QUANTIFICATION AND HEALTH IMPLICATIONS OF SELECTED HEAVY METALS IN LAKE VICTORIA, TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN PUBLIC HEALTH AND FOOD SAFETY OF THE SOKOINE UNIVERSITY OF AGRICULTURE MOROGORO, TANZANIA.

2016

ABSTRACT

Increased human population and anthropogenic activities around Lake Victoria leads to pollution and health risks to consumers of water and fish. This study was conducted to assess the levels of Mercury (Hg), Cadmium (Cd) and Lead (Pb) in Nile perch muscles, water, and sediment in Lake Victoria in Mwanza, Mara and Kagera in Tanzania. A total of 180 samples were collected from 60 national designated sampling stations. From each region, 20 sampling stations were selected and three samples including water, sediment and Nile perch muscles were collected from each station. The collected samples were analyzed using Graphite Furnace, Flame and Cold Vapour Atomic Absorption Spectrometers techniques. The human health risk due to the consumption of Nile perch was established by calculating the daily exposure rates, hazard quotients and the total hazard indices of the toxic metals. In sediments, the concentration of heavy metals ranged from 0.05 – 2.11, 16.06 – 39.07 and 520.25 – 1086.88 µg/kg for Hg, Cd and Pb, respectively. The corresponding concentrations in the water ranged from 0.0004 – 0.161, 2.34 – 31.06 and 0.13 – 99.54 µg/L for Hg, Cd and Pb, respectively. The concentrations in Nile perch muscles ranged from 0.03 – 0.38, 20.93 – 79.17 and 166.33 – 527.97 µg/kg for Hg, Cd and Pb, respectively. The highest levels of Hg and Pb were recorded in sediment samples and for Cd in Nile perch muscle samples. The lowest levels of Hg, Cd and Pb were recorded in the water. The total hazard indices of Hg, Cd and Pb indicated no risk outcome from the consumption of the Nile perch from Lake Victoria. Based on the findings of this study, it is concluded that the concentrations of Hg, Cd and Pb were lower compared to the WHO permissible limits; hence the consumption of Nile perch may not pose any significant threat to human health.

DECLARATION

I, MHINA, MICHAEL PETER, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work, done within the period of registration and that it has neither been submitted nor being concurrently submitted for a higher degree award in any other institution.

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ACKNOWLEDGEMENT

Praise be to God for sustaining my soul with nourishment to end this research work. I thank the Trade and Agriculture Support Programme phase II (TASP II) coordinator Mr. S. A. Lukanga for the great support provided which made this study at Sokoine University of Agriculture to be successful. I am grateful to European Union (EU) for financial support through the TASP II project.

I also thank Dr. B.P. Ngatunga, the Director General of the Tanzania Fisheries Research Institute (TAFIRI), the Director of Research Dr. S. Mzighani, and the acting Centre Director (TAFIRI – Mwanza) Ms. M. Musiba, who offered a great support during sample collection. I would like as well to thank a team of scientists, technicians and crew who worked in a teamwork spirit to ensure a successful completion for the tasks.

Iam highlyindebtedtothemanagementandstaffoftheFisheries Development Division of TanzaniaandNationalFish Quality Control Laboratory (NFQCL)forthe kindassistanceofferedtomeatvariousstages duringtheresearch.My heartfelt thanks are further extended to Prof. R.H. Mdegela and Dr. E.M. Mkupasi, my supervisors, for their sincere commitment and guidance during the research work and writing up of the dissertation. Many thanks to my friends and my family for the moral and material support they gave me. God bless all of you.

DEDICATION

I dedicate this work to the Almighty God who made all things possible and to all men and women of God who have given my life a meaning.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrometer
ADI	Acceptable Daily Intake
ANOVA	Analysis of Variance
APHA	American Public Health Association
ATSDR	Agency for Toxic Substances and Disease Registry
CNS	Central Nervous System
CVAAS	Cold Vapour Atomic Absorption Spectrometer
EU	European Union
FAAS	Flame Atomic Absorption Spectrometer
GFAAS	Graphite Furnace Atomic Absorption Spectrometer
HQ	Hazard Quotient
IARC	International Agency for Research on Cancer
IPCS	International Programme on Chemical Safety
NFQCL	National Fish Quality Control Laboratory
PTWI	Provisional Tolerable Weekly Intake
TAFIRI	Tanzania Fisheries Research Institute
TASP II	Trade and Agriculture Support Programme Phase II
TF	Transfer Factor
THI	Total Hazard Index
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Urban environmental pollution by chemicals from wastewater and industrial effluents has become of public interest particularly in developing countries (Kihampa, 2013). This is especially because industrial development, poor planning and rapid population growth which utilize a wide range of chemicals often introduce contaminants into wastewater (Hakami, 2014). Lake Victoria, which is situated in three countries namely Tanzania, Uganda, and Kenya sustains livelihood of millions of people in the region (Makalle*et al*., 2008).The growing population around the lake has led to increased human activities which, if not controlled, are likely to result to pollution of aquatic system. For instance, increased mining, agricultural, industrial activities, and domestic discharges around the lake, if not properly managed, are likely to result to heavy metal contamination (Owa, 2013). Earlier studies in the area indicate the existence of high levels of heavy metals pollutions in places with high concentration of industries (Machiwa, 2003). The analysis of fish from Ugandan side of the lake was found having relatively high levels of some heavy metal contamination (Mbabazi and Wasswa, 2010). Such contamination was attributed to discharge of industrial and domestic effluent into the lake (Walakira, 2011).

Different studies have demonstrated the health effect of heavy metals in humans. The toxicity of heavy metals contamination depends on such factors as the dose, the route of exposure, and nutritional status of the exposed individuals (Tchounwou*et al*., 2012). Heavy metals such as Hg, Cd and Pb have no identified physiological activity but have been proven to be detrimental beyond certain limits (Nhapi*et al*., 2012). The toxicity and the potential caused by Cd and Pb to kidneys and to the central nervous system (CNS) respectively makes the assessment of the levels of the selected heavy metals in Lake Victoria a necessity to avoid health hazards due to its bioaccumulation in fish (Govind and Madhuri, 2014).

Limited surveyshave reportedhighlevels ofheavy metalsin Lake Victoria water,sediment andfish(Mwamburi, 2016). Such excessive pollution of lake water is considered to pose health hazards to humans who may likely be affected either by drinking the water or by consuming contaminated fish (Jaishankar*et al*., 2014). Thus, the assessment of the levels of the selected heavy metals in Lake Victoria is important in order to advice the government on management measures for sustainable exploitation of aquatic resources.

1.2 Problem Statement and Study Justification

Agricultural, mining, industrial and domestic discharges result to the exposure of Nile perch found in Lake Victoria to heavy metals. This is likely to end in bioaccumulation in Nile perch and later to the consumers of the fish and hence causing health complications. This is especially because the surrounding rivers that pour their waters into Lake Victoria pass through mining, industrial and agricultural areas as well as areas with densely populated human settlements. The analysis of Hg, Cd and Pb is therefore crucial in providing baseline data. The findings of this study will equip policy and decision makers with the necessary information which would guide them on measures to be taken in minimizing the damage of heavy metals in Lake Victoria to the environment and human health.

1.3 Objectives

1.3.1 Main objective

To assess the levels of Hg, Cd and Pb in Lake Victoria and their implications on the health of consumers of water and Nile perch in Tanzania.

1.3.2 Specific objectives

i. To establish the levels of Hg, Cd and Pb in water, sediment and Nile perch muscles from Lake Victoria
ii. To determine the transfer factors (TFs) for Hg, Cd and Pb in Nile perch against water and sediment matrices
iii. To investigate the public health hazards associated with Hg, Cd and Pb exposure in Nile perch

1.4 Research Questions

i. What are the concentrations of Hg, Cd and Pb in water, sediment and Nile perch muscles from Lake Victoria?
ii. Are there any accumulations of Hg, Cd and Pb in Nile perch from water and or sediment of Lake Victoria?
iii. To what extent do Nile perch are exposed to Hg, Cd and Pb from Lake Victoria?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview of Heavy Metal Contamination in Aquatic System

Heavy metals are naturally occurring elements that have a relatively high density compared to that of water (Ratan and Verma, 2014). These area groupofmetals withanatomicdensity greater than 5 g/cm^3. Such metals include Hg, Cd and Pb with densities of 13.546, 8.65 and 11.34 g/cm^3 respectively (Tchounwou*et al*., 2012). Their various applications in industrial, domestic, agricultural, medical and technological spheres have led to their wide distribution in the environment. However, their potential effects on human health and the environment have raised concerns among researchers. This is especially because these metals arecommonlyassociatedwithpollutionandtoxicityproblems(Ratan and Verma, 2014).

Because of their high toxicity levels, Hg, Cd and Pb rank highly among the priority metals with public health significance (Khillare*et al*., 2015). These metallic elements are considered as systemic toxicants which are known to induce multiple damages to human organs, even at lower levels of exposure (Jan *et al*., 2015). They are also classified carcinogenic to humans according to the United States Environmental Protection Agency (USEPA) and International Agency for Research on Cancer (IARC) (Mehrnoosh*et al*., 2014). Heavy metalsarepersistent and are not eliminatedbybiodegradation, chemical,orbiochemicalmeans (Ashraf *et al*., 2012).

The three metals Hg, Cd, and Pb, whose toxicity has been recognized for many years, have caused major human health problems in many parts of the world

(Jaishankar*et al*., 2014). In Africa including Tanzania, an increase of industrialisation and urbanisation have inevitably lead to an increase of Hg, Cd and Pb levels in the continent (Nziku and Namkinga, 2013). In many African countries, where mining activities have thriven, there has been a significant increase in the heavy metals input to the environment. Good examples include the prevalence of Mercury in Algeria, Arsenic in Namibia and South Africa, Tin in Nigeria and Copper in Zambia (Ikenaka*et al*., 2010). Other sources of toxic metals in the region include such activities as leather tanning, electroplating, sewage treatment plants, and soap as well cosmetics industries (Muwanga and Barifaijo, 2006). Such activities have been held responsible for the continued widespread distribution of heavy metals to the environment in the continent.

2.2 Heavy Metals in Aquatic Ecosystem

An aquatic ecosystem is formed by communities of organisms that are dependent on each other and on their aquatic environment. The two main types of aquatic ecosystems are marine ecosystems and freshwater ecosystems (Christian, 2003). Pollution of aquatic systems by heavy metals has become a worldwide problem during recent years (Canpolat, 2013). Heavy metals may enter aquatic systems from different natural and anthropogenic sources, including industrial wastes, domestic wastes and geological weathering of the earth crust (Mohamed and Osman, 2014).

2.2.1 Heavy metals in sediment

Sediment as a significant component of aquatic environment is not only the source of heavy metals accumulation from water bodies, but it is also a source of secondary pollution which has a possible impact on water quality (Varol and Sen, 2012).

Sediment is one of the critical sinks for heavy metals which are discharged into the aquatic environment. Therefore, sediment, where heavy metals tend to concentrate, is a good indicator of pollution in the aquatic body (Edokpayi*et al*., 2016).

In aquatic ecosystems, heavy metals accumulate in sediments, where they may reach concentrations greater than the ones available in the covering water (Emoyan*et al*., 2006). Due to the ecological significance of heavy metals in the aquatic ecosystem, sediments are considered to be more appropriate for investigation of the potential public health hazards (Pedro *et al*., 2014).

2.2.2 Heavy metals in water

Water is a necessary requirement for human and industrial development, and it is also the most delicate part of the environment. A constant monitoring of water quality is essential to establish the status of pollution in the lakes. Small amounts of heavy metals are always present in fresh waters from terrigenous sources resulting to geochemical recycling of heavy metals in these ecosystems (Laar*et al*., 2011). These small amounts of elements are influenced by such environmental factors as dissolution from sediment and anthropogenic pollutants (Zhao *et al*., 2014). Metals in minerals and rocks are normally harmless and can only become potentially toxic when they dissolve in water (Malhat, 2011).

2.2.3 Heavy Metals in Fish

Fish represent the top of consumers of heavy metals in aquatic ecosystem. They accumulate heavy metals from food, water and sediment (Abdel-Mohsien and Mahmoud, 2015). Fish accumulate these heavy metals in concentrations higher than the ones available in the water and sediments due to biomagnifications (Abdel-Mohsien and Mahmoud, 2015). The amount of heavy metals that enters the fish is dependent not only on the concentrations of these metals in the food and in the surroundings, but also on the detoxification rate (Ezejiofor*et al.,* 2013). In the aquatic ecosystem, metals are conveyed to the fish through food chain and finally from the fish to humans through fish consumption. Heavy metal accumulation in fish is influenced by such factors as age, physiological status, pH, and hardness of the water (Authman*et al*., 2015).

2.3 Heavy Metals and Human Health

The exposure of humans to some heavy metals has been associated with either beneficial or harmful effects on human life (Jan *et al*., 2015; Tchounwou*et al*., 2012). Heavy metals can affect vital cellular components such as structural proteins, enzymes and nucleic acids, and interfere with their normal functioning. Furthermore, although some heavy metals are needed for human's development, they (the metals) can still be hazardous at relatively high concentrations (Jaishankar*et al*., 2014). Considering their potential toxicological significance, levels of Hg, Cd and Pb in water and fish are worth investigating for safeguarding the public health.

2.3.1 Mercury

Mercury is a naturally occurring metal that is present in several forms. Metallic Hg is shiny, silver-white, and odourless liquid. Mercury has the lowest melting point (−39°C) of all the pure metals and is the only pure metal which is liquid at room temperature. Mercury has several physical and chemical advantages such as having low boiling point (357°C) and being easy to vaporize. Although Hg is a toxic metal, it is still an important material in many industrial products (Tangahu*et al*., 2011). Many artisanal gold miners use Hg to amalgamate gold and separate it from gangue minerals, because it is relatively inexpensive and readily available. Unfortunately, the inappropriate handling and use of Hg has created environmental and health concerns in artisanal mining throughout the world (Drace*et al*., 2012).

Mercury is number three in the ATSDR's (Agency for Toxic Substances and Disease Registry) top twenty list of most toxic and hazardous substances. Mercury is generated naturally in the environment from degassing of the earth's crust and from volcanic emissions. The most common natural forms of Hg found in the environment are metallic mercury, mercuric sulfide, mercuric chloride, and methyl mercury. Methyl mercury is of a specific concern because it can build up in certain fish at levels which can be greater than the levels in the surrounding water (Sarasiab*et al*., 2014). Thus, the bigger the fish in the food chain, the higher its trophic level and the higher its methyl mercury concentration. In this respect, big predatory fish like Nile perch are more likely to have higher levels of methyl mercury than the levels available in the surrounding water (Sarasiab*et al*., 2014).
Mercury and its compounds are cumulative toxins and can be hazardous to human health even in small quantities. The health effects of Hg to humans include adverse effects to the cardiovascular system, renal disorders and impaired neurological development in infants and children (Rice *et al*., 2014).

2.3.2 Cadmium

Cadmium is a metal with an oxidation state of +2. It is a soft white solid with the density of 8.64 gcm^{-3}, melting point of 320.9°C and boiling point of 765°C at 100

KPa. Cadmium is found to be number seven in the ATSDR's top twenty list of most toxic and hazardous substances. It is found in very low concentration in most rocks, and it is a by-product of the mining and smelting of lead and zinc. Geologic deposits of Cd can serve as a source of pollution in an aquatic compartment to the ground and surface waters when it is in contact with acidic water.

In larger doses, Cd can accumulate in the liver and kidneys, and can replace calcium in bones, leading to painful bone disorders and renal failure. Furthermore, targetorgans for Cd damage includeplacenta, lungs and the brain (Kim *et al*., 2016). In addition to its cumulative properties, Cd is also a highly toxic element that can disrupt many biological systems. A good example is endocrine disruption, commonly at doses that are much lower than most toxic metals (Amutha and Subramanian, 2013). The World Health Organisation (WHO) has established a daily tolerable intake level of 70 µg of Cd per day for the average of 70 kg man and 60 µg of Cd per day for the average of 60 kg woman.

2.3.3 Lead

Lead is a bluish or silvery-grey metal with a melting point of 327.5°C and a boiling point of 1740°C. Leadisobtainedfromitssulphidemineral galena,carbonatecerussite,andsulphateanglesite. Lead was placed in position two of the ATSDR's top twenty list of most toxic and hazardous substances. Itaccountsformostofthecasesofpaediatricheavy metalpoisoning. Most of the Pb in the environment is in the inorganic form and exists in a number of oxidized states (Wuana and Okieimen, 2011; Tangahu*et al*., 2011).

Notably, many of Pb health effects may occur without evident signs of toxicity. Health effects associated with exposure to inorganic Pb is mainly deficiency in cognitive function. Other health effects are neurotoxicity, developmental delays, hypertension, nephrotoxicity, muscle and joint pain and male reproductive impairment (Doke and Gohlke, 2014).

2.4 Transfer Factor (TF)

Transfer factor is the net accumulation of a metal in a tissue of interest that results from exposure to both biotic and abiotic sources (Abdel-Baki*et al*., 2011). Although fish can regulate metal concentration, they can only do so within certain limits beyond which bioaccumulation occurs (Noor and Zutshi, 2016). Having a good understanding of the transfer factor is important in foreseeing the relative contributions of abiotic media as a possible source of heavy metals accumulation in fish.

The presence of high levels of heavy metals in aquatic environment does not indicate a direct toxic risk to fish. This is only possible if there is a significant bioaccumulation of toxic metals to fish tissues (Authman*et al*., 2015). The transfer factor shows how many times a fish concentrates a metal above a certain environmental level. Heavy metals entering the aquatic ecosystem can be deposited in fish tissues through bioaccumulation and become toxic when reaches a considerably high level (Bat and Arici, 2016).

2.5 Risk Assessment of Heavy Toxicity Metals in Human

Risk assessment is a process of estimating the probability that a chemical substance will cause adverse effects to a given population. Under particular conditions of exposure, risk assessment provides the logical basis for public health decisions and actions aimed at reducing or eliminating the risk involved. Health risk assessments are used to determine if a particular chemical poses a significant risk to human health and, if so, under what circumstances. It is important to assess the daily intake of metals from fish and compare it with the Acceptable Daily Intake (ADI) values set by international organizations for health safety (Hajeb*et al*., 2009).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Site

The study was conducted in the Tanzanian water of Lake Victoria. The Lake Victoria is bordered by Tanzania, Kenya and Uganda, and covers the total area of 35,088 Km^2. The lake stretches for 412 Km from North to South between latitudes 0º30'N and 3º12'S, and 355 Km from West to East between longitudes 31º37'E and 34º53'E. It is situated at an elevation of 1,134 m above sea level, and has a volume of 2,760 Km^3, and an average depth of 40 m and a maximum depth of 80 m.

3.2 Study Design

A cross-sectional study was conducted to assess the levels of Hg, Cd and Pb in Lake Victoria. Specific study sites were the designated National sampling stations located in the bays, gulfs, islands and fish landing sites in Lake Victoria. The study sites were selected from three regions namely, Mwanza, Mara, and Kagera (Fig. 1).

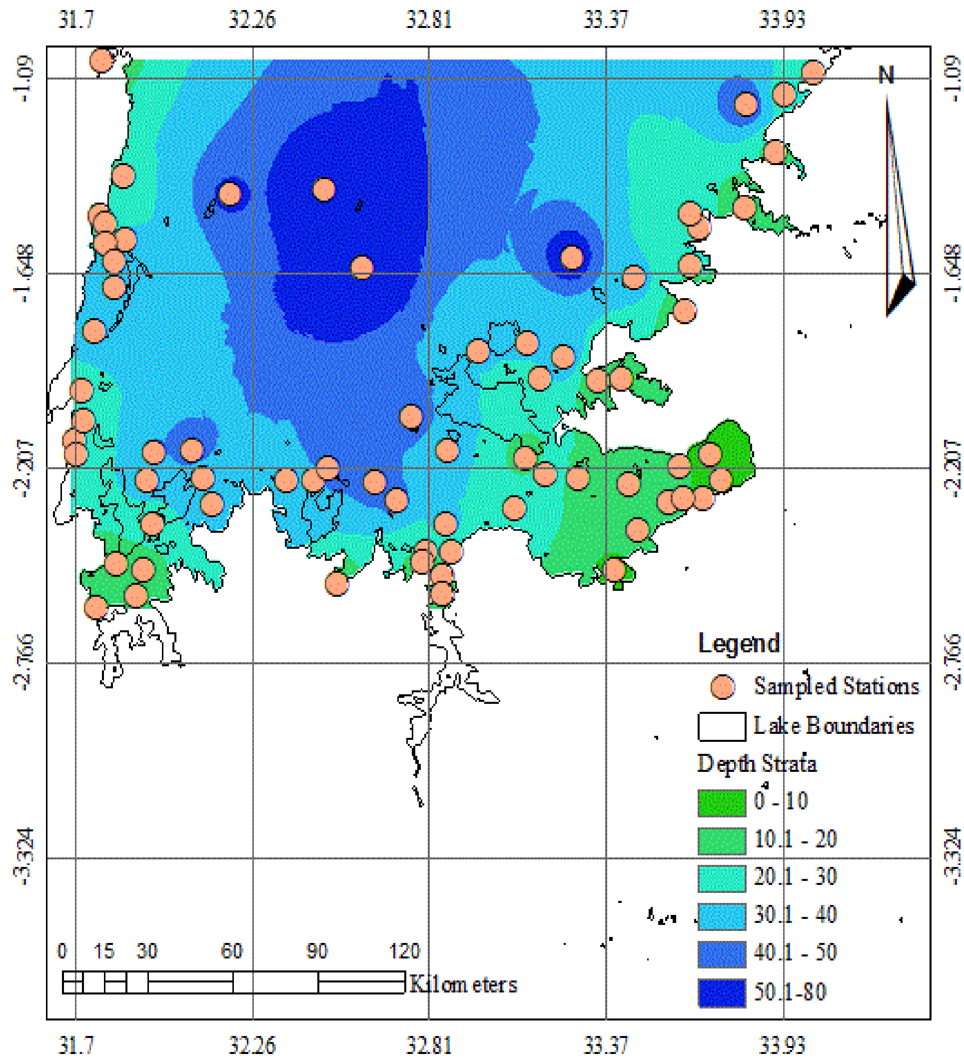

Figure 1: A mapshowingthe sampling stations in Lake Victoria, Tanzania

3.3 Sample Size

Sixty (60) designated National sampling stations were used tocollect samples for the analysis of Hg, Cd and Pb levels inLakeVictoria. Twenty (20) sampling stations in each region based on six strata were used (Fig. 1). At each sampling station, three different samples were collected and which included sediment, water and fish.

3.4 Collection of Samples

Fish samples were obtained from the gillnet traps and/or bottom trawl at each sampling station in Lake Victoria. The samples were stored in labelled plastic bags, temporally put in a cooler box before transferred to the laboratory for storage at – 20ºC prior digestion. Sedimentsampleswerecollectedin1.0litrewide mouthplasticbottles,whichwerepre-washed with10%nitricacid and deionisedwater.Beforesampling,thebottleswere rinsedthreetimeswithwaterfromthesamplingstation, and then the grab sampler was used to obtain the benthic sediment sample in each station. These samples were stored at – 20ºC prior digestion. Watersampleswerecollectedin1.0litreplasticbottles,whichwerepre-washed with10%nitricacid and deionisedwater. Beforesampling,thebottleswererinsedthreetimeswithwaterfromthesamplingstation.Th ebottleswereimmersedto about 20 cm belowthewatersurfacetoprevent them from contaminationwithheavymetalsfrom the air.All the watersamples were acidifiedwith2 ml concentrated HNO_3 while in the field and then transported to the laboratory for storage at 4ºC prior digestion.

3.4.1 Digestion of fish samples for heavy metals analysis

Fish samples from each sampling station were dissected for muscles. About 50 g of muscles were taken into crucibles and dried for 2 hours at 70ºC in the oven. Further, samples were burned by Muffle furnace at 450 - 500ºC for four hours. One gram of samples ash was transferred into the beaker. Six millilitre of concentrated HNO_3 and 2 ml of concentrated HCl were added into the beaker. The sample was warmed into water bath at 70ºC for 1 hour. After cooling, the solution was filtered through

Whatman filter paper (0.45µm). The solution was then completed to 25 ml with deionised water then labelled and stored in a plastic container at 4ºC prior analysis. A Flame Atomic Absorption Spectrometer (AAS) was used to determine concentration of Hg, Cd and Pb from the solution. The results were in µg/kg dry weight of a fish sample (Seady, 2001).

3.4.2 Digestion of sediment sample for cadmium and lead analysis

Water was decanted from sediment samples, which were air dried in an air conditioned room set at 25ºC and 65% relative humidity. Sediment samples were further dried in an oven at 45ºC for 48 hours, and then milled by using mortar and pestle. About 1 g of fine dry sediment powder was weighed into a graduated test tube. The sediment sample was digested with 15 ml of 5:1:1 mixture of HNO_3, H_2SO_4 and $HClO_4$ in the water bath maintained at 80ºC until a transparent solution was obtained. After cooling, the solution was filtered through a Whatman filter paper (0.45 µm). The solution was then completed to 100 ml with deionised water, labelled and stored in a plastic container at 4ºC prior to the analysis. Flame Atomic Absorption Spectrometer (FAAS) was used to determine the concentration of Cd and Pb from the solution. The results were in µg/kg dry weight of a sediment sample (APHA, 2005).

3.4.3 Digestion of sediment sample for mercury analysis

Water was decanted from sediment samples, which were air dried in an air conditioned room set at 25ºC and 65% relative humidity. The sediment samples were further dried in an oven at 45ºC for 48 hours, and then milled by using mortar and pestle. About 0.5 g of fine dry sediment powder was weighed into a graduated test tube. The sample was digested with 2 ml aqua regia (3:1 parts of HCl to HNO_3) in the water bath maintained at 70ºC. After cooling, the solution was filtered through a Whatman filter paper (0.45 µm). The solution was then completed to 20 ml with deionised water. The digested sample was allowed to settle for overnight, and then labelled and stored in a plastic container at 4ºC prior to the analysis. Cold VapourAtomic Absorption Spectrometer (CVAAS) was used to determine the concentration of Hg from the solution. The results were in µg/kg of a sediment sample (Mdegela*et al*., 2009).

3.4.4 Digestion of water sample for cadmium and lead analysis

One litre of water sample was filtered by using Whatman filter paper (0.45 µm). About 250 ml of the filtered water was transferred to a 600 ml beaker and then acidified with 5 ml of concentrated HNO_3. The beaker was covered with a watch glass. The solution was evaporated on a hot plate without boiling at 85ºC until the volume was reduced to about 25 ml. The sample was allowed to cool and filtered through a Whatman filter paper (0.45 µm) before being transferred to 50 ml volumetric flask. The solution was diluted to meniscus with deionised water. The solution was labelled and stored in a plastic container at 4ºC prior to the analysis. Graphite Furnace Atomic Absorption Spectrometer (GFAAS) was used to determine the concentration of Cd and Pb from the solution. The results were in µg/L of water sample (APHA, 2005).

3.4.5 Digestion of water sample for total mercury analysis

For the total mercury analysis in water, 50 ml of a sample was mixed with 10 ml 1:1 H_2SO_4 to 2% $KMnO_4$ solution. The mixture was allowed to stay for 15 minutes, before adding 1 ml of 5% K_2SO_4. The mixture was heated in the water bath at 95ºC for one hour. After cooling, 3% hydroxylamine solution was added, until the permanganate turned colourless. Then, 10 ml of digested sample was acidified using 10 ml 6 M HCl. The solution was labelled and stored in a plastic container at 4ºC prior to the analysis. Cold VapourAtomic Absorption Spectrometer (CVAAS) was used to determine the concentration of Hg from the solution. The results were in µg/L of water sample (Mdegela*et al*., 2009).

3.5 The Transfer Factors (TFs)

The transfer factor of Hg, Cd and Pb from water and sediment for Nile perch were calculated using the formula below (Ibrahim *et al*., 2013).

Accumulation Factor = Level of metal in fish muscle / Level of metal in abiotic media

Where;

Theabioticmedia representsthewater andsediment.

If theTFbecomesgreaterthan1.0,then the bioaccumulationof Hg, Cd and Pb occurs in Nile perch. The greater accumulation factor for any abiotic media indicates that the metals accumulated to fish tissues from that source is more than is the case from other sources (Rashed, 2001).

3.6 Health Risk Assessment for Fish Consumption

The human health risk assessment associated with fish consumption was characterized using Hazard Quotient (HQ) and Total Hazard Index (THI) developed by USEPA following the model below.

$$D = (C \times IR \times AF \times EF \times CF) / BW$$

Where;

D = Exposure dose (mg/kg/day)

C = Contaminant concentration (mg/kg)

IR = Intake rate of contaminated fish (mg/day)

AF = Bioavailability factor (unit less)

EF = Exposure factor (unit less)

CF = Conversion factor (10¯6 kg/mg)

BW = Body weight (kg)

In this study, the IR for an adult was calculated from the annual per capita consumption of fish to be 150000 mg/day, and for the child to be one third of the adult consumption, which is 50000 mg/day. The standard default values for body weights of adult and child are 70 kg and 16 kg, respectively (USEPA). Bioavailability Factor (AF) represents the percentage of the total amount of the heavy metals ingested. The actual amount that enters the blood stream and which is available to possibly harm human beings is assumed to be 1 (100%). The exposure factor is taken as 1; as the fish intake rate is a daily average.

Hazard Quotient (HQ) is the ratio between exposure dose (D) and oral reference dose (RfD). The Total Hazard Index (THI) is the summation of all calculated HQ, and is normally described by the equations below.

$$HQ = D / RfD$$

$$THI = \sum HQ = HQ_{Hg} + HQ_{Cd} + HQ_{Pb}$$

Again, RfD values for the studied heavy metals were taken from USEPA table developed for ingestion as estimates of daily exposures to the substance (USEPA). These are likely to be without a visible risk of deleterious effects to the general population during a lifetime of exposure. If HQ or THI is below one, no health risk may occur as a result of ingestion of the fish. The greater the value of HQ and THI above 1, the greater is the level of risk associated with the fish consumption. Hence, THI ranging from 0.0 to 1.0 means no hazard. The THI ranging from 1.1 to 10 means moderate hazard while THI greater than 10 means that there is a risk.

3.7 Data Analysis

Data were recorded and stored using MS Excel. The stored data were analysed using MS Excel spread sheet 2010. Descriptive statistics were used to assess the spread of the data. The data were reported as Mean ± SD, while one way Analysis of Variance (ANOVA) was used to compare the mean values of heavy metals based on sites. The differences in the mean values obtained were considered significant if the calculated P-values were < 0.05. Correlation analysis was done to test the association between matrices and heavy metals across the sampling sites.

CHAPTER FOUR

4.0 RESULTS

4.1 Heavy Metal Concentrations in Sediment

4.1.1 Mercury (Hg) concentration

The mean Hg concentrations at the three sampling sites showed uncertain variations (Fig. 2). The mean Hg concentrations recorded in this study were 1.53 ± 0.58, 1.09 ± 0.59 and 0.74 ± 0.68 µg/kg for Mwanza, Kagera, and Mara respectively. One way ANOVArevealed significant differences across the sampling sites (p = 0.0006). The variations in Hg concentrations in this study are indicated in Fig. 2. The highest level of Hg concentrations was recorded at Mwanza (2.11 µg/kg) and the lowest level was recorded at Mara (0.05 µg/kg).

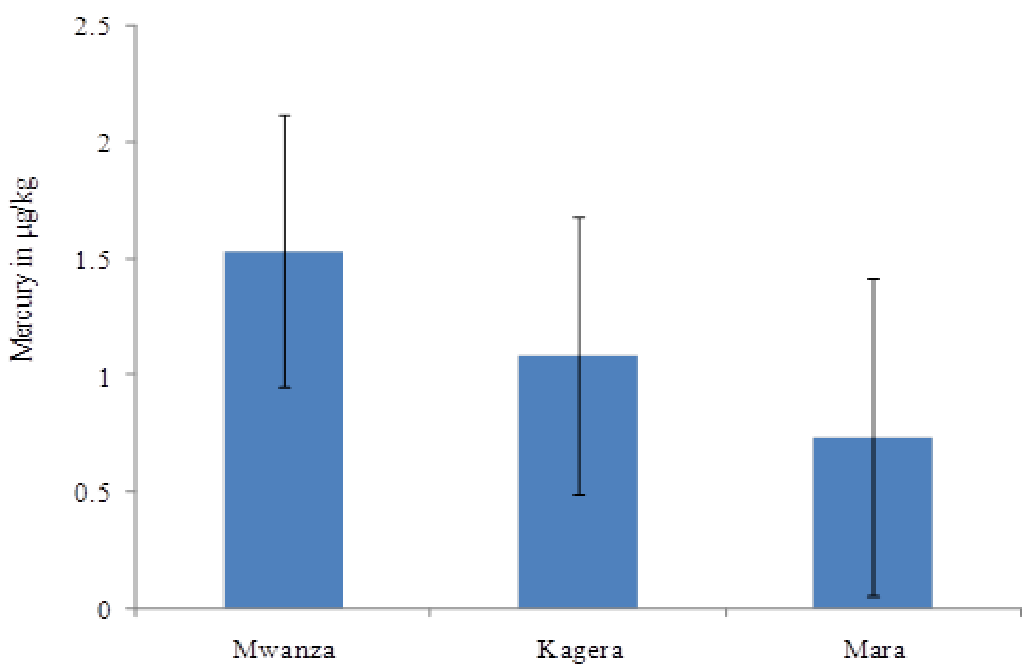

Figure 2: Variations in mercury levels in sediment of Lake Victoria

4.1.2 Cadmium (Cd) concentration

The mean concentration levels for Cd recorded in sediment during the study showed no variations (Fig. 3). The mean Cd concentrations recorded in this study were 28.91 ± 10.15, 26.82 ± 10.76 and 26.89 ± 8.96 µg/kg for Mwanza, Kagera, and Mara respectively. One way ANOVA revealed no significant difference in Cd levels across the sampling sites ($p = 0.746$). The variations in Cd concentrations in this study are indicated in Fig. 3. The highest level of Cd concentrations were recorded at Mwanza (39.07 µg/kg) and the lowest level was at Kagera (16.06 µg/kg).

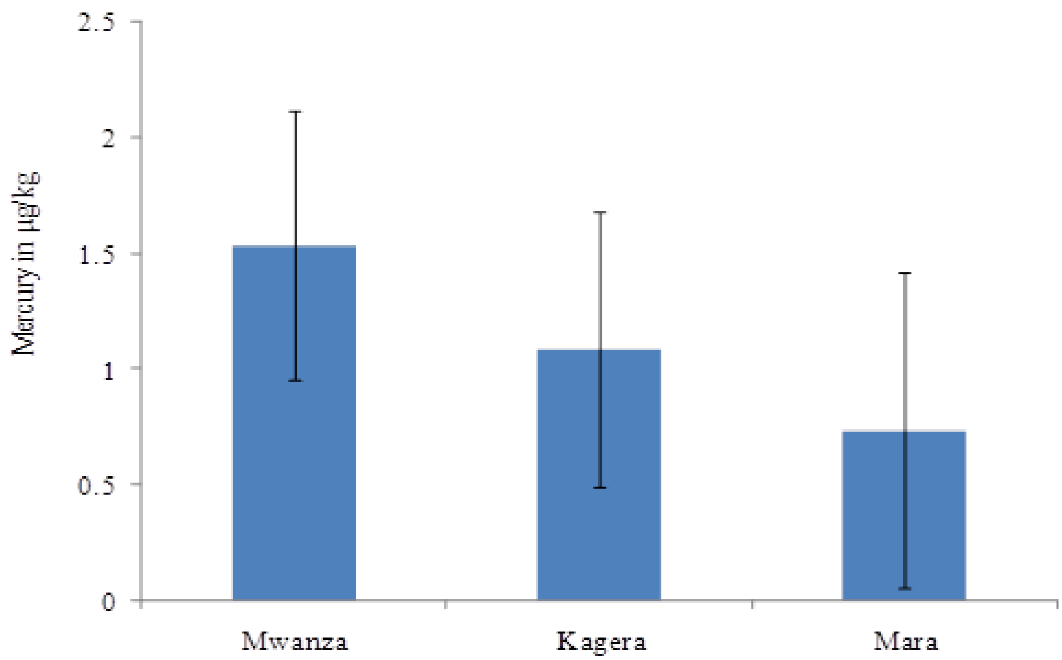

Figure 3: Variations in cadmium levels in sediment of Lake Victoria

4.1.3 Lead (Pb) concentration

The mean Pb concentration levels recorded in sediment during the study showed no significant variations (Fig. 4). The mean concentrations recorded in this study were 829.83 ± 250.05, 861.11 ± 225.77 and 749.56 ± 229.30 µg/kg of Pb in sediments for

Mwanza, Kagera, and Mara respectively. One way ANOVA revealed no significant difference across sampling sites (p = 0.348). The variations in Pb concentrations in this study are indicated in Fig. 4. The highest level of Pb concentrations was recorded at Kagera (1086.88 µg/kg) and the lowest level was recorded at Mara (520.25 µg/kg).

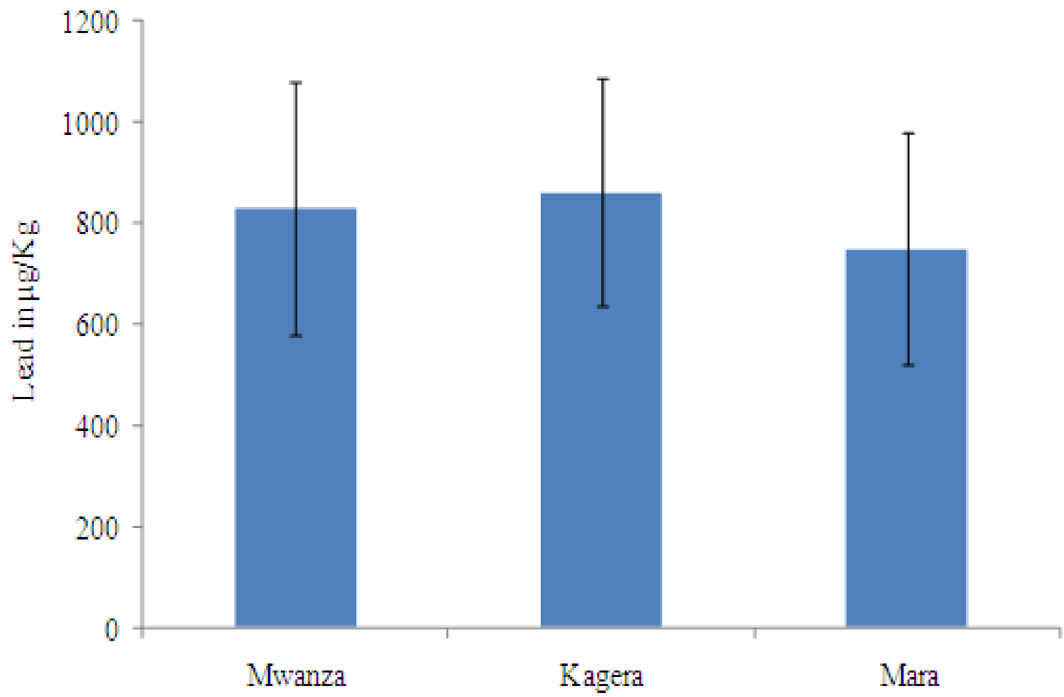

Figure 4: Variations in lead levels in sediment of Lake Victoria

4.2 Heavy Metal Concentrations in Surface Water

4.2.1 Mercury (Hg) concentration

The mean concentrations of Hg in surface water from all sampling sites varied. In Mwanza, 20 samples were analyzed, but only 13 samples were positively detected and whose concentrations ranged from 0.0004 to 0.161 µg/L; the recorded Hg average concentration was 0.029 µg/L of water. In Kagera, 20 samples of surface water were analyzed, but only 3 samples were positively detected, and whose concentrations ranged from 0.0009 to 0.0157 µg/L, with the mean concentration of 0.009 µg/L of water. In Mara, 20 samples of surface water were analyzed, but only one sample was positively detected, and whose Hg concentration was 0.006 µg/L of water.

4.2.2 Cadmium (Cd) concentration

The mean concentration levels for Cd recorded in the water during the study showed significant variations (Fig. 5). The mean Cd concentrations recorded in this study were 16.70 ± 14.36, 10.94 ± 4.48 and 8.95 ± 1.99 µg/L of water for Mwanza, Kagera and Mara respectively. One way ANOVA revealed a significant difference in Cd levels across the sampling sites ($p = 0.023$). The variations in Cd concentrations in this study are indicated in Fig. 5. The highest level of Cd concentrations was recorded at Mwanza (31.06 µg/L) and the lowest level was also at Mwanza (2.34 µg/L).

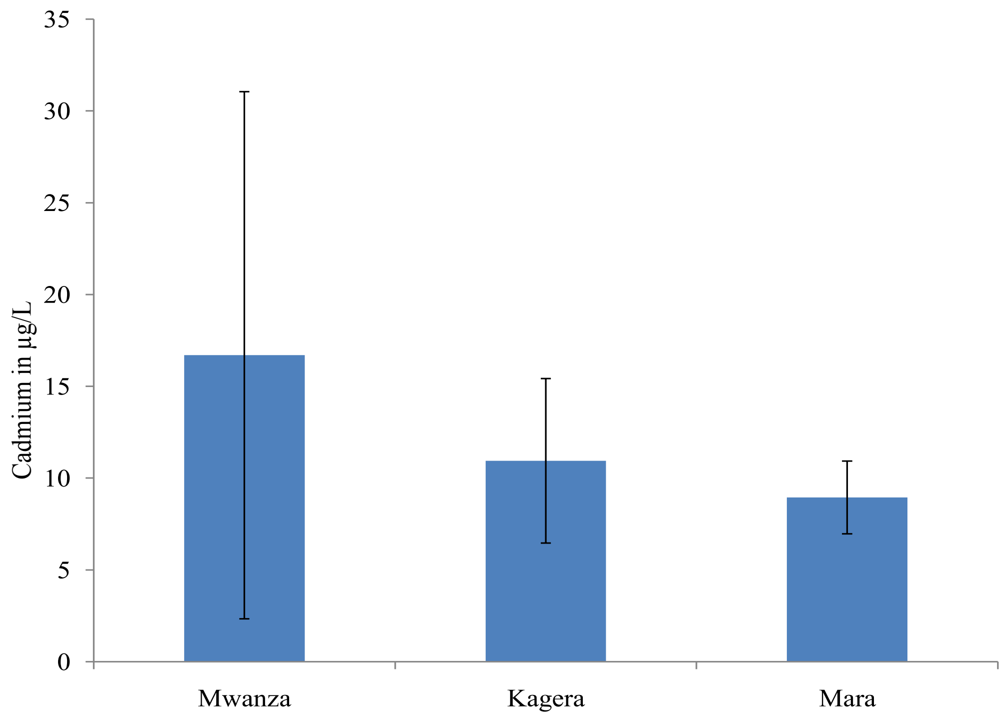

Figure 5: Variations in cadmium levels in water of Lake Victoria

4.2.3 Lead (Pb) concentration

The mean concentrations of Pb in the surface water from all the sampling sites varied. One way ANOVA revealed a significant difference ($p = 0.0014$) in Pb levels across the sampling sites. In Mwanza, 20 samples were analyzed and their concentrations ranged from 0.13 to 99.54 µg/L of water. The average concentration of Pb was 12.18 µg/L of water. In Kagera, 20 samples were analyzed and their concentrations ranged from 11.25 to 59.75 µg/L of water. The average concentration of Pb was 30.48 µg/L of water. In Mara, 20 samples were analyzed and their concentrations ranged from 0.62 to 71.36 µg/L. The average concentration of Pb was 9.47 µg/L of water.

4.3 Heavy Metal Concentrations in Nile perch muscles

4.3.1 Mercury (Hg) concentration

The mean Hg concentrations at the three sampling sites showed unpredictable variations (Fig. 6). The mean Hg concentrations recorded in this study were 0.23 ± 0.15, 0.08 ± 0.04 and 0.09 ± 0.03 µg/kg for Mwanza, Kagera and Mara respectively. One way ANOVAshowed significant differences across the sampling sites (p = 6.18 E $^{-06}$). The variations in Hg concentrations in this study are indicated in Fig. 6. The highest level of Hg concentrations was recorded at Mwanza (0.38 µg/kg) and the lowest level was recorded at Kagera (0.04 µg/kg).

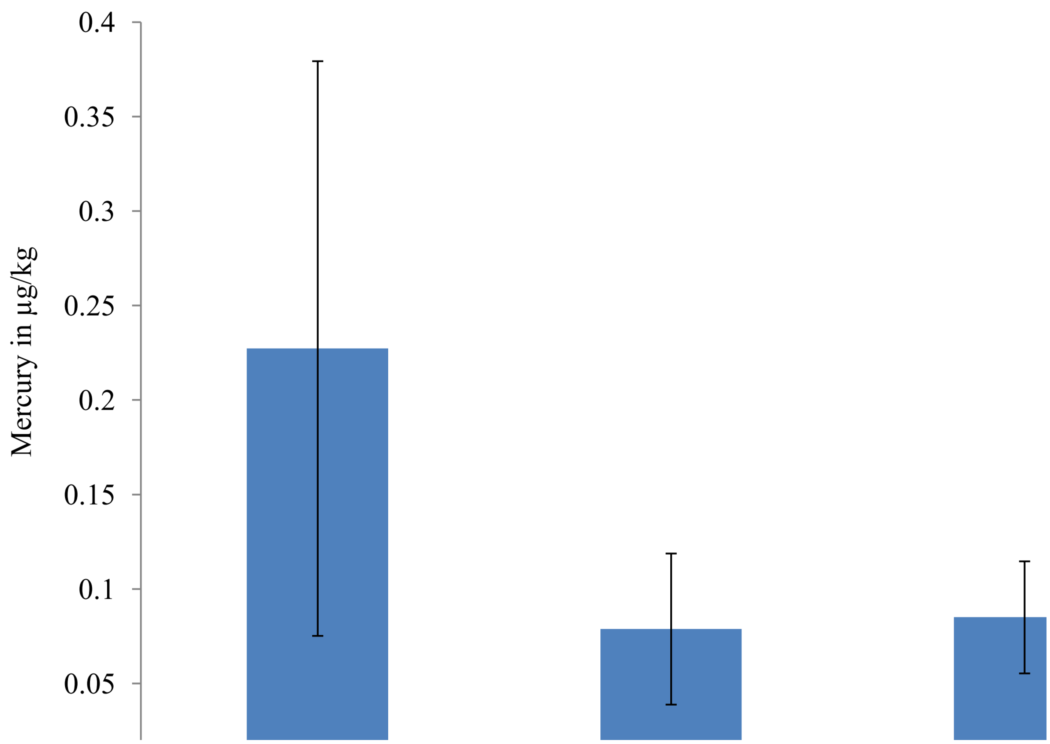

Figure 6: Variations in mercury levels in Nile perch muscles

4.3.2 Cadmium (Cd) concentration

The mean Cd concentrations recorded in this study were 53.09 ± 16.43, 55 ± 19.14 and 50.05 ± 29.12 µg/kg fish muscles for Mwanza, Kagera and Mara respectively. One way ANOVArevealed no significant differences across the sampling sites (p = 0.789). The variations in Cd concentrations in this study are indicated in Fig. 7. The highest level of Cd concentrations was recorded at Mara (79.17 µg/kg) and the lowest level was also recorded at Mara (20.93 µg/kg).

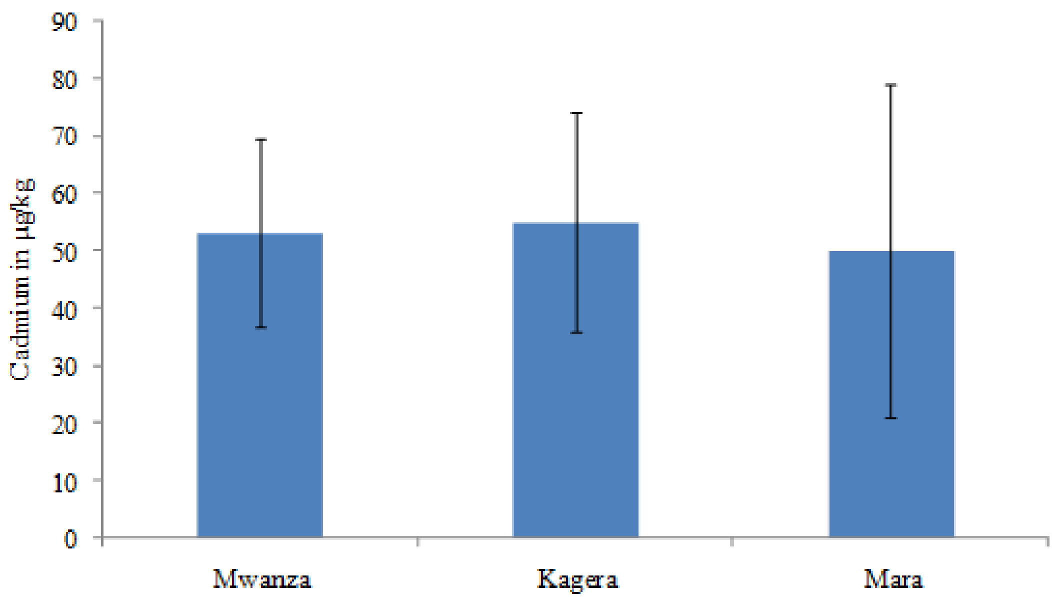

Figure 7: Variations in cadmium levels in Nile perch muscles

4.3.3 Lead (Pb) concentration

The mean Pb concentrations recorded in this study were 375.39 ± 151.25, 406.44 ± 121.53 and 277.16 ± 110.84 µg/kg fish muscles for Mwanza, Kagera and Mara respectively. One way ANOVArevealed significant differences across the sampling sites (p= 0.008). The variations in Pb concentrations in this study are indicated in

Fig. 8. The highest level of Pb concentrations was recorded at Kagera (527.97 µg/kg) and the lowest level was recorded at Mara (166.33 µg/kg).

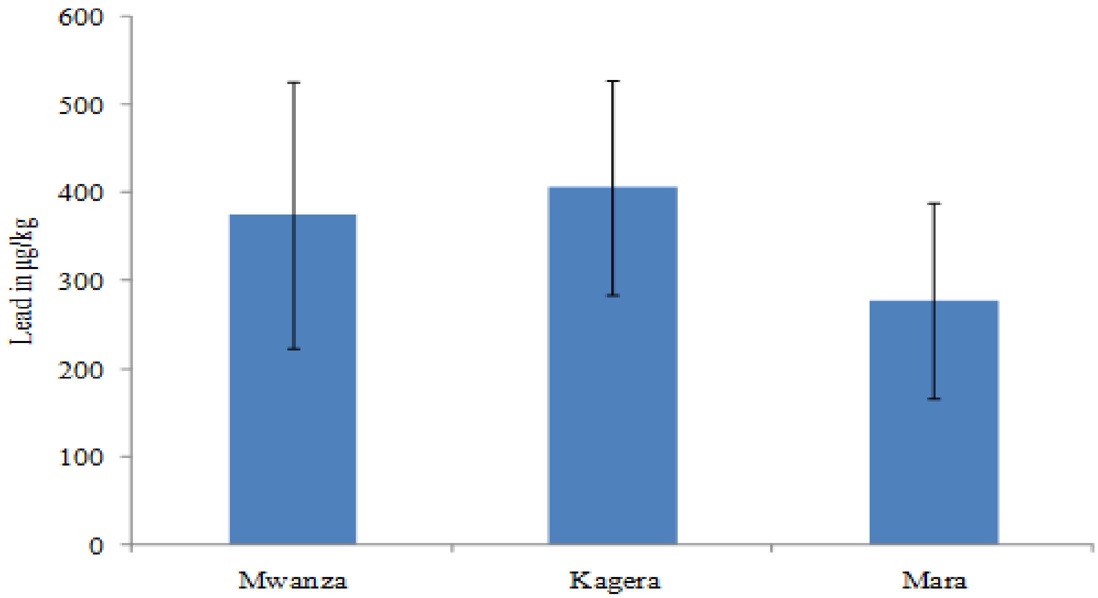

Figure 8: Variations in lead concentrations in Nile perch fish muscles

4.4 Relationships of Heavy Metal Levels in Water, Sediment and Fish

Pearson correlation coefficients were calculated to obtain the associations between heavy metal variables in water, sediments, and fish (Tables 1 and 2). The concentration of Hg in water showed a positively significant correlation with Hg levels in sediment (r = 0.458) and Hg levels in fish (r = 0.330). The Cd levels in water had a significant correlation with Hg levels in water (r =0.332). The concentration of Pb in fish showed a positively significant correlation with Cd levels in fish (r = 0.311). The concentration of Cd in sediment showed a positive significant correlation with Pb levels in sediment (r = 0.703).

Table 1:Pearsoncorrelationmatrixforheavymetalsinsediment, Nile perch fish musclesandsurfacewater,*Correlationissignificantatp<0.05 level

	Hg sediment	**Cd sediment**	**Pb sediment**	**Hg fish muscles**	**Cd fish muscles**	**Pb fish muscles**	**Hg water**	**Cd water**	**Pb water**
Hg sediment	1								
Cd sediment	-0.069	1							
Pb sediment	-0.113	**0.703***	1						
Hg fish muscles	0.117	0.176	0.056	1					
Cd fish muscles	0.012	-0.108	0.013	-0.114	1				
Pb fish muscles	0.233	-0.112	0.016	-0.107	**0.311***	1			
Hg water	**0.458***	0.045	-0.013	**0.330***	0.134	0.075	1		
Cd water	0.268	0.092	0.039	0.179	0.017	0.133	**0.332***	1	
Pb water	-0.052	-0.215	-0.063	-0.247	0.020	0.182	-0.224	0.050	1

Table 2: Correlation matrix for heavy metal levels in Nile perch fish muscles against surface water and sediment matrices. *Correlation is significant at p<0.05 level

	Hg in sediment	**Cd in sediment**	**Pb in sediment**	**Hg in water**	**Cd in water**	**Pb in water**
Hg in fish muscles	0.117	0.176	0.056	**0.330***	0.179	- 0.247
Cd in fish muscles	0.012	- 0.108	0.013	0.134	0.017	0.020
Pb in fish muscles	0.233	- 0.112	0.016	0.075	0.133	0.182

4.5 Transfer Factor (TF)

The transfer factors (TFs) of Hg, Cd and Pb in the Nile perch from water and sediment are presented in Table 3. The TF of Hg from water to the Nile perch was 5.750 while from sediment was 0.121. The TF of Cd from water to the Nile perch was 4.215 while that from sediment was 1.901. The TF of Pb from water to the Nile perch was 21.169 while that from sediment was 0.432. The trends of TF for heavy metals from water to Nile perch ranked in the following order Pb>Hg>Cd.

Table 3: Transferfactor of heavymetalsinNile perch muscles from Lake Victoria

Ecosystem Component	Hg	Cd	Pb
Water	5.750	4.215	21.169
Sediment	0.121	1.901	0.432

4.6 Health Risk Assessment for Fish Consumption

The daily exposure (D) of Hg in the studied Nile perch was 4.313×10^{-7} mg/day for a child of 16 years old and 2.957×10^{-7} mg/day for an adult of 70 years old. For a child, daily exposures of Cd and Pb from Nile perch consumption were 1.644×10^{-4} and 1.104×10^{-3} mg/day respectively. For an adult of the average weight of 70 Kg, the daily exposures of Cd and Pb from Nile perch consumption were 1.128×10^{-4} and 7.750×10^{-4} mg per day respectively. Furthermore, the hazard quotients (HQ) of the Hg, Cd and Pb from Nile perch were 2.157×10^{-4}, 0.113 and 0.164 respectively. But also, the total hazard indices (THI) of the Hg, Cd and Pb ingestion in Nile perch muscles were 0.440 and 0.302 for a child and an adult respectively as summarized in Table 4.

Table 4:TotalHazard Indices (THI) for a child and an adult

Exposure	**Hg**	**Cd**	**Pb**	**THI**
Child	4.313×10^{-7}	1.644×10^{-4}	1.104×10^{-3}	
HQ child	2.157×10^{-4}	0.164	0.276	0.440
Adult	2.957×10^{-7}	1.128×10^{-4}	7.570×10^{-4}	
HQ adult	1.479×10^{-4}	0.113	0.189	0.302

CHAPTER FIVE

5.0 DISCUSSION

The present study detected the heavy metal contamination in the study area. However, the study showed variations in the concentrations of heavy metals between the elements, sampling stations and sampling sites. Mercury pollution of Lake Victoria sediment is of great interest due to its economic and domestic implication in East African region. The concentrations of Hg were ranged from 0.05 to 2.11 µg/kgin the sediment (Fig. 2). There was a significant difference in the levels of Hg reported across the sampling stations. The highest level of Hg concentration was recorded in Mwanza. AnthropogenicHgsourceshaveincreasedprobably due to the escalation of agricultural and developmental activities in the lakeregion(Campbell*etal*.,2003a). The lowest level of Hg concentration was recorded in Mara. The lowlevelsofHgfoundinthisstudycouldhave been brought aboutby the dilutionresulting fromtheinfluenceofrainfallandriversdrainingintothe lake. The sedimentation couldalsoaccountforthelowlevels of mercury observed in different sampling stations in the lake. Although the levels of Hg in the sediment were below the recommended limits, the sediment is an important abioticenvironmentalmonitorfor Hgcontamination.

The concentrations of Cd ranged from 16.06 to 39.07 µg/kg in the sediment (Fig. 3). The current study showed no significant differences in the levels of Cd across the sampling stations. The Cadmium levels from the sampling stations were found to be lower than 4900 µg/kg recommended limit for sediment set by WHO (Malami*et al*., 2014). Thus, the levels of Cd in the sediment from Lake Victoria did not pose immediate health hazard to Nile perch consumers. Comparable concentrations of Cd in sediment found in the current study have been recorded in a number of other studies in Lake Victoria. Cadmium concentration of 0.0019 µg/kg in the sediment from the Tanzanian water has been reported by Machiwa (2003). Also, Cd concentration of 3.3 ± 0.5 mg/kg in the sediment in the Kenyan water has also been reported by Muinde*et al*. (2013). The study findings indicate that Cd accumulates in the sediment, and that it is toxic even at low levels.

The concentrations of Pb ranged from 212 to 1188 µg/kg in the sediment (Fig. 4). There was no significant difference in the levels of Pb across the sampling stations. Lead levels from the sampling stations were found to be lower than 35800 µg/kg, which are the recommended limits, in the sediment set by WHO (Malami*et al*., 2014). This means that pollution was low and did not pose a threat to either the ecosystem or to humans through food chain. Comparable concentrations of Pb in the sediment with the current study have been recorded in other previous studies in Lake Victoria. The concentrations which ranged from 13.6 to 122.7 µg/kg in the sediment were recorded in the Kenyan waters by Mwamburi and Oloo (1996). Again, the concentrations which ranged from 31.97 to 109.9 mg/kg in the sediment were also recorded in the Kenyan waters by Mutuku*et al*. (2014).

In Tanzania and other developing countries, industrial, agricultural, mining and domestic wastes are dumped extensively into water bodies. These wastes have been confirmed to contain toxic and hazardous substances including heavy metals. Relatively low concentrations of Hg were found in the surface water of Lake Victoria. The resultsof thecurrentstudyshowed that Hgconcentrationsranged from

0.0004 to 0.161 µg/L in water. These results are comparable to those in the earlier studies which were conducted elsewhere. For instance, a study conducted by Campbell*etal*. (2003b) showedthattheHgconcentrations in waterrangedfrom, 0.7to200ng/L, although the Hg concentrationswereconsistently elevatednearthe citiesof JinjaandKisumu.This is because the untreatedsewageeffluents arecommonly dischargedinthisshallow water near the shores(Campbell *et al*., 2003a).

The results of the current study showed that the maximum value of Cd concentration was 31.06 µg/L in water whereas the minimum value was 2.34 µg/L in water (Fig. 5). Cadmium mean concentrations recorded in 29 sampling stations out of 60 sampling stations were higher than 10 µg/L in water, which is the recommended limit set by WHO (Nazir*et al*., 2015). These high levels of Cd in water could be attributed to the discharge of untreated sewage, industrial effluent or domestic waste disposal to the lake. Other sources of high levels of Cd in water could be attributed to agricultural discharges where phosphate fertilizers are used, possibly by leaching (Meshram*et al*., 2014). The concentration of Cd found in this study is considered low when compared to previous studies, for example 72.3 µg /L in water has been recorded in Kenyan water (Okoth*et al.,* 2010).

The concentrations of Pb ranged from 0.62 to 99.54 µg/L in water. Lead concentration values in four sampling stations were found to be higher than 50 µg/L in water, which is the recommended limit of Pb in water set by WHO (Nazir*et al*., 2015). A significant difference was observed across the sampling stations, with Pb concentration of 99.54 µg/L in water recorded in Mwanza. The high levels in this sampling station could be attributed to the discharge of untreated industrial, agricultural and urban effluents to the lake. It was reported that Pb concentration in natural water increases mainly through anthropogenic activities (Krishna *et al*., 2014). Comparable concentrations of Pb in water have been recorded by a number of studies conducted in the Lake. The concentrations, which ranged from 1.0 to 7.0 µg/L in water, have been recorded in the Kenyan water by Mwamburi and Oloo (1996). Another study comparable to the current one in Lake Victoria in Kenya recorded the mean Pb concentration of 64.9 µg/L in water (Okoth*et al*., 2010).

Fish are an excellent source of omega-3-fatty acids, which may protect humans against coronary heart diseases and strokes, and are also considered to aid the neurological functioning also in humans (Harris *et al*., 2008). Furthermore, fish have been used as an indicator of water quality, because the fish are excellent biological markers of metals in water (Rashed, 2001).

The assessmentofenvironmental andhumanexposuretoHghasrevealedlowlevelsin Nile perch muscle. And the concentrationsrangedfrom 0.03 to 0.38 µg/kg Nile perch muscle (Fig. 6). The Hg concentrations in this study were below the recommended limit of 5 µg/100 g of a fish set by World Health Organization (WHO, 2003). The low Hg concentrations in Nile perch muscles reported in this study suggest that the aquatic system have not been polluted by Hgcontamination to alarming level.Based on this study, the results agree with the results in earlier studies suggestingthatmost of the fishspeciesinLakeVictoriaaresafetoeat (Nnamuyomba*et al*., 2015).Thisis goodnewsforfish exporters,whomustmeetinternational acceptablestandards of Hglevels.

The mean levels of Cd recorded for all the sampling stations ranged from 20.93 to 79.17 µg/kg of Nile perch muscle (Fig. 7). All the sampling stations recorded Cd mean levels that were below the recommended limit of 2000 µg/kg in fish. This implies that the Cd mean levels recorded do not have immediate threat to consumers (WHO, 2003). However, due to bioaccumulation, the concentrations are possible to reach toxic levels and these call for constant assessment. Cadmium concentration that is not different from the one in the current study has been reported by Francis (2003). The study recorded Cd mean levels at the range of from 2 to 30 µg/kg of Nile perch muscle from Kenyan water. This level also did not exceed the WHO maximum permissible limit of 2000 µg/kgfor fish and fish products.

The concentration of Pb ranged from 166.33 to 527.97 µg/kg in the Nile perch muscle (Fig. 8). Although the levels were elevated, they were lower than the recommended limit of 2000 µg/kg for Pb in fish and fish products (WHO, 2003). These levels therefore did not constitute any immediate health hazards to both aquatic fauna and humans who consume the fish from the study area. Therefore, the elevated levels of Pb recorded in the current study could probably be attributed to agricultural and domestic wastes discharged into the rivers and later to the lake. The concentration of Pb found in this study is considered higher when compared with the concentrations reported in earlier studies carried out in Kisumu. The concentrations which were recorded at Kisumu ranged from of 0.001 to 0.003 µg/kg of Nile perch muscle (Makokha*et al*., 2008). This could be due to geographical isolation of the sampling locations.

Pearson correlation analysis of metals in the Nile perch muscles, sediment, and water was performed to assess possible similar sources of metals. The relationship between the concentrations of Hg, Cd and Pb in the Nile perch muscles with the concentrations of those metals in water and sediment were investigated. The correlation between different metals may have resulted from similar accumulation behaviour of the metals in the fish species and their interactions (Ghani, 2015).

The concentrations of Hg in sediments were correlated with Hg in water but not Hg in the Nile perch muscles. Conversely, Cd concentrations in sediment showed a positive correlation with Pb concentrations in sediment. Again, the Cd concentrations in sediment neither correlated with Cd concentrations in water nor in Nile perch muscles. The Hg concentrations in the Nile perch muscles directly correlated with Hg in water. Also, Cd concentrations in Nile perch muscles correlated with Pb in the Nile perch muscles. Moreover, the Hg concentrations in water correlated with Cd in water. The considerable correlations among the heavy metals may be the evidence of a common source of occurrence. This could be an indication of similar biogeochemical pathways for subsequent accumulation in the Nile perch muscles (Nzeve, 2015).

The results showed that the TF of Hg, Cd and Pb in the Nile perch muscles from water were greater than one. This is an indication of close correlation between heavy metals concentrations in water and in Nile perch. Therefore, it can be inferred that the major source of Hg, Cd and Pb contamination in Nile perch is the lake water. Comparable TFs with the current study have been recorded from a number of studies done elsewhere. For instance, Rashed (2001) who determined the TFs for Cr, Cu, Zn and Mn in fish from Lake Nasser, found only TFs from the water were more than one. Similarly, Abdel-Baki*et al*. (2011) observed comparable findings when determining the TFs of heavy metals from water and sediment in tilapia fish in Saudi Arabia. This has proven that fish accumulates metals from water by diffusion through the skin, gills as well as oral consumption of the water (Aderinola*et al*., 2012).

Hazard Quotient (HQ) based risk assessment method provides an indication of the risk level resulting from the exposure to toxic metals. The hazard quotients of the Hg, Cd and Pb were all less than one ($HQ < 1$). This signifies that there is no health hazard in consuming Nile perch from Lake Victoria, in Tanzania. Based on the findings of this study, it is concluded that Nile perch from Lake Victoria in Tanzania are safe for human consumption.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The present study confirms that Hg, Cd and Pb concentrations in Nile perch muscle were below the permissible limits set by WHO. Thus, the consumption of Nile perch may not pose any threat to human health. However, the comparative study of water and biotic components in the ecosystem showed variations in their concentrations across locations. This might be due to geographical isolation, and hence variations in anthropogenic influence. Therefore, periodic assessments of heavy metals in Nile perch are important in order to prevent excessive build up in the food chain.

6.2 Recommendations

Based on the findings in the current study, itisrecommendedthataperiodicmonitoringofheavymetalshouldbecarried out sincetherearevariationsintheir levels.Itis alsorecommendedthat, people should not be allowed to dispose their domestic and industrial wastes in the Lake Victoria waters. Research should be carried out to assess the accumulation of heavy metals in other fish species in Lake Victoria. Furthermore, agricultural and mining discharges should not be channelled to the Lake Victoria waters, and for this reason there should be public awareness programs. Regulators and decision makers should be vigilant and constantly work to improve the quality of Lake Victoria water.

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