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ANALYSIS OF HEAVY METAL CONCENTRATIONS IN SMOKED FISH FROM THE MAJOR FOOD MARKETS IN THE ACCRA-TEMA METROPOLIS

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DECLARATION

I hereby declare that this submission is my own work towards the Master of Science in Occupational Hygiene degree and that to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the university, except where due acknowledgement has been made in text.

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DEDICATION

I dedicate this work to God, my parents Mr. and Rev. Mrs. Abboah-Offei and my sister Ofosua Abboah-Offei.
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ABSTRACT

Introduction: Heavy metals contaminate soils, water bodies, and also the ambient environment. Fish could be contaminated by heavy metals through pollution of water bodies, as a result of industrial discharge, agricultural run-offs, mining activities, and weathering of rocks. Many of the food markets in Ghana are open markets where foodstuffs are usually displayed in the open, often exposed to the environment. Processed fish, especially smoked fish is a major source of protein and a delicacy in Ghana. Smoked fish, as in other foodstuffs is sold on flat trays and open baskets, which results in direct exposure to the environment. Contamination of fish may occur at source (in aquatic environment), or through ambient exposure to elemental heavy metal dust.

Objective: To assess the concentrations of Arsenic (As), Mercury (Hg), Lead (Pb), and Nickel (Ni) in smoked fish from major food markets in the Accra-Tema Metropolis.

Method: Smoked fish was sampled from six (6) major food markets in the Accra-Tema Metropolis and analyzed for heavy metals (Pb, As, Hg and Ni) contamination using a Pinnacle 900T Atomic Absorption Spectrophotometer (AAS).

Results: The mean concentrations of mercury and nickel were (0.365-0.738 mg/kg) and (0.47 – 0.52 mg/kg) respectively, whereas lead and arsenic were not detected. The mean concentrations of Ni and Hg were detected in all fishes sampled: Tilapia (Oreochromis niloticus), Mudfish (Clarias anguillaris), Tuna (Thunnus albacores) and Salmon (Oncorhynchus sp.)

Conclusion: The study revealed that smoked fish sold on the open markets have various levels of mercury and nickel, with marine fishes recording the highest levels of these metals.
TABLE OF CONTENTS

DECLARATION .......................................................................................................................... I
DEDICATION .......................................................................................................................... II
ACKNOWLEDGEMENTS ......................................................................................................... III
ABSTRACT .............................................................................................................................. IV
TABLE OF CONTENTS ........................................................................................................... V
LIST OF TABLES ................................................................................................................... VIII
LIST OF FIGURES ............................................................................................................... IX
LIST OF ABBREVIATIONS ................................................................................................. X

CHAPTER ONE ...................................................................................................................... 1
1.0 INTRODUCTION ............................................................................................................. 1
  1.1 Background ................................................................................................................... 1
  1.2 Problem Statement ....................................................................................................... 4
  1.3 Main Objective ............................................................................................................. 5
  1.4 Specific Objectives ..................................................................................................... 6
  1.5 Justification ................................................................................................................ 6

CHAPTER TWO .................................................................................................................... 7
2.0 LITERATURE REVIEW ................................................................................................. 7
  2.1 Background of heavy metals ....................................................................................... 7
  2.2 Health effects of heavy metals ................................................................................... 8
  2.3 Fish processing .......................................................................................................... 9
2.4 Some heavy metals in fish

2.4.1 Nickel

2.4.2 Mercury

2.4.3 Lead

2.4.4 Arsenic

2.4.5 Cadmium

CHAPTER THREE

3.0 METHODOLOGY

3.1 Type of study

3.2 Study area

3.3 Variables of interest

3.4 Study population

3.4.1 Tilapia (Oreochromis niloticus)

3.4.2 Mudfish (Clarias anguillaris)

3.4.3 Tuna (Thunnus albacores)

3.4.4 Salmon (Oncorhynchus sp.)

3.5 Sampling Procedure/Method

3.6 Data collection techniques and tools

3.7 Laboratory analysis

3.7.1 Sample Preparation

3.8 Quality Control

3.9 Data Processing and Analysis
LIST OF TABLES

Table 1.0 (a): Comparison of Hg levels across different fish species 29
Table 1.0 (b): Comparison of Ni levels across different fish species 29
Table 2.0 (a): Comparison of Hg levels across different markets 30
Table 2.0 (b): Comparison of Ni levels across different markets 30
LIST OF FIGURES

Figure 1: Map of Accra-Tema Metropolis, indicating the location of the various markets. .......................................................................................................................................................................................................................................................... 16

Figure 2: Smoked Tilapia (Oreochromis niloticus) ................................................................................................................................. 18

Figure 3: Smoked Mudfish (Clarias anguillaris) ................................................................................................................................. 19

Figure 4: Smoked Tuna (Thunnus albacores) ................................................................................................................................. 20

Figure 5: Smoked Salmon (Oncorhynchus sp.) ................................................................................................................................. 21

Figure 6: Comparison of heavy metal concentrations across marine and fresh water species from six major food markets in Ghana. ................................................................................................................................. 28
LIST OF ABBREVIATIONS

As: Arsenic

ATSDR: Agency for Toxic Substances and Disease Registry

Cd: Cadmium

EU: European Union

E-waste: Electronic Waste

FAO: Food and Agriculture Organisation

Hg: Mercury

HM: heavy metals

IARC: International Agency for Research on Cancer

ND: Non Detectable

Ni: Nickel

Pb: Lead

sp.: species

WHO: World Health Organization

ww: wet weight
CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Heavy metals are elements that are said to be at least five times denser than water, and cannot be metabolized by the body. Heavy metals can be released into the soil, water and air through industrial, domestic, agricultural run-offs medical and technological activities. Their main portals of entry into humans, fish and general aquatic life are basically through ingestion, inhalation or through the skin. Humans are more often than not, exposed to these heavy metals when they are passed up the food chain and are ingested. Some examples of heavy metals are lead (Pb), arsenic (As), cadmium (Cd), mercury (Hg) and nickel (Ni), chromium (Cr), and thallium (Tl). Since heavy metals cannot be metabolized by the human body, they tend to bio-accumulate in the liver, muscles and the bones of man, thus could be poisonous to the health of man when ingested in sufficient quantities. (Ekpo et. al., 2008).

In recent times, the pollution of water bodies and general aquatic habitats have been a great source of worry to scientists all over the world. Heavy metals can pollute water bodies in mainly two ways; through either natural or anthropogenic activities. The anthropogenic activities could be from industrial and domestic wastes, agricultural run-offs, wastewater from landfills, oil spills, mining activities, as well as pesticide and fertilizer usage. Likewise, water bodies may be naturally contaminated as a result of iron or manganese that may be found in the rocks and the sediments in the water table beneath the ground. Heavy metal pollution also occurs during venting and flaring of gases by petroleum industries,
from incinerators, and from flaring of general industrial wastes (Duruibe, Ogwuegbu, & Egwurugwu, 2007)

Fish, and smoked fish for that matter is a major source of protein for humans. Ghana’s average per capita consumption of fish in general, is estimated around 20-25kg, which exceeds the world’s average consumption of 13kg. According to Mensah (2012), about 60 per cent of animal protein found in the diet of Ghanaians is derived from smoked fish, which accounts for 22.4 per cent of household food expenditures. In recent years, individuals have come to appreciate the importance of adding fish to their diet. Research has shown that people who tend to consume more fish have a lower risk of contracting cardiovascular diseases, due to the omega-3-fatty acids that are abundant in fish (Budiati, 2010). Furthermore, fish and smoked fish, for that matter also contains many essential nutrients such as zinc, calcium, and selenium, which are necessary for the normal functioning of the body (Thurstan & Roberts, 2014; El-Moselhy, et., al; 2014)

Regardless of all the beneficial factors of smoked fish, they are also known to possess a bio-accumulative property, which can cause a build-up of metals within their tissues. This accumulation of metals may occur through contamination of water bodies which serve as habitat to the fish as well as from elemental heavy metals, which is mainly caused by anthropogenic activities(Anim-Gyampo, Kumi, & Zango, 2013). The ions of heavy metals are transported through the blood of the fish as it lives in the polluted waterbody, and bind to the proteins in the fish. Due to the strong affinity of the ions to the cysteine bonds in protein molecules, strong sulfhydryl bonds are formed between the muscles, the gills or the liver of the fish, and the metal ions. Furthermore, these non-biodegradable, metals have the propensity of remaining in the fish, and as the fish grows the metals continue to form
the strong sulfhydryl bonds, thus bioaccumulation occurs. In the event where a smaller fish with these bio-accumulated metals is eaten by a larger fish, bio-magnification of the metal ions would occur in its tissues, thus causing this larger fish to have more heavy metals accumulating in its organs (Kaoud, 2010). Subsequently, these deleterious metals are passed on to humans through the food chain thus leading to bioaccumulation, as well as bio-magnification in humans. The adverse effects of bioaccumulation in humans include difficulty in swallowing, muscle cramps, hypoxia, diarrhea, and in the worst event, death occurs (Anim-Gyampo et al., 2013).

A study conducted by Anim-Gyampo and colleagues in Navrongo found elevated concentrations of Lead (Pb), Cadmium (Cd), Manganese (Mn), and Iron (Fe) in the muscles of Tilapia (*Sarotherodon gallecallus*) and African Giraffe Bagrid (*Auchenoglanis occidestalis*) both species from the Tono irrigation dam. The levels of these metals far exceeded international acceptable limits/standards set by WHO for fish (Anim-Gyampo et al., 2013). Results from our group (unpublished data) found higher levels of Hg in Tilapia from the Volta Lake, near Assesewa (Takyi, 2015, unpublished).

In contrast, Voegborlo and Adimado (2010) reported lower concentrations of mercury in five fish species from the Atlantic Coast of Ghana, with levels lower than the FAO/WHO limit of 0.5 µg/g wet weight (Voegborlo & Adimado, 2010). These authors suggested that ambient exposure could lead to contamination of foods sold on the open markets, including smoked fish. Several of these food markets in Accra and Tema are closely situated to major industries, an e-waste recycling site or close to busy highways (Amankwaa, 2014; Adekunle & Akinyemi, 2004). This is evidently seen as in the case of the Tema Community One market, Agbogbloshie market, and the Madina market, respectively. The market's
environments may be contaminated with elemental heavy metals in the form of dust, smoke, fumes, and vapour. Thus, contamination of smoked fish sold at these markets could occur from ambient pollution, and handling and processing of fish (Adekunle & Akinyemi, 2004).

Apart from the fact that contamination of fish can occur at source, in aquatic environment, they might also be exposed to environmental contaminants during processing, as well as storage and transport (Anim et al., 2011). This study sought to compare the levels of selected heavy metals such as Mercury (Hg), Lead (Pb), Arsenic (As) and Nickel (Ni) in some of the commonest and widely consumed smoked fish in Ghana, usually sold in the open at the major food markets in the Accra-Tema Metropolis.

1.2 Problem Statement
Due to the surge in industrial activities such as mining, agrochemical industries, steel and plastic manufacturing companies in the country, there has been an increase in the release of toxic materials into the environment. In addition to this, Ghana has been recognized as the largest e-waste dumpsite in West Africa (Wittsiepe et al., 2015a). The dismantling and handling of these electronic wastes creates an avenue for pollution of the environment with toxic substances including heavy metals. These heavy metals found in the environment could be directly taken in through ingestion of contaminated food and water and also through inhalation (Tue et al., 2015).

In foods, heavy metals could be found in vegetables, meat, fish, fruits just to mention a few. Studies conducted have shown significant concentrations of heavy metals such as
mercury, chromium, nickel, cadmium, and many others in fish (Leung et al., 2014; Makedonski, Peycheva, & Stancheva, 2015).

In Ghana, fish is a major source of protein, and smoked fish is a delicacy for most Ghanaians. Processed fish is mostly sold on the open food markets. Fish sold on the open market are obtained from several sources, including both fresh water (lagoon, ponds, streams lakes and rivers) and the sea. These fishes could come from already polluted sources, or their contamination could arise during handling and processing. Moreover, some of these food markets are situated not too far from industries and/or E-waste recycling sites. Toxic substances suspended in air (ambient pollution) can be a source of food contamination. With regards to heavy metals, the elemental forms could settle on food items including smoked fish, which is often sold in trays without any protection from the elements. Also, because smoked fish is well preserved, it can stay for longer periods without spoilage, thereby allowing enough time for accumulation of elemental heavy metals. Continuous consumption of contaminated fish could have health implications. There is therefore the need to investigate and determine whether fish sold on the open markets in the Accra-Tema metropolis are potential sources of heavy metal contamination.

1.3 Main Objective

To assess the concentration of As, Hg, Pb and Ni in smoked fish from major food markets in the Accra-Tema Metropolis.
1.4 Specific Objectives

- To determine the concentration of heavy metals As, Hg, Pb, Ni in selected freshwater fish sold at major food markets in the Accra-Tema Metropolis.
- To determine the concentration of heavy metals As, Hg, Pb, Ni in selected marine fish sold at major food markets in the Accra-Tema Metropolis
- To determine if any differences in heavy metal concentrations between fresh and marine fish could be explained by elemental contamination at the markets.

1.5 Justification

Due to the possible adverse effects of heavy metals in humans, it is important to identify major sources of contamination so that the necessary steps could be taken to eliminate or minimize them. Since smoked fish is consumed by the majority of Ghanaians, it is absolutely necessary to assess whether the way fish is processed and sold on the open markets could lead contamination by heavy metals. Results from this study will hopefully provide the requisite information on food safety and how their contamination with toxic substances may be eliminated.
CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Background of heavy metals

Heavy metals are ubiquitous and can be found anywhere in the environment; in water, in foods, in the soil and in the air. Contamination of the environment with these heavy metals has been associated mainly with anthropogenic activities. Such activities include discharge of effluents and emissions from mines and illegal mining activities (“galamsey” operations), smelters, agricultural runoffs, and improper disposal of domestic waste. Some of the waste materials such as paint wastes, electronic goods, and used batteries increase the quantity of heavy metals found at dumpsites, and invariably, in the atmosphere (Cui et al., 2005). Slow leaching of these metals into the acidic environment could result in leachates with high metal concentrations such as arsenic, cadmium, mercury, lead, and nickel, among others (Bortey-Sam et al., 2015; Polat, 2015). The leachates, usually end up in water bodies, and in the soils and pollute our fish and vegetation in the long run. Food consumption has been identified as the major pathway of human exposure to heavy metals, compared to other ways of exposure such as inhalation and dermal contact (Monferran, et al., 2016; Zhuang, et. al., 2009). In Ghana, there has been a surge in industrialization, especially in the Accra-Tema metropolis, including aluminum processing plants, oil industries, plastic manufacturing industries and agro chemical industries, which pose as a source of threat to inhabitants residing within the metropolis.
2.2 Health effects of heavy metals

Heavy metals such as lead, cadmium, mercury, arsenic, chromium can have deleterious effect on the health of humans. They may produce neurotoxic, nephrotoxic, as well as carcinogenic effects. In addition, heavy metals result in the poor functioning of the various systems in a person’s body. Their effects include the penetration of the blood-placenta barrier, which could have dire effects on an unborn child. Other effects include damage to the cardiovascular system, the brain and also the bone structure, thus causing osteoporosis (Ekpo, et al., 2008). Cadmium may be found accumulated in the cortical tissues of the liver and kidneys, while methyl-mercury compounds could be mostly deposited in the cerebral tissue, and lead would likely be found hidden in bone tissues. Clinical symptoms of their toxic effect at little exposure are usually not immediately noticed, however, many months, years or generations after, their effect may be finally noticed (Rudy, 2009). Chromium, another heavy metal, can cause skin ulcers when it comes into contact with the skin thus eliciting severe redness and swelling of the skin. The effects of chromium also includes irritation to the lining of the nose, cough, asthma, and wheezing (Griswold & Sabine, 2009)

Abbas and Rahman (2012) showed that some diseases are associated with heavy metal pollution in the city of Kasur, caused by the tanning industry. The most prevalent diseases included Asthma, Acute (upper) respiratory infections, Diarrhea/dysentery among children under five years as well as Typhoid, Hypertension, Dermatitis, Neuro-psychiatric diseases, Nephritis and prolonged cough, all resulting from the inhalation of polluted air, contaminated soil dust, and drinking polluted water (Abbas & Rahman, 2012). Furthermore, Honda et. al., (2015) also confirmed Abbas and Rahman’s study, by showing that a high concentration of ambient Zn was seen to have been associated with increases in
cases of asthma among children under 14 years. Again, proven by Honda et al. was the fact that hexavalent chromium was a major cause of lung cancers (Honda et al., 2015).

2.3 Fish processing

Fish is an essential component of food which is cheap and has high protein content. In West Africa, fish has been reported to provide 40–70% of the protein intake of the population and is a critical source of dietary protein. (Mafimisebi, 2012). Generally, fish is made up of 15-24% of protein, 0.1-22% of fat, 1-2% of minerals, and 70-84% of water. Due to the large quantity of water contained in fish, it is expedient to devise measures by which its shelf-life could be increased. Fish processing methods include cooking, frying, drying and smoking, which are carried out based on the consumer’s preference and importantly, to also reduce the water content in the fish, thus increasing its shelf-life. Smoking of fish is carried out by burning wood which kills bacteria in the fish thus adds a preservative value to the fish. Due to its longer shelf life, relatively compared to fresh fish, smoked fish is consumed by most households in West Africa. Hot smoking, which is mostly carried out in Ghana, involves smoking fish at a temperature between 70-80°C. This aims at cooking the flesh of the fish and provides the consumer with the opportunity of eating the fish without further cooking. Hot smoking is carried out between 10-18 hours and produces fish with a low moisture content of less than 10%. As a result of this low moisture content fish smoked by this process can have a shelf life of five months if it has been well-smoked and stored properly (Gordon, Pulis, & Owusu-Adjei, 2011).

Aside smoked fish having a relatively longer shelf-life, as compared to fresh fish, research has shown that smoked fish has a higher tendency of remaining whole in soups and stews,
making it a preference for more consumers, as compared to fresh fish which has the tendency to break up into tiny pieces (Mckenzie, 2013). The final product is mostly purchased by the consumer, from open markets where the fishes are usually found uncovered on top of tables in the market places. This exposes the products to contamination due to unsanitary handling by both sellers and buyers, dust, insects such as flies, as well as elemental heavy metals from the environment.

2.4 Some heavy metals in fish

Aquatic organisms such as fishes possess the capacity to accumulate heavy metals in their tissues. These fishes accumulate these heavy metals by absorbing them into their gills and also in their body tissues. When bioaccumulation occurs, it creates a much higher concentration of the metal than what may be found in the environment. This poses a threat to higher organisms up the food chain as organisms like human beings might end up feeding on these fishes that have bio-accumulated these metals. (Atobatele & Olutona, 2015).

2.4.1 Nickel

Nickel, another widespread heavy metal can exist in several different oxidation states, with the most prevalent state being Ni$^{2+}$. As compared to most metal pollutants Ni is less toxic and more soluble in water. It is a transition metal that shows a wide range of both redox behavior and complex formation. Humans may be exposed to nickel by breathing polluted air, drinking contaminated water, eating food or smoking cigarettes. Skin contact with nickel-contaminated soil or water may also result in nickel exposure. Nickel has been
enlisted by the National Toxicology Program (NTP) as being carcinogenic (retrieved from: https://www.atsdr.cdc.gov/ToxProfiles/tp15-c2.pdf on 18-02-16). Furthermore, the International Agency for Research on Cancer (IARC) has listed some nickel compounds as being in Group 1 indicating that “there is sufficient evidence for carcinogenicity in humans” and other nickel compounds as Group 2B, which also connotes its carcinogenicity in humans (retrieved from: https://www.atsdr.cdc.gov/ToxProfiles/tp15-c2.pdf on 18-02-16).

High nickel concentration in sandy soils can cause a damaging effect in plants, as well as stop the growth rates of algae. (Abbas & Rahman, 2012) When this occurs, it could reduce the amount of feed that becomes available to the fish. Being exposed to Ni could result in nausea, vomiting, abdominal discomfort, diarrhea, headache, cough and shortness of breath.

2.4.2 Mercury

In water bodies, soils, the air, and general earth surface, Mercury poses as one of the most toxic heavy metals present in the environment. Mercury can be found in three states; in the mercurous, mercuric, and the methyl mercury states. However, the most toxic form of mercury is the methyl mercury. This form of mercury causes health effects to both organisms and the environment. Most of the mercury pollution found in the environments is caused by anthropogenic activities. The contamination chain of Hg follows, closely, the cyclic order: industry, atmosphere, soil, water, phytoplankton, zooplankton, fish and human (Kadar et al., 2000). Activities such as mining, combustion, urban discharges, and the current e-waste activities in Ghana are a major cause of mercury pollution in the
environment. Humans are mostly exposed to mercury pollution through two sources. One of these is through eating sea foods such as fish, lobsters, and crabs, shrimps, and the likes that have methyl mercury in their tissues. The second most common is through the release of mercury from dental amalgam. This may dissolve in saliva and be ingested, causing mercury poisoning (Castro-González & Méndez-Armenta, 2008).

A study conducted by Obodai et al. (2011) from the Benya and Nakwa Lagoons in the Central region of Ghana revealed that the concentration of mercury in the black chin tilapia (Sarotherodon melanotheron) was 0.33 mg/kg. This far exceeds the EPA standards for mercury (0.001 mg/kg) contamination. These high levels of mercury concentration could cause kidney failure to the inhabitants whose source of fish is mainly from these rivers (Obodai, 2011).

2.4.3 Lead

Lead is a metal, which occurs naturally in the earth’s crust. It may be found in minute quantities, and is often found as a complex with other elements such as silver, zinc, or copper (retrieved from https://www.niehs.nih.gov/health/materials/lead_and_your_health_508.pdf on 19-02-16). Lead could be found in certain products such as paint pigments, batteries, cosmetic products as well as dietary supplements. The effects of lead poisoning in the human body cannot be underestimated. Lead poisoning may result in the malfunction of the tubular structures of the kidneys, and thus lead to chronic renal diseases. Lead exposure could also lead to enormous repercussions on the reproductive health of humans. In women, lead...
poisoning could lead to miscarriages, still births, as well as sterility, with men also exhibiting signs of reduced semen quality (Juberg, Ross, & Ponirovskaya, 2000).

Exposure to lead bullets can also have adverse effects on humans. This occurs when these bullets are used in game hunting. The lead bullets, more importantly those of shell burst type, could serve as the secondary source of lead in meats, and could become an associated risk to human health as reported by Jarzyńska and Falandysz, (2011).

Tabari et. al., 2010 documented that lead may be found in the selected fish in the Gorgan coast. However, the results indicated that fishes from the Caspian Sea at the Gorgan coast were below the FAO standards, of 0.1- 0.2 mg/L thus may not cause hazardous effects and was wholesome for consumption (Tabari et al., 2010).

2.4.4 Arsenic

Arsenic is a widely distributed metalloid which is naturally found in rock, soil, water and air. Arsenic may occur in either organic or inorganic forms, and more often than not, the inorganic form poses a greater threat to life whereas the organic form represents a lesser hazard. Its inorganic form exists in groundwater, while the organic forms such as arsenobetaine are primarily found in fish. “As” is mostly found in large quantities in the environment (air, water and soil) as a result of anthropogenic activities. Some of these activities include smelting of non-ferrous metals and the production of energy from fossil fuel, contamination of soils by mine-tailings as well as the manufacture and use of arsenical pesticides and wood preservatives (Saha, et al., 2016). Arsenic exposure and toxicity to human life may occur through inhalation, absorption through dermal contact, and predominantly, through ingestion of contaminated food and water, whose sources may be
polluted by man’s activities (Olmedo et al., 2013). The inorganic form of arsenic is toxic and when ingested in large quantities, it results in gastrointestinal symptoms, disturbances of the cardiovascular and central nervous systems, and eventually death. The WHO in 2004 stated that arsenic exposure via drinking water is causally related to cancer in the lungs, kidney, bladder and skin (retrieved from: http://www.who.int/mediacentre/factsheets/fs372/en/ on 19-02-16). Victims of As poisoning who survive the effect tend to live with bone marrow depression, haemolysis, hepatomegaly, melanosis, polyneuropathy and encephalopathy. Ingestion of inorganic arsenic may induce peripheral vascular disease, which in its extreme form leads to gangrenous changes (Raissy et al., 2011).

### 2.4.5 Cadmium

Cadmium, another heavy metal is one of the equally lethal elements that affect mankind and animals alike. It can have adverse effects on respiratory, neurological, gastrointestinal and cardiovascular systems. Workers who are susceptible to cadmium exposure include workers at incinerators, those who deal in electroplating, those at landfills, and also those who deal in the recycling of electronic parts, as well as that of plastics (Chahid, et al., 2014). Having Ghana as the hub of e-waste recycling in West Africa could mean an increase in the cadmium concentration in soils, water bodies close to the e-waste site, as well as in the air. Cadmium’s lethal property is heightened mainly due to the bio-accumulative property it possesses. Research has shown that cadmium level in the body can be even recorded above permissible levels when it stays for long in its elemental forms.
in the atmosphere. Another property of Cadmium is its long half-life period, which ranges between ten and thirty years (Rudy, 2009).

There are several biomarkers that could be used in detecting cadmium accumulation in the organs of the body. Blood and urine are two of the biomarkers that are used in this exercise. Blood is able to give an indication of the amount of Cadmium in the body. Likewise, urine is able to give an indication of the cadmium concentration in the body. In order to account for variation of dilution in urine, the cadmium levels are divided by urinary creatinine or specific gravity determined in the same urine sample (Nordberg, 2010).

Heavy metal concentrations that tend to occur above permissible limits do not only have repercussions on the animal or fish but it could also pose deleterious effects on human health, especially when consumption is regular and in enough quantity (Ihedioha & Okoye, 2013).
CHAPTER THREE

3.0 METHODOLOGY

3.1 Type of study

The study was a comparative cross-sectional study, and involved sampling of smoked fish sold on the open markets at the major food markets in the Accra-Tema metropolis.

3.2 Study area

Figure 1: Map of Accra-Tema Metropolis, indicating the location of the various markets.

Smoked fish was sampled from the Mallam Atta Market (Accra New Town), Kaneshie Market (Kaneshie), Agbogbloshie Market (Old Fadama), Makola Market (Accra city...
centre) and Tema Community One Market (Tema) which are located at different geographical areas of the Accra-Tema metropolis.

Accra is the capital city of Ghana with a population of about 4,010,054 as recorded in 2010 (retrieved from www.ghana.gov.gh/index.php/about-ghana/regions/greater-accra on 20-02-16) accounting for 15.4% of Ghana’s total population. The Greater Accra Region occupies a total land surface of 3,245 square kilometers, which is approximately 1.4% of the total land area of Ghana. Though the smallest region in terms of size, the regional capital Accra is the largest city in terms size, population, industrial establishment and infrastructural development. The region is divided into five administrative districts namely, Accra Metropolitan Area, Tema Municipal Area, Ga East District, Ga West District, Dangme West District and Dangme East District (retrieved from www.ghana.gov.gh/index.php/about-ghana/regions/greater-accra on 21-02-16). The seat of government (Executive) and the two other branches of government, the Legislature and Judiciary, as well as most governmental agencies are situated in the capital Accra.

3.3 Variables of interest
Outcome or dependent variables: Levels of heavy metals concentration in smoked fish

3.4 Study population
The study population comprised these selected fish species: Tilapia (*Oreochromis niloticus*), Mudfish (*Clarias anguillaris*), Tuna (*Thunnus albacores*) and Salmon (*Oncorhynchus sp.*) from Mallam Atta, Kaneshie, Agbogbloshie, Makola, Tema Community One and Madina Markets. These species were selected because they are
commonly sold on every food market, and a common delicacy in Ghana. In total, seventy-two (72) fish samples (12 from each market) were randomly collected and analyzed.

3.4.1 Tilapia (*Oreochromis niloticus*)

Tilapia, which is scientifically known as *Oreochromis niloticus*, is found in the family Cichlidae and class Actinopterygii. It is a deep-bodied fish, which possesses scales, and is silvery in colour. In addition to its silvery colour, it possesses either black or grey body bars to complement its silvery colour. Upon smoking, tilapia assumes a dark brown colour, and is able to stay several days without spoilage. This fish has an average body length of 20 cm, but it can obtain a maximum length of 62 cm, while attaining a maximum weight of 3.65 kg. Tilapia is a fresh water species, and it is preferably found in the shallow still waters on the edges of lakes and rivers with lots of vegetation (Watanabe et. al., 2002).

![Smoked Tilapia](http://ugspace.ug.edu.gh)

**Figure 2: Smoked Tilapia (*Oreochromis niloticus*)**
3.4.2 Mudfish (*Clarias anguillaris*)

*Clarias anguillaris*, also known as Mudfish, is a freshwater fish, which is commonly found in the areas of the lake or lagoon that is well inundated with water. They feed mainly on other fish, molluscs, crustaceans, and organisms found in the bottom of the pond. It has a large depressed head, which is usually found attached to an elongated body, and it also has small eyes found on the head. Mudfish also has a terminally large mouth, long dorsal fins. Mudfish usually, grows to a length between 22 and 24cm, and usually attains a maximum weight of 7 kg. The colour of mudfish varies from sandy-yellow through gray to olive with dark greenish-brown markings. However upon smoking, it assumes a black colour (Azeroual et. al., 2010).

Figure 3: Smoked Mudfish (*Clarias anguillaris*)
3.4.3 Tuna (*Thunnus albacores*)

*Thunnus albacores*, most commonly known as Tuna, is a relatively large species of fish, whose habitat is the seas and oceans. Tuna have very long second-dorsal and anal fins, in addition to a swim bladder with no striations on the ventral surface of the liver. The spawning period of Tuna occurs throughout the year, with high spawning peaks, being recorded during the months of summer. Tuna possesses a black metallic, dark blue colour, which is still seen when it is initially smoked on the first day. However, upon further smoking, the colour of the smoked tuna changes to a darker version of black and brown, thus, reducing the moisture content and greatly increasing its shelf-life (Collette & Nauen, 1983).

![Figure 4: Smoked Tuna (*Thunnus albacores*)](http://ugspace.ug.edu.gh)
3.4.4 Salmon (*Oncorhynchus sp.*)

Salmon, which is scientifically known as *Oncorhynchus sp.* has its habitat as the seas and oceans. Salmon possesses an elongate body, which becomes more pronounced as they age. The tip of the upper jaw of *Oncorhynchus sp* reaches well behind the eye and its snout and lower jaw become strongly hooked in spawning males. They feed on smaller fishes, squids, pteropods and insects while in the sea. Salmon may grow to a maximum length of about 75 cm and have a corresponding weight of approximately 5 kg. During spawning, adults are often of a length between 40-56 cm. Each develops dark black spots on its head, upper flanks and the caudal fin. Fresh Salmon is silvery in colour, however it assumes a golden brown colour, with its dorsal part, giving of a black after it has undergone smoking (Collette & Nauen, 1983).

![Smoked Salmon](http://ugspace.ug.edu.gh)

**Figure 5: Smoked Salmon (*Oncorhynchus sp.*)**
3.5 Sampling Procedure/Method

A simple random sampling procedure was used to collect fish from each market. Four fish species, Tilapia (*Oreochromis niloticus*), Mudfish (*Clarias anguillaris*), Tuna (*Thunnus albacores*) and Salmon (*Oncorhynchus sp.*.) were purchased from vendors at various points at each market with each purchase further apart from the other. Three smoked fish samples of each specie was purchased from three different vendors who were situated far apart each other.

3.6 Data collection techniques and tools

Smoked fish samples were obtained randomly from various vendors in six of the major food markets in the Accra-Tema Metropolis.

Three samples each of Tilapia (*Oreochromis niloticus*), Mudfish (*Clarias anguillaris*), Tuna (*Thunnus albacores*) and Salmon (*Oncorhynchus sp.*.) were purchased from each of the six markets. This gave a total of 72 samples from all markets (12 samples from each of the six markets).

The smoked fish samples were placed in zip locked bags and labelled appropriately based on the location. The markets, Mallam Atta, Kaneshie, Agbogbloshie, Makola, Tema Community One and Madina Markets were coded as A, B, C, D, E and F respectively. Fish species were then further coded as 1, 2, 3 and 4, representing the species, Tilapia, Mudfish, Tuna and Salmon respectively. The samples were then sent to the laboratory for analysis of heavy metals.
3.7 Laboratory analysis

Laboratory analysis of heavy metals in fish was conducted using the atomic absorption spectrophotometer (AAS) (Perkin Elmer Atomic Absorption Spectrometer Pinnacle 900T, Perkin Elma, USA) at the Ecological Laboratory (ECOLAB), University of Ghana, Legon. 

Atomic Absorption (AA) takes place when an atom at ground state absorbs energy in the form of light of a specific wavelength and is elevated to an excited state. The quantum of light energy absorbed at this wavelength will increase as the number of atoms of the selected element in the light path increases (Sarojam, 2011). The relationship between the amount of light absorbed and the concentration of analytes present in known standards can be used to determine the concentrations of unknown samples, and this can be done by measuring the amount of light the unknown samples absorb (Sarojam, 2011). Atomic absorption spectroscopy requires a primary light source, an atom source, a monochromator to isolate the specific wavelength of light to be measured, a detector to measure the light accurately, and electronics to process the data signal and a data display or reporting system to display the results (Sarojam, 2011). The light source often used is a hollow cathode lamp (HCL) or an electrodeless discharge lamp (EDL). Most often, a different lamp is used for each element to be determined. In the past, photomultiplier tubes have been used as the detector. However, in most modern instruments, solid-state detectors are now used (Sarojam, 2011). Flow Injection Mercury Systems (FIMS) are specialized, easy-to-operate atomic absorption spectrometers for the determination of mercury. These instruments use a high-performance single-beam optical system with a low-pressure mercury lamp and solar-blind detector for maximum performance. The source of energy for free-atom production is heat, most commonly, in the form of an air/ acetylene or nitrous-oxide/
acetylene flame. The sample is introduced as an aerosol into the flame by the sample-introduction system consisting of a nebulizer and spray chamber. The burner head is aligned so that the light beam passes through the flame, where the light is absorbed. The major limitation of Flame AA is that the burner-nebulizer system is a relatively inefficient sampling device. Only a small fraction of the sample reaches the flame, and the atomized sample passes quickly through the light path. An improved sampling device would atomize the entire sample and retain the atomized sample in the light path for an extended period of time, enhancing the sensitivity of the technique (Sarojam, 2011).

3.7.1 Sample Preparation

1. Five grams of fish muscle from each sample was weighed and transferred into a macro-Kjeldahl digestion flask.

2. Twenty millilitres (20 ml) of concentrated nitric acid and 20 ml water were added to the sample.

3. The content of the flask was boiled for about 15 minutes until the total volume was reduced to approximately 20 ml. The digested fish solution was cooled and additional 10 ml of concentrated sulphuric acid was added and boiled again.

4. Small volumes of nitric acid was added as the contents begun to blacken, and heating continued till white fumes evolved.

5. At this stage, the solution was cooled and 10 ml of saturated ammonium oxalate solution was added and boiled again until copious white fumes was produced. The oxalate treatment assisted in removing yellow colouration due to nitro compounds, fats, etc. so that the final solution is colourless. Every trace of nitric acid was
removed, as a result of the addition of the ammonium oxalate before assaying of metals.

6. After the sample became colourless, it was topped up with distilled water to make it to the 100ml mark, and sent to the AAS for heavy metals analysis. This procedure was used for all the metals analyzed; Hg, Pb, As and Ni. Absorbances were read at 253.65, 283.31, 193.70, and 248.3 respectively. The detection limits for each of these metals being read with Perkin Elmer 900T was 0.6ug/l, 0.05ug/l, 0.05ug/l, and 0.07ug/l respectively.

7. A blank (without fish) but treated with all reagents was used as negative control (Kirk & Sawyer, 1991).

3.8 Quality Control

Quality control measures were done during the analysis to confirm the accuracy of the results. In every analytical batch, all samples were analyzed repeatedly to ensure the precision and accuracy of analysis. Standard reagents and blanks were also used during the analysis to ensure precision.

3.9 Data Processing and Analysis

Processing

Data collected was coded and entered into an Excel spreadsheet and exported to SPSS version 17 for statistical analyses.
Analysis

Means, standard errors and standard deviation, ranges and p-values were used in describing data obtained. Graphical representation of data was done where appropriate using tables and bar charts. For the comparisons among Agbogbloshie, Mallam Atta, Kaneshie, Makola, Madina and the Tema Community One Markets, One way ANOVA was used to test the differences in these groups.

3.10 Ethical Consideration/ Issues

The proposal was submitted to the Ethical Review Committee of the Ghana Health Service, before the study was embarked upon. Permission was also sought from the chief market women of the individual study sites.
CHAPTER FOUR

4.0 RESULTS

4.1 Concentration of heavy metals (As, Hg, Pb, Ni) in muscle of all fishes sampled (freshwater and marine species)

Nickel (Ni) and Hg were detected in Tilapia (*Oreochromis niloticus*), and Mudfish (*Clarias anguillaris*) (both freshwater species) across all six markets. Arsenic (As) and Lead (Pb) were not detected in all six markets sampled. Freshwater fish obtained from the Madina market recorded the highest mean Hg concentration (1.13 mg/kg), followed by Kaneshie, Makola, Agbogbloshie, Tema Community One, and Mallam-Atta, with mean Hg concentrations of 0.294, 0.267, 0.231, 0.0417 and 0.023 mg/kg respectively. For Ni, mean concentrations ranged from 1.36, 0.6, 0.23, 0.2, 0.19 and 0.18 mg/kg for Agbogbloshie, Makola, Madina, Mallam Atta and Tema Community One markets respectively.

Arsenic (As) and Lead (Pb) were not detected in all marine fishes sampled from the six markets investigated. However, various concentrations of Hg and Ni were measured in smoked marine fishes sampled from the different markets, except Madina market where Ni was not detected. Smoked marine fish from Kaneshie market had the highest mean Ni concentration of (2.0 mg/kg), followed by Mallam Atta market (0.53 mg/kg), Makola (0.4 mg/kg), Agbogbloshie (0.1 mg/kg) and Tema Community One market (0.06 mg/kg) respectively, as presented in Fig. 6.0.

With regards to Hg in marine species, Agbogbloshie recorded the highest concentration (1.72 mg/kg), followed by Makola (0.91 mg/kg), Madina (0.58 mg/kg), Mallam Atta (0.42
mg/kg), Tema Community One (0.41 mg/kg) and Kaneshie market (0.39 mg/kg), as shown below.

Figure 6: Comparison of heavy metal concentrations across marine and fresh water species from six major food markets in Ghana.

4.2 Concentration of Hg and Ni across fish species

The *Thunnus albacores* had the maximum concentration of mercury with a mean of 5.64 ±1.377 mg/kg ww, whereas *Oncorhynchus sp* recorded the highest concentration of Ni at 10.4 ± 2.43 mg/kg ww. There was no significant difference (p = 0.525) in mercury concentration across the various smoked fish species, as shown in Table 5.0. Also, there was no significant difference (p = 0.792) in Ni concentrations of the smoked fish samples (Table 1.0 (b)). Median concentrations of Hg were recorded at 0.05026, 0.04697, 0.2005, and 0.17818 mg/kg for Tilapia, Mudfish, Tuna and Salmon respectively, while median
concentrations of Ni were recorded at 0.32915, 0.052, 0.02542, and 0.04096 mg/kg ww, respectively.

Table 1.0 (a): Comparison of Hg levels across different fish species

<table>
<thead>
<tr>
<th>Fish</th>
<th>Mean</th>
<th>S.D</th>
<th>S.E</th>
<th>Max</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilapia</td>
<td>0.341</td>
<td>0.52746</td>
<td>0.12432</td>
<td>1.6</td>
<td>0.63</td>
</tr>
<tr>
<td>Mudfish</td>
<td>0.388</td>
<td>0.85337</td>
<td>0.20114</td>
<td>2.73</td>
<td>0.9</td>
</tr>
<tr>
<td>Tuna</td>
<td>0.726</td>
<td>1.37712</td>
<td>0.334</td>
<td>5.64</td>
<td>0.849</td>
</tr>
<tr>
<td>Salmon</td>
<td>0.75</td>
<td>1.13073</td>
<td>0.29195</td>
<td>3.29</td>
<td>0.875</td>
</tr>
</tbody>
</table>

Table 1.0 (b): Comparison of Ni levels across different fish species

<table>
<thead>
<tr>
<th>Fish</th>
<th>Mean</th>
<th>S.D</th>
<th>S.E</th>
<th>Max</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilapia</td>
<td>0.405</td>
<td>0.3847</td>
<td>0.09067</td>
<td>1.29</td>
<td>0.833</td>
</tr>
<tr>
<td>Mudfish</td>
<td>0.531</td>
<td>2.42985</td>
<td>0.57272</td>
<td>10.4</td>
<td>0.908</td>
</tr>
<tr>
<td>Tuna</td>
<td>0.168</td>
<td>0.55888</td>
<td>0.13555</td>
<td>1.75</td>
<td>0.971</td>
</tr>
<tr>
<td>Salmon</td>
<td>0.85</td>
<td>1.46703</td>
<td>0.37879</td>
<td>5.66</td>
<td>0.957</td>
</tr>
</tbody>
</table>

4.3 Comparison of mean concentration of Hg and Ni in both freshwater and marine fishes across the six food markets

Various levels of Hg and Ni were detected in both marine and freshwater fish across markets. The mean concentration of Hg in fishes across markets; Agbogbloshie, Makola, Mallam Atta, Kaneshie, Madina, Tema Community One markets were 0.97, 0.60, 0.22, 0.32, 0.96 and 0.23 mg/kg respectively. The mean concentration of Ni in fishes across markets were; Kaneshie market (1.08 mg/kg ww), Agbogbloshie market (0.73 mg/kg ww), Makola (0.52 mg/kg ww) and Mallam Atta markets (0.37 mg/kg ww) as shown in Figure 1.0. Maximum concentrations of Hg and Ni were recorded at Agbogbloshie Market at 5.64
and 5.66 mg/kg ww respectively. One way ANOVA which compared the differences between the means showed that there was no significant difference in the concentrations of heavy metals (HM) across markets for Hg ($p = 0.483$) and Ni ($p = 0.400$), as shown below in Tables 2.0(a) and 2.0(b).

**Table 2.0 (a): Comparison of Hg levels across different markets**

<table>
<thead>
<tr>
<th>Market type</th>
<th>Mean</th>
<th>S.D</th>
<th>S.E</th>
<th>Max</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallam Atta</td>
<td>0.22</td>
<td>0.43026</td>
<td>0.1242</td>
<td>1.26</td>
<td>0.8636</td>
</tr>
<tr>
<td>Agbogbloshie</td>
<td>0.973</td>
<td>1.62917</td>
<td>0.4703</td>
<td>5.64</td>
<td>0.749</td>
</tr>
<tr>
<td>Kaneshie</td>
<td>0.324</td>
<td>0.57563</td>
<td>0.16617</td>
<td>1.67</td>
<td>0.8916</td>
</tr>
<tr>
<td>Makola</td>
<td>0.604</td>
<td>0.85717</td>
<td>0.24744</td>
<td>2.73</td>
<td>0.9506</td>
</tr>
<tr>
<td>Tema Community 1</td>
<td>0.228</td>
<td>1.23503</td>
<td>0.35652</td>
<td>3.29</td>
<td>0.949</td>
</tr>
<tr>
<td>Madina</td>
<td>0.959</td>
<td>0.68843</td>
<td>0.2434</td>
<td>1.68</td>
<td>0.9838</td>
</tr>
</tbody>
</table>

**Table (b): Comparison of Ni levels across different markets**

<table>
<thead>
<tr>
<th>Market type</th>
<th>Mean</th>
<th>S.D</th>
<th>S.E</th>
<th>Max</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallam Atta</td>
<td>0.366</td>
<td>1.57495</td>
<td>0.45465</td>
<td>5.66</td>
<td>0.9056</td>
</tr>
<tr>
<td>Agbogbloshie</td>
<td>0.726</td>
<td>0.3665</td>
<td>0.1058</td>
<td>1.29</td>
<td>0.89275</td>
</tr>
<tr>
<td>Kaneshie</td>
<td>1.08</td>
<td>2.95481</td>
<td>0.85298</td>
<td>10.4</td>
<td>0.6994</td>
</tr>
<tr>
<td>Makola</td>
<td>0.52</td>
<td>0.49724</td>
<td>0.14354</td>
<td>1.14</td>
<td>0.9574</td>
</tr>
<tr>
<td>Tema Community 1</td>
<td>0.121</td>
<td>0.40965</td>
<td>0.11825</td>
<td>1.41</td>
<td>0.8728</td>
</tr>
<tr>
<td>Madina</td>
<td>0.117</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.8548</td>
</tr>
</tbody>
</table>
CHAPTER FIVE

5.0 DISCUSSION

The study aimed at investigating the general public’s exposure to heavy metals (HM) through consumption of smoked fish bought from some of the major food markets in the Accra-Tema Metropolis.

Heavy metal contamination of fish can occur through pollution of the aquatic environment, as well as through anthropogenic sources; ambient exposure to metallic dust particles. The former can result in bioaccumulation of metals whilst the latter results in direct contamination. Consequently, many researchers have investigated the concentration levels of various heavy metals such as cadmium (Cd), copper (Cu), Iron (Fe), Nickel (Ni), Lead (Pb), Chromium (Cr), Arsenic (As), Mercury (Hg), Zinc (Zn) and Magnesium (Mg) in different fish species (Diop et al., 2014; Ekpo, et al., 2008; Jayaprakash et al., 2015; Leung et al., 2014). In this study, concentrations of Arsenic (As), Mercury (Hg), Nickel (Ni) and Lead (Pb) in smoked fishes; (2) freshwater and two (2) marine species were analyzed. Hg and Ni were detected at varying concentrations across different markets; with concentrations $0.5513 \pm 0.98451$ and $0.4887 \pm 1.40761$ respectively.

The detection limits for the spectrophotometer used in this study; Pinnacle 900T, were (As) 0.05 ug/l, (Pb) 0.05 ug/l, (Hg) 0.6 ug/l and (Ni) 0.07 ug/l. Pb and As were undetected in all fish sampled from all the six markets.
Heavy metal concentration in the two freshwater fish species, Tilapia (*Oreochromis niloticus*) and Mudfish (*Clarias anguillaris*) across markets showed that *Clarias anguillaris* from the Agbogbloshie market had the highest mean Ni concentration (2.878 ±2.891mg/kg ww). For Hg, *Oreochromis niloticus* (from the Madina market) recorded the highest mean concentration 1.13±1.869 mg/kg.

These values were above the EU recommended concentrations of 0.5 mg/kg for Hg and Ni, indicating that consumers were at a higher risk of being exposed to Hg and Ni contamination from these markets; which in the long term could lead to serious health problems. Although the reason for these high levels could be partly due to aquatic contamination, the fact that these markets happen to have the worst sanitation management record, as well as being near an e-waste recycling site (Agbogbloshie market) may account for the high levels observed. Nickel is considered to be an essential trace element for human health and development. However, very high levels of Ni in humans could cause undesired health effects such as decreased body weight, skin irritation, chronic bronchitis, reduced lung function, and lung cancer (Eletta et al., 2003; Elkady et al., 2015; Griswold & Sabine, 2009; Psoma et al., 2014; Yabe et al., 2010). Nickel has been classified under class A1 by the International Agency for Research on Cancer (IARC), indicating that it is a carcinogenic substance.

Low levels of Hg were recorded in *Oreochromis niloticus* and *Clarias anguillaris* (0.0078±0.28 mg/kg and 0.076±0.11mg/kg), especially at the Tema Community One market.

Between the two (2) marine species, Salmon (*Oncorhynchus sp.*) recorded the maximum Ni concentration of 10.403 mg/kg ww, which is far above the EU recommended level of
0.5 mg/kg and 0.3 mg/kg (for WHO/FAO); whilst *Thunnus albacores* recorded a mean concentration of 1.6753 mg/kg, also exceeding the EU permissible limit.

The results above suggest that marine fish species may bio-accumulate more heavy metals, particularly *Oncorhynchus sp.* Ingestion of these fish species with higher HM levels could have deleterious effects on consumers. It is possible that the salinity or otherwise of aquatic environment may greatly affect the extent of HM bio-accumulation and the concentrations of heavy metals in those fish species. Higher heavy metal levels were recorded in the marine fish species than the freshwater fish species. This may be due to the many oil exploration activities and spillages that occur on the seas, increasing heavy metal contaminations in marine water, as opposed to fresh water sources such as lakes or lagoons.

Overall, across different markets, the average concentrations of Hg and Ni in fishes obtained from the Kaneshie market was very high (1.08 mg/kg), followed by Agbogbloshie (0.73 mg/kg), Makola (0.52 mg/kg) and Mallam Atta market (0.37mg/kg), with Tema Community One and Madina markets recording the least concentrations (0.12mg/kg) and (0.11mg/kg). The Tema Community One market is an enclosed market, and so partially shielded from ambient pollution. The Mallam Atta market is situated on an elevated ground, compared to the major roads, and thus may be partially protected from pollutants from vehicular traffic. These factors might have accounted for the lower heavy metal concentrations recorded in these markets. Also, higher levels in the mean Hg concentrations were recorded from fish samples collected from the Agbogbloshie and Kaneshie markets (Table 3.0), which were greater than the EU recommended values of 0.5 mg/kg for mercury. These elevated levels of the mercury in these markets may be due to the e-waste recycling plant that is in the heart of Agbogbloshie. It is therefore likely that
there will be possible contamination from this e-waste site, hence higher Hg concentrations in the smoked fishes sold there. This can also be said of the concentrations recorded for the Kaneshie Market, since the market is about a five-minute drive from the Agbogbloshie Township, where all sorts of e-waste activities go on (Wittsiepe et al., 2015b). Burning of e-waste materials from this dumping site may lead to release of mercury and other heavy metals into the atmosphere, which would eventually settle on the fishes. Research has shown that elemental metals such as nickel and mercury are able to remain in the environment for a very long time; thus having the propensity to settle on the fish and causing them to have or record high levels.

However, there was no significant difference ($p \geq 0.483$) in Hg concentrations in fish species collected from all the markets sites. Also, there was no significant difference ($p \geq 0.6994$) in Ni concentrations across the various markets.

In assessing the difference in heavy metal concentrations across fish species, there was no statistical difference ($p$-values $\geq 0.525$) in HM levels across the fish species, although actual concentrations of Hg and Ni varied in the different fish species.

In Ghana as in many places, industrial wastes, agricultural runoffs, burning of fossil fuels, animal and human excretions, geologic weathering, waste, geochemical structure and mining of metals have led to heavy metal pollution in the aquatic environment, contributing to higher HM levels in aquatic organisms such as fish species.
CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Arsenic and Lead were not detected in all fish species collected from markets in the Accra-Tema Metropolis. Mercury (Hg) and Nickel (Ni) were detected in all fish species.

It is possible that the levels measured came from the source and through ambient exposure.

Conclusively, heavy metals (i.e. Hg and Ni) were found to be very high in *Oncorhynchus* *sp* than any other fish species analyzed.

6.2 Recommendations

- Thorough laboratory analysis and monitoring of toxic heavy metals must be carried out constantly and periodically on the smoked fishes sold at the various market places in Accra.
- A machine with a higher detection limit, such as ICPM-S should be used in further studies during the laboratory analysis. This machine is more sensitive thus, lead and arsenic concentrations in the fish can be detected.
- Government agencies such as Food and Drugs Authority as well as other health and public health agencies should educate the public on dangers of heavy metals in smoked fish and also educate them on how much fish to eat in a day or week, since this would reduce possible heavy metal poisoning.
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