

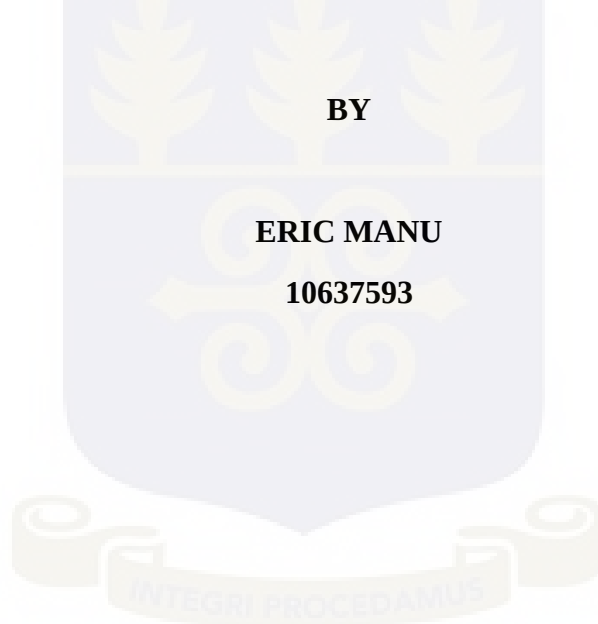
**SCHOOL OF PUBLIC HEALTH
COLLEGE OF HEALTH SCIENCES
UNIVERSITY OF GHANA**

**BIO-INDICATOR ANALYSIS OF POLLUTION DUE TO ELECTRONIC
WASTE RECYCLING ACTIVITIES: THE HEAVY METAL
CONCENTRATIONS IN EARTHWORMS, FEATHERS AND EGGS OF BIRDS
COLLECTED AROUND AGBOGBLOSHIE**

BY

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**THIS DISSERTATION IS SUBMITTED TO THE UNIVERSITY OF GHANA,
LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE
AWARD OF MASTER OF PUBLIC HEALTH DEGREE**

JULY, 2018

DECLARATION

I, Eric Manu hereby declare that apart from references to other people's work which have been duly acknowledged, this proposal has been written independently by me and has not been submitted for the award of any degree in any institution.

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DEDICATION

This research work is dedicated to my parents, Mr. and Mrs. Owireko Manu, my wife Aba Aboagyewa Morrison-Manu and to my brother and mentor, Dr. Alexander Ansah Manu for their awesome encouragement throughout this programme.

ACKNOWLEDGEMENT

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ABSTRACT

Introduction: Informal sector recycling of e-waste could lead to release of various toxic substances; including the oxides of heavy metals into the ambient environment and therefore contributes significantly to environmental pollution.

Objectives: The aim of the study was to analyze heavy metals concentration levels in bird feathers and eggs and earthworm found at the Agbogbloshie e-waste dumpsite.

Methods: A cross sectional study was conducted at the Agbogbloshie e-waste site near Accra. Cattle egret quill feathers and eggs as well as earthworms were collected around the e-waste site and analyzed for heavy metals concentrations (As, Cd and Pb) using an Atomic Absorption Spectrophotometry. Data was entered into STATA 15 and analyzed. Medians, inter quartile range and correlation analysis were done to establish relationship of between heavy metals levels in feathers, eggs and earthworms.

Results: median As concentration was [6.672 (IQR: 5.78-7.18)] $\mu\text{g/g}$ in feathers; [6.203 (IQR: 0.26-9.50)] $\mu\text{g/g}$ in eggshell; [6.229 (IQR: 4.53-7.14)] $\mu\text{g/g}$ in egg content and [18.46 (IQR: 8.24-24.33)] $\mu\text{g/g}$ in earthworm, followed by Pb [1.886 (IQR: 1.44-2.25)] $\mu\text{g/g}$ in feathers; [1.1741 (IQR: 1.11-1.99)] $\mu\text{g/g}$ in eggshell; [1.181 (IQR: 0.86-1.47)] $\mu\text{g/g}$ in egg content and Pb [5.39 (IQR: 4.71-9.99)] $\mu\text{g/g}$ in earthworm, while Cd was the least with median level [0.024 (IQR: 0.01-0.05)] $\mu\text{g/g}$ in feathers; [0.142 (IQR: 0.00-0.41)] $\mu\text{g/g}$ in eggshell; [(0.000 (IQR: 0.00-0.00)] $\mu\text{g/g}$ in egg content and [5.102 (IQR: 4.98-5.99)] $\mu\text{g/g}$ in earthworm.

A rank spearman correlation showed strong positive correlations for heavy metals concentration between BF and EGC, EGS and EGC and EGS and BF with [$r = 0.8558$; $n = 90$; $p < 0.05$]; [$r = 0.8572$; $n = 90$; $p < 0.05$] and [$r = 0.8487$; $n = 90$; $p < 0.05$] respectively.

Conclusion: Pollution levels of bird feathers, eggshell, egg content and earthworm are reflective of the extent of environmental pollution within the Agbogbloshie ecosystem.

Keywords:

Contamination levels, Exposure, Plumage, Toxic substance, Earthworms, Heavy metal contamination

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LIST OF ABBREVIATIONS

ATSDR-	Agency for Toxic Substance and Disease Registry
As-	Arsenic
BF-	Bird feather
Cd-	Cadmium
CDC-	Center for Disease Control
CNS-	Central Nervous System
CRT-	Cathode Ray Tube
Cu-	Copper
DVD-	Digital Video Disc
EEE-	Electrical and Electronic Equipment
EGC-	Egg content
EGS-	Egg shell
E-WASTE-	Electronic waste
Hg-	Mercury
LCD-	Liquid Crystal Display
Ni-	Nickel
Pb-	Lead
UNEP-	United Nations Environment Programme

DEFINITION OF TERMS

E-waste: End of life unwanted, obsolete or unusable electronic products such as computers, computer peripherals, televisions, Video Cassette Recorders (VCRs), Digital Video Disc (DVD) Players, hand cell phones and stereo equipment which is dependent on electrical currents or electromagnetic fields in order to work properly comprising of toxic metallic and plastic components.

Contamination level: The concentration of heavy metal burden in samples analyzed in $\mu\text{g/g}$.

Toxicant: Any naturally occurring heavy metal such as As, Cd and Pb that has poisonous effect on the environment and organisms.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The terrestrial ecosystem in the Agbogbloshie e-waste dump site exists as a landform which covers agricultural areas, swamps with mangroves and urban slums which is involved in heavy recycling of e-waste with adjoining industrial and commercial business. It therefore serves as a major location for the deposition of chemical substances due to human and natural processes. These human and natural processes have affected both the terrestrial and the aquatic ecosystem. This has caused the rise of levels of many chemicals in this ecosystem. (Hashmi, 2015).

The current trend in globalization has witnessed the extensive use of technology and this has led to the frequent production, replacement of software, audio-visual components and planned withdrawals of obsolete technological materials including computers from the markets of high income countries and dumped in low income countries. This results in an imbalance of electronic waste (e-waste) disposal around the world (Lundgren, 2012). Disposal of electronic waste is an emerging public health problem because of massive volumes generated and the absence of management policy as well as recycling facilities in a lot of countries (Ogunseitan, 2009). The open burning and disposals of the e-waste owing to the lack of or very limited access to designated recycling centers leads to subsequent discharge of heavy metals like Mercury, Lead, Cadmium and Arsenic which have a great effect on the flora and fauna and the general environment around such dumping sites.

The living organisms, water, soil and air around the Agbogloshie dumping sites are adversely affected due to this practice (Chi et al., 2011; Feldt et al., 2014). The bird population around the dump site are largely exposed to the heavy metals under consideration via earthworm intake, breathing and picking up of other food particles from the environment.

Lead, Arsenic and Cadmium are heavy metals with known adverse effects in living organisms and are known to be toxic even at low concentrations (Vashishat & Kler, 2014). High Cadmium exposure in feathers of birds at the population level affect the strength of flying as it is known to weaken muscles coupled with an impairment in bone development (Spahn & Sherry, 1999). These toxicants from e-waste recycling gain access into the body by inhalation, dermal contact and ingestion and if not metabolized accumulate in the soft tissues of the organisms (Agbeko, 2015).

The feeding and life processes of the Cattle Egrets (*Bubulcus ibis*) expose them to the harmful effects of these heavy metals such as pigmentation of egg shell, reduction in egg shell thickness, pigmentation of feathers, plumage, natural plucking of feathers, unsuccessful reproduction ability, habitat adaptation in new areas due to migration of birds and consequently reduction in bird population. Burger,(2002); Roux & Marra, (2007) and Smith et al., 2009) have also stated that, the accumulation of heavy metals in birds inhibit the synthesis of haemoglobin, cause damage to the cardiovascular system, the central and peripheral nervous systems, reproduction, impairment in thermoregulation, decreased survival of gull nestlings, and delayed recognition of siblings. Considering the cattle egrets (*Bubulcus ibis*) which occupies a high trophic level in the food chain, accumulation of these heavy metals poses a threat not only to their health but also, the health of other organisms

along the food chain such as humans that use them for food directly or indirectly (Burger, 2002).

The Earthworms that live in the soils of the e-waste site are among the important soil organisms that are accountable for the maintenance of soil fertility and its enrichment. They also serve as a major source of bird diet that represent a dangerous source of route of exposure to certain heavy metals like Lead and Arsenic (Tchounwou et al., 2012) which further pose as an indicator of environmental contamination.

In Ghana, high levels of heavy metals and other pollutants have been reported in soil, water and air in communities close to the e-waste recycling site (Caravanos et al., 2011; Feldt et al., 2014) but the adverse effect in the food chain population remains unknown.

Biomonitoring approaches using bird's eggs and feathers as well as food sources for birds such as insects and worms as bio-indicators to assess the integrity of different ecosystems have been used by several researchers over the decade (Hashmi et al., 2015).

The study determined the concentration levels of As, Cd and Pb in feathers, egg shell and contents of the Cattle Egrets and whole earthworms and also analyzed the relationship of co-exposure of the selected heavy metals of known toxicity in bird feather, egg content and egg shells of the cattle egrets.

1.2 Problem Statement

Heavy metals contamination influences the functional and structural purity of an ecosystem. This poses threat to all organisms in the food chain, with species at high trophic levels having a higher capacity for bioaccumulation, and therefore higher risk. The Odaw River is in the catchment area of the Agbogbloshie e-waste site which is home to various organisms in the ecosystem including fishes, insects, worms and birds, predominantly Cattle Egrets. These

organisms are potentially at a high risk of being exposed to varying levels of heavy metals pollution from the recycling site. Contamination levels in birds i.e. feathers or eggs or earth burrowers such as earthworms will directly reflect the levels of pollution in the ecosystem. Studies around the e- waste site so far have focused mostly on the levels of pollution on the e-waste workers, school children, soil, water and air, but not on fauna such as earthworms and birds. Although Cattle Egrets are mostly migratory birds, those found at Agbogbloshie are known to be partially or permanently resident at the area. There is therefore the need for data on the burden of heavy metal contamination levels in birds and earthworms.

1.3 Conceptual framework.

The informal recycling of e-waste involves a lot of processes which includes collection, sorting, dismantling and open air burning (Akormedi et al.,2013). Burning of e-waste to retrieve valuable metals cause the release of highly toxic substances, including heavy metals, fumes and organic pollutants into the air, food, soil, ground and surface water. Exposure of organisms to these heavy metals may occur through ingestion of contaminated food and water and direct deposits onto the feathers of birds and skin of earthworm.

Birds can be exposed through ingesting contaminated water or food. These toxic substances could then be distributed to various parts of the birds' body including feathers, egg shell and egg content. Birds additionally, apart from direct exposure through air and water also get exposed through feeding on earthworms. Contamination may bio-accumulate over time and this can remain in the food chain where they can invariably be transferred across trophic levels.

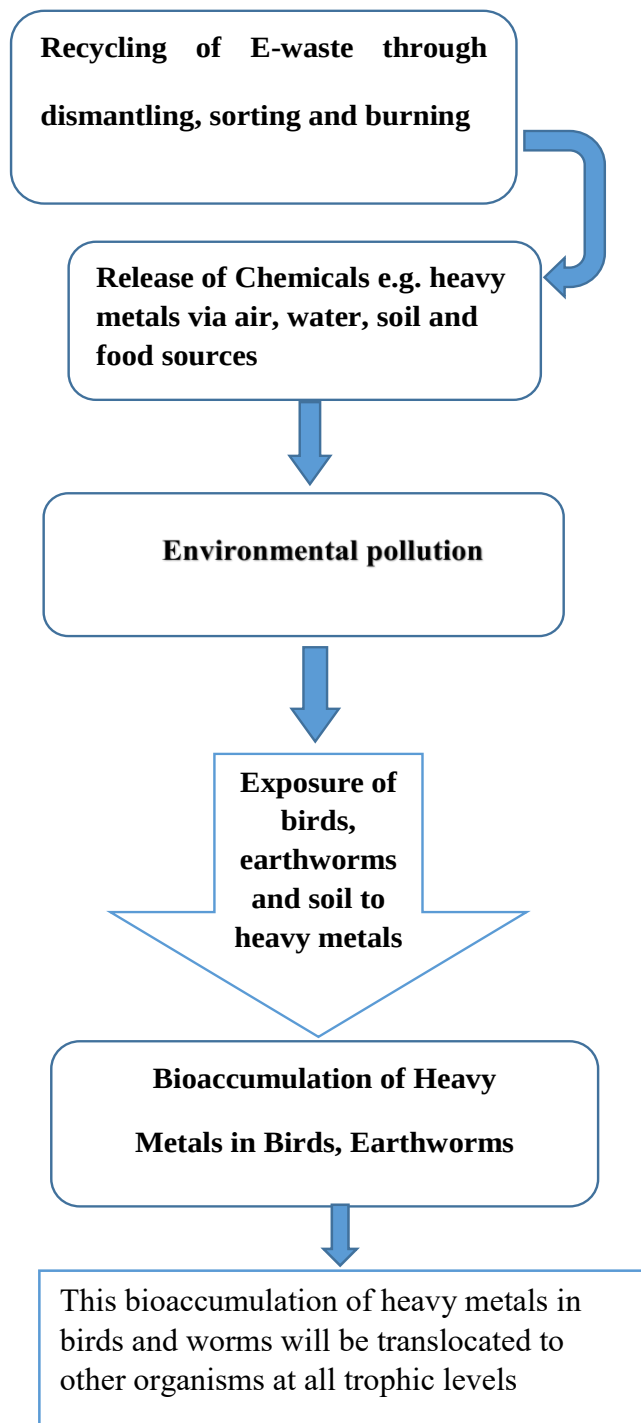


Figure 1.1: Conceptual Framework showing relationship between e-waste recycling and exposure of birds and earthworms to toxic substances

1.4 Justification

Recently, there has been a series of international initiatives that aim at dealing with global e-waste management, trade and the menace of environmental pollution due to e-waste recycling (WHO, 2013). Studies conducted to assess the levels of heavy metals along the West African sub-region including Ghana have centered on human and aquatic samples. The dumping of e-waste in Ghana as a whole and Accra being the capital, specifically the area bordering Agbogbloshie has increased substantially over the decade. Agbogbloshie remains an environmental threat and is reported to be inhabited by over 40,000 people (Feldt et al., 2014). Studies indicate that e-waste is a fundamental source through which the environment is contaminated by heavy metals and this poses a threat to the ecosystem which cannot be over emphasized.

Regardless of the possible health implications posed by e-waste, insufficient work has been done to assess the concentration of Lead, Cadmium and Arsenic and other heavy metals in Cattle Egrets and Earthworms around the e-waste dumping site.

Earthworms, for instance, contribute to the maintenance of the soil fertility; recycling of nutritious component, increasing aeration and drainage of the soil, and forms a vital constituent of the diet of animals including small mammals, reptiles and birds (Allen et al., 2001). Conceptually, high levels of Mercury, Lead, Cadmium and Arsenic pose a direct threat to other organisms in the food web including humans. This study was therefore essentially conducted to assess the extent of exposure and consequently provide scientific evidence that would inform policy formulation to safeguard the Cattle Egret which play key roles in the food chain from becoming extinct.

1.5 Research Questions

The following will constitute the research questions of the study;

- What are the levels of heavy metals in feathers, eggs (egg shell or egg content) of cattle egrets around Agbogbloshie e-waste site?
- Are earthworms around the Agbogbloshie e-waste site exposed to heavy metals contamination?
- Is there any relationship between heavy metals concentrations in birds and earthworm?

1.6 Study Objectives

1.6.1 General Objective

The aim of the study was to analyze heavy metal concentrations the feathers and eggs of cattle egrets and earthworms around Agbogbloshie e-waste site.

1.6.2 Specific Objectives

- i. To determine the concentrations of Arsenic, Cadmium and Lead in feathers of cattle egret
- ii. To determine the concentrations of arsenic, cadmium and lead in eggs of cattle egret
- iii. To determine the concentrations of arsenic, cadmium and lead in earthworms.
- iv. To find the correlation (association) between heavy metals concentrations in birds and earthworms.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Definition of E-waste

E-waste is defined as discarded obsolete computers, entertainment electronic devices, office electronic gadgets, television sets, mobile phones and refrigerators which rely on electrical currents or electromagnetic fields to enable them function appropriately. They are made up of toxic metallic (inorganic) and plastic (organic) components. It could be divided into 3 main categories: (i) bulky home appliances that include refrigerators and washing machines, (ii) information technology (IT) and telecom gadgets like personal computers, monitors and laptops and (iii) consumer equipment like Televisions, Digital Video Display (DVD) players, mobile phones, Motion Picture layer 3 (MP3) players, leisure and sporting equipment (Nwagwu & Okuneye, 2016).

2.2 E-waste and the Ecosystem

The current earth's population is estimated to be seven (7) billion. About half of these individuals reside in the urban areas of the world (United Nations / Department of Economic and Social Affairs, 2009). Urban population is quickly developing and the amount of e-waste generated is expanding more than ever (Kumar et al., 2017). Waste generation increases proportionally with population number and income, making it a need for effective management (Kumar et al., 2017).

Legally or illegally e-waste imported from the high income countries are deposited on municipal landfills of low and middle income countries, where crude, primitive and rude processes are employed in the recycling of the e-waste to obtain valuable chips. Lead (Pb),

Arsenic (As), Cadmium (Cd), Mercury (Hg) are some of the hazardous chemicals found in E-waste. Other harmful chemicals such as brominated flame-retardants and polychlorinated biphenyl (PCB) are also found in electronic waste. Research have shown that substantial amount of these chemicals are contained in e-waste and as a result of crude processes of recycling in un-engineered landfills. These result in ecological damage to crop, aquatic and human life as chemicals gradually permeate into the soil, surface and ground water. (Chen et al., 2010). The practice of discharging poisonous pollutants into soil, water and air due to unregulated means of e-waste disposal could directly have a negative effect on the health of the inhabitants around the dumpsite and through the environment and their local food chain (Kiddee et al., 2013). The compound effects of e-waste are in-built in the structure and manufacturing of Electrical and Electronic Equipment (EEE) which are well-known to show features which are hazardous in nature (Kiddee et al., 2013) and are made up of precious or important metals (Reck & Graedel, 2012). Handling of e-waste in an unregulated fashion has negative impacts on life.

Initially, researches had challenges associating the impact of e-waste recycling to environmental pollution however, studies conducted by Caravanos et al., (2011) and Sepúlveda et al., (2010) have produced evidence which clearly show a strong association between e-waste and environmental pollution. Several studies have also reported traces of chemical pollutants that are higher than their minimum accepted levels in water and soil. Soil, water and plants heavy metal burden in the Agbogbloshie e-waste processing area has been established (Leung et., 2008; Lu et al., 2009; Spalvins et al., 2008).

Studies conducted on e-waste disposal sites in Ghana have reported high concentrations of heavy metals on these sites. Despite these findings, little or no studies have been done on the impact of these heavy metals on the food chain or the ecosystem at large.

For instance, a study by Atiemo et al.,(2012) on heavy metal on recycling sites of e-waste in Ghana reported that surface soil were contaminated by heavy metals. In addition, (Asante et al., (2012) showed that urine samples from workers at Agbogbloshie e-waste dumpsites had traces of Arsenic (As). (Otsuka et al.,(2012), also found heavy metals including Cd, Pb Hg, As, Ni and Cu in water and soil at the Agbogbloshie e-waste recycling sites but did not consider the impact of these metals on the ecosystem along the sites. This work aims at bridging that knowledge gap.

2. 3 Heavy Metal Toxicity and the Ecosystem

2.3.1 Lead

Naturally, the human body is not made up of lead. However, studies have shown that Lead is a threat to the health of living organisms since it exists in their surroundings. For instance the presence of lead in humans even at low concentrations can cause disabilities in learning in children below seven (Abagale et al., 2013). Lead can naturally be found in the soil but mostly of low concentrations. The human use of lead goes back at least 5000 years (Bradl, 2005).

Accumulation of lead in the human body impede the transport of oxygen to the cells of human body. This is because lead can hinder the synthesis of haemoglobin which is responsible for the transport of oxygen by inhibiting the activities of the two enzymes involved in its synthesis. This event leads to anemia in humans (Bradl, 2005).

Lead mostly bio accumulates in certain parts of organisms such as kidneys, liver of fish instead of the muscle of the skin and bones but does not bio-magnify up the food chain. As a

result, when one is exposed to Lead through any of these routes, the effect of lead is minimized (Wright & Welbourn, 2001). However, individuals who consume all the body parts of organisms have a higher risk of exposure to lead in high concentrations.

In algae, the process of photosynthesis is hindered as the concentrations of Lead exceeds 500 ppb due to inhibition of the action of enzymes needed for photosynthesis (Abagale, et al., 2013). There is a minimum amount of food produced by the algae for aquatic life when the process of photosynthesis is reduced. Less food for aquatic life has repercussions on the ecosystem in general.

2.3.2 Cadmium

Eisler, (1988) and Nordberg, (2004) have shown that there is no established fact about the importance of cadmium to human life. However, cadmium is a metal that is essential for industrial purposes. Cadmium is extracted during the production of other metals, such as copper and zinc. Aside its importance in the industrial setting, it is also used in products used in the home such as in pigments, metal coatings batteries, plastics and some metal alloys (Keith et al., 2008). Cadmium is a well-known pollutant in industries and the environment. In addition, low concentrations can be found in food and e-waste (Wang & Du, 2013) and smoke from cigarette (Jacobo-Estrada et al., 2017). Cd is also reported to cause impairment to different organs such as the lungs and the brain and also exposure to high dose may cause death (Wang & Du, 2013).

Cadmium is toxic to the life of all living organisms even at low concentrations (Eisler, 1988; Keith et al., 2008; Nordberg, 2004). Ingestion of foods contaminated with cadmium is the common source of cadmium toxicity in humans (Keith et al., 2008). Regular consumption of shellfish and fish entrails such as liver and kidney increases the likelihood of cadmium

exposure in humans. Within the ecosystem, how Cadmium intake affects birds that feed on soil organisms is not widely reported around e-waste sites in Ghana. Unfortunately, cadmium's effect in the environment has not been studied extensively. As such, the effect of heavy loading of cadmium in the environment is unpredictable. While there is no doubt that cadmium is extremely poisonous, which likely limit its ability to bioaccumulation, ecosystem wide impact have not been well studied.

2.3.3 Arsenic

Arsenic is a common, toxic, carcinogenic in nature, and hazardous to environmental health. Arsenic is continually cycled through all environmental packets. It can be found in small amounts in soil, rock, air and water. The chemical nature of arsenic is complex. Arsenic has four valency states -3 , 0 , $+3$ and $+5$. Arsenic exists in many forms, mostly in compounds together with other chemical elements (Baroni et al., 2004). The chemical form of arsenic influences its effects both physiologically and toxicologically as well as its bioavailability. The species differs in their way of movement and toxicity. Arsenites have a higher toxicity than arsenates and they are also more soluble and mobile in nature. Generally, arsenates and arsenites are more toxic than organoarsenic compounds. (Allen et al., 2001; Schultz & Joutti, 2007). However, through oxidation and bacterial demethylation reactions, arsenic can be converted back to inorganic forms (Allen et al., 2001; Baroni et al., 2004). The dynamic and complex nature of soil enable it function as a habitat for flora, animals, microorganisms and humans. Soils that are contaminated are a threat to human and environmental health since they bring about the contamination of groundwater by chemicals through food webs (Hund-Rinke et al., 2003). The dilapidating effects of As on some soil organisms which forms part

of the food chain like earthworms are yet to be established along the dumping sites of e-waste in Ghana; this therefore calls for an in depth investigation into it.

One of the most harmful inorganic arsenic is released into the environment; because of the unregulated method of electronic waste disposal. Arsenic can be found in LCD, circuit boards and computer chips. The arsenic contained in the electronic waste disposed at landfills usually drains gradually into the soil. The ground water composition and the soil is affected as the chemicals leach into the soil.

2.5 Health Implication of the Heavy Metals exposure

The three metals, namely cadmium, lead, mercury and then arsenic (a metalloid) have been reported to have caused major health complications in humans across several parts of the world. Increased amounts of mercury for example can be lethal to individuals. In addition, small amount of mercury can have severe effects on the nervous system, and have recently been associated with possible harmful effects that plague the central nervous system, kidneys, liver, cardiovascular, immune and reproductive systems of mammals (Feldt et al., 2014).

2.5.1 Mercury

Studies of mercury in wild birds showed effect on eggs produced, reproduction, liver and other organs as well as the feathers. Though mercury also causes thinning of eggshell, most field studies conducted do not investigate the presence of mercury. However, those who investigate for mercury mostly do not find substantial amount of mercury. Researches that have been conducted on mercury in organs of animals such as the liver were mostly on moribund or dead birds. This was done to determine the source of death but this means the killing of more birds. This was both inconvenient and undesirable. With regards to the

mercury affinity for the sulfhydryl groups on proteins, high mercury concentrations are deposited in developing feathers which are primarily made of the sulfhydryl keratin which is a rich protein. Several researches therefore relied on measuring mercury in feathers which yielded many results (Mallory et al., 2015).

2.5.2 Lead

Exposure to lead has been associated to several health effects in adult mammals. The major health challenges associated with lead toxicity are evidently observed in three organ systems namely the renal system, hematological system, and the central nervous system (CNS). As a general rule of thumb, the more the body is exposed to lead the more likely the health challenges (Church et al., 2006). Elevated levels of lead (greater than 15 µg/dL) in the blood for example, is associated with impaired kidney function, cardiovascular disorders, nerve disorders, and fertility complications, which includes delay in conception and antagonistic effects on sperm including low sperm counts and motility (Raymond & Brown, 2016). Experimental studies in birds have shown that, among other effects, lead can impair blood synthesis, immune function and reproduction. As a result, free-living birds exhibiting lead poisoning will likely be more susceptible to disease, starvation and predation, and an increased probability of death from other causes (Cade, 2007).

2.5.3 Cadmium

Cadmium remains a widespread industrial and environmental pollutant; it is present in low amounts in food, and dietary intake and also in e-waste (Wang & Du, 2013). The first effect

on human health related to cadmium exposure, was the damage to the lungs of cadmium-exposed workers was published in 1938 (Nordberg, 2004).

Some years later, pathological bone fractures and severe pain named Itai-Itai disease occurred after World War II, in Toyama Japan, as a consequence of cadmium exposure (Nordberg, 2004). After long-term exposure to cadmium the kidney becomes the most affected organ. Some recent studies indicate that a glomerular pattern of dysfunction may also be an early effect of cadmium exposure, as evidenced by an increased excretion of high molecular weight proteins. Exposure to high dose may therefore cause death (Wang & Du, 2013).

2.5.4 Arsenic

Inorganic arsenic has been proven to very toxic acute and chronic. Arsenic is a protoplasmic poison due to its effect on sulfhydryl group of cells interfering with cells enzymes, cell respiration and mitosis. It enters into the human body primarily through skin absorption, ingestion, or inhalation. It is then spread to several organs including the skin, kidney, liver, and lungs. Arsenic poisoning clinically manifests in myriad forms, and accurate diagnosis is principally contingent on the awareness of the problem (Caroli et al., 1996)

Reports from research conducted on earthworms have shown that these organisms have the ability to gather heavy metals from substrate that have been contaminated (Spurgeon & Hopkin, 1996). *Eisenia fetida* is one of the species mostly used in assessing the risk of heavy metals and chemicals and their impact on their general life processes (Spurgeon et al., 2004). Earthworms in general play a major role by serving as a link in the food chain hence they can lead in the transfer of hazardous chemicals contained in the soil to other trophic levels (Spurgeon & Hopkin, 1996). When these earthworms are used as an additive to feed for

poultry, there is higher possibility of transferring heavy metals to human and its associated effects (Popek et al., 2009).

2.6 Bird Feathers as biomonitoring units.

In assessing the contamination of heavy metals in birds, the use of their feathers has been put forward as a non-destructive way of examining the concentration of heavy metals (Thyen et al., 2000). Using the feather as a monitoring unit has several advantages. This includes the ease to obtain and observe for a long period of exposure. That is, feathers are useful for studies focusing on cumulative exposure. Nevertheless, other reasons exist that make the using of feathers to examine heavy metal exposure debatable; the results may be influenced by bird types, feather type on body part and migratory movements of birds.

(Malik & Zeb, 2009) conducted a study in Pakistan and analyzed the level of heavy metals in feathers of cattle egrets (*Bubulcus ibis*) from three breeding colonies in Pakistan. They reported that heavy metals contamination in birds can be analyzed by using their feathers.

Feathers of birds have been used for studies involving heavy metal accumulation. This is because collection can be done without any harm to the birds' life and they also provide critical information which is not possible to get using other parts of the bird (Dauwe et al., 2000).

2.7 Bird Eggs as biomonitoring units

Eggs of birds are a good source of studies pointing to the sequestration of heavy metal pollution. This is due to specific breeding periods of birds. Advantages of using eggs as biomonitoring units are that, the method is non-invasive, non-destructive, and easy to obtain as well as storing for long periods.

Birds before breeding spend several hours in their niche eating food particles within their environment for egg laying (Dauwe et al., 2005). Unlike feathers, information obtained from eggs is consistent over time.

Arsenic, Cadmium and Lead can bio-accumulate in egg shells and egg contents thus, eggs are very susceptible to heavy metal accumulation (Burger & Gochfeld, 1993).

Several researches have reported the direct relationship and differences in contamination due to differences among species in trophic level. In addition, there are variations within the same species of adults birds in terms of their age, fat content and size. The presence of traces of metals in eggs could be associated with an exposure to heavy metals and its possible effects (Bize et al., 2002). Birds that are found within temperate and tropical regions use several weeks on the breeding grounds to enable them obtain adequate resources to produce. As a result, the eggs of the birds can be said to be a good indicator for examining exposure to heavy metals (Burger, 2002).

Kertész et al.,(2006) reported that several inorganic elements accumulate in the eggshell and these could affect the proper structure and functioning of the eggshell.

Dauwe et al., (2005) found less number of spermatozoa in eggs obtained from the two most polluted sites on the perivitelline layer as compared to those obtained from the least polluted site. A total mercury analysis was conducted by (Jordão et al., 2006) on monitored Gannet (*Morus bassanus*) eggs which were obtained from Ailsa Craig (eastern Atlantic) and Bass Rock (North Sea) and report from the study showed that there was spatial variation in both the absolute concentrations and temporal trends for Hg residues in gannet eggs (Goodale et al., 2008). Analysis on the trends of Mercury Dipper conducted on egg content of (*Cinclus cinclus*) in south-west Ireland also showed similar results. (Cid et al., 2009).

2.7 Earthworms as biomonitoring units

The pollution of water and soils can be determined with the presence of earthworms (Jin-fen, Rong-gen & Li, 2000). This is because they feed on local soil as they carry out their burrowing activity in soil. Soil supports the life of various organisms on earth and forms an important component of the ecosphere by providing space for animals and plants. Over time, the soil become burdened with pollution of heavy metals due to the activities of man. This pollution has suddenly reached threatening thresholds (Meli et al., 2013).

Soils become polluted with heavy metals through land/soil and water movements. Soil is the main avenue where heavy metals can be deposited from several sources and subsequently disseminated to animal body parts and plants via feeding.

Earthworms act as quantitative monitors of the total-soil metal and also estimators of ecologically substantial soil metal concentration (Morgan & Morgan, 1999) because they feed on soil. Earthworms are predominantly an essential part of the soil structure since their activities affect soil structure and function positively. Their role in the soil increases soil richness by the formation of an organic matter layer in topsoil. The most widely studied earthworm species is the *Lumbricus terrestris*. However, a little work on the use of it as a biological indicator to measure the state of the environment has been done. Furthermore, researches that measure concentrations levels of heavy metals in biota are very few due to the fact that they only focus on aquatic plants or invertebrates. There is a transfer of heavy metal compounds in earthworms to other species at higher trophic levels. These compounds may be toxic to animals, which consumes earthworms (Ernst et al., 2008) such as cattle egret found in the Agbogbloshie e-waste study site. Monitoring programs, with a well-founded scientific base and defined management outcomes, using biological indicators such as earthworms will

expand our knowledge on soil-river-aquatic function (Burns & Ryder, 2001). This work was aimed at reporting on the levels of possibly dangerous elements that can be found in the Odaw River bank soils where the earthworms were sampled. Furthermore, assessments of metal buildup in earthworms for potential bio monitoring are explored.

CHAPTER THREE

3.0 METHODS

3.1 Study Area

Agbogbloshie is a former wetland and suburb of Accra in Ghana known as a destination for locally generated used electronics from the city of Accra. The Agbogbloshie site began as a market place for selling yam and onions. The place has developed into a slum and dumping site for the disposal of household waste, obsolete electronic and electrical appliances. The scrap yard has grown steadily into a popular recycling area, where old and discarded electronic and electric equipment could be put to use. Hundreds of tons of e-waste end up there every month as a final resting place, where they are broken apart to salvage copper and other metallic components that can be sold. The Agbogbloshie e-waste site is among the top ten most polluted places in the world (Ericson et al., 2013). The site covers about 15 acres of land and is located west to the Odaw River where many businesses such as banks, breweries, various manufacturing companies, pharmaceutical companies and shops, many self-employed and petty traders operate on a daily basis. Located east to the e-waste site is a large residential community about 100 meters across the Odaw River that primarily houses Agbogbloshie workers and their families. This densely populated squatter community consists of small informal wooden settlements with little or no basic amenities such as electricity, treated water, toilets and bathing facilities. Inhabitants live, eat, work and relieve themselves on the site and amongst the waste. Fig.3.1 below shows the map of the study area.

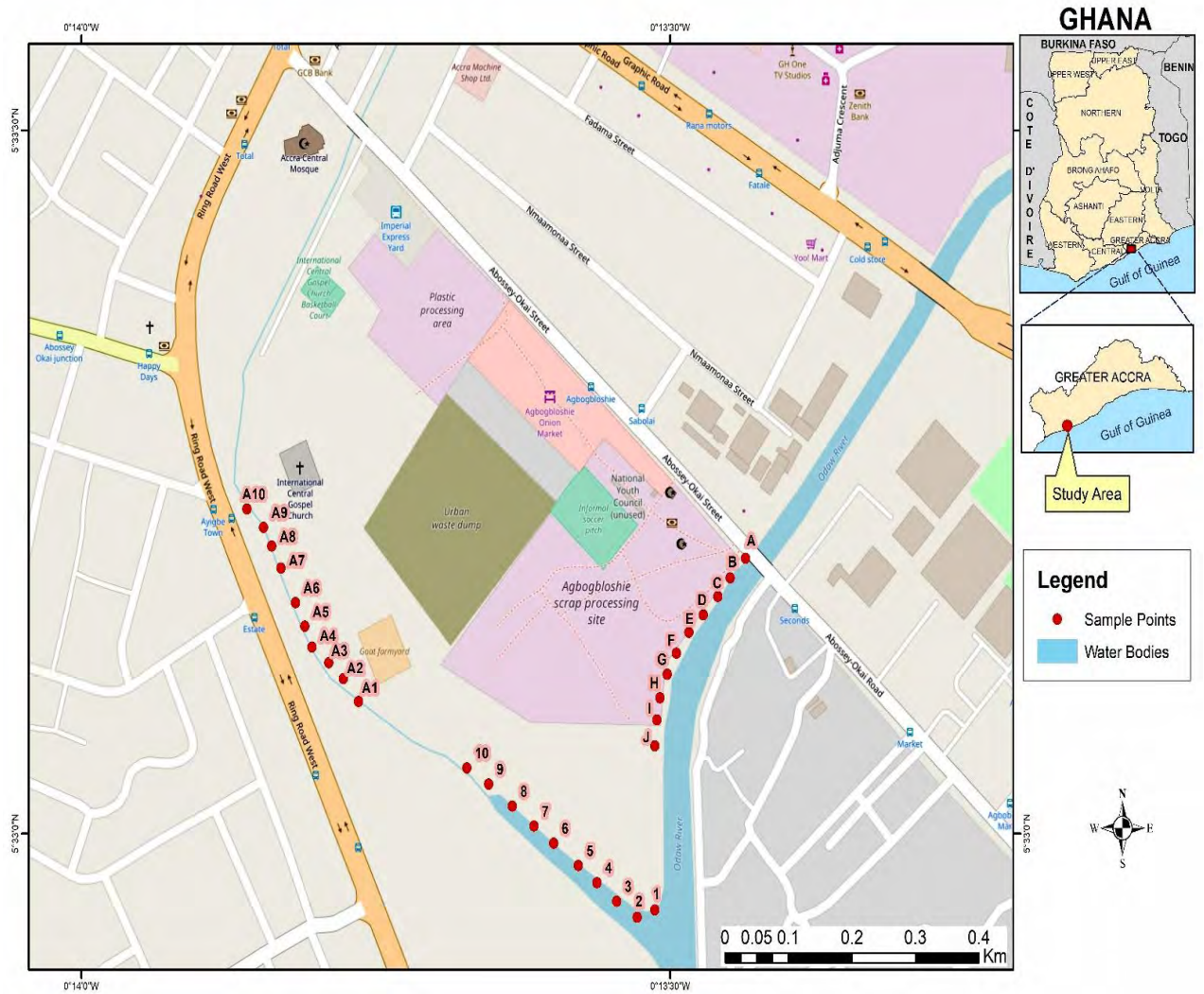


Figure 3.2: Map of Agbogbloshie e-waste site and its surroundings

3.2 Study Design

An analytical cross-sectional study was conducted over a three month period spanning May, 2018 to July, 2018 along the banks of the Odaw River near the e-waste site at Agbogbloshie where the cattle egrets are found living in nests on branches of the white mangrove along the river stretch.

3.3 Variables

3.3.1 Dependent Variables

The independent variables were cattle egret feathers, egg shell, egg content and earthworms.

3.3.2 Independent Variables

The dependent variables were concentrations of As, Cd and Pb.

3.4 Study Sampling

Purposive sampling technique was used. Thirty (30) quill feathers and eggs were collected from different parts along the Odaw river for analyses. In addition, earthworms which are potential source of food for the cattle egrets were also sampled from soils around the same study area. The earthworms were sampled along the banks of the river stretch at intervals of 300m from 3 zones. Ten (10) earthworms were collected from each zone.

3.5 Sample/Data Collection Techniques, Method and Tools

3.5.1 Collection of cattle egret (Bird) feathers

Five different 9 meter long fixed nets were placed randomly within the demarcated zone to trap the cattle egrets, early in the morning between 5am to 11 am. The mounted fixed nets were intermittently checked for possible catch after every 20 minutes. The birds that were trapped in the net were carefully removed as shown in Fig. 3.3 and one quill feather from the right wing of each bird was plucked as shown in Fig 3.5 till all the thirty birds were captured. The birds were marked with food dyes on their heads and released so that they may not be sampled again. The whole procedure was done in a maximum of two (2) minutes to prevent unnecessary stress on captured birds. The plucked feathers were kept in zip locked synthetic rubber, labeled and sent to the laboratory for analysis.

3.5.2 Collection of cattle egret (Bird) eggs

The mangrove at the midstream of the Odaw River was identified as the site where bird nests were found. The nests contained the eggs of the birds and also served as the breeding grounds of the birds. As shown in Fig. 3.2. A purposive sampling of the eggs was done. In all, thirty nests were sampled and in each nest, an egg was picked. This was done to prevent destruction of the eggs of the entire species. Egg samples were labelled as shown in Fig 3.4 and stored in synthetic egg crates and transported to the laboratory.

3.5.3 Collection of earthworms

Samples of earthworm were collected from thirty demarcated zones spread out at 500 meters intervals, along the entire stretch of the Odaw River that flows through the e-waste recycling site. In all a total of 30 worm samples were collected from the polluted site.

Purposive sampling technique was used in the sample collections. At each point where the worm was sampled, a quadrat (measuring 25 cm x 25 cm) was marked on the soil surface and the soil was dug out to a depth of 40 cm from within each quadrat. The soil was hand sorted after wearing gloves and an earthworm was picked into sterilized vial tubes and labeled before transporting to the laboratory for heavy metal analysis

3.6 Laboratory analysis for Pb, As and Cd in feathers, egg shells, egg contents and earthworms

3.6.1 Laboratory analysis procedure for bird feathers

The feathers were washed with distilled water and then acetone for three (3) times to remove any contaminant that might have come into contact externally with the feathers. The feathers were then air dried for about 6 hours. They were further dried in an oven at 60°C for 2 hours. Sterilized stainless steel scissors was then used to cut the feathers into very tiny pieces for acid digestion.

The feathers were digested with a mixture of concentrated hydrochloric acid (HCl) and nitric acid (HNO₃) in a ratio 3:1 by volume (aqua regia). The digested sample was topped with distilled water to a volume of 100ml and stored in sample bottles at a temperature of 20°C and

finally analyzed using the atomic absorption spectrophotometer (AAS) Perkin Elmer 9000 for heavy metal concentrations.

3.6.2 Laboratory analysis procedure for egg shell

The outside of each eggs were cleaned with 70% ethanol to make it contaminant free. They were then weighed on an electronic scale to ascertain their individual weights. They were cracked open afterwards to separate the shell from the contents. They were oven dried at a temperature of 60°C for 2hours. The shells were grounded with mortar and pestle into fine powder. One gram of the powder was sub-sampled for acid digestion.

The egg shells were digested with a mixture of concentrated hydrochloric acid (HCl) and nitric acid (HNO₃) in a ratio 3:1 by volume (aqua regia). The digested sample was topped with distilled water to a volume of 100ml and stored in sample bottles at a temperature of 20°C and finally analyzed using the Atomic Absorption Spectrophotometer (PerkinElmer PinAAcle 9000).

3.6.3 Laboratory analysis procedure for egg content

The egg contents were placed in falcon tubes that have been sterilized with nitric acid labelled. The egg contents were homogenized using the robotic homogenizer. The homogenate were first frozen for 24 hours at a temperature of -20°C and then freeze dried at a temperature of -40°C for three (3) days. The dried samples were transferred into sterilized zip lock rubber bags and pulverized using a laboratory wooden roller. The powder was sub-sampled and acid digested using the fish method of digestion.

3.6.4 Laboratory analysis procedure for earthworm

The earthworms were washed with distilled water and oven dried at a constant temperature of 20 °C. The dry earthworms were crushed with pestle and mortar to < 0.2 mm particles, and then the powdered earthworm sample dissolved as follows: 100 mg of sample was mixed with 4 ml conc. HNO₃ + 2 ml conc. HCl for 12 hours, heated progressively to 150 °C at 800 kPa in a closed Teflon bottle in a micro-wave oven for 2 h. After cooling at ambient temperature, the solution was made up to 100 ml with ultrapure distilled water. The metal contents were determined using Atomic Absorption Spectrophotometer (AAS) Perkin Elmer 9000 for heavy metal concentrations.

3.7 Quality control

The following measures were taken so as to ensure that the data collected will be of a high quality. Field workers were trained to handle tools and collect samples professionally. The samples were handled with the required standards of precautions and measure. Samples collected were transported to the laboratory under careful supervision of the researcher and stored appropriately using standard procedures of the ecotoxicology laboratory of the University of Ghana outlined.

Samples were analyzed by qualified individuals using the appropriate equipment and procedures. The laboratory have well written procedures that document its analytical capabilities for the heavy metals of interest and a Quality Assurance/Quality Control (QA/QC) program that documents the compliance of the analytical process with established criteria.

3.8 Processing and Statistical Analysis of Data

The data was entered using excel and later exported into STATA version15 (Stata Corp., College Station) for the analysis. To begin with, individual box plot analyses for concentrations of As, Pb and Cd in bird feather, egg content, egg shell and earthworms were used to ascertain normality of distributed data and median values determined set at 25th and 75th percentiles. To verify for the existence of any significant differences between the median values, Kruskal Wallis equality of population tests were conducted. Using the Spearman correlation matrix, the associations between the heavy metals under study were also conducted and the relationships between the concentration levels of heavy metal accumulation in the samples were established.

3.9 Ethical Consideration/Issues

Ethical approval for this study was sought from the Accra Metropolitan Assembly. Permission was also sought from the e-waste Association Leaders, as well as the Community Leaders where the study was conducted. Strict confidentiality was maintained.



Figure 3.3: Eggs of cattle egret in a nest



Figure 3.3: Captured cattle egret



Figure 3.4: Labelled eggs for laboratory analysis



Figure 3.5: Feathers of cattle egrets

CHAPTER FOUR

4.0 RESULTS

4.1 Concentrations of arsenic, cadmium and lead in feathers of Cattle Egrets

Overall, all three heavy metals (As, Pb and Cd) were detected in feathers of cattle egrets ranging from 2.71-7.38 $\mu\text{g/g}$, 0.01-0.15 $\mu\text{g/g}$ and 0.88-2.66 $\mu\text{g/g}$ respectively. The median and interquartile ranges for As, Cd and Pb were as follows; As [6.672 (IQR: 5.78-7.18)] $\mu\text{g/g}$; Cd [0.024 (IQR: 0.01-0.05)] $\mu\text{g/g}$ and Pb [1.886 (IQR: 1.44-2.25)] $\mu\text{g/g}$. the distribution of concentration levels of As, Cd and Pb are compared in figure 4.1 below. Kruskal-Wallis equality-of-populations rank test, there was statistically significant difference between the median As, Cd and Pb concentration levels in feathers of cattle egrets ($p=0.0001$)

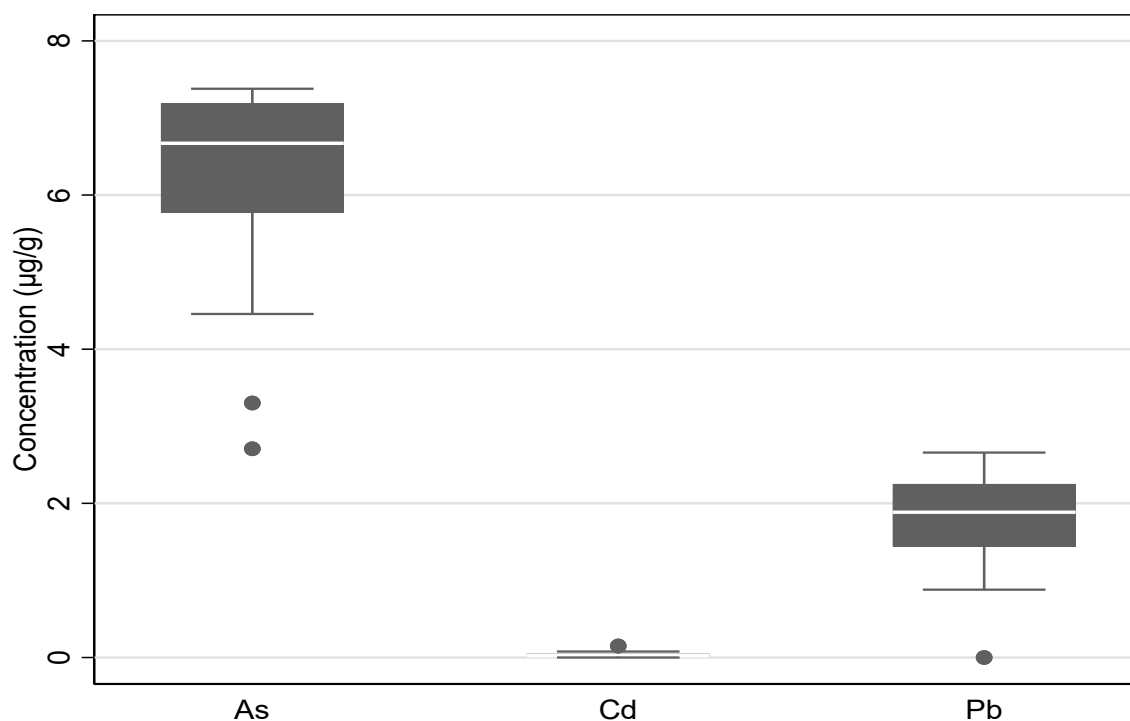


Figure 4.1: Distribution of As, Cd and Pb concentration levels in feathers of cattle egret in µg/g

4.2 Concentration of arsenic, cadmium and lead in egg content of Cattle Egrets

Egg content (yolk and white) was collected and analyzed together for levels of heavy metals. Concentrations were as follows; 3.21-7.41 µg/g, 0.03-0.05 µg/g and 0.17-1.67 µg/g for As, Cd and Pb respectively. The median and interquartile range for As, Cd and Pb were as follows; As [6.229 (IQR: 4.53-7.14)] µg/g, Cd [(0.000 (IQR: 0.00-0.00))] µg/g and Pb [1.181 (IQR: 0.86-1.47)] µg/g (As > Pb > As). the distribution of concentration levels of As, Cd and Pb are compared in figure 4.2 below. Kruskal-Wallis equality-of-populations rank test, there was statistically significant difference between the median As, Cd and Pb concentration levels in egg content of cattle egrets ($p=0.0001$)

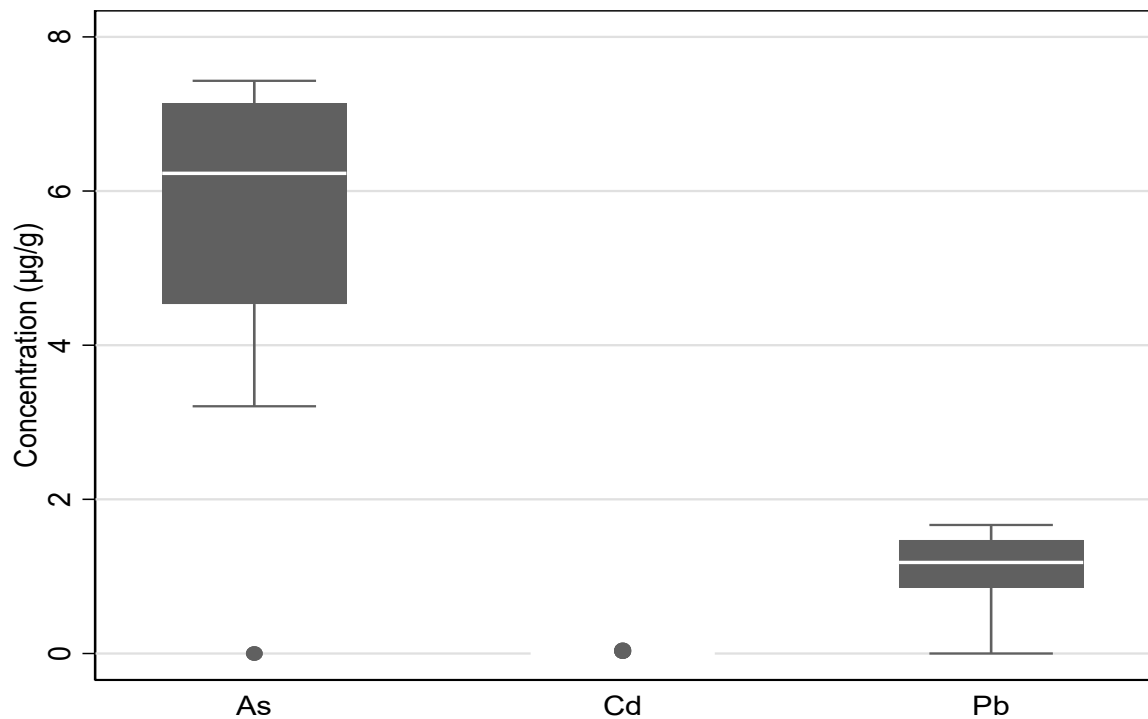


Fig 4.2: Distribution of As, Cd and Pb concentration levels in egg content of cattle egret in µg/g

4.3 Concentration of arsenic, cadmium and lead in egg shells of Cattle Egrets

All three heavy metals (As, Cd and Pb) analyzed were detectable in egg shells, with concentrations range as follows; (1.64-9.95 µg/g, 0.06-0.52 µg/g and 0.12-2.33 µg/g) respectively. The median and interquartile ranges for As, Cd and Pb were [6.203 (IQR: 0.26-9.50)] µg/g, [0.142 (IQR: 0.00-0.41)] and [1.174 (IQR: 1.11-1.99)] µg/g. the distribution of concentration levels of As, Cd and Pb are compared in figure 4.3 below. Kruskal-Wallis equality-of-populations rank test, there was statistically significant difference between the median As, Cd and Pb concentration levels in egg shells of cattle egrets ($p=0.0001$)

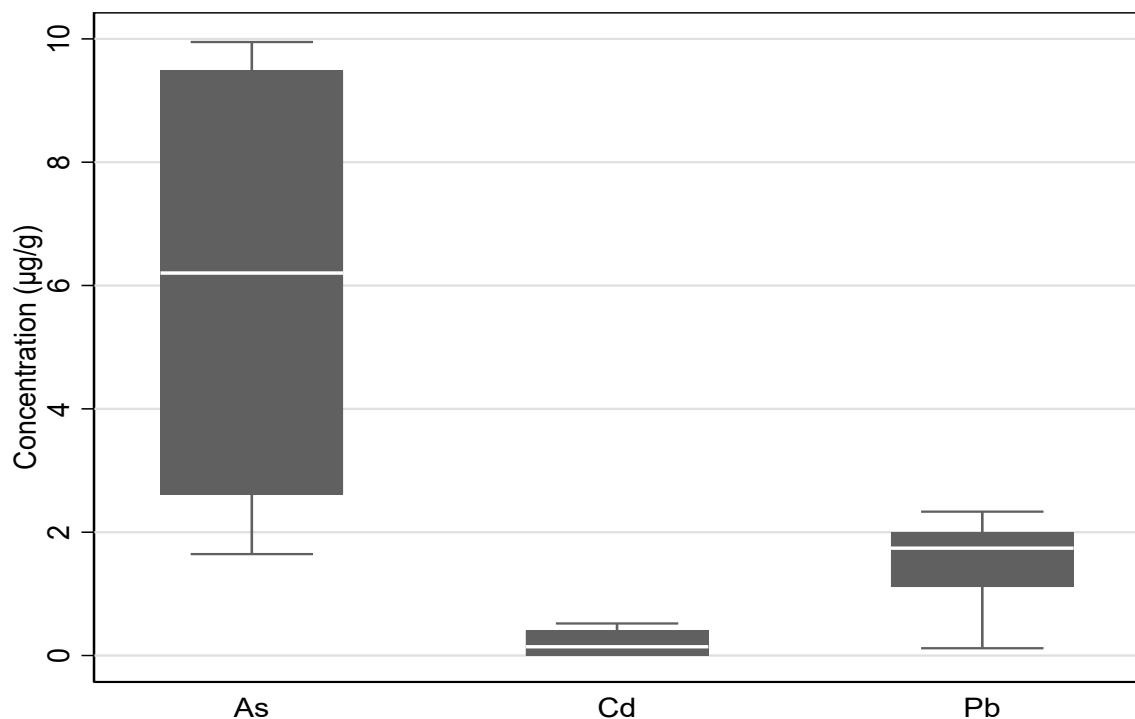


Figure 4.3: Distribution of As, Cd and Pb concentration in egg shell of cattle egret in $\mu\text{g/g}$

4.4 Concentration of lead, cadmium and arsenic in earthworms

Concentrations of As, Cd and Pb in earthworm ranged from 7.72-52.21 $\mu\text{g/g}$, 2.34-6.74 $\mu\text{g/g}$ and 1.29-11.2 $\mu\text{g/g}$ respectively. The concentrations were in the order $\text{As} > \text{Pb} > \text{Cd}$ and median and interquartile range were; As [18.46 (IQR: 8.24-24.33)] $\mu\text{g/g}$, Pb [5.39 (IQR: 4.71-9.99)] $\mu\text{g/g}$ and Cd [5.102 (IQR: 4.98-5.99)] $\mu\text{g/g}$. Median levels of As, Pb and Cd are presented in figure 4.4 below.

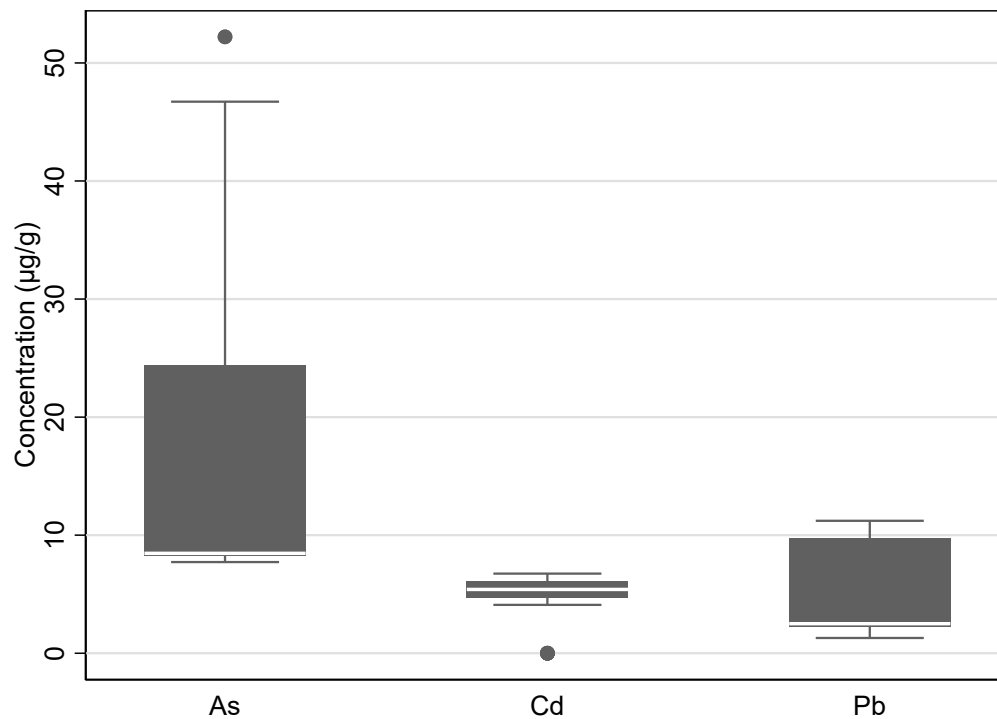


Figure 4.4: Distribution of As, Cd and Pb concentration in earthworm in $\mu\text{g/g}$

4.5 Concentrations of As, Cd and Pb in bird feather, egg content and egg shell in $\mu\text{g/g}$. (n=30)

In summary, mean concentration of As was as follows; $6.25 \pm 1.23 \mu\text{g/g}$; $6.02 \pm 3.46 \mu\text{g/g}$ and $5.70 \pm 1.75 \mu\text{g/g}$ respectively (BF>EGS>EGC). For Cd mean concentration was $0.19 \pm 0.02 \mu\text{g/g}$; $0.03 \pm 0.03 \mu\text{g/g}$ and $0.01 \pm 0.03 \mu\text{g/g}$ respectively. (EGS>BF>EGC). For Pb, mean concentration was, $1.81 \pm 0.59 \mu\text{g/g}$; $1.59 \pm 0.53 \mu\text{g/g}$ and $1.09 \pm 0.45 \mu\text{g/g}$ respectively (BF>EGS>EGC). Mean concentrations of As, Cd and Pb in BF, EGC and EGS are presented in table 4.1 below.

Table 4.1: Concentration levels of As, Cd and Pb in feathers, egg shell and egg content of cattle egrets ($\mu\text{g/g}$)

Heavy metal	Monitoring Units	Maximum	Minimum	Median	Interquartile ranges	p-value
As	BF	7.38	2.71	6.68	5.78-7.18	0.0001
	EGC	7.41	3.21	6.23	4.53-7.14	
	EGS	9.95	1.64	6.20	0.26-9.50	
Cd	BF	0.15	0.01	0.02	0.01-0.05	0.0001
	EGC	0.05	0.03	0.00	0.00-0.00	
	EGS	0.52	0.06	0.14	0.00-0.04	
Pb	BF	2.66	0.88	1.89	1.44-2.25	0.0001
	EGC	1.67	0.17	1.18	0.86-1.47	
	EGS	2.33	0.12	1.17	1.11-1.99	

As= Arsenic; Pb=Lead; Cd= Cadmium; BF= Bird feather; EGS= Egg shell; EGC= Egg content; p-values were estimated from the Kruska Wallis test

4.6 Correlations between heavy metals concentrations in bio-monitoring units- bird feather (BF), egg shell (EGS) and egg content (EGC)

A Spearman rank correlation was conducted on the data obtained to ascertain the relationships between As, Pb and Cd concentrations in BF, EGC and EGS and results are as summarized in Table 4.2 below;

From table 4.2, Spearman correlations conducted to ascertain the relationship between heavy metal concentrations in BF, EGS and EGC. A strong positive correlation between BF and EGC, $r = 0.7370$; $n = 30$; $p = 0.0000$, EGS and EGC, $r = 0.6466$; $n = 30$; $p = 0.0001$ and EGS and BF, $r = 0.8166$; $n = 30$; $p = 0.0000$ for As were observed. Cd showed a weak positive

relationship between BF and EGC $r = 0.3656$; $n = 30$; $p = 0.0467$ and similarly in Pb, only EGS and BF correlated positively with $r = 0.4536$; $n = 30$; $p = 0.0118$ with weak relationship.

Table 4.2: Relationship in As, Pb and Cd concentrations in BF, EGS and EGC.

Metal	Monitoring units Correlated	Sample size N	Correlation Co-efficient R	p-value
As	BF/EGC	30	0.7370	0.0000*
	EGS/EGC	30	0.6466	0.0001*
	EGS/BF	30	0.8166	0.0000*
Cd	BF/EGC	30	0.3656	0.0469*
	EGS/EGC	30	0.0996	0.6006
	EGS/BF	30	0.2676	0.1528
Pb	BF/EGC	30	-0.3166	0.0883
	EGS/EGC	30	-0.0492	0.7964
	EGS/BF	30	-0.4536	0.0118*
As, Pb, Cd combined	BF/EGC	90	0.8558	0.0000*
	EGS/EGC	90	0.8572	0.0000*
	EGS/BF	90	0.8487	0.0000*

As= Arsenic; Pb=Lead; Cd= Cadmium; BF= Bird feather; EGS= Egg shell; EGC= Egg content;
r=correlation coefficient

* Significant value

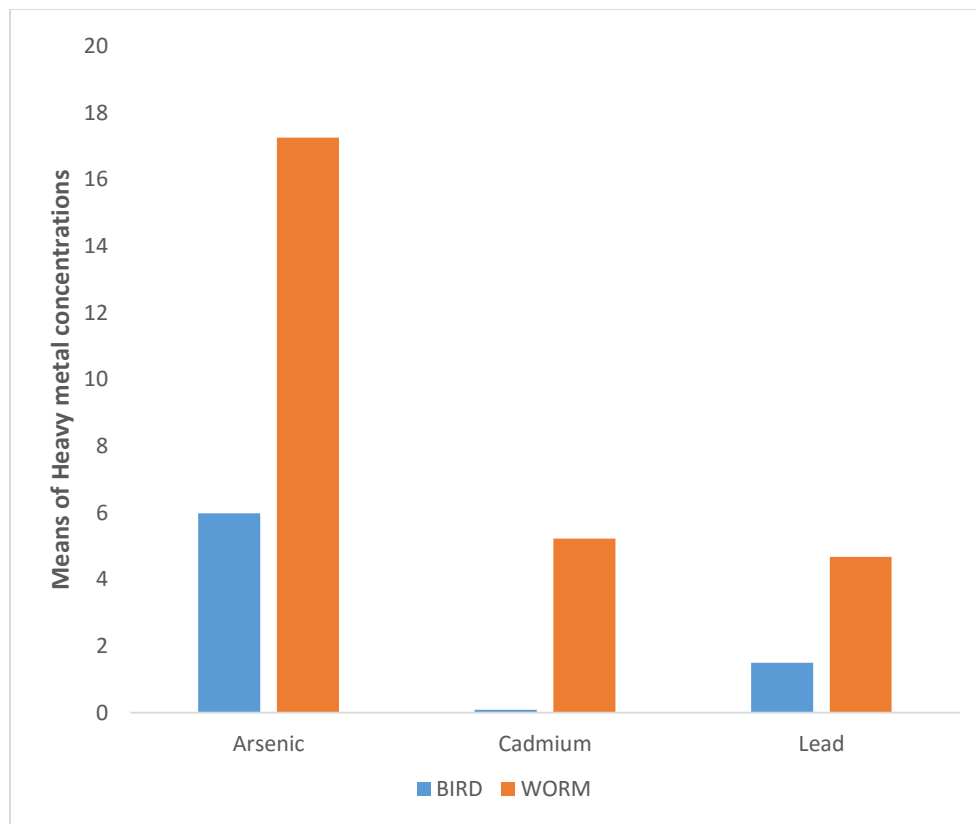


Figure 4.1: Comparison between heavy metal concentrations in bird and earthworm

The mean heavy metals concentration in birds (feathers, egg shell and egg content) was compared to that of earthworms. In all three heavy metals; As, Pb and cd concentrations in earthworm were higher compared to birds. Whiles As levels were high in concentration in birds and earthworms, Cd was significantly higher in earthworms compared to birds; 5.23 $\mu\text{g/g}$ vs 0.08 $\mu\text{g/g}$.

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Summary of main findings

Overall, As, Cd and Pb were all detected at different concentrations in bird feathers, eggs and earthworms. Although this is the first time heavy metals have been analyzed in birds and earthworms around the e-waste recycling and dumpsite, several studies have found different levels of toxic and transitional metals in environmental media (water and soil) at the e-waste site.

In the current study As was found to be the highest of the heavy metals detected in the biomonitoring units. This could be because the bulk of e-waste recycled at Agbogbloshie comprise LCD monitors, computer chips and circuit boards which contain As. In a similar study near an e-waste site at Gboko in Nigeria, lower detectable levels of As were measured in dump site soils (Asemave & Anhwange, 2013). They however concluded that the e-waste recycled there were mostly lead-acid accumulated batteries which contain high levels of lead. A similar study by (Asante et al., 2012) at the Agbogbloshie e-waste site also indicated that Arsenic was high in urine of e-waste workers which confirms results of this study. They explained that piled up e-waste at the dumpsite could result in leaching of As into the soil and ground water. This can adversely affect organisms such as the earthworms, fishes in nearby water bodies and other food crops which are consumed by humans. Keith et al.,(2008) further attest that some adverse effect of Arsenic in organisms including humans that are exposed to such contaminated soil and water which may have effects such as late development of their foetus, stunted growth, skin and liver cancers.

The concentration of cadmium in the current study was low in all the bio-monitoring units. Low Cd concentrations obtained compared to As and Pb in the biomonitoring units can be attributed to rapid mobility of Cd through the soil strata, Adelekan & Abegunde, (2011), have stated in their report that, Cd is more likely to be more mobile in soil systems than almost all heavy metals. Anaemia, lung problems and kidney defects, bone diseases and severe joint pains are caused by high Cd accumulation. Cd may also affect spermatogenesis, low birth weight, hypertension and cardiovascular diseases (Adelekan & Abegunde, 2011).

Pb in the current study was high in concentration compared to Cd in all the bio-monitoring units. This could probable due to electronic parts that are high in Pb. Leung et al.,(2008) also reported similarly high levels of Pb but attributed it to the differences in the electronic product part recycled, the intensive nature of the activities and the method used. A similar study by Feldt et al., (2014), also reported similar levels. They attributed this to the open burning of e-waste that contain some lead- acid accumulated batteries that are high in lead concentrations. Lead as indicated by Abagale et al.,(2013), may contribute to mental retardation and learning disabilities in children under the age of seven.

The grand total mean of all the heavy metals in the worm was high as compared to all the biomonitoring units in bird. This could be as result of the worm being in direct contact with the soil and their bio-accumulative ability which is well known.

Hashmi et al., (2015), have asserted that bio monitoring method using the eggs of bird and feathers as well as food sources such as insects and earthworms to assess the reliability of different areas of the terrestrial ecosystems have been employed by several researchers over the decades. This statement supports the choice of feathers, egg shell and egg content and the earthworm for this study very appropriate and reliable to assess heavy metal contamination.

Several researchers have studied heavy metals such as As, Pb, Hg, Se, Cu, Ni, Co, and Cd in bird feathers and egg shells but none reports on As as well as the use of egg content, This research explored the use of egg content and also determined the concentration of As. In this current study As which is rather under-researched proved to be the highest in concentration found, though others have identified Pb rather as being highest bio-accumulated metal.

It can therefore be concluded that As is an environmental contaminant in Agbogbloshie that should be considered for further investigations.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Overall, the three heavy metals studied (As, Pb and Cd) were detected in birds and earthworms. Significant positive correlations existed in heavy metal concentrations between BF and EGC, EGS and EGC and EGS and BF. Arsenic levels were the highest among the three toxic metals analysed.

6.2 Recommendations

1. To reduce the health effects of heavy metals such as Arsenic (As) and Lead (Pb) within the Agbogbloshie e-waste ecosystem, there should be constant monitoring of these toxic metals in the environment at Agbogbloshie.
2. The use of egg content must also be included in future research in ascertaining local and recent exposures to heavy metals since it also provide a marked indication of environmental pollution.

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