Short Communication

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Prevention-intervention strategies to reduce exposure to e-waste

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Abstract: As one of the largest waste streams, electronic waste (e-waste) production continues to grow in response to global demand for consumer electronics. This waste is often shipped to developing countries where it is disassembled and recycled. In many cases, e-waste recycling activities are conducted in informal settings with very few controls or protections in place for workers. These activities involve exposure to hazardous substances such as cadmium, lead, and brominated flame retardants and are frequently performed by women and children. Although recycling practices and exposures vary by scale and geographic region, we present case studies of e-waste recycling scenarios and intervention approaches to reduce or prevent exposures to the hazardous substances in e-waste that may be broadly applicable to diverse situations. Drawing on parallels identified in these cases, we discuss the future prevention and intervention strategies that recognize the difficult economic realities of informal e-waste recycling.

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Introduction

Electronics are an increasingly large part of daily life, and millions of electronic devices are discarded every year in countries around the world. An estimated 65 million tons of electronic waste (e-waste) was created globally in 2017, with further increase projected in the years ahead (1). Due to the great expense of proper disassembly and disposal of electronics, e-waste is frequently shipped to developing countries (2).

In this commentary, we focus on informal e-waste recycling sites in Asia, South America and West Africa, where the work is often performed by women and children, with few occupational or environmental protections, and with little or no public health infrastructure (1, 2). We present case studies to illustrate the range of activities and conditions at these sites and the health hazards associated with them. In addition, we describe the intervention approaches that may be broadly applicable to diverse scenarios. We also discuss the future prevention and intervention strategies while recognizing the difficult realities of the informal e-waste recycling economy.

This commentary arose out of discussions held at a workshop on exposure to e-waste convened jointly by the U.S. National Institute of Environmental Health Sciences (NIEHS) and the World Health Organization (WHO), in collaboration with the Chulabhorn Research Institute of Thailand, the Children's Health and Environment Program (The University of Queensland), and Pure Earth. The workshop received financial support from NIEHS. It was held immediately following the 16th Annual Conference of the Pacific Basin Consortium on August 14, 2015, in Depok, West Java, Indonesia.

E-waste and informal recycling

In developing countries, e-waste is predominantly recycled informally in rural communities, in urban or non-urban neighborhoods, and in small family workshops rather than at dedicated facilities (3, 4). Informal recycling sites can range from small, microscale operations in homes or neighborhoods, to sprawling sites as large as entire towns. Informal recycling often uses uncontrolled methods and employs practices that can produce byproducts with considerable negative impacts on the environment and human health. Although recycling practices and exposures vary by geographic region, e-waste workers often do not wear personal protective equipment, and may be engaged in similar activities to dismantle and recycle electronics (5). These activities involve extracting the valuable components, such as gold, copper and silver, from electronic products, including cell phones, computers, DVD players, game stations, televisions, refrigerators and washing machines (5).

Economic considerations

E-waste contains not only hazardous substances, but also valuable materials such as copper, palladium and gold, which are driving the recycling process. Extracting these commodities provides a much-needed living for people in developing countries with limited alternative sources of income. Recycling and other informal activities represent the largest source of financial support for many economically disadvantaged families. For example, in West Africa, workers can make between $16 and $52 USD per 10–12 h workday, far higher than the national values (6). Unfortunately, these informal recycling entrepreneurs often endanger their own health, the health of their families and of people in their communities in their quest for a livelihood, pointing to the need for interventions that reduce health risks while recognizing these economic realities (3, 4).

Potential hazards

E-waste contains a mixture of hazardous substances released during the recycling process. These include metals (e.g. lead, mercury, cadmium); brominated flame retardants; and chemicals found in plastics (e.g. phthalates). When the materials are burned during recycling, toxic and carcinogenic substances are produced and released (e.g. dioxins, furans and polycyclic aromatic hydrocarbons) (7).

As a result, significantly elevated levels of such contaminants can be found in soil, road dust, air and water, in residential, school and park areas near recycling sites (8, 9).

Increased levels of some of these contaminants have been measured in the blood of exposed workers in the informal e-waste recycling industry and in children living in nearby contaminated areas. Exposure to these contaminants are associated with adverse health effects. For example, a systematic review (10) pointed to associations between exposure to polybrominated diphenyl ethers (PBDEs) in e-waste and alterations in thyroid function and higher levels of thyroid stimulating hormone leading to hypothyroidism. In addition, children whose mothers were exposed to higher levels of perfluorooctanoic acid showed increased risk of slowed neonatal physical development and adverse birth outcomes such as premature delivery, low birth weight and stillbirth compared to children whose mothers were not exposed (11).

Lead exposure is also a significant concern in nearly all informal recycling areas, which in some cases comprise entire towns. Studies have linked lead and other heavy metal exposures in children in e-waste recycling areas to attention-deficit/hyperactivity disorder and other neurodevelopmental disorders (12, 13). Children represent a population uniquely vulnerable to the exposure of environmental chemicals. They breathe more air and consume more food than adults per surface area of the respiratory tract and pound body weight. They are still growing and developing, and at certain stages of development, exposure to environmental chemicals can lead to irreversible damage (14). This together with their frequent hand-to-mouth behaviors, can increase their exposures. As children often work directly in informal recycling operations, they may be vulnerable to long-term adverse health effects resulting from exposures to toxicants in e-waste released from its recycling processes. These are just a few examples of documented negative health effects linked to e-waste recycling. A major concern is that the full scope of the problem is not well characterized, as workers in the informal sector are not screened or monitored for blood lead levels or other toxic exposures.

E-waste case studies

Although family and informal e-waste recycling practices and exposures vary by geographic region and scale of operations, our examination of case studies from several different countries show some parallels that may be useful to consider for sites that are not well characterized. While solutions to reduce exposure and protect human health must be locally tailored, we can learn valuable lessons from work that has been done to reduce exposures and protect health in the case studies presented.

Uruguay

Description of site

Informal e-waste recycling sites in Uruguay are largely located in Montevideo, where they are scattered throughout suburban residential neighborhoods, particularly in those with higher social and economic vulnerability. It is estimated that there are more than 550 such urban settlements with more than 165,000 inhabitants, although not all settlements are involved in e-waste activities (15). Typically workers will dismantle electronic products manually and burn cables to extract copper, without any proper personal protective equipment (16). These microscale recycling activities often occur near homes and where children often play, and children participate in these activities by gathering metals.

Exposure information

As noted, participating in recycling activities and living and playing around recycling-contaminated sites increase children's exposure to lead (16). Elevated blood lead levels have been measured in children exposed to lead through the burning of cables in or around the home, through soil, or through lead-based paint. In one study in Uruguay, even though some activities, such as gathering metals, were not associated with increased blood lead levels, the average blood levels among the children at the first consultation were substantially higher (mean 9.19 μg/dL) than the U.S. Centers for Disease Control and Prevention's (CDC) current reference level of 5 μg/dL, suggesting the need for primary prevention (16, 17). The highest lead levels were seen in the youngest children (16).

Intervention approaches

In response to measured elevated blood lead levels among children living in an e-waste recycling area in Uruguay, researchers implemented several intervention approaches. These included family education, home visits and outreach and communication with community members. In addition, the non-profit organization Pure Earth conducted indoor and outdoor remediation, such as excavating and replacing contaminated soil, to reduce exposure (16, 18). As a result of the various intervention approaches, blood lead levels were found to be decreased by a mean of 6.96 μg/dL (16, 18). These reductions were paralleled by decreases in lead measured in soil after remediation. The researchers suggest that educational interventions for families that focus on environmental hygiene and nutrition may be useful to reduce children's exposures as part of a multi-pronged approach, though direct evidence is limited (16).

Ghana

Description of site

Agbogbloshie, centrally located in the capital city of Accra and home to about 40,000 people, is one of the largest and best-studied e-waste sites on the African continent. The waste is processed in Agbogbloshie by recyclers working out of small sheds and out in the open, scattered among residences and Accra's largest food market (6). Common e-waste recycling practices at Agbogbloshie include scavenging for electronics, manual dismantling of electronic equipment and open burning to isolate valuable metals (3, 4, 6). Non-valuable materials are dumped out in the open (6). In most cases, workers at these informal facilities do not use any personal protective equipment (PPE) (6).

Exposure information

Plumes of smoke from this site can be seen from afar due to open burning of cables during recycling. Not surprisingly, the main environmental exposure has been estimated to be from the burning process, although contaminated food and soil are also of concern (3, 4, 6). Informal e-waste workers who were studied at this site were found to have significantly higher concentrations of blood lead compared to a control population that lived in a suburb of Accra not involved in e-waste processing (19). Studies have also shown higher blood levels of polychlorinated dibenzo-p-dioxins and dibenzofurans, which are produced during the burning process, among workers (6). Elevated levels of polycyclic aromatic hydrocarbon (PAH) metabolites, lead, nickel, arsenic and cobalt have also been measured in the urine of e-waste workers compared to controls (6).

Intervention approaches

A model intervention implemented by Pure Earth in Ghana has had some success. A new e-waste recycling center is helping to reduce toxic exposures by providing electric-powered, automated wire-stripping machines (20). In the initial stages, the machines provided were not well suited to the small wires and cables being dismantled. These machines were later replaced with ones that were more practical for the workers who used them (20). In the most recent stage, mechanized equipment to handle larger devices (e.g. motors, capacitors, rotors) were added, and workers are being trained on their use.

Pure Earth incorporated community feedback, that led to new machines that worked better for the recyclers, highlighting the importance of engaging stakeholder needs in the intervention process. Although burning and other unsafe practices have not been eliminated, there is more community support for the project as the tools and technologies more closely align with their needs. These tools are now providing an alternative to open burning and are offering greater safety to workers (20).

China

Description of site

Until recently, Guiyu, a town in Shantou, China, was one of the largest e-waste recycling and dismantling communities in the world, with an estimated 1.7 million tons dismantled there annually (11, 21). In 2015, more than 6000 small, family-run workshops were reported to be participating in e-waste dismantling and recycling activities (8). In 2014, researchers observed that 80 percent of families in Guiyu were engaged with individual recycling workshops, nearly 160,000 workers. Recycling activities were scattered throughout many villages and communities in Guiyu.

Common practices include baking printed circuit boards, soaking parts in acid baths, open burning to extract metals and manually stripping plastic materials from electronic products and crudely classifying them (e.g. sorting by burning smell) (22–24). Researchers have documented workers wearing no protective equipment while participating in these activities.

Exposure information

Due to the large amount of open burning, contaminated air is a large contributor to environmental exposures. Levels of fine particulate matter (PM2.5), cadmium and lead in the ambient air were found to be much higher in Guiyu than in a reference area (9).

Children living near an e-waste recycling area in Guiyu have been shown to have significantly higher blood lead levels (22, 25). Elevated levels of other metals such as cadmium and mercury have been reported (12, 26, 27), as have increased levels of polybrominated diphenyl ethers (PBDEs), PAHs, polychlorinated biphenyls (PCBs), perfluorooctanoic acid, phthalate esters, and bisphenol A in blood, urine and other samples (21, 23, 26, 28–31).

Intervention approaches

Guiyu has seen major, rapid changes in its e-waste recycling practices following a December 2015 decree from the Chinese government that required all informal e-waste recycling in residences to shut down and move to a new industrial park where protective measures are in place (32, 33). In addition, new domestic and industrial sewage treatment plants were constructed by the government. These approaches combined with a series of educational outreaches on topics including heavy metal detection, health risk assessment and medical services have contributed to a reduction in blood lead levels (24, 34).

India

Description of site

While there is a great deal of information on larger, formal registered e-waste dismantlers and recyclers in India (largely concentrated in the southern state of Karnataka [52 facilities], Maharashtra [22 facilities] and Haryana [13 facilities]), like other countries, the scale of informal recycling activities are not well documented (35). This is concerning as it is estimated that more than 95 percent of e-waste ends up in the informal sector (35). As one example, many such operations exist in and around Delhi, including Seelampur, the largest subdivision of the North-East District of Delhi (36). Over 30,000 people participate in e-waste recycling in Seelampur (37), which is known as the largest scrap market in the country. Typical activities include manual dismantling of electronics, use of acid baths, baking circuit boards and burning wires (38). Workers, many of whom are children, are often not aware of the dangers of the chemicals and acids they handle without protective gloves and breathe without protective masks (38).

Exposure information

Similar to other countries, recycling activities in India release toxic fumes and contaminate water when e-waste is dumped into streams. In addition, metals and other contaminants have been measured at elevated levels in soils and sediments (39).

High levels of blood lead and urinary chromium have been found in workers from the informal e-waste sector in Delhi, India (5). For lead, values ranged from 8 to 58 μg/dL; these values are well above the CDC's current reference level of 5 μg/dL (5).

Intervention approaches

The Centre for Occupational Health at New Delhi is working with the University of Cincinnati to initiate a major project in India to study health outcomes of e-waste recycling (5). In addition, the Indian government proposed laws in 2011 that were later expanded upon in 2016 to regulate e-waste management and trade (35). The more recent regulations are more broad and cover a wider range of materials and industrial stakeholders (35). A major remaining challenge is the large number of informal workers who, unlike larger companies, are not covered by these rules (38), and the rules do not incorporate health and safety measures to protect workers and the environment (35). A key need in India is regulations that protect workers' interests, particularly those of vulnerable populations and children, and that cover the large informal recycling industry (5).

Philippines

Description of site

E-waste recycling in Manila, Philippines, is scattered in many different communities throughout the metropolitan area and surrounding suburban areas. Thousands of self-organized recyclers carry out microscale recycling activities in front of homes, on the streets, in backyards or along the river in this densely populated area (40). These recyclers are connected to more than 2000 junkshops that collect recycled materials (40). Recycling activities include manual dismantling and crushing, burning power cords and heating circuit boards. Recyclers often work with bare hands, wear flip-flops and do not wear personal protective equipment (40).

Exposure information

Limited research in informal e-waste recycling sites in metro Manila suggests increased levels of cadmium, cobalt, copper, manganese, nickel, lead and zinc in soil samples, similar to other large recycling sites in Asia (41–44). In addition, open burning of e-waste led to increased PAH exposure in soil samples (44). While not directly tested at this site, PAH levels were likely high in the air similar to what has been tested at other Asian sites (41–44). Very few studies have measured chemical exposures in recycling communities in the Philippines. In one of the few such studies, women living near a metro Manila e-waste dumping site presented slightly higher PBDE concentrations in breast milk compared with a control site (45).

Intervention approaches

In Manila, researchers found that going door-to door and interacting on an individual level with the residents was the best way to gain the trust of the community and assess their needs. Through these personalized interactions, they found that most workers had little understanding of the potential health risks associated with e-waste recycling and the particular vulnerability of children and pregnant women (40). The community perceived e-waste dismantling as an easy source of income, with their major health concern focused on limited access to health care (40). The needs assessment also showed that even health center physicians in Manila were unaware of the e-waste dismantling occurring in their community and its health hazards (40).

A pilot outreach intervention followed a risk-reduction approach focusing on the decreasing of exposures, community organizing and development and access to quality health care. Advocacy and sensitizing activities cut across each of the components. Outreach activities included using posters to educate workers about the need for protections, distributing protective equipment, providing tours of formal recycling facilities where protections are used and educating local healthcare workers about the health effects from exposure to e-waste recycling (40). In educating workers and their families, the goal was to reduce risks to health while providing a message easily understood by the audience. A needs assessment found that many of the workers were young boys, so this goal was accomplished by using a graphic cartoon featuring a character named “E-boy” to demonstrate safe recycling practices (40).

Emerging themes and needs: the way forward

The case studies presented here illustrate how local conditions and context for e-waste recycling can vary widely. Solutions to reduce exposure and protect human health must be locally tailored and take into consideration the large differences in the scale of recycling sites, which range from vast facilities to tiny family operations. Acknowledging these differences, we identified several overarching themes and common needs from these studies and experiences.

Economic considerations

E-waste recycling work is often conducted by informal workers who are focused on the urgent need to provide for their families, not the long-term health effects from exposure to e-waste. Thus, interventions to reduce the health threat of e-waste must recognize that informal e-waste recycling provides a living for many people with limited sources of income (46). While preventing children and pregnant women from working in informal e-waste recycling is a priority (4), banning all workers from participating in the practice is currently not a viable option because of this need for a livelihood (46).

It is critical to make the economic case for improvements in practices, conditions and preventive measures as economic incentives are strong motivators to encourage adoption of safer methods and technologies (34). Approaches may include discussing the economic consequences of exposures in light of disease burden outcomes and proving through business cases that profitability can increase with newer technologies that maximize recovery and minimize exposure (34).

Culturally appropriate communication

In any intervention, messages that pertain to e-waste recycling should be tailored to communities or regions based on insights gained from listening to the group’s concerns. This process is necessary to help gain the community’s trust and to learn about their needs. When community members feel that they are heard and understood, there is less room for miscommunication or mistrust of outsiders. Building relationships with the community and listening to their concerns is vital to the success of any community intervention or prevention initiative.

Stakeholders also have a large role to play in evaluating interventions. Iterative and multidirectional approaches are important, as stakeholders provide feedback to help determine which technological solutions are best suited to local cultural needs and expectations (40, 47). It is important to include community perspectives and involve a wide variety of stakeholders such as healthcare providers, local authorities, regulatory agencies and site community organizers (5, 40). Doing this in multiple stages of the intervention not only helps refine the approaches and tools to be more relevant for the target audience, but it may also improve buy-in from the community and promote continued success.

Cultural considerations, as well as those of age and gender, should be taken into account in outreach approaches (e.g. word choice, media and graphical messaging). While no single message will be appropriate or successful in all contexts, key factors for effective messaging include simplicity and accuracy (48). Communication tools that may be useful include posters, brochures, radio messages, presentations, videos and social media, either alone or combined (48).

Better exposure measurement

One of the first steps to understanding the potential impacts and designing intervention approaches for communities engaged in e-waste recycling is to quantify exposure levels and dominant exposure routes. While there are some commonalities between sites, the case studies illustrate that exposure can vary depending on the materials being recycled and the specific methods employed. Given the health effects observed from these exposures, environmental, biological, occupational and health monitoring is therefore important (34). Measuring environmental indicators of contamination left behind and collecting and archiving environmental samples should be a priority. Levels of contamination in soil, water and air should be measured. Monitoring should include PM2.5, metals, persistent organic pollutants (POPs) and PAHs.

This information can inform the scope of personal exposure monitoring in workers and residents, which carries more ethical concerns and is more expensive than measuring environmental indicators. For instance, if environmental monitoring does not detect POPs in soil, water or air, there may be no need to monitor their presence in the local population (34). Evaluating intervention approaches requires both baseline and post-intervention exposure data (48). These evaluations must include population monitoring in addition to environmental samples, to truly determine whether a prevention or intervention initiative has been successful (34). As baseline samples are not available in many cases, it is critical to collect samples before interventions begin. Technologies to more accurately measure personal exposures and population exposures will be needed to accomplish this (48).

Linking exposure to health outcomes is challenging, and in most areas affected by e-waste, publicly collected population data are not available. Thus, it will be important to monitor at the local level and identify and follow a set of defined health and exposure measures. Following trends over time will also be important to better understand the link between exposures and health outcomes (48).

Reducing exposures

There is a need to pilot test new technologies and approaches to reduce exposure (34). While these solutions must be locally tailored, technological and non-technological approaches, such as engineering controls, remediation tools and education, are critically important to decrease direct and indirect exposure.

Improvements in technologies to reduce exposures are necessary to allow clean-up of existing sites and establishment of better recycling practices. In places where e-waste recycling is performed informally by individuals in public spaces and in homes, remediation of contaminated sites is necessary to prevent additional exposure (4, 16, 49).

Education is also a priority. There is a need to highlight the importance of PPE availability and to train workers on its use (34). Likewise, there is a need to improve health education for medical doctors and nurses who work at the community level. Health education programs should include both community workers and traditional healers, who are the front-line health professionals in many areas (34).

Similarly, educational programs about e-waste exposures should be appropriate for and promoted among the most vulnerable populations, including children, pregnant women and workers (34).

Regulatory and policy considerations

Regional and national regulations regarding e-waste management must be reviewed and updated, including those mandating the use of PPE in the formal and informal e-waste recycling sectors. These measures will require strengthened interactions between policy makers and the business sector (34). Educating and protecting workers will require other stakeholders from many different arenas to work together to develop multi-sectoral e-waste regulations and policies that address environmental, economic, social and health aspects of e-waste recycling (4).

Conclusion

One of the key challenges of prevention and intervention studies is addressing the disconnect between the long-term risk from exposure to contaminants because of e-waste recycling activities, and the immediate, acute economic needs of the communities involved in these practices. E-waste recycling is often conducted by informal workers, who are more concerned about feeding their families than preventing later-life health effects from exposure to e-waste. These difficult realities must help inform how intervention and prevention approaches are designed and presented to communities. Their input can help researchers determine appropriate messaging that will resonate with their intended audience and help make the case for economic benefits that can be tied to improvements in practices, conditions and preventive measures, as well as benefits to human health.

Another key challenge is the fact that the e-waste problem has been growing for decades. Even after primary exposure is reduced or mitigated, the legacy of contamination will remain. Some of the hazardous substances in e-waste are persistent in the environment and can bioaccumulate or biomagnify in plants and animals. This means long after primary exposure has been reduced or removed, people in the community can continue to be impacted by chemicals that remain in their soil, water and food sources. Methods that remove these legacy sources of exposure, such as excavating contaminated soil, may be necessary and appropriate in some cases. There is still a great need for more research on effective remediation technologies to protect people from legacy exposures.

As e-waste recycling can be beneficial and sustainable, for recovering valuable resources, it is important to develop and incentivize business models that encourage safe, sustainable and efficient recycling practices. For example, by facilitating research and interactions among stakeholders in academic institutions, industry, governments and international organizations, the Solving the E-waste Problem (StEP) Initiative has been a leader in global management and development of environmentally, economically and ethically sound e-waste recovery, re-use and prevention (50).

As informal e-waste practices and interventions continue to evolve in various regions, continued collaboration and exchange of ideas among the various stakeholders will be vital to sustained progress toward making e-waste recycling a safer way to make a living. Continued and expanded research is needed, including improved design of electronics, safer extraction practices and advancements in remediation technologies. Developing an open-access catalogue of current e-waste research and resources describing state-of-the-art best practices that are affordable, usable and realistic for different recycling operations is also necessary to improve intervention and prevention approaches.

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