Environmental and health impacts of informal electronic waste recycling

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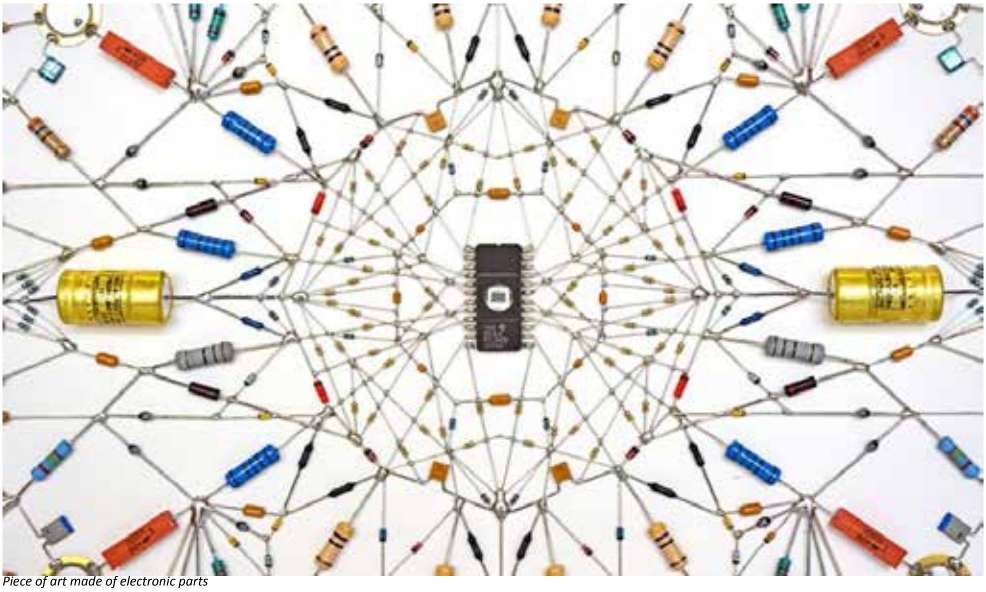
Chapter 1

General Introduction

Do you still remember your old electronic devices?



Piece of art made of electronic parts

Source: Technological mandala 02,
"Electronic echnology has become an important part in our daily life, almost something to worship"
- Leonardo Ulian

1.1 Background

Across the globe, electronic or electrical devices have become indispensable in our daily lives and the use of electronic electrical device is growing at great speed. It is characterized by an increasing number of users and rapid technological advances driven by efficiency, social and economic development. Many people now own multiple personal electronic devices such as information and communication technology (ICT) devices, but the life span of these devices is getting shorter mainly because they become obsolete more quickly compared to the past. In addition, most of these devices are disposed even before they become dysfunctional so as to make space for newer devices with better specifications/ functions. This is evident as most homes possess at least one obsolete electrical device lying somewhere, probably covered in dust and which has not been used in a long time. There is also increasing tendency to electric power previously non-electrical equipment (Baldé, *et al*., 2017; Baldé, *et al*., 2015; Lundgren, 2012. My interest in e-waste recycling sprang during my Master's project on medical waste handling which involved electronic medical equipment waste handling. My findings were quite overwhelming, hence the birth of this PhD research.

The exponentially growing demand for electronic equipment has led to a rapid increase in the rate of electronic waste (e-waste) generated (Baldé *et al*., 2015). E-waste, also known as Waste Electrical and Electronic Equipment (WEEE), consists of electrical and electronic devices at the end of their useful life which includes all separate components such as batteries, circuit boards, plastic casings, cathode-ray tubes, lead capacitors (Baldé, *et al*., 2015; Lundgren, 2012; Robinson, 2009). E-waste is one of the fastest growing municipal waste streams. The annual growth rate is 3–5%, which is approximately three times faster than other municipal solid waste. In 2016, 44.7 million metric tonnes (Mt) of e-waste were generated globally, with Asia generating the highest 18.2Mt (because of their population), Europe (12.3Mt), The Americas (11.3Mt), Africa (2.2Mt), and Oceania (0.7Mt); and this amount is expected to increase to 52.2 million metric tonnes by 2021 (Baldé *et al*., 2017). Only 20% (8.9Mt) of the e-waste generated is collected and recycled formally, the remaining (about 80%) is undocumented (Baldé *et al*., 2017), and is recycled in informal settings or are simply sent to dumpsites/landfills in many developing countries; but large quantities of informal recycling has been reported China, India, Philippines, Vietnam, Thailand, Ghana and Nigeria (Grant *et al*., 2013) Perkins *et al*., 2014). Informal electronic waste recycling includes the dismantling of end-of-life electronics to retrieve valuable elements using crude unsafe methods, without or with very little health and safety precaution. This recycling method releases hazardous substances to the environment (Wong *et al*., 2007a). While, formal electronic waste recycling facilities use specifically designed equipment to safely remove salvageable materials from obsolete electronics while protecting workers from adverse health effects. However, these centres are very expensive to build and run and are rare in less developed countries (Wang, 2008). Especially in countries with no national e-waste regulations, e-waste is treated informally along other general waste, causing health and environmental risks as the e-waste mixture chemicals are released into the environment.

In most developing countries, e-waste is managed informally usually through low-end management alternatives such as product reuse, refurbish/repairs, dismantling to recover valuable parts, disposal in landfills, and open burning. In developing countries there are lots of reuse and repair activities. However, e-waste recycling has provided employment and source of income for many. Also, there are significant economic values of materials recovered from e-waste, especially if the recovery activities are carried out in the developing countries where labour is cheap and environmental and health standards are lax or not enforced (Lundgren, 2012; Terada, 2012). The total value of raw materials present in e-waste is under estimated at 55 billion Euros in 2016, this value is expected to be higher if circular economy models are applied (Baldé *et al*., 2017).

The e-waste management challenges facing the developing countries include:- an absence of infrastructure for appropriate waste management, an absence of legislation dealing specifically with e-waste, an absence of any framework for end-of-life product take-back system, or implementation of extended producer responsibility (EPR) schemes. The take-back system is an ideal scenario aimed at reducing environmental impact. It is usually set up under national e-waste legislations where the e-waste is collected by designated organisations through retailers, municipal collection points and/or pick-up services. The e-waste is then transferred to a formal e-waste treatment facility where the materials are recovered and recycled. Extended Producer Responsibility (EPR) is a policy principle to promote total life cycle environmental improvements of product systems by extending the responsibilities of the manufacturer of the product to various stages of the entire life cycle of the product, and especially to the take-back, recycling and final disposal of the product (Lindhqvist, 2000). EPR focuses on the end-of-life/use treatment of products, and primarily aims at increasing the amount and degree of product recovery to reduce the environmental impact of waste materials. In most developing countries, people who are self-employed go from door-to-door to collect the e-waste, and sell to refurbishers and informal recyclers. These informal collections are not documented (Ogungbuyi *et al*., 2012; Baldé *et. al*, 2017). In Africa only 1% (4Kt) of e-waste is documented to be collected and recycled. And little information is available on the e-waste collection rate in Africa.

Informal work is defined as all economic activities by workers and economic units that are in law or in practice not or insufficiently covered by formal arrangements, i.e., beyond the reach of formal laws; Or Informal sector is any income-generating activities that operate outside the regulatory framework of the state (International Labour Office (ILO), 2014; Meagher, 2013). Workers are casually employed, often by family members, relatives or are self-employed and do not have job security or benefit from social protection (Okechukwu, 2014). In addition, many of them are not aware of available protections or their occupational legal rights. In developing countries, the informal sector is vast and cuts across several different economic fields, including e-waste recycling. It provides services at low cost and is characterised by unsafe working conditions and poor health standards (Fasanya & Onakoya, 2012,The Rockefeller foundation, 2014; Barnes *et al*., 2014). Informal economy flourishes in a context of soaring (formal) unemployment. As a fast growing sector, informal work provides employment for the majority of the African and Asian populations, covering 66% of employment in Sub-Saharan Africa and 82% in South Asia excluding employment in the agricultural sector. Most of the workers work mainly for economic benefits. In this sector, labour standards are not enforced, practices are unregulated or under-regulated, official governance is lacking, and the sector is generally overlooked (The Rockefeller foundation, 2014; Barnes *et al*., 2014). In Africa, over 300,000 work-related deaths, over 44,000 work-related injuries occurred, and over 49 million workers were absent from work for at least four days due to occupational accidents in 2008. Globally, an estimated 2.3 million work-related deaths occur annually, and the economic cost of work-related injury and illness is estimated at 4% of the world's GDP (Gross Domestic Product) (Takala *et al*., 2014; Hämäläinen, 2010). Furthermore, about 2.9 billion workers globally are estimated to be at risk at work, and about 3.5 years of healthy life are lost per 1000 workers globally. Figures of work-related injuries and deaths in the informal sector alone are unavailable. Employment in the informal sector is no longer a journey, but has become the destination of many, and it should be supported by the government (Sparks & Barnett, 2010).

Within the informal sector, the e-waste recycling industry is a young rapidly growing industry. It has created many employment opportunities; affordable access to electronics and parts used for repairs; a continuous supply of raw materials to manufacturers without further exploration of natural resources; and conservation of natural resources and energy required to manufacture new electronics from virgin resources. In Nigeria, the e-waste recycling sector has provided employment opportunities for about 80,000 people. Another advantage of e-waste recycling is that on the average a repair shop receives 20-50 electronic devices daily, and about 68% of the devices are successfully repaired. Unrepairable devices are used as parts for repairs, the remaining is stored for their perceived value for about 6 - 36 months before finally disposal with general waste or sold to scrap dealers, who dismantles to recover valuable materials (Ogungbuyi *et al*., 2012).

About 68% of the informal e-waste recycling involves labour-intensive manual dismantling, shredding, isolation of materials, open burning of plastics from electronics, heating of circuit boards, use of toxic acid baths for metal recovery as practiced in Asia, and open dump disposal (Manomaivibool, 2009, Wong *et al*., 2007b). These unsafe recycling techniques are used to recover valuable materials without or with very little technology to minimise exposure, thus allowing the emission of dangerous chemicals. Occupational safety and environmental protection are clearly not prioritised. In contrast, formal recycling is carried out by organisations with focus on toxicity and pollution control and has an environment, health and safety system in place. Formal recycling also operates under relevant legislations and policies. It involves big-scale investment in infrastructure, high operation cost and overhead internalized environmental cost subsidized by the government.

1.1.1 Legislative Responses to E-waste Management

Due to the international attention on the challenges of informal e-waste recycling, there has been a number of international regulations such as the 1989 Basel convention (Basel convention and UNEP, 1989), the 1991 Bamako Convention (UNEP, 1991), the 1998 Rotterdam convention (UNEP, 2004), 2001 Stockholm convention, 2001 Aarhus Convention (UNECE, 2002), the 2003 Waste Electrical and Electronic Equipment (WEEE) directive (EU, 2003), and the 2006 Nairobi Declaration on Environmentally sound management of e-waste (UNEP, 2006), among others. Countries are encouraged to domesticate these regulations. There is an increase of 44% on the number of countries adopting e-waste regulations since 2014. By 2017, there are 67 countries that have e-waste management laws, of which Nigeria is one of the few countries in Africa that have enacted specific national e-waste policies and legislations. However, the existence of e-waste policies and legislations does not imply effective enforcement of the laws, or a presence of infrastructure for e-waste management. Many of the countries, also do not have the correct statistics of amount of e-waste imported or generated (Baldé *et al*., 2017).

In 2007, Nigeria established a body- National Environmental Standards and Regulations Enforcement Agency (NESREA). NESREA is in charge of e-waste management and environmental protection. Nigeria is a signatory to international treaties and has e-waste specific national legislations regulating import and management of e-waste in Nigeria. Nigerian legislations covering e-waste management include, The National Environmental (Electrical/Electronic Sector) Regulations, (2011), The National Environmental Regulations and the Harmful Waste Act (2011), The National Toxic Dump Watch Programme (NTCWP) (2011), and the guide for Importers of UEEE (Amachree, 2013); among others. Unfortunately, the enforcement of these legislations are weak in developing countries (Terada, 2012). Despite the increasing volumes of e-waste generated over the years, collection and recycling of e-waste are still not improved in developing countries (Ackah, 2017; Baldé *et al*., 2017). Nigeria imports the largest volume of new and used electronic and electrical equipment in Africa (Ogungbuyi *et al*., 2012). In 2005, an estimated 60,000 metric tonnes of used or scrap computers were imported and about 25–75% of these were non-functional (Osibanjo & Nnorom, 2007), (Puckett, *et al*., 2005). Following the stricter legislations, in 2016 only about 19% of the imports were non-functional (Baldé *et al*., 2017). The amount of e-waste generated in Nigeria increased from 219 kilo tonnes in 2014. (Baldé *et al*., 2015), to 277 kilo tonnes in 2016 (Baldé *et al*., 2017). This is an increase of 26% in just 2 years. The majority of the e-waste is recycled in an unsafe/informal manner (Ogungbuyi *et al*., 2012; Baldé *et al*., 2017), releasing chemicals into the surrounding environment, which consequently has become a serious burden on the Nigerian environment and health. Functional but used (second-hand) electronical devices are not considered as hazardous.

1.1.2 Justification for the Study

E-waste contains over 1000 different substances, some of which are hazardous (such as lead, mercury, cadmium, arsenic and beryllium) and persistent organic pollutants (POPs) (including polychlorinated biphenyls and brominated flame retardants) (UNEP-DTIE, 2007). These substances are released as mixture chemicals, so is difficult to assess the effects of exposure to a specific element or compound. When e-waste is improperly recycled or disposed at the landfills or dumpsites, heavy metals, persistent organic pollutants and other chemicals from e-waste are released into the environment compromising the quality of air, water and soil, and affect the biodiversity (animals and plants) in the immediate environment. These hazardous substances can travel hundreds of miles away from the recycling sites, thereby increasing the risk of exposure to a wider range of people and other living organisms. Some pollutants may remain in the soil for a long time, changing the soil chemistry, and may contaminate surface and underground water. The pollutants may also be harmful to micro-organisms in the soil as well as animals that relay on the micro-organisms.

Metal pollution can also affect the plants causing phytotoxicity resulting in weak plant growth, reduced nutrient uptake, reduce nitrogen fixation in legume plants, disorders in plants metabolism (Guala *et al*.; 2010). Metals released into the environment can also settle into the sediment, which would be eventually taken up by aquatic macrophytes and other aquatic organisms (Peng *et al*., 2007). Ingestion of mercury by fish can cause gill damage, and bio-accumulation in organisms like fish can also lead to contamination of the food chain, for example ingestion of mercury contaminated fish can cause neurological problems in humans. In some Asian countries, acids are used to extract precious metals from e-waste. Acidification of the surface water can disrupt marine biodiversity, leading to the reduction of some species. In addition, heavy metals and POPs are non-biodegradable, highly persistent in the environment, and can disturb the ecological balance of the aquatic environment, thus affecting the diversity of the aquatic organisms depending on the extent of the pollution (Ayandiran *et al*., 2009).

The primary and secondary exposure to these mixtures of chemicals is generally via inhalation, dermal contact and ingestion of contaminated soil, dust, air, water, and food. Animals and humans can be exposed via multiple routes. The health effects from exposure to e-waste mixture chemical are a complex process which depend on the route, duration, and frequency of exposure, and age at exposure. Studies have shown that exposure to the mixture of chemicals emitted during e-waste processing induces adverse effects including eye irritation, asthma, acute bronchitis, severe headaches, abdominal pain skin disease, under-development of the brain in children (Wang *et al*., 2012), damage to the nervous system, malfunctioning of the kidneys, respiratory problems, endocrine disruption, adverse pregnancy and birth outcomes, and poor health burden perpetuated through the mother-to-child etc. (Lundgren, 2012; Frazzoli *et al*., 2010; Grant *et al*., 2013). Children are a particularly sensitive group because of additional routes of exposure (e g, breastfeeding and placental exposures), high-risk behaviours (e g, hand-to-mouth activities in early years) (WHO), 2005) Exposure to children can result in not only immediate health effects but health effects at later life. These health problems are most evident when there is direct occupational exposure like in the case of informal e-waste recycling in family homes. Children of e-waste recycling workers also face take-home contamination from their parents' clothes and skin and direct high-level exposure if recycling is taking place in their homes (Grant *et al*., 2013) Despite, the draw backs associated with informal e-waste recycling, it creates employment and livelihood opportunities for many families and their dependents, especially in countries with high unemployment rate. Therefore any policy should consider the socio-economic benefit of this sector, which helps people to earn a decent living without choosing between poverty and poison. This situation in Nigeria is a typical case of informal e-waste recycling practices in countries that lack the resources for safe e-waste recycling. There is low public awareness of the health and the environment risks inherent in unsafe recycling of e-waste in Nigeria. This poses a challenge to policy makers to design effective environmentally sound e-waste management strategies, or tailor made intervention programmes for the reduction/prevention of the negative health effects of informal e-waste recycling. Currently, enforcement of e-waste regulations in Nigeria is weak. The regulations appear to be only made through the lens of the formal sector, which does not consider the challenges and benefits of the informal sector. Therefore, the suggestion that there could more appropriate tailor made intervention programmes in tackling the negative effects of e-waste recycling may be an effective strategy to explore. That strategy must aim to improve the working conditions in informal settings and consider the inputs from the informal sector in decision making processes. This PhD research stems from these concerns. Below is the conceptual framework of impact of informal e-waste recycling, as well as this study. The data and recommendations for better e-waste management offered in this research can be applied in similar situation like Nigeria.

1.1.3 Objectives

Considering the health risks of exposure to e-waste mixture chemicals, the focus of this PhD research is on the impact of informal e-waste recycling on the health of e-waste workers and the environment, this study therefore aims to answer the following questions:

- Are e-waste workers in Nigeria aware of health risks inherent in their daily jobs and what factor influences their awareness?

- What is the prevalence and injury pattern among e-waste workers in the informal sector in Nigeria?

- What is the environmental impact of informal electronic waste recycling on metal, concentrations in soils and dusts?

- Polybrominated Diphenyl Ethers (PBDEs) being one of the most harmful substance, what quantity of Polybrominated Diphenyl Ethers (PBDEs) are released into soils and dusts as a result of various activities at informal electronic waste recycling sites?

- Are there health risks associated with exposure to metal and PBDE at informal e-waste recycling sites? What are the estimated health risks?

Conceptual Framework of Impact of Informal E-waste Recycling

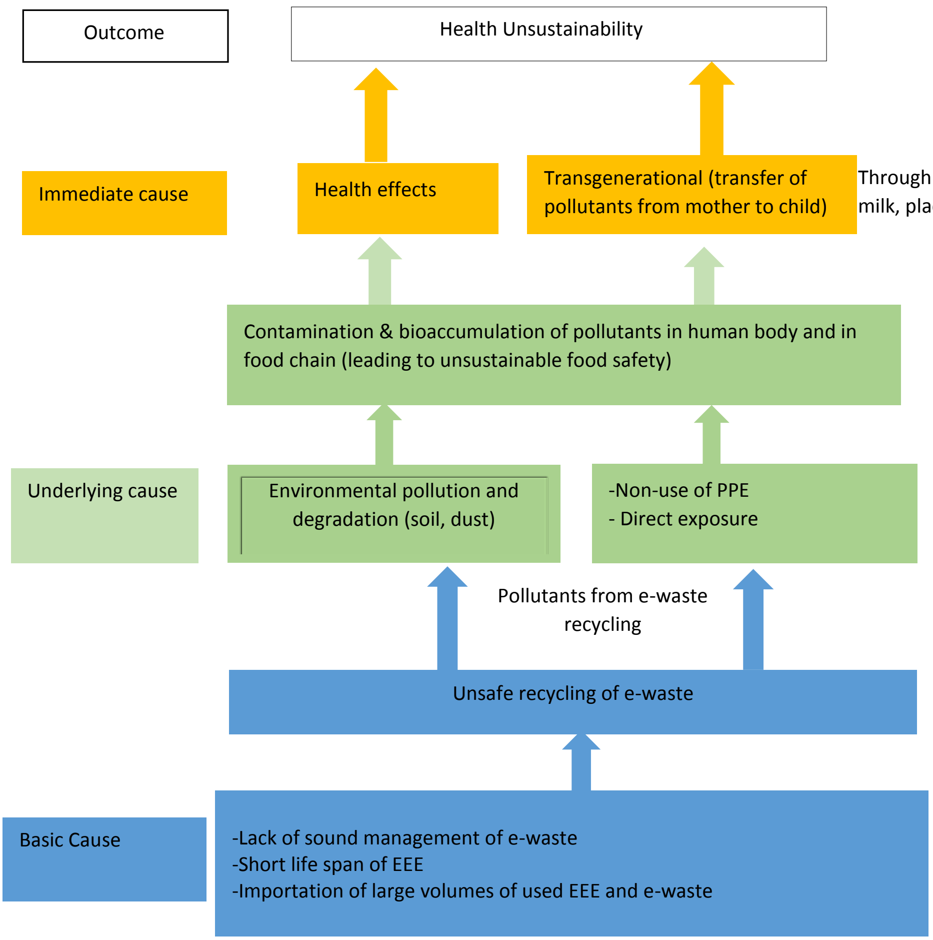


Figure 1.1 Conceptual Framework of Impact of Informal E-waste Recycling

1.2 Methods

1.2.1 Study Location

Figure 1.2: Map of Nigeria showing the Study Locations

The study took place in Nigeria. Nigeria is Africa's most populous nation. Nigeria is grouped into six geopolitical zones and has 36 states and the federal capital territory-Abuja. Nigeria runs three tiers of government structure; Federal Government, State Government and Local Government. The population is estimated at more than 178 million people from the last 2006 census. The population is characterized by a strong rural to urban migration, and annual growth rate estimates are over 3%. As a federation, environmental regulation in the country concerns the thirty six states and one federal capital territory. Each one is mainly responsible for its own environmental issues under various environmental and planning laws. The apex body in Nigeria is the Federal Ministry of Environment with the National Environmental Standards and Regulations Enforcement Agency as the main enforcement body.

The study took place in three cities (Lagos, Ibadan, and Aba) where e-waste is recycled/activities take place. These are some of Nigeria's busiest cities and commercial centers, which attract lots of migrants in search of greener pasture. These cities are densely populated and import a wide range of electronic products. Ibadan (in Oyo State) and Lagos are located in the South-Western and Aba (in Abia State) is located in the South-Eastern geopolitical zones of the country, respectively. The emphasis of the study will be on national tracer products based on prevalence in the market. These national tracer products are the information and communication technologies (ICT) products such as televisions, computers, and mobile phones.

Lagos is Africa's largest city, one of the world's largest cities and the economic centre of Nigeria with a population of 21 million. Lagos has developed into West Africa's main entry point for used and end-of-life electrical and electronic equipment. Annually 71,000 tonnes of used electronics enter Nigeria through the two main sea ports in Lagos (Baldé *et al*., 2017). This quantity excludes importation by air, and personal luggage. Although this equipment is mostly refurbished and sold to households and traders from Nigeria and other West and Central African countries, this sector generates significant amounts of e-waste, a problem that was first brought to public attention in 2005 with the film "The digital dump" by the NGO Basel Action Network (BAN). Lagos has very diverse ethnic groups with Yorubas as the dominant ethnic group. Ibadan is also a major urban settlement and commercial centre in the southwest of Nigeria. Yorubas are the major ethnic group in Ibadan. Aba is a major urban settlement and commercial centre in the southeast of Nigeria. The major ethnic group in Aba is the Igbos. Aba has high lots of markets, industries and fabricating industries. It is surrounded by small villages, towns and other states which depend on Aba for refurbished electronics. The major ethnic group in Aba is the Igbos.

1.2.2 Study Design

This study will adopt comparative cross-sectional study design. A comparative cross-sectional study is a study carried out at one time point or over a short period comparing multiple groups. Cross sectional studies provide a 'snapshot' of the outcome and the characteristics associated with the outcome, at a specific point in time. Cross-sectional studies indicate associations that may exist and are therefore useful in generating hypotheses for future research. Therefore, the comparative cross-sectional study was adopted over other study designs because it would help find the prevalence of health and environmental problems associated with e-waste recycling in Nigeria at a given time point. A multi-stage random systematic sampling technique was used to select the participants from each study location.

Stage one: Selection of a minimum of two study sites from the list of sites per study location

Stage two: Stratification of e-waste workers by type of e-waste recycled

Stage three: Selection of units/clusters

Stage four: Systematic selection of eligible participants from the units

1.2.3 Study Sites

At each study location (city), there were a couple of areas where e-waste is recycled, of which two major e-waste recycling areas were selected. In Lagos, the selected areas were the Computer village Ikeja and the Alaba international market Ojor. Alaba international market is the largest market for new and second-hand electronics in West Africa, with approximately ten to fifteen containers arriving daily from Europe and Asia (with each container containing about 400,000 second-hand units) (Osibanjo & Nnorom, 2007). Computer village Ikeja is a popular place where electronics and their parts (new and second hand) can be purchased and repaired in Lagos. In Ibadan, the selected sites were Ogunpa and Queens Cinema areas. Ogunpa area is known for its activities in scrap/second-hand businesses, which include electronics, while Queens cinema is known for sales and repair of both new and second-hand electronics. In Aba, the shopping centre and Port-Harcourt Road/Cementary and Jubilee road/St Michael's Road were selected. The shopping center area is the biggest market for new and used electronics, while the Port-Harcourt road/Cemetery area is known as an area for scrap/second-hand metal businesses in Aba.

In each selected study area, two sampling e-waste recycling sites and a control site were selected randomly in order to ensure sufficient samples for the required sample size. Within the sampling sites, there is a mix of recycling units (repair workshops, dismantling units, non-electronics shops, offices, and so on) where various e-waste and non e-waste products are processed/sold. The open burning sites are usually far from the other sampling units. Burning sites were also selected at each location. Each sampling site was comprised of hundreds of units/clusters/shops where e-waste is either repaired/refurbished or dismantled/recycled. At each sampling site, systematic sampling techniques were used to select the recycling units. The participants (e-waste workers) were selected from the recycling units to ensure that the selected participants are a representative sample of the selected area. Control groups were also selected from the area. Information on the participant were used to answer research question 1 and 6.

Various E-waste Recycling Sites
Photo credit: Chimere May Ohajinwa, 2015

1.2.4 Study Population

The e-waste workers were split into two job designations (repairers and dismantlers/scavengers). Repairers repair or refurbish old and/or non-functioning electric and electronic equipment into second-hand and functioning equipment either by replacing or repairing defective components and/or by performing cleaning and repair activities in order to make the second hand equipment appealing to the customers. They extend the life time of equipment and feed the second hand market. Most refurbishers also engage in marketing and sales of the refurbished products. Most refurbishers typically specialize on a distinct group of products such as cooling and freezing equipment, air-conditioners, small household equipment, TVs, computers or mobile phones. Dismantlers collect/scavenge, dismantle, and burn e-waste to recover valuable materials. The majority of the scavengers/collectors also engage in dismantling of collected e-waste while some focus on only collection. Informal collectors are typically connected to the scrap metal business, therefore collectors usually do not solely focus on e-waste, but usually on several similar types of waste at the same time.

Butchers were selected as participants for the control group in each study location, because like e-waste workers, butchers constitute a male dominated profession of a comparable socio-economic status. Although a small part of the meat sector is regulated the government, it is also largely an informal sector. Moreover, butchers are also engaged in small-scale enterprises. They make a living from slaughtering and selling meat in abattoirs and markets within the city. Their work involves contact with live animals, their carcasses, blood and body fluids. The inclusion criteria for selecting the study population include those who have been working on e-waste/ used electronics/butchering for at least six months. The person must be at least 18years, and must consent to participate in the study.

1.2.5 Sample Size Determination for the Participants

When conducting research, it is usually impractical to study the whole target population, therefore a subset of the target population which adequately represents the target population is sampled(selected), and every individual has equal chance of been selected. If the sample is small, the results cannot be generalized to the population as the sample is not representative of the target population, and may not be able to detect the difference between groups. On the other hand, if the sample is too large, resources are wasted. Therefore, calculation of an adequate sample size required to be able to arrive at ethically and scientifically valid results. For this study we employed the sample size formula for a comparative study by Kirkwood 2003. In the literature used for the sample size calculation, the solid waste workers had higher health effects (systolic blood pressure) than the workers from control sites (Adienbo *et al*., 2013) Information on the environmental samples were used to answer research question 3,4 and 5.

Using formula for comparative study by (Kirkwood, 2003)

$$n = \frac{2(Z_{\alpha/2}+Z_{1-\beta})^2\ \sigma^2}{(\mu_1 - \mu_2)^2}$$

Where, n = required sample size

$Z_{\alpha/2}$ = Standard normal deviation corresponding to 95% confidence level set at 1.96

$Z_{1-\beta}$ = Standard normal deviation corresponding to 80% statistical power set at 0.84

σ^2 = Standard deviation of the outcome, set at 19.48 (Adienbo *et.al* 2013)

μ_1 = Mean Outcome of experimental group, set at 134.04 (Adienbo *et.al* 2013)

μ_2 = Mean outcome of control group, set at 124.95 (Adienbo *et.al* 2013)

$$n = \frac{2(1.96 + 0.84)^2\ (19.48)^2}{(134.04 - 124.95)^2}$$

$$n = \frac{2(7.28)\ (379.4704)}{(9.09)^2} = 66.8$$

$n = 67$

Calculating for 10% non-response rate

$$n_f = \frac{n}{1 - NR}$$

Where NR= 10% non-response rate

n_f = Adjusted sample size due to attrition

$$n_f = \frac{67}{1 - 10\%}$$

$n_f = 74$

Therefore, the sample size was set at 74 cases and 74 controls =148 for each study location; for three study locations, 444 participants were sampled.

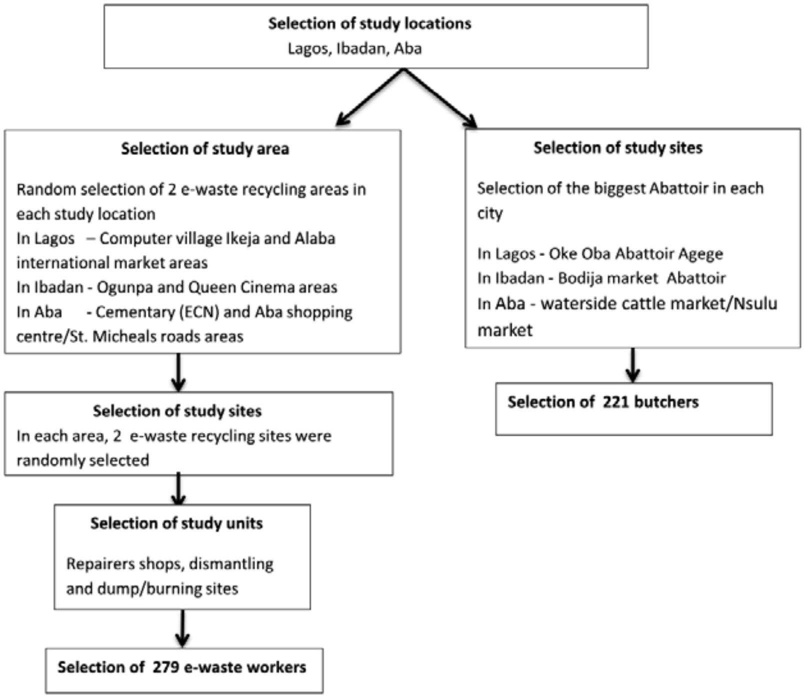


Figure 1.3: Schematic Diagram of Selection of Study Participants

1.2.6 Data Collection from Participants

A semi-structured interviewer-administered questionnaire containing open- and closed-ended questions (see appendix 1) was used to obtain information from the respondents between May and October 2015. One week prior to the actual data collection period, the questionnaire was pre-tested at an area different from the selected sampling areas and the questions were modified based on the experiences gained during the pre-test. Daily monitoring and evaluation was carried out to ensure accurate data collection. The workers were interviewed on their socio-demographic backgrounds, income, occupational history, knowledge, attitude, and work practices (KAP) to assess their awareness level. Information on the health problems experienced, injuries, lung function using peak flow meter, Body Mass Index (BMI) using studio-meter, and cardiovascular parameters using sphygmomanometer. In-depth interview guide and observation checklist was used to obtain information from participants and stakeholders. The questionnaires were serially numbered, to remove identifiers, for retrieval and to ensure completeness. The numbering on the questionnaires was also used to correlate information on questionnaire with other parameters obtained from participants. The data collection instruments will be pre-tested, modified based on information collected, and pre-tested again on 20 participants, and results compared to ensure reliability.

1.2.7 Ethical Considerations

Ethical approval was obtained from the University of Ibadan/University College Hospital Ethical Review Board (No. UI/EC/15/0096), see attached in the appendix. Verbal and written consent of the workers was obtained at the start of the interview, after explaining to the workers their full rights to refuse and to withdraw at any time during the interview. To ensure that the participant remains anonymous each questionnaire was coded with number identifiers. They were also assured that the data will not be used for other purposes than for scientific reasons and for the development of safety promotion programs for the sector. Permission to conduct the study was also obtained from the butchers' union at each abattoir/market and from association of second-hand electronics dealers at each study site.

1.2.8 Environmental (Soil and Dust) Sampling

Environmental samples (soil and dust) were sampled to also investigate the impact of informal e-waste recycling. To know the adequate sample size required to be able to arrive at scientifically valid results, we used the formula below for comparing e-waste sites and the control sites. In the literature used for the sample size calculation, the samples from the e-waste workshop had higher $\sum_8$PBDE concentrations than the samples from the control sites (Leung *et al*., 2008)

1.2.9 Sample size determination for soil and dust sampling

Using the formula for comparative studies by (Kirkwood, 2003):

$$n = \frac{2(Z_{\alpha/2}+Z_{1-\beta})^2\,\sigma^2}{(\mu_1 - \mu_2)^2}$$

Where,

n = required sample size

$Z_{\alpha/2}$ = Standard normal deviation corresponding to 95% confidence level set at 1.96

$Z_{1-\beta}$ = Standard normal deviation corresponding to 80% statistical power set at 0.84

σ^2 = Standard deviation of the outcome, set at 4200ng/g (Leung *et al*., 2008)

μ_1 = Mean Outcome of the experimental group, set at 13600ng/g (Leung *et al*., 2008)

μ_2 = Mean outcome of the control group, set at 144ng/g (Leung *et al*., 2008)

$$n = \frac{2(1.96 + 0.84)^2\,(4{,}200)^2}{(13{,}600 - 144)^2}$$

$$n = \frac{2(7.84)\,(4{,}200)^2}{(13{,}456)^2} = 1.5, \text{ approx. } n = 2$$

Thus, a minimum of two soil samples from the control sites and for each category of e-waste with focus on the four tracer products (TV, mobile phone, computer, and fridge/Air conditioner) was sampled from the e-waste recycling sites in each study location. At each e-waste recycling site, three soil samples of different depths (0-10cm, 10-20cm, 20-30cm) were collected, and where was not possible to collect soil samples, available dust samples (floor dust and/or roadside) were collected, mostly from the repair sites/workshops. Direct dust samples were also collected from inside an outside the body of electronic devices. Three types of e-waste recycling activities sites (burning sites, dismantling sites, and repair sites/shops) were sampled and analysed. In Alaba, Lagos, we found only one big e-waste burning site, which is the largest, oldest, and most studied e-waste burning and dismantling site in Nigeria. In Ogunpa, Ibadan and Cemetery area Aba, the burning sites/spots were much smaller but more spread out in small clusters around the areas.

The control sites were between 100 and 500 meters away from the e-waste recycling sites, and consisted of areas with reduced human activity such as play grounds, parks, fields, and a university garden. Historical information on the control site were taken to ensure that that the control sites has not been used as e-waste recycling site in the past. The purpose of the control site was to serve as a base line against which the results of the soil sampling study could be evaluated. The locations of the sampling spots were georeferenced using a global positioning system (GPS) application on a phone.

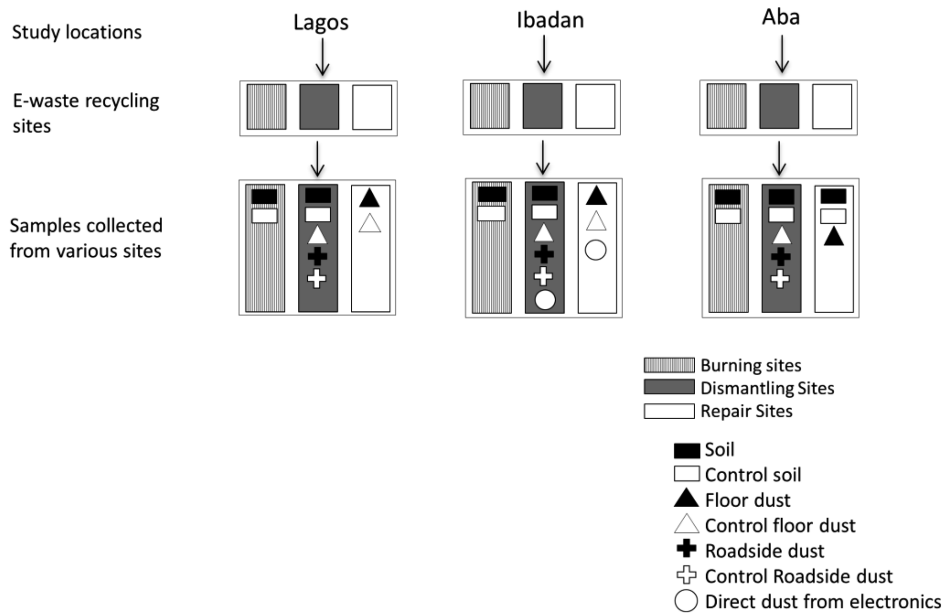


Figure 1.4: Schematic Diagram of Sample Collection for Metal Analysis

The samples were collected between May and November 2015. For soil sampling, each site was divided into grids of about 10m radius, and samples were systematically collected from 3 to 6 points within the site. The samples were bulked together for the top soil (0-10 cm depth) to form a composite representative sample for the specific site. The soil samples were collected using a soil auger, and a soil trowel was used in the transfer of soil from the auger into sample wraps. To avoid cross contamination, the soil probe/auger and trowel were decontaminated (cleaned first with a brush and wiped thoroughly with wet wipes) before each sample collection at each sampling site. Dust samples were collected using plastic brushes to gently sweep the dust and collect it with a dustpan. On the field, the soil and dust samples were wrapped in a treated aluminum foil (treated with acetone and oven dried at 120°C to ensure no traces of POPs in the aluminum foil), labelled, and transported to the laboratory. Soil and dust samples were later air dried for 7 days, avoiding exposure to sunlight homogenized (ground with a mortar and pestle), and sieved through a 1 mm mesh sieve to remove bigger particles, transferred into treated aluminum foil (for metal analysis) and then into a zip-lock bag, and stored at -20 C. Samples for PBDE analysis were transferred into treated individual 10ml amber bottles, labelled and stored at -20º C until shipping to the laboratory for analysis. The amber bottles were washed with tap water and laboratory detergent, rinsed with copious amounts of tap water, rinsed with distilled water for 3 times, then rinsed acetone, hexane, and oven dried. Detail of the laboratory analyis of the samples are in the chapters 3 and 4.

Figure 1.5: Soil Sampling using Dutch Soil Auger (left) at one of the E-waste Recycling Sites
Photo credit: Chimere May Ohajinwa, 2015

1.3 Thesis Outline

The study described the level of awareness of the dangers and impacts of informal e-waste recycling. The thesis comprises seven chapters. The present chapter gives a general overview of the topic and presents the research aims, methods and steps used in the study. Chapter 2 presents the Health Risks Awareness level of the informal e-waste workers on the dangers associated with their daily jobs. The awareness level was determined by assessing the knowledge, attitude, and work practices of the e-waste workers compared to their counterparts in the same informal sector. Chapter 3 unveils impact of informal Electronic Waste Recycling activities on Metal Concentrations in Soils and Dusts. Chapter 4 also unveils Polybrominated Diphenyl Ethers (PBDEs) Concentrations in Soils and Dusts as a result of various activities at Informal Electronic Waste Recycling sites. The environmental impact of the recycling was determined by detailed analysis of effects of various e-waste recycling activities in different types of samples – soil, floor dust, roadside dust, and direct dust from the electronics. Based on the findings, the health effects were assessed. Chapter 5 presents the current prevalence and injury patterns of e-waste workers. Chapter 6 estimates the health risks exposure to e-waste mixture chemicals (PBDE) on the e-waste workers, the synthesis of the findings, and discusses strategies appropriate effective e-waste management in informal sector.

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