Assessing Worker and Environmental Chemical Exposure Risks at an e-Waste Recycling and Disposal Site in Accra, Ghana

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Introduction

Background and Significance
The term e-waste describes electronic and electrical devices such as computers, cell phones, televisions and refrigerators that have outlived their useful life. Consumption and replacement of these computing and electrical goods in the developed world is quickly growing and as a result the lifespan of e-waste materials is quickly decreasing.¹ The need to dispose of or recycle this waste stream will become more important as the number of obsolete items increases. It is estimated that globally 20-50 million tons of e-waste is generated per year, representing 1-3% of the world’s municipal waste.² ³

Recycling and disposing of e-waste in high-income countries is relatively more expensive and difficult due to more stringent regulations. In countries where e-waste is regulated, producers are required to establish systems for collection and treatment of items generated, however, as stated in a study on e-waste recycling and disposal by Brigden, Labunska, Santillo and Johnston as much as 75% of items produced in the EU and 80% in the US go unaccounted.² Some of the e-waste that is deemed obsolete by developed countries is still of use to nations in the developing world which accept e-waste items as second-hand donations. The shipment of e-waste falls under the regulation of the Basel Convention, which is an international treaty to control the transportation of hazardous waste.⁴ Companies use a loophole in the treaty that allows for the shipment of second-hand donations as a way to also ship unusable items that will end up in landfills or scrap yards, accounting for 75% of what is shipped.³

E-waste products contain intricate blends of plastics and chemicals, which when not properly handled can be harmful to people and the environment.⁵ In developing countries where e-waste is dismantled and recycled by hand, harmful chemicals and plastics are introduced into the environment via water, air and soil. Workers dismantling and burning the e-waste to retrieve valuable metals and other materials are exposed to harmful chemicals such as heavy metals, PAHs and inorganic acids, which have the potential for long-term and...
serious health risks. E-waste recycling processes pose dangers of hazardous chemicals through accidental releases and spills as well as releases from toxic dusts during unsafe dismantling and burning of the materials.

Allowable worker airborne exposure standards are usually set by individual countries. In the United States, the Occupational Safety and Health Administration lists permissible exposure limits for hundreds of airborne toxic agents. However, these are not generally accepted internationally as are the Threshold Limit Values (TLVs) set by the American Conference of Governmental Industrial HygienistS (ACGIH). This organization has produced scientifically based airborne exposure limits since 1941 that are used worldwide. The standards are based on a time-weighted average (TWA) to account for an eight-hour work shift and referenced in this report. The United States Environmental Protection Agency (USEPA) also sets standards for environmental contamination under the Clean Air Act, the Clean Water Act and the Toxic Substance Control Act, which limit the amount of harmful chemicals released into the air and the amount of lead that is allowed in the soil.

Prevalent Studies

The exportation of e-waste as second hand electronics to developing countries is gaining attention with researchers and the public as the global production of e-waste products in developed countries rapidly grows. Although the transportation of hazardous waste is regulated globally by the Basel Convention and locally with numerous acts and laws created in China such as the Prevention and Mitigation of Environmental Pollution by Solid Wastes Act 1996, companies can still find loopholes for exportation. For example, the Basel Convention allows for the exportation of e-waste if it is to be used as second-hand items, therefore computers and other electronics can be shipped with the intention of being donated even though many of the items will go straight to landfill or recycling centers. The local laws in China passed to control the importation of e-waste are fairly strict yet highly ineffective due to lack of enforcement. Ni and Zeng state that developed countries find these loopholes in the laws pertaining to the exportation and importation of e-waste to China and other developing countries as a less expensive and easier alternative than recycling at home where regulations are more stringent. Therefore, the unaccounted and untreated e-waste from developed countries is being exported to countries in Asia and Africa at an alarming rate. Short-term studies and sample collections have been conducted at sites in Asia and Africa, however, many of the potential contaminants associated with e-waste are uncommon therefore very little research is currently available on the long-term occupational and environmental effects of e-waste recycling sites.

It has been estimated that 70-80% of e-waste is exported to countries in Asia and Africa. Many of these countries are lacking in law enforcement and regulations pertaining to recycling or disposal of e-waste, therefore most of the dismantling and burning of waste is performed by hand and often done by or around children. One review found that 80% of children in Guiyu, China exposed to unsafe e-waste recycling practices suffer from respiratory diseases and are often overexposed to harmful heavy metals such as lead.

Cohort studies have been conducted on occupational exposures from e-waste dismantling in China. In a study conducted in South China researchers measured the levels of Polybrominated Diphenyl Ethers (PBDE) present in workers and the environment at an e-waste site. PBDE is a chemical commonly found in electronic plastics as a flame retardant and is found at e-waste recycling sites in the form of dust. The e-waste workers in China who were tested had levels that were among the highest reported in studied subjects.

Only recently has studies produced causal evidence that there is a strong relationship between environmental pollution and e-waste. Research on air pollution has showed that activities at e-waste sites, including dismantling and burning, produce hazardous emissions that may have damaging health effects. Workers at these sites are also exposed to dust via inhalation, ingestion and dermal contact, which may contain harmful levels of heavy metals. Other studies have shown that e-waste recycling sites pose major threats to waterways such as contamination to nearby streams and rivers. Heavy metals and inorganic acids can leach into the waterways through wastewater or ambient air emissions and have the risk of contaminating natural resources such as soil, crops, drinking water, fish and livestock.
Setting

This 6.2 hectare site (15 acres) is located on the west side of the Odaw River in the city of Accra, the capital of Ghana and is adjacent to the Agbogbloshie Food Market. It is the largest center for e-waste recycling and disposal in Ghana. The site is a flat and heavily industrialized area that consists of scattered recyclers working out of small sheds and in the open. Car parts, heavy machinery, refrigerators, and other industrial and residential equipment are brought in and disassembled for economic value. Remnants of disassembled machinery litter the area and the soil is heavily stained with industrial oils. A large residential community primarily housing Agbogbloshie workers and their families is located to the east of the site (100 meters across Odaw River) and consists of small informal settlements with little electricity and running water.

Work at Agbogbloshie is done on a large scale by manual disassembly of e-waste parts and by burning other items such as computer wires and refrigerator coils to recover profitable metals such as copper and aluminum that are covered with plastic encasements. Often dismantling and burning are performed by young adults (our study found that 73% are aged 21 – 30 years) using handmade tools and without protection from chemicals leaving them susceptible to respiratory diseases and overexposure to lead.1

Public health concerns associated with e-waste recycling and disposal in developing countries, such as Ghana, have gained the attention of researchers and many organizations worldwide. Activities at the site pose threats of contamination to the soil and air, which may leach into waterways and food sources. Air pollution produced when burning e-waste materials not only affects those working and living at the site but also those living nearby.13 Agbogbloshie is also a dumping site for unused items including tin cans and poly-ethane bags, which obstruct gutters and sewer systems and litter the land.13

Currently research conducted at the Agbogbloshie site has only been on a small scale, therefore, the extent of contamination that has impacted the site remains unknown. Organizations such as Greenpeace have conducted site assessments and performed sampling but no organizations have conducted anything on a large scale or studied the long-term health and environmental impacts.2 Ghana has no current regulations for recycling and disposing of e-waste and does not enforce any regulations for the air, water and soil quality. The purpose of this study was to help raise awareness of government officials and the people of Ghana.14 Awareness through
research and data collection will assist in the development of policies and regulations aimed at the adoption of safe recycling practices and proper disposal of e-waste.

**Agencies Involved**

Green Advocacy (GreenAd) is an organization in Accra that strives to improve sustainability and environmental practices in Ghana through research, partnerships, awareness and implementation of programs and regulations. GreenAd’s involvement with Agbogbloshie is in partnership with The Ghana Health Service, Ministry of Health and the Ghana EPA. GreenAd also partnered with Blacksmith Institute to assist with data collection for further awareness raising and education of operatives at Agbogbloshie. The purpose for partnership involves a four-part goal of improvement for the Agbogbloshie site that will also improve practices at other e-waste sites throughout Ghana. The first goal is for implementation of policies for recycling that would include education, awareness and incentives for safe disposal of e-waste. The second is to work on the improvement of methods used for dismantling and retrieving profitable parts including availability of tools and alternatives for burning. The third is developing better accountability for the usage and lifespan of imported electronic and electrical materials. And the last goal is to better organize the market in terms of the location of materials being dismantled, traded and sold, which will help with the general housekeeping of the site and reduce dumping and contamination.

**Project Description**

For the study of the Agbogbloshie site, GreenAd worked with the Ghana Health Service, Ministry of Health, the Ghana Environmental Protection Agency (EPA) and Blacksmith Institute. With funding provided by Hunter College, a study team traveled to Accra, Ghana to conduct a site assessment and take air and soil samples at Agbogbloshie.

**Methods**

**Site**

The sampling was conducted in March 2010 at Agbogbloshie market located in Ghana’s capital city Accra (Geographical location shown in Figures 1 and 2). The scrap metal portion of the Agbogbloshie Market is separated into two main areas. The front of the market is where numerous electronic and electrical items and car parts such as batteries and engines are hauled in, dismantled, sold and traded. In this area women and children cook food and sell plastic bags of water. The second area is located on the edge of the market where workers use the field to build small fires, which are used to burn the plastic off of electrical wires and coils exposing valuable metals such as copper. On one side of the market is a popular food market and on the other side across the Odaw River are shanty homes.

**Sample Collection and Preparation**

**Equipment**

Air sampling equipment brought from the USA to Accra included 15 Mine Safety Appliances (MSA) Escort Personal Air Sampling pumps, two charging packs, one box of volatile organic chemical (VOC) Passive Sampler badges, one box of clear cassettes with cellulose ester membrane filters, one box
Remediation of Legacy Arsenic Mining Areas in Yunnan Province, China

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Table 1 — Project Schedule for Day 1, 2 and 3 at Agbogbloshie

| Location            | Scope                  | Activity                                      |
|---------------------|------------------------|-----------------------------------------------|
| Day 1               | GreenAd Office and Agbogbloshie | Introductions, project description, goals and logistics for the project. |
| Day 2               | Agbogbloshie            | Subject briefing (6 participants) and worker air sampling |
| Day 3               | Agbogbloshie            | Subject briefing (5 participants) and worker air sampling |

- **Location**
  - GreenAd Office and Agbogbloshie
  - Agbogbloshie

- **Scope**
  - Meetings
  - Visual Site Assessment
  - Worker sampling
  - Env air samples;
  - Soil samples

- **Activity**
  - Introductions, project description, goals and logistics for the project.
  - Subject briefing (6 participants) and worker air sampling
  - Subject briefing (5 participants) and worker air sampling

**Environmental Samples:**
- 4 tripods, 7 air pumps with cassettes, filters and sorbent tubes.
- 4 VOC passive sampling badges.

**Soil Samples:** 100 samples

**Schedule of sampling is shown in Table 1.**

Polycyclic aromatic hydrocarbons (PAHs): For day 2 and 3, two workers wore samplers for PAHs, which are highly adsorptive particulate matter such as fly ash or diesel soot. They each had an MSA Escort pump calibrated with a flow rate of 2 liter per minute. The pumps were connected with PVC tubing to an activated charcoal sorbent tube and the other end of the sorbent tube connected to a PTFE filter in a brown colored cassette to shield the sample from the intense sunlight.

**Heavy Metals:** Three workers (on Day 2 and 3) were sampled for heavy metals such as lead, aluminum, chromium, copper, manganese, nickel and zinc. They each had a MSA Escort Air Sampling Monitoring pump calibrated at a flow rate of 2 liters per minute (lpm). The pumps were connected with PVC tubing to a 37 mm sampling cassette with CEM filter.

**Volatile Organic Compounds (VOCs):** All 10 of the workers wore a 3M VOC Passive Dosimeter Sampling badge on both study days.

**Soil Samples**

On day two at the Agbogbloshie site, 100 soil samples were taken to assess the levels of lead (Pb). The first sample was taken in the center of the site next to the office in the brick building. Samples were then taken from the top layer of soil (approximately 2-4 cm deep) counter clockwise around the site's perimeter and inside the scrap market. Samples were placed in an individual plastic bag and a box of clear polyvinyl chloride (PVC) tubing.

A volunteer with sampling equipment is shown in Figure 3. The pumps were connected with PVC tubing to an activated charcoal sorbent tube and the other end of the sorbent tube connected to a PTFE filter in a brown colored cassette to shield the sample from the intense sunlight.

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Environmental - Air

On the second day of sampling four ambient air sampling stations were set up with a tripod stand to test for PAHs, heavy metals and VOCs. The tripods were stationed around the perimeter of the field where the burning of wires and plastics takes place. Station one had two air pumps, one testing for heavy metals with the flow rate at 2 lpm. Station two had one air pump sampling for PAHs with a flow rate of 2 lpm. Station four was the control and had three air pumps, one sampling for heavy metals, the second testing for PAHs with the flow rate at 2 lpm. The control station, shown in Figure 5, was placed away from the burning fires and away from the direction of the wind. All four stations also had a VOCs Passive Sampler badge. The stations ran for two hours in the late afternoon.

Sample analysis

Air – Workers’ Breathing Zone and Environmental

The cassettes with filters and the sorbent tubes were plugged with stoppers then packed and labeled. These were also taken back to the United States for analysis at the Accredited Laboratory, EMSL Analytical, Inc. in Westmont, NJ. All analytical methods followed established NIOSH analytical methods.

Soil

Samples were taken back to the United States for analysis. The samples were dried and analyzed using a portable X-Ray fluorescence analyzer (Innov-X XRF Model Alpha) with a lower detectable level of 10 mg/kg Lead. The results and GPS coordinates for each site were entered into and Excel database and analyzed using ESRI ArcGIS and Google Earth™ for visual representation.
Results

During the visual site assessment and walk through on day one of sampling, the site was scattered with scrap metal, engine parts, computer parts, circuit boards and tangled wires filled with valuable copper. The weather was hot and dry and the air filled with smoke from the nearby burning of wires, parts of refrigerators used to fuel the fires, and melting plastic from computer monitor shells. The scrap metal market is bustling with people hauling in parts, trading, selling, dismantling and burning. In the middle of the site a passerby will stumble upon a lead smoldering area where hundreds of lead acid car batteries are melted and shaped into lead blocks preparing to be sold and shipped off to other countries. Children play on the soiled ground blackened from oil and fire, while women cook food for the workers. A busy produce market is open next to the scrap metal and e-waste recycling site, the other side lined with a small, winding river.

Worker Breathing Zone Results

Due to technical problems, laboratory results were only available for heavy metals in worker’s breathing zones for 2 volunteers on the second day and three volunteers on third day of testing. Results are shown in Table 2. Levels for aluminum, copper, iron, lead and zinc are above the ACGIH Threshold Limit Values (TLV).

Environmental (Ambient) Air Results

The one environmental sampler and one control set up for heavy metals collection, while limited in scope, produced significant results (Table 3). Station 1 was positioned downwind from the “burn site” while the control was positioned an equivalent distance up wind. Only lead (Pb) has an applicable ambient (environmental)
air level for which to compare the findings. There are no US or international standards for copper and iron in ambient air. Lead was observed at over 4 times the permissible USEPA ambient air quality.

Soil Sampling Results
Over half of the soil samples were above the USEPA standard for lead in soil (400 mg/kg or ppm). The data is displayed in concentrations of parts per million (ppm) and separated by five groups and displayed with the GPS readings where each sample was collected. The lowest level of lead in the soil is 134 ppm and the highest is 18,125 ppm. To compare the means of the five groups of soil samples SPSS was used in analyzing in descriptive statistics and comparing means in a one-sample t-test. Table 4 shows the results for the five groups organized by the mean, median, minimum, maximum and 95% confidence interval.

Discussion
Of the 10 workers sampled for heavy metals analysis only 5 collectors contained enough mass for the laboratory to achieve analytically detectable levels. In those results, aluminum, copper, iron, lead had levels above ACGIH TLV guidelines. For aluminum the ACGIH TLV is 1.0 mg/m$^3$ and the highest reading was 6.5 mg/m$^3$. One volunteer (F4) had an airborne exposure level of 0.98 mg/m$^3$ or 20 times the allowable ACGIH TLV level of 0.05 mg/m$^3$. Another volunteer had aluminum exposure levels of 17 mg/m$^3$ seventeen times the SCGIH TLV guideline of 1.0 mg/m$^3$.

The US EPA’s standard for lead in bare soil in children’s play areas is 400 ppm and 1200 ppm for non-play areas. The bar graph shown in Figure 6 represents the samples with levels above USEPA standard. Of the 100 soil samples 16 were found to be in compliance with the USEPA lead in soil standard in children’s play areas and 44 samples were in compliance with the lead in soil standard in non-play areas. In Figure 7 the pie chart is separated by percentages of samples below and above the USEPA standard. The largest percentage is 56%, which is above both the USEPA standards. Of that 56%, the highest lead in soil content sample taken is 18,125 ppm, which is 15 times higher than the non-play areas standard.

When the samples are grouped into five different areas the two areas of the property with the highest means and median for lead in soil and the highest confidence intervals (CI) are group 1 and group 2. Group 1 is on the south end of the site and is a field where the workers burn wires and plastics. The
mean at 3278.5 ppm is 3 times higher than the USEPA standard for lead in soil in non-play areas and the lower 1830.7 ppm and higher 4726.3 ppm CI are both well above the USEPA standard. Group 2 has the highest lead level of the five groups and makes up the samples taken along the eastern side of the property along the banks of the Odaw River, shown in Figure 8. The mean of the samples in group 2 at 5882.6 ppm is five times higher than the USEPA standard for lead in soil in non-play areas and the lower 3247.9 ppm and higher 8517.3 ppm CI are also well above the USEPA standard. The soil sample with the highest level of lead at 18,125 ppm was taken from group 2. Group 4, located inland on the north/western side of the property was the only group with the mean below the USEPA standard at 913.4 ppm.

As a result of low sampling volumes, results were not available for workers’ breathing zones and environmental air samples for polycyclic hydrocarbons, volatile organic compounds and select heavy metals.

Results of soil samples show there is contamination at the site likely due to dismantling of e-waste and wire burning. More extensive soil analysis for additional metals would also produce a better understanding of the extent of contamination.

**Conclusion**

The myriad of complex materials that comprise common e-waste create significant challenges to effective recycling and disposal. The waste site at Agbogbloshie effectively deals with relatively simple, easily recyclable components such as copper wires and coils, ferrous metals, large computer “mother” boards and select computer chips but not in an environmentally safe and healthy manner. For example, the burning of plastic covering and shielding from wires and coils creates substantial airborne emissions such that human health will likely be impacted. Given these sites include extensive support facilities such as housing and food preparation, chemical exposure goes beyond workers. Indeed, at the Agbogbloshie waste site, it is often difficult to separate industrial processing locations from residences. Workers, families and children comingle extensively throughout the day.

Soil samples alone indicate that the e-waste recycling and disposal process in Ghana has caused contamination that may have detrimental health effects on the site workers and residents. Soil sample results taken along the banks of the Odaw River indicate that lead may have the potential to leach into the river. While lead has been identified as one contaminant, other harmful chemicals are likely leaching into the environment through soil and water.

While this preliminary survey identified lead in air and soil as significant chemical hazards present during e-waste processing, additional agents are likely present. The burning of plastics is known to create cancer causing agents such as polycyclic aromatic hydrocarbons and respiratory irritant gases such as hydrochloric acid. Additional air sampling is needed to better understand the types of materials released so that proper interventions can be designed and tested. Also standards for safe recycling and disposal need to be set in place. Finally, in view of the fact that there is a fresh food market adjacent to the e-waste site, this high risk of food contamination may suggest the market be relocated or better protected. These measures would help to protect the workers and children from high levels of exposure to chemicals.
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