UNIVERSITY OF CAPE COAST

EFFECTS OF XENOBIOTICS ON THE HEALTH OF E-WASTE WORKERS IN AGBOGBLOSHIE, ACCRA, GHANA

LUQMAN ABDUL KADIR

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BY

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Thesis submitted to the Department of Environmental Science of the School of Biological Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfillment of the requirements for the award of Master of Philosophy degree in Environmental Science

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:.. Date:..........................

Name: Luqman Abdul Kadir

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:.................................. Date:........................

Name: Prof. Frederick Ato Armah

Co-Supervisor's Signature: .... Date:........................

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ABSTRACT

This thesis evaluated the self-reported health effects of xenobiotics on electronic waste workers in Agbogbloshie, Accra, Ghana. In this occupational setting, many workers do not wear personal protective equipment (PPE), which exposes them to xenobiotics through inhalation, ingestion and dermal contact. The study was mainly quantitative consisting of measurements of concentrations of volatile organic compounds (VOCs) including formaldehyde and methane, and particulate matter of size 2.5 microns in the low, medium and high intensity zones of exposure. In addition, more than two hundred electronic waste workers were surveyed to ascertain linkages between E-waste activity, exposure and reported disease symptoms. There was a strong positive correlation between $PM_{2.5}$ and concentrations of VOCs. However, there were no significant non-carcinogenic health risks to E-waste workers in Agbogbloshie in either the central tendency exposure (CTE) or reasonable maximum exposure (RME) scenarios. The results also indicated a significant positive relationship between educational attainment and level of knowledge of the human health risks associated with exposure to E-waste related smoke. The level of knowledge regarding the environmental and health effects of E-waste was a significant predictor of use of multiple PPE by E-waste workers. Moreover, there was a strong association of E-waste worker use of multiple PPE and reduced self-reported adverse human health outcomes. Based on the above, E-waste workers should be educated and encouraged to use PPE and embrace mechanical alternatives to removing valuable metals from E-waste instead of burning. Also, the government of Ghana and other non-governmental organisations working in the E-waste sector should initiate programmes that subsidize the cost of PPE in order to eventually ensure widespread use by E-waste workers.

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DEDICATION

I dedicate this thesis to my parents Alhaji Abdul Kadir Adam and Hajia Ayishatu Abdul Kadir.

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LIST OF ABBREVIATIONS

AEPS	Agbogbloshie E-waste Processing Site
AQG	Air Quality Guideline
AQI	Air Quality Index
ATSDR	Agency for Toxic Substances and Disease Registry
CADD	Chronic Average Daily Dose
DLI	Department of Labor Industries
EEE	Electrical and Electronic Equipment
EPA	Environmental Protection Agency
GPS	Global Position System
IARC	International Agency for Research on Cancer
ILO	International Labour Office
LADD	Lifetime Average Daily Dose
PAHs	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
PPE	Personal Protective Equipment
VOCs	Volatile Organic Compounds
WHO	World Health Organisation

CHAPTER ONE

INTRODUCTION

Background to the Study

During the last century, many chemicals have been introduced into the biosphere as food additives, herbicides, pesticides, insecticides, industrial waste and medicines. The array of potential hazards which these chemicals can pose to humans is not always clear (Brondz & Brondz, 2011). One class of such chemicals is xenobiotics, which are mainly man-made and found in the environment, mostly including organic substances such as pharmaceuticals, biocides, illicit drugs, cosmetics and surfactants. Simply, xenobiotic refers to chemicals that are either foreign to the body or ecological systems. These chemicals are largely products of industrial synthesis processes, and their ubiquitous presence in the environment is essentially the consequence of human activities (Polesel, 2016). The term xenobiotic also includes substances, which are present in much higher concentrations than are usual in the environment or biota. Drugs such as antibiotics are normally specified as xenobiotics in humans.

Characteristics of xenobiotics include their lipophilic potential, penetration of membranes by diffusion, transport by lipoproteins in the blood, and the requirement of chemical conversion to facilitate excretion. Microorganisms play a major role in degradation of xenobiotics by transforming toxic contaminants into non-hazardous or less hazardous substances. Most of the micro-organisms, particularly bacteria are known for their detoxifying abilities (Tropel & Van der Meer, 2004).

The environment, defined as all the biotic and abiotic factors surrounding a given population, has a significant influence on the health and well-being of a population (Adeola, 2004). Different aspects of the environment including the biological (biotic), physical (abiotic), social, cultural, and technological factors affect the health status of human populations as well as other species within ecosystems (Adeola). Environmental contamination and ecological degradation have a tremendous negative impact on people's well-being (Yassi et al., 2001). Polluted environments escalate the possibility or threat of exposure to agents that may induce illnesses, both for human and non-human species. The principal factor driving the concerns about environmental quality is its connection to human health. Directly through exposure to xenobiotics and indirectly through systemic environmental events, many health problems are inextricably connected to environmental factors (Smith, 2001).

One of the major environmental problems today is the accumulation of recalcitrant xenobiotics in the ecosphere which are relatively stable and persist in the environment for several decades (Hamsavathani, Aysha, & Valli, 2015). Principal xenobiotics include pesticides, fuels, solvents, alkanes, polycyclic hydrocarbons (PAHs), antibiotics, synthetic azo dyes, pollutants (dioxins and polychlorinated biphenyls), poly aromatic, chlorinated and nitro-aromatic compounds (Sinha et al., 2009). The main concern with xenobiotic compounds is the toxicity threat they pose to public health. Xenobiotic compounds can have various toxic effects on humans including acute carcinogenic, mutagenic, teratogenic effects, and so on. The overall damage to the ecosystem caused by xenobiotic compounds has motivated researchers to develop new strategies for their removal from contaminated environments (Hamsavathani et al., 2015).

Humans are exposed to several environmental chemicals including the legacy and emerging persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs) and brominated flame retardants (BFRs) such as polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecanes (HBCDs). PCBs are a complex group of industrial chemicals, whose properties were useful in part because of their resistance to degradation (Asante et al., 2013). Unfortunately, this capability has enabled PCBs to become a wide spread environmental contaminant throughout the global ecosystem. PCBs were widely used as dielectric fluids (in transformers and capacitors) and insulators, in addition to other applications such as plasticizers, surface coatings, inks, adhesives, paints and flame retardants (Agency for Toxic Substances and Disease Registry (ATSDR), 2000).

In the 21st century, electrical and electronic waste (E-waste) has become an emerging environmental and human health problem (Schmidt, 2006, 2002). E-waste refers to the end-of-life electronic products including televisions, monitors, computers, audio and stereo equipment, video cameras, fax/photocopy machines and printers, telephones, motherboards, mobile phones, chips, wire- less devices, cathode ray tubes, and other peripheral items (Frazzoli et al., 2010). These contain harmful chemicals such as brominated flame retardants (BFRs) and classical toxic trace elements like lead (Pb), Cadmium (Cd), Mercury (Hg), Arsenic (As), and Chromium (Cr). Furthermore, rare trace elements, including antimony (Sb), indium (In), and thallium (Tl), which have recently been a topic of concern because of their environmental, behavioural and toxic effects (Ha et al., 2009), are also present in E-waste.

Electronic waste (E-waste) is a growing occupational and environmental health issue around the globe. According to the United Nations Environment Programme (UNEP, 2005), 20–50 million tons of E-waste is generated annually across the world. Of these quantities, significant amounts of E-waste have been exported to developing countries such as China, India, Pakistan, Vietnam, and the Philippines for recycling (UNEP, 2005). Recently, developing nations of West Africa (e.g., Ghana and Nigeria) have become major destinations for E-waste. In these developing countries, there are few infrastructure and protocols to safely recycle and dispose of hazardous E-waste and legislation dealing specifically with their flow and regulations for maintaining the environment and human health are not always effective. Recyclers use primitive methods (manual shredding and open burning) to remove plastic insulation from copper cables. This technique can release highly toxic chemicals and severely affect the environment and human health if improperly managed (Asante et al., 2012).

E-waste recycling is a green industry of emerging importance, especially in low-and middle-income countries where much of this recycling work is performed, and where many people's livelihoods depend on this work (Edumadze et al., 2013). Humans are progressively subjected to exposure to various foreign chemicals (xenobiotics), drugs, food additives, and environmental pollutants. More than 200,000 xenobiotics have been identified.

The lung constitutes the primary site of entry into the body for a wide variety of inhaled chemicals. Many of these chemical substances, including carcinogens and toxicants, pose a risk to the lung (Gram, 1997). As a consequence, the lung is a major target for chemically induced diseases, most notably lung cancer (Hecht, 1999). Inhaled chemicals may also cause deleterious effects outside the respiratory system, as exemplified by tobacco smoke and its harmful effects throughout the body. Similarly, to liver, another site of entry, human lung has defence mechanisms against substances entering the body. Mechanical, cellular, and enzymatic defence mechanisms act to eliminate hazardous chemicals (Hukkanen, 2000).

Volatile Organic compounds (VOCs) which are a category of xenobiotics are chemicals that easily enter the air as gases from some solids or liquids. Volatile organic compounds (VOCs) are carbon-based compounds (with 2-10 carbon atoms) that have vapour pressures high enough to significantly vaporize and enter the atmosphere (Hellén, 2006). Examples of VOCs that may be present in our daily lives include benzene, ethylene glycol, formaldehyde, methylene chloride, tetrachloroethylene, toluene, xylene, and 1, 3-butadiene. Exposure to VOCs can cause acute and chronic toxicity in humans. Volatile organic compounds (VOCs) are emitted from both anthropogenic and biogenic sources (Hewitt, 1999).

The most important anthropogenic sources of VOCs are stationary fuel related (combustion from power plants, extraction and handling of fossil fuels, service stations), transport related (combustive and evaporative emissions from cars) and industrial (mainly solvent use, storage and transport) (Barletta et al., 2005). Biogenic compounds are emitted by vegetation (e.g. isoprene, monoterpenes, sesquiterpenes and oxygenated compounds), by oceans (e.g. methyl iodide, methyl nitrate, dimethyl sulphide), or by soils (e.g. carbonyl sulphide).

Polycyclic aromatic hydrocarbons (PAHs) are produced during incomplete combustion of organic materials, and some are known to be carcinogenic (Strickland, Kang, & Sithisarankul, 1996). PAHs also occur naturally in coal, crude oil and gasoline. PAHs also are present in products made from fossil fuels, such as coal-tar pitch, creosote and asphalt. When coal is converted to natural gas, PAHs can be released into the air during the incomplete burning of fossil fuels and garbage. The health effects of PAH exposure have been widely studied, mainly because they are potentially carcinogenic and mutagenic (Wang et al., 2015). Examples of PAHs include anthracene, phenanthrene, tetracene, chrysene and pyrene. PAHs are emitted to the atmosphere primarily from the incomplete combustion of organic matter. The combustion sources can be either natural or anthropogenic. The natural sources include volcanoes and forest fires. While the anthropogenic sources are vehicle exhaust, agricultural fires, power plants, coke plants, steel plants, foundries and other industrial sources (Abdel-shafy & Mansour, 2016).

One of the largest E-waste dumps in the world is located in Accra, Ghana. Global media attention has been given to the E-waste problem in this West African nation of 26 million people. Specifically, at Agbogbloshie in Accra, the capital of Ghana, where heaps of old computers and their accessories that are unusable are continually being dumped without any regard for the hazard that they pose to the environment and to the people living within the environs of the dump site. In contrast to numerous studies available on environmental pollution by these persistent compounds in developed countries, limited information on human exposure and medium to long term health effects is available in most developing countries, particularly in Africa (Asante et al., 2011).

Particulate Matter (PM) is a mixture of solid particles and or liquid droplets smaller than 10 micrometres that are inhalable by the lung. PM contains chemicals of dust or smoke. There are three different groups of PM, which are all inhalable into our lungs. According to the United States Environmental Protection Agency (EPA) in 2013, PM is differentiated based on its size into PM_{10} (coarse) and $PM_{2.5}$ (fine), and an extended subdivision is additionally the ultrafine PM (USEPA, 2013). PM can either be human-made or occurs naturally. Anthropogenic activities that produces PM include agricultural operations, industrial processes, combustion of wood and fossil fuels, construction and demolition activities, and entrainment of road dust into the air. Natural (non-anthropogenic or biogenic) include windblown dust and wildfires.

Formaldehyde ($H_2C=O$) also known as methanal, formic aldehyde, formol or formalin is a colourless, flammable gas at room temperature which has a pungent, distinct odour and may cause a burning sensation to the eyes, nose, and lungs at high concentrations (WHO, 2002). Formaldehyde is used in embalming fluid, tissue preservative, sterilizer and fumigant in laboratories. It is also commonly used to produce resins, urea-formaldehyde foam insulation, plywood, latex paints, cosmetics, particleboard, adhesives, textiles, plastics and many other products. Formaldehyde is formed primarily by the combustion of organic materials and by a variety of natural and anthropogenic activities. Anthropogenic sources of formaldehyde include fuel combustion, industrial onsite uses, and off-gassing from building materials and consumer products. Secondary formation of formaldehyde occurs in the atmosphere through the oxidation of natural and anthropogenic volatile organic compounds (VOCs) in the air (WHO).

Methane is a natural gas and is denoted CH_4. The gas is colourless, with a melting point at -182.5° C, a boiling point at -164° C, and it is the simplest hydrocarbon, being the first member of the alkane series (Daintith et al., 2010). Methane is a well know greenhouse gas. Human-related sources primarily in the areas of agriculture (livestock and rice cultivation), waste management (landfills, sewage treatment, and manure), and energy (coal, oil and gas production).

Personal Protective Equipment (PPE) is designed to protect employees from serious workplace injuries or illnesses resulting from contact with chemical, radiological, physical, electrical, mechanical, or other workplace hazards (OSHA, 2007). Personal Protective Equipment includes face shields, safety glasses, hard hats, safety shoes, coveralls, gloves, ear protection, vests and respirators (OSHA). Gloves can protect workers' hands from chemicals, hot and cold temperatures, vibration and sharp objects. Full body suits are used by workers to protect most or all of their bodies against heat, cold, radiation, hot metals and liquids, body fluids, or hazardous materials. Also earplugs or earmuffs can help prevent damage to hearing. Exposure to high noise levels can cause irreversible hearing loss as well as physical and psychological stress.

Statement of the Problem

Recent restrictions on import and informal recycling of E-waste in Asian countries are expected to shift the E-waste flow further towards destinations such as Africa (Tue et al., 2016). The developing nations of West Africa (e.g. Ghana and Nigeria) have become major destinations for E-waste worldwide (Asante, Pwamang, Amoyaw-osei, & Ampofo, 2016). In Ghana, most of this electronic equipment ends up as E-waste in Agbogbloshie where workers manually dismantle, heat and openly burn E-waste materials to recover metals and other valuables contained E-waste materials. However, at Agbogbloshie, there are a lot of unprotected workers, who are exposed to these xenobiotic through inhalation, ingestion and dermal contact and also residents in the vicinity are at risk. Lots of work has been done on the effects of these xenobiotics on the quality of the work environment in Agbogbloshie. However, few studies have evaluated disparities in adverse human health outcomes between E-waste workers who use PPE and their counterparts who do not use PPE. It is therefore necessary to assess whether adverse human health outcomes in this work environment systematically varies with continued use of PPE or not. Few workers use personal protective equipment and there is the need to drive their behaviour in the occupational setting towards more sustainable environmental health practices. This observational study will inform the enforcement of policy on environmental health and safety practices in the E-waste occupational setting in Ghana.

Purpose of the Study

The purpose of the study was to assess the health effects of xenobiotics on electronic waste workers.

Objectives

The objectives of the study were to

1. Determine the relationship between educational attainment, level of knowledge of health risk associated with smoke from burning E-waste and use of multiple PPE by E-waste workers.

2. Determine whether there are associations between occupational and residential status and self-reported experiences of disease symptoms.

3. Measure the concentration of VOCs (methane and formaldehyde) in ambient air of the E-waste work environment.

4. Measure the levels of particulate matter ($PM_{2.5}$) in the E-waste work environment.

5. Assess the non-carcinogenic human health risk associated with exposure to the measured contaminants in the air inhaled by E-waste workers.

Hypotheses

The following hypotheses were formulated to guide the study:

1. H_0: There is no relationship between educational attainment, level of knowledge of health risk associated with smoke from burning E-waste and use of multiple PPE by E-waste workers.

   H_1: There is a relationship between educational attainment, level of knowledge of health risk associated with smoke from burning E-waste and use of multiple PPE by E-waste workers.

2. H_0: There is no relationship between occupational and residential status and self-reported experiences of disease symptoms.

   H_1: There is a relationship between occupational and residential status and self-reported experiences of disease symptoms.

3. H_0: There is no relationship between the use of PPE and self-reported human health outcomes of E-waste workers.

   H_1: There is a relationship between use of PPE and self-reported human health outcomes of E-waste workers.

4. H_0: There is no relationship between the level of $PM_{2.5}$ and VOC at each zone.

   H_1: There is a relationship between the level of $PM_{2.5}$ and VOC at each zone.

5. H_0: There is no difference in the level of non-carcinogenic health risk posed to E-waste workers and their non-E-waste counterparts.

   H_1: There is a significant difference in the level of non-carcinogenic health risk posed to E-waste workers and their non-E-waste counterparts.

Significance of the Study

The environmental contamination found in the Ghanaian samples, suggests children working on and living near E-waste sites in Ghana could be exposed to toxic chemicals (Kuper & Hojsik, 2008). This calls for research on the exposure of E-waste workers to contaminants in their work environment. It also requires the need to assess how use of PPE systematically reduces exposure of E-waste workers to the deleterious effects of contaminants in environment in order to drive the behaviour of non-compliant workers towards sustainable practices.

Human health effects of xenobiotics on the health of E-waste workers will continue to engage the attention of both research scholars and policy makers. The significance of the study cannot be overrated. The result generated will add up to existing literature. Again, the result will contribute to better understanding of the importance of using PPE by E-waste workers. Also, the findings will provide useful information to guide NGOs, environmental agencies and policy makers in formulation and implementation of policies on the side effects of burning E-waste and the adverse human health outcomes to both the E-waste workers and people staying in and around Agbogbloshie.

Delimitation of the Study

The scope of this study was to find the human health risks associated with exposure to xenobiotics by E-waste workers in Agbogbloshie in Accra, Ghana. The findings of this research cannot be generalized to other occupational settings in Ghana.

Limitations of the Study

Findings of this study should be considered in the light of some limitations. One of such limitations was that only concentration of methane and formaldehyde was used to assess the non-carcinogenic health risk. Also, although there are several exposure routes, only inhalation was considered. Consequently, the overall human health risk calculated in this study may be an underestimation. The Risk Integrated Software for Clean ups (RISC) used in the assessment was built on several assumptions that definitely influence the results of the study. The symptoms experienced by participants are events in the past. The capacity of respondents to recall or remember accurately how many times and how long they experienced health problems is a potential limitation. In addition, the UNI-T (UT338C) hand held air monitoring was very sensitive. Social desirability bias where respondent provides information that will be viewed favourably rather than their actual day to day practice may also have affected the study.

Definition of Terms

Xenobiotics: xenobiotics refers to harmful chemicals which are part of E-waste and are released into the environment during burning and dismantling of E-waste.

E-waste: discarded electronic equipment including fan, laptops and television sets.

E-waste worker: a person who scavengers, dismantles and or is involved in burning of E-waste materials.

Resident non E-waste worker: a person who stays around the E-waste site and is exposed to E-waste related smoke but is not involved with working on E-waste, for example, food sellers/hawkers.

Non-resident non E-waste worker: a person who stays at the control location (Winneba Zongo) and is not exposed to E-waste related smoke.

Organisation of the Study

The rest of the thesis is organised as follows: Chapter two situates the study within the broader context of the burgeoning literature on E-waste. Chapter three focuses on the specific methods that were used to collect data in the field and how the data were analysed. Chapter four deals with the presentation of results obtained. Chapter five is concerned with the discussion of the result presented in Chapter four and Chapter six deals with the conclusion and recommendation.

CHAPTER TWO

LITERATURE REVIEW

Xenobiotics are man-made chemicals found in the environment. The aim of this work was to determine health effects of xenobiotics on people working on E-waste occupational setting. This chapter gives an overview on E-waste and xenobiotics. The selected xenobiotics talked about were Polycyclic Aromatic Hydrocarbons, Volatile Organic Compounds, Particulate Matter 2.5, Formaldehyde and Methane with their sources and effects on human health based on works that earlier researchers have reported. In addition, the importance of personal protective equipment was also reviewed.

E-waste

The term E-waste describes electronic and electrical devices such as computers, cell phones, televisions and refrigerators that have outlived their useful life. Consumption and replacement of these computing and electrical goods in the developed world is quickly growing and as a result the lifespan of E-waste materials is quickly decreasing (Sepúlveda, 2010). The need to dispose of or recycle this waste stream will become more important as the number of obsolete items increases. It is estimated that globally 20-50 million tons of E-waste is generated per year, representing 1-3% of the world's municipal waste (Robinson, 2009). Recycling and disposing of E-waste in high-income countries is relatively more expensive and difficult due to more stringent regulations. In countries where E-waste is regulated, producers are required to establish systems for collection and treatment of items generated, however, as stated in a study on E-waste recycling and disposal by Brigden, Labunska, Santillo and Johnston as much as 75% of items produced in the EU and 80% in the US go unaccounted (Brigden, Labunska, Santillo, Johnston, & 2008).

Some of the E-waste that is deemed obsolete by developed countries is still of use to nations in the developing world which accept E-waste items as second-hand donations. The shipment of E-waste falls under the regulation of the Basel Convention, which is an international treaty to control the transportation of hazardous waste (Caravanos, Clark, Fuller, & Lambertson, 2011). Companies use a loophole in the treaty that allows for the shipment of second-hand donations as a way to also ship unusable items that will end up in landfills or scrap yards, accounting for 75% of what is shipped (Robinson, 2009). E-waste products contain intricate blends of plastics and chemicals, which when not properly handled can be harmful to people and the environment (Leung, Cai, & Wong, 2006). In developing countries where E-waste is dismantled and recycled by hand, harmful chemicals and plastics are introduced into the environment via water, air and soil.

Workers dismantling and burning E-waste to retrieve valuable metals and other materials are exposed to harmful chemicals such as heavy metals, PAHs, VOCs and inorganic acids, which have the potential for long-term and serious health risks (Robinson, 2009). E-waste recycling processes pose dangers of hazardous chemicals through accidental releases and spills as well as releases from toxic dusts during unsafe dismantling and burning of the materials (Tsydenova & Bengtsson, 2010).

Importation of E-waste into Ghana

As new products are continually introduced into the marketplace, consumers replace existing electronic products that are damaged or simply outdated. The resulting mass of electronic products discarded is becoming the fastest growing waste stream in the world leading to polluted environments (Heacock et al., 2015). Although E-waste is not exclusively generated by wealthy countries, such countries contribute substantially to E-waste problems in low to middle income countries due to regulatory ambiguities that allow electrical and electronic equipment (EEE) export for re-use, regardless of actual product functionality (Heacock et al.). Consequently, the export of much discarded EEE infringes transboundary shipment frameworks, such as the Basel Convention, that are meant to reduce waste shipment across national or other political borders (Heacock et al. ; UNEP, 2001).

Despite laws in the European Union (EU) prohibiting the export of hazardous E-waste, thousands of tonnes of EU E-waste end up in developing countries, such as Ghana. It is shipped there in containers labelled "second-hand goods;" as EU law allows reusable goods to be exported. Despite EU guidelines which say electronics can only be considered second-hand reusable goods if they are tested for use and properly packed and labelled, an EU Commission official estimates that 25-75% of such "second hand goods" imported to Africa, are broken and cannot be reused (Van der Herten, 2008).

Ghana has an unregulated and unrestricted import regime for second-hand EEE. In 2009, seventy percent of EEE imports into Ghana were labelled as second-hand products, but most of these imports were near or at end-of-life, and quickly designated as waste due to little or no utility value (Amoyaw-Osei et al., 2011). There are no guidelines in Ghana to differentiate waste from second-hand equipment. Goods that might be usable are often missing vital components or parts. For example, they may not have the correct plug fitted, or the right software installed (Amoyaw-Osei et al.).

The Environment and Human Health

Myers (2002) indicated that scientific knowledge of the impacts of toxic chemicals on health and the environment lags behind our knowledge and ability to synthesize these chemicals. Furthermore, traditional risk assessment is limited because it permits commercialization, distribution and use of these products without a complete understanding of their adverse effects. Among the consequential problems are pervasive environmental contamination and diminution of human health after exposure (Adeola, 2004). Even though environmental hazards and risks have always been present in societies, the technological and chemical revolutions of the 19th and 20th centuries have increased the levels of toxic materials and associated health problems to an unprecedented level in human history (Graham & Miller, 2001). Scientific and technological breakthroughs in the synthesis, production, and release of heterogeneous toxic chemical compounds have contributed to remarkable prosperity on one hand whilst on the other hand, new arrays of unexpected dreadful health problems have been introduced by these chemicals (Adeola).

Asante et al. (2012) conducted studies in Ghana using human breast milk samples (n=42) that were collected from primiparous mothers in 2009 from three locations in Ghana namely Accra (coastal), Kumasi (forest zone), and Tamale (savannah). Prior to this, 25 samples collected from Accra in 2004 were assessed for temporal variation. Total PCBs concentration (sum of 62 congeners) in all the human milk samples varied between 15 and 160 ng/g lipid weight (ng/g lw), with a mean of 62 ng/g lw. At the three locations, concentrations averaged 82 ng/g lw in Accra, 65 ng/g lw in Kumasi, and 30 ng/g lw in Tamale. Statistically significant differences were found between Accra and Tamale ($p<0.001$) as well as Kumasi and Tamale ($p=0.002$). The authors explained that the relatively high concentrations obtained from mothers in Accra suggest that inhabitants of Accra are more exposed, probably due to their higher varied sources of PCBs as Accra is the capital with lot of industries and pollution. The data obtained from all the samples collected from the outskirts of the three cities were pooled together (as rural) and compared with those collected in the three cities (as urban). The comparison between urban and rural areas led to the understanding urbanization influences contamination and exposure. Moreover, lack of statistical difference between urban and rural locations suggests that mothers are uniformly exposed to PCBs regardless of location.

Xenobiotics

Gren (2012) defined xenobiotics as (Greek xenos + bioticos, which means “strange” and “life-related” respectively) a chemical substance that is not a natural component of a living organism. This definition of xenobiotics covers substances that are strange to the target organisms therefore being used mostly as poisons and drugs. A vital group of xenobiotics are those produced by human with artificial chemical structure, to which organisms have not adjusted through prior evolution (Greń).

Environmental xenobiotics are substances, which did not exist in nature before their synthesis by humans. They are becoming increasingly problematic in medicine and environmental systems, since they are relatively new substances and difficult to categorize, and since it is challenging to assess their effects on human health and the environment (Bulucea, Rosen, Mastorakis, Bulucea, & Brindusa, 2012). Xenobiotics could be classified according to their nature (solid, liquid, gas, mineral, organic), their radiation (X-ray, ultraviolet, infrared, radioactivity) and their origin (natural, synecological, autoecological, chemical, industrial) (Delmail & Labrousse, 2012). They may be also distinguished depending on their environmental targets (air, soil, and water), their biological targets (e.g. plants, fungi, mammals, invertebrates) and their cytotoxicity (e.g. cell types, organites) (Delmail et al., 2011). The mode of action of xenobiotics brings information as some xenobiotics have an acute (death) or chronic toxicity (e.g. carcinogenesis, mutagenesis), or synergistic effect on organisms (Delmail et al.).

They could be toxic at infinitesimal concentrations (micro-pollutants) or at a more concentrated range (macro-pollutants) (Delmail et al., 2011). Moreover, their effects have different duration of action so they could be degradable or persistent, or have a half-life like radioelements from several microseconds to many thousands of years (Delmail et al.). Ecological exposure to environmental stressors occurs when a xenobiotic in a form that is bioavailable, reaches an organism (Hinsinger et al., 2005). In order to be bioavailable, a xenobiotic must reach a location on or in an organism where it can cause an effect (Hinsinger et al.).

Degradation of Xenobiotics

Xenobiotic compounds are human-made chemicals that are present in the environment at unnaturally high concentrations (Hamsavathani, Sathak, & Nadu, 2015). Microorganism has the capability of degrading all naturally occurring compounds; this is known as the principle of microbial infallibility (Hamsavathani et al., 2015). Microorganisms are also able to degrade many of the xenobiotic compounds, but they are unable to degrade many others (Hamsavathani et al.). The compounds that resist biodegradation and thereby persist in the environment are recalcitrant (Hamsavathani et al.).

The controlled biodegradation of toxic substrates is substantially hampered by the challenge of substrate delivery. If substrates are added at too high a concentration, the microbes could be inhibited or killed, and if added at too low a concentration the cells metabolic activity could be reduced by substrate limitation. Substrate delivery is further complicated by the fact that as the cell population increases and or the environmental conditions of pH, temperature, etc., change, the desired rate of substrate addition changes as well (Amsden, Bochanysz, & Daugulis, 2003).

Microbial Degradation of Xenobiotics

Microorganisms play a major role in degradation of xenobiotics. They transform toxic contaminants into non-hazardous or less hazardous substances. Most of the micro-organisms, particularly bacteria, are known for their detoxifying abilities (Hamsavathani et al., 2015; Tropel & Van der Meer, 2004). They mineralize, transform or immobilize the pollutants. Examples of aerobic and anaerobic xenobiotics degradative bacteria are *Pseudomonas*, *Gordonia*, *Bacillus*, *Moraxella*, *Micrococcus*, *Escherichia*, *Sphingobium*, *Pandoraea*, *Rhodococcus*, and anaerobic xenobiotics degradative bacteria are *Pelatomaculum*, *Desulphovibrio*, *Methanospirillum*, *Methanosaeta desulfotomaculum*, *Syntrophobacter*, *Syntrophus* (Hamsavathani et al. ; Varsha, Naga & Chenna, 2011).

Aerobic Biodegradation Pathway

Some of the xenobiotics like petroleum hydrocarbons, chlorinated aliphatics, benzene, toluene, phenol, naphthalene, fluorine, pyrene, chloroanilines, pentachlorophenol and dichlorobenzenes are rapidly and potentially degraded by the aerobic degradation process. Many bacterial consortia are capable of growing on these chemicals and they produce enzymes which degrade toxic compounds to non-toxic compounds (Hamsavathani et al., 2015), as shown below.

Xenobiotic compound + O_2 $\rightarrow$ CO_2 + H_2O + biomass + residue(s) (Hamsavathani et al. ; Shimao, 2001).

The process of conversion of biodegradable materials to gases like carbon dioxide, methane, and nitrogen compounds is called mineralization (Hamsavathani et al., 2015). Mineralization process is completed, when all the biodegradable biomass is consumed and all the carbon is converted into carbon dioxide (Hamsavathani et al. ; Kyrikou & Briassoulis 2007).

Effect of Xenobiotics on Human Health

The immune system is especially vulnerable to detrimental effect of xenobiotics and immunotoxicity can result in reduced resistance towards infection, generation of tumours that escape immune surveillance or increased incidence of auto-immune disorders (Vial, Nicolas & Descotes, 1996). Studies on experimental animals and humans have shown that exposure to pesticides, heavy metals, solvents, halogenated and aromatic hydrocarbons and so on can adversely affect the function of immune system. Therapeutic administration of immuno-stimulating agents can have detrimental effects and few environmental chemicals that have immuno-stimulating properties (beryllium, silica, hexachlorobenzene) can have clinical consequences. Besides, a variety of other factors like polymorphisms in xenobiotic-metabolizing enzymes, nutritional status, age, gender etc. can also substantially alter susceptibility to xenobiotics (Banerjee, Chakraborti, Suke, Ahmed, & Tripathi, 2008).

Exposure to Environmental Toxins

Multiple chemical load comes from daily exposure to chemical compounds in indoor and outdoor air, food and water. Xenobiotics like pesticides are now an all pervasive and almost an inescapable part of the environment.

Asante et al. (2016) conducted a research on the release of chlorinated, brominated and mixed halogenated dioxin-related compounds (DRCs) to soils from open burning of E-waste in Agbogbloshie Accra, Ghana. The study examined the concentrations of DRCs including chlorinated, brominated, mixed halogenated dibenzop-dioxins/dibenzofurans (PCDD/Fs, PBDD/Fs, PXDD/Fs) and dioxin-like polychlorinated biphenyls (DLPCBs) in surface soil samples from the Agbogbloshie E-waste recycling site in Ghana. PCDD/F and PBDD/F concentrations at areas where open burning of E-waste goes on ranged between 18–520 and 83–3800 ng/g dry, respectively and were among the highest reported in soils from informal E-waste sites. The concentrations of PCDFs and PBDFs were higher than those of the respective dibenzo-p-dioxins, suggesting combustion and PBDE-containing plastics as principal sources of xenobiotics.

Some Trace Elements found at Agbogbloshie Scrap Yard

Cadmium (Cd) occurs in electronics both as cadmium metal, in some switches and solder joints, and as cadmium compounds in rechargeable batteries, UV stabilisers in older PVC cables and “phosphor” coatings in older cathode ray tubes. Antimony (Sb) is a metal with a variety of industrial uses, including as a flame retardant (as antimony trioxide) and as a trace component of metal solders. Lead (Pb) is widely used in electronic goods, as a major component of solders (as an alloy with tin) and as lead oxide in the glass of cathode ray tubes (televisions and monitors), as well as in lead-acid batteries. Its compounds have also been used as stabilisers in some PVC cables and other products. Phthalates are commonly used to soften plastics, especially PVC. There are substantial concerns about their toxicity.

As a natural element mercury is ubiquitous in the environment approximately 10,000 tons originates from degassing of earth's crust, to this amount approximately 20,000 tons/year is added by anthropogenic activity (Zahir, Rizwi, Haq, & Khan, 2005 ; Hansen & Dasher, 1997). Mercury emissions from the coal smoke are the main source of anthropogenic discharge and mercury pollution in atmosphere. Mothers consuming diet containing mercury pass the toxicant to foetus and to infants through breast milk (Grandjean et al., 1995).

Ostuku et al. (2012) conducted research on trace element contamination around the E-waste recycling site at Agbogbloshie, Accra, Ghana, to determine the concentration of selected trace elements. A total of 10 soil/ash mixtures were collected from the Agbogbloshie market. Concentrations of Cu (50— 22000 mg/kg), Zn (200 — 160000 mg/kg), Pb (100 — 14000 mg/kg) and Sn (<50 — 1000 mg/kg) were extremely high in residual ash derived from combustion of coatings of wire, and Br (20 —1500 mg/kg), As (<50 — 1100 mg/kg) and Hg (<20 — 150 mg/kg) were also at moderately high levels. Concentrations of these metals were found to increase with higher L* value which represents darkness of soil colour. As the black colour of the soil is due to the burning of E-waste materials, it can be presumed that these metals were from E-waste products, and released into the surrounding environment through open burning. Concentration of HCl extractable Pb, As, Se and Cd were 0.01 mg/L and that for Cr was 0.05 mg/L. Pb and As in soil/ash mixtures were at toxic levels. Concentrations of HCl extractable Cu (1 – 200 mg/L), Zn (3 – 1100 mg/L) and Pb (1 – 360 mg/L) were considerably high. Arsenic (0.03 – 0.2 mg/L), Cr (0.05 – 0.4 mg/L), Se (0.1 – 0.3 mg/L) and Cd (0.03 – 0.9 mg/L) were also high. It is clear that soil/ash mixture has significant negative effects on human health. As a result, it is expected that recycler's health might be affected by accidental ingestion of toxic heavy metals through soil.

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds that are mostly colourless, white, or pale yellow solids (Abdel-shafy & Mansour, 2016). They are a ubiquitous group of several hundred chemically related compounds, environmentally persistent with various structures and varied toxicity (Abdel-shafy & Mansour). They have toxic effects on organisms through various actions. Generally, PAHs enter the environment through various routes and are usually found as a mixture containing two or more of these compounds.

Some PAHs are manufactured in the industry. The mechanism of toxicity is considered to interfere with the function of cellular membranes as well as with enzyme systems which are associated with the membrane (Abdel-shafy & Mansour, 2016). It has been proved that PAHs can cause carcinogenic and mutagenic effects and are potent immune-suppressants (Abdel-shafy &

Mansour). PAHs tend to be found in greater concentrations in urban environments than in rural environments because most PAH sources are located in or near urban centres (Abdel-shafy & Mansour). Sixteen PAHs are considered as environmental priority pollutants by the US Environmental Protection Agency (USEPA, 2009).

PAH in Air

Polycyclic aromatic hydrocarbons (PAHs), which are generated from the incomplete combustion of organic (carbonaceous) material, are ubiquitous contaminants in ambient air (IARC, 2010). The atmosphere is the most important means of PAH dispersal; it receives the bulk of the PAH environmental load resulting in PAHs being ubiquitous in the environment Their occurrence in the air has been substantial during the past centuries due to emissions from industrial processes , energy production, motor vehicular traffic, incineration of refuse, and residential heating (Dybing, Schwarze, Nafstad, Victorin, & Penning, 2010).

Mobile sources of PAH are mostly from combustion engine and this include aircraft, shipping, railways, automobiles and other motor vehicles including off-road vehicles and machinery. Agricultural sources of PAH includes the following activities: Stubble burning, open burning of moorland heather for regeneration purposes, open burning of brushwood and so on. All of these activities involve the burning of organic materials under sub-optimum combustion conditions. Natural sources of PAH include the accidental burning of forests, woodland, moorland and so on due to lightning strikes.

Meteorological conditions (such as wind, temperature, humidity) and fuel type (moisture content, green vs. seasoned wood, etc.) may play an important role in the degree of PAH production (EC, 2001). Polycyclic aromatic hydrocarbons are perhaps the most extensively studied components in polluted air, water, soil, and foodstuffs (Kabziñski, Cyran, & Juszczak, 2002) due to their carcinogenicity.

PAH in Soil

Pollution of the environment with petroleum substances containing many highly toxic compounds is extremely dangerous to living organisms. Petroleum substances contain polycyclic aromatic hydrocarbons (PAHs) (Turrio-Baldassarri et al., 2004). Due to their very slow migration persistence and insolubility of their molecules, PAHs accumulate and remain in soil for a very long time (Wyszkowski & Ziółkowska, 2013). It is worth noticing that PAHs are hardly biodegradable. They can undergo biotransformation by attaching to other organic compounds and entering biochemical cycles (Zabłocki et al., 1998). The uptake of PAHs by edible and fodder plants as well as their permeation to potable water may have serious ecological, sanitary and health related consequences (Vácha et al., 2010). PAHs often degrade naturally in the soil. However, if the concentration is very high and solid particles are present, this process is impeded. This process is also a slow one because of the structure of the molecules (Brown, Cruz, Guerrero, Krauthamer, & Rocha, 2007).

Levels and profiles of PAHs have been analyzed in soils from different land uses such as big cities and industrial or agricultural soils around the world revealing that, in general, the greatest amounts of PAHs are found in big cities and heavy industrial areas (Nadal et al., 2007). Rural soil contains carcinogenic PAHs at levels of 10–100 µg/kg originating mainly from atmospheric fallout (Menzie, 1992). For both forest and rural soil, values as high as 1000 µg/kg may occasionally be found. Metropolitan areas have higher PAH concentrations than forest and agricultural areas because of the many sources of fossil fuel combustion. The majority of urban soil concentrations fall in the 600–3000 µg/kg range (Menzie). Values in the order of 1000–3000 µg/kg are regarded as being in the upper range. However, levels of 8000–336000 µg/kg have been reported for road dust (Menzie).

PAH in Water

PAHs in the environment deserve increasing attention for their widespread occurrence and mutagenic, carcinogenic and teratogenic effects (Grimalta, Van-Droogea, Ribes, Fernandez, & Appleby, 2004). Different water sources can be contaminated with PAHs from dry and wet deposition, road runoff, industrial waste water and petroleum spills (Mahgoub, 2016). Generally, the high molecular weight PAH ($\geq$ 4 aromatic rings) are less water soluble, less volatile and more liophilic than lower molecular weight ones (PAHs $\leq$ 3 rings 0.07-32 mg/L; PAHs $\geq$ 4 rings 0.003-0.26 mg/L) (Maliszewska, 1999).

Volatile Organic Compounds (VOCs)

Volatile Organic Compounds are man-made and or naturally occurring highly reactive hydrocarbons, they are among the most toxic chemicals which are detrimental to humans and environment (Berenjian, Chan, & Malmiri, 2012). Benzene, toluene, ethylbenzene and xylenes (BTEX) are the major VOCs emitted mainly through fuel evaporation (Amodio, Gennaro, Marzocca, & Trizio, 2011). Exposure to VOCs can cause acute and chronic toxicity in humans. Common short-term health effects of VOC exposure include eye, nose, throat, and skin irritation, headaches, nausea, dizziness, fatigue and shortness of breath may occur (USEPA, 2007). In addition to cancer risk, VOCs may adversely affect the liver, kidney, spleen, stomach, and heart, as well as the nervous, circulatory, reproductive, and respiratory systems. Some VOCs may affect cognitive abilities, balance, and or coordination (Zogorski et al., 2006).

VOCs in Air

Volatile organic compounds are carbon-based compounds (with 2-10 carbon atoms) that have vapour pressures high enough to significantly vaporize and enter the atmosphere (Hellén, 2006). Many different kinds of VOCs can be found in the air: alkanes, alkenes, alkynes, halogenated hydrocarbons, aromatic hydrocarbons, terpenes, aldehydes, ketones and alcohols. Some of these compounds are toxic or carcinogenic, and therefore there are limit values for their concentrations in the air (U.S. EPA, 2005; EU, 2000). VOCs affect atmospheric chemistry in many ways. In the atmosphere they are oxidized by hydroxyl radicals, ozone, nitrate radicals and halogens

(Cl, Br, I), in addition, some of them can be photolysed. In the presence of nitrogen oxides, they contribute to ozone formation in the lower troposphere (Atkinson, 2000).

Ozone is toxic to humans and nature (WHO, 2003). Each volatile organic compound reacts in the air at a different rate and with different reaction mechanisms. These compounds react with OH radicals, ozone, NO_3 radicals or Cl atoms, or they photolyse. For most of the studied VOCs, the OH reactions are the most important in the daytime (Atkinson, 2000). Nitrite (NO_3) photolyses rapidly in the troposphere and therefore only exists in sufficient concentrations to play a role in night-time chemistry.

VOCs in Soil

Soils act as sources or sinks of volatile organic compounds. In soils, VOCs are mainly produced by plants (Kesselmeier & Staudt, 1999) and microorganisms (Leff & Fierer, 2008). Fuels and chlorinated hydrocarbons may occur in soils in four different forms: dissolved in water, absorbed on solid particles, comprising the soil gas and forming an individual liquid phase known as NAPL (non-aqueous phase liquid) (Konečný, Boháček, Müller, Kovářová, & Sedláčková, 2003).

VOCs in Water

Volatile organic compounds (VOCs) present in ground water are a major concern because most VOCs persist and migrate with ground water to drinking-water supply wells. Some VOCs have very large and ubiquitous usage (Zogorski et al., 2006). The large scale use of solutions of VOCs and products containing some VOCs has resulted in considerable quantities of VOCs released to the environment. Historically, many waste chemicals were disposed of indiscriminately (Zogorski et al.). Because of this practice, VOCs often are the most frequently detected contaminants in soil and ground water at abandoned landfills and dumps, and at many industrial, commercial, and E-waste sites.

The presence of elevated VOC concentrations in drinking water may be a concern to human health because of their potential carcinogenicity (Zogorski et al., 2006). If improperly discarded onto the ground, these chemicals can travel downward through the soil and eventually end up in groundwater. VOCs are not usually found in drinking water that comes from a surface water source, such as a lake, reservoir, or stream, because they tend to evaporate from the water into the air (DEOHS, 1997).

Particulate Matter

Particulate matter (PM) is composed of inert carbonaceous cores with multiple layers of various adsorbed molecules, including metals, organic pollutants, acid salts and biological elements, such as endotoxins, allergens and pollen fragments (Gualtieri et al., 2009). Total suspended particulate (TSP) is a name given to particles of sizes up to about 50µm. The larger particles in this class are too big to get past our noses or throats, and so, they cannot enter our lungs. They are often from wind-blown dust and may cause soiling of buildings and clothes. However, TSP samples may also contain the small PM_{10} and $PM_{2.5}$ particles that may enter into our lungs (Environment

Agency, 2004). PM can exist in solid or liquid form and includes smoke, dust, aerosols, metallic oxides and pollen (USEPA, 2004). The ambient air concentration of particulate matter is universally high in developing areas because of higher road dust loading contributed from ongoing construction or industrial activities (Yang et al., 2001). The extent to which airborne particles penetrate the human respiratory system is determined mainly by size, with possible health effects resulting from the presence of toxic substances (Milford and Davidson, 1985). Visibility degradation is known to be a function of both the size and composition of the airborne particles (Milford & Davidson). A clear distinction is that particles smaller than 2.5 µm penetrate into the alveoli and terminal bronchioles; larger particles of up to 10 µm will deposit primarily in the primary bronchi, and much larger particles (up to 100 µm) will deposit in the nasopharynx (Kelly & Fussell, 2012).

Particulate Matter 2.5

The construction industry is considered an important source of atmospheric pollution due to particulate matter emissions, causing negative impacts on human health and the environment (Araújo, Costa, & Moraes, 2014). Worldwide, it is estimated that air pollution caused by $PM_{2.5}$ (particulate matter less than 2.5 µm in diameter) in the atmosphere is responsible for approximately 0.8 million premature deaths and 6.4 million years of life lost annually (Cohen et al.,2005). Most recent studies focus their attentions on finer particulates ($PM_{2.5}$) because of their ability to penetrate deep into the respiratory system. Aerosol particles are likely to have a long residence time in the atmosphere and can undergo dispersion and transport processes. As the particulate matter is transported from a source to a potential receptor, the pollutant disperses into the surrounding air causing various effects to the floral or fauna inhabitants and the environment (Jimoda, 2012). WHO last revised its AQG values for PM in 2005, as follows: for $PM_{2.5}$: 10 $\mu g/m^3$ for the annual average and 25 $\mu g/m^3$ for the 24-hour mean (not to be exceeded for more than 3 days/year)(World Health Organisation, 2013).

Sources of $PM_{2.5}$ include all types of combustion, such as motor vehicles, power plants, residential wood burning, forest fires, agricultural burning and some industrial processes (USEPA, 2004). Size and chemical composition are among the most important parameters influencing the way in which airborne particles interact with the environment.

Health Effect of Particulate Matter

According to Daly and Zanetti (2007), air pollution is defined as the anthropogenic emission of harmful chemicals that alter the chemical composition of the natural atmosphere and have an adverse effect on the health of living things, an adverse effect on anthropogenic or natural non-living structures or reduce the air's visibility (Araújo et al., 2014). Particulate matter is characterized with major health effects that include effects on the breathing and respiratory systems, the aggravation of existing respiratory and cardiovascular diseases, the alteration of the body's defence systems against foreign materials, damage to lung tissue, carcinogenesis and premature mortality. These health effects are more noticeable in the elderly and children

(USEPA, 2004). The detrimental health impacts of $PM_{2.5}$ emissions are that, they can travel further than coarser dust (particulate matter between 2.5 µm and 10 µm in diameter) and can, therefore affect the health of people living and working in the surrounding area (Resende, 2007). Emissions of particles and dust from construction and burning can also have an impact on indoor air quality in the neighbouring area (Councils London, 2006).

Dust and other air pollution from demolition, burning and construction can impact greatly on the health and quality of the lives of people working on and living close to these sites if they are badly managed (Councils London, 2006). Particulate air pollution can affect the cardiovascular system as well as the lungs, triggering heart attacks and strokes. Lives are shortened not just by days or weeks, but by months or years. Air pollution from particulate matter targets not just the elderly, but also foetuses, infants, children and adolescents. People most at risk are not only those with asthma but also those with heart conditions (USEPA, 2014).

Formaldehyde

Formaldehyde is a gaseous pollutant produced by both human activity and natural sources. It is a colourless, flammable gas at room temperature, has a pungent, distinct odour, and may cause a burning sensation to the eyes, nose, and lungs at high concentrations (ATSDR, 2008). Formaldehyde is produced worldwide on a large scale by catalytic, vapour-phase oxidation of methanol. Formaldehyde is used mainly in the production of various types of resin. Phenolic, urea, and melamine resins have wide uses as adhesives and binders in the wood production, pulp-and-paper, and the synthetic vitreous-fibre industries, in the production of plastics and coatings, and in textile finishing (IARC, 2006). Formaldehyde is also used extensively as an intermediate in the manufacture of industrial chemicals, such as 1,4-butanediol, 4,4′-methyl- one diphenyl diisocyanate, pentaerythritol, and hexamethylenetetramine. Formaldehyde is used directly in aqueous solution (known as formalin) as a disinfectant and preservative in many work environments (IARC).

Formaldehyde is found as a natural product in most living systems and in the environment. It occurs naturally in fruits and some foods, and it is formed endogenously in mammals, including humans, as a consequence of oxidative metabolism. In addition to these natural sources, common non-occupational sources of exposure to formaldehyde include combustion processes, e.g. through emissions from motor vehicles, power plants, incinerators, refineries, wood stoves, and kerosene heaters. Formaldehyde may be released from particle boards, carpets, paints, and varnishes, during cooking of some foods, and during its use as a disinfectant. It is also present in tobacco smoke (IARC, 2006; NTP, 2005). Formaldehyde has a short half-life in the environment because it is removed from the air by photochemical processes and by precipitation and biodegradation (NTP).

Concentrations of formaldehyde in outdoor air are generally below 0.001 mg/m^3 in remote areas and below 0.02 mg/m^3 in urban settings. The levels of formaldehyde in indoor air of houses are typically 0.02–0.06 mg/m^3; indoor combustion sources can significantly increase these levels. Cigarettes may contribute as much as 10–25% of the indoor exposure. A recent study of emissions from mosquito coils found the average concentration of formaldehyde exceeded 100 μg/m^3 (IARC, 2010, 2006; Lee & Wang, 2006). Automobile exhaust is a major source of formaldehyde in ambient air. Recent reports suggest that formaldehyde emissions may be higher from vehicles powered by compressed natural gas compared with those running on ethanol or gasohol (Corrêa & Arbilla, 2005). These emissions may be decreased by substitution of an ethanol-biodiesel-diesel blend for diesel fuel (Shi et al., 2006).

Health Effects of Formaldehyde

A lot of factors determine the harm one will experience from exposure to formaldehyde (ATSDR, 2000). These factors include the dose (how much), the duration (how long), and how you come in contact with it. Also the effect from formaldehyde will depend on age, sex, diet, family traits, lifestyle, and state of health (ATSDR). Formaldehyde is genotoxic, showing properties of both a cancer initiator and promoter (early and late stage carcinogen).

In humans, formaldehyde exposure has been associated with cancers of the lung, nasopharynx and oropharynx, and nasal passages (Berry, McNeely, Beauregard, & Haritos, 2013). When humans are exposed to excess levels of formaldehyde, adverse health effects can result. Symptoms of excess exposure include respiratory irritation; itchy eyes; itchy, runny, or stuffy nose; dry or sore throat; and headache. Contact with formaldehyde can cause skin irritation and dermatitis (Berry et al., 2013). Normally, reactions to formaldehyde end within days or a few weeks of the cessation of exposure. Most people become acclimated to formaldehyde and come to experience its effects more mildly. But some people, especially those with allergic asthma, allergic hay fever, or infantile or childhood eczema, become sensitized and suffer a condition known as allergic contact dermatitis. Those with allergic contact dermatitis suffer itching, redness, swelling, multiple small blisters and scaling whenever subsequent exposure occurs. Sensitized individuals are usually unable to remain in formaldehyde-related jobs (Berry et al.).

Methane

Atmospheric methane (CH_4) is an important greenhouse gas and major contributor to elevated surface ozone concentrations worldwide (Fiore, Jacob, Field, Streets, & Fernandes, 2002). Current atmospheric CH_4 concentrations are 2.5 times greater than preindustrial levels due to anthropogenic emissions from both biological and fossil fuel sources (Mckain et al., 2014).

Methane is a colourless, tasteless gas which is the primary component of natural gas. It is present beneath the earth's surface in vast quantities, but levels in the atmosphere are relatively low. Methane is produced naturally by volcanoes, ruminant animals such as cattle and sheep, decaying plants, extraction of natural gas, coal mining and waste disposal such as landfills. It is a major 'greenhouse gas' that results from such human activities (Bull, 2010) which includes burning of E-waste. In homes, methane is used for cooking and heating. In industry, methane is used to refine petrochemicals and in power stations to drive turbines to create electricity (Bull).

Health Effect of Methane

As methane is present naturally in the atmosphere, the general public may be exposed to very low levels when breathing in air. Using gas appliances in the home may also increase exposure due to improper use or leakage. Occupational exposure to methane may occur in the workplace where it is extracted, produced or used (Bull, 2010). If exposed to methane, the potential adverse health effects that may occur depend on the way people are exposed and the amount to which they are exposed. High levels of methane can displace oxygen in the air and cause oxygen deprivation, which can lead to suffocation (Bull). Breathing high levels of methane can also lead to agitation, slurred speech, nausea, vomiting, facial flushing and headache. In severe cases, breathing and heart complications, coma and death may occur. Skin contact with liquefied methane may cause frostbite (Bull). In terms of routes of exposure, methane is slightly toxic via inhalation. Asphyxia may result if the oxygen concentration is reduced to below 18% by displacement. Methane is an anaesthetic at high concentrations, producing dizziness, headache, loss of coordination and narcosis; extremely high concentrations can cause asphyxiation and death by displacement of oxygen from the breathing atmosphere (Voltaix, 2011). The target organ of methane is the Central Nervous System (Voltaix). Exposure to high levels of methane produces weak central nervous system depressant effects without significant potential for systemic toxicity. At very high levels they act as asphyxiant gases by diluting and displacing oxygen. Signs and symptoms of exposure to methane includes: Nausea, vomiting, difficulty breathing, irregular heartbeat, headache, drowsiness, fatigue, dizziness, disorientation, mood swing, tingling sensation, loss of coordination, suffocation, convulsions, unconsciousness and coma (Voltaix).

Personal Protective Equipment

A healthy workforce is essential for productivity and economic development (WHO, 2015). However, the burden of work-related diseases and injuries is high in developing countries. An estimated 2 million people die each year from work-related diseases causing an economic loss of about 2.8 trillion USD annually, or 4.0 % of the global gross domestic product (GDP) (ILO, 2013). In developing countries, only 5–10 % workers have limited access to basic occupational health services aiming for the primary prevention and control of occupational and work-related diseases and injuries (Ivanov, 2015). It is estimated that about 100 million workers are exposed to occupational hazards (Ma and Yuan, 2009). Due to limited education, workers tend to have poor occupational health knowledge, attitudes, and behaviours. Lack of use of personal protective equipment (PPE) makes them prone to occupational diseases (Chen et al., 2016). There is an urgent need to improve the use of PPE, as a primary prevention to protect workers against occupational hazards.

When an injury occurs in the workplace, not only does the worker suffer but the costs of medical and time loss payments, loss in productivity, costs for a replacement worker, and a potential increase in insurance premium costs can be great (DLI, 2003). Hazards exist in every workplace in many different forms: sharp edges, falling objects, flying sparks, chemicals, noise and a myriad of other potentially dangerous situations (OSHA, 2004).

Personal Protective Equipment (PPE) is an equipment worn by workers to protect against hazards in the environment. Examples of PPE include safety glasses, face shields, respirators, gloves, hard hats, steel-toed shoes, and hearing protection. Moreover, PPE can be a device that protects a worker's body from hazards and any harmful conditions (existing and potential) that may result in injury, illness, or possibly death. PPE may be an item worn on the body, such as gloves, or a device, such as a protective shield or barrier (DLI, 2003). PPE is the least effective way to protect workers because it does not eliminate or reduce the hazard; it only places a barrier between the worker and the hazard. If the PPE fails or is not used, then the worker is not protected from the hazard (DLI). PPE is designed to protect employees from serious workplace injuries or illnesses resulting from contact with chemical, radiological, physical, electrical, mechanical, or other workplace hazards.

Chapter Summary

In this chapter, the available literature reviewed has elucidated important points on E-waste and xenobiotics. With the xenobiotics the sources and human effects of PAH, VOCS, $PM_{2.5}$ methane and formaldehyde were reviewed. Also the use of PPE and its importance were also reviewed. The literature review in relation to E-waste, PAHs, VOCs, $PM_{2.5}$, methane formaldehyde and PPE helped in the development of the questionnaire.

CHAPTER THREE

RESEARCH METHODS

The purpose of the study was to assess the health effects of xenobiotics on people working on E-waste occupational setting in Agbogbloshie, Ghana.This chapter gives information on the study area and how the study was conducted. The order of presentation is as follows: research design, study area, population, sample and sampling procedure, data collection procedure, and data processing and analysis.

Research Design

This is a cross-sectional study which applied the quantitative research methods. Quantitative research involves the collection of data so that information can be quantified and subjected to statistical treatment in order to support or refute “alternate knowledge claims” (Creswell, 2003). Quantitative data can be measured, more or less accurately because it contains some form of magnitude, usually expressed in numbers (Nicholas, 2010). Examples of quantitative data includes; Census figures (population, income, living density, etc.), economic data (share prices, gross national product, tax regimes, etc.) and all measurements in scientific endeavour (Nicholas).

The quantitative research method which was employed through field studies focused mainly on the measurement of $PM_{2.5}$, formaldehyde, methane, VOCs in the E-waste work environment. The concentration of $PM_{2.5}$ and VOC were taken with Air Quality Meter (UNI-T) UT338C. The concentration of methane and formaldehyde were taken with Aeroqual Series 500 monitor.

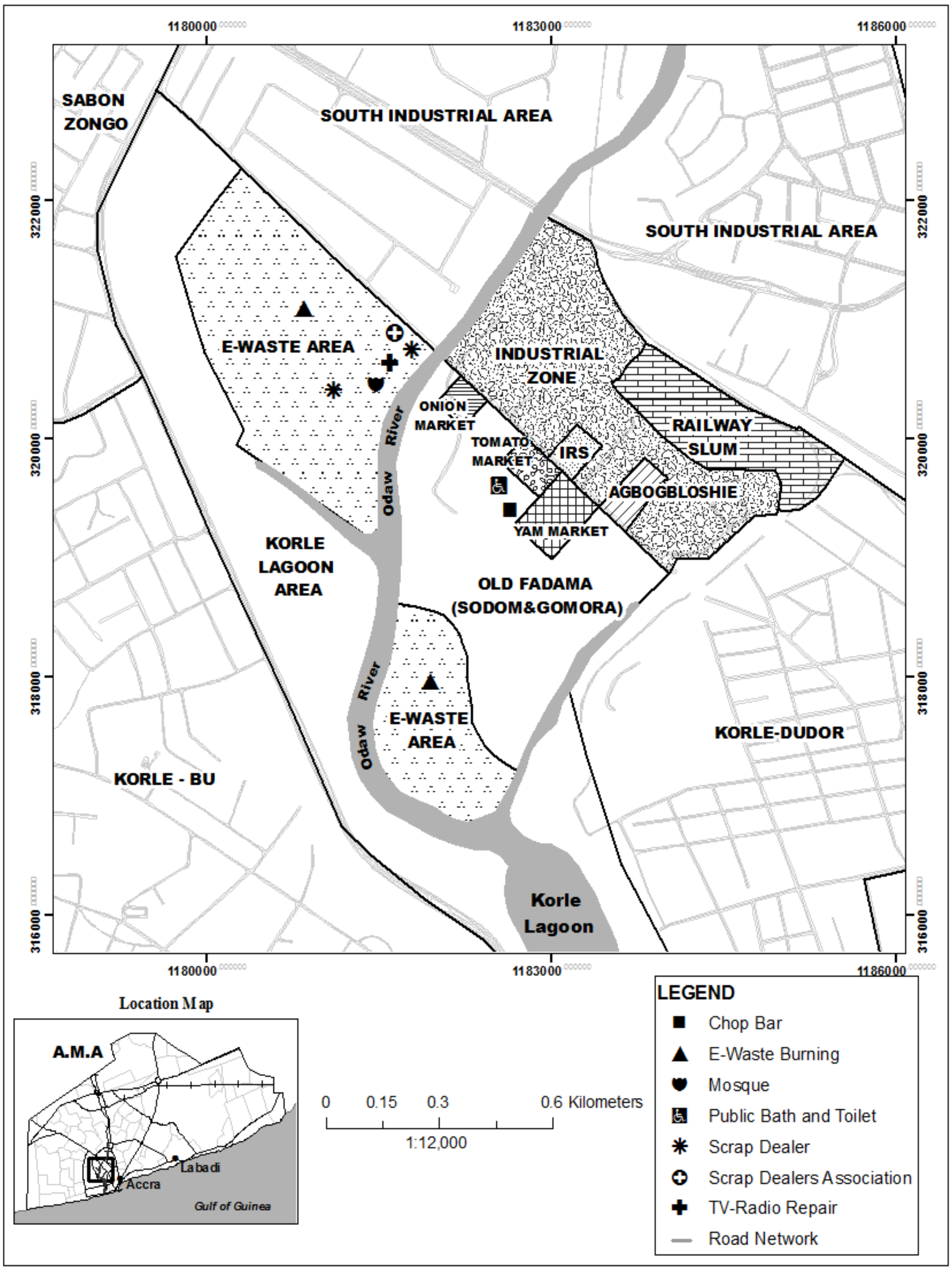

Figure 1: Map of Agbogbloshie Source: Oteng-Ababio, (2012).

Study Area

Location

The work area is the Agbogbloshie scrap yard. The Agbogbloshie scrap yard is located along the banks of the Odaw River and the Korle Lagoon northwest of the Central Business District of the national capital between latitudes 5° 32’ 30’’N and 5° 33’ 30’’ N and on longitude 0° 13’ 30’’W. The Agbogbloshie scrap yard covers an expanse of about 6.2 ha.

Climate

The Agbogbloshie scrap yard lies within the Savanna zone with two rainy seasons and an annual rainfall average of 730 mm during the rainy periods. The zone has fairly uniform temperatures ranging from a monthly mean of 24.7° C in August (coolest) to 28° C in March (hottest) and an annual norm of 26.8°C.

Brief History

According to Amoyaw-Osei et al. (2011), the formation of Agbogbloshie was driven by spill-over population associated with the exodus from the north of Ghana as an outcome of tribal differences, social downward movement by people forced out of more prime areas in the national capital, Accra. Although it started as a foodstuff market for onions and yam, Agbogbloshie has over time turned into a slum with residents and workers dealing in all sorts of activities. Agbogbloshie is well known as a disposal site for old electrical and electronic products and household waste. Dozens of containers of E-waste end up at Agbogbloshie on daily base, where they are taken down to extract copper and other valuable fractions. The custodians of the land, National Youth Council (NYC), permitted the scrap dealers to erect temporary structures to house their wares and activities and in 1994 registered with the NYC as the Scrap Dealers' Association of Ghana. The positioning, now recognized as the Agbogbloshie E-waste processing site (AEPS) has become the primary hub of the informal E-waste recycling industry in Ghana.

Population

AEPS has an estimated population of 40,000 inhabitants who are mainly Ghanaians and other foreign nationals from West Africa. The indigenous ethnic group within the city and the AEPS is Ga, however Oteng-Ababio (2012) indicates that most of the inhabitants or workers within the AEPS are migrants from the northern part of Ghana. Despite the varied age groups within the AEPS, the workforce is mostly young between 15 and 35 years and children as young as 8 years are involved in the E-waste activities. The target population was those working on E-waste and also food sellers and or hawkers at the Agbogbloshie scrap yard. It was estimated that, there were about 500 E-waste workers based on interaction with the E-waste workers.

Sample size

The sample size of 218 respondents was calculated using the sample size calculator based on 5% margin of error and confidence level of 95%. The population of E-waste workers was estimated to be 500 based on inquires made from the E-waste workers. In all 260 respondents were used based on the increasing number of respondents who were willing to participate in the research.

Calculating Sample Size

$$Sample\ size = \left[\frac{\frac{Z^2\ x\ p\ (1-p)}{e^2}}{\left(1+\frac{Z^2\ x\ p\ (1-p)}{e^2\ N}\right)} \right]$$

Where,

N=population size=500

e=margin of error=0.05

z= z-score=1.96

Occupation

Amoyaw-Osei et al. (2011) showed that E-waste and scrap processing as well as foodstuffs trading are the main occupations in the AEPS. The main activities on the E-waste site are dismantling and burning of E-waste.

Social Amenities

Observations made during fieldwork in this study showed that there were no school facilities at the AEP. Some workers live at the worksite environment with their families in wooden structures. Others live 100 metres across the Odaw River in the informal settlement called Sodom and Gomorrah. In addition, there were Mosques around the E-waste site.

Sampling Procedure

The purposive and random sampling method was used in this research. In the first instance, the purposive sampling was used to approach respondent who were 15 years or older and have lived in the study areas for at least one year. Also, the purposive sampling, also known as judgmental, selective or subjective sampling, was used to ascertain which zones could be classified as low, medium or high intensity zones based on the volume of E-waste processed per day, the burning of E-waste and visual smoke. Purposive sampling is a type of non-probability sampling in which sample selection is based on the judgement of the researcher. It has the advantage of enabling the researcher to target subjects (informants) who have specific experiences and special expertise in the subject area under discussion (Marshall, 1996). Due to the cost, resources and time involved in using a very large sample size, it was imperative to make use of purposive sampling technique so as to get enough expert opinions on the subject matter. Once the low, medium and high intensity zones were mapped, random sampling was then used in measuring the concentration of $PM_{2.5}$ and VOCs using the Air Quality meter (UNI-T) UT 338C.

Data Collection Instruments

Data were generated through the use of structured questionnaire based on literature which were in relation to the research objectives. In addition, the hand-held Air Quality meter (UNI-T) UT 338C was used to measure the concentration of VOC and $PM_{2.5}$. The Aeroqual Series 500 monitor was used to measure the concentration of methane and formaldehyde, which are volatile organic compounds. Also, a GPS was used to document the specific locations where air quality was monitored during the period of study.

Data Collection Procedures

Questionnaire

One of the quantitative approaches used in this study was structured questionnaire. Questionnaire was administered by the researcher. There were two separate questionnaire: one for E-waste workers and the other for resident non E-waste workers and non-resident non E-waste workers. In all, 260 copies of the questionnaire were administered. Of the lot, one hundred and forty (140) copies of the questionnaire were given out to the E-waste workers, whereas sixty (60) copies of the questionnaire each were administered to the resident non E-waste workers and non-resident non E-waste workers. This was done from done for 12 weeks (January to March, 2017).

Measurements of concentration of Methane and Formaldehyde

The second quantitative approach involved measurements of indoor air quality parameters carried out at the two geo-referenced location using an air quality monitor (Aeroqual Series 500). The Aeroqual Series 500 monitor is a handheld air quality monitor with the ability to accurately detect and measure multiple gases at different concentrations in real time. During the monitoring process, methane and formaldehyde gas sensors were connected to two Series 500 monitors. The Series 500 monitor was calibrated prior to field deployment using the appropriate span gas. The monitoring period for this location was done for sixty minutes (60) each for each location for both methane and formaldehyde.

Measurement of $PM_{2.5}$ and VOCs

The third quantitative approach involved measurements of particulate matter and volatile organic compounds. The Agbogbloshie scrap yard was divided into three zones (high, medium and low) based on the intensity of visual smoke from burning E-waste and dismantling activities. The low intensity zone had no dismantling and burning of E-waste. The medium intensity zone had few quantities of E-waste being dismantled, medium intensity of visual smoke from burning of E-waste. The high intensity zone had large quantities of E-waste being dismantled and high intensity of visual smoke from burning E-waste. The UNI-T (UT338C) hand held air monitoring device was used to take readings of $PM_{2.5}$ and VOCs. Thirty readings were taken at each zone, and within each location of a selected zone three readings were taken with aid of a GPS. Each reading lasted for three minutes. The control location was Winneba, Zongo and thirty readings were taken with three reading at each location. The readings were taken for a period for eight weeks (February-March, 2017). Winneba Zongo was chosen for two reasons. First, there is no E-waste burning in the community. Second, the community members in Winneba Zongo are closely related to residents of Agbogbloshie in terms of culture, ethnicity, dominant religion and age distribution. This suggests that combustion of E-waste was the main distinguishing feature between the two communities. This is necessary to limit the influence of confounding factors in the study.

Reliability and Validity of Instruments

The Aeroqual Series 500 air quality monitor was properly calibrated with span gas before field deployment. This was done according to the manufacturer's calibration procedures as outlined in the Series 500 Manual. Also, field calibrations of the various sensors were carried out to ensure the quality of the data obtained. Data collected during the monitoring of formaldehyde and methane were ensured through expert validation by Envaserv Research Consult. Also, the UNI-T (UT338C) handheld monitored was calibrated by restarting it using the user manual before taken readings at each visit to study areas.

Informed consent

Permission was sought from the leaders of the study areas and the purposes and details of the study were explained to them. Participant were not forced to participant in the study or financially induced to participate in this study and therefore could choose to participate or not. They were informed that the information provided will contribute to the overall knowledge about the effects of E-waste on their health.

Data Processing and Analysis

Data were analyzed using the IBM SPSS version 20, Stata version 13 and the Risk Integrated Software for Clean Ups (RISC 4.02). The quantitative data analyses employed descriptive statistics, Pearson chi-square and correlation.

The Pearson chi-square statistics was used to determine association between educational attainment and level of knowledge of health risk associated with inhaling E-waste smoke. Also, the Pearson chi-square was used to determine association between educational attainment and use of multiple PPE by E-waste workers. In addition, the Pearson chi-square was used to determine associations between occupational and residential status and self-reported experiences of disease symptoms such as headache, weakness of joints and so on. Again, the Pearson chi-square was used to find associations between E-waste worker use of PPE and self-reported experiences of disease symptoms.

The descriptive statistics was used to evaluate the mean, standard deviation, kurtosis, skewness, minimum and maximum readings of $PM_{2.5}$ and VOCs at each location. The Pearson correlation was used to find the correlation between concentration of $PM_{2.5}$ and VOCs. The RISC software was used to estimate the non-carcinogenic effects.

Assessment of the Carcinogenic Risk and Non-Carcinogenic Risk

The Risk Integrated Software for clean ups was used to estimate the carcinogenic and non-carcinogenic effects. Human health risk assessment can be defined as the characterization of the potential adverse effects on human life or health. US EPA's Risk Assessment Guidance for Superfund, or the "RAGS" manual (US EPA, 1989), characterizes the risk assessment process by dividing it into four basic steps which are data collection and evaluation (hazard identification), exposure assessment, toxicity assessment and risk characterization.

Data collection and evaluation

The Aeroqual Series 500 was used to gather the concentrations of methane and formaldehyde in the sampling locations. With the aid of a Global Position System (GPS) at the Agbogbloshie scrap yard, coordinates of the locations were taken.

Exposure assessment

There may be sundry volatile organic contaminants released at the Agbogbloshie scrap yard but particular attention was given to methane and formaldehyde, and the exposure pathway considered to be inhalation of outdoor air. People living in and around Agbogbloshie scrap yard are at risk to fugitive pollutants**.**

Toxicity assessment

Toxicity Assessment establishes the relationship between the contaminant/s of concern and the receptor. It asks the question, 'what does the contaminant do to the receptor?' The objective of Toxicity Assessment (also known as hazard assessment) is to determine 'what potential adverse effects might the contaminants of concern cause and at what concentration? The contaminants of concern are methane and formaldehyde and the receptors are the individuals working or living in and around Agbogbloshie in Accra.

Risk characterization

Risk characterization is the final phase of the human health risk assessment process. The RISC 4.02 software was used to estimate cancer and non-cancer hazard quotients. This was done for a number of scenarios namely adult resident reasonable maximum exposure, adult resident central tendency exposure, child resident reasonable maximum exposure, child resident central tendency exposure, worker reasonable maximum exposure, worker central tendency exposure as well as trespassers reasonable maximum exposure.

Calculating the Air Quality Index

Air quality index is calculated by a linear function based on the concentration of the pollutant. The equation below is used to compute AQI.

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}} (C - C_{low}) + I_{low}$$ (USEPA, 2014).

Where:

I = the (Air Quality) index,

C = the pollutant concentration,

$C_{\{low\}}$ = the concentration breakpoint that is $\leq$ C,

$C_{\{high\}}$ = the concentration breakpoint that is $\geq$ C,

$I_{\{low\}}$ = the index breakpoint corresponding to $C_{\{low\}}$,

$I_{\{high\}}$ = the index breakpoint corresponding to $C_{\{high\}}$.

Air Quality Index Categories

The AQI is divided in six categories and each category is meant to correspond to different health concern levels. Below is an explanation of the categories and their meanings (USEPA, 2014).

0 – 50 indicates "Good" AQI: At this level the quality of air is deemed to be satisfactory, and air pollution poses little or no risk.

51 – 100 indicates "Moderate" AQI: This means acceptable air quality. However, some pollutants might arouse modest health concern for a limited number of people. For instance, persons who are remarkably sensitive to ozone may experience respiratory symptoms.

101 – 150 indicates "Unhealthy for Sensitive Groups" AQI: This category may not be able to affect the general health of the public. However, children, older adults, and persons with lung disease are at a greater risk from ozone exposure. Older children, adults and people with lung and heart disease are at greater risk from exposure to particulate matter.

151 – 200 indicates "Unhealthy" AQI: In this category, every person might experience some adverse health effects. Sensitive group members may experience more serious effects. People with heart or lung disease, older adults and children should cut back or reschedule strenuous activities.

201 – 300 indicates "Very Unhealthy" AQI: This would issue a health alert to mean that everybody may experience very serious health implications. People with heart or lung disease, older adults and children should significantly cut back or reschedule strenuous activities.

Greater than 300 indicates "Hazardous" AQI: Air quality at this level is life-threatening and would issue warnings of emergency conditions for the entire population.

Chapter Summary

The study was undertaken to assess the health effects of xenobiotics on people working on E-waste. The quantitative approach was used to obtain data. This included measuring the concentration of $PM_{2.5}$, VOCs, methane and formaldehyde. Also, copies of questionnaire were administered to E-waste, non-E-waste workers and non-residents as part of the study.

CHAPTER FOUR

RESULTS

The purpose of the study was to assess the health effects of xenobiotics on people working on E-waste in Accra, Ghana. The quantitative research method was used and the data analyses employed descriptive statistics, Pearson correlation and correlation. Also, carcinogenic and non-carcinogenic health risk assessments were carried out using the RISC (4. 02) software. The results of the study will be presented as follows: descriptive statistics on survey respondents, association of educational attainment and use of multiple PPE, on the one hand, and E-waste workers level of knowledge of the health risk of exposure to smoke, on the other hand. The relationship between the use of multiple PPE and frequency of self-reported adverse health outcomes (skin irritation, eye problems, breathing difficulty, coughing, etc.) will also be presented. Subsequently, descriptive statistics analysis on the chemical contaminants in ambient air in the study area will follow. Then, the human health risk assessment results will be presented, which will be followed by the summary of the chapter.

Characteristics of Study Population

Overall, 70% of respondents were males. Most of the respondents had ages between 21 and 50 years old. Close to 80% of respondents were not formally educated beyond primary school. Only two respondents had attained some form of tertiary education. Half of the respondents were resident in households consisting of 1-5 individuals. Most respondents were of northern extraction with ethnicities such as Dagomba (35%), Konkomba (16%), Gonja

(18%), Sisala (9%) and Akan (10%). Respondents who belonged to Ewe, Ga or other ethnic groups were less than 13% in the sample. Muslims were more than two-thirds of the survey participants.

Table 1: *Characteristics of study population*

		Frequency	**Percent (%)**
Gender	Male	184	70
	Female	76	30
Age	Below 20years	35	13
	21 - 30 years	74	28
	31 - 40 years	91	34
	41 - 50 years	49	19
	51 - 60 years	10	5
	Above 60 years	1	1
Marital Status	Single	126	48
	Married	118	45
	Divorced	6	2
	Widow / Widower	10	5
highest level of educational attainment	Non-Formal Education	99	38
	Primary Education	98	37
	Junior High School/ Middle School	43	16
	Senior High School / Vocational Training	18	8
	Tertiary	2	1
status in the family	Head	176	67
	Spouse of head	21	8
	Child	62	25
house hold size	1 – 5	131	51
	5 – 10	112	42
	Above 10	17	7

Table 1 continued

religion	Muslim	177	67
	Christians	82	32
	Traditional	1	1
nationality	Ghanaian	252	96
	Nigerian	1	1
	Other specify	7	3
ethnicity	Dagomba	90	35
	Komkomba	40	16
	Gonja	48	18
	Sisala	23	9
	Akan	26	10
	Ga	13	5
	Other specify	11	4
	Ewe	9	3

Association of Educational Attainment and Level of Knowledge of Health Risk Associated with Inhaling E-Waste Smoke

Chi-square test indicated that there was a statistically significant relationship between level of knowledge of environmental and human health effects of inhaling E-waste smoke and educational attainment of respondents. From Figure 2, it can be seen that 58% of workers without formal education had high level of knowledge of environmental and human health effects of inhaling E-waste smoke. Forty percent of workers without formal education had moderate knowledge of environmental and human health effects of inhaling E-waste smoke. In addition, 42% of workers without formal education had low knowledge of environmental and human health effects of inhaling E-waste related smoke. Considering those with primary education, 50% had low levels of knowledge on environmental and human health effects of E-waste related smoke, 31% had moderate knowledge on environmental and human health effects of E-waste related smoke and 30% had high levels of knowledge on environmental and human health effects of E-waste smoke.

Considering workers with junior high school education, 11% had high level of knowledge on environmental and human health effects of inhaling E-waste smoke, with 17% and 5% having intermediate and low knowledge on environmental and human health effects of inhaling E-waste smoke, respectively. Considering workers with secondary educational attainment, 11% had intermediate level of knowledge on environmental and human health effects of E-waste smoke, 3% and 2% had low and high levels of knowledge on environmental and human health effects of E-waste smoke, respectively.

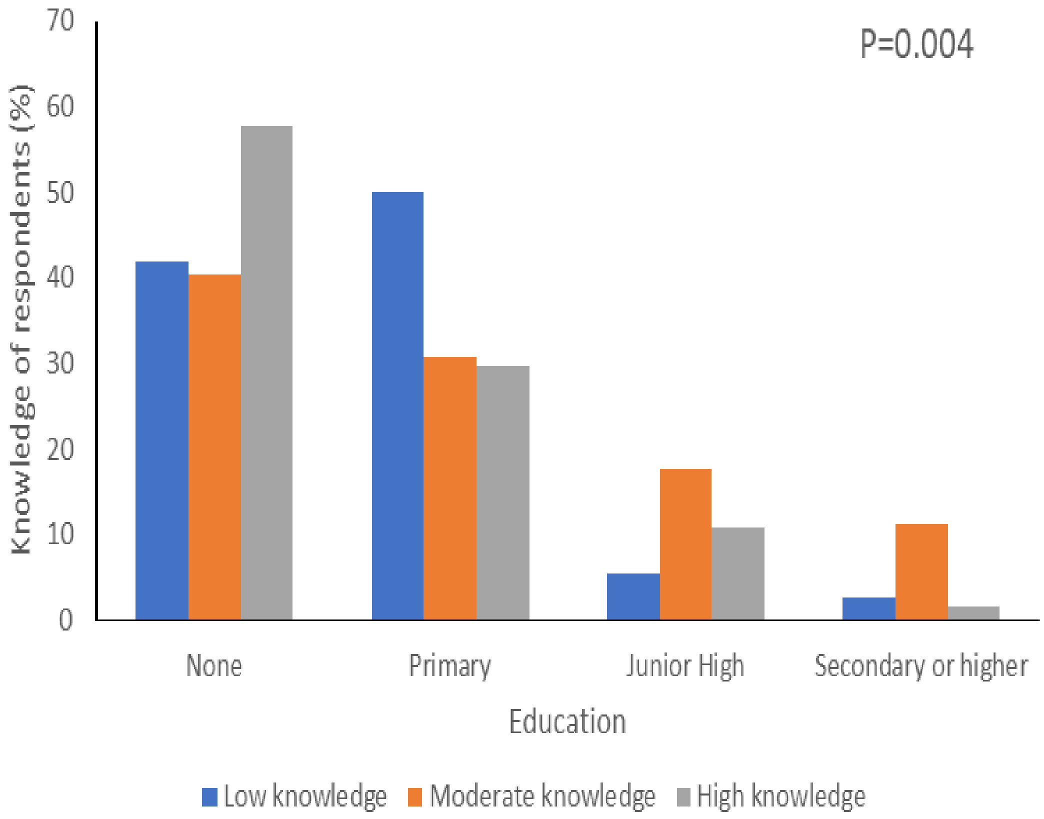

Figure 2: Level of knowledge of health risk associated with inhaling E-waste smoke and educational attainment (n=140).

Association of Knowledge of Health Effects of E-waste and Use of Multiple Personal Protective Equipment by E-waste Workers

The relationship between use of multiple PPE and level of knowledge of human health and environmental effect of E-waste was statistically significant. From Figure 3, 46% of workers who did not use any PPE had low knowledge about human health and environmental effect of E-waste. Also, 33% and 21% of the same group had moderate and high level of knowledge of human health and environmental effects of E-waste. Regarding workers who used at least one form of PPE, 85% had high level of knowledge, and 15% had intermediate knowledge. In general, it can be seen that those who used two or three PPE simultaneously had higher levels of knowledge about the human health and environmental effects of E-waste compared with those who did not use any PPE at all.

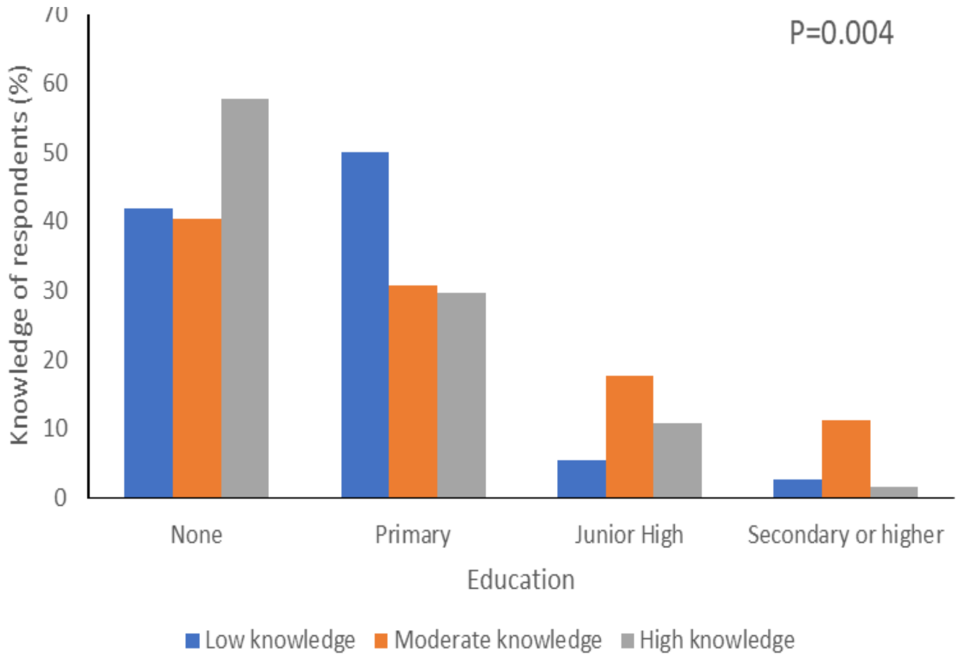

Figure 3: Level of knowledge of health effects of E-waste and use of multiple PPE by E-waste workers (n=140).

Association of Occupational and Residential Status and Self-Reported Experiences of Disease Symptoms

Association of residential and occupational status and self-reported skin rashes

There was a statistically significant relationship between occupational and residential status and self-reported skin rashes. The Cramer's V which was greater than 0.3 indicates there was a strong relationship between where respondents live, their occupation and self-reported skin rashes (Pr = 0.000 Cramér's V = 0.4269). In all, 155 respondents reported of experiencing skin rashes. With reference to Figure 4, it can be seen that, 67% of E-waste workers reported skin rashes which was the highest followed by 28% of resident non E-waste workers. The non-resident non E-waste workers reported the least. Moreover, 35% of non-resident non E-waste workers did not report any skin rashes.

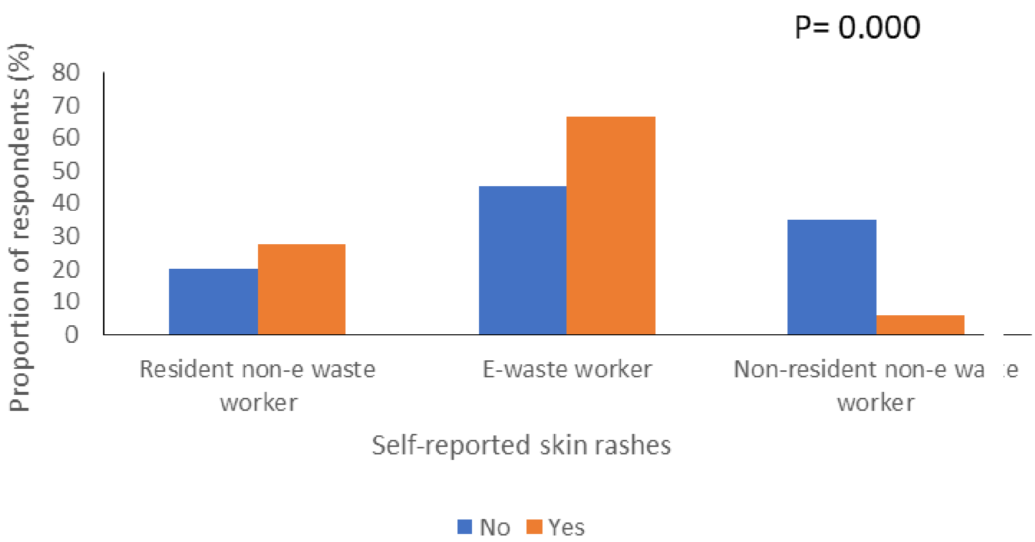

Figure 4: Association of residential and occupational status and self-reported skin rashes (n=260).

Association of residential and occupational status and self-reported eye problems

There was a statistically significant relationship between occupational and residential status and eye problems. The Cramer's V, which is greater than 0.3 indicates there is a strong relationship between where respondents live, their occupation and self-reported eye problems (Pr = 0.000 Cramér's V = 0.3178). In all, 124 respondents reported of experiencing eye problems. With reference to Figure 5, it can be seen that 69% of E-waste workers reported eye problems. Thirty-five percent of non-resident non E-waste workers reported that they do not experience any eye problems.

Figure 5: Association of residential and occupational status and self-reported eye problems (n=260).

Association of residential and occupational status and self-reported skin burns

The Pearson chi-square value indicated that there was a statistically significant relationship between occupational and residential status and skin burns. In all, 99 respondents reported of experiencing skin burns. From Figure 6, it can be seen that 76% of E-waste workers reported skin burns followed by 19% of resident non E-waste workers. Thirty-four percent of non-resident non E-waste worker reported they do not experience any skin problems. The Cramer's V which is greater than 0.3 indicates there is a strong relationship between where respondents live, their occupation and self-reported skin burns (Pr = 0.000 Cramér's V = 0.3814).

Figure 6: Association of residential and occupational status and self-reported skin burns (n=260).

Association of residential and occupational status and self-reported breathing difficulty

The P-value indicated that there was a statistically significant relationship between occupational and residential status and self-reported breathing difficulty. One hundred and nine respondents reported of experiencing breathing difficulty. From figure 7, 77% of E-waste workers reported experiencing breathing difficulty. However only 6% of non-resident non E-waste workers reported experiencing breathing difficulty. The Cramer's V which was greater than 0.3 indicates that there was a strong relationship between where respondents live, their occupation and self-reported breathing difficulty (Pr = 0.000 Cramér's V = 0.4269).

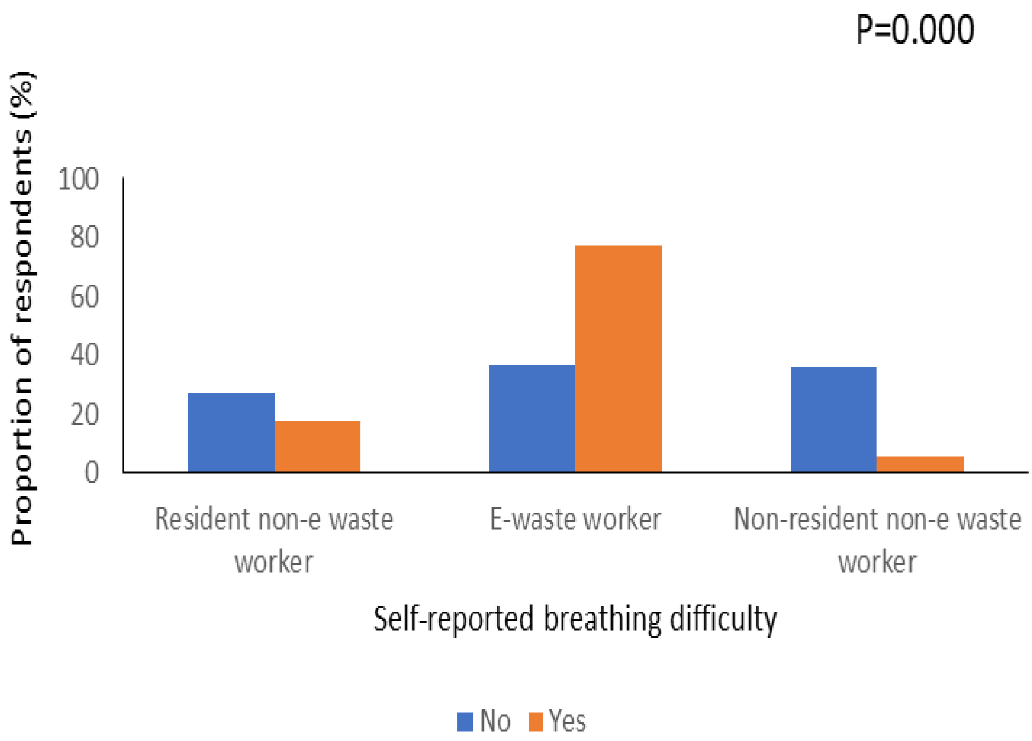

Figure 7: Association of residential and occupational status and self-reported breathing difficulty (n=260).

Association of residential and occupational status and self-reported throat irritation

The P-value indicated that there was a statistically significant relationship between occupational and residential status and self-reported throat irritation. One hundred and two respondents reported of experiencing throat irritation. From figure 8, it can be seen that 75% of E-waste workers reported experiencing throat irritation. Thirty-four percent of non-resident non E-waste worker reported they do not experience eye problems. The Cramer's V which is greater than 0.3 indicates the relationship between where respondent live, their occupation and self-reported throat irritation is strong (Pr = 0.000 Cramér's V = 0.3814).

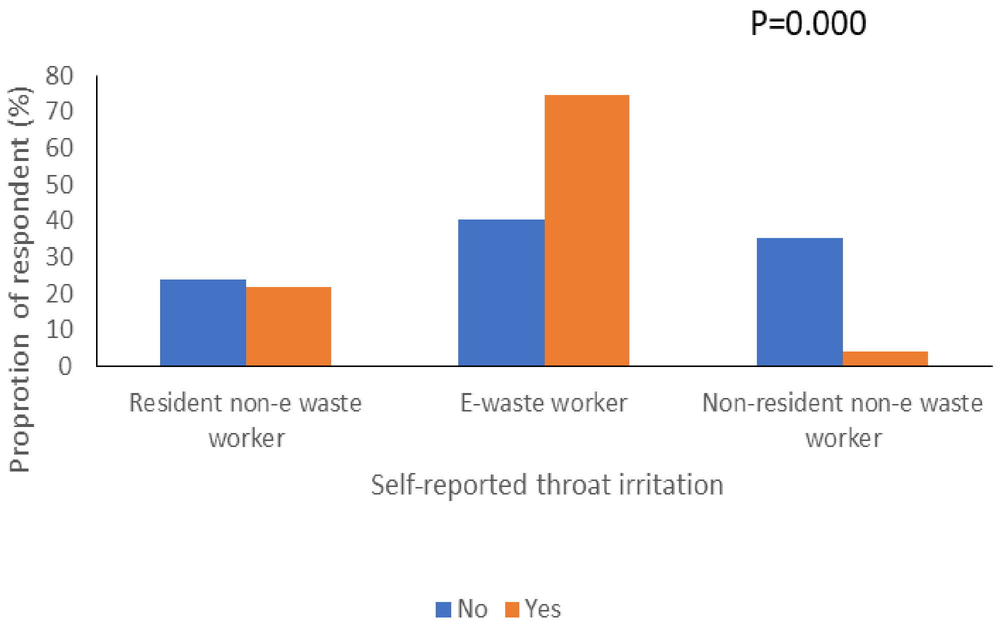

Figure 8 : Association of residential and occupational status and self-reported throat irritation (n=260).

Association of residential and occupational status and self-reported coughing

The P-value indicated that there was a statistically significant relationship between where respondents live, their occupation and self-reported coughing. One hundred and sixty-two respondents reported of experiencing coughing. From figure 9, it can be seen that sixty-three percent of E-waste workers reported experiencing coughing followed by 23 % of resident non E-waste workers with 14% of non-resident non e–waste workers reporting the least. The Cramer's V which is greater than 0.3 indicates a strong relationship (Pr = 0.000 Cramér's V = 0.3004).

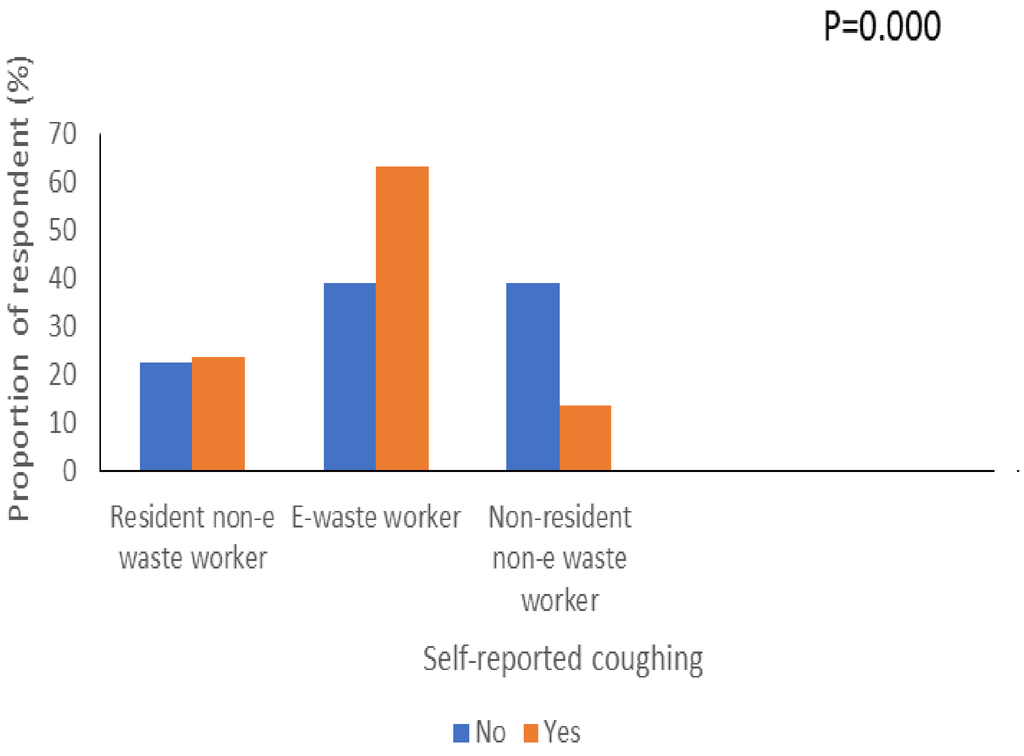

Figure 9 : Association of residential and occupational status and self-reported coughing (n=260).

Association of residential and occupational status and self-reported weakness of joints

The P-value indicated that there was a statistically significant relationship between where respondents live, their occupation and self-reported weakness of joints. One hundred and twenty-four respondents reported of experiencing weakness of bones. From figure 10, it can be seen that 67 % of E-waste workers reported the highest number of experiencing joint pains followed by 27 % of resident non E-waste workers. Thirty-nine percent of non-resident non E-waste workers reported they do not experience weakness of joint. The Cramer's V which is greater than 0.3 indicates a strong relationship (Pr = 0.000 Cramér's V = 0.3956).

Figure 10 : Association of residential and occupational status and self-reported weakness of joints (n=260).

Association of residential and occupational status and self-reported chest pains

There was a statistically significant relationship between where respondents live, their occupation and self-reported chest pains. The Cramer's V which is greater than 0.3 indicates a strong relationship (Pr = 0.000 Cramér's V = 0.3956). One hundred and twenty-two respondents reported of experiencing chest pains. From Figure 11, it can be seen that 78% of E-waste workers reported of experiencing chest pains followed by 18% of resident non E-waste worker. Moreover 40 % of non-resident non E-waste worker reported they do not experience chest pains

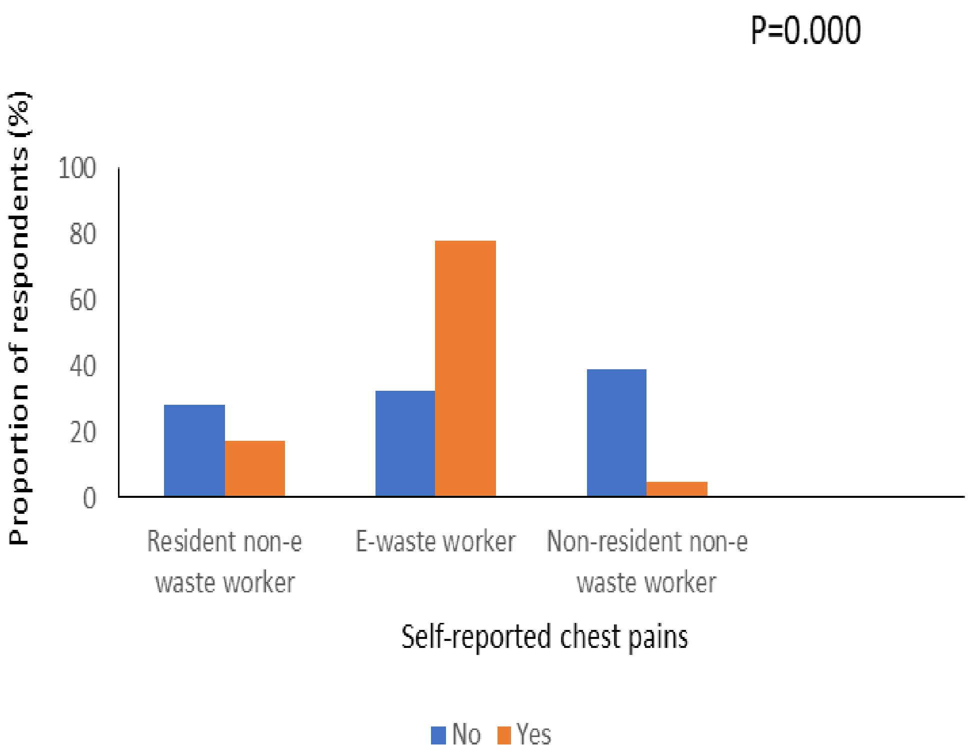

Figure 11 : Association of residential and occupational status and self-reported chest pains (n=260).

In sum, there are associations between where respondents live, their occupation and self-reported disease symptoms (chest pain, skin rashes, eye problems skin burns, difficulty in breathing, coughing, throat irritation and weakness of bones). On these bases, the null hypothesis of no association in each instance was rejected.

Association of residential and occupational status and frequency of experience of catarrh

The Pearson chi-square value indicated that there was a strong relationship between where respondents live, their occupation and frequency of experience of catarrh. From Figure 12, it can be seen that, 60% and 63% of E-waste workers reported catarrh once and twice in a week, respectively. Seventy-nine percent of resident non E-waste workers reported experiencing catarrh several times in a week. None of the non-resident non E-waste workers reported experiencing catarrh spanning twice and several times in a week. In general, it can be seen that E-waste workers reported higher percentages of experiencing catarrh. The Cramer's V which is greater than 0.3 indicates there is a strong relationship between where respondents live, their occupation and frequency of experience of catarrh (Pr = 0.000 Cramér's V =0.3286).

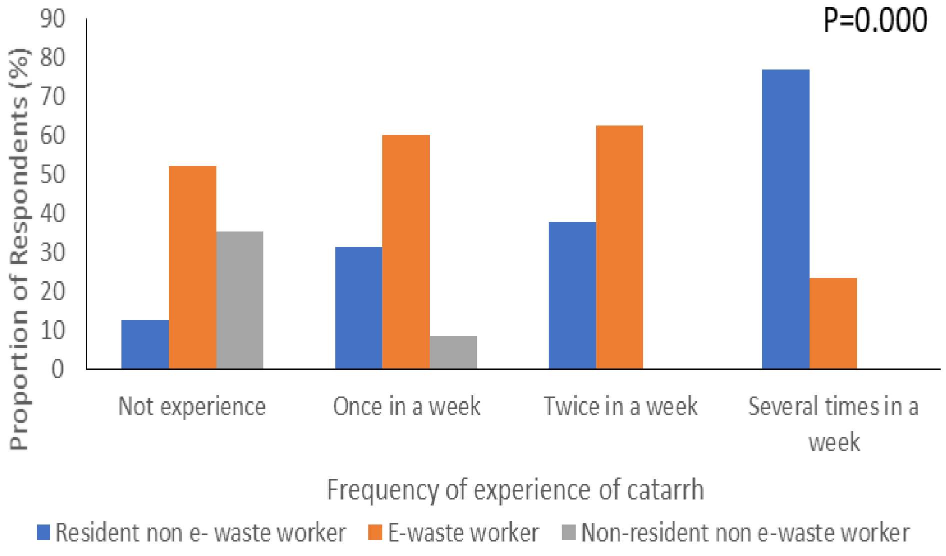

Figure 12: Association of residential and occupational status and frequency of experience of catarrh (n=260).

Association of residential and occupational status and frequency of experience of skin burns

The P-value indicated that there was a statistically significant relationship between where respondents live, their occupation and frequency of experience of skin burns. From Figure 13, it can be seen that, E-waste workers reported high percentages of experiencing skin burns. For instance, 71% and 80% of E-waste workers reported of experiencing skin burns once and twice in a week, respectively. None of the non-resident non E-waste workers reported of experiencing skin burns twice and several times in a week.

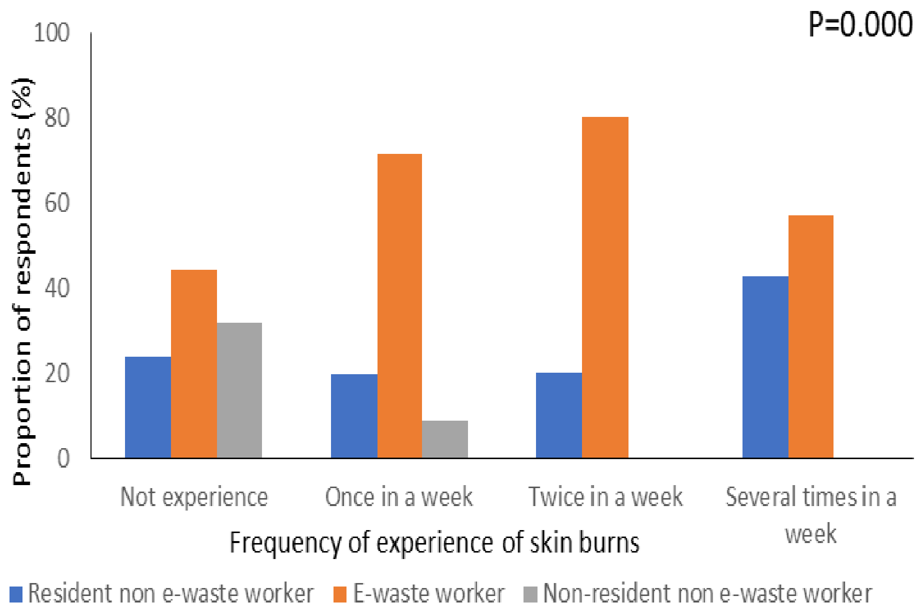

Figure 13 : Association of residential and occupational status and frequency of experience of skin burns (n=260).

Association of residential and occupational status and frequency of experience of eye problems

The Pearson chi-square statistic indicates there was a statistically significant relationship between where respondents live, their occupation and frequency of experience eye problems. With reference to Figure 14, 66% and 71% of E-waste workers reported frequently experiencing eye problems once and twice in a week, respectively. None of the non-resident non E-waste workers reported eye problems spanning several times in a week. In general, most E-waste workers reported experiencing eye problems.

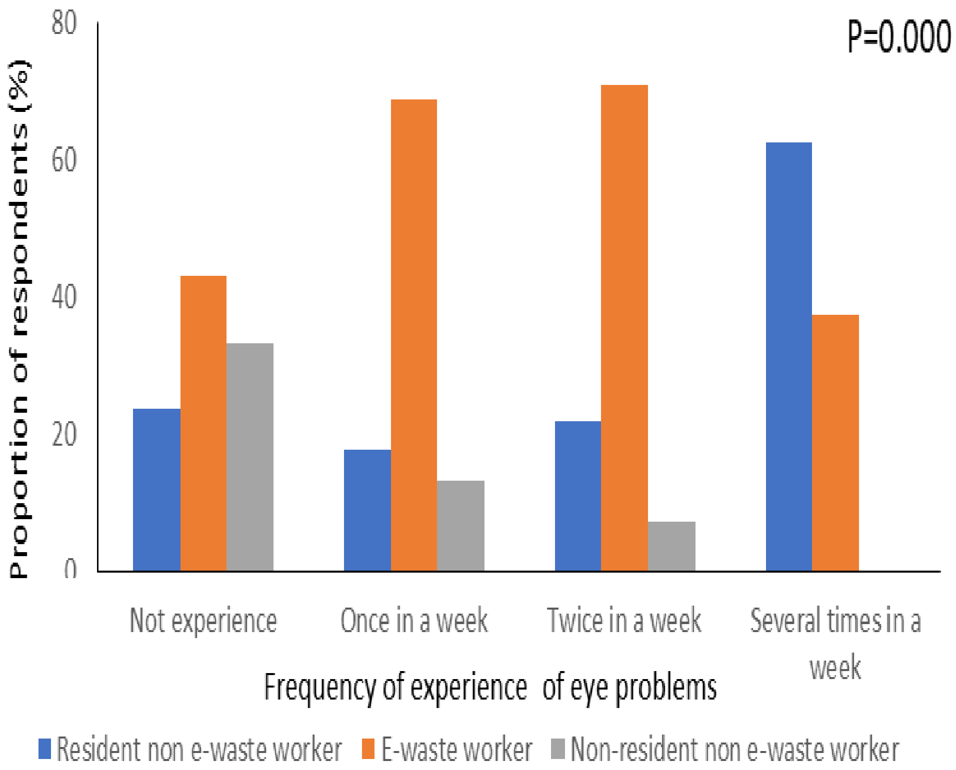

Figure 14 : Association of residential and occupational status and frequency of experience of eye problems (n=260).

Association of residential and occupational status and frequency of experience of coughing

The Pearson chi-square statistic indicated that there was a statistically significant relationship between where respondents live, their occupation and frequency of experience coughing. From Figure 15, eight-one percent of E-waste workers had the highest occurrence of coughing reporting it twice in a week. Forty-one percent of non-resident non E-waste workers did not report experiencing coughing. Also, none of non-resident non E-waste workers reported experiencing coughing spanning several times in a week. In general, E-waste workers reported higher frequency of experiencing coughing followed by resident non E-waste workers.

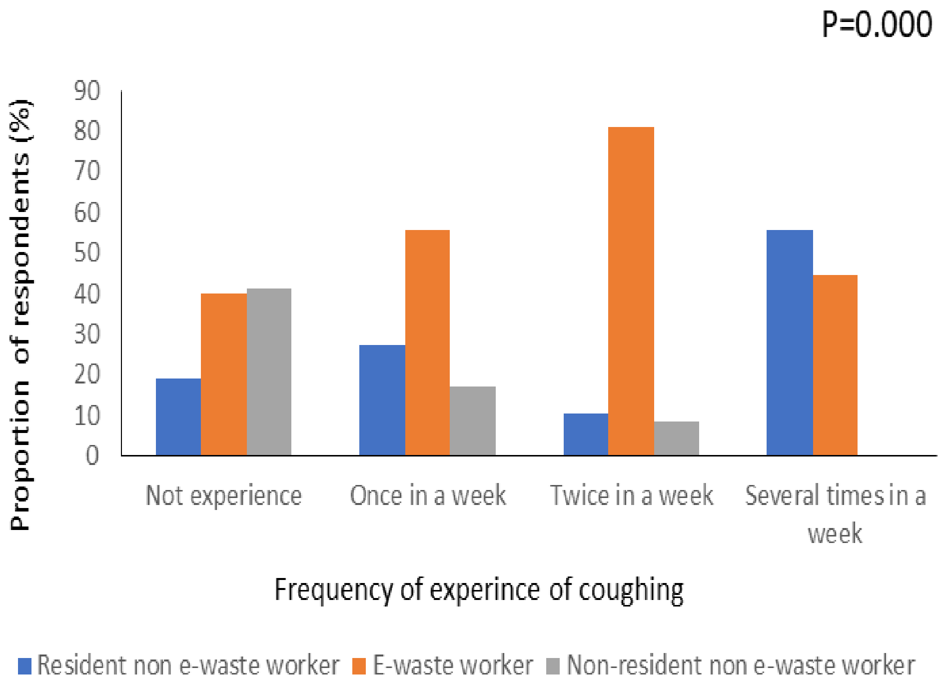

Figure 15: Association of residential and occupational status and frequency of experience of coughing (n=260).

Association of residential and occupational status and frequency of experience of headache.

The chi-square statistic indicated that there was a statistically significant relationship between where respondents live, their occupation and frequency of experience headache. With reference to Figure 16, it can be seen that 83% and 62% of E-waste workers reported the highest occurrence of headache twice and once in a week, respectively. Sixty-four percent of non-resident non E-waste workers reported they do not experience headache. Generally, it can be seen that E-waste workers reported the highest percentages of headache followed by resident non-E-waste worker with non-resident non E-waste workers reporting the least. The Cramer's V suggest that, there is strong relationship between residential status and frequency of experience headache (Pr = 0.000 Cramér's V = 0.4408).

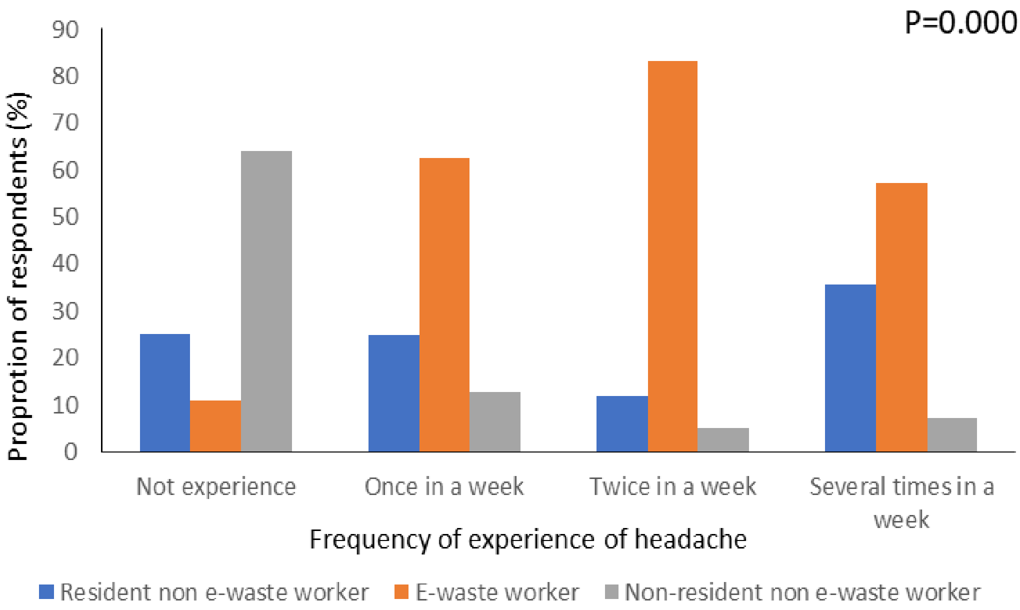

Figure 16 : Association of residential and occupational status and frequency of experience of headache (n=260)

Association of residential and occupational status and frequency of experience of breathing difficulty

The chi-square statistics indicated that there was a statistically significant relationship between where respondents live, their occupation and frequency of experience of breathing difficulty. With reference to Figure 17, it can be seen that 89% and 83% percent of E-waste workers reported breathing difficulty twice and several times in a week, respectively. Thirty-three percent of non-resident non E-waste workers did not report experiencing any breathing difficulty. None of the non-resident non E-waste workers reported experiencing breathing difficulty spanning twice and several times in a week, respectively. In general, most E-waste workers reported experiencing breathing difficulty followed by resident non E-waste workers and non-resident non-e-waste workers being the least.

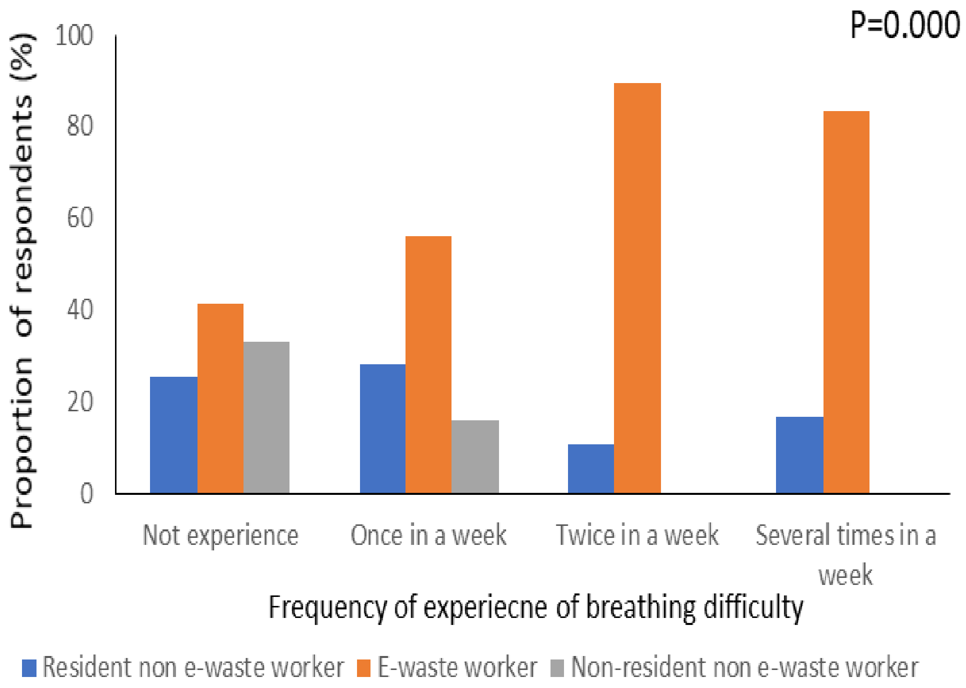

Figure 17: Association of residential and occupational status and frequency of experience of breathing difficulty (n=260).

Association of residential and occupational status and frequency of experience of urinary problems

The P-value indicated that there was a statistically significant relationship between where respondents live, their occupation and frequency of experience of urinary problems. From Figure 18, seventy-seven percent, 96% and 86% of E-waste workers reported the highest occurrence of experiencing urinary problems once twice and several times in a week, respectively. None of the non-resident non E-waste workers reported of experiencing urinary problems spanning once, twice and several times in a week, respectively. In general E-waste workers reported the higher percentages of experiencing urinary problems. The Cramer's V indicates that, there is a strong relationship between occupational and residential status and frequency of experience of urinary problems (Pr = 0.000 Cramér's V = 0.3083).

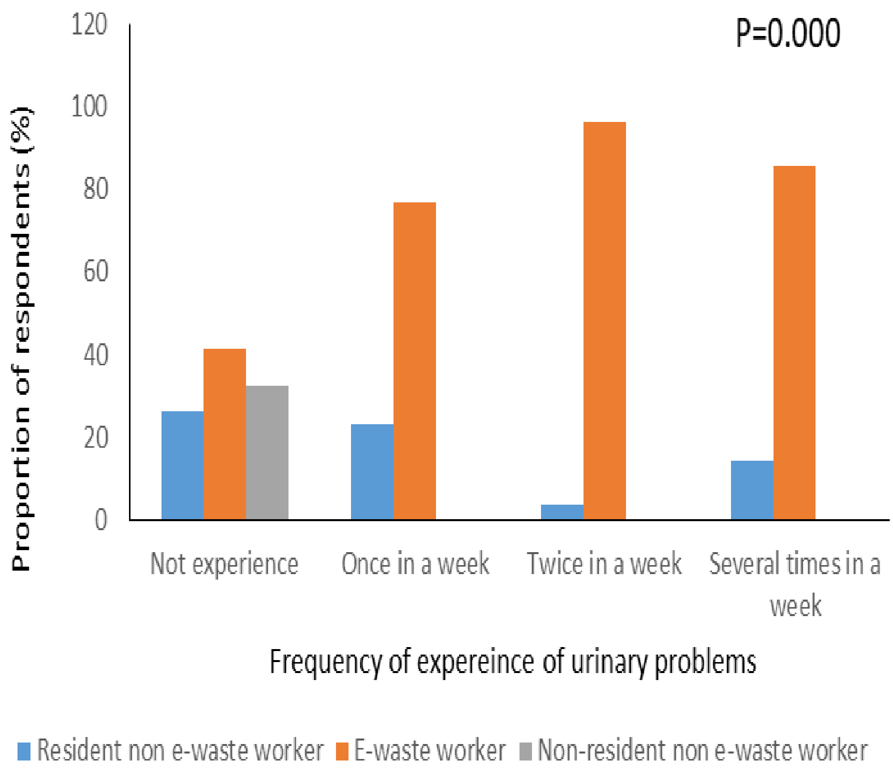

Figure 18 : Association of residential and occupational status and frequency of experience of urinary problems (n=260).

Association of residential and occupational status and frequency of experience of weakness of bones

The chi-square statistics indicated there was a statistically significant relationship between occupational and residential status and frequency of experience of weakness of bones. From the Figure 19, 77%, 66% and 71% of E-waste workers reported the highest occurrence of weakness of joints once, twice and several times in a week, respectively. None of the non-resident non E-waste workers reported experiencing weakness of joints spanning twice and several times in a week. Forty percent of non-resident non-E-waste worker reported they do not experience any weakness of bones. In general, E-waste workers reported experiencing weakness of joints the most followed by resident non-E-waste workers and non-resident non E-waste workers reporting the least. The Cramer's V which is greater than 0.3 indicates that, there is a strong relationship between where respondents live, their occupation and frequency of experience of weakness of bones (Pr = 0.000 Cramér's V = 0.3151).

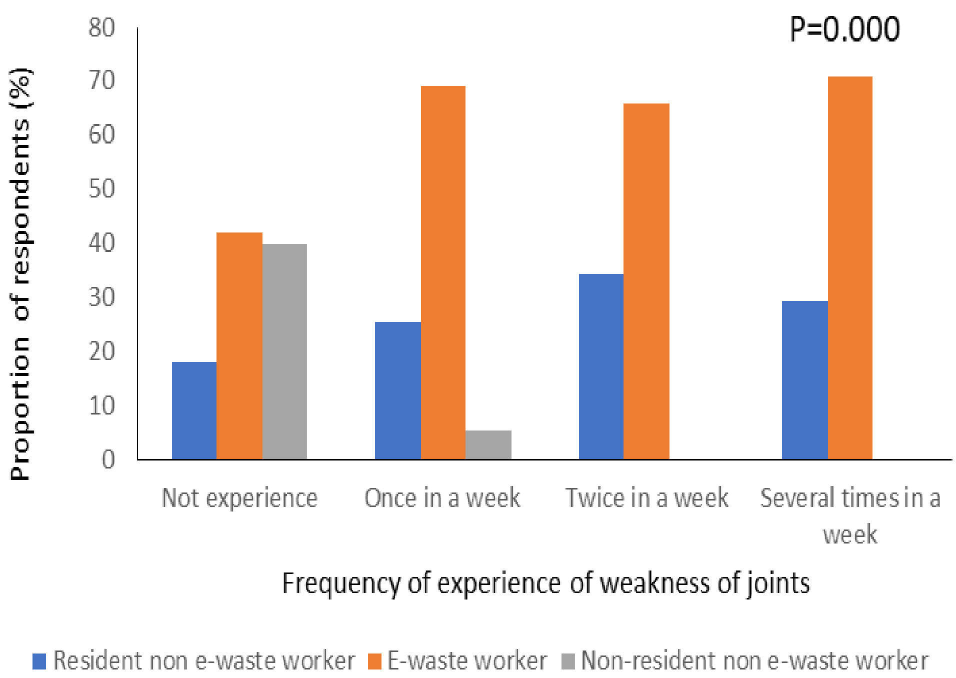

Figure 19 : Association of residential and occupational status and frequency of experience of weakness of bones (n=260).

In sum, there are associations between where respondents live, their occupation and self-reported experiences of disease symptoms (headache, catarrh, eye problems, skin burns, difficulty in breathing, coughing, urinary problems and weakness of bones) thus the null hypothesis in each instance was rejected.

Association of E-waste Worker Use of Multiple PPE and Self-Reported Adverse Human Health Outcomes

Skin irritation and use of personal protective equipment

There was a statistically significant relationship between non-use of PPE and reporting of skin rashes. From Figure 20, workers who do not use any form of PPE reported the most cases of skin irritation, for example, 86% reported skin irritation once in a week, and 75% reporting skin irritation twice and several times in a week. Regarding workers who used three PPE simultaneously, none reported having skin irritations several times in a week. Figure 20 shows generally that those who do not use any kind of PPE reported experiencing skin irritation more compared with those who use multiple PPE.

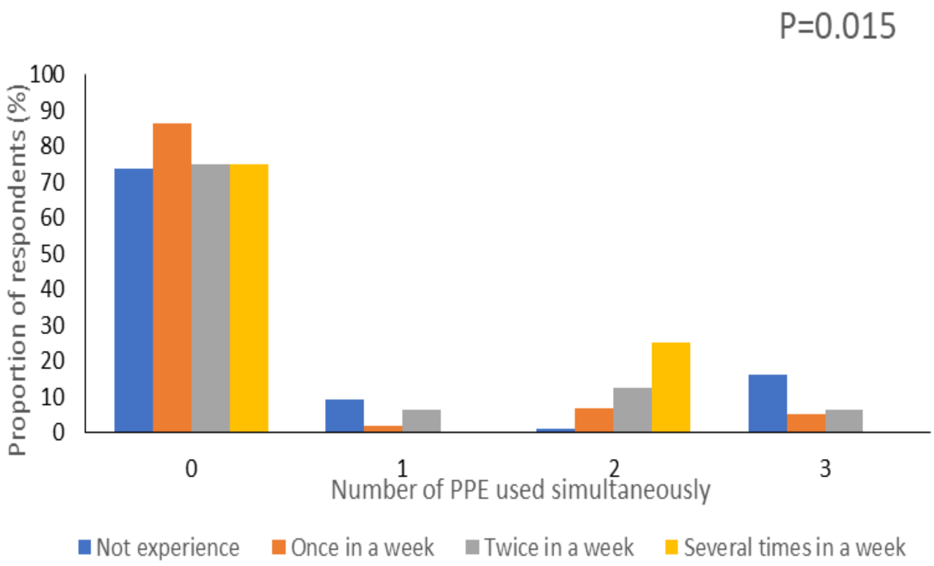

Figure 20: Skin irritation and use of personal protective equipment (n=140).

Use of personal protective equipment and breathing difficulty

There was no statistically significant relationship between non-use of PPE and breathing difficulty. From Figure 21, considering workers who do not use any form of PPE, eighty-six percent reported experiencing the highest number of breathing difficulty. None of those who use two PPE simultaneously reported that they experience any form of breathing difficulty several times a week. It can be seen from Figure 21 that workers who do not use any form of PPE reported high occurrence of breathing difficulty.

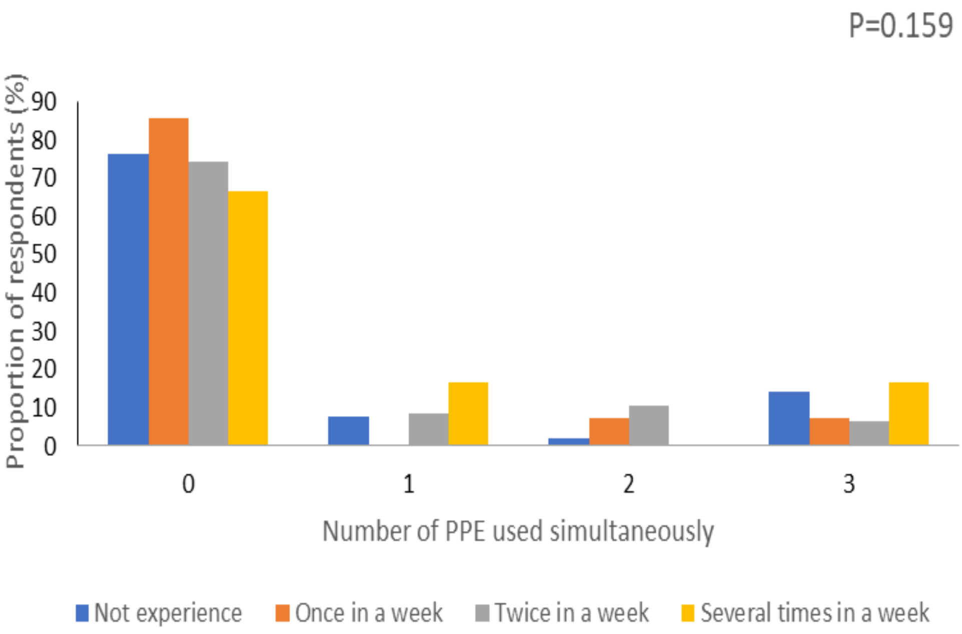

Figure 21: Use of personal protective equipment and breathing difficulty (n=140).

Use of personal protective equipment and skin burns

The Pearson chi-square value indicated that there was statistically significant relationship between non-use of PPE and self-reported skin burns. From Figure 22, it is evident that workers, who do not use any PPE, reported that they experienced skin burns the most. None of those who use at least one type of PPE reported that they do not experience skin burns. None of the respondents who use three PPE simultaneously reported that they experience skin burns several times in a week. It can be seen from Figure 22 that, those who do not use any form of PPE reported higher percentages of skin burns compared with those who use one or more PPE.

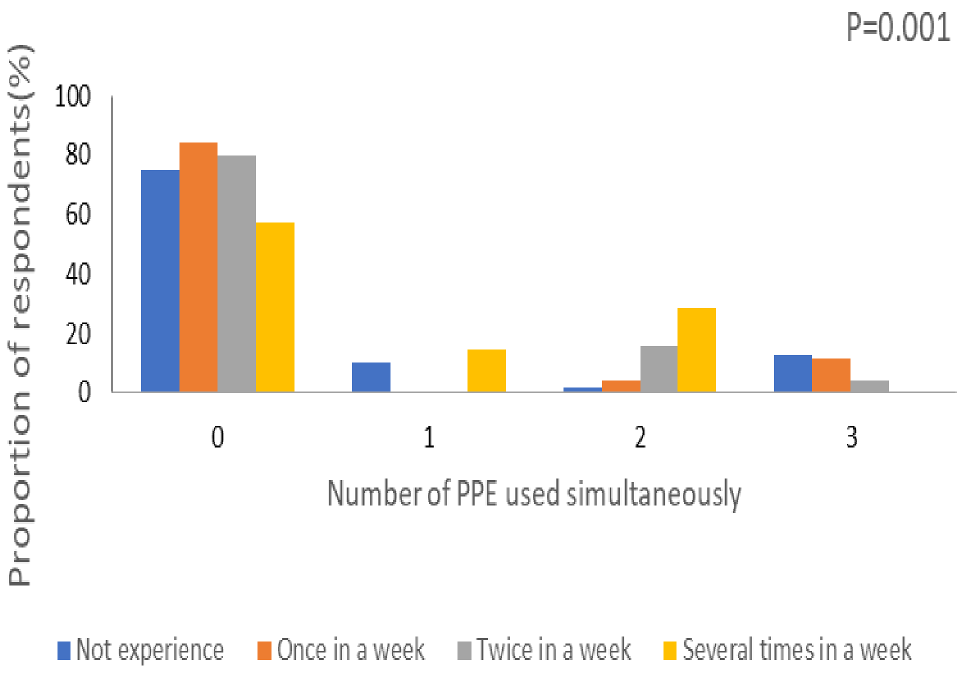

Figure 22: Use of personal protective equipment and skin burns (n=140).

Use of personal protective equipment and eye problems

The Pearson chi-square value indicated that there was no relationship between non-use of PPE and self-reported eye problems. From Figure 23, eighty-two percent of workers who do not use any type of PPE had the highest occurrence of eye problems reporting it twice in a week. Regarding those who use one only type of PPE, none reported eye problems spanning several times a week. Generally, it can be seen from the Figure 23 above that, those who do not use any form of PPE reported high frequency of eye problems.

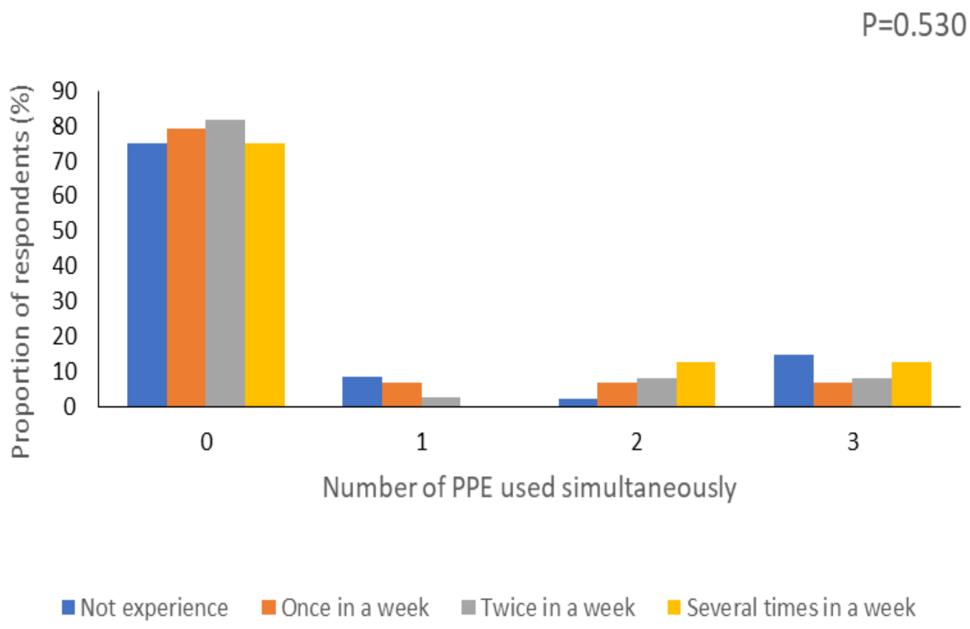

Figure 23: Use of personal protective equipment and eye problems (n=140).

Use of personal protective equipment and urinary problems

The Pearson chi-square value indicated that there was a statistically significant relationship between non-use of PPE and self-reported urinary problems. From Figure 24, ninety-three percent of those who do not use any form of PPE reported urinary problems once week, which was the highest. E-waste workers who use at least one type of PPE, did not report experiencing any urinary problems. Eighty-one percent of their counterparts who use at least two PPE simultaneously, reported that they do not experience urinary problems either. It can be seen generally that those who do not use any form of PPE reported high incidence of urinary problems than those who use one or more PPE simultaneously.

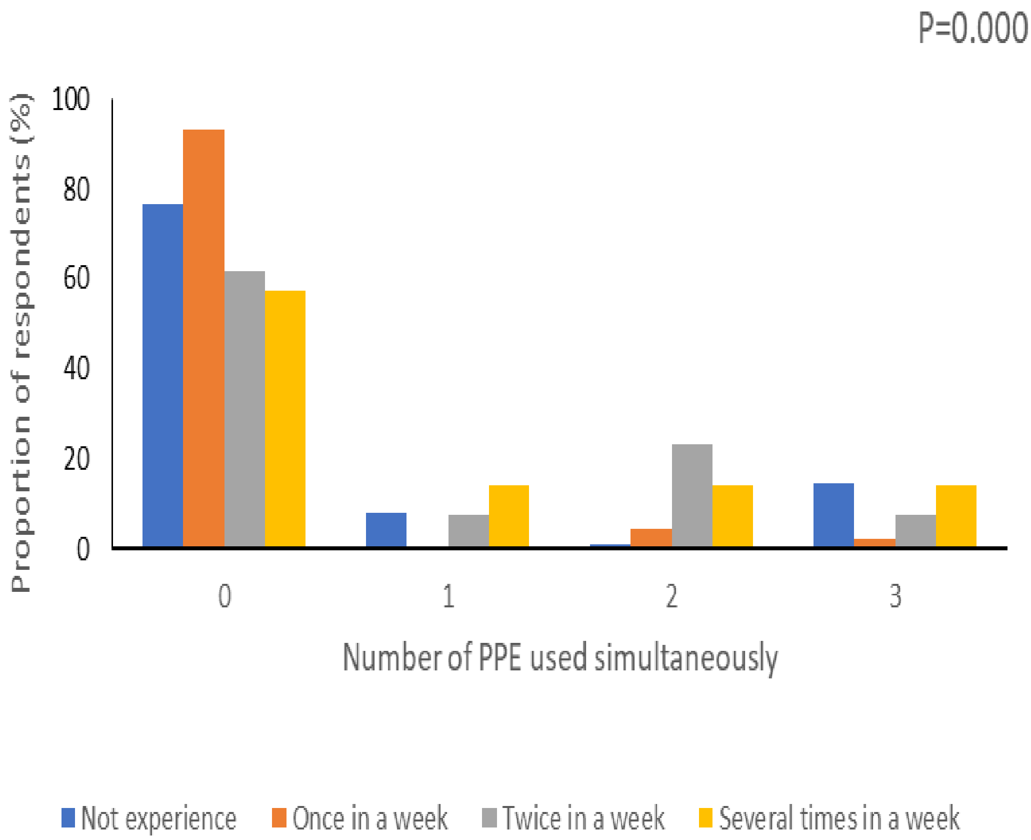

Figure 24: Use of personal protective equipment and urinary problems (n=140)

Use of personal protective equipment and weakness of joints

The Pearson chi-square value indicated that there was a statistically significant relationship between non-use of PPE and self-reported weakness of joints. With reference to Figure 25, it can be seen that 92% of workers who do not use any form of PPE reported that they experience weakness of joints once a week. In general, workers who do not use any form of PPE reported weakness of joints the most compared with those who use one or more PPE simultaneously.

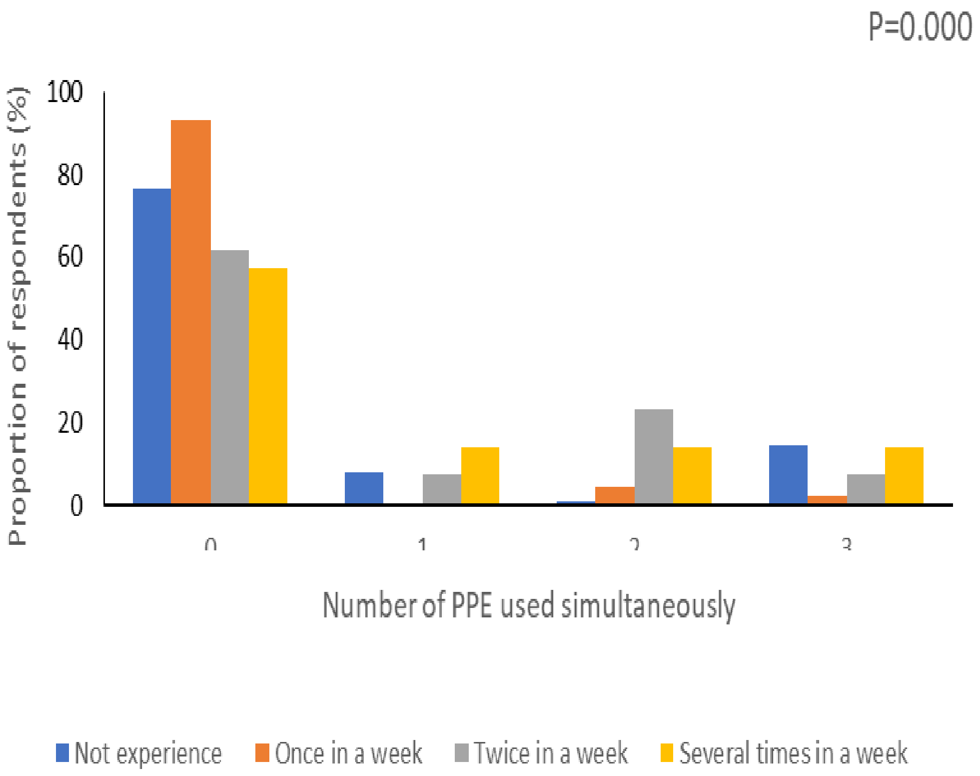

Figure 25: Use of personal protective equipment and weakness of joints (n=140)

Use of personal protective equipment and coughing

The Pearson chi-square value indicated that there was a statistically significant relationship between non-use of PPE and self-reported coughing. From Figure 26, eighty-four percent of workers who do not use any form of PPE reported coughing once in a week. Regarding their counterparts who use at least one form of PPE, 16% reported that they have not experienced coughing. By and large, workers who do not use any form of PPE reportedly experienced more coughing compared with their co-workers who use one or more PPE simultaneously.

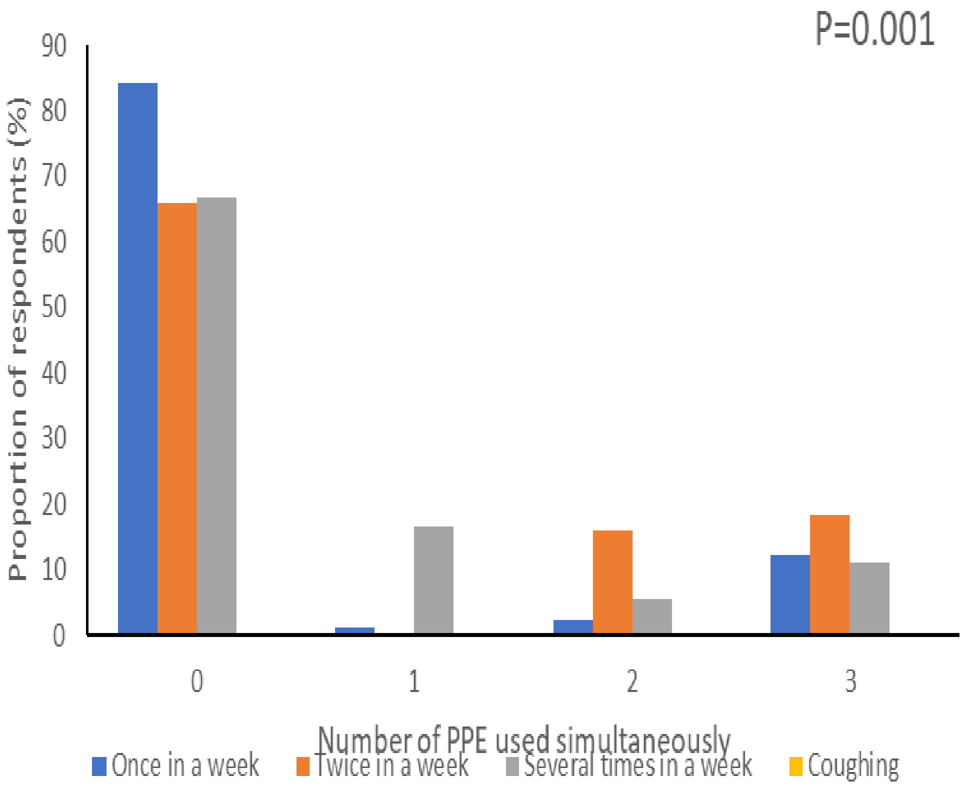

Figure 26 : Use of personal protective equipment and coughing (n=140).

In sum, there are associations between limited use of PPE by E-waste workers and self-reported adverse human health outcomes including skin irritation, skin burns, urinary problems as well as weakness of joints and coughing.

Descriptive Statistics of PM 2.5 (µg/m3) and VOC (mg/m3) in the Various Zones

Descriptive statistics of PM 2.5 (µg/m3) and VOC (mg/m3) in low intensity zone

From table 2, the mean readings for $PM_{2.5}$, in the low intensity zone, ranged from 219.2-222.3 µg/m3. The minimum and maximum $PM_{2.5}$ reading were 187 and 350 µg/m3, respectively. The skewness for all $PM_{2.5}$ readings were greater than zero which means the PM readings had a right skewed distribution, that is, most values are concentrated on left of the mean, with extreme values to the right. The kurtosis for $PM_{2.5}$R1 and $PM_{2.5}$R2 were greater than three, meaning it had a leptokurtic distribution, sharper than a normal distribution, with values concentrated around the mean and thicker tails. This indicates high probability for extreme values. The $PM_{2.5}$R3 had a value of 1.026 which is less than 3, meaning it had a platykurtic distribution, flatter than a normal distribution with a wider peak. The probability for extreme values is less than for a normal distribution, and the values are widely spread around the mean.

Table 2: *Descriptive statistics of PM $_{2.5}$ (µg/m^3) and VOC (mg/m^3) in low intensity zone*

Measures	$PM_{2.5}$R1	$PM_{2.5}$R2	$PM_{2.5}$R3	VOCR1	VOCR2	VOCR3
Mean	219.20	221.93	222.30	6.966667	7.000000	7.076667
Std. Deviation	32.420	29.749	20.267	.3506972	.4218187	.3568863
Skewness	2.568	2.653	1.026	-.416	-.269	-.839
Kurtosis	8.678	7.757	1.050	.018	-.109	.919
Minimum	187	187	193	6.1000	6.0000	6.1000
Maximum	350	331	280	7.7000	7.7000	7.7000

Descriptive statistics of $PM_{2.5}$(µg/m^3) and VOC (mg/m^3) in the medium intensity zone

From table 3, the mean $PM_{2.5}$ reading, in the medium intensity zone, ranged from 326-337µg/m^3, with a minimum reading of 248 µg/m^3 and maximum reading of 398 µg/m^3. The skewness for all $PM_{2.5}$ readings were less than zero, indicating a left skewed distribution and most values concentrated on the right of the mean, with extreme values to the left. The probability for extreme values is less than for a normal distribution, and the values are widely spread around the mean. The mean VOC reading ranged from 7.1-7.5 mg/m^3, minimum reading of 6.5 mg/m^3 and with a maximum reading of 8.5 mg/m^3. The skewness of VOCR1 and VOCR2 were greater than zero, having a right skewed distribution and most values were concentrated on left of the mean, with extreme values to the right but that of VOCR3 was less than zero implying, it had a left skewed distribution and most values were concentrated on the right of the mean, with extreme values to the left. The kurtosis for both $PM_{2.5}$ and VOC were less than 3 indicating a platykurtic distribution, flatter than a normal distribution with a wider peak. The probability for extreme values is less than for a normal distribution, and the values are widely spread around the mean.

Table 3: *Descriptive statistics of $PM_{2.5}$(µg/m3) and VOC (mg/m3) in the medium intensity zone*

Measures	$PM_{2.5}$R1	$PM_{2.5}$R2	$PM_{2.5}$R3	VOCR1	VOCR2	VOCR3
Mean	326.90	329.73	336.83	7.166667	7.293333	7.490000
Std. Deviation	34.645	30.737	24.470	.4237219	.3685323	.3826856
Skewness	-.229	-1.100	-.266	1.050	.570	-.076
Kurtosis	-.620	1.652	-.430	1.877	.606	1.180
Minimum	260	248	290	6.6000	6.6000	6.5000
Maximum	398	379	380	8.5000	8.3000	8.4000

Descriptive statistics of $PM_{2.5}$ (µg/m^3) and VOC (mg/m^3) in high intensity zone

From table 4, the mean $PM_{2.5}$ readings, in the high intensity zone, ranged from 421-429 µg/m^3. The skewness for all the PM readings were greater than zero which means readings had a right skewed distribution, most values are concentrated on left of the mean, with extreme values to the right. The minimum and maximum $PM_{2.5}$ reading was 349 µg/m^3 and 490 µg/m^3, respectively. The mean VOC readings ranged from 8.30-8.54 mg/m^3. The skewness for VOCR1 and VOCR2 were greater than zero, indicating that readings had a right skewed distribution, most values are concentrated on left of the mean, with extreme values to the right. The skewness of VOCR2 was less than zero meaning it has a left skewed distribution, most values are concentrated on the right of the mean, with extreme values to the left. The kurtosis of both VOC and $PM_{2.5}$ were less than three, signifying a platykurtic distribution, flatter than a normal distribution with a wider peak. The probability for extreme values is less than for a normal distribution, and the values are wider spread around the mean.

Table 4: *Descriptive statistics of $PM_{2.5}$(µg/m3) and VOC (mg/m3) in the high intensity zone*

	$PM_{2.5}$R1	$PM_{2.5}$R2	$PM_{2.5}$R3	VOCR1	VOCR2	VOCR3
Mean	421.93	425.90	428.50	8.363333	8.316667	8.543333
Std. Deviation	30.834	31.710	32.134	.8868710	.7095814	.5811305
Skewness	.758	.243	.107	.085	-.520	.292
Kurtosis	-.160	.574	-.276	-.859	-.158	-.804
Minimum	380	349	375	6.9000	6.7000	7.7000
Maximum	490	488	495	9.9000	9.5000	9.8000

Descriptive statistics of $PM_{2.5}$ (µg/m^3) and VOC (mg/m^3) in control zone

From table 5, the mean readings for $PM_{2.5}$, in the control zone, ranged from 32.03-33.03 µg/m^3. The minimum and maximum PM $_{2.5}$ reading were 26 and 39 µg/m^3, respectively. The skewness for $PM_{2.5}$ R1 and $PM_{2.5}$R3 were less than zero meaning it is left skewed distribution and most values are concentrated on the right of the mean, with extreme values to the left. $PM_{2.5}$ R2 readings was greater than zero which means the PM readings had a right skewed distribution, that is, most values are concentrated on left of the mean, with extreme values to the right. The kurtosis for all $PM_{2.5}$ readings were less than three, meaning it had a platykurtic distribution, flatter than a normal distribution with a wider peak. The probability for extreme values is less than for a normal distribution, and the values are widely spread around the mean.

The mean of VOC readings ranged from 3.7- 4.07mg/m^3 with a minimum reading of 2.4 mg/m^3 and maximum reading of 5.5 mg/m^3. The skewness for all VOC readings was greater than zero, meaning VOCs right skewed distribution and most values are concentrated on left of the mean, with extreme values to the right. The kurtosis for all the VOC readings were less than three, meaning it had a platykurtic distribution, flatter than a normal distribution with a wider peak. The probability for extreme values is less than for a normal distribution, and the values are widely spread around the mean.

Table 5: *Descriptive statistics of $PM_{2.5}$(µg/m3) and VOC (mg/m3) in the control location*

	$PM_{2.5}$R1	$PM_{2.5}$R2	$PM_{2.5}$R3	VOCR1	VOCR2	VOCR3
Mean	33.03	32.03	32.20	4.076667	3.776667	3.716667
Std. Deviation	3.168	3.102	2.483	.7596203	.6495002	.6863614
Skewness	-.047	.219	-.231	.153	.787	1.055
Kurtosis	-.614	-.988	.182	-.373	.175	.241
Minimum	27	27	26	2.4000	2.7000	3.0000
Maximum	39	38	37	5.5000	5.3000	5.4000

Correlation of the Concentration of $PM_{2.5}$ and VOC at Each Zone

There is a strong positive correlation of 0.922 between average $PM_{2.5}$ and average VOCs at each zone which implies that as the concentrations of $PM_{2.5}$ increase the concentrations of VOC also increase. The R^2 which is 85% indicate how much variation in $PM_{2.5}$ is directly related to or accounted by the variation in VOCs.

Non Parametric Test of Association between VOC and $PM_{2.5}$ Distribution Across Zones

From Table 6, concentration of $PM_{2.5}$ systematically varies across the low, medium and high intensity zones. Similarly, the concentration of VOC (formaldehyde and methane) systematically varies across the low, medium and high intensity zones. The null hypotheses of no difference in $PM_{2.5}$ and VOCs concentration between the low, medium and high intensity zones were therefore rejected. Moreover, the AQI distribution is not the same across the categories of activity zone.

Table 6: *Non Parametric Test of Association between VOC and $PM_{2.5}$ distribution across zones*

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Average PM 2.5 is the same across categories of zone.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
2	The distribution of Average VOC is the same across categories of zone.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
3	The distribution of AQI is the same across categories of zone.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Relationship between Zonal Category of Average $PM_{2.5}$ and AQI Category

The test of statistical significance, based on Pearson's chi-square, showed that there was a strong relationship between the zonal categories of $PM_{2.5}$ concentrations and AQI category. The Cramer's V of 0.9118 which is greater than 0.3 further indicates that there is a strong relationship between the zonal categories of $PM_{2.5}$ and AQI categories (Pr = 0.000 Cramér's V = 0.9118). From Figure 27, it can be seen that all the readings from the control location fell within the AQI category of unhealthy for sensitive groups which means it may not be able to affect the general health of the public. However, children, older adults, and persons with lung disease are at a greater risk from ozone exposure. Also, older children, adults and people with lung and heart disease are at greater risk from exposure to particulate matter. Moreover, almost all readings from the low intensity zone fell under AQI category very unhealthy meaning that everybody may experience very serious health implications. All readings from medium and high intensity zone fell under AQI category of hazardous and there was no reading which fell under AQI categories of unhealthy for sensitive groups and very unhealthy. Air quality at this level is life-threatening and would issue warnings of emergency conditions for the entire population.

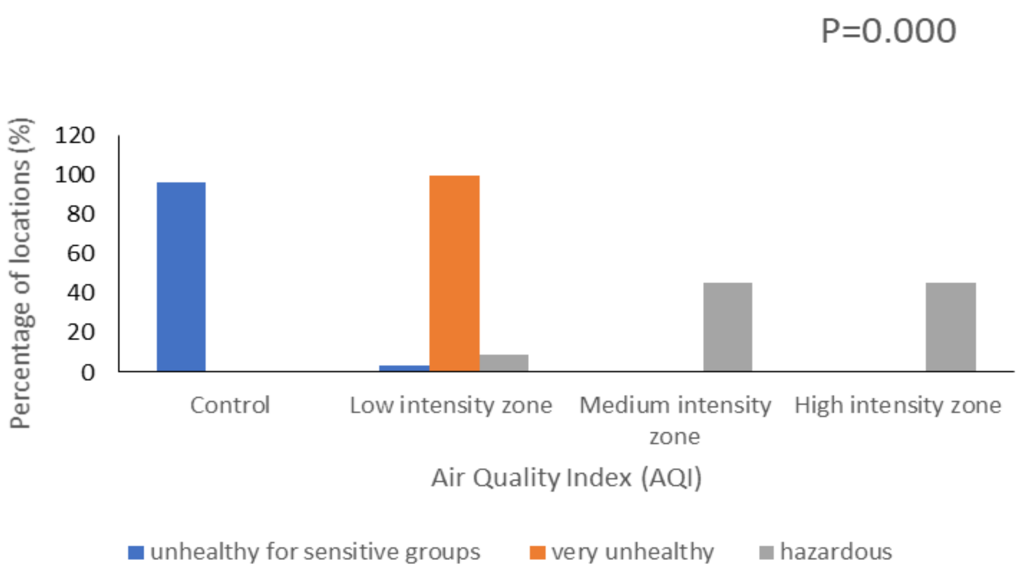

Figure 27: Relationship between zonal category of average $PM_{2.5}$ and AQI category (n=120).

Level of Non-Carcinogenic Health Risk Posed to E-waste Workers and their Non E-waste Worker Counterparts

The mean concentration of methane (0.01ppm) and formaldehyde (2.02ppm) were used in estimating the non-carcinogenic health risk posed to E-waste workers and their non E-waste counterparts.

Non-carcinogenic health risk for Adult Residents in the Central Tendency Exposure (CTE) scenario

With reference to Table 7, an adult who has a life time of 70 years, body weight of 70 kg, who spends 1.1hr/day outdoors will have a chronic average daily dose (CADD) (mg/kg-day) of 1.56 x 10^{-4} from exposure to formaldehyde and 3.15 x 10^{-2} from exposure methane, respectively. Also, the adult will have a lifetime average daily dose (LADD) (mg/kg-day) of 2.01 x 10^{-5} from exposure to formaldehyde and 4.05 x 10^{-3} methane, respectively. In addition, the adult will not be subject to any cancer risk.

Table 7: *Non-carcinogenic health risk for Adult Residents in the Central Tendency Exposure (CTE) scenario*

Daily Dose and Risk	Formaldehyde	Methane
CADD [mg/kg-day]	1.56 x 10^{-4}	3.15 x 10^{-2}
LADD[mg/kg-day]	2.01x 10^{-5}	4.05 x 10^{-3}
Cancer Risk (-)	0.00	0.00
Hazard Index (-)	0.00	0.00

Non-carcinogenic health risks for Adult residents in the reasonable maximum exposure (RME) scenario

From Table 8, in the reasonable maximum exposure scenario, the adult resident who has a life time of 70 years, body weight of 70 kg, who spends 2.5 hr/day outdoors will have a CADD (mg/kg-day) of 3.55 x 10^{-4} from exposure to formaldehyde and 7.16 x 10^{-2} methane, respectively. Also, the adult will have a LADD (mg/kg-day) of 1.52 x 10^{-4} formaldehyde and 3.07 x 10^{-2} methane, respectively. In addition, the adult resident RME will not be subject to any potential cancer risk.

Table 8: *Non-carcinogenic health risks for Adult residents in the reasonable maximum exposure (RME) scenario*

Daily Dose and Risk	Formaldehyde	Methane
CADD [mg/kg-day]	3.55 x 10^{-4}	7.16 x 10^{-2}
LADD[mg/kg-day]	1.52 x 10^{-4}	3.07 x 10^{-2}
Cancer Risk (-)	0.00	0.00
Hazard Index (-)	0.00	0.00

Non-carcinogenic health risks for Child Residents in the RME scenario

From Table 9, the child resident in the RME scenario who has a life time of 70 years, body weight of 15 kg, who spends 24 hr/day outdoor will have a CADD (mg/kg-day) of 1.59 x10^{-2} from exposure to formaldehyde and 3.21 x10^{0} from exposure to methane, respectively. Also, the adult will have a LADD (mg/kg-day) of 1.36 x10^{-3} from exposure to formaldehyde and 2.75x 10^{-1} from exposure to methane, respectively. In addition, the child in the RME scenario will not experience any cancer risk.

Table 9: *Non-carcinogenic health risks for Child Residents in the RME scenario*

Daily Dose and Risk	Formaldehyde	Methane
CADD [mg/kg-day]	1.59×10^{-2}	3.21×10^{0}
LADD[mg/kg-day]	1.36×10^{-3}	2.75×10^{-1}
Cancer Risk (-)	0.00	0.00
Hazard Index (-)	0.00	0.00

Non-carcinogenic health risks for Child Residents in the CTE scenario

From Table 10, the child resident, in the CTE scenario, who has a life time of 70 years, body weight of 15 kg, who spends 2.2 hr/day outdoor will have a CADD (mg/kg-day) of 1.46×10^{-3} from exposure to formaldehyde and 2.94×10^{-1} from exposure to methane, respectively. Also, the adult will have a LADD (mg/kg-day) of 1.25×10^{-4} from exposure to formaldehyde and 2.52×10^{-2} from exposure to methane, respectively. In addition, the child resident, in the CTE scenario, will not experience any cancer risk.

Table 10: *Non-carcinogenic health risks for Child Residents in the CTE scenario*

Daily Dose and Risk	Formaldehyde	Methane
CADD [mg/kg-day]	1.46×10^{-3}	2.94×10^{-1}
LADD[mg/kg-day]	1.25×10^{-4}	2.52×10^{-2}
Cancer Risk (-)	0.00	0.00
Hazard Index (-)	0.00	0.00

Non-carcinogenic health risks for E-waste Workers in the RME scenario

With reference to Table 11, the RME worker who has life time of 70 years, body weight of 70 kg, who spends 8 hr/day outdoor will have a CADD (mg/kg-day) of 2.45×10^{-3} from exposure to formaldehyde and 4.93×10^{-1} from exposure to methane, respectively. Also, the adult will have a LADD (mg/kg-day) of 8.74×10^{-4} from exposure to formaldehyde and 1.76×10^{-1} from exposure to methane, respectively. In addition, the worker, under the RME scenario, will not experience any cancer risk.

Table 11: *Non-carcinogenic health risks for E-waste Workers in the RME scenario*

Daily Dose and Risk	Formaldehyde	Methane
CADD [mg/kg-day]	2.45×10^{-3}	4.93×10^{-1}
LADD[mg/kg-day]	8.74×10^{-4}	1.76×10^{-1}
Cancer Risk (-)	0.00	0.00
Hazard Index (-)	0.00	0.00

Non-carcinogenic health risks for Workers in the CTE scenario

From Table 12, an E-waste worker who has a life time of 70 years, body weight of 70 kg, who spends 4 hr/day outdoor will have a CADD (mg/kg-day) of 2.03×10^{-04} from exposure to formaldehyde and 4.69×10^{-02} from exposure to methane, respectively. Also, the adult will have a LADD (mg/kg-day) of 2.32×10^{-05} from exposure to formaldehyde and 4.68×10^{-03}

from exposure to methane, respectively. The E-waste worker, in the CTE scenario, will not experience any cancer risk.

Table 12: *Non-carcinogenic health risks for Workers in the CTE scenario*

Daily Dose and Risk	Formaldehyde	Methane
CADD [mg/kg-day]	2.03 $x10^{-4}$	4.69 $x10^{-2}$
LADD[mg/kg-day]	2.32 x 10^{-5}	4.68 x 10^{-3}
Cancer Risk (-)	0.00	0.00
Hazard Index (-)	0.00	0.00

Non-carcinogenic health risks for Trespassers

From Table 13, the trespasser who has a life time of 70 years, body weight of 70 kg, who spends 3hr/day outdoor will have a CADD (mg/kg-day) of 2.93 $x10^{-4}$ from exposure to formaldehyde and 5.90 x 10^{-5} from exposure to methane, respectively. Also, the Trespasser will have a LADD (mg/kg-day) of 5.02 x 10^{-5} from exposure to formaldehyde and 1.01$x10^{-2}$ from exposure to methane, respectively. The Trespasser will not experience any cancer risk. With references to Tables 2 through 8, it can be said that there was no carcinogenic health risk associated with E-waste workers and their non-E-waste counterparts, thus the null hypothesis that there is carcinogenic health risk posed to E-waste workers failed to be rejected.

Table 13: *Non-carcinogenic health risks for Trespassers*

Daily Dose and Risk	Formaldehyde	Methane
CADD [mg/kg-day]	2.93 x10^{-4}	5.90 x10^{-2}
LADD[mg/kg-day]	5.02x 10^{-5}	1.01x10^{-2}
Cancer Risk (-)	0.00	0.00
Hazard Index (-)	0.00	0.00

CHAPTER FIVE

DISCUSSION

The results presented in chapter four are discussed here to guide and help draw conclusions on the study. This study sought to assess the level of knowledge of E-waste workers regarding the health risk associated with E-waste, the relationship between knowledge of E-waste workers on health risk and use of PPE and the correlation of concentrations of $PM_{2.5}$ and VOCs at each zone. This study further assessed the level of non-carcinogenic health risk posed to E-waste workers from exposure to VOCs namely methane and formaldehyde in ambient air of the study sites.

The Relationship between Educational Attainment and Level of Knowledge of Health Risk Associated with Inhalation of E-waste Smoke

This study found that, there is a significant relationship between levels of knowledge of environmental and human health effects of E-waste related smoke and educational attainment. It can be seen that, those without any educational attainment had the highest knowledge on environmental and human health effects of E-waste related smoke, with those with secondary education and above having the lowest. This may be due to the fact that those without education are more experienced, may have abandoned school early and have been on the job for much longer time compared with those with some form of formal education.

In order to improve knowledge of E-waste workers on the deleterious effects of E-waste burning, there are a number of interventions going on at the Agbogbloshie E-waste site where some researchers educate the E-waste workers on the human health and environmental effects of their activities. For instance, Asante et al. (2016) reported that the Green Advocacy of Ghana and the Blacksmith Institute (USA) had visited the Agbogbloshie dumpsite as part of studies conducted earlier in 2010. The researchers found that a major problem on the site was the burning of cables to remove their plastic sheathing to expose the copper and aluminium found in them. Currently, equipment to strip both large and small cables are available in the country via the Blacksmith Institute (USA) and it is expected that the E-waste workers will embrace the use of these technologies, which will go a long way to help prevent the burning of E-waste. It has been suggested that this intervention will be replicated in other smaller E-waste centres across Ghana (Asante et al., 2016).

In other occupational settings, knowledge, attitude and practices (KAP) survey was conducted in South India by Kishore et al. (2008). This survey focused on the effectiveness of an education programme to promote pesticide safety among pesticide handlers of South America. The education was provided using a structured individualized training programme to pesticide handlers. Three point KAP assessments were carried out at baseline, immediately after training and after 1 month of training. The study found out that educational interventions among pesticide handlers improved the KAP score for safe pesticide handling. Besides, it was recommended that continuous education and training programmes for agricultural workers would promote awareness and minimize the hazards of occupational pesticide exposure.

In a study conducted by Sabitu et al. (2009) on the awareness of occupational hazards and utilization of safety measures among welders in Kaduna Metropolis, Northern Nigeria, it was observed that there was an association between educational attainment and awareness of hazards, which was attributed to better understanding of instructions by educated welders, which is in line with this study.

A study conducted by Tadesse et al. (2016) on awareness of occupational hazards and associated factors among welders in Lideta found that workers' awareness of occupational hazards was dependent on their increased level of educational attainment and attributed it to the fact that higher level of education has the tendency to change available information into mature decision-making, which increased their awareness of hazards. This supports the present study as worker's ability to read and understand will increase his /her knowledge on health effects.

A study by Budhathoki et al. (2014) in Nepal on welders found that level of education had a significant relationship with awareness of hazard. This is consistent with the present study.

Relationship between Level of Knowledge of Health Effects and Use of Multiple PPE By E-waste Workers

The study found out that, people with high levels of knowledge of the human health effects of E-waste burning were more likely to use multiple PPE compared with people with low levels of such knowledge.

Although it is anticipated that, higher levels of knowledge of health effect will ensure that an individual protects him/herself in the occupational environment, it is well known that sometimes this may not necessarily be the case. There are instances where high level of knowledge has not necessarily translated into behavioural change. This is often referred to as the knowledge—action or value—action gap. For instance, a study conducted by Cristina, Juliana and Minas (2015) on adherence and knowledge about the use of personal protective equipment among manicurists found out that the knowledge of professionals about the importance and the correct use of PPE did not reflect the same extent in practice, represented by low adherence to them adherence, which is consistent with this findings of this study.

In 2005, a study on knowledge, attitude and practice regarding organic solvents among printing workers was carried out by Ignatius, Nga and Wong (2005) with a view to finding out the prevalence of good knowledge, appropriate attitude and safe practice among printing workers exposed to organic solvents. In this context, safe practice was found not to depend on knowledge and attitude, but was positively associated with being informed of safety precautions and being supplied with chemical information by supervisors, which is contrary to the findings of the present study. This may be due differences in the type of hazards workers are exposed to and also differences in the working environment.

Paramasivam, Raghavan, and Kumar (2007) conducted a study on knowledge, attitude and practices related to occupational health problems among Garment workers in Tamil Nadu, India. The result of that study showed that there was a wide gap between their knowledge level and practice with protective devices, which is contrary to the findings of this study and maybe due to the variations of work cultures and safety practices in working environment as well as related exposures and health problems.

A study conducted by Adewoye et al. (2013) found that, knowledge of the welders on the health hazards of welding smoke was not statistically related to the use of eye google during welding operation. This is contrary to this study and may be due to the fact that, most welders consider eye problems to be a symptom of the work, thus there is was no need to use face mask.

Moreover, Norm and Frank (1991) reported that majority of welders did not take adequate precaution to protect their eyes due to lack of knowledge on the adverse effects of welding (Norn and Frank, 1991). This is contrary to the present study and may be due to the fact the differences in work environment.

A study by Jensen et al. (2011) reported that the farmers had some awareness of the health hazards associated with pesticide use, they did not protect themselves adequately from acute pesticide poisoning and all farmers wore inadequate personal protective equipment leading to unsafe protection when mixing and spraying pesticides. This is also contrary to this study and may be due to occupational differences and hazards worker as exposed to.

Associations between Occupational and Residential Status and Self-Reported Experiences of Diseases Symptoms

The study found that E-waste workers reported the most of disease symptoms and experiences followed by resident non E-waste worker. Non-resident non E-waste worker reporting the least percentages of disease symptoms and experiences. This is expected as both E-waste workers and resident non E-waste workers spend most time at the working environment and reside around the E-waste site which increases their exposure to toxic E-waste related smoke and chemicals as compared to non-resident non E-waste workers.

Gordon et al. (1992) exposed four adults to 5 mg/m^3 zinc oxide fumes or furnace gases for 2 hours. All subjects reported symptoms 4-8 hours after zinc oxide exposure; the symptoms included chills, muscle/joint pain, chest tightness, dry throat, and headache. This is consistent with this study as most of the E-waste workers and resident non E-waste workers reported as exposed to lot of smoke and reported higher percentages of headache as compared to the control.

Study conducted in Nigeria by Ige and Awoyemi (2002) found that, flour workers reported most cases of respiratory diseases as compared to the control group which is in line with this study and may be due to the fact that, the flour workers as well as E-waste workers don't use PPEs and also had higher exposure duration compared to the control group.

Mohammadien and El-Sokkary conducted a research on effects of exposure to flour dust on respiratory symptoms and pulmonary function of mill workers found that respiratory symptoms such as cough, expectoration, wheezing, and shortness of breath, were significantly higher among exposed workers as compared to unexposed. The result indicates exposure to flour dust as the cause of respiratory symptoms which is in line with this study.

A study conducted by Neghab et al. (2012) in Iran showed that prevalence of regular cough, productive cough, wheezing, phlegm and dyspnea was significantly higher in exposed subjects to wheat flour than in an non-exposed employee which is consistent to the findings of this study.

A study conducted by Thorn, Beijer and Rylander (2002) among sewage workers reported a significantly increased risk for airway symptoms, chronic bronchitis, and toxic pneumonitis, as well as central nervous system symptoms such as headache, unusual tiredness and concentration difficulties were found among the sewage workers compared with controls. Also, sewage workers reported more joint pains as compared to the control which is consistent to the findings of this study.

Randem et al. (2002) reported that asphalt workers reported significantly more respiratory symptoms than the reference group of outdoor construction workers which supports this study.

The Relationship between E-waste Worker Use of PPE and Self-Reported Adverse Human Health Outcomes

This study found that those who do not use any form of PPE reported more health problems compared with those who use PPE. The use of PPE was associated with reporting of reduced health effects generally compared with those who do not use any PPE. This is expected as PPE are used to curb/reduce the potential health effects associated with the E-waste work environment.

Field observations indicate that the most of the PPE used were in very bad state and needed repair/maintenance which presumably affected its effectiveness. Similarly, those who used body protection did not wear it correctly as most had folded sleeves, open buttons or thorns in their work outfit. In addition, those who used the PPE might have had a false sense of protection against the hazards regardless of the fact that the PPE did not offer the protection intended. Moreover, majority of E-waste workers do not use any form of PPE given the claim that PPE are expensive.

Also, some workers complained that the use of PPE makes them feel inconvenient or discomfort. For example, a number of workers said that the use of hand gloves hampered their grip and thus reduced their efficiency. It was found that most of the workers just wore PPE which they thought is right for the job and used unconventional PPE such as sun glasses which offers no or minimal protection and very few used nose masks. Also, the problems of bone joint pains may have been caused by constrained posture coupled with inconvenient working environment and long hours of work, heavy lifting as well as pushing and pulling of scrap metals on a cart.

The findings from the present study indicates that these hazards seem as a less obvious threat to those exposed, which might be the reason E-waste workers do not use multiple PPE. Moreover, severe health consequences due to exposure manifest after longer exposure periods thus workers avail themselves to lot of harmful and toxic substance related to E-waste.

A study by Budhathoki et al. (2014) in Nepal observed that more than half of the welders did not use any PPE during work which is in line with the present study.

Heacock et al. (2015) reported that in general, communities with primitive, informal recycling operations tend to be populated by poor people with scarce job possibilities who are desperate to feed themselves and their families, and this primary concern overrides that for personal health and safety. This is in line with this study as the E-waste workers live in slums and surviving and feeding their families is their ultimate aim rather than buying PPE they claim is expensive.

A study on welders conducted by Sabitu et al. (2009) in Northern Nigeria observed lower prevalence of arc eye related symptoms because most of the welders used welding goggles during their work. This is in line with this study as using of right PPE will reduce the health impact of the hazard and also a statement from ILO 2011 which says “for PPE to be effective, it is important to ensure that the workers know the right type of PPE to be used and that it is used in the correct way for the periods when the worker is exposed to harmful substances or situations” also supports the present study.

Mohammed and Abdul Latif, (2014) conducted a research on possible health risk associated with garbage/refuse collectors and found that waste collection was conducted manually and posed a serious threat of sustaining musculoskeletal injuries and other forms of physical injuries while collecting municipal waste as workers do not use the right PPE and equipment, this also supports the current study.

A study conducted by Alim et al. (2015) documented that only few ceramics workers who were using PPE suffered from respiratory problems. On the other hand, majority of workers who did not use PPE had higher prevalence of respiratory problems among the ceramic workers i.e. Bronchitis, bronchial asthma, pulmonary tuberculosis, and silicosis. The study by Alim et al. (2015) also showed that a considerable number of workers were suffering from other health problems such as occupational dermatitis, musculoskeletal pain, back pain and headache which supports this study and this may be attributed to the heavy lifting and lack of use of PPE. This finding is consistent with the present study as PPE are used to reduce/curb health effects.

In addition , Hur et al. (2014) found out that wearing PPE significantly impaired functional balance by slowing down movement speed and increasing errors of firefighters. This is line with the present study as most workers complained of reduced speed and feeling uncomfortable when using PPE such as hand gloves.

Chan et al. (2017) also reported that direct exposure to toxic substances includes skin contact with harmful substances, inhalation of fine and coarse particles, and ingestion of contaminated dust. Individuals who directly engage in E-waste recycling with poor protection incur high levels of direct, occupational exposure. The potential adverse health effects of exposure to E-waste have been reviewed recently and may include changes in lung function, thyroid function, hormone expression, birth weight, birth outcomes, childhood growth rates, mental health, cognitive development, cytotoxicity, and genotoxicity. Given that majority of E-waste workers who did not use PPE reported several symptoms of diseases, it may be likely that the symptoms reflect underlying diseases of which they are presently not aware.

The human health effect of E-waste has been well demonstrated using human bio-monitors such as blood, serum, hair, scalp hair, human milk and urine and these health effects tend to increase if workers do not use PPE. Asante et al. (2012) found significant levels of Fe, Sb and Pb in urine samples of E-waste workers higher than that of the reference site. Ha et al. (2009) found that a concentration of Cu, Sb and Bi in the hair of E-waste recycling workers was higher than at the reference site. Zheng et al. (2008) also found high concentration of Cd in the blood of children around E-waste recycling regions. These findings confirm that human exposure to E-waste related activities pose significant health risks to workers.

Correlation of the Concentration of PM $_{2.5}$ and VOC at Each Zone

There was a strong positive correlation between $PM_{2.5}$ and VOC readings at each location. In all, $PM_{2.5}$ readings, thirty-one (31) locations fell within AQI category unhealthy for sensitive groups, twenty-three (23) locations fell under AQI very unhealthy and sixty-six (66) locations fell under AQI category hazardous. Moreover, $PM_{2.5}$ readings were much higher than the WHO AQI and AQG.

The $PM_{2.5}$ findings from this study are much higher compared with the WHO AQG and WHO AQI which has numerous health related issues and this is a public health concern as persons who do not work, but just stay in the area or happens to be in the area even for a short period, may also be at risk of experiencing acute health effects related to exposure of higher concentration of $PM_{2.5}$ and VOCs.

Even though all the workers at Agbogbloshie scrap yard are at risk, their exposure to $PM_{2.5}$ and VOC is heterogeneous implying the health risk will not be the same. E-waste workers will be prone to more disease as they are nearer to the smoke compared with other types of workers at the Agbogbloshie scrap yard.

Work conducted by Ziadat and Sood (2014) on the environmental impact assessment of open burning of scrap tires indicated that the mean concertation of PM_{10} recorded 500m away from where burning of tire taked place was much higher than the readings taken prior to burning, the difference in PM_{10} concentrations was attributed to scrap tire burning. Moreover, Ziadat and Sood found that, the concentration of PM_{10} were higher than the WHO AQI permissible limit and thus have a lot of health impacts. The research by Ziadat and Sood support the findings of this study.

A study conducted by Gangwar et al. (2016) on appraisement of heavy metals in respirable dust (PM_{10}) around E-waste burning and industrial sites of Moradabad found that PM_{10} values were higher than the recommended concentration of WHO for PM_{10} (50 μgm^{-3}) at all the study area and was attributed to the combination effects of industrial emissions, burning and processing of E-waste, vehicular movement and so on which will have a lot of health effects and supports this study.

A study conducted in Hong Kong on a territory wide survey on indoor particulate level by Tung et al. (1999) found that PM_{10} concentrations in Hong Kong homes where there is smoking and/burning incense burning was higher compared with home where there was no smoking and/burning, which is also in line with this study that burning increases concentrations of PM.

Lee, Guo and Kwok (2002) conducted a study on emissions of air pollutants from burning of incense by using large environmental chamber found that mass concentration of $PM_{2.5}$ in the chamber increased rapidly when the incense was ignited and average concentrations of other individual VOCs also increased with the burning of incense. The results indicate that, there is a strong correlation between $PM_{2.5}$ concentration and VOC concentrations which is also in line with this study.

Level of Non-Carcinogenic Health Risk Posed to E-waste Workers Non E-waste Worker Counterparts

There was no carcinogenic health risk posed to E-waste workers and non-waste workers. However, the concentration of LADD and CADD values for methane and formaldehyde in relation to child RME, adult RME and worker RME were high as compared with their corresponding groups (i.e. worker CTE, adult and child resident CTE).

The difference in concentrations of LADD and CADD for methane and formaldehyde between the child RME, adult RME and worker RME and their corresponding groups (i.e. worker CTE, adult and child resident CTE) may be due to the difference in exposure time. In addition, the concentration of formaldehyde was too low to warrant carcinogenic effect. On methane, the gas is not listed in the IARC, NTP or by OSHA as a carcinogen or potential carcinogen but higher concentration of methane may cause human related diseases such as headache.

A study by Monticello et al. (1996) exposed male F344 rats to different concentration of formaldehyde for different exposure duration. Epithelial cell proliferation at seven sites within the nasal cavity was determined after certain periods of months of exposure. The overall incidence of nasal squamous cell carcinoma in animals exposed to different concentration of formaldehyde was indicated that, the higher the concentration of formaldehyde, the higher the carcinogenic risk, which is in line with this study.

Soffritti et al. (2002) conducted a study on results of long-term experimental studies on the carcinogenicity of formaldehyde and acetaldehyde in rats and concluded that formaldehyde administered with drinking water, was shown to be carcinogenic based on an increased incidence of total malignant tumors and oncological lesions varying in site and histotype. This is contrary to this study because the exposure route of formaldehyde was ingestion whereas the present study considered inhalation of formaldehyde. Moreover, the present study did not analyze human tissues but used software to model the carcinogenicity of formaldehyde.

A study conducted in Beijing by Huang et al. (2013) on health risk assessment of inhalation exposure to formaldehyde and benzene in newly remodeled buildings concluded that, the median cancer risks (per million) of indoor exposure to formaldehyde was estimated to be 1,150 (based on US EPA IRIS IURs) if adult males and females work and live in the newly remodeled indoor environment over lifetime. This is contrary to the findings of this study and may be due to the differences in concentration of formaldehyde, the model used in estimating the carcinogenic and non-carcinogenic risk and this study measured concentration of formaldehyde in outdoor air.

Sousa et al. (2011) conducted a study on the exposure and cancer risk assessment for formaldehyde and acetaldehyde in the hospitals in Fortaleza, Brazil and found that the obtained ranges of cancer risk for formaldehyde was higher than the acceptable cancer risks of 106 (one in 1,000,000) and 105 (1 in100,000) recommended by USEPA. This is also contrary to the present study and may be due to differences in the models used during the estimation of the carcinogenic effects and also the differences in concentrations of formaldehyde.

Although this study did not find any potential carcinogenic risk to children, lots of studies have shown that children are at higher risk of carcinogenic health effects because exposures to hazardous substances at E-waste sites are higher for children than for adults due to the fact that children are still growing and their intake of water, food, and air in proportion to their height and weight is significantly higher compared with the intake of adults. Children have much larger ratio of surface area to body weight than adults, resulting in a higher risk for dermal absorption of toxic substance (Duffert, Brune, Prout, 2009; Perkins et al., 2014). In addition, children have a decreased ability to detoxify substances and their organs are more sensitive to damage (Perkins et al., 2014). Finally, children have a longer life expectancy during which the harm will be accumulating in which they will live with the injuries of the toxic substances (Perkins et al., 2014).

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This study was to assess the health effects of xenobiotics on people working in the E-waste industry. The research sought to find answers to the following questions:

1. What is the relationship between educational attainment, level of knowledge of health risk associated with smoke from burning E-waste and use of multiple PPE by E-waste workers?
2. Is there an association between occupational and residential status and self-reported experiences of disease symptoms?
3. What is the relationship between E-waste worker use of PPE and self-reported human health outcomes?
4. Is there correlation between the concentration of $PM_{2.5}$ and VOC at each zone?
5. What is the level of non-carcinogenic health risk posed to E-waste workers and their non-E-waste worker counterparts?

The quantitative study was carried out at the Agbogbloshie scrap yard. A total of 260 copies of the questionnaire were given out to respondents using the purposive sampling method. Also the concentrations of $PM_{2.5}$ and VOCs were taken from the Agbogbloshie scrap yard with Winneba Zongo as the control. In addition, concentration of methane and formaldehyde were also measured at the Agbogbloshie scrap yard.

The data from the questionnaire and concentration of $PM_{2.5}$ and VOC were analyzed statistically using inferential statistics. Inferential statistics was used determine whether or not the null hypothesis should be rejected or not and to establish relationships among the parameters measured. The results of the $PM_{2.5}$ concentrations were discussed in relation to permissible limits established by the WHO. The RISC 4.02 software was used to determine the non-carcinogenic health risk.

Summary of Findings

There were statistically significant relationships between educational attainment and level of knowledge of health risks associated with E-waste related smoke, between level of knowledge of health effects and use of multiple PPE as an E-waste worker. There was a statistically significant relationship between occupational and residential status and self-reported experiences of diseases symptoms. There was also a statistically significant relationship between use of multiple PPE as an E-waste worker and self-reported human health outcomes except that eye problems and breathing difficulty. Also there was a strong correlation between the concentration of $PM_{2.5}$ and VOCs at each of the zones within the study site. The study also revealed that the concentrations of $PM_{2.5}$ were far higher compared with the AQI and AQG of WHO. Moreover, there was a non-carcinogenic health risk assessed from the inhalation of methane and formaldehyde for both E-waste workers and their counterpart.

Conclusions

In conclusion, this research found a significant relationship between educational attainment of E-waste worker and level of knowledge of health risk associated with smoke from E-waste burning. Also there was relationship between E-waste workers level of knowledge of health effects and use of multiple PPE. There was a relationship between occupational and residential status and self-reported experiences of diseases symptoms. Again, there was significant relationship between use of PPE and reduced self-reported human health outcomes of E-waste workers. Moreover, there was a strong correlation between concentrations of $PM_{2.5}$ and VOC at each zone but there was no carcinogenic health risk posed to E-waste workers.

The relationship between educational attainment of E-waste worker and level of knowledge of health risk associated with E-waste related smoke indicates that, there should be workshops seminars and educational programs developed and organized by stakeholders and opinion leaders at Agbogbloshie to educate the e-workers and increase the knowledge which will help mitigate the effects of burning of E-waste.

The relationship between worker's level of knowledge of health effects and use of multiple PPE indicates that there should also be health education and safety promotion programmes for E-waste workers to have a better understanding of the importance of PPE, know the right type of PPE to use and how to effectively wear the right PPE. Also, the government should subsidize prices of PPE. In addition, opinion leaders and policy makers at the

Agbogbloshie scrap yard should make it compulsory for all E-waste worker to use PPE.

The relationship between occupational and residential status and self-reported experiences of diseases symptoms suggest that both E-waste workers and resident around the E-waste site are at risk of E-waste related diseases and health education should be designed for the E-waste workers as well as resident of the Agbogbloshie scrap yard.

The strong correlation of concentrations of $PM_{2.5}$ and VOCs at each zone indicates that e-workers must use an alternative method like stripping of metal from copper instead of burning of E-waste to reduce the concentration of $PM_{2.5}$ and VOCs.

Although this study did not find a significant difference in the level of non-carcinogenic health risk posed to E-waste workers and their non-E-waste counterparts, the workers at the Agbogbloshie E-waste scrap indicated that they had experienced several episodes of skin irritation, skin burns, urinary problems and coughing within one month. Therefore, the E-waste workers should visit the hospital for regular check-ups, use the right PPE, reduce or stop burning of E-waste and follow simple hygiene procedures such as washing of hand before eating.

Recommendations

Though there are a lot of health-related problems associated with working with E-waste in Agbogbloshie, the health risk can be reduced by educating the workers to use mechanical equipment to strip off rubber from copper instead of burning. In addition, NGOs and philanthropic organisation should also aid with the education and provision of the necessary PPE to the E-waste workers. Also, the government should subsidize the prices of PPE to make affordable and thereby increase patronage by the E-waste workers.

Suggestions for Further Research

With the established findings derived from the study, the following recommendations have been made out

1. Further studies should include the measurement of concentrations of individual VOCs.
2. A longitudinal study on the health effects of specific xenobiotics on the health of E-waste workers should be carried on.

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APPENDICES

Appendix A: Questionnaires for E-waste workers

SECTION A: BIODATA

1	What is your Gender?	Male	1
		Female	2
2	What is your Age?	Below 20years	1
		21 - 30 years	2
		31 - 40 years	3
		41 - 50 years	4
		51 - 60 years	5
		Above 60 years	6
3	What is your Marital status?	Single	1
		Married	2
		Divorced	3
		Widow / Widower	4
4	What is your highest level of educational attainment?	Non-Formal Education	0
		Primary Education	1
		Junior High School/ Middle School	2
		Senior High School / Vocational Training	3
		Tertiary	4
5	What is your status in the family?	Head	
		Spouse of head	
		Child	
6	What is your house hold size?	1 – 5	1
		5 – 10	2
		Above 10	3

7	What is your religion?	Muslim	1
		Christians Traditional	2 3
		Other Specify	7
8	What is your nationality?	Ghanaian	1
		Nigerian	2
		Liberian	3
		Togolese	4
		Other specify	7
		If not Ghanaian move to question 11.	
9	If Ghanaian, which region do you come from?	Central Region	1
		Greater Accra	2
		Western Region	3
		Ashanti Region	4
		Northern Region	5
		Upper West	6
		Upper East	7
		Volta Region	8
		Brong – Ahafo Region	9
		Eastern Region	10
10	What is your ethnicity?	Dagomba	1
		Komkomba	2
		Gonja	3
		Sisala	4
		Akan	5
		Ga	6
		Ewe	8
		Other specify	7

SECTION B: DURATION OF WORK, COMPONENT OF E- WASTE BURNT AND INCOME

11	Are you a full-time E-waste worker?	No	0	
		Yes	1	
12	If No, what other work do you do?			
13	How many hours do you work a day?	4	1	
		6	2	
		8	3	
		10	4	
		12	5	
14	How many days do you work in a week?	2 – 3	1	
		4 – 5	2	
		6 – 7	3	
15	What kind of electronic gadget do you work on?	T.V.	No	0
			Yes	1
		Radio	No	0
			Yes	1
		Fridges	No	0
			Yes	1
		Computer	No	0
			Yes	1

		Fan	No	0
			Yes	1
		Printers	No	0
			Yes	1
		Other		7
16	Which part of the gadget do you extract for burning?	Cathode ray tube	No	0
			Yes	1
		Circuit Boards	No	0
			Yes	1
		Copper Wire	No	0
			Yes	1
		Steel	No	0
			Yes	1
		Aluminum	No	0
			Yes	1
		Zinc	No	0
			Yes	1
		Other specify		7
17	What is your average daily sale in Gh¢?	Record as mentioned	Gh¢	
18	What is your average monthly sale in Gh¢?	Record as mentioned	Gh¢	

SECTION C: SAFETY PRACTICES AND MEASURES EMPLOYED DURING E. WASTE SCAVENGING, DISMANTLING AND BURNING.

19	Do you protect yourself during scavenging, dismantling and burning of E-waste? If no skip to question 23.	No	0	
		Yes	1	
20	Which of these safety materials do you use during scavenging?	Safety boots	No	0
			Yes	1
		Safety goggles	No	0
			Yes	1
		Hand gloves	No	0
			Yes	1
		Dust mask	No	0
			Yes	1
		Other		7
21	Which of these safety materials do you use during dismantling of E-waste?	Safety boots	No	0
			Yes	1
		Safety goggles	No	0
			Yes	1
		Hand gloves	No	0
			Yes	1
		Dust mask	No	0
			Yes	1
		Other		7
22	Which of these safety materials do you use during burning of E-waste?	Safety boots	No	0
			Yes	1
		Safety goggles	No	0
			Yes	1
		Hand gloves	No	0
			Yes	1
		Dust mask	No	0
			Yes	1
		Other		7
23	Do you practice any safety measures scavenging, dismantling and burning of E-waste? If no skip to 27.	No	0	
		Yes	1	

24	Which of the following safety measures do you practice during scavenging?	Avoidance of eating	No	0
			Yes	1
		Avoidance of talking	No	0
			Yes	1
		Avoidance of direct contact on skin	No	0
			Yes	1
		Other specify		7
25	Which of these safety materials do you use during dismantling?	Avoidance of eating	No	0
			Yes	1
		Avoidance of talking	No	0
			Yes	1
		Avoidance of direct contact on skin	No	0
			Yes	1
		Other specify		7
26	Which of these safety materials do you use during burning?	Avoidance of eating	No	0
			Yes	1
		Avoidance of talking	No	0
			Yes	1
		Avoidance of direct contact on skin	No	0
			Yes	1
		Other specify		7

SECTION D: HEALTH EFFECT ASSOCIATED WITH WORKING ON E-WASTE.

27	How often do you go for medical checkup?	Don't go for checkup	0
		Once every 6 month	1
		Twice every 6 months	2
		Other specify	7
28	Have you heard of xenobiotics?	No	0
		Yes	1
29	Are you aware most of these products you handle contain dangerous substance that can affect your health if mishandled? If No skip to question 32.	No	0
		Yes	1
30	What are some of the effect of E-waste mishandling?	It may poison the body	1
		It may cause skin diseases	2
		It causes eye problems	3
		It can cause respiratory diseases	4
		Other specify	7
31	Are you aware burning of E-waste	No	0

	could result in inhalation of toxic substance such as heavy metals?	Yes	1	
32	Have you experienced the following health problems before?	Chest pain	No	0
			Yes	1
		Skin rashes	No	0
			Yes	1
		Eye problems	No	0
			Yes	1
		Skin burns	No	0
			Yes	1
		Difficulty in breathing	No	0
			Yes	1
		Coughing	No	0
			Yes	1
		Throat irritation	No	0
			Yes	1
		Weakness of joints	No	0
			Yes	1
		Other specify		7

33. **HOW OFTEN DO YOU EXPERIENCE THE FOLLOWING ILLNESS**

		0	**1**	**2**	**3**
	Symptoms	Not experience	Once in a week	Twice in a week	Several times in a week
A	Chest pain				
B	Catarrh				
C	Skin rashes / irritation				
D	Skin burns				
E	Eye problems				
F	Headache				
G	Breathing difficulty				
H	Coughing				
I	Urinary problems				
J	Weakness of joints				

Appendix B

QUESTIONNAIRES FOR RESIDENT NON E-WASTE WORKERS AND NON-RESIDENT NON E-WASTE WORKERS

SECTION A: BIOTA

1	Gender	Male	1
		Female	2
2	Age	Below 20years	1
		21 - 30 years	2
		31 - 40 years	3
		41 - 50 years	4
		51 - 60 years	5
		Above 60 years	6
3	Marital status	Single	1
		Married	2
		Divorced	3
		Widow / Widower	4
4	Educational Attainment	Non-Formal Education	0
		Primary Education	1
		Junior High School/ Middle School	2
		Senior High School / Vocational Training	3
		Tertiary	4
5	What is your Status in the Family	Head	
		Spouse of head	
		Child	
6	House hold Size	1 – 5	1
		5 – 10	2
		Above 10	3
7	What is your religion	Muslim	1

		Christians Traditional	2 3
		Other Specify	7
8	What is your nationality	Ghanaian	1
		Nigerian	2
		Liberian	3
		Togolese	4
		Other specify	7
		In no not Ghanaian move to question.	
9	If Ghanaian, which region do you come from	Central Region	1
		Greater Accra	2
		Western Region	3
		Ashanti Region	4
		Northern Region	5
		Upper West	6
		Upper East	8
		Volta Region	9
		Brong – Ahafo Region	10
		Eastern Region	11
10	What is your ethnicity	Dagomba	1
		Komkomba	2
		Gonja	3
		Sisala	4
		Akan	5
		Ga	6
		Ewe	8
		Other specify	7

SECTION B: DURATION OF WORK

11	Are you a full time hawker/food seller	No	0
		Yes	1
12	If No, what other work do you do?		
13	How many hours do you work a day	4	1
		6	2
		8	3
		10	4
		12	5
14	How many days do you work in a week	2 – 3	1
		4 – 5	2
		6 – 7	3
15	What is your average daily sales in Gh¢?	Record as mentioned	Gh¢
16	What is your average monthly sales in Gh¢	Record as mentioned	Gh¢

SECTION D: HEALTH EFFECT ASSOCIATED WITH WORKING ON E-WASTE.

17	How often do you go for medical checkup	Don't go for checkup	0	
		Once every 6 months	1	
		Twice every 6 months	2	
		Other specify	7	
18	Have you heard of xenobiotics	No	0	
		Yes	1	
19	Are you aware burning of E-waste could result in inhalation of toxic substance such as heavy metals?	No	0	
		Yes	1	
20	Have you experienced the following health problems before ?	Chest pain	No	0
			Yes	1
		Skin rashes	No	0
			Yes	1
		Eye problems	No	0
			Yes	1
		Skin burns	No	0
			Yes	1
		Difficulty in breathing	No	0

			Yes	1
		Coughing	No	0
			Yes	1
		Throat irritation	No	0
			Yes	1
		Weakness of joints	No	0
			Yes	1
		Other specify		7

Q21 **HOW OFTEN DO YOU EXPERIENCE THE FOLLOWING ILLNESS?**

	Not experience 0	Once in a week 1	Twice in a week 2	Several times in a week 3
Chest pain				
Catarrh				
Skin rashes / irritation				
Skin burns				
Eye problems				
Headache				
Breathing difficulty				
Coughing				
Urinary problems				
Weakness of bones				

Appendix C

Images from Agbogbloshie Scrap Yard

Images showing how E-waste is burnt

Image showing smoke from E-waste burning