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CONCENTRATIONS OF METALS IN TILAPIA (*OREOCHROMIS NILOTICUS*) FROM MAJOR FOOD MARKETS IN ACCRA, GHANA

BY

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DECLARATION

I, Faith Nelson hereby declare that this submission is my work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person, nor material that has been accepted for the awarded of any other degree of the University, except where the acknowledgment has been made in the text.

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DEDICATION

I dedicate this dissertation to my family and friends for their immense support and prayers throughout my program. I also dedicate it to Dr. Essien, Isaac Buah and my beloved Terry Zahi for their great support throughout the process. God richly bless them.

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I am extremely grateful to the Almighty God for the grace to finish this work. I thank him, especially for the excellent mentors he gave me in my supervisors Dr. John Arko-Mensah and Prof. Julius Fobil. I am also grateful to my mentor Dr. Essien To them, I say a big thank you for going over and beyond to see me through this process. My sincere gratitude also goes to Mr. Prince Owusu of Ecological Laboratory who technically helped in the analysis of heavy metals.

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ABSTRACT

Background: Fish is a primary protein source for many Ghanaians, with tilapia being a popular choice. Despite the health benefits of fish consumption, the presence of toxic metals like lead, cadmium, arsenic, and mercury poses risks to human health. Monitoring metal levels in fish is crucial to ensure food safety and protect consumers.

Objective: This study aimed to assess metal levels in fresh tilapia (*Oreochromis niloticus*) from major markets in Accra.

Method: Tilapia samples were obtained from four markets (Madina, Kaneshie, Makola, and Agbogbloshie) and analyzed for lead (Pb), arsenic (As), cadmium (Cd), mercury (Hg), and iron (Fe) concentrations using standard methods and Atomic Absorption Spectrometer. Statistical analysis was performed using Microsoft Excel 2016 and STATA.

Results: Metal concentrations in tilapia heads and muscles varied across markets. For instance, in Kaneshie market, levels of Pb, Hg, As, Fe, and Cd were found to be (0.045 ± 0.025 mg/kg), (0.038 ± 0.0123 mg/kg), (0.02 ± 0.013 mg/kg), (9.5 ± 1.247 mg/kg), and (0.016 ± 0.006 mg/kg) in the head, respectively. In the muscle, the concentrations were (0.023 ± 0.01 mg/kg), (0.03 ± 0.011 mg/kg), (0.011 ± 0.0014 mg/kg), (2.88 ± 1.158 mg/kg), and (0.047 ± 0.029 mg/kg) for Pb, Hg, As, Fe, and Cd, respectively.

Conclusion: While detectable, the metal levels in most analyzed tilapia samples remained within the permissible limits set by FAO/WHO. Therefore, tilapia sold in major Accra markets is considered safe for human consumption.

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LIST OF ABBREVIATIONS

As - Arsenic

ATSDR - Agency for Toxic Substances and Disease Registry

Cd - Cadmium

Fe - Iron

Hg - Mercury

Pb - Lead

DEFINITION OF TERMS

Heavy metal	A metal that has a relative density of five or higher.
Bioaccumulation	Build-up of heavy metals in the tissues of organisms.
Metabolize	A biochemical activity of a particular chemical substance

CHAPTER ONE

INTRODUCTION

1.1 Background

Fish constitutes a major source of protein for most Ghanaians. In Ghana, tilapia is the popular delicacy enjoyed by many, hence, has seen an increase in its production. Most individuals farm tilapia in various waterbodies including the blackish water in Ghana. However, most of these waterbodies have been polluted by metals in recent times as a result of industrialization and mining.

Metals contamination, especially heavy metals contamination of the environment is currently a serious environmental and safety issue confronting the world. Naturally, heavy metals leak into water bodies through processes such as rock weathering and can be carried away by surface runoff and wind. Human activities, on the other hand, have resulted in increased pollution of the environment, including the marine environment. Exhumation of soil and minerals, as well as the clearance of large swaths of land for mining activities, has led to the discharge of contaminants from bedrock into aquatic ecosystems (Wuana & Okieimen, 2011). "The waste generated after extraction (commonly referred to as tailing damp) also contains harmful chemicals including toxic metals and thus poses a threat to the environment (Cobbina *et al*., 2015). Environmental pollution has significant consequences on water quality, marine ecosystems, food security, and human health (Taylor, 2012).

Approximately 60% of animal protein found in Ghanaians' diets is obtained from fish, which accounts for 22.4% of family food expenditures (Mensah, 2012) Research indicates omega-3 fatty acids found in fish could reduce the development of cardiovascular diseases in individuals who eat more of it. Furthermore, fish contains several critical elements like zinc, calcium, and selenium, which are required for the body's regular functioning (Thurstan & Roberts, 2014). Contamination of fish with heavy metals can expose consumers to the hazardous metals' acute and chronic health consequences. Metals can accumulate in water bodies where these fish are present and later passed on to humans via the food web. For example, Anim-Gyampo *et al*. (2013), discovered that tilapia caught in the Tano irrigation dam had increased levels of lead (Pb), cadmium (Cd), manganese (Mn), and iron (Fe). The levels shown exceeded the international guidelines by the WHO for acceptable limits of heavy metals in fish (Anim-Gyampo *et al*., 2013). Also, research published by Nyantakyi et al., (2021) showed that *Oreochromis niloticus* samples from the Tano River contained levels of lead Pb), cadmium (Cd), arsenic (As), mercury (Hg), etc.

There is ample evidence that toxicants such as Hg, Pb, Cd, and As cause cognitive impairments, particularly in children, as well as cancers, with a high incidence of upper gastrointestinal cancer rates, decreased immunological defenses, malnutrition-related disabilities, intrauterine growth retardation, nervous system disease, kidney problems, reproductive disorders, and skepticism (Cobbina et., al 2015).

The goal of this research is to assess the levels of heavy metal concentration in tilapia (*Oreochromis niloticus*) across different markets in Ghana. These fish are mostly sold openly at the major seafood markets in the Greater Accra region of Ghana.

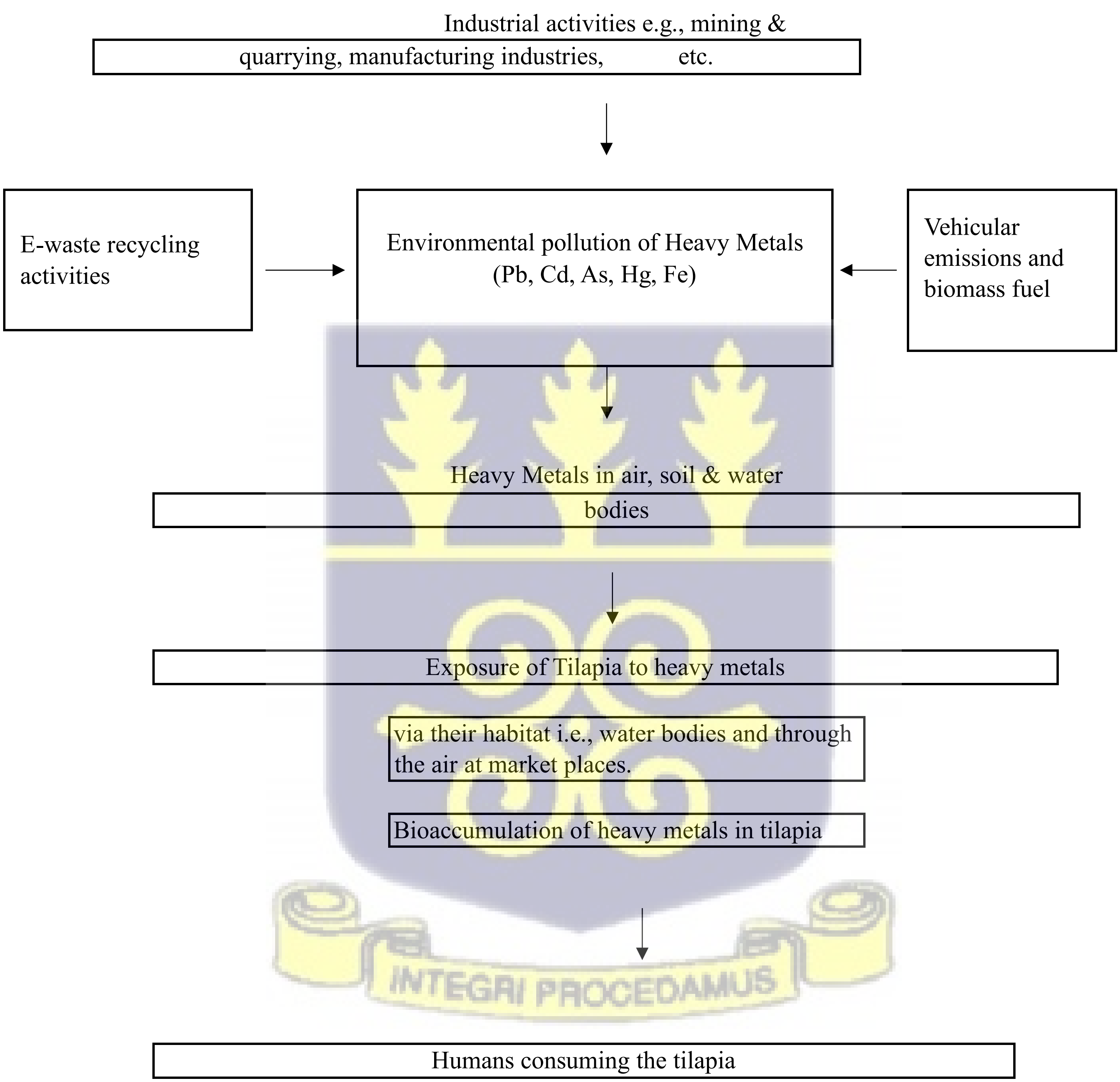
1.2 Problem Statement

Illegal mining has seen the introduction of mercury and other heavy metals into water bodies which end up getting to humans upon the consumption of fish (Omosileola et al., 2016). “Lung injury, coronary heart infection, neurologic and neurobehavioural disorders, dermatologic conditions, developmental anomalies, haematologic disorders, and high cumulative mortality rates due to cancers have all been linked to the ingestion of infected fish with heavy metals beyond the standards" (Jarup, 2003; Tchounwou et at., 2003). As a result, heavy metal concentrations in commercial fish, particularly tilapia, and their environment must be monitored regularly.

Different kinds of processed fish are sold on the open food market and these fish are acquired from both the sea which is salt concentration as well as the freshwater which includes ponds, rivers, lagoons, etc. There is a likelihood that these water sources have been polluted as a result of industrial waste and mining activities. Aside from contamination at the source, processed fish could also be contaminated during the period of handling and processing as most of the major markets are not far from major roads, industries, inner city settlements, and in the case of Agbogbloshie market, a large electronic recycling site. Therefore, toxic substances in the form of smoke from chimneys of industries, vehicular exhaust, and recycling sites could settle on these fishes through ambient pollution and this is one major form of food contamination. This is because tilapia is mostly sold without covering and this causes dust or elemental forms of these heavy metals to settle on them thereby contaminating them. Hence the goal of this research is to assess the impact of heavy metals on fresh tilapia (*Oreochromis niloticus*) across different markets in Ghana.

1.3 Conceptual framework

Heavy metal contamination is caused by a variety of anthropogenic activities, such as industrial processes, vehicular traffic, artisanal gold mines, and biomass fuel consumption. E-waste dumping and recycling have recently been identified as a source of heavy metals discharge and environmental damage in poor countries. The aforementioned activities discharge toxic compounds into the environment, including heavy metals, which pollute the environment and contaminate water bodies, air, and soil. When tilapia is exposed to contaminated waterbodies in their habitat, heavy metals can bioaccumulate in them and these heavy metals are likely to be passed on to humans through the food chain after consumption of the tilapia.



contaminated with heavy metals which can cause health risks

Figure 1. ***Metals contamination of tilapia (****Oreochromis niloticus)* ***due to anthropogenic activities***

1.4Justification

This research aimed to assess the concentration of heavy metals in fresh tilapia (*Oreochromis niloticus*) commonly sold at major markets in Accra, Ghana. These heavy metals include lead (Pb), arsenic (As), cadmium (Cd), mercury (Hg), and iron (Fe). Since heavy metal exposure is harmful to one's health, it is critical to identify and address the major sources and extent of the contamination. Due to the consumption rate of fresh tilapia in Ghana, it is vital to evaluate if how the fish is prepared and sold in open markets contributes to heavy metal pollution.

These methods of processing and sale could be adjusted to enhance fish accessibility while lowering the health risk associated with eating infected fish to the barest minimum and improving fish safety by focusing on contamination points. Information on these topics may also affect potential policies and initiatives aimed at reducing fish pollution and addressing food safety concerns with fresh

tilapia.

1.5 Main Objective

To assess contamination from heavy fresh tilapia sold at major food markets in Accra and compare levels to WHO-acceptable threshold limits in fish.

1.5.1 Specific Objectives

1. Measure and compare the concentrations of heavy metals between the fish tissues (head and muscle) to determine which bioaccumulates selected heavy metals.
2. Compare the concentrations of metals in fresh tilapia sampled among the selected markets

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter provides insight into the importance of fish and the toxicity and health risks of metals have on them. The literature used in this section was retrieved and obtained from Science Direct, PubMed, Google Scholar, and ResearchGate.

2.1 Fish as a major component of diet

Fish consumption is regarded as a healthy component of a balanced diet since it provides important nutritional advantages. Fish is abundant in omega-3 fatty acids, proteins, and other micronutrients, all of which are essential for good health. Fish contains omega-3 fatty acids, which aid in neurotransmission and have cardioprotective qualities. Fish or fish oil consumption has been related to enhanced growth and appropriate brain development, as well as decreased weight and waist circumference (Bender, 2014). Fishing and fish-eating are also important components in numerous cultures' social, emotional, and spiritual well-being (Johnston, Hoffman, Wing & Lowman, 2016).

Metal concentrations in fish, notably mercury, as well as other organic pollutants like Polycyclic Aromatic Hydrocarbons (PAHs), make determining the health benefits of fish challenging. Each year, two upwellings in the coastal seas of Ghana disrupt marine fishing. This cyclical process causes frigid, nutrient-rich water to rise to the top, increasing organism biomass and, as a result, several marine fish species not found elsewhere in the ocean (Gordon et al., 2011).

2.2 Aquaculture

According to Antwi-Asare and Abbey (2011), tilapia and catfish output dominate aquaculture in Ghana. They claim that, despite the lack of data on real production volumes, tilapia accounts for up to 80% of total production. Because of the great demand for fresh tilapia within Ghana, there are almost no exports of fresh tilapia (Antwi-Asare and Abbey, 2011). Tilapia is the generic name for three important aquaculture genera of African cichlids.: Tilapia, Oreochromis, and Sarotherodon (Popma and Masser, 1999). The Nile tilapia (Oreochromis niloticus) contains a moisture content of 79.86 to 82.43 percent, protein percentage of 15.68 to 17.24 (fresh weight), and percentage lipids of 0.71 to 0.37, according to a paper by Younis et al (2015). Similar moisture levels were observed by Al-Souti and Claereboudt (2014), and 2.81% of the dry weight of total lipids was recorded (Aboagye, 2016).

2.3 Fish contamination in Ghana

In recent years, however, the issue of fish contamination with heavy metals has become pervasive in Ghana. A heavy metal (HM) is any metallic chemical element with a relatively high density that is hazardous or dangerous even at low concentrations (Cobbina et al., 2015). Human activities have caused an astronomical increase in the amount and concentration of many heavy metals. Heavy metals are prevalent and may be detected in almost any environment, including water, food, soil, and air. Heavy metal concentrations rise due to waste disposal, smelting firms, oil company air deposition, mining, fertilizer and pesticide usage, and the usage of sewage sludge on agricultural land. Heavy metal contamination is linked with anthropogenic actions. These include mining and smelter effluents and emissions, agricultural runoff, lead-based paint, and residential garbage, all of which end up in bodies of water. All of them often include significant levels of hazardous metals such as arsenic, cadmium, mercury, and lead. (Bortey-Sam et al., 2015). Consuming food has been recognized as the foremost route that exposes humans when it is related to the different kinds of exposure including inhalation and dermal contact. Research published by Nyantakyi et al., (2021) showed significant amounts of metals were found in the Tano basin, but there are small quantities found in fish samples and therefore risk they bring to consumers.

Human and anthropogenic sources also contribute to the introduction of heavy metals into aquatic environments. The principal natural sources include volcanic eruptions, landslides, surface runoffs, and dust particles from the atmosphere containing heavy metals that are released into marine ecosystems. Human activities have significantly boosted the discharge of heavy metals from the earth's crust into surface water bodies since the beginning of the industrial age. Breaking the link that holds these molecules together in the bedrock, acid mine drainage (AMD) causes additional heavy metals to leak into water bodies. The chemical leaching of heavy metals into solution is further facilitated by the mining process's artificial pulverization of huge bedrocks, which increases the surface area of particle sizes. In the last 40 years, global fish consumption has doubled, reaching 16 kg per year (WHO, 2013, cited in Awuah, 2016). Fish protein is mostly preferred to other animal proteins as a result of its low cholesterol levels.

Considering the diminishing worldwide fish supply, fish consumption is anticipated to rise by 30% between now and 2030. Heavy metals can be harmful to people's health. They may have neurotoxic, nephrotoxic, and carcinogenic consequences, according to Abboah-Offei (2016). Heavy metals also affect the body's systems, causing them to malfunction. They include but are not limited to, blood-placenta barrier penetration, which might have serious consequences for an unborn child, the cardiovascular system, and bone structure.

Mercury is harmful to humans and poses a health concern if levels rise above specified limits. The main reasons for the higher amounts of mercury in the atmosphere may be urbanization and population growth (Voegborlo and Akagi, 2007). Humans are mostly exposed to mercury through fish consumption, which can lead to severe and progressive poisoning (Clarkson, Magos, and Myers, 2003). Toxicity varies depending on the chemical forms of mercury and their proclivity to damage the cellular structure and interfere with enzyme-mediated activities (Laws, 2017). Because of its peculiar biochemical features, the organic form, methylmercury, is the most dangerous and widely documented. Although fish-eating provides important nutritional benefits, it may be contaminated with mercury, posing a risk to the health of the consumers. Pollutant levels in fish, particularly mercury, are of concern not just for the possible negative effects on the fish, but also for the potential health risk to humans who consume them. Mercury poisoning causes several unfavorable health effects, including neurological impairments, cardiovascular risks, immune system damage, and adverse pregnancy outcomes (Tour, 2017).

2.4 Toxicity and Health Risks of Heavy Metals

2.4.1 Mercury

Mercury is an important element with applications in research, agriculture, manufacturing, dentistry, and medicine, among other professions. Mercury may be found in the earth's crust through anthropogenic (man-made) activities such as mining. Mercury is released in an inorganic form, typically as metallic vapor, by both natural and anthropogenic sources. In the aquatic environment, inorganic mercury is converted into organic compounds such as methyl mercury, making them biomagnifiable in food chains (Voegborlo & Adimado, 2010). High mercury amounts have been detected in a range of fish and crustaceans, notably sharks, swordfish, and tuna (Abrefah et al., 2011). The size of the fish, on the other hand, has been proven to be an important factor in accumulation. There is a relationship involving fish size and the rate of Hg accumulation, with larger fish having greater levels of accumulation (Akoto et al., 2012). As a result, eating mercury-contaminated freshwater fish poses a major health risk. Mercury can cause lung damage, neurological and psychiatric problems, kidney damage, and fetal defects (Järup, 2003). The worldwide threshold for permitted quantities of mercury in tainted food is 0.5 ppm; thus, consuming more than this poses a considerable health risk to consumers (Lagoon, 2011; Jilai, 2014). Research conducted in Ghana has shown low mercury levels in fish species obtained from the Atlantic Ocean around Ghana's coast, which are less than the FAO/WHO standard of 0.5 g/g, indicating low mercury levels in the marine environment. (FAO & WHO, 2011; Voegborlo & Adimado, 2010).

2.4.2 Lead (Pb)

Lead (Pb) is a dangerous element that was originally found in the earth's crust and is present in all parts of the environment. The vast majority of lead concentrations, on the other hand, are the result of human activities such as mining, agriculture, fossil fuel combustion, and industry. Pb in most river basins primarily comes from mining such as transporting ore, prospecting minerals, smelting, refining, tailings disposal, and wastewaters, which release Pb and other harmful compounds over time (Cobbina et al., 2015). Pb levels were found to be higher in fish tissues such as bones, gills, liver, kidneys, and scales, with gases traveling from the gills to the circulation being the primary absorption mechanism (Akan et al., 2012). Pb has been discovered as a significant health risk to the human body. Pb is dangerous at extremely low levels, with some studies stating that there may be no limit of exposure below which Pb is safe (Ekpo et al., 2013). The accumulation of Pb in our bodies by consumption, replaces calcium in the bones, causing a slew of health issues including kidney failure, miscarriage, cognitive impairment, lung cancer, hypertension, and even death (Jilai, 2014). In Kenya, it was discovered that Pb concentrations in tilapia were higher than WHO guidelines throughout both the wet and dry seasons in the Athi-Galana-Sabaki tributaries. Pb concentrations in water increased owing to evaporation and were associated with higher Pb concentrations found during the dry season (Nzeve et al., 2014). In Nigeria, Pb levels in fish from the Ogba, Warri, and Ikpoba Rivers were lower than what the WHO and FAO authorized (2.0mg/kg), indicating that fish from these rivers were safe to eat (Asante et al., 2014; Perera et al., 2015).

2.4.3 Arsenic

Although arsenic is widely distributed in natural streams and is typically associated with geological sources, human inputs such as the use of arsenic pesticides and the burning of fossil fuels can be significant supplemental sources in some places. Inorganic arsenic is a recognized carcinogen that may cause malignancies of the skin, lungs, liver, and bladder (Yunus et al., 2011). Fish is a significant source of arsenic in the diet, with arsenobetaine (an organic arsenic molecule) accounting for more than 90% of the arsenic in marine fish. Arsenobetaine is an arsenic derivative that is not poisonous (Chen et al., 2009). According to Uneyama et al. (2007), organic arsenic in food and seafood appears to be significantly less dangerous than inorganic arsenic. The study also revealed that, although the majority of the fish had low arsenic levels, the muscles had the highest bioaccumulation (Vieira et al., 2011). Fish from India's northeast coast had lower amounts than those from India's northwestern coast's Gulf of Cambay, while larger concentrations were identified in fish from Indonesia's Gresik coastal waters (Agoes and Hamami, 2007).

2.4.4 Cadmium

Cadmium is extensively dispersed throughout the Earth's crust, with an average concentration of 0.2 mg/kg in rocks, sediments, and soils, and it is commonly found in conjunction with zinc" (WHO, 1992). Phosphate-based fertilizers contribute significantly to cadmium pollution in the environment. Cadmium's solubility in water is highly influenced by its acidity; when acidity increases, suspended or sediment-bound cadmium may dissolve (Ros and Slooff, 1988). Cadmium is commonly found in the bottom sediments and suspended particles of natural streams (Friberg et al., 1986). Nonferrous metal mines are a major source of cadmium in the aquatic environment. Cadmium is emitted into the environment by mines, metal smelters, and firms that utilize cadmium compounds in alloys, batteries, pigments, and plastics, even though many nations have tight emission limits in place (Harrison, 2001). Cadmium compounds are used in electric batteries, electronic components, and nuclear reactors (Friberg et al., 1986; Ros and Slooff, 1988). Cadmium accumulates in the human body, causing damage to organs such as the liver, kidneys, lungs, bones, placenta, brain, and central nervous system (Castro-González and Méndez-Armenta, 2008). Apostoli and Catalani (2011) discovered reproductive and developmental damage, as well as hepatic, hematological, and immunological effects. Chronic cadmium exposure causes emphysema, anemia, renal failure, and spontaneous fractures (Kinsella, 1987). In addition, epidemiological studies have connected cadmium to cancer. Lead and cadmium have both been related to an increased risk of heart disease death (Kinsella, 1987). Tobacco is a plant that contains a substantial quantity of Cadmium, a pack-a-day smoker's Cadmium consumption roughly doubles. In Belgium, hypercalcemia has been related to cadmium pollution, particularly among older women (Buchet et al., 1990). "It has been shown that cadmium induces harmful free radical species that cause lipid peroxidation and liver damage" (Gil, et al., 1989).

2.4.5 Toxicity and Health Risks of Iron (Fe)

"Due to its abundance in the earth's crust, iron is a non-conservative trace element found in significant amounts in drinking water" (Ghulman et al., 2008). In its native condition, metallic iron may be discovered. Most living species, as well as normal human physiology, require it for survival. "Human activities such as coke and coal combustion, acid mine drainage, mineral processing, sewage, and landfill leachates all contribute to excessive iron concentrations in aquatic bodies" (NCSU, 2006). However, iron's chemical behavior in the aquatic environment is influenced by oxidation-reduction processes, pH, and the presence of concurrent inorganic and organic complexing agents. A shortage of iron causes anemia, and drinking water with a high iron content may induce liver disease if drunk often (Rajappa et al., 2010).

In a nutshell, fish is a major component of the human diet, because it has nutritional advantages, particularly its rich content of omega-3 fatty acids, proteins, and micronutrients. Fish consumption has been associated with various health benefits, including improved brain development, weight management, and cultural importance in many societies.

However, there are challenges posed by metal contamination in fish, particularly mercury and other pollutants like Polycyclic Aromatic Hydrocarbons (PAHs). These contaminants have raised concerns about the health benefits of fish consumption.

Aquaculture in Ghana has increased over the years, with a focus on tilapia production and its high demand within the country.

Fish contamination in Ghana due to heavy metals, particularly mercury also been on the rise. Sources of heavy metals, including human activities such as mining, industrial processes, and agricultural runoff have been the major causes. There are potential health risks posed by heavy metals, which can have neurological, renal, cardiovascular, and developmental consequences. Mercury, in particular, is singled out for its toxic effects on humans, primarily through fish consumption.

Overall, the importance of fish as a dietary component cannot be overlooked, as it has nutritional benefits, and cultural significance, and there is an anticipated rise in consumption. However, it also an urgent need to address heavy metal contamination in fish, especially mercury, to ensure the safety and health of consumers.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study Design

This research used a cross-sectional investigation to determine the quantities of heavy metal in smoked and fresh tilapia obtained from the Agbogblosie Market, Makola Market, Kaneshie Market and Madina Market.

3.2 Study Area

Figure 2: Map of Accra-Tema Metropolis (Google maps, 2022).

The research took place at the Agbogblosie, Makola, Kaneshie, and Madina markets. These markets were chosen due to their significance as major food markets in the Accra metropolis. Additionally, the literature indicates that the Agboblohsie market is located near Accra's largest e-waste recycling zone. The selection was also influenced by their proximity to lorry stations, as research suggests that vehicular emissions are a contributing factor to environmental metal pollution.

3.2.1 Kaneshie market

Kaneshie market has a structure where independent vendors sell goods and food from their stalls. This market has been termed as an indoor market. It is located in the suburbs of Accra Metropolitan district.

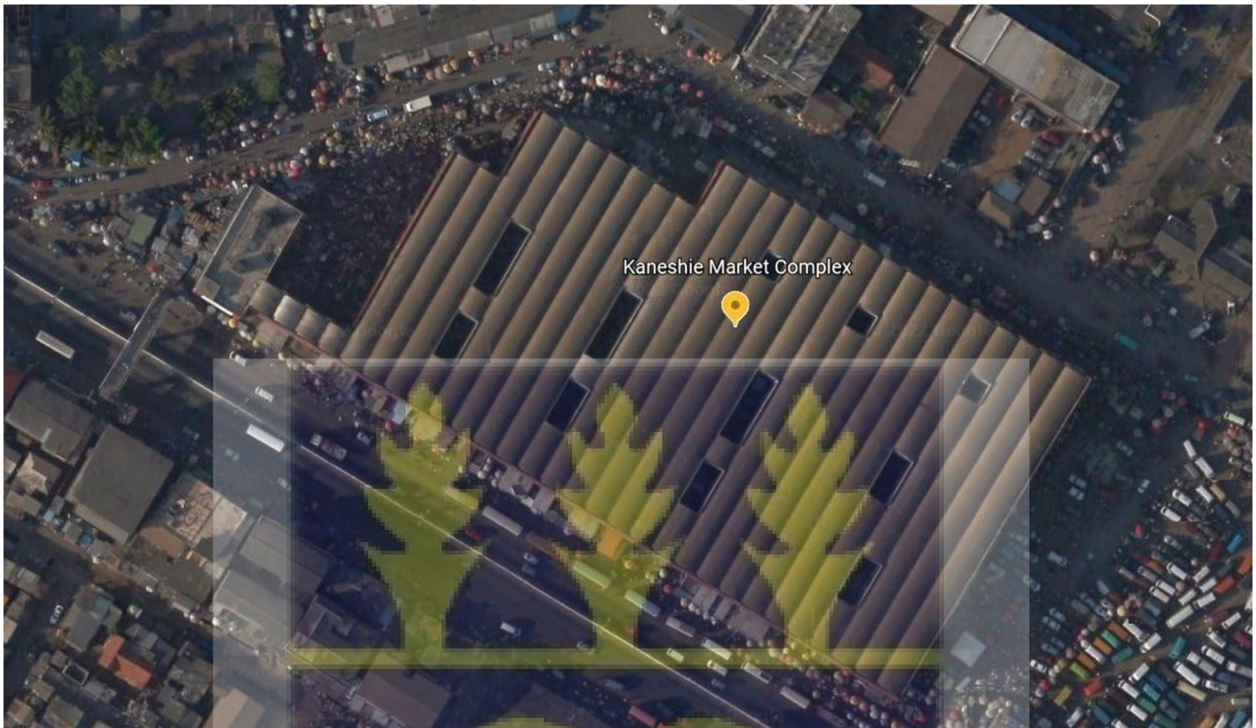


Figure 3: Aerial photo of Kaneshie Market (Google maps, 2022).

Madina market

Madina market being the second-largest market in Accra is located in the La Nkwantanang Madina Municipal District in the Greater Accra region. This market has an indoor section where people sell from the stalls but most of them sell on the streets, pavement, and bus stops.

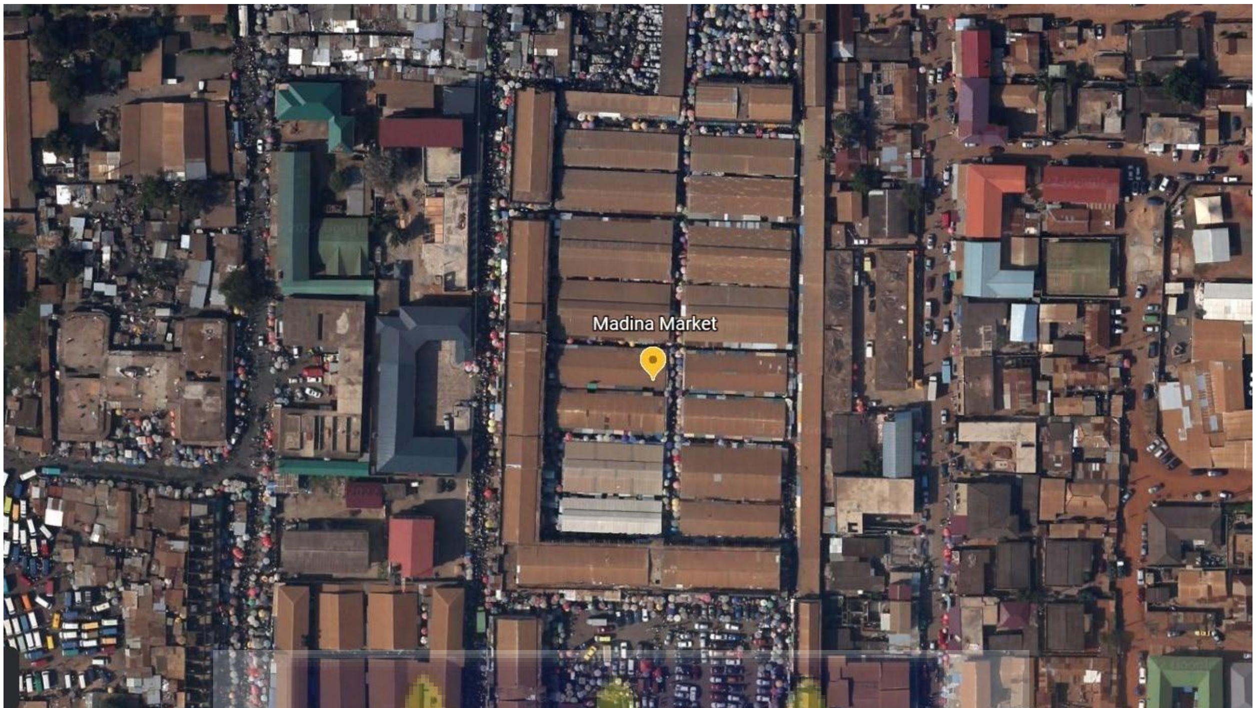


*Figure 4: Aerial view of Madina market (*Google maps, 2022).

Makola market

Makola market has a wide range of products being sold both in the market and the surrounding streets. It is a renowned marketplace for selling and shopping in the central district of Accra.

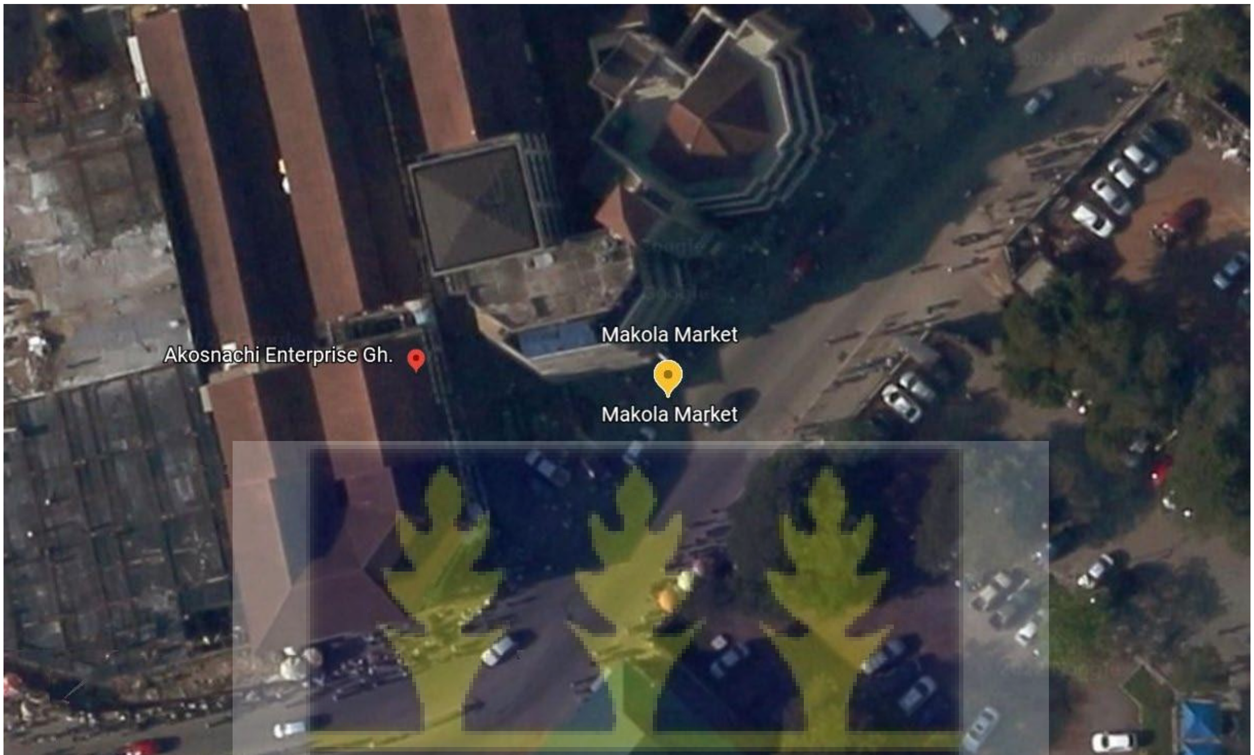


*Figure 5: Aerial view of Makola market (*Google maps, 2022).

Agbogbloshie market

Agbogbloshie market is an open market located in the Korle Lagoon district of Accra. It is known for the activities of the scrap dealers who are around that area.

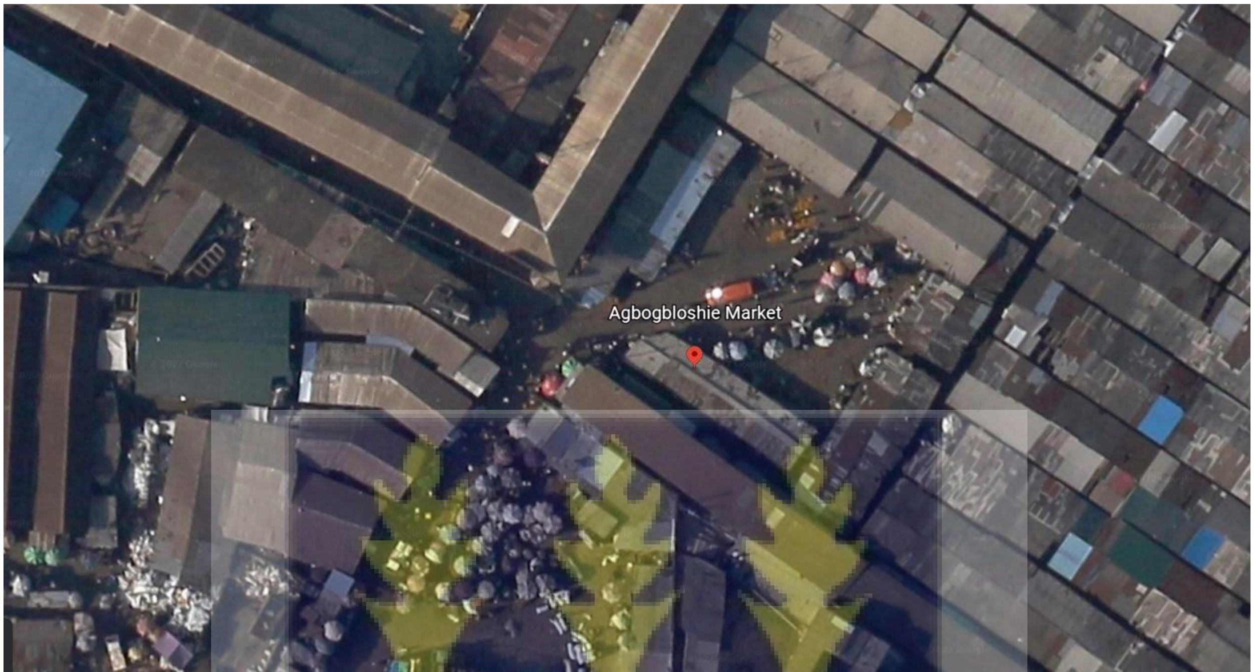


*Figure 6: Aerial view of Agbogbloishie market (*Google maps, 2022).

3.2 Study Population

Using a random sampling approach, a total of 40 samples were collected (10 from each market) and evaluated. Samples of each fish species were obtained from the various marketplaces. These fish samples were chosen based on their availability and popularity among Ghana's various socioeconomic classes.

3.2.1 Tilapia (Oreochromis niloticus)

Tilapia, scientifically known as *Oreochromis niloticus*, belongs to the Cichliformes family and the Actinopterygii class. It is a silvery-coloured, deep-bodied fish with scales. It has either black or grey body bars to complement its silvery color. This fish has an average body length of 20cm, but it may grow to a maximum length of 62cm and a weight of 3.65

Figure 7: Fresh tilapia from the makola market kg.

Tilapia is a freshwater species that prefers shallow, quiet waters at the borders of lakes and rivers with dense vegetation (Watanabe et. al., 2002).

:

Figure 8: Fresh Tilapia from Agbogbloshie Market

Figure 9: Fresh tilapia from Kaneshie market

Figure 10: Fresh tilapia from Madina market

3.3 Variables of Interest

The degree of heavy metal content in fresh tilapia was the outcome or dependent variable.

3.4 Sampling Procedure /Method

Fresh tilapia was collected at Agbogblosie Market, Makola Market, Kaneshie Market, and Madina Market using a random sampling approach. Vendors in the markets were grouped according to what they sold. Therefore, tilapia vendors were all grouped at a particular place in the markets. Tilapia vendors were selected randomly from which 10 pieces of tilapia were bought from each market.

3.4.1 Fish sampling and treatment

A total of forty fish were purchased from the four markets, stored in well-labeled Ziplock bags, and transported in an ice chest with ice packs to the laboratory for treatment and analysis. Before acid digestion, fish samples were dissected and the muscle tissue of the samples was cut using a clean stainless-steel knife. All samples were then stored in well-labeled zip polyethylene bags and frozen at -30 °C for 72 hours before laboratory analysis and heavy metal determination were performed.

3.4.2 Digestion of Samples

3.4.2.1 Digestion of fish samples

Portions of 1.0±0.01g of tilapia (muscle and head) were cut accurately weighed and placed into a digestion tube. 10 mL of concentrated HNO_3 and 5 mL of concentrated H_2SO_4 were added to the sample and allowed to stand overnight. The content was then heated on a hot plate for about one to three hours at 95 °C. 1-3 mL of 30 % H_2O_2 was added while heating until the solution became colorless. Thereafter, the solution was then removed from the hot plate to cool. Then deionized water was added, rinsed thoroughly, and filtered through Whatman No. 42 filter paper and then transferred quantitatively into a 100 mL volumetric flask and made up to the mark with deionized water.

3.4.3 Determination of heavy metals

The concentration of metals was measured using a PINAAcle 900T Atomic Absorption Spectrophotometer (Perkin Elmer, Massachusetts, United States). Cadmium (Cd) and lead (Pb) were determined using a flame atomic absorption spectrophotometer (FAAS). Arsenic (As) was determined using flow injection analysis system – atomic absorption spectrophotometer (FIASAAS) (Hydride Generation Technique) while mercury (Hg) was determined using flow injection analysis system – atomic absorption spectrophotometer (FIAS-AAS) (Cold Vapour Technique).

Air-acetylene gas was used as the source of fuel for Fe, Pb, and Cd while argon gas was used for As and Hg.

Table 1: *Instrument analytical condition of investigated metal ion*

Spectrometer parameter	Fe	Pb	Cd	As	Hg
Wavelength (nm)	248.33	283.3	228.8	193.7	253.7
Slit width (nm)	0.7	0.7	0.7	0.5	0.2
Lamp current (mA)	10	10	8	10	5
Fuel	Acetylene	Acetylene	Acetylene	Argon	Argon
Support	Air	Air	Air	Air	Air

3.5 Data Collection

From the markets, fresh tilapia was bought and immediately prepared and arranged into similar kinds. After that, the samples were sealed in plastic Ziplock bags, labeled with the markets from which they were obtained, placed in an ice chest with ice packs, and delivered to the lab for analysis. The heavy metal analysis was done at the ecotoxicological laboratory (Ecolab), the Institute for

Environmental and Sanitation Studies at the University of Ghana, Legon using the Atomic Absorption Spectrophotometer (AAS).

3.6 Quality control

All the reagents used were of analytical grade. Plastic and glass wares were soaked in 10% HNO_3 for 24 hours, rinsed with distilled water, and oven-dried overnight. A blank was run for each digestion procedure to correct the measurement. Each sample was analyzed in triplicates and two standards were tested after every 10 samples to check for interference and cross-contamination. The percent recovery of the metals analyzed is presented in Tables 2 and 3 respectively. Standard reference material SRM 1947 Lake Michigan Fish Tissue from the National Institute of Standards and Technology (NIST), USA, was used to ensure the data's accuracy. The samples will then be wrapped in plastic Ziplock bags, labeled with the markets from whence they were obtained, stored in a refrigerator with ice packs, and delivered to the lab for analysis. In the lab, the Ghana Atomic Energy Commission will analyze heavy metals in fish species using the Atomic Absorption Spectrophotometer (AAS) (GAEC). Atomic absorption spectrometry (AAS), which measures the absorbed radiation by the chemical element of interest, is used to determine the number of chemical components present in environmental samples. As part of the quality control methodology, OLT3 Dogfish Liver from the National Reference Council of Canada was included in each batch of sample digestion and analysis. To calculate mean concentration, it was assumed that the values below the limit of detection (LOD) were equal to half the LOD. For several samples, the concentration of metals was below the limit of detection (LOD) or quantification.

Table 2: Certified mass fraction (wet-mass basis) and measured concentration of Fe, As, and Hg in SRM 1947 Lake Michigan Fish Tissue

Analyte	Certified value (mg/kg	Measured value (mg/kg)	% Recoveries
Fe	3.79 ± 0.42	3.99 ± 0.31	97.6
As	0.732 ± 0.039	0.863 ± 0.079	99.3
Hg	0.254 ± 0.005	0.270 ± 0.008	99.6

Table 3:Certified and measured concentration of Pb and Cd in DOLT-3 dogfish liver National Reference Council Canada

Analyte	Certified value (mg/kg	Measured value (mg/kg)	% Recoveries
Cd	1.94 ± 0.06	1.85 ± 0.09	98.2
Pb	0.03 ± 0.005	0.045 ± 0.005	99.6

3.7 Data Processing and Analysis

Microsoft Excel version 16 was used to code and enter the data received and then exported to STATA for analysis. Means, standard deviation, ranges, p-values, and percentages were employed to describe data that has been obtained. Graphical representations were also used in the study, including appropriate tables and bar charts. ANOVA was used to compare the means of Agbogbloshie, Kaneshie, Makola, and Madina Markets.

CHAPTER FOUR

4.0 RESULTS

Heavy metal concentrations; Fe, Pb, Cd, As, and Hg were measured in sampled tilapia (*Oreochromis niloticus*) across four different markets namely Madina, Makola, Kaneshie, and Agboloshie as shown in the Tables below.

4.1 Concentration of Metals in fresh Tilapia

The mean concentration of Fe in fish samples collected across markets varied significantly. At the Agbogboloshie market, the head had the highest mean concentration of Fe at 21.75 mg/kg (±SD), while the lowest mean concentration of 4.90 mg/kg was found at Madina market. In terms of muscle, the Agbogboloshie market also had the highest mean concentration of Fe at 6.65 mg/kg, while the Madina market had the lowest at 1.77 mg/kg. Moving on to Pb concentrations, the highest level, 0.024 mg/kg, was observed at the Agbogboloshie market, whereas the lowest mean concentration of 0.04 mg/kg was found at the Makola market in muscle samples. For fish heads, the Kaneshie market had the highest Pb concentration at 0.04 mg/kg, while the Madina market had the lowest at 0.02 mg/kg. In the case of Cd, the muscle samples from the Kaneshie market exhibited the highest concentration at 0.04 mg/kg, while the lowest concentration of 0.009 mg/kg was recorded at the Madina market. For fish heads, Makola market had the highest Cd concentration at 0.05 mg/kg, and Madina market had the lowest at 0.008 mg/kg. Regarding As concentrations, the Agbogboloshie market recorded 0.02 mg/kg for muscle and 0.04 mg/kg for the fish head, whereas the Madina market had 0.01 mg/kg for muscle and 0.02 mg/kg for the fish head. Lastly, Hg concentrations were 0.03 mg/kg at the Kaneshie market and 0.009 mg/kg at the Agbogboloshie market for muscle samples. For fish heads, the highest Hg concentration of 0.08

mg/kg was found at the Makola market, and the lowest concentration of 0.01 mg/kg was recorded at the Agbogboloshie market. These variations across markets are illustrated in the tables below.

Markets	Pb	Cd	As	Hg
Madina	0.0075	0.0092	0.0123	0.0138
Markola	0.0040	0.0262	0.0121	0.0236
Agbogbloshie	0.0244	0.0142	0.0207	0.0099
Kaneshie	0.0226	0.0469	0.0114	0.0300

Table 4: Mean concentration of Pb, Cd, As, and Hg in the muscle of tilapia sampled across target markets

Markets	Pb	Cd	As	Hg
Madina	0.0234	0.0087	0.0315	0.0822
Markola	0.0322	0.0599	0.0461	0.0390
Agbogbloshie	0.0353	0.0490	0.0291	0.0188
Kaneshie	0.0450	0.0160	0.0203	0.0340

Table 5 Mean concentration of Pb, Cd, As, and Hg in the head of tilapia sampled across target markets

Fe in tilapia was the highest heavy metal recorded across markets. The total mean concertation for the head of the tilapia was 11.97 mg/kg and highest at Agbogbloshie Market (21.75 mg/kg) and that of the muscle was 3.66 mg/kg and highest at Agbogbloshie (6.65 mg/kg). This is demonstrated in the tables below:

Markets	Mean concentration of Fe in mg/Kg
Madina	1.7793
Markola	3.340
Agbogbloshie	6.650
Kaneshie	2.8800

Table 6 Mean concentration of Fe in the muscle of tilapia sampled across target markets

Markets	Mean concentration of Fe in mg/Kg
Madina	4.900
Markola	11.3550
Agbogbloshie	21.7556
Kaneshie	9.500

Table 7Mean concentration of Fe in the head of the tilapia sampled across target markets

4.2 Concentration of Heavy Metals in Tissues of Tilapia

Tilapia sampled across markets were tested for the concentration of heavy metals in its tissues, specifically, the muscle and head. This is shown in the tables below:

Metals	Mean	SD	S. E	Min	Max
Fe	3.340	2.7800	0.0890	0.3000	8.8000
Pb	0.0040	0.0030	0.0001	0.0010	0.0130
Cd	0.0262	0.0120	0.0040	0.0070	0.0420
As	0.0121	0.0080	0.0020	0.0080	0.0300
Hg	0.0236	0.0070	0.0020	0.0160	0.0360

Table 8: Metal concentration in the muscle of fresh tilapia sampled from Makola market

Metals	Mean	SD	S. E	Min	Max
Fe	11.2600	1.6610	0.5250	8.600	14.400
Pb	0.0300	0.0253	0.0080	0.0020	0.0770
Cd	0.0610	0.0110	0.0035	0.0190	0.0870
As	0.0430	0.0190	0.0060	0.0870	0.0520
Hg	0.0389	0.0090	0.0030	0.0260	0.0520

Table 9: Metal concentration in fresh tilapia head sampled from Makola market

The results from the table above show the mean concentration of each metal measured in the muscle of tilapia sampled from the Makola market. Fe is seen to have a mean concentration of 3.340, which is the highest followed by Cd with a concentration of 0.0262, Hg with a concentration of 0.0236, As with a mean concentration of 0.0121, and Pb with the lowest mean concentration of 0.004. Heavy metal concentrations recorded in the muscle of tilapia sampled from Makola are arranged in increasing concentrations Fe>Cd>Hg>As>Pb. With regards to the concentration levels recorded in the head, Fe recorded a mean concentration of 11.26 with Cd recording 0.061, followed by As with a concentration of 0.043. Hg and Pb also recorded concentration levels of 0.0389 and 0.030 respectively. Results recorded for tilapia heads sampled from the Makola market showed an increasing concentration order of Fe>Cd>As>Hg>Pb. Comparing the concentration levels of heavy metals in the head and muscle of tilapia sampled from the Makola market, the result showed that Fe had very high concentration levels in both the head and muscles of the sampled tilapia followed by Hg. Although the level of concentration of Hg was relatively low compared to that of Fe, it was high compared to As, Hg, and Pb.

Metals	Mean	SD	S. E	Min	Max
Fe	1.780	1.0900	0.3450	0.3300	4.1700
Pb	0.00700	0.003	0.0090	0.0030	0.0120
Cd	0.0090	0.0110	0.0030	0.0050	0.0400
As	0.0120	0.0050	0.0020	0.0080	0.0250
Hg	0.0140	0.0030	0.0010	0.0100	0.0220

Table 10: Metal concentration in the muscle of fresh tilapia sampled from the Madina market

Metals	Mean	SD	S. E	Min	Max
Fe	4.900	1.8070	0.5720	1.900	7.9000
Pb	0.0230	0.0190	0.0060	0.0040	0.0620
Cd	0.0090	0.0020	0.0007	0.0070	0.0150
As	0.0310	0.0400	0.0130	0.0100	0.1110
Hg	0.0820	0.0350	0.0110	0.0110	0.1190

Table 11 Metal concentration in fresh tilapia head sampled from Madina market

The mean concentrations levels of Fe, Pb, Cd, As, and Hg recorded in the muscle of tilapia sampled from the Madina market are 1.78, 0.007, 0.009, 0.012, and 0.014 respectively. The results recorded showed an increasing concentration order of Fe>Hg>As>Cd>Pb. Also, in the head of the tilapia sampled from the Madina market, concentration levels of Fe, Pb, Cd, As, and Hg recorded are 4.9, 0.023, 0.009, 0.031, and 0.082 respectively. The concentration levels of Fe were higher in the head than in the muscle of tilapia sampled from the Madina market. In addition, Cd recorded the same concentration levels in both parts of the fish. Results recorded show an increasing order of concentration as Fe>Hg>As>Pb>Cd. The metal Fe recorded the highest concentration followed by Hg and Cd recording the lowest level of concentration.

Metals	Mean	SD	S. E	Min	Max
Fe	6.6500	1.3180	0.4170	4.9000	9.6000
Pb	0.0240	0.0160	0.0060	4.9000	9.6000
Cd	0.0140	0.0050	0.0020	0.0090	0.0260
As	0.0207	0.0108	0.0034	0.0110	0.0440
Hg	0.0100	0.0040	0.0010	0.0060	0.0170

Table 12 Metal concentration in the muscle of fresh tilapia sampled from Agbogbloshie market

Metals	Mean	SD	S. E	Min	Max
Fe	22.2300	2.4180	0.7640	17.9000	26.5000
Pb	0.0330	0.0190	0.0060	0.0170	0.0680
Cd	0.0480	0.0210	0.0060	0.0330	0.1020
As	0.0310	0.0190	0.0060	0.0110	0.0610
Hg	0.0190	0.0030	0.0010	0.0140	0.0230

Table 13: Metal concentration in fresh tilapia head sampled from Agbobloshie market

For tilapia samples from the Agbogbloshie market, the mean concentration of heavy metals Fe, Pb, Cd, As, and Hg are 6.65, 0.024, 0.014, 0.0207, 0.01respectively. Fe had the highest level of concentration 6.65mg/kg. Hg recorded the lowest concentration level as compared to the other heavy metals measured. Also, the concentration level of Fe was very high compared to the other heavy metals measured in the muscle of sampled tilapia from the Agbogbloshie market. Results recorded show an increasing order of concentration as Fe>Pb>As>Cd>Hg. For concentration levels of heavy metals recorded in the head, Fe recorded a mean concentration of 22.23mg/kg with Cd recording 0.048mg/kg, followed by Pb with a concentration of 0.033mg/kg. As and Hg also recorded concentration levels of 0.031mg/kg and 0.019mg/kg respectively. Results recorded for tilapia heads sampled from the Agbogbloshie market showed an increasing concentration order of Fe>Cd>Pb>As>Hg. Comparing the concentration levels of heavy metals in the head and muscle of tilapia sampled from the Agbogbloshie market, the result showed that Fe had very high concentration levels in both the head and muscles of the sampled tilapia. Although the level of concentration of Cd was relatively low compared to Fe, it was high compared to As, Hg, and Pb.

Metals	Mean	SD	S. E	Min	Max
Fe	2.880	1.1580	0.3660	1.9000	5.7000
Pb	0.0230	0.0100	0.0030	0.0120	0.0420
Cd	0.0470	0.0290	0.0090	1.9000	5.7000
As	0.0110	0.0014	0.0004	0.0090	0.0130
Hg	0.0300	0.0110	0.0034	0.0190	0.0490

Table 14Metal concentration in the muscle of fresh tilapia sampled from Kaneshie market

Metals	Mean	SD	S. E	Min	Max
Fe	9.5000	1.2470	0.3940	7.9000	11.7000
Pb	0.0450	0.0250	0.0070	0.0040	0.0750
Cd	0.0160	0.0060	0.0020	0.0080	0.0260
As	0.0200	0.0130	0.0070	0.0090	0.0870
Hg	0.0380	0.0123	0.0040	0.0190	0.0590

Table 15Metal concentration in the head of fresh tilapia sampled from Kaneshie market

The mean concentrations levels of Fe, Pb, Cd, As, and Hg recorded in the muscle of tilapia sampled from the Kaneshie market are 2.88, 0.023, 0.047, 0.011, and 0.03mg/kg respectively. The results recorded showed an increasing concentration order of Fe>Cd>Hg>Pb>As. Fe is seen to have a mean of 2.88mg/kg, which is the highest followed by Cd with a concentration of 0.047mg/kg, Hg with a concentration of 0.03mg/kg, Pb with a mean concentration of 0.023mg/kg and As with the lowest mean concentration of 0.011mg/kg. With regards to concentration levels recorded in the head, Fe recorded a mean concentration of 9.5mg/kg with Pb recording 0.045mg/kg, followed by Hg with a concentration of 0.038mg/kg. As and Cd also recorded concentration levels of 0.0389 and 0.030 respectively. The results recorded showed an increasing concentration order of Fe>Cd>Hg>Pb>As

Table 16: Mean Concentration of selected Heavy Metals in Tilapia compared with standard permissible requirements (mg/kg)

Tilapia	Cd	Hg	Fe
Head	0.0300	0.0400	11.9700
Muscle	0.0200	0.0100	3.6600
WHO/FAO MPL	0.5000	0.5000	43.0000

*MPL= maximum permissible limit

The table above compares the mean concentrations of Cd, Hg, and Fe with that of WHO/FAO maximum permissible limits. It can be seen that all selected metals fall below the maximum permissible limits set by the WHO/FAO.

CHAPTER FIVE

5.0 DISCUSSION

Fish is consumed all over the world as an important source of protein, and is rich in calcium, phosphorus, omega-3 fatty acids, and vitamins and a great source of minerals, such as iron, zinc, iodine, magnesium, and potassium. Depending on their environment, fish can absorb chemicals including metals, and sometimes bioaccumulate these chemicals. Therefore, fish are sometimes used as bio-indicators of aquatic ecosystems to estimate heavy metal contamination and human ingestion risk (Argawa et al., 2007). Metal bioaccumulation in fish occurs both directly from the water via the gills and indirectly via diet (Barron, 1990). The relationships between physiological factors (growth, weight loss, absorption, and accumulation), chemical factors (metal concentration, speciation, and bioavailability), and environmental factors (temperature, pH, water hardness, conductivity, salinity, and food concentration) result in metal bioaccumulation by an organism (Casas and Bacher, 2006).

Across markets, the mean concentration of the metals analyzed in the head of the tilapia saw Fe having the greater concentration and Hg and Pb having the lowest concentration. Similarly, the mean concentration of the metal analyzed in the muscle of the tilapia saw Fe having the highest concentration and Hg, Cd, and Pb having the lowest. The mean concentration of metal in the muscle and head of the tilapia at Madina market were in the following order Fe>Hg>As>Cd>Pb and Fe>Hg>As>Pb>Cd respectively. At the Makola market, the mean concentration of metal in the muscle and head were Fe>Cd>Hg>As>Pb and Fe>Cd>As>Hg>Pb respectively. Kaneshie market had the same order of mean concentration in both the muscle and head of the tilapia. This was Fe>Cd>Hg>Pb>As. The mean concentration of metal in the muscle and head of the tilapia at the Agbogbloshie market were in the following order Fe>Pd>As>Cd>Hg and Fe>Cd>Pb>As>Hg respectively.

Cadmium contents measured were less than the WHO-recommended limit of 2.0mg/kg for fish and fish products. Mercury concentrations were likewise lower than the EU's suggested limit of 0.5 mg/kg for Hg and lower than the WHO/FAO maximum permitted level of 0.6 mg/kg. (FAO/WHO, 2011). However, caution should be exercised while consuming fish since the cumulative effects of Cd may pose health risks to aquatic life and humans who consume fish (Oronsaye et al., 2010). Cadmium is commonly recognized as a very poisonous non– essential heavy metal that has no part in the biological processes of living creatures. As a result, even at low concentrations, cadmium may be toxic to living creatures (Tsui and Wang, 2004). Ingestion of Cd can quickly produce nausea, vomiting, abdominal cramps, headache, diarrhea, and shock. Itai-itai illness, which affects the liver, placenta, kidneys, lungs, brain, and bones, was discovered in Japan among persons living in Cd-polluted areas where rice was irrigated (Reilly, 2002).

Cadmium, which frequently accumulates in the human body through diet, harms various organs, including the liver, kidney, lungs, bones, placenta, brain, and central nervous system (Chouba et al., 2007). Other documented consequences include reproductive and developmental toxicity, as well as hepatic, hematological, and immunological impacts. Cadmium is discharged into the environment through wastewater, and diffuse pollution is created by fertilizer contamination and local air pollution. Obasohan (2008) and Kar et al. (2008) conducted similar research and found that the presence of Cd in the fish gills from all sample sites might be ascribed to the discharge of industrial effluents and municipal wastes, as well as the geology of the river bed and catchment region. High mercury amounts have been detected in a range of fish and crustaceans, including sharks, swordfish, and tuna (Abrefah et al., 2011). The size of the fish, on the other hand, has been proven to be an important factor in accumulation. There is a relationship between fish size and the rate of Hg accumulation, with larger fish having greater levels of accumulation (Akoto et al., 2012).

As a result, eating mercury-contaminated freshwater fish is extremely dangerous to one's health. Mercury can cause lung damage, neurological and psychiatric problems, kidney damage, and fetal defects (Järup, 2003). "The worldwide threshold for permitted quantities of mercury in tainted food is 0.5 ppm; thus, consuming more than this poses a considerable health risk to consumers" (Jilai, 2014; Lagoon, 2011). Research conducted in Ghana has shown low mercury concentrations in fish species obtained from the Atlantic Ocean around Ghana's coast that are less than the FAO/WHO limit of 0.5 g/g, indicating low mercury levels in the marine environment (FAO & WHO, 2011; Voegborlo & Adimado, 2010).

Among all markets, Fe had the greatest mean concentration. The concentration of iron was so high that it had to be analyzed individually to get the whole picture. Iron had a total mean content of 11.97 mg/kg in the head of tilapia sampled across markets and 3.66 mg/kg in the muscle of tilapia sampled across markets. This demonstrates how prevalent this heavy metal is in fresh tilapia in all markets, particularly in the head, although levels were still below the WHO/FAO maximum permitted values of 43mg/kg. There was a significant variation in iron concentration levels among markets. Most living species and basic human physiology require iron. Iron is a necessary component of proteins involved in the transfer of oxygen from the lungs to the tissues in humans (Dallman, 1996). It is also required for the control of cell proliferation and differentiation (Andrew, 1986). Similar to the findings of this study, Mohammed, A. A. (2009) found significant levels of Fe in tilapia with low levels of other metals. Human activities such as coke and coal combustion, acid mine drainage, mineral processing, sewage, and landfill leachates all contribute to high iron concentrations in aquatic bodies" (NCSU, 2006). However, iron's chemical behavior in the aquatic environment is influenced by oxidation-reduction processes, pH, and the presence of concurrent inorganic and organic complexing agents. A shortage of iron causes anemia, and drinking water with a high iron content may induce liver disease if drunk often (Rajappa et al., 2010). Overall, greater levels of Hg and Cd were found in fish obtained from the Madina market Hg Cd for the Kaneshie market (Figures 4.1 and 4.2), which were lower than the WHO/FAO recommended standards of 2.0 and 0.6 mg/kg for cadmium and mercury, respectively.

These increased mercury levels in the market may be owing to Kaneshie market's closeness to Agbogbloshie Township, which is approximately a five-minute drive from where all types of e-waste operations take place (Wittsiepe et al., 2015b). The burning of e-waste items from this dumping site may cause mercury and other heavy metals to be released into the atmosphere, eventually settling on the fish. "Research has shown that elemental metals such as mercury may linger in the environment for a very long period, allowing them to settle on the fish and cause them to have or record excessive amounts" (Abboah-Offei, 2016 p.34). Cadmium concentrations in the Madina market may be attributable to significant air pollution in the region, as well as excessive carbon emissions from automobiles owing to its proximity to the major road. "In Ghana, as in many other places, industrial wastes, agricultural runoffs, the burning of fossil fuels, animal and human excretions, geologic weathering, waste, geochemical structure, and metal mining have all contributed to heavy metal pollution in the aquatic environment, contributing to higher HM levels in aquatic organisms such as fish species" (Abboah-Offei, 2016 p.34).

The head of the fish accumulated more metals as compared to the muscles. The majority of metals tend to accumulate predominantly in the liver, kidneys, and gills of fish. In contrast, when compared to other bodily tissues, fish muscles typically exhibit the least amount of metal content. The allocation of metals to different organs depends on the duration of exposure (Jezierska et al., 2006). The head therefore had more metal concentration because the gills are located in the head region.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Although varying concentrations of metals were measured in fresh tilapia across markets, concentrations were below WHO/FAO standards for maximum permissible limits. Different levels of concentration probably indicate pollution in water bodies and, to some extent, pollution in the surroundings of food markets. However, the tilapia available in these markets appears safe and suitable for human consumption. Also, from the results the head of Tilapia accumulated more heavy metals as compared to the muscles.

6.2 Recommendations

- Further studies are needed on other fish species to compare with studies done on some species like fresh tilapia.
- Government agencies such as the Food and Drug Administration, as well as other health and public health groups, should educate the public about the hazards of heavy metals in tilapia, as well as how much fish to consume each day or week to avoid heavy metal poisoning.
- The government should put in place policy guidelines to stop pollution at all levels, within our water bodies, and at the markets to ensure the safety of our fish species.

6.2.1 Aspects for Additional Research

The analysis of Cd, As, Hg and Fe levels in tilapia offered incredibly important and comprehensive baseline data on the contaminated situation of our markets. This data may be utilized as a resource for academics and environmental managers to detect potential anthropogenic influences on the metals under investigation, as well as to better predict the requirement for bioaccumulation remediation by monitoring changes from existing levels. The presence of significant levels of many metals in the fish samples showed that the fish may absorb metals from their surroundings. Another important factor to consider for future study is the fish samples' capacity to assimilate the components into their tissues.

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