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Soil contamination from lead battery manufacturing and recycling in seven African countries

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ABSTRACT

Lead battery recycling is a growing hazardous industry throughout Africa. We investigated potential soil contamination inside and outside formal sector recycling plants in seven countries. We collected 118 soil samples at 15 recycling plants and one battery manufacturing site and analyzed them for total lead. Lead levels in soils ranged from < 40–140,000 mg/kg. Overall mean lead concentrations were ~23,200 mg/kg but, average lead levels were 22-fold greater for soil samples from inside plant sites than from those collected outside these facilities. Arithmetic mean lead concentrations in soil samples from communities surrounding these plants were ~2600 mg/kg. As the lead battery industry in Africa continues to expand, it is expected that the number and size of lead battery recycling plants will grow to meet the forecasted demand. There is an immediate need to address ongoing exposures in surrounding communities, emissions from this industry and to regulate site closure financing procedures to ensure that we do not leave behind a legacy of lead contamination that will impact millions in communities throughout Africa.

1. Introduction

Lead battery recycling plants around the world have been identified as major sources of soil contamination that contribute to lead exposures in surrounding communities. The remediation of soils from impacted communities around these plants is a complex and expensive undertaking that is often postponed for years due to the lack of a legally responsible party to pay for the cleanup. In Africa, very few sites have been tested, but extensive contamination from both formal and informal sector lead battery recycling has been documented in communities in Kenya and Senegal in recent years (Haefliger et al., 2009; Kenya Ministry of Health, 2015).

The lead battery recycling industry is expanding globally along with the market for lead batteries. African countries are importing a growing number of used vehicles each with a used lead battery that will require replacement contributing to the approximately 42 million vehicles already in use on the continent (Deloitte Touche Tohmatsu Limited, 2017). Off-grid solar power installations are expected to continue to expand at a Combined Annual Growth Rate (CAGR) of 34% through 2020 and reach 44 million households in Africa (Bloomberg New Energy Finance, 2016). The majority of these off-grid systems will continue to rely on lead batteries for storage. Additional industries reliant on lead batteries including cellular phone networks, and uninterrupted power supplies (UPS) used to backup computers and other equipment are experiencing significant growth. It is expected that the capacity to recycle lead batteries will continue to expand in Africa to process this growing volume of used batteries.

Currently, few industry-specific regulations are in place to mandate pollution control technology or limit emissions from lead battery recycling plants in Africa. Most countries rely on general provisions within environmental laws to oversee lead battery recycling plant performance and operational requirements. In recent years, countries

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including China and the U.S. have tightened regulations governing this extremely hazardous industry as there has been a growing awareness of the impacts of these operations on public health in neighboring communities.

Many lead battery recycling plants around the world have been recognized as sources of airborne lead emissions that have resulted in lead contamination of soil and dust. Other research has focused on informal lead battery recycling and documented soil contamination in and around such activities. For example, a cluster of lead poisoning cases linked to soil contamination from informal lead battery recycling was recorded in an area outside of Dakar, Senegal that was addressed with extensive site remediation (Haefliger et al., 2009). Extensive soil contamination was also noted in sample locations throughout a village in Vietnam that was a known center for lead battery recycling and other metal reclamation (Daniell et al., 2015). Blood lead levels among children tested in this village were also significantly elevated.

Recycling plants in China, Kenya, and Brazil, have been identified as sources of elevated blood lead levels in surrounding communities (Zhang et al., 2016; Kenya Ministry of Health, 2015; de Freitas, 2007). Some of these sites have only come under scrutiny after the recycling plants have ceased to operate. In these cases, and from others reported in the U.S., investigations have demonstrated a link between blood lead levels and lead contamination that persists in topsoil (California Department of Public Health, 2016; U.S. Agency for Toxic Substances and Disease Registry, 2011). Most studies focused on these exposure sources have shown an inverse relationship between blood lead levels and distance from the recycling plant location (Zhang et al., 2016; Dugan, 1983). A 2011 literature review found that children living near formal sector lead battery manufacturing and recycling facilities had a mean blood lead level (BLL) of 29 μg/dl, in ten studies from seven developing countries (Gottesfeld and Pokhrel, 2011).

To better assess contamination around formal sector industrial sites, we sampled soils for lead content around 15 lead battery recycling plants and one lead battery manufacturing facility in seven African countries. We focused our study on representative formal sector recycling plants operating with government approval to recycle used lead batteries. At seven of the plants we also tested soil samples from inside the properties at locations surrounding the processing and smelting facilities. In two cases, the facilities had closed before the time of our testing.

2. Methods

We selected countries in Africa with licensed or formal sector lead battery recycling facilities from geographically diverse regions to include at least one country in West, North, East and Southern Africa. We developed lists of licensed recycling facilities in Cameroon, Ghana, Kenya, Mozambique, Nigeria, Tanzania, and Tunisia. Lead battery recycling plants were identified through Internet websites, interviews, site visits, and government records. A total of 16 sites were selected for testing. In most of the countries, all identified plants were included in the testing protocol except in Nigeria where sampling was limited to four plants that were located in or around Lagos.

A standard sampling protocol was used to collect surface soil from the top 0–3 cm at representative locations within a 0.5 km radius from each facility. At each sample location, 5–10 sub-samples from bare soil within a one square meter area were included as a composite and placed in a labeled and sealed plastic sampling bag. An attempt was made to collect off-site samples from each direction (North, South, East and West) of the facility to account for variable prevailing winds and dispersion patterns. In some cases there was no access to adjacent properties and therefore additional samples were taken from one of the other sides of the facility. Individual sample locations were selected by convenience to be representative of bare soil conditions. Samples were collected from soil inside lead battery recycling plant properties where access was provided at four plants in Ghana and three plant sites in Nigeria.

Each facility address was recorded along with location coordinates from a handheld GPS unit. Information on land use in the surrounding area around the plants was recorded from direct observation and from reviewing aerial satellite images. Descriptions for samples collected off-site included information on land use characteristics, direction from plant and approximate distance from the property fence line. For samples collected inside the plant sites, data were recorded on the direction and distance from the structure housing the smelter at each facility. Photographs were also taken to document land usage in representative sample locations.

A total of 118 soil samples were collected including 73 from areas outside of the facilities and 45 from inside plant boundaries. Samples were transported via air freight carrier to EMSL Laboratories (USA) for analysis. Total lead concentrations were analyzed by flame Atomic Absorption Spectroscopy (AAS) with EPA method SW 846 3050B/7000B. Sample results less than the limit of detection were replaced with the detection limit (36 mg/kg) divided by 2 for the purpose of providing a statistical summary (U.S. Environmental Protection Agency, 2000).

3. Results and discussion

The arithmetic mean soil lead concentration for the 118 sample locations was 23,200 mg/kg and results ranged from < 40–140,000 mg/kg. However, average lead concentrations were 22-fold greater for samples collected from inside plant sites than from samples collected outside the fence line at these facilities. Arithmetic mean lead concentrations were 2600 mg/kg on the outside of plants and 57,700 mg/kg on the inside of plants (See Tables 1 and 2). In addition, all samples collected inside the facilities exceeded the U.S. Environmental Protection Agency residential soil hazard level of 400 mg/kg whereas 42% of samples from locations outside of the plants exceeded this value. In addition, 93% of samples collected from inside the facilities had lead soil concentrations greater than or equal to 1200 mg/kg the U.S. Environmental Protection Agency criteria for industrial sites.

Overall, 85% of the soil samples taken inside and outside these 16 facilities exceeded 80 mg/kg lead – the soil screening level criteria used by the California Department of Toxic Substances Control for residential site remediation (California Environmental Protection Agency, 2009). At least one sampling site in all seven countries included in this study exceeded 80 mg/kg.

These results suggest that extensive contamination from the operation of lead battery recycling and manufacturing plants in Africa are a potential health concern to neighboring communities. Surface and groundwater sources may also be impacted from both soil contamination and wastewater discharge. The ongoing release of airborne lead from process stacks, along with fugitive emissions from these facilities, are contributing to soil lead levels that are associated with elevated blood lead levels in children (Kenya Ministry of Health, 2015).

At many of the plant locations tested residential communities were located within 500 m from the recycling plant fence line. Some of the licensed lead battery recycling plants were located close to schools. For example, one of the two facilities included in Cameroon is located within approximately 100 m of a High School and residential district with 30,000 inhabitants. Two of the plant locations in Dar es Salaam, Tanzania are located within 150 m of a large residential area (see Fig. 1). Animal herding has been observed in the direct vicinity of plants in Cameroon and Ghana. In some areas we observed that properties adjacent to recycling plants were used for agriculture purposes.

Piles of used battery cases and uncovered slag and other waste materials were observed inside some of the facilities. The extreme levels of contamination observed in soil from locations within these plants suggest that extensive site cleanup will be required to utilize these locations for any future purpose. One of the plants we tested in Ghana was operating on land leased from another owner (International Lead

Table 1
Soil Lead Levels Inside Lead Battery Recycling Plants.

Country	Lead battery Recycling Plant	Sample #	Lead (mg/kg)
Ghana	Gravita Ltd	GL – 01	42,000
Ghana	Gravita Ltd	GL – 02	24,000
Ghana	Gravita Ltd	GL – 03	17,000
Ghana	Gravita Ltd	GL – 04	100,000
Ghana	Gravita Ltd	GL – 05	54,000
Ghana	Gravita Ltd	GRA 01	110,000
Ghana	Gravita Ltd	GRA 02	59,000
Ghana	Gravita Ltd	GRA 03	8400
Ghana	Gravita Ltd	GRA 04	91,000
Ghana	Success Africa Ghana Ltd.	SAGL – 01	110,000
Ghana	Success Africa Ghana Ltd.	SAGL – 02	100,000
Ghana	Success Africa Ghana Ltd.	SAGL – 03	120,000
Ghana	Success Africa Ghana Ltd.	SAGL – 04	110,000
Ghana	Success Africa Ghana Ltd.	SAGL – 05	120,000
Ghana	Success Africa Ghana Ltd.	SAF 01	120,000
Ghana	Success Africa Ghana Ltd.	SAF 02	130,000
Ghana	Success Africa Ghana Ltd.	SAF 03	100,000
Ghana	Success Africa Ghana Ltd.	SAF 04	100,000
Ghana	Non-ferrous Metal Ghana Ltd.	NFMGL – 01	740
Ghana	Non-ferrous Metal Ghana Ltd.	NFMGL – 02	7100
Ghana	Non-ferrous Metal Ghana Ltd.	NFMGL – 03	14,000
Ghana	Non-ferrous Metal Ghana Ltd.	NFMGL – 04	86,000
Ghana	Non-ferrous Metal Ghana Ltd.	NFMGL – 05	3200
Ghana	Non-ferrous Metal Ghana Ltd.	NFL 01	3400
Ghana	Non-ferrous Metal Ghana Ltd.	NFL 02	13,000
Ghana	Non-ferrous Metal Ghana Ltd.	NFL 03	1,000
Ghana	Non-ferrous Metal Ghana Ltd.	NFL 04	19,000
Ghana	Goldline Ghana Ltd.	GGL – 01	98,000
Ghana	Goldline Ghana Ltd.	GGL – 02	81000
Ghana	Goldline Ghana Ltd.	GGL – 03	29,000
Ghana	Goldline Ghana Ltd.	GGl – 04	14,000
Ghana	Goldline Ghana Ltd.	GGL – 05	37,000
Ghana	Goldline Ghana Ltd.	GL 01	86,000
Ghana	Goldline Ghana Ltd.	GL 02	19,000
Ghana	Goldline Ghana Ltd.	GL03	4200
Ghana	Goldline Ghana Ltd.	GL04	7200
Ghana	Goldline Ghana Ltd.	GL05	5400
Nigeria	Metal World	S1/01/01	83,000
Nigeria	Metal World	S1/01/02	12,000
Nigeria	Metal World	S1/01/03	140,000
Nigeria	Metal World	S1/01/04	100,000
Nigeria	Everest Metal	S2/02/08	130,000
Nigeria	Lloyds Ind. Ltd.	S3/03/09	480
Nigeria	Lloyds Ind. Ltd.	S3/03/010	42,000
Nigeria	Lloyds Ind. Ltd.	S3/03/011	1700
		Mean	**56,730**
		Median	**42,000**
		Std. Dev.	**47,400**
		Range	**480 – 140,000**

Management Center, 2011). To the extent that there are generally no provisions in place to require that lead battery recycling companies set aside funds for eventual site remediation, it is likely that these sites may remain contaminated for generations if abandoned by the current owners and/or operators.

Contaminated soil is a significant source of lead exposure particularly for children. The Centers for Disease Control and Prevention (CDC) estimates that blood lead levels among children generally rise 3–7 micrograms per deciliter (μg/dL) for each increase of 1000 mg/kg of lead in soil. (U.S. Department of Health and Human Services, 2011) In addition, topsoil can be resuspended and has been shown to be a significant source of atmospheric airborne lead which contributes to increased blood lead levels particularly among the youngest children in surrounding communities (Zahran et al., 2013).

Lead hazard levels for soil used by US EPA were set to maintain children's blood lead levels below 10 μg/dl. However, guidelines in the U.S. now call for keeping children's blood lead levels as low as possible and established an action level at 5 μg/dl (Centers for Disease Control and Prevention, 2012). Given that there is no known blood lead level

Table 2
Soil Lead Levels Outside Lead Battery Recycling and Manufacturing Plant Sites.

Country	Lead battery Plant	Sample #	Lead (mg/kg)
Mozambique	Gravita Recycling	22816–01	2900
Mozambique	Gravita Recycling	22816–02	66
Mozambique	Gravita Recycling	22816–03	< 40
Mozambique	Gravita Recycling	22816–04	< 40
Mozambique	Gravita Recycling	22816–05	< 40
Mozambique	Gravita Recycling	22816–06	< 40
Tunisia	ASSAD Recycling	10816–01	83
Tunisia	ASSAD Recycling	10816–02	240
Tunisia	ASSAD Recycling	10816–03	< 40
Tunisia	ASSAD Recycling	10816–04	84
Tunisia	ASSAD Recycling	10816–05	190
Tunisia	ASSAD Recycling	10816–06	< 40
Cameroon	Metafrique	M001	170
Cameroon	Metafrique	M002	240
Cameroon	Metafrique	M003	170
Cameroon	Metafrique	M004	19,000
Cameroon	Metafrique	M005	320
Cameroon	Metafrique	M006	240
Cameroon	Metafrique	M007	< 40
Cameroon	Metafrique	M008	550
Cameroon	Bocom Recycling	B001	260
Cameroon	Bocom Recycling	B002	15,000
Cameroon	Bocom Recycling	B003	2300
Cameroon	Bocom Recycling	B004	1200
Ghana	Gravita Ltd	SGRA 001	680
Ghana	Gravita Ltd	SGRA 002	720
Ghana	Gravita Ltd	SGRA 003	2000
Ghana	Gravita Ltd	SGRA 004	1700
Ghana	Goldline Ghana Ltd.	SGL 001	< 40.0
Ghana	Goldline Ghana Ltd.	SGL 002	5900
Ghana	Goldline Ghana Ltd.	SGL 003	9900
Ghana	Goldline Ghana Ltd.	SGL 004	4500
Ghana	Success Africa Ghana Ltd.	SSAF 001	11,000
Ghana	Success Africa Ghana Ltd.	SSAF 002	350
Ghana	Success Africa Ghana Ltd.	SSAF 003	230
Ghana	Success Africa Ghana Ltd.	SSAF 004	48,000
Ghana	Non-ferrous Metal Ghana Ltd.	SNFL 001	810
Ghana	Non-ferrous Metal Ghana Ltd.	SNFL 002	80
Ghana	Non-ferrous Metal Ghana Ltd.	SNFL 003	260
Ghana	Non-ferrous Metal Ghana Ltd.	SNFL 004	280
Kenya	Lead Battery Recycling Athi River	4500–01	210
Kenya	Lead Battery Recycling Athi River	4500–02	470
Kenya	Lead Battery Recycling Athi River	4500–03	1000
Kenya	Lead Battery Recycling Athi River	4500–04	2600
Kenya	Lead Battery Recycling Athi River	4500–05	1500
Kenya	Lead Battery Recycling Athi River	4500–06	< 40
Kenya	Lead Battery Recycling Athi River	4500–07	46
Kenya	Lead Battery Manufacturing Nairobi	3000–08	610
Kenya	Lead Battery Manufacturing Nairobi	3000–09	930
Kenya	Lead Battery Manufacturing Nairobi	3000–010	490
Nigeria	Everest Metal	S2/02/05	2700
Nigeria	Everest Metal	S2/02/06	1900
Nigeria	Everest Metal	S2/02/07	320
Nigeria	Lloyds Ind. Ltd.	S3/03/012	29,000
Nigeria	Lloyds Ind. Ltd.	S3/03/013	4200
Nigeria	Lloyds Ind. Ltd.	S3/03/018	< 40
Nigeria	Lloyds Ind. Ltd.	S3/03/019	75
Nigeria	Sfurna Global	S4/04/014	370
Nigeria	Sfurna Global	S4/04/015	690
Nigeria	Sfurna Global	S3/04/016	72
Nigeria	Sfurna Global	S4/04/017	< 40
Nigeria	Sfurna Global	S4/04/20	9800
Nigeria	Sfurna Global	S4/04/21	800
Tanzania	OK Plast Limited	311016–01	< 40.0
Tanzania	OK Plast Limited	311016–2	1000
Tanzania	OK Plast Limited	311016–3	390
Tanzania	OK Plast Limited	311016–4	250
Tanzania	OK Plast Limited	311016–5	84
Tanzania	OK Plast Limited	311016–6	210
Tanzania	Gaia Eco Solution	011116–01	210
Tanzania	Gaia Eco Solution	011116–02	350

(continued on next page)

Table 2 (*continued*)

Country	Lead battery Plant	Sample #	Lead (mg/kg)
Tanzania	Gaia Eco Solution	011116–03	54
Tanzania	Gaia Eco Solution	011116–04	210
		Mean	**2600**
		Median	**320**
		Std. Dev.	**7140**
		Range	**< 40 – 48,000**

without impacts on child development, the State of California Environmental Protection Agency revised its action levels to equate to the concentration of lead in soil that can increase a child's blood lead level by 1 µg/dl (California Environmental Protection Agency, 2009). Therefore, in 2009 the State set the California Human Health Screening Level for residential soil to 80 mg/kg and 320 mg/kg for commercial or industrial sites (California Environmental Protection Agency, 2009).

Soil remediation has been shown to be effective at reducing children's blood lead levels in impacted communities (Schoof et al., 2016). A recent review of the literature suggests that some lower cost soil remediation methods may be effective at reducing exposures in lead-contaminated communities (Laidlaw et al., 2017).

3.1. Comparative studies

In one of the plants that was included in our survey Omanwa et al. found lead levels in soil around the plant site in Athi-River, Kenya averaged 3920 mg/kg and 3710 mg/kg in the dry and wet season respectively (Omanwa et al., 2016). In addition, they found considerably higher levels of lead in soil at a location within the recycling plant premises that was used in the past as a dumpsite for slag.

In other countries similar soil contamination from lead battery recycling and manufacturing plants have been reported. For example, samples collected near a secondary lead smelter in northern France showed soil lead values ranging from 880 to 9030 mg/kg (Schneider et al., 2016). Samples collected within one kilometer of a lead battery recycling plant in China included 25 soil samples collected from the top 1–2 cm of the surface. Although median soil lead levels were relatively low at 100 mg/kg, the data showed a statistically significant relationship with the direction and distance from the facility (Zhang et al., 2016). Testing of surface soil lead concentrations in an area outside of a formal sector lead battery recycling plant in Banten Indonesia ranged from 240 to 1780 mg/kg at distances from 300 to 600 m from the plant (Adventini et al., 2017). In addition, lead concentrations in surface soil were inversely proportional to the distance from the smelter.

Several studies have noted that lead levels in topsoil around lead battery recycling plants decreases with depth. A French study near a lead recycling plant found lead concentrations in topsoil of 1930 mg/kg that rapidly decreased to background levels at a depth of 60 cm below ground surface (Cecchi et al., 2008). A recent review article summarizing soil contamination from nonferrous smelters reported that lead is less mobile in soils than cadmium and zinc (Ettler, 2016). The same study also confirmed that prevailing wind direction is a key factor in dispersion and soil deposition patterns.

Our study reported lead contamination of soil collected within seven lead battery recycling plants had an arithmetic mean level of 56,730 with 100% of the samples exceeding 400 mg/kg and 96% exceeding 1000 mg/kg. Few studies have provided similar data on soil lead contamination inside such facilities. One earlier study reported lead concentrations in soil collected on the premises of a shuttered lead battery manufacturing plant in Nigeria. Soil lead levels ranged from 243 to 126,000 mg/kg and 98% of the samples exceeded 400 mg/kg (Adie and Osibanjo, 2009).

Several studies have demonstrated that soil contamination near lead battery recycling plants can lead to significant lead exposures in surrounding communities (Daniell et al., 2015; Levallois et al., 1991; Wang et al., 1992). A review summarizing ten published studies showed that average blood lead levels among children living in the proximity of lead battery recycling plants in developing countries averaged 29 µg/dl

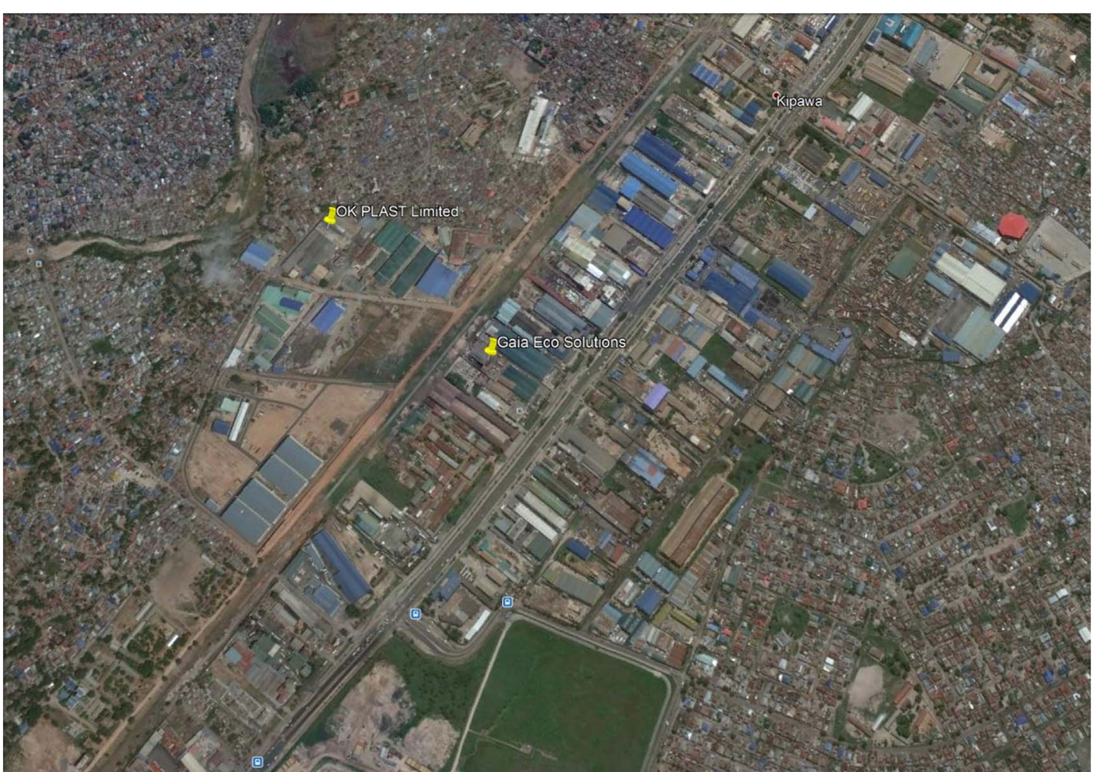

Fig. 1. Location of two Lead Battery Recycling Plants in Dar es Salaam, Tanzania in close proximity to residential areas. NNN.

(Gottesfeld, and Pokhrel, 2011). However, there are many countries with few or even no facilities for testing blood lead levels and there are no population based surveillance systems in the countries included in our survey. There is a need to build capacity for blood lead testing to better assess exposures particularly in high-risk communities near lead battery manufacturing and recycling plants.

3.2. Future challenges

More than 800,000 t of lead is generated from used lead batteries every year in Africa (Reintjes, 2016). As noted, the quantity of lead batteries generated in Africa will grow rapidly in future years following the growth in cell phone towers, UPS systems, solar power and vehicle sales. The projected growth in the use of this technology will necessitate investments in new and/or expanded recycling facilities in Africa. Care should be taken to ensure that improvements are made to reduce emissions and prevent ongoing contamination of soils.

It is important to note that most of the plants included in our study are very small facilities as compared with lead battery recycling plants operating in the U.S., China or EU. For example, one of the included facilities in Ghana has a capacity of 6000 t per annum and the recycling plant in Mozambique can process 4500 t per annum (Gravita, 2016). By contrast, regulations in China require that new facilities have a minimum capacity of 50,000 t per year and existing facilities must have a capacity of 10,000 t per year to ensure the feasibility of installing and operating adequate pollution control equipment (Occupational Knowledge International, 2012). Significant investment is needed to incorporate sufficient baghouse technology, Wet Electrostatic Precipitator (WESP), and High Efficient Particulate Air filters to minimize stack emissions. Significant costs are also incurred in placing production areas under negative pressure enclosures to sufficiently reduce occupational exposures and fugitive emissions.

The United Nations Environment Assembly (UNEA) adopted a resolution during its meeting in 2016 recognizing the growing threat of lead battery recycling to public health and the environment. The resolution noted "the lack of adequate infrastructure needed to recycle the rapidly growing number of waste lead-acid batteries" and "the need to further reduce releases, emissions and exposures" (United Nations Environment Assembly, 2016). The UNEA resolution specifically called for governments to address emissions and exposures from lead battery recycling.

4. Conclusions

Soil lead contamination in and around lead battery recycling and manufacturing facilities in Africa is a long-term health hazard that is unrecognized and generally not being addressed. In many cases the proximity of these plants to residential areas jeopardizes the health and well-being of these communities. Few countries in Africa have industry-specific regulations governing the operations and emissions from lead battery recycling. There is an immediate need to establish such regulation to prevent ongoing emissions and the resulting soil contamination.

As it is apparent that the soil is contaminated outside many of the plants investigated where people are being exposed, there is an immediate need for further investigation and remediation to protect these communities. It is not acceptable to wait until closure of these facilities to address the soil contamination in the community. Environmental regulators should be systematically investigating and ordering the remediation of contaminated soil in these communities. As an interim measure, plant operators should be required to provide appropriate notification to inform the public that the soil where they live is contaminated and the health implications of lead exposure.

As noted, key elements of comprehensive industry-specific regulations should include performance measures for stack emissions, ambient air, occupational exposure levels (airborne and blood lead levels), minimum production capacity for new and existing recycling plants, and waste disposal. In addition, regulatory or permitting provisions should ensure the financial resources are in place to cover the anticipated cost of on-site and off-site remediation following plant closure. Facilities could be required to develop a mitigation plan and secure an adequate bonding mechanism to cover such costs. In some African countries similar provisions are already in place for mining operations and could be extended to these hazardous industrial sites (Morrison-Saunders et al., 2016). In addition to regulation to prevent emissions, it would be ideal to mandate an ongoing assessment of contamination outside lead battery manufacturing and recycling plants, even when they are still operating.

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Competing interests

The authors declare no actual or competing financial interests.

Appendix A. Supporting information

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