAHs at e-waste sites are products of incomplete combustion. Workers and residents at e-waste sites encounter PAHs primarily through inhalation and dermal exposure. PAH exposure has been associated with cancers in adults [109][110], DNA damage in newborns [109], respiratory and cardiovascular effects in schoolchildren [111][112] and adverse neuro- and physical development outcomes in children [113][114]. Elevated levels of PAH metabolites have been found in the urine of e-waste workers in Ghana [17]. Cancer risk from inhalation of PAHs near an e-waste recycling area in South China was reported to be 1.6 times that of a control area [115]. Carcinogenic PAH congeners have been positively associated with BMI and child physical growth indicators, such as reduced head circumference and Apgar1 score, at e-waste sites [116][117]. PAHs were observed in preschool children at an e-waste recycling site in China and linked to exacerbated vascular endothelial inflammation [118].

**Particulate air pollution:** The joint effects of ambient and household air pollution caused an estimated 543,000 deaths in children under five years and seven million premature deaths across the globe in 2016 [119]. Children in African countries are exposed to a double burden of toxicants from air pollution. While children are exposed to ambient air pollution, including from e-waste activities, they also spend a lot of time at home, indoors, where they may be exposed to toxic pollutants from the incomplete combustion of polluting fuels and technologies used for cooking, heating, and lighting. African countries have some of the highest burdens of disease and disability-adjusted life-years among children due to household air pollution [119].

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