Away' is a place: The impact of electronic waste recycling on blood lead levels in Ghana

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HIGHLIGHTS

• E-waste recycling as a livelihood strategy is fraught with significant health risk
• The mean blood lead level (BLL) of non-e-waste workers is slightly higher than that of e-waste workers
• Workers who burn e-waste tend to have the highest and elevated blood lead levels
• Residents and traders in the nearby market are equally at risk to the health impact of e-waste activities
• Government’s policy should target e-waste activity-specific categories rather than prescribing one-size-fits-all strategy

GRAPHICAL ABSTRACT

Informal recycling activities High blood lead levels (BLLs) People with high BLLs earn low incomes

ABSTRACT

E-waste recycling remains a major source of livelihood for many urban poor in developing countries, but this economic activity is fraught with significant environmental health risk. Yet, human exposure to the toxic elements associated with e-waste activities remains understudied and not evidently understood. This study investigates the impact of informal e-waste processing on the blood lead levels (BLLs) of e-waste workers and non-e-waste workers (mainly females working in activities that serve the Agbogbloshie e-waste site), and relates their lead exposure to socio-demographic and occupational characteristics. A total of 128 blood samples were analysed for lead levels. Surprisingly, the mean BLL (3.54 μg/dL) of non-e-waste workers was slightly higher than that of e-waste workers (3.49 μg/dL), although higher BLLs ranges were found among e-waste workers (0.50–18.80 μg/dL) than non-e-waste workers (0.30–8.20 μg/dL). Workers who engaged in e-waste burning tended to have the highest BLLs. In general, the BLLs are within the ABLES/US CDC reference level of 5 μg/dL, although 12.3% of the workers have elevated BLLs, i.e. BLL ≥ 5 μg/dL. The study concludes that the impact of e-waste recycling is not limited to workers alone. Traders and residents within the Agbogbloshie enclave are equally at risk through a range of environmental vectors. This calls for increased public awareness about the effects of human exposure to lead and other toxic elements from e-waste recycling. A key contribution is that government and stakeholder projects for safe e-waste infrastructure should disaggregate the e-waste value chain, recognize differential risk and resist one-size-fits-all strategies.

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1. Introduction

Information and communication technologies are central to modern life. However, there is a technology gap between developed and developing countries, and this “digital divide” spurs the importation and
shipment of used electronic and electrical equipment (EEE) in many developing countries (Grant and Oteng-Ababio, 2012). Meanwhile, technological innovation coupled with planned product obsolescence has fostered a throwaway culture. This culture causes electronic and electrical waste materials (popularly called e-waste) to be the fastest growing segment of the municipal waste stream in most nations (Schmidt, 2006). Jim Puckett reminds us, “wherever we live, we must realize that when we sweep things out of our lives and throw them away… they don’t ever disappear, as we might like to believe. We must know that ‘away’ is in fact a place…likely to be somewhere where people are impoverished, disenfranchised, powerless and too desperate to be able to resist the poison for the realities of their poverty. ‘Away’ is likely to be a place where people and environments will suffer for our carelessness, our ignorance or indifference” (Puckett, 2011, p. 6).

E-waste entails various forms of old EEE that no longer have any value to their possessors (Tiwari and Dhawan, 2014), including broken wires and parts as well as still-functional yet out-of-date computers and handheld devices. These various forms of e-waste are subsequently appropriated through reuse, reselling, salvage or disposal. However, markets for e-waste in disposal, recycling or reselling have crossed borders, meaning safety and equitable management is now a global issue (Amankwaa et al., 2016a).

The plethora of studies conducted in China, South East Asia, Latin America and Africa have established that e-waste has occasioned informal recycling activities which are mostly done under adverse environmental and health conditions (Brigden et al., 2008; Hull, 2010). Ghana is no exception. In the national drive to catch up with advanced information technology (IT) Ghana has turned to e-waste. Importing used products means that electronics are now affordable to a wider population. This has culminated into colossal importation of mostly second-hand IT gadgets from developed countries in Europe and North America (Oteng-Ababio and Amankwaa, 2014). Large-scale imports have opened a thriving ancillary recycling market – taking place mostly in the informal sector. Amoyaw-Osei et al. (2011) revealed that out of around 215,000 tons of electronic and electrical products imported into the country as much as 15% could be classified as waste at the time of importation. Moreover, many imported electronic products are close to the end of their lifespan and quickly became obsolete, thereby increasing the amount of e-waste in the general waste stream. Adding to this stream, 40 to 60% of domestically generated e-waste is recycled, out of which 95% is done by the informal sector (Oteng-Ababio and Amankwaa, 2014).

Accompanying these imports are e-waste components like cathode ray tubes, liquid crystal display screens, batteries, circuit boards, and plastics that contain toxic substances such as brominated flame retardants (BFRs) and polychlorinated biphenyls (PCBs), and toxic metals like lead (Pb), copper (Cu), mercury (Hg) and cadmium (Cd). Many of these substances are released during recycling and are known to cause significant physiologic harm or death to humans upon exposure. And not just immediate exposure but also through environmental degradation (Akortia et al., 2017). Amankwaa (2014a) for example draws our attention to how the families of e-waste recycling workers including vulnerable populations such as children, pregnant women, and elderly stand to suffer from high-level contact as well as take-home contamination from workers’ clothes.

In Ghana, Agbogbloshie, arguably the biggest e-waste dumpsite in Africa, is the heart of e-waste recycling. In 2013, the Blacksmith Institute ranked the site among the world’s top ten toxic threats (Blacksmith Institute, 2013). The area occupies 31.3 ha of land along the banks of the Odaw River and Korle Lagoon, situated northwest of Accra’s central business district. The informal recycling activities at the site are vertically integrated into a functional e-waste economy. There are people who scavenge the waste, dismantle the scrap into segregated components, or burn it in open-air pits to recover precious metals including gold, silver, copper, aluminum, and iron (see Amankwaa, 2013, 2014a, 2014b).

Local advocacy groups and international media have raised concerns about the environmental health implications of e-waste recycling in Agbogbloshie (Frontline, 2009; Afrol News, 2010), but little research exists to attest to the veracity of the claims. For instance, the pioneering work by Brigiden et al. (2008), which garnered international attention around e-waste activities in Agbogbloshie, only referenced earlier reports for e-waste open burning sites in China. The authors reported that certain metals were present at concentrations over 100 times the world permissible standards, but did not attempt to quantify damage caused to the environment or off-site human health in Ghana. A similar study by Caravanas et al. (2011), which assessed workers’ and environmental chemical exposure risks at Agbogbloshie revealed elevated levels of heavy metals through personal air samples collected from workers and their immediate environment. The study found extensive lead contamination in both ambient air and topsoil, but was inconclusive on the potential human health impact.

Asante et al’s (2012) study, which sought to understand human contamination by multi-trace elements (TEs) at Agbogbloshie, found that concentrations of lead in urine of recycling workers were significantly higher than those of reference sites. A more recent study by Akortia et al. (2017) to evaluate the concentrations of polybrominated diphenyl ethers (PBDEs) and some selected trace metals in Agbogbloshie concludes that the surface soils deteriorated from moderate to high metal pollution, particularly for copper (Cu), lead (Pb) and iron (Fe). In a similar study to ascertain the presence of polybrominated diphenyl ether (PBDE) in the vegetables grown in Agbogbloshie, Oteng-Ababio et al. (2014a) discovered massive contamination of five toxic trace elements, but were unable to determine how they impact consumers.

Given this difficulty, this current study goes one step further by examining the health risk of workers in relation to lead contamination. The study builds on the scholarships discussed above. It examines the extent to which e-waste recycling is a matter of concern for the blood lead levels (BLLs) of e-waste and non-e-waste workers within the Agbogbloshie recycling enclave. By doing so, we provide the necessary empirics to substantiate the actual health risks of e-waste workers. Going further, this study disaggregates e-waste workers into their respective occupations, identifying specific potentials for risk. Our study adds weight to Srigboh et al.’s (2016) work that characterized exposures to metals and toxic elements in the blood and urine of male e-waste workers and female service workers at Agbogbloshie, and concluded that workers have elevated cadmium and lead levels in their blood and arsenic levels in their urine. Other research works elsewhere in China have established that e-waste recycling can result in elevated BLLs (Huo et al., 2007; Liu et al., 2011).

The rest of the paper is divided into three sections. (1) The next section presents the materials and methods used to collect data. (2) This is followed by the analysis and discussions of the study findings, with a reflection of how the pathways of lead exposure are differentiated and permeate unevenly across occupational categories and social groups. The final section summarizes the study findings, especially in regards to future policy, and makes suggestions for future research.

2. Material and methods

2.1. Study population

This study was approved by the Institutional Review Board (IRB) of the Noguchi Memorial Institute for Medical Research (NMIMR) – University of Ghana (IRB064/13-14). Field work was conducted at the Agbogbloshie scrap yard using multiple methods including the collection of blood samples, questionnaire surveys and focus groups. Fig. 1 presents a map of the study area. A total of 128 participants were included in the study. To ensure the absence of selection bias the multi-stage cluster sampling technique was employed. The first step involved a stratification to distinguish the various e-waste clusters for each stratum. Six clusters were identified within the chain of e-waste activities: collectors, dismantlers, recyclers/burners, refurbishers/repairers,
middlemen, and scrap dealers. Five clusters were identified within the category of workers secondary to e-waste processing: food vendors, water vendors, beverage vendors, petty traders, and a driver.

This strategy was selected because variations in the population are within the clusters and not between them; thus, each cluster has its own peculiar dynamics (e.g. procedure of entry, start-up capital and networking). The sample size for each stratum was determined with the help of the executives of the Greater Accra Scrap Dealers Association (GASDA) who estimated the population size of the different work categories. And the overall estimate of 4500 to 6500 individuals working at Agbogbloshie come from Prakash et al. (2010). Inclusion criteria for participating in the study were: 1) the concentration of population within the clusters; 2) the intensity of the impact of e-waste activities; 3) involvement in the e-waste recycling activities for at least 6 months; and 4) workers between the ages of 15 and 60 years. Thereafter, a random sampling technique was employed and workers who were accessible and willing were sampled and interviewed within each cluster. The same method was employed for the selection of donors from the non-e-waste workers category. In terms of measurements as to how each group is exposed to lead from e-waste activities; the e-waste workers have 'full exposure', workers secondary to e-waste have 'partial exposure', and the control group have 'no exposure'.

In all, 81 blood donors were sampled from the 6 clusters of e-waste workers: 8 collectors, 28 dismantlers, 3 refurbishers/repairers, 8 recyclers/burners, 25 scrap dealers and 9 middlemen. Also, 33 blood donors were sampled from secondary workers: 20 chop bar operators and food vendors, 2 water vendors, 4 beverage sellers, 4 petty traders (clothing, footwear), 2 onion traders, and 1 driver. Out of 114 participants, 83 were male and 31 were female. In addition, 14 people whose occupations were office-based with no direct relationship to e-waste acted as a control group. They were conveniently sampled because of the difficulty in getting donors from nearby residential areas where the population, lifestyle, and socioeconomic status are comparable to those of Agbogbloshie (see Guo et al., 2014). A semi-structured questionnaire, based on our previous exposure assessments and occupational health studies (Amankwaa, 2014a; Amankwaa et al., 2016a), was used to gather information on socio-demographics and work history. Participants were compensated for their involvement with a monetary gift of GHS 20 ($5.57 USD) and a non-alcoholic beverage.

2.2. Blood collection and analysis

Verbal consent was obtained from each volunteer following detailed explanations of the study and its potential consequences in English and
the local languages (via hired translators). With consent approximately 4 ml of blood was drawn by a professional nurse at the on-site office of GASDA. The samples were collected into a trace-elements free polypropylene tubes containing K3 EDTA as an anticoagulant. The blood samples were stored in a 4 °C refrigerator until transported to the Ghana Atomic Energy Commission (GAEC) laboratory prior to pretreatment and digestion. The digested sample solutions were assayed for lead using a VARIAN AA-240FS Atomic Absorption Spectrometer (AAS). The main parameters employed for the lead determination are presented in Table 1. For quality assurance and quality control, reagent blanks and certified reference blood obtained from the International Atomic Energy Agency 452 (International Atomic Energy Agency, IAEA, 2011) of known composition were analysed using the same method with each batch of samples to ensure accuracy and to detect any contamination during the analytical procedure. Recoveries on IAEA 452 ranged 108.3 ± 21.86. All the digested samples were analysed at least three times; and typically, precision was < 5% for all elements (see Table 2). The BLLs were expressed in micrograms per deciliter (1 μg/dL = 0.0484 μmol/l).

2.3. Statistical analyses

We performed statistical analyses of the data using SPSS (version 16). We used independent sample t-tests or covariance analyses for comparisons of mean, chi-square analyses for test of frequency and categorical data. We used linear regression analysis for the possible association between BLLs and influential factors. Differences were considered statistically significant with a P-value < 0.05 and 0.01. The BLL results were compared with the United States Center for Disease Control’s (CDC) standards for lead levels to ensure consistency with the literature.

3. Results and discussions

3.1. BLLs among e-waste and non-e-waste workers and control group

In 2015, the Adult Blood Lead Epidemiology & Surveillance (ABLES) program of the CDC designated 5 μg/dL (five micrograms per deciliter) of whole blood as the reference blood lead level for adults. An elevated BLLs is thus defined as a BLL ≥ 5 μg/dL. Table 3 presents participants’ mean BLLs.

The finding reveals that the mean BLLs of workers not in e-waste was slightly higher (3.54 μg/dL) than that of e-waste workers (3.49 μg/dL) although higher BLL ranges were found among e-waste workers (0.50–18.80 μg/dL) than workers not in e-waste (0.30–8.20 μg/dL). Overall, 41.4% of the participants have some amount of lead in their blood, with 12.3% having elevated lead levels. Among the e-waste workers, 44.4% (36/81) had BLLs above the detection limit (0.001 μg/dL), compared with 51.5% of workers not in e-waste (17/33). A t-test analysis gave a value of −0.05 at a significant level of 0.52, implying that there is no statistically significant difference between the BLLs of e-waste workers and workers not in e-waste.

This finding suggests that in addition to the e-waste chain of activities other factors such as years of stay in business and length of time spent on the site are significant contributory factors to BLLs. With Pearson's chi-square analysis we found that there is statistically significant difference among the variables 'working years' and 'working hours'. Therefore, both indicators are contributory factors to the differences observed in workers BLLs (see Table 4). In a similar study, Srigboh et al. (2016) found statistically significant associations when elemental biomarker data were correlated with key demographic variables. For example, the number of years spent in the e-waste business correlated with blood copper (Cu), Zinc (Zn), cadmium (Cd), selenium (Se), and mercury (Hg), as well as with urinary nickel (Ni) and lead (Pb). Quite expectedly, our results further show that the mean BLLs of e-waste workers and workers not in e-waste were significantly higher than the control group (P = 0.01) at 1% significant level.

Ingestion through food, dermal contact and inhalation of e-waste contaminants concentrated in the air via dust and smoke are plausible pathways for BLL accumulation. A study by Ha et al. (2009) reveals that e-waste workers in Bangalore breathe dust laden air containing lead. These vectors and our findings are cause for concern because research has found adverse health effects, such as decreased renal function, associated with BLLs at 5 μg/dL and lower, and increased risk of hypertension and essential tremor at BLLs below 10 μg/dL (see Huseman et al., 1992; Canfield et al., 2003; Lanphear et al., 2005; Bellinger, 2013). The implication of these findings for a national e-waste regulatory framework is salient.

3.2. BLLs and e-waste occupational variations

Although the general trend among the whole population showed lower BLLs when compared to the US CDC/ABLES reference level, we explored the distribution of lead levels across the various occupational categories. Fig. 2 compares the BLLs of the e-waste work categories based on the CDC standard. The results indicate activity-specific human exposure to lead from e-waste recycling depending on the recycling processes and modus operandi at each stage of the value chain. The mean BLLs from the six occupational categories were the following, in descending order: Burners/recyclers (4.98 μg/dL) > Middlemen (4.00 μg/dL) > Dismantlers (3.63 μg/dL) > Collectors (3.53 μg/dL) > Scrap dealers (2.76 μg/dL) > Refurbishers/repairs (0.00 μg/dL).

Burners/recyclers recorded higher BLLs relative to workers of the other e-waste categories. The burners specialize in extracting valuable metals from equipment through open pit burning. This category of

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<td>Instrument parameters for AAS analysis.</td>
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<td>Comparison of values and percentage recovery for standard reference material.</td>
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<td>Descriptive statistics of BLLs among e-waste and non-e-waste workers and control group.</td>
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<td>Source: Field work, 2014.</td>
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The comparative mean t-statistics of e-waste and non-e-waste workers is −0.05 and the probability is 0.52; and e-waste workers and control group is 3.04 and the probability is 0.01. Below detection limit (BDL) is < 0.001 μg/dL.

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<td>Pearson chi-square test for working years and weekly working hours.</td>
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<td>Working years</td>
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work is a transit point for most of the new market entrants, who are enticed by the opportunity to access quick cash with little training. Once they are established, burners often graduate to the next level within the e-waste hierarchy. The burners use insulating foam from dismantled refrigerators, or old car tyres, as the main sources of fuel for the open fires. Despite their short occupational longevity they are exposed to lead through direct skin contact and inhalation of toxic fumes. This work may account for their high BLLs. Indeed, a remarkably high concentration of lead (18.8 μg/dL) was found in the blood of a 23-year-old burner who had worked on the site for 4 years with a working time of 98 h per week. This finding is similar to Srigboh et al.'s (2016) study, which found that workers who engaged in burning activities had among the highest levels of most elemental biomarkers compared to those in the other e-waste categories. This is evidentiary support for the public concerns of environmental NGOs about the pollution caused by burners.

Middlemen are intermediaries who provide an easy market for collectors and recyclers who have gathered relatively small amounts of material and lack the economic means to access the larger scrap dealers’ market. They are the ‘connection-men’ found mostly on the site weighing, negotiating and handling all sort of materials from collectors and recyclers before or after processing. Most of the middlemen in our study had considerably longer working years and spent longer hours at the site. This can plausibly account for their higher BLLs as highlighted by previous studies at the site (see for example Akormedi et al., 2013; Amankwaa, 2014a; Yu et al., 2016; Srigboh et al., 2016).

Dismantlers specialize in equipment categorization, sorting, and separation to recover valuable metals. They also supply other workers with stock. Their activities involve intensive manual disassembly of all kinds of equipment and they relate to nearly all the other activities on the site. Most of them stay and work at the site for longer periods to meet deadlines. This long-term exposure to lead through direct skin contact or inhalation of lead vapour might have contributed to the observed BLLs.

Collectors travel throughout major trade centers and neighborhoods in different parts of the city to gather waste materials. Even though some collectors are occasionally involved in rudimentary dismantling of their goods after their scavenging expeditions, most of them spend relatively little time at the site. Returning to the site only after obtaining a substantial sum of materials, which explains their comparatively lower BLLs.

Scrap dealers occupy the top echelon in the e-waste hierarchy. They are workers who trade in metals and other valuable materials. They own their individual sheds, have the means to build bulk inventory and control the spatial organisation of the site. Most of the scrap dealers have worked at the site for a considerable number of years, building their skills and capital in the e-waste business. They now spend less time on the site as many of them move out to IT shops and offices to forge better business connections. Similarly, many now travel to the industrial processing center, Tema, to negotiate the market price of their consignments. Thus, their relatively short working hours at the e-waste site could possibly account for the low BLLs observed.

Repairers/refurbishers recorded no BLL. This is surprising because repairing activities elsewhere mostly involve using electric solder, which is a major source of lead exposure. Yet, field interaction with the three (3) key repairing shops on the site revealed that the refurbishing business is still in the developing stages. Thus, repairers at Agbogbloshie prefer to cannibalize unserviceable equipment for workable components, using those components to repair others for the burgeoning second-hand market. This requires little to no lead soldering. Additionally, the repairers mostly worked from their enclosed container shops, which reduced exposure to the open-pit burning and they use protective equipment to reduce their exposure to their own burning. This finding reveals that the working environment, including the shop make-up, material type and positioning, largely reduce workers’ exposure to toxic substances.

As earlier noted, there was no significant difference between the e-waste workers and workers not in e-waste, and by implication the e-waste workers like their supporting counterparts are at similar risk. This finding adds weight to previous studies that e-waste recycling activities result in the release of lead contaminants into the immediate environments in dust, water and air. This release contributes to the observed BLLs of e-waste and secondary participants (see Huo et al., 2007; Guo et al., 2014; Amankwaa et al., 2016a; Srigboh et al., 2016). These realizations therefore make it imperative to consider the interplay of other related factors that may influence participants’ BLLs.

### 3.3. Relationship between BLLs, age, working years, and working hours

The study further explored the relationship between socio-demographic backgrounds and participants’ BLLs. These background traits include age, the number of years spent in the business and weekly working hours at the site. The results show that BLLs in e-waste workers tend to increase with age; older participants tend to have higher BLLs than younger ones. For instance, workers below 20 years had a lower mean BLL (1.95 μg/dL), while those between the age categories of 21 and 30 years and 31 to 40 years had higher mean BLLs of 3.38 μg/dL and 4.27 μg/dL respectively. Although the mean BLL of workers above 40 years was 3.67 μg/dL, the result fits the explanatory trend because the majority of participants in this age category are scrap dealers who spend less time on the site. This finding is consistent with Srigboh et al. (2016) who found significant associations between age of e-waste workers and blood cadmium (Cd) and selenium (Se) as well as with urinary nickel (Ni), zinc (Zn), and arsenic (As) at the Agbogbloshie site.

Elsewhere, this study resonates with the work of Huo et al. (2007) in Guiyu, China, which showed that older men tend to have higher BLLs than their younger peers. According to these scholars, the observed trend might have resulted from older workers’ increased exposure over time coupled with their lower rate of excretion. Even though children are particularly vulnerable to lead contamination, because they absorb more lead from their environments, children also have higher rates of excretion, which may help to expel lead more quickly (Huo et al., 2007).

Our study also explored whether participants’ working years and hours spent at the site predispose them to higher BLLs. Table 5 presents the mean BLLs of e-waste workers and their respective years of work as well as weekly working hours. In terms of working years, the findings reveal that participants’ number of years spent in the business ranged from 1 to 20 years with most them (75.3%) working for 10 years while the remaining (24.7%) have worked for 10 years and more. The results show an inverse relationship between the BLLs of the various e-waste categories and the number of years spent in the business. For instance, scrap dealers who recorded the highest mean working years
of 8.7 had the lowest BLL (2.8 μg/dL), while the burners who had the lowest mean working years of 5.8 had the highest mean BLL (4.9 μg/dL).

In the case of working hours, the results show that 77.8% of the participants worked between 36 and 70 h per week (5–10 h. a day) while 22.2% operated between 71 and 105 h per week (11–15 h. a day). Clearly, the results indicate that BLLs in e-waste workers correlate positively with working hours. Table 5 shows that burners recorded the highest mean working time of 78.3 h per week followed by dismantlers who had 76.8 h per week, with scrap dealers, repairers and collectors recording the lowest mean working time of 75.5 h, 74.5 h and 67.6 h respectively. A t-test analysis gave a value of −2.87 at a significant level of 0.007, implying that there is a statistically significant difference between working hours and BLLs. Thus, working hours spent on the site tend to influence the variations in BLLs. This finding reiterates our earlier claim that longer stays at the site tend to increase participants' BLLs. This is consistent with Akormedi et al. (2013) who found that the average length of a workday for e-waste workers was between 10 and 12 h/day, adding that there are disparities in working hours among the various e-waste echelons which, in turn, lead to unequal degrees of occupational risk.

The findings also confirm our previous argument that lead contamination is not only through direct contact (e.g. burners) alone, but also through the long-term exposure to contaminated air. Thusly, the study has demonstrated that those who trade at the adjoining food market, or stay at the nearby settlements, have high risk of exposure to lead from e-waste activities.

### 3.4. Regression analysis of BLLs and related factors

The study further sought to identify other personal and lifestyle factors that influence the BLLs of e-waste and secondary workers. However, the previous research of Amankwaa (2014a) and Srigboh et al. (2016) looked at common factors such as demographic information and social habits. This study builds on their work by looking at age, gender, and on-site residence. Our study goes further by also looking at social habit/lifestyle variables such as smoking, alcohol intake, hand washing, and frequent changing of work clothes. Tables 6 and 7 present a Tobit regression model of the factors that influence participants' BLLs.

The overall goodness of fit of the Tobit regression model is significant at 1%. This implies that all the independent variables in the model jointly explain the variations in the dependent variable (participants’ BLLs) at a precision of 99.9%. However, the R Squared value was low.

The results reveal that only two variables have a significant relationship with the amount of lead in the blood of e-waste workers and workers not in e-waste. These were residence (place of stay) and frequency of changing work clothes. Residence was measured as a dummy variable where the a priori hypothesis was that e-waste and secondary workers who permanently reside in on-site housing would record higher BLLs compared to those who only come to the site to work. This a priori hypothesis was met and the coefficient of 2.05 suggests that residents at the site are more likely to record 2.05 μg/dL of lead in their blood more than their counterparts who live off-site. This variable was significant at 1% implying that we are 99.9% sure about making this claim. This finding supports our earlier claim that people who spend more time at the site have higher exposure risk of BLLs than those who do not.

Participants’ frequency of changing work clothes was also measured as a dummy variable where those who change their clothes everyday were expected to record lower levels of lead in their blood compared to those who seldom change their clothes. The coefficient was negative implying that our a priori hypothesis was met and the magnitude was −1.34. This implies that, not changing work clothes everyday can increase the lead levels of participants by 1.34 μg/dL compared to their counterparts who change their clothes every day. The level of significance of this variable was 10% implying 90% accuracy and consistency in this claim. The implication of this finding is that participants who do not change their clothes frequently can potentially increase their household members’ (including children’s) exposure to lead. This is most likely because their working clothes normally end up in the household laundry and are mixed with other household clothing, especially before and during washing (see Amankwaa, 2014a, Amankwaa et al., 2016a).

The rest of the variables were not statistically significant but had signs that meet our hypothesis. Age, gender, and alcohol intake meet our a priori expectation which is males, elderly people and those who drink alcohol tend to have higher lead levels in their blood compared to their counterparts. However, the sign for smokers did not meet our a priori expectation which we believe is attributable to they being occasional smokers (see Table 8), Grandjean et al. (1981) and Taylor (2009) have indicated that there is a significant association between smoking and alcohol consumption and blood lead levels.

### 4. Economic/environmental (in)justice in the e-waste economy

The study uses environmental/economic (in)justice to illustrate the distribution of environmental and economic burdens and benefits at the e-waste site (see Schlosberg, 2007). We explored the extent to which workers gave priority to economic rewards (income and job...
progression) and/or occupational health rewards (environmental quality and health safety). Unsurprisingly, given the diversity and complexity in the e-waste economy, and the variations in income of workers within the six occupational categories, income remains a high priority for most workers. Indeed, a desire to climb the income ladder as quickly as possible was a motivating factor for job choice by most workers. The majority of participants had ambitions to reach senior positions such as middlemen and scrap dealers, and for this reason, could be seen to have an economic reward orientation. Only a handful of workers had no such ambitions and were happy to remain at their present level while working to improve their occupational and environmental conditions, and on this basis, could be seen to be oriented toward occupational health reward.

The results demonstrate that there is a discernible pattern between one’s position in the e-waste value chain and average daily income and BLLs. At the apex of the income ladder are the scrap dealers who on the average earn GHS 102 (USD 28.41) per day. Just below them are the middlemen, average earning up to GHS 85 (USD 23.67) daily, but with high fluctuations. Refurbishment is a steadier income stream and earnings average GHS 83 (USD 23.11) per day. Recyclers, dismantlers and collectors were the lowest earners recording averages of GHS 65 (USD 18.10), GHS 55 (USD 15.32) and GHS 25 (USD 6.96) per day respectively.

Fig. 3 shows the mean BLLs of e-waste workers and workers not in e-waste and their average daily income. We found that there is a positive relationship between an orientation to economic reward, type of e-waste activity and participants BLLs. For example, while scrap dealers who occupy the highest echelon recorded the lowest BLLs (2.8 μg/dL) collectors and burners, who are at the bottom of the chain, had higher BLLs of 3.5 μg/dL and 5.0 μg/dL respectively.

This finding is important as it suggests that the low earners among the six occupational groups face adverse health effects. This uneven weight of occupational health risks borne by the marginalized in the e-waste economy contravenes the principles of environmental justice, which seeks to ensure equitable spatial distribution of environmental risks (in combination with broader social and economic justice issues) irrespective of class, nationality, ethnicity, gender or religion (see Schlosberg, 2007; Hull, 2010). Clearly, the findings underscore an unequal distribution of income and the double burden of health risks among workers at the Agbogbloshie site. It is those with the lower income that also carry the highest health risk. This observation of possible ‘environmental/economic injustice’ constitutes a useful frame for further work at the site. This frame will help to target interventions that can empower those with the least economic standing while simultaneously improving environmental and public health protections. This call relates to the United Nations Environmental Programme’s position that there is an established link between poverty and the increased risk of exposure to toxic and hazardous chemicals (UNEP, United Nations Environment Programme, 2010). Hull (2010) for example indicates that activities that emit toxic chemicals into the environment are carried out in areas where land values are depressed; where the residents are poor, uneducated, or otherwise marginalized; and where businesses are likely to encounter little resistance to proceeding.

5. Conclusions

Media and civil society groups have been critical about the health and environmental safety of the Agbogbloshie site almost since it opened (Brigden et al., 2008; Frontline, 2009; Afrol News, 2010). Scholarship has only recently caught up with rigorous studies of the occupational health risks of e-waste workers on the site (see Amankwaa, 2014a; Amankwaa et al., 2016a; 2016b; Srigboh et al., 2016). This study adds to the conversation by disaggregating the e-waste value chain, examining various possible risk factors and using BLLs to empirically observe existing health contaminants.

E-waste recycling in Agbogbloshie is still rudimentary and the industry depends mainly on manual processing. Although there is significant coordination between market units, e-waste recycling is still organized into occupationally-segregated small business units (e.g. wooden sheds and shipping containers converted into shops). Within this archipelago of small business and overlapping economic activity our study found that health risks are not dependent just on what occupation a worker holds but also on where a worker spends their days. For example, we found that workers who support e-waste activities, such as cooks, stationary vendors and mobile water sellers, have higher average BLLs. And we found that there was no statistical difference between elevated BLLs for e-waste workers and those in supporting occupations.

However, we did find a higher range of BLLs within the population of e-waste workers, and there is a correlation between BLLs and occupational type. For example, we found that those who perform open-pit burning recorded much higher BLLs than those who repair still functional electronic equipment. The findings for open-pit burners put empirical weight behind existing concerns from environmental groups and the international media (Brigden et al., 2008; Frontline, 2009; Afrol News, 2010). We agree with their assertions that burners are most likely contaminated through ingestion and direct skin contact to lead. We also agree with other researchers that open-pit burning may cause lead concentration in the environment, which puts others on the site at risk (Caravanos et al., 2011; Chama et al., 2014; Akortia et al., 2017). However, this requires further study to determine the

### Table 8

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Measurement</th>
<th>A priori sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Gender of workers at site</td>
<td>1 = Male 0 = female</td>
<td>+</td>
</tr>
<tr>
<td>Age</td>
<td>Age of workers at site</td>
<td>Age in years</td>
<td>+</td>
</tr>
<tr>
<td>Residence</td>
<td>Workers place of residence</td>
<td>1 = Resident at site 0 = Otherwise</td>
<td>+</td>
</tr>
<tr>
<td>Alcohol intake</td>
<td>Alcohol intake habits</td>
<td>1 = Takes alcohol 0 = otherwise</td>
<td>+</td>
</tr>
<tr>
<td>Smoke</td>
<td>Smoking habits</td>
<td>1 = Smokes 0 = otherwise</td>
<td>+</td>
</tr>
<tr>
<td>Wash hands</td>
<td>Washing of hands</td>
<td>1 = Yes 0 = no</td>
<td>-</td>
</tr>
<tr>
<td>Change cloths</td>
<td>Frequent changing of cloth</td>
<td>1 = Everyday 0 = otherwise</td>
<td>-</td>
</tr>
</tbody>
</table>

NB: the signs are stated with respect to the amount of lead expected to be in blood samples of workers (dependent variable).
relationship between BLLs, the lead contamination in the environment and the actual risk vectors.

The study also demonstrates significant increasing trends in BLLs with factors secondary to occupation such as residence at the site, on-site working hours, age and frequency of changing work clothes. For instance, older participants tended to have higher BLLs than younger ones. This might have resulted from older participants’ increased exposure over time coupled with their lower rates of excretion. With lead and other metals the level of lead excreted in urine over time coupled with their lower rates of excretion. With lead and other metals the level of lead excreted in urine reflects a person’s body burden and/or long-term exposure in developing any symptom like renal damage (Lanphear et al., 2005). Other factors that may influence the risk of lead toxicity in adults include pre-existing diseases affecting relevant target organs (e.g., hypertension, renal disease, or neurological dysfunction), nutritional deficiencies that modify the absorption or distribution of lead (e.g., low dietary calcium or iron deficiency), and genetic susceptibility (Canfield et al., 2003; Lanphear et al., 2005; Kosnett et al., 2007; Bellinger, 2013). Therefore, we recommend further studies into the health effects of lead concentration in the blood for both the working and non-working populations at the Agbogbloshie site.

The lead exposure among female service workers is particularly worrisome. Prenatal exposure to lead tends to affect several parameters in a developing child (Bellinger, 2013). Studies from China indicate that elevated levels of blood cadmium and lead impair growth, activity levels, adaptability, and mood in children living in e-waste areas with parents working as recyclers (Zheng et al., 2008). Thus, not only e-waste workers or traders are vulnerable. Women who trade at the adjoining food market as well as those who grow vegetables and rear cattle along the Korle Lagoon and Odaw River need to be included in any prevention and mitigation efforts. Indeed, prior studies at the Agbogbloshie site reveal high mean levels and ranges of polybrominated diphenyl ethers (PBDEs) (4.5; 0.86–18 ng/g lw) and polychlorinated biphenyls (PCBs) (62; 15–160 ng/g lw) in breast milk of mothers (Asante et al., 2011, 2012).

Children are another population for concern. Though this study did not look at the relationships between BLLs, it has been established that lead is associated with physical development of children by blocking the absorption of calcium, iron and other elements, and inhibiting the synthesis and utilization of hormones (Huseman et al., 1992; Kosnett et al., 2007; Zheng et al., 2008). Future studies should include children and explore how risk factors interplay to influence their BLLs and development.

It is important to note that there is a current reappraisal of the levels of lead exposure that can be safely tolerated in the workplace. This reappraisal is prompted by recent studies into the effects of exposure to lead, other metals and organobromine compounds like PBDEs through e-waste recycling (Zheng et al., 2008; Liu et al., 2011; Guo et al., 2014). However, the scholarly reappraisal has not engaged Ghana in the way China and India have been studied. Future studies should continue to incorporate the bodies of Ghanaians into the global literature on public health and this locally influential market.

In summary, our findings indicate that all on-site workers, both e-waste and supporting sectors, have high exposure levels to lead contamination. But it is difficult to conclude on the degrees of impact, because of the limited scope of the study and the fact that it did not have prior comparable data on participants’ health. However, the study provides a useful baseline into how informal e-waste recycling, which remains a major source of livelihood for many people, is fraught with health risk (Amankwaa, 2013, 2014b; Yu et al., 2016). The study disaggregates the e-waste sector and raises questions about the health and safety of traders, visitors, and residents in the immediate environment. This includes food safety in the nearby market, and vegetables grown and animals reared on the site. Therefore, it is important to raise public awareness and involve local government to invest in occupational health and safety through infrastructure for the safe management of e-waste. Structures that must consider the variable risks, the existing market for e-waste and the livelihood demands of workers (Oteng-Ababio et al., 2014b).

We believe that severe limitations on the e-waste economy are not the right solutions, and urge instead investments in safe handling of materials. The e-waste economy provides a valuable economic lifeline to scavengers who roam the city collecting waste items and thereby beautify the city while reducing government expenditures on waste transportation. The e-waste economy is vital to dismantlers who salvage electronic components that would otherwise go into the landfill, bringing them back into the economy. E-waste is crucial to the lives of burners who extract valuable metals like gold, aluminum and iron to feed the local smelting industries and reduce the demand for mining rare earth metals. The e-waste market supports repairers whose entrepreneurial ingenuity extend the lifespan of electronic products, providing affordable alternatives to the next generation of local IT students and professionals. E-waste provides important inputs for scrap dealers who sustain local manufacturing and the export market. And finally, all sectors of the e-waste market provide significant remittances for Northern Ghanaian families that props up the local economy and reduces north-south migration and poverty.

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