NUTRITIONAL CONTENT OF FORMULATED FEEDS AND IN-SITU BASED FEEDS OF AQUACULTURE FISH IN THE WINAM GULF OF LAKE VICTORIA, KENYA

BY

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DECLARATION

Declaration by the Student

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This thesis has been submitted with our approval as University supervisors.

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DEDICATION

I dedicate this research project report to my beloved and amazing parents Mr.Akite Jerim Otieno and Mrs.Monicah Adhiambo, and my siblings Joseph Akite, Winnie Achieng, Richard Omondi and Charles Onyango for their relentless efforts in supporting me morally and financially. I say may God bless them and fulfill their hearts desire.

ABSTRACT

The uses of feeds are critical to success of aquaculture farming on Lake Victoria Basin. The composition of the feeds can either be derived from in situ plants or animals i.e. the lake shrimp or omena within the ecosystem of Lake Victoria or externally sourced from outside the Lake i.e. imported formulated fish feeds. The net effect from the input of those feeds from outside could increase eutrophication within the lake while feeds derived from fauna and flora from the lake may not impact as negatively. The nutritional values of the feeds and the potentials of the feeds derived from outside the Lake and those utilizing local flora and fauna within the ecosystem of the lake are compared. The consequences of nutritional level from the different sources on the quality of fish product were estimated. Samples from both the formulated and in-situ based fish feeds were collected from aquaculture farms or from local sources around the Lake area. The samples were then freeze-dried and ground to fine local powder and dissolved using acid digest process. The resulting sample-acid solution was then analyzed using an Agilent 7500cx inductively -coupled plasma mass spectrometer (ICP-MS). With the exception of Arsenic (As), Barium (Ba) and Tin (Sn) wild fish muscle had significantly high PTEs in Silver (Ag), Chromium (Cr), Lithium (Li), Aluminium (Al), Cadmium (Cd), Mercury (Hg) and Lead (Pb) and also high in trace element concentrations in boron (B) and selenium (Se) compared to the caged fish muscle. Cadmium (Cd) and lead (Pb) contents in caged and wild fish samples were all below the FAO/WHO recommended limits. This study also showed that the differences were not quite discernable and that the data indicated are important preliminary findings that indicate that the differences in concentrations of micronutrients were wider than the differences in the concentrations of the macronutrients of the omena and lake shrimps of both closed and open lakes. The potentials of sustainable production of aquaculture especially caged culture from Lake Victoria is presented taking into account the optimal ratios measured in both formulated and in-situ based feed and their possible impact both economically and environmentally. Our study therefore; presents an environmentally sustainable means of solving food insecurity among the rapidly growing human population that suffers malnutrition, hunger, joblessness and diseases.

Keywords: Aquaculture, fish, eutrophication, PTEs, ecosystem, malnutrition, hunger

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AA	Arachidonic acid
Al	Aluminium
Ar	Arsenic
ANHMRC	Australian National Health and Medical Research Council
ANOVA	Analysis of variance
AMR	Antimicrobial resistance
As	Arsenic
B	Boron
Ba	Barium
Ca	Calcium
Cd	Cadmium
Conc.	Concentration
Cr	Chromium
Cu	Copper
DNA	Deoxyribonucleic Acid
DOC	Dissolved organic carbon
DRC	Democratic Republic of Congo
EBH	Environmental Health and Biology

EPA	Environmental Protection Agency
et-al	and others
e t c.	etcetera
FAO	Food and Agriculture Organization
Fe	Iron
Fig.	Figure
FM	Fish Meal
GI	Gastrointestinal
GPS	Global Positioning System (GPS)
Hg	Mercury
I	Iodine
i. e.	That is.
IUCN	International Union for Conservation of Nature
K	Potassium
KEBS	Kenya Bereau of Standards
LVB	Lake Victoria Basin
mg/L	milligrams per litre
mg/kg	milligrams per kilogram
Mg	Magnesium
Mn	Manganese
Mns	Micronutrients
Mo	Molybdenum
MeHg	Methyl mercury
Na	Sodium
P	Phosphorus
Pb	Lead
PTEs	Potentially Toxic Elements
PUFA	Polyunsaturated fatty acid
RBC	Red Blood Cells
S	Sulphur
Se	Selenium
Si	Silicon
sig.	Significance
Sn	Tin
SOD	superoxide dismutase
SPSS	Statistical Package for the Social Sciences

STC	Stanniocalcin
UoE	University of Eldoret
USA	United States of America
USD	United States Dollars
WBC	White Blood Cells
WHO	World Health Organization
Zn	Zinc
α	Alpha
≈	Approximate
β	Beta
HI	High
"	Inches
<	Less than
≤	Less than or equal to.
$\bar{x}$	Mean
μ	Mean
μM	Micrometre
μl	Microliter
>	More than
%	Percent (Parts per 100)
±	Plus, or Minus
($AgCl^{1}{}_{n}{}^{-n}$)	Silver chloride
(MoO_4)$^{2-}$	Molybdate ion
(SiO2NPs)	Silicon dioxide nanoparticles

OPERATIONAL DEFINITION OF TERMS

***Biodiversity*-** The term used to describe the diversity of life on Earth. Every flora and fauna, animals, and microorganisms, as well as the environments in which they live and interact, are diverse (Swingland, 2001).

Carbohydrates- Carbohydrates are the most cost-effective energy sources for fish. Carbohydrates are used in aquaculture diets to lower feed costs and for their binding activity throughout feed manufacture, while they are not required. Nutritional starches and sugars are important in the production of buoyant feeds through extrusion. Cooking starch makes it more physiologically bioavailable to fish during the extrusion process.

Food security- Food security, according to the World Bank (1986), is "access by all people at all times to enough food for an active healthy life." 'All people have physical and economic access to sufficient, safe, and nutritious food to suit their dietary needs and food preferences for an active and healthy life,' according to the World Food Summit.

Formulated fish diets -Extruded (floating or buoyant) or pressure-pelleted (sinking) feeds are available. Although both buoyant and sinking feeds can generate sufficient development, certain species of fish prefer floating while others prefer sinking.

Lipids - Lipids (fats) are elevated nutrients that can be used to substantially spare (substitute for) protein in fishmeal. They account for 7 to 15 percentage points of fish diets, provide important fatty acids, and act as fatsoluble vitamin carriers.

Malnutrition- Malnutritiom refers to energy and/or nutrient deficits, excesses, or imbalances in a person's diet. Malnutrition is a broad phrase that refers to two distinct conditions. Stunting, wasting, anorexia, and micronutrient deficiencies or insufficiencies are all examples of 'undernutrition'. Obese, and nutrition-related Non-communicable disorders (NCDs) such as cardiovascular disease, stroke, hypertension, mental health diseases, cancer and chronic respiratory diseases (WHO, 2020).

Minerals/elements- These are inorganic elements that must be consumed in order for the body to function properly. Based on the amount needed in the diet and the proportion found in fish, they can be separated into two groups: macrominerals/macroelements and microminerals/microelements. Many minerals may be absorbed directly from the water by fish through their gills and skin, enabling them to supplement for nutrient shortages in their diet to a certain extent. Calcium, sodium, chloride, potassium, chlorine, sulphur, phosphorus, and magnesium are common dietary macrominerals. These minerals help with bone development and integrity by regulating osmotic equilibrium.

Protein- Because protein is the most expensive component of fish feed, it's crucial to figure out how much protein each species and life stage needs. Individual amino acids are linked together to generate proteins. When these sources of protein are utilized to replace fishmeal, certain essential amino acids (such as valine, leucine, histidine and methionine) must be provided in the diet. To achieve optimal growth and health, it's critical to understand and meet each fish species' dietary protein and particular amino acid requirements.

Vitamins - These are organic substances that are obtained in the diet in order for fish to grow as well as stay healthy. They are frequently not generated by fish and therefore must be consumed.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Good animal nutrition is critical for the cost-effective production of healthy, high-quality fish meal products (Bohsale et al., 2010). Nutrition is crucial in fish aquaculutre farming since feed accounts for almost half of the variable production cost of about 50 percent (Mousavi et al., 2021). With the development of new, balanced commercial diets that support optimal fish growth and health, fish nutrition has evolved substantially in recent years. The expansion of the aquaculture business is aided by creation of novel species-specific food formulations in order to meet rising demand for economical, safe, high-quality fish and seafood (Craig et al., 2017). Regardless of the culture system in which they are kept, fish and other aquatic creatures rely on an adequate supply of nutrients, both in terms of quantity and quality, for growth, health, and reproduction. The nutrients and energy requirements of the species under cultivation are fulfilled, and the system's production goals are reached, with an adequate supply of inputs (feeds, fertilizers, etc.). Malnutrition is one of the world's most serious issues (Hasan et al., 2001). Generally fish is known to be rich in protein diet that is becoming increasingly popular among individuals who feed on it. Fish, which are high in nutrients, can help a lot in the fight against malnutrition (Farzad, et al., 2019). Fish are a good supply of Omega 3, a polyunsaturated fatty acid, as well as a very reliable source of high-quality protein (PUFA). Essential fatty acids can help prevent heart disease and are necessary for brain development. Furthermore, fish are high in highly accessible micronutrients including minerals and vitamins, which are essential for human health, growth, and development, as well as illness prevention (Golden and Allison, 2016). However, the importance of fish as a source of micronutrients in the diet is underappreciated and understudied (Beveridge et al., 2013).

Characteristics in fish include pigmentation and structure, flavor, nutrient content (protein, essential fatty acids, fat, unsaturated fats and their mix, vitamin supplements, elements, and microelements), and, most importantly, oxidation resistance. Fish size and nutrition, genotype, age, sex, physiologic status, inherent composition of fish, and some environmental factors all affect the nature of the fishes and the products made from it (Torstensen et al., 2001). Lake Victoria is the world's second largest freshwater lake. Its shoreline stretches across three countries: Kenya (6%), Uganda (43%), and Tanzania (51%). The Winam gulf, sometimes known as "a lake inside a lake," is a Kenyan detachment from the larger Lake Victoria, with very minor interaction via the Rusinga channel (Opande et al., 2014).

Several research articles acknowledge that fish has the ability to improve the dietary diversity of poor in developing countries, especially the vulnerable individuas like the children and women. Global fish consumption increased at an annual rate of around 1.5 percent each year, from 9.0 kg in 1961 to 20.2 kg in 2015. From 2015 to 2017, the average amount of fish eaten internationally increased to 21.3 kilogram in 2027, up from 20.5 kg in 2015. Africa's rapidly expanding human population outpaces the continent's fish source, as well as the vast majority of the continent's native fish species are depleted. To meet expected fish consumption, aquaculture production will need to more than double by 2050 (Obiero et al., 2019).

Fish and fishery products are an excellent source of animal protein, minerals, and other critical micronutrients, as well as an important nutritional food source for humans (FAO, 2016; Asha et al., 2014). In poor nations such as those in Africa, fish accounts for more than half of total animal protein consumption (2.5 tonnes for 25%) (FAO, 2016; Marriott et al., 2018; Watts et al., 2019). With rising demand for sustainable fishing in Lake Victoria and dwindling stocks of over-exploited wild caught fish, aquaculture raised fish must be used to supplement wild caught fish supplies (locally known as cage cultured fish) (Nyombi et al., 2004).

With increasing constraints on catch fisheries, aquaculture is increasingly meeting global fish demand, with aquaculture supplying more than half of all fish consumed by humans (Marriot et al., 2020). As the aquaculture sector expands, it is adopting a nutrition-conscious approach, moving away from maximizing productivity and toward enhancing animal nutrition and health. Human consumers' health may be improved as a result of the creation of better, higher-nutritional-value fish. In rare situations, aquaculture goods may be supplemented with a nutrient to improve the proper functioning of alternative product that is already healthy (Farzad et al., 2019).

Minerals are involved in a variety of critical biological processes in both humans and animals since they are part of numerous enzymes. The micronutrients boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), and zinc (Zn)) as well as the macronutrients such as phosphorus (P), calcium (Ca), potassium (K), sulfur (S) and magnesium (Mg), are the most interesting elements in this perspective. For example, Selenocysteine, a selenium-containing organic compound that is genetically programmed for integration into the catalyst surface of distinct selenoproteins i.e glutathione peroxidase present in all vertebrates, contains selenium as a functional component (Nieder et al., 2018). By catalyzing the processes required for the conversion of hydrogen peroxide and fatty acid hydroperoxides to water and fatty acid, this enzyme shields cell membranes from oxidative damage (Bansal et al., 2005). The fuctional condition of Se in humans and livestock tissues for example is determined by measuring and evaluating glutathione peroxidase (Hu et al., 2003).

Selenium is beneficial to human health in a variety of ways, including immunological function, thyroid hormone metabolism, cardiovascular health, neurodegeneration prevention, anti-cancer, and antagonism to methylmercury and other heavy metal toxicity (Alissa et al., 2003). The health of fish depends on selenium, and a lack of it might damage the animal's immunity and increase mortality. Previous research has shown that nile tilapia fish may require a greater Se element in their food, and it will be more absorbed and biologically active if administered in organic form (Wang et al., 2006).

Kenya began intensive cage farming in 2013, and the number of cages has expanded dramatically in the following five years, from 1663 cages in 2016 to 3398 cages in 2017. Only one species, the Nile tilapia (*Oreochromis niloticus*), is currently being cultivated in these cages, with each cycle generating approximately upto 15 million kg of fish (Anjejo et al., 2019).

For *O. niloticus*, formulated fish meals in Kenya typically contain upto 30% protein in the diet. Unfortunately, some of the smaller local fish farmers cannot afford these formulated fish meals, therefore they must rely on locally created varied rations of feeds. The meals are thereafter, created by combining dried freshwater shrimp as well as the omena in the area. Due to a lack of inexpensive feeds in the country, some aquaculture fish farmers have resorted to feeding fish with less-than-ideal pig feed pellets and chicken feed especially the layer mash and grower (Jacobi et al., 2013 and Liti et al., 2005). Antibiotics, probiotics, and growth boosters are included to some animal diets, which farmers may unwittingly introduce to their caged fish (Soles et al., 2008).

Tropical vegetation and seeds from grain legumes shrubs and trees, as well as crops, macroalgae, all land and marine species, rice, wheat, corn, seed cakes, and butcher byproducts suffocation in the form of blood and carcasses are normally used as feeds (Munguti et al., 2006).

Farmers and nutritionists working with Nile tilapia, particularly in Kenya, confront obstacles such as developing cost-effective commercial feeds using indigenous, low-cost components and unconventional resources (El-Sayed et al., 2006). In intensive fish farming expenditure, feed nutrition forms a major part of the operational costs, with protein being a very costly nutritional component. Poor quality feeds can affect the taste, color, and, most significantly, the quality of the finished product, which is mostly used for "the fish." As a result, a greater understanding of how to close knowledge gaps in order to provide well-balanced and economical feeds is required for the success and long-term sustainability of Nile tilapia in cage culture (White et al., 2018).

For the cage culture industry, in most cases the details on nutrient requirements is needed in order to improve feed quality for optimal fish growth including; specific location of aquaculture cages and quality of water and, more importantly, to lower production costs, which in turn lower costs for end users, such as fish farmers and managers (El-Sayed et al., 2006 and Chhorn et al., 2006). Despite the fish's nutritional value to humans, there are concerns that widespread environmental contamination caused by man-made activities in and around the Lake Victoria basin and the Winam Gulf could have negative consequences due to toxic element bioaccumulation in both wild and cage-cultured fish. Mercury (Hg), one probable pollutant, has been the most extensively researched hazardous element (Hightower et al., 2003), from Minamata phenomenon in Japan to the consequences of gold mining in the Amazonian rivers (Forsberg et al., 1988). Hazardous elements for example; mercury (Hg), lead (Pb), arsenic (As) and cadmium (Cd) have been detected in fish and feed samples from different parts of the Winam Gulf of the Lake Victoria Basin in Kenya. Contamination from this type of source raises the danger of harmful consequences on local riparian and indigenous communities, which rely significantly on fish as a daily food source (Kiema et al., 2017).

There are few research addressing the hazardous and important components in Kenyan feeds and fish (Huntington et al., 2009). As a result, one of the goal of this study is to investigate dietary intake of vital micronutrients and mactonutrients, and hazardous components in fish and fish feeds from various aquaculture cages and sites within the Winam Gulf of Lake Victoria by Kenyans. This research looked at the quality of various feeds, such as element content (both essential and potentially toxic components) and the element content of nile tilapia fish, and also the effects on the fish's quality in terms of human health (Kundu et al., 2017).

1.2 Statement of the problem

In Africa, food insecurity is a severe issue. Many initiatives have been made to encourage fish farming as a means of alleviating poverty and ensuring food security in Africa. Millions of Kenyan people are suffering from poor food nutrition and malnutrition which could be addressed with quality fish diet. Increased fishing pressures due to the ever growing population have led to declining wild fish stock and reduced catches (Verschuren et al., 2002) and aquaculture is seen as a replacement for this deficit. Also more people countrywide are eating tilapia. The feed supplied to the cage farmers may support the development of the fish without improving the standard quality of the flesh in terms of value on their bodies' mineral content. For example the micronutrients like selenium (Se) and zinc (Zn) may be ignored yet they are nutritional/feed factors affecting fish quality**.** Omena (*Rastrineobola argentea*) is the most crucial small pelagic fish species in the Lake Victoria and Lake shrimp (*Caridina nilotica*) may play an essential role in the feeding of the cage fish that has been ignored. The stocks of fishmeal; both *C. nilotica* and *R. argentea* have been used to feed terrestrial animals such as poultry and swine. There is paucity of knowledge on the roles that could be played by in situ based products vis a vis the formulated feeds applied in aquaculture in Lake Victoria Kenya. The transfers of nutritional elements via fish diet and a better understanding of potentials for contamination with toxic elements in the Lake Victoria would elucidate the roles that the fish could play in to the consumers' health.

1.3 Justification of the study

Lake Victoria is known to be the world's largest tropical freshwater lake, supplying both huge populations and further afield with locally and commercially caught fish. The *Rastrineobola argentea* that is, omena is a good source of protein and critical elements that helps with food security and nutrition. Wild tilapia being omnivorous have a varied diet and feed on zooplankton, benthic organisms such as small aquatic animals and algae and other fish. Considerable number of poor cage farmers use another locally sourced food/prey item *Caridina nilotica* (lake shrimps) as feed, while more financially secure cage farmers tend to use imported “non-native/natural” commercial compound feeds which are formulated (from multiple studies conducted in laboratories and experimental farms) (Munguti et al., 2007). Aquaculture practice can either introduce good quality or compromised quality of fish for human consumption depending on the feeds used (Brummett et al., 2008). An understanding of the advantages of use of in situ based diet as opposed to commercial feed is investigated in this thesis. Both nutritional (macro and micro-nutrient) and toxic elements were analysed in the laboratory in order to highlight the often ignored aspect of commercial fish farming that mostly target productivity based on the catch's weight that is produced vis a vis the costs of input.

1.4 Objectives

General objectives

To determine the difference in trace element content of fish feeds and their effects /input on the nutritional quality of aquaculture fish for human consumption.

Specific objectives

1. To compare the concentrations of Potentially Toxic Elements (PTEs) and essential elements in in-situ derived fish feed components with those in formulated commercial fish feeds applied in cage aquaculture fish of the Winam Gulf of Lake Victoria
2. To establish the suite of nutritional elements and PTEs that are present in the dietary (market ready) cage and wild *Oreochromis niloticus* (Nile tilapia) of the Winam Gulf of Lake Victoria.

3. To determine any spatial differences in mineral content, PTEs and essential elements among the different aquaculture cages on the Winam Gulf of Lake Victoria

1.5 Hypothesis

The following hypothesis is to be tested for this experimental study design of the effects of feed on mineral content of caged and wild *Oreochromis niloticus* in Winam Gulf of Lake Victoria.

1.5.1 Alternative hypothesis

H_a: Aqua-culture growing of fish supports the supply of mineral-balanced food.

H_a: Feeds have effects on mineral content of caged fish and wild fish.

H_a: There are differences of the quantity of Potentially Toxic Elements (PTEs) and essential elements in wild fish and caged fish.

CHAPTER TWO

LITERATURE REVIEW

2.1 Lake Victoria Basin

Millions of in-lake creatures rely on the Lake Victoria for nourishment, and it is also the primary supply of protein for lake ecosystems (Oyoo-Okoth et al., 2010). It hosts' and has high productive fish species diversity (circa 350 species) The key commercial species are omena, nile perch, and nile tilapia (FAO, 2017). In many developing countries fish is known to be cheaper and affordable as compared to poultry, meat and dairy products. There is high demand for these fish and are mainly exported to readily available markets as well as for fishmeal and home consumption. The current scenerio is a result of the Lake Victoria fishery's massive commercial development over the last two decades. The modified fishery has contributed to higher fish prices, which equates to an increase in the fishery's quantity produced (Abila et al., 2003). All crucial metals required for diverse biological functions in fish are primarily obtained from the fish feed. Aquatic species, on the other hand, have a water-based alternate absorption mechanism (Bury et al., 2003). Essential metal elements in fish flesh that are vital for human biological functions and are integral in metabolism of proteins include; selenium, zinc, iron, copper, manganese and cobalt. Lake Victoria continuously receives increased toxic metals including copper, lead, cadmium and chromium (Oyoo-Okoth et al., 2010) from the various activities in its catchment. Several important factors influence bioaccumulation of these toxic metals by fish which include; growth rate, temperature, feeding behavior, metals interactions, sex, age, salinity and hardness (Pourang et al., 1995). In Kenya, the in-situ based fish feeds i.e. omena and the lake shrimps are the most commonly used as animal protein sources. However, omena is also a key source of protein of riparian inhabitants used for human food while Lake shrimp is a by-product of the omena fishery in Lake Victoria is exclusively used as animal feed. The supply of the lake shrimp as a feed is impeded by the lake's fisheries being closed on a regular basis (Kirimi et al., 2016). Fish farming is the fastest-growing animal production sector due to higher demand for fish products in the market and it is responsible for increased in the world fish production in the recent years (Jiang et al., 2016).

Oreochromis niloticus

Oreochromis niloticus, the nile tilapia is currently the most available and economically valuable fish in Lake Victoria Basin (Yongo et al., 2018). *Oreochromis niloticus* is a typical omnivorous warm water fish species, with global tilapia production exceeding 2500 thousand tonnes per year (FAO, 2006). Because the species consumes a wide range of foods, it's important to check *C. nilotica's* potential as a protein ingredient in fish feed. We used the lake shrimp to substitute Fish Meal (FM) in order to advance aquaculture growth by utilizing locally underutilized feed sources (Mugo-Bundi et al., 2015).

2.2 Formulated fish feeds

In terms of palatability and nutrient availability, animal protein is present in most fish feeds and is perceived to be superior to other sources (Turchini et al., 2019). Most fish species can be trained to accept a floating pellet, but shrimp will not. Due to the greater manufacturing expenses, extruded feeds are more expensive. Using a extruded feed is usually preferable since the cage farmer has to monitor the intensity of the fish's feeding and modify feeding frequency accordingly. In order to maximize fish development and feed efficiency, it's critical to determine if feeding frequency are lower or higher (Treves-Brown et al., 2013).

Fish and shrimp meals, on the other hand, are becoming increasingly rare and expensive due to a global drop in fisheries products. As a result, nutritionists and feed suppliers have been exploring for non-traditional sources of dietary animal protein to replace traditional sources and lower feed prices (Munguti et al., 2009). Omena and Lake shrimp diet are two fish protein sources extensively utilized in Kenya. Omena, on the other hand is consumed by humans, whereas Lake shrimp, a waste of the omena fishery in the Lake Victoria, is becoming highly minimal and more costly due to the lake's constant closures (Munguti et al., 2006). As an outcome, substituting Lake shrimp with the less expensive and readily accessible animal protein feedstuffs is likely to lower the cost of *Oreochromis niloticus* diets.

Large farms typically purchase formulated fish feed in bulk truckloads and store it in outdoor bins. Smaller farms frequently purchase 22.68 kilograms packages of prepared feed. Bagged feed should be kept as cool as possible and out of direct sunlight. Vitamins, proteins, and lipids are particularly heat-sensitive, and high storage temperatures can easily denature them. Mold growth and feed degradation are aided by high moisture levels. Avoid inappropriate handling and damage to the feed bags, which could cause the pellets to shatter and powder to form, which the fish will not ingest.Fish feed should not be stockpiled for more than 90 to 100 days for storage considerations, and inventories should be undertaken on a continuous basis (Craig et al., 2017). Bags should not be stacked further than ten bags high since the weight of the upper bags will crush pellets in the lower bags, resulting in excess fines (dust). Prior to feeding, older fish feed should be used first, and all feed should be tested for mold on a continuous basis. Every contaminated feed should be disposed instantly. In the feed storage, pets like roaches, rats, mice, and others should be tightly controlled. (Craig et al., 2004).

Commercial fishing, particularly for tilapia and Nile perch, has led to a reduction in fish populations and availability for Lake Victoria communities. The drop in fish not only jeopardizes the livelihoods of artisanal fishermen and processors, but it also jeopardizes the region's population's nutrition and food security. As the populations of Nile perch and Nile tilapia in Lake Victoria continue to decline, artisanal fishermen are shifting to low-value species like *Rastrineobola argentea* (Odada et al., 2004).

2.3 *Rastrineobola argentea* (Omena)

Omena as locally termed in Kenya, is a native fish to the Lake Victoria region and a diminutive endemic silver cyprinid that is approximately 5cm long. It is a significant economic and commercial product that drifts in massive shoals and is exploited for human consumption as well as animal feed production (FAO, 2017). *Lates niloticus* (Nile perch) were introduced to consume and utilize some of these pelagic fish which were numerous in Lake Victoria with the aim of growing large fish of commercial value hence decline in biomass and catch of omena. Besides its commercial value, omena is also considered a low-value fish product due to the poor perceptions that local communities hold towards this fish to human food. Omena has been labeled poor man's food because it is mostly consumed by low and middle income fish consumers (Ahern et al., 2021). In comparison to other fish products accessible in the Lake Victoria region, it has gained wide acceptance as a fish for direct human eating in recent decades since it is inexpensive and affordable, has a longer shelf life, and is easily divisible.Omena is mostly sun dried (unsalted) before consumption but it's eaten whole including head, bones, scales and fins due to its small size which makes it a major source of calcium and magnesium. In Uganda, mukene is popular in the northern part of the country and, due to recent declines in Nile perch and tilapia; omena is also increasingly being used by populations around Lake Victoria. Omena is also often used in hospitals and by humanitarian organizations to augment the meals of malnourished children due to its rich protein and mineral value (Kabahenda et al., 2009).

With the growth of fishmeal factories, a large proportion of omena is being used to make fish meal for both human consumption and poultry and fish feeds. In Kenya, the whole catch of omena harvested used to be for direct human consumption but currently more than half to six fifths of the omena landed is used to generate fishmeal. Fishmeal meant for human consumption is often mixed with staples such as rice, millet or maize meal to make complementary foods for young children. With the dwindling stocks of commercial fish and improvement in quality control measures, omena is likely to move onto the high value fish products. All the three riparian countries currently export mukene to neighboring countries with major stocks going to DRC, Rwanda, Sudan, and the Central African Republic, and this trade is expected to expand further. There are also good prospects for exporting mukene as fish feed to Europe, USA, Japan and Israel. As Abila 2003 observed, this increased exportation of mukene may pose threats to the food security of riparian communities that depend on mukene as their major animal-source food. This calls for measures to control mukene processing and trade in order to ensure availability of this fish for local human consumption (Kabahenda et al., 2009).

In essence, fishing on Lake Victoria has shifted from a predominantly subsistence occupation to a largely commercial one. The majority of the catch is turned into export products or animal feed ingredients rather than meeting local food demands. There are three ways fishing access can be hampered. For starters, processing firms' comparatively high prices make it inaccessible for local consumers. Second, the export market consumes practically all of the good-quality Nile perch, and they are still unable to meet demand. Locals can only buy Nile perch that factories have rejected as being too little or of low quality. Third, concentrating fish harvesting resources in the hands of a few wealthy fishermen disenfranchises the vast majority of potential fishermen. The fishmeal business in Kenya consumes between 50 to 65 percent of all 'omena' caught in the country, according to annual catches. In the early 1990s, Kenya's animal feeds sector began using omena as the primary source of crude protein in feeds. In late 1990s, omena was relied on by six major animal feed producing enterprises in Kenya (Manyala et al., 2011). Since 1997, at least two new factories using 'omena' have been established, indicating that omena has maintained its popularity. The fishmeal industry's interest in omena has significant ramifications for the country's food security crisis. The price of dried omena for human consumption increased dramatically from less than Ksh 20 ($ 0.3) per kilogram which increased up to around Ksh 60 ($ 0.8) per kilogram in 1990 and 1995 respectively (Bokea et al., 2000).

The oversupply of omena continues to drive investors into the fishmeal processing industry. The prolonged usage of omena for fishmeal will deplete the product and drive up prices. Because the majority of its customers are low-income locals, they are likely to be vulnerable to any competition from fishmeal factories, no matter how minor. Despite the fact that its use in the fishmeal business has raised its price, omena remains to be in high demand in many settlements near Lake Victoria (Obwanga et al., 2017). According to a fish consumption survey undertaken for the IUCN Socio-economics of the Lake Victoria Fishery Project, omena is readily consumed by 89 to 95 percent of rural communities. However, 79 percent of these households say it is now more difficult to obtain or afford omena than it was five years ago. Since the use of fish frames for fishmeal can be partially rationalized by the fact that it is a by-product of fish processing that is only consumed as a last resort, the use of omena for animal feeds cannot be justified. Its high protein content and meat composition are beneficial to customers, particularly children who are malnourished. Nonetheless, as the fishery is becoming more commercialized, these 'omena benefits will be lost to local inhabitants (Olago et al., 2006)

2.4 *Caridina nilotica* (Lake shrimps)

Many fish species, including the invasive Nile perch in Lake Victoria (Goudswaard et al., 2006), feed on the Lake shrimp, *Caridina nilotica* (Budeba et al., 2007). The average size of gravid shrimps and the size at initial maturity both decreased over the same time period hence adult shrimps appear to be under heightened predation pressure. Prior to the rise of the Nile perch, specialized shrimp eaters and piscivores among haplochromine cichlids only ate adult shrimps, but we believe that most haplochromines ate immature shrimps (Goudswaard et al., 2006).

C. nilotica and other micro-invertebrates thrive in the anaerobic environment of L. Victoria. It's been found in trawl catches, Nile perch stomachs, and as a by-catch in the Lake Victoria *Rastrineobola argentea* (omena) fishery. Although there are limited quantitative records available, the number of *C. nilotica* in Lake Victoria waters has increased dramatically since 1986 (Mugo-Bundi et al., 2015). Hydroacoustic investigations calculated the average biomass of *C. nilotica* for the entire lake to be 22 694 metric tons (Getabu et al., 2003). The cattle feed industry in Kenya discovered *C. nilotica's* underused position and began using it as a dietary protein on a small scale (Munguti et al., 2009). It's also exploited as bait in haplochromine hand-line fisheries, despite the fact that the haplochromine fishery has dwindled rapidly in recent decades (Budeba et al., 2007).

2.5 The Essential micronutrients elements, macronutrients elements and potentially toxic elements in fish

The essential micronutrient elements include boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), silicon (Si) and zinc (Zn).

Boron is a trace mineral micronutrient that plays a variety of key roles in metabolism, making it essential for the well-being of flora, fauna, and people. It aids in the movement of cell membranes. Boron, at low concentrations in water of up to 0.50 mg/L, stimulates embryonic development and boosts growth rate in fish, as well as bone maintenance (Rosborg et al., 2018).

Copper is an essential element that is required for the synthesis of hemoglobin and is essential for enzymatic activity. Higher concentrations, on the other hand, may pose health risks to both animals and people. Cu is essential for cellular metabolism, oxidation activities, gene communication, Genome stability, oxidative phosphorylation, regulatory component for many enzymatic reactions, cell regeneration, and collagen synthesis, among other things (Rubino et al., 2012). Cu plays a variety of roles in cellular biochemistry, including cellular respiration and acting as a cofactor for approximately 30 enzymes (Kurutas et al., 2015). Cu content in plant and animal products typically ranges from 5 to 30 mg/kg, with fish diet being particularly high in Cu. Cu levels in animal by-products have also been revealed to be significant (Moreno-Caselles et al., 2002).

Cu can be absorbed by fish from both the water and the food they eat. Tilapia absorb copper from the surrounding freshwater, unlike in a marine habitat, is insufficient to meet their needs, necessitating the use of a nutritional Cu supplement. Although it is difficult to achieve, in order to restore the balance between providing nutritional demands and avoiding contamination, it is strongly recommended to add Cu to fish within defined levels. (Makwinja et al., 2020).

For example, several scientists (De-Yang Zhang et al., 2015) recommended that the Cu supplied to fish can surpass the needed concentrations for growth-stimulatory effects and antibacterial properties. In several tilapia species, a dietary copper requirement of 3 to 5 mg/kg was advised by De-Yang Zhang et al., (2015). Cu concentrations fatal to the host fish tissue are predicted to be 30 mg/kg (Javed et al., 2013). It's crucial to remember that dietary Cu and Zn increases one but decreases the availability of the other (Clearwater et al., 2002).

Iron is considered a vital metal element in fish nutrition because of its biochemical and physiological involvement in blood cells and hemoglobin formation, as a cofactor for numerous enzymes, and for oxygen transport and cellular respiration. However, in living organisms, high levels of Fe above the physiological range can lead to iron overload (Slaninova et al., 2014). The most prevalent dietary shortfall in humans is iron insufficiency. Fe aids active oxidation, electron transport, growth, and anemia prevention in tilapia. Tilapia obtains iron primarily from its diet, with gill membrane and intestinal mucosa uptake being insignificant (Jampilek et al., 2019). Due to the low quantities of soluble iron in natural waterways, fish food is regarded to be the primary source of iron for fish. In the freshwater ecosystem, iron comes from natural sources including aquatic biota, as well as worn boulders and sediment near rivers. Iron is also prevalent as an electrolytic in both fresh water and marine settings, and species of fish require homeostatic to thrive. Large amount of Fe approximately 1300 mg/kg and above in the ecosystem is hazardous to fish because it disrupts it's body balance, leaving the fish exposed to bacteria invasion that need the iron for development and, as a result, cause active infection (Wang et al., 2016).

In other research, fish with a dietary iron intake of 200 mg/kg have been found to be potentially fatal (Eslambo et al., 2012). Iron rich- feed ingredients include livestock (blood meal, organs of beef, meat) fish and poultry by-products (Makwinja et al., 2020), legumes, vegetable oils, and cereals. Fe levels in pig dung have also been reported to be excessive (Moreno-Caselles et al., 2002).

Manganese is a metal that is required for the enzyme pyruvate carboxylase and is found in abundance in fish and animal tissues (Khayatzadeh et al., 2010). It functions as an activator and a metalloenzyme in the biochemical system and Mn is required for bone development (mucopolysaccharide synthesis), red blood cell regeneration, glucose metabolism, and the reproductive cycle as a cofactor (Saad et al., 2014). Mn is required for human health at low levels, but excessive amounts can cause oxidative stress and harmful effects in aquatic creatures. In the body parts of the fish and crustaceans, the gills, fins, skin and gastro-intestinal systems are all good sources of Mn. In the presence of phytates, dietary manganese availability and absorption are reduced, while excessive calcium intakes diminish manganese availability and absorption (Lall et al., 2021).

Molybdenum is a micronutrient element available in a few parts per million concentrations in plants and animals. It is necessary for life and is far less hazardous than other industrial metals (Alloway et al., 2013). Molybdenum has a high bioavailability, but it varies depending on the form, with molybdenum preparations having a higher bioavailability than food-bound molybdenum. Because the body can adapt to a wide variety of molybdenum intake levels, molybdenum insufficiency and toxicity are uncommon. With low molybdenum intakes, the percentage transfer of molybdenum from plasma to urine is reduced, and a larger fraction is deposited into tissues, whereas with high molybdenum intakes, the opposite occurs (Novotny et al., 2011).

Molybdenum is required for the catalysis of redox reactions such as the reduction of molecular nitrogen and nitrate in plants and the oxidation (hydroxylation) of xanthine and other purines and aldehydes in animals. Molybdenum can form complexes with a variety of biologically important molecules, including carbohydrates, amino acids, flavins, and porphyrins, although it is most likely taken up, transported, and excreted in animals as the simple molybdate ion, $[MoO_4]^{2-}$.

Molybdenum affects protein synthesis as well as phosphorus, sulfur, potassium, iron, copper, zinc, and iodine metabolism in animals. Dietary molybdenum boosts growth in some animals such as red trout fish and poultry (Lall et al., 2022).

Nickel concentrations in aquatic habitats are typically low. Nickel (Ni) has been shown to have negative health effects in humans, including carcinogenic effects and allergenicity. It can also lead to pulmonary complications such asthma and other respiratory, fibrosis, bronchitis, allergies, dermatitis, eczema, and cancer. Animals and humans ingest about 1 to 10% of dietary nickel, according to the Environmental Protection Agency (EPA) (Cempel et al., 2006). Drinking water exposure and gavage delivery yielded similar results. Nickel metal is weakly absorbed through the skin, however some nickel derivatives, such as nickel chloride or nickel sulphate, can permeate blocked skin and absorb up to 77 percent within 24 hours (Das et al., 2008).

Selenium is an essential trace element in fish that is specifically incorporated into proteins as selenocycysteine. Se is extremely toxic to fish with a narrow margin between essentiality and toxicity (Yang etal., 2017). The anomalous intakes of selenium with the risks of certain degenerative diseases such as cancer, cardiovascular disease and cerebral thrombosis. The possibility that increased intakes of selenium might protect against the development of cancer in humans has generated great interest. Moreover, in several animal studies of pancreatic and melanoma, increasing selenium consumption promotes the rapid carcinogenesis. Laser hair removal and abnormalities in fingernail structure are the most common symptoms of severe selenium toxicity in adults. Skin lesions (discoloration, peeling) and central nervous disorders (nerve impingement, numbness, hemiplegia) have been reported in certain cases (WHO 1996). Selenium's task is in the formation of ubiquinone (a coenzyme associated with cell electron transfer) and regulates vitamin E intake and storage. Fish and crustaceans readily absorb selenium from the gastro-intestinal tract and the surrounding water environment (Lawrence et al., 2008).

Selenium is a catalytic stimulant for enzymatic that seem to be important to the fish's metabolism, endocrinology, and immunological systems. As previously observed in Salmon, selenium deficiency causes growth retardation, death, and Hitra illnesses. Anemia, haemorrhages, fertility problems, fluids substances in the peritoneum and pericardium, and metabolic problems are all symptoms of Hitra illnesses (Khayatzaseh et al., 2010). Silicon dioxide nano-sized silica particles (SiO2NPs), which are widely dispersed into the aquatic system, have been shown to bind to naturally existing sediments or suspended particles and enter cellular divisions, causing harm to aquatic species. Because of their capacity to created to serve with both a variety of polymers and other compounds, they have a huge variety of biomedical uses (Vidya et al., 2018). SiO_2NPs are commonly employed in heterogeneous catalysis, bioseparation, spectroscopy, enzyme - linked immunosorbent assay, DNA identification, isolation, and purification in nanomedicine (Slowing et al., 2008), as well as cancer treatment (Hirsch et al., 2003). Although SiO2NPs are also utilized in industry, nutritional supplements, beauty products, pharmaceuticals, and pharmacies, the danger of exposure in humans through diet, medical, or personal hygiene products is substantial. As a result, the route and implications of these widespread nanomaterials subjected to aquatic environment are of major concern, as the hazards to aquatic creatures actively or passively affect human health via the food web. Fish is an useful indicator of water quality among aquatic creatures because it is sensitive to variations in water chemistry such as pH, chemical oxygen demand, salinity, and temperature, which can be affected by a range of environmental factors or contaminant exposure. The increased usage of nanomaterials puts non-target animals, such as fish, at threat (Vidya et al., 2018).

Zinc is a trace mineral component of several enzymatic engaged in metabolism, including those active in glucose, fat, protein, and fatty acid production and breakdown. It's role as a structural element of regulatory proteins or as a functional element of enzymes (Ananda et. al., 2020). Zinc also aids healthy growth performance, metabolic processes, maintaining homeostasis, bone and scale development, biomineralization, and intrinsic immunological capabilities (Evans et al., 2001). Connections between zinc and genes promote growth. The availability of tricalcium phosphate is differently related to the amount of zinc in various animal components such as fishmeal. Lower digestibility of carbohydrates and protein, glaucoma, skin lesions, reduced growth and low serum zinc levels, and down's syndrome were all discovered in tilapia fed a low-Zn diet (Chou et al., 2013).

Zn bioavailability is reduced in formulated meals with the greatest quantity of tricalcium phosphate. Similarly, most high phosphate content substances have limited Zn bioavailability. Livestock manures contain a significant Zn level, according to reports. Furthermore, nile tilapia fed the minimum levels of additional zinc (1 and 5 mg/kg) had poor growth and significant mortality, but those fed more than 30 mg/kg had lower death and faster growth (Antony Jesu Prabhu et al., 2016). The hybridized tilapia fed a diet enriched with 127 mg/kg Zn had excellent development and a higher survival rate (Li et al., 2016).

The essential macronutrient elements include; calcium (Ca), cobalt (Co), potassium (K), magnesium (Mg), phosphorus (P), Sodium (Na) and sulphur (S). Calcium is a necessary macronutrient in significant quantities. In a fish's body, calcium is amongst the most ubiquitous cations. It has a role in bone development and support, as well as maintaining homeostasis, muscular contraction, bone metabolism, red blood cell production, neurological signal transmission, cell membrane integrity, and the activation of various key enzymes. (De Valle et al., 2011). This macronutrient is easily obtained from water and is present in sufficient levels in most fish diets. Ca influx and efflux are controlled by the gills, fins, and oral epithelia. Hyper- and hypocalcemic hormones influence the endocrinology regulation of Ca metabolism in fish (Lall et al., 2017). Calcitonin, secreted by the ultimobranchial gland, and stanniocalcin (STC), secreted by the Stannius corpuscles, are two hypocalcemic hormones found in teleosts (Pandey et al., 2013). Calcium, in conjunction with phospholipids, regulates the permeability of cell membranes and, as a result, controls the absorption of nutrients by the cell. Calcium is also required for vitamin B12 absorption from the gastrointestinal system. Calcium is quickly absorbed through vitamin D3 and fish body parts (gills, skin, and fins of fish) and crustaceans. Nutritional lactose which forms a soluble sugar-calcium complex has a high stomach acidity help with calcium absorption in general; this is enabled by aiding solubilization of the calcium salt (Haskisson et al., 2007).

Cobalt is vital to human health and is required for the production of vitamin B12. An average daily Co intake of (0.3 to 1.77 mg/kg) is indicated for optimal blood pressure management and healthy thyroid function. A greater concentration of Co, on the other hand, could be harmful to humans, causing polycythemias, anemia, and heart problems. As a result, when planning a fish diet, it's critical to consider the Co requirement. Co is a key component of cyanocobalamin (vitamin B12) in tilapia, accounting for roughly half of its molecular weight. Vitamin B12 improves regular metabolic processes, as well as the production and assimilation of muscle proteins. Cobalt salts are used as accelerators in the manufacture of a variety of colors. This element is required for the production of vitamin B in the majority of mammals. As a result, cobalt shortage lowers vitamin B12 production in the intestine (Makwinja et al., 2020).

Potassium maintains intracellular osmotic pressure and acid-base balance as the most abundant cation in intracellular fluid. Potassium, like sodium, has a stimulating impact on irritability in muscles. Glycogen and protein production, as well as the metabolic breakdown of glucose, all require potassium. The gastrointestinal system, skin, fins, and gills of fish and crustacea are all good sources of potassium, sodium, and chloride (Mehaffey et al., 2006). Magnesium is required for fish to maintain intracellular and extracellular equilibrium. Magnesium is ingested by fish through their gills or the gastrointestinal tract. It is a component of bone, cartilage, and the exoskeleton of crustaceans, as well as an activator of several key enzyme systems, such as kinases (enzymes that catalyze the transfer of the terminal phosphate of ATP to sugar or other acceptors), mutases, muscular ATPases, and the enzymes cholinesterase, alkaline phosphatase, enolase, isocitric. Like calcium, magnesium increases muscle and nerve contraction through its function in enzyme activation, is involved in the control of intracellular acid-base balance, and is crucial in carbohydrate, protein, and lipid metabolism (Wei et al., 2018).

Magnesium is easily absorbed by fish and crustaceans through their gastrointestinal tracts, gills, skin, and fins. A part of the magnesium in plant meals, like calcium and phosphorus, may be available in the form of phytin (Ca or Mg salt of phytic acid). The large percentage of nutrients, particularly those of plant origin, are high in magnesium and meet the mineral's requirement in fish (Prabu et al., 2017). Magnesium concentrations in blood plasma were shown to be higher in fish from magnesium-rich water. Magnesium in fish meal is scarce, and some commercial feeds may fall short of fish Mg needs (Lall et al., 2021). Poor development, starvation, lethargy, muscular flaccidity, seizures, vertebral curvature, high mortality, and low magnesium concentrations in the whole body, blood serum, and bone are all indicators of dietary magnesium shortage (Brucka-Jastrzêbska et al., 2010).

Sodium accounts to close to 100 or 93 percent of all ions bases in the body fluids such as blood. Although sodium's primary function in the animal is the management of osmotic pressure and the preservation of acid-base balance or equilibrium, sodium also affects muscular irritability and plays a specific role in glucose absorption. Sodium, like potassium and chloride, is easily absorbed through the gastrointestinal system, fish and crustacean skin, fins, and gills, and plays a significant part in water metabolism (Raji et al., 2019).

Phosphorus is required for the formation of bone, cartilage, and the exoskeleton of crustaceans. Phosphate (HPO^{42-}) is an important component in the functioning of all cells. Phosphorus is found in phospholipids, coenzymes, deoxyribonucleic acids (DNA), ribonucleic acids (RNA), phosphoproteins, Adesosine tryphosphate, hexose phosphates, creatine phosphate, and other important enzymes. Phosphorus, as a result, plays a crucial function in energy and cellular metabolism (Coloso et al., 2003).

The normal acid-base balance (i.e. pH) of animal bodily fluids is regulated by inorganic phosphates, which act as critical buffers (Dwyer et al., 2002). Although fish and lake shrimp can absorb soluble phosphorus salts through their body parts like; gills, skin and fins, the content of phosphorus in fresh and sea water is low, so body phosphorus necessities met by dietary sources (King et al., 2018).

Because fish have a low phosphate content, diet is their primary source of P. As a result, phosphate management is regarded more important than Ca regulation since fish must properly absorb and conserve phosphate in a variety of settings (D'Alessandro et al., 2015). In fish, dietary P concentration is a key regulator of P metabolism. The level of phosphate in the blood influences the amount of phosphate absorbed from diet. Phosphate concentrations in the blood and total body content are tightly controlled, and sodium-phosphate co-transporters control phosphate transfer into cells. Information on the endocrine regulation of P homeostasis in fish is limited (Lall et al., 2021) ST, prolactin, and parathyroid-like hormones are among the hormones implicated in phosphate control (Wang et al., 2016)

Sulphur is found in a variety of amino acids, vitamins, the insulin hormone, and the exoskeleton of crustaceans. Heparin, chondroitin, fibrinogen, and taurine all include sulphur in the form of sulphate (Espe et al., 2008). Free sulphydryl groups are required for the action of several essential enzyme systems. The detoxification of aromatic chemicals in the animal body is thought to be aided by sulphur. Poultry by-products and fish diet are all excellent dietary sources of sulphur element. Fish and lake shrimp's gastrointestinal tract rapidly absorbs sulfur and, to a smaller version of the inorganic sulphates (Nguyenet et al., 2007).

Potential harmful elements like arsenic (As), chromium (Cr), cadmium (Cd), and lead (Pb) ingested in food at relatively low amounts might have major negative health consequences, with the possibility of biomagnification along the food web. Chromium (as CrVI) and lead

(Pb) are neurotoxic and carcinogenic, with health risks ranging from cognitive impairment to kidney and damage of liver.

Cd and As are both carcinogenic, and exposure to either can result in skeletal damage, hyperpigmentation, keratosis, and vascular disorders. GI (gastrointestinal) diseases, diarrhoea, stomatitis, tremor, hemoglobinuria, ataxia, paralysis, skin lesions, vomiting, and convulsions are also problems associated with excessive zinc (Zn), copper (Cu), aluminum (Al), and mercury (Hg) exposure. However, several of these metals, such as iron (Fe), zinc (Zn), copper (Cu), selenium (Se), iodine (I), calcium (Ca), and magnesium (Mg), are critical for physiological functioning in humans, and their excessive ingestion can result in catastrophic medical effects and conditions (Marriot et al., 2020).

From a fisheries viewpoint, toxic metal bioaccumulation through the trophic levels is becoming a significant problem in populations that consume a lot of fish (Kumar et al., 2013), with fish accounting for approximately 60 percent of the Sundarban fishermen's diet (including protein).

There has been genuine controversy that the export of fish products, particularly Nile perch, has reduced the supply of a vital food source for communities and limited choices for those historically involved in processing and marketing, especially women (Abila et al., 2007). As a result, riparian communities have turned to collecting juvenile fish, adding significantly to illicit fishing. Kenyans consume less fish per capita (4.0 kg per year) than their Lake Victoria riparian neighbors (6.0 kg per year in Tanzania and 7.0 kg per year in Uganda). Ironically, this is lower than the global and African consumption rates in 2005, which were 16.4 and 8.3 kg per year, respectively. The human population, fish production, fish export and import, purchasing power, tastes and preferences, cultural influences, and the availability of other foods that the population can consume all influence per capita consumption (FAO, 2009 and FAO, 2008).

Fish being an important source of nourishment, they can provide a food safety risk in specific situations, such as when metals are present, which can act as hidden drivers of antimicrobial resistance (AMR) (Marriott et al., 2019).Tilapia is a lacustrine fish that is well adjusted to confined water and generates better profits, making it a significant human protein source. Tilapia production has been on the rise all around the world, with more expected in the future (Hamilton et al., 2020).

Lead element is a common metals in the ecosystem and biological systems, despite having no recognized physiological effects in humans. It may be found in all phases of the anaerobic environment and biochemical pathways. Pb has also been linked to neurotoxicity, nephrotoxicity, hepatotoxicity, and a variety of other health problems in people (Muawiya et al., 2017).

Silver sulfides and silver chloride complexes are the most common forms of silver in the environment. Colloid complexes with silver and dissolved organic carbon (DOC) are also likely to be present. While silver sulfide predominate in declining circumstances, other silver species play a larger role in oxidizing waters, where fish are more commonly present. Only freshwater, not salty water or ocean, contains quantities of the free silver ion (Ag^+), which is unquestionably the most hazardous species of silver (Wood et al., 2011).

Aluminum is a hazardous element in the freshwater ecosystems, causing toxic effects events with major environmental consequences. This element has yet to be linked to any regular biological roles in living organisms. Aside from structural gill damage, the most common physical responses observed in different fish species exposed to Al include cardiovascular, hematological, respiratory, ionoregulatory, reproduction, hepatic, and endocrine abnormalities (Correia et al., 2010).

The deposition of aluminium ions, the gills produces acute ionoregulatory and respiratory abnormalities in freshwater fish. Al also impacts rainbow trout reproduction by reducing stage in a concentration-dependent manner. This is due to a decrease in the expression of the mRNA that codes for vitellogenin production (Hwang et al., 2000). Acidic waters, in turn, have been shown to alter fish breeding, affecting fertility, egg survival, hatching performance, gonad growth, and zygote synthesis. Fish populations suffer major problems as a result of these impacts, including a decrease in the amount and quantity of fish (Diwan et al., 2020).

Arsenic (As) is a potentially harmful element found in fish mostly as a result of its presence in the aquatic systems. As enters aquatic ecosystems by weathering of bedrock, but it is more commonly derived from man - made sources (Garelick et al., 2009). The respiratory and gastrointestinal tracts, liver, neurological, dermatology, cardiovascular, and hematological systems have all been documented to be affected by chronic inorganic arsenic exposure (Flora et al., 2015). The degree of element buildup in these fishes is influenced by abiotic parameters such as pollution kind and severity, alkalinity, water pH, and temperatures, as well as biotic factors such as size, age, eating patterns, and reproduction cycle. Arsenic leachate from geological sites is one of the most common sources of As pollution in drinking water worldwide (Garelick et al., 2009).

Barite is mostly made of barium (II) sulphate ($BAS0_4$), and its increased density supports its usage as a weighing component in fluids in oil well drillers, which are frequently discharged into the environment as part of petroleum and diesel exploration and production activities. Around exploration and production facilities, generated water discharge can be a significant source of barium sulfate which has a long-term chronic adverse effects on fish health more often. Visible epidermal and organ abnormalities, fish and tissue condition indices, histological abnormalities in liver, gill, and kidney tissues, and levels of ethoxyresorufin O-deethylase (EROD), a catalytic activity linked with cytochrome P4501A1 induction, are only a few of the health implications (Payne et al., 2011).

Cadmium is one of the hazardous metals whose biochemical significance to humans is unknown. The main danger of cadmium is kidney toxicity, although it has also been found to be fatal and capable of causing testicles damage, persistent respiratory problems (including lung tumor induction), and skeletal alterations in exposed to high levels persons exposed. Cadmium is poorly absorbed into the body, but once ingested, it is eliminated slowly, like other elements, and accumulates in the kidney, causing renal dysfunction. Chronic kidney disease, osteoporosis, lung cancer, and high blood pressure can all be caused by eating fish with high Cd concentrations (>0.05 mg/kg), and these diseases are lethal to humans.

Mercury is a well-known contaminant all around the world. Methyl mercury (MeHg), which can be transformed from inorganic forms of Hg in aquatic habitats such as rivers and lakes, is of special significance. Through air deposition or industrial wastewaters, mercury can reach freshwater habitats. Fungicides and organic fungicides, according to Authman et al., are the primary sources of mercury and mercurial organic compounds in the ecosystem. Mercury has been linked to a wide range of negative health consequences, including effects on the central nervous system (neurotoxicity) and the kidneys. The potentially neurotoxicity of organic forms of mercury in both adults and children is the principal concern regarding mercury poisoning in the general public exposure to low amounts of mercury in their diet (Kortei et al., 2020).

Lithium is also known as a psychoactive drug, used since the 1950s as a mood stabiliser. Through environmental exposure, it has the potential to affect the physiology and body regulation of some species. The 2006 EU Batteries Directive (2006/66/EC) provides guidelines for the production, market distribution, recycling and disposal of batteries in order to avoid environmental pollution. Although it includes restrictions on the use of heavy metals (e.g. cadmium or mercury) in batteries or accumulators, it does not include any specific provisions on Li-based batteries. The number of studies on the environmental monitoring and impact of Li in aquatic systems is limited, which the authors suggest is due to the lack of regulation of this element. Whereas the mode of action is still an unknown, Li has been shown to affect the levels of arachidonic acid (AA), has a lot of fatty acids within the brain, potentially explaining its action as a mood stabiliser. Free fatty acids such as AA play a role in active cellular transport (the movement of ions or molecules across a cell membrane) via their impact on compounds that affect osmosis, leading the researchers in this study to look at ion composition and ion-transporting proteins which are involved in active transport.

Tin may be found in a variety of living organisms especially animals and human components. In addition, dietary supplements constitute a minor source of dietary tin. Despite the fact that humans subjects' uptake and overall apparent retention of tin in balancing studies is modest, tin has been discovered in at least trace levels in most mammalian organs. Industrially, a variety of organic tin derivatives are employed, some of which are exceedingly hazardous. The toxic effects of these substances is determined by the tin compounds' organic contents, the method of exposures, and the species of animals investigated (Roy Choudhury et al., 2014)

2.6 Dietary mineral requirements

The nutritional element needs of fish especially the lake shrimp which is one of the insitu based feeds are poorly understood. This is primarily owing to the complexity that result from aquatic creatures' ability to extract elements from the aquatic environment in addition to the food they feed on, as well as their variability in reaction to salt regulation or osmotic pressure (Tacon et al., 2002). Marine fish and shrimp, for example, they experience dehydration since the reside in aquatic environment containing excessive salt. To compensate for this water loss, marine fish must consume small amounts of water on a continuous basis, with the excess salt in the intestinal saltwater being pumped out of the gill to the outside. As a result, because consuming up to 50 percent of total of their entire body mass per day has been reported in marine fish, implying that drinking water could cover a significant percentage of their nutrient demands. Given the direct uptake of minerals through the gills, fins, and skin, direct absorption and/or drinking appear to satisfy the nutritional need for the remaining physiologically important minerals. Freshwater fish and prawns, on the other hand, suffer from gill hydration as a result of the constant salt loss. To compensate for bladder salt loss, their gills aggressively pump salt from the external medium into the bloodstream.

Freshwater fish and prawns, on the other hand, are more reliant on an appropriate mineral supply in their diet than marine fish and shrimp. As a result of the foregoing, a fish dietary need for a certain nutrient will be heavily influenced by the concentration of that element in the water body. The contribution of waterborne elements to the total mineral balance of fish or shrimp is currently unknown (Tacon et al., 2006).

Dietary mineral requirements are commonly established by feeding graded levels of each element in a pure or semi-purified test diet, with dietary requirements taken at a calculated 'break-point' based on observed growth response, feed efficiency, or tissue enzyme indicator level (Mohammed et al., 2002). The majority of studies on the dietary mineral requirements of fish or shrimp under practical semi-intensive or intensive farming conditions using practical diets have been conducted under controlled laboratory conditions, as has been the case with vitamins. As a result, there is very little information on the dietary mineral requirements of fish or shrimp under semi-intensive or intensive farming conditions using practical diets (Amaya et al., 2007).

Essential minerals can occur under rigorous culture systems owing to the unavailability of a particular macro or trace mineral binder inside the daily intake. Despite the presence of sufficient macro and microelements in nearly all basic ingredients, frequently used for tilapia nourishment, and the ability of tilapia and shrimp to accumulate certain trace elements from the aquatic environment (Brewer et al., 2020). Mineral accessibility can also be affected by dietary abnormalities. The element's nutritional source as well as form, body retail locations, interconnections with other macro and micronutrients in the gastro-intestinal tract and internal organs (class distinctions), and finally the element's connections with several other metabolites (which includes; fibre, phytic acid and vitamins) or dietary ingredients all influence the management and accessibility of nutritional substances in fish and shrimp. (Hassan et al., 2020).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The field work study was done in the Winam Gulf of Lake Victoria, Kenya, and laboratory preparations and analysis were done in UoE, SES biotechnology laboratories center, and the British Geological Survey, UK.

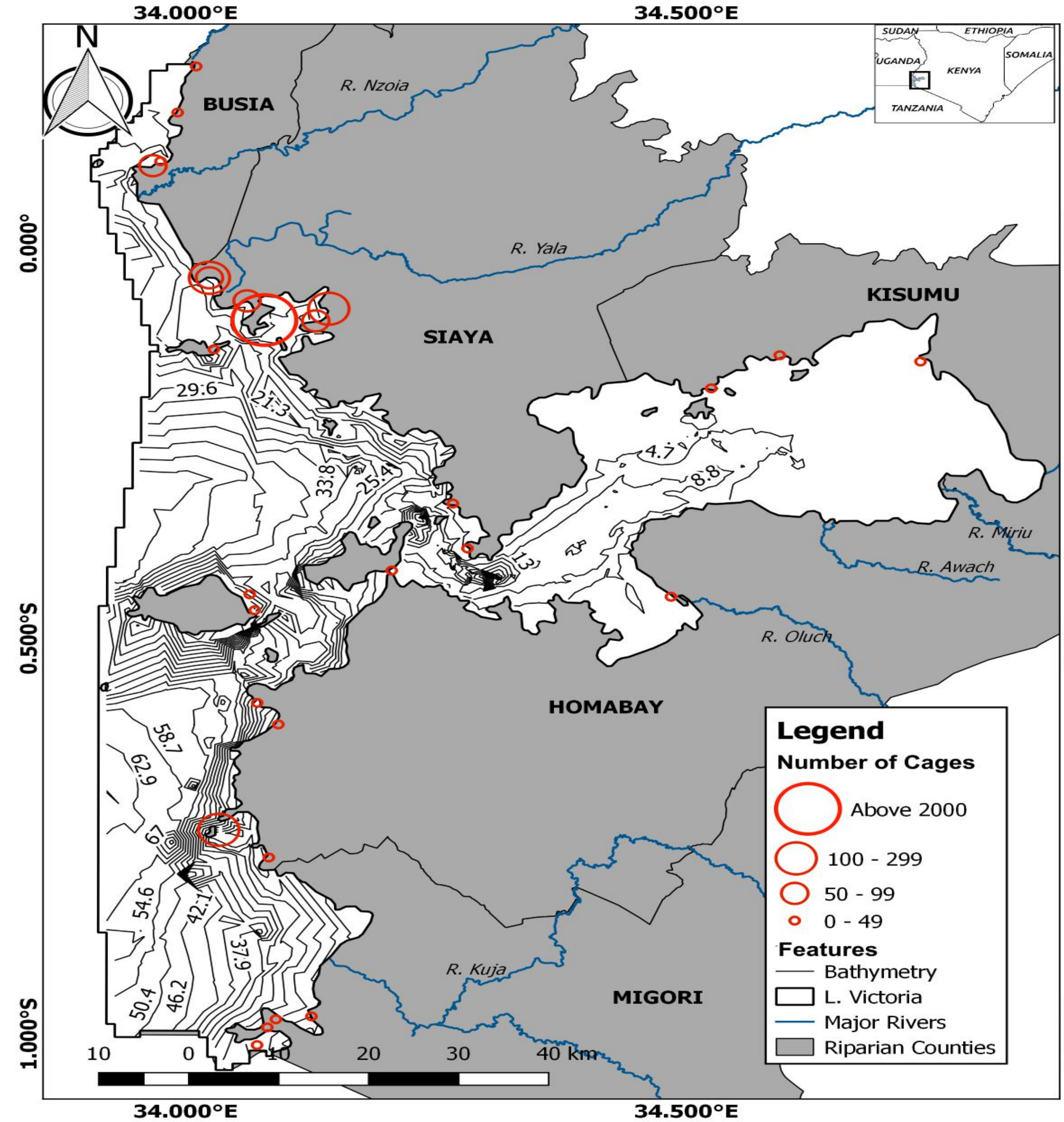

Figure 1: Map of the Kenyan Lake Victoria basin (Kenyan side), indicating number of aquaculture cages and their locations. (KMFRI) (Source : Author, 2019)

3.1.1 Description of the study site

Fieldwork was carried out in the Winam Gulf of the Lake Victoria Basin in Kenya, between the latitudes of 0°20′N and 3°00′S and 31°39′E and 34°53′E, at an elevation of 1134 m. It is the 2nd biggest tropical basin on the world, with a surface area of 68 800 km2 (Awange et al., 2018).The Winam Gulf study site (Fig. 1) due to the blockage of the Mbita Channel, it is artificially divided from Lake Victoria. The Rusinga Channel is insufficient to connect the Gulf to the main lake, and water analyses show that Winam Gulf and Lake Victoria should be treated separately. (Awange & Obiero 2006). The Lake is quite shallow, with a mean depth of 40 meters (Abila et al., 2000) and is shared by Kenya, Uganda, and Tanzania, with each country owning 6%, 43%, and 51% of the shoreline, respectively. The main Lake and the semi-enclosed Nyanza Gulf, also known as Kavirondo or Winam Gulf, make up Kenya's half of Lake Victoria. The Sio, Nzoia, Yala, Nyando, Sondu Miriu, and Kuja rivers all originate on the western ridge of the East Africa Rift Valley highland.The temperature in the air varies from 17.1 and 34.8 degrees Celsius. Between December and March are the hottest months. Throughout the year, the water temperature and sun radiation are rather stable (mean 23 °C; 1200 140 ME M –1S –1, respectively). The yearly precipitation fluctuates between 400 and 800 mm, with two distinct seasons: "long rains" from March to May and "shorter rains" from November to December which are no loger the same due to climate change. The east and south monsoons, as well as westerly air streams, are the key primary determinants of the annual cycle of water mixing in the lake (Budeba et al., 2007).

The Lake is home to one of the planet's greatest commercial lake basin fisheries as well as a vital source of nutrition for millions of people (Simonit et al., 2005). The Lake's watershed sustains a fast rising population of almost 40 million people, whose activities have a significant impact on it (Yongo et al., 2005). As a result, the importance of the Lakes from a socioeconomic viewpoint cannot be overstated. It provides a source of money through fishing and fisheries employment, as well as goods and services like as food to the riparian settlement (Bokea and Ikiara, 2000). Nile perch (*Lates niloticus*), omena (*Rastrineobola argentea*), and Nile tilapia (*Oreochromis niloticus*) are the most important commercial fish types (Njiru et al., 2005; Njiru et al., 2007). Omena, is known to provide protein diet source for a certain population living in the Lakeside (Wanink, 1999).

3.2 Study design

A randomized sampling design was employed due to the wide spread of beaches at the lake. At each sampling points, random samples of fish, and potential fish feeds i.e. formulated feeds and the in-situ based feeds (omena and lake shrimps) samples were collected from the twenty stations of the Winam Gulf of the Lake Victoria Basin (LVB) (mean values ±standard error). The sampling points was guided by the presence of aquaculture farming activities. Samples were collected from all accessible aquaculture farming sampling points.

Plate 1: Formulated fish pellets and Nile tilapia collection at a cage farming site of Winam Gulf of LVB (Source: Author, 2019)

3.2.1 Fish feeds samples collection

The species sampled included *Oreochromis niloticus* (Nile tilapia), *Rastrineobola argentea* (omena), *Caridina niloticus* (shrimp) and formulated feed pellets.

i) *Caridina nilotica* and *Rastrineobola argentea* sampling

The number of samples collection for each feed were collected from at least three vendors dealing in the feeds and local fishermen / cage owners on two sampling occasions in May 2019 and November 2019 from five Sites. The sampling sites were defined using a Global Positioning System (GPS) and using a mobile application Maps. Me®. The feed samples *Caridina niloticus* (Lake shrimp) were collected alongside the *Rastrineobola argentea* (omena) within the same sites of the Winam Gulf as shown in the map (**Fig 1**) and were locally sundried. The feed samples were well stored in a clean plastic bag and placed in the cooler box for transportation to the University of Eldoret Biotechnology laboratory, Eldoret, Kenya, for freeze drying prior to transportation for analysis at the British Geological Survey, UK. Lake shrimp samples (**Plate 2**) and Omena samples (**Plate 3**) were collected from local vendors whereas the formulated feed pellets (**Plate 4**) were collected from local cage-fish farmers.


Plate 2: *Caridina niloticus* (Lake shrimps) samples (Source: Author, 2019)


Plate 3: *Rastrineobola argentea* (omena) sample (Source: Author, 2019)


Plate 4: Pellets samples (formulated fish feeds) (Source: Author, 2019)

3.2.2 Fish sampling

The station identification sheet for the sampling were initiated by recording the station/site number, date, site description, start time, freezing method being used and the names of the team members. The water temperature in the general area from which fish were collected, measured and recorded on the station Identification Sheet. Fishers at Winam Gulfs captured commercially valuable Nile perch (*L. niloticus*) and Nile tilapia (*O. niloticus*), and cage-cultured fish were procured and purchased directly from local caged fish farmers (**Plate 5 & 6**). All of the fish were dissected, and a 10 cm^3 muscle sample was taken from the lateral muscle of the large fish. Adult and mature wild fish, as well as caged farmed fish, were deliberately caught to obtain the requisite amounts of fish muscle tissues, as well as to determine the fish gender and weigh organs in the field. The fish (cage fish and wild fish) were acquired from local fish farmers and fishermen.

Plate 5:Type 1 fish cages of Winam Gulf of LVB (Source: Author, 2019)

Plate 6: Type 2 fish cages at Winam Gulf of LVB (Source: Author, 2019)

Plate 7: Sample collection done by UoE, BGS and KMFRI Research team at the LVB (Source: Author, 2019)

3.2.3 Sample preparation and storage of fish feeds prior to digestion

The commercial feeds, as well as omena and Lake shrimp meat, were sampled individually and homogenized samples (50g each) were stored at -20 °C until further examination. Each sample was freeze dried at -60 °C using a freeze drier (Harvest right) until a homogeneous weight was attained before proximate analysis. Using a grinder, the samples were ground into powder (MX-151SG1, Panasonic, China). After that, the samples were sealed and held at -20 °C until the formation in close proximity was determined.

3.2.4. Acid digest process for feeds and Multi-element analysis

All the samples were analyzed at the British Geological Survey. In-situ based fish feed samples of *R. argentea* and *C. nilotica* (0.25 g) were digested using a mixed acid solution of Nitric acid, HNO_3: 10mL, HNO_3: 5mL, Hydrogen peroxide, H_2O_2: 1Ml in an open vessel on a programmable hot block as described previously by Joy et al. (2015) and Watts et al. (2013, 2017) and left to cool for 10 minutes, 20 minutes, and 30 minutes, respectively.

As detailed by Joy et al. (2015) and Watts et al. (2015), multi-elemental studies were performed using an inductively coupled plasma mass spectrometer (ICP-MS; Agilent 7500cx) (2013, 2017). Using a DMA-80 direct mercury analyser (Milestone Inc.) and 0.07–0.010 g of freeze-dried fish, total mercury (Hg) in fish feed was determined. Feed samples were weighed into individually pre-cleaned nickel weighing boats (heated to 550°C for 5 minutes), randomized in batches of 10, thermally degraded (using an O_2 rich furnace) at 650°C, and quantifiably analyzed by atomic absorption.

3.2.5 Statistical Analyses

The element concentrations in the fish meals were statistically examined using a one-way analysis of variance (ANOVA), this aid in removing them as the dry weight in the results section. For differentiation between significantly different means, post-hoc analysis was utilized. Following an outlier analysis, linear regression analysis was used to examine the correlations between nutritional element concentration in fish feeds at different sites. The 5 percent significance threshold (significance probability level of $p<0.5$) were subjected to parametric analyses and computations.

CHAPTER FOUR

RESULTS

4.1 Micronutrients concentrations in the different cage aquaculture feeds

The different feeds comprising the commercially formulated pellets (Pellets) and in-situ derived feed consisting of *R. argentea* (omena) and *C. niloticus* (lake shrimp) were compared for concentrations of the micronutrients boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si) and zinc (Zn). The different feeds contain comparable mineral content for Omena, Shrimp and pellet (**Fig. 2**).

Higher concentrations of the elements B (6.87 ± 1.49 mg/kg), Cu (32.97 ± 6.62 mg/kg), Fe (942.70 ± 246.01 mg/kg), Mn (137.30 ± 34.13), Mo (0.68 ± 0.13 mg/kg) and Si (105.48 ± 16.04 mg/kg) were observed in shrimp compared to omena where B (1.89 ± 0.72 mg/kg), Cu (5.59 ± 0.50 mg/kg), Fe (203.11 ± 10.30 mg/kg), Mn (52.59 ± 4.70 mg/kg), Mo (0.19 ± 0.01 mg/kg) and Si (35.78 ± 2.01 mg/g) were in lower concentrations. While in lower levels of Se (1.03 ± 0.10) and Zn (181.16 ± 18.76) were observed in the shrimp compared to omena samples Se (1.44 ± 0.06 mg/kg) and Zn (286.33 ± 19.05) (**Fig. 2**).

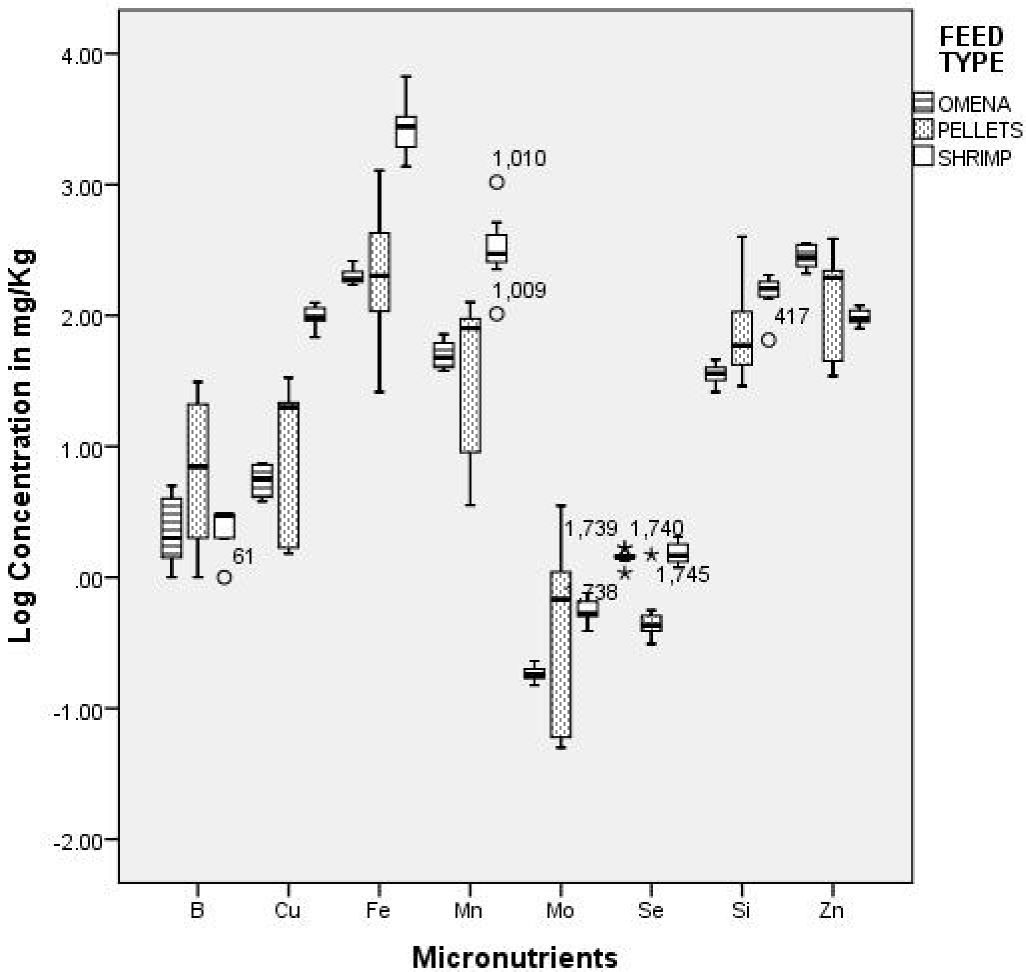

Figure 2: Box plots showing Micronutrients concentration in in-situ based feeds and formulated feeds (mg/kg; wet weight)

4.2 Macronutrients concentrations in the different cage aquaculture feeds

The different feeds comprising the commercially formulated pellets and in-situ derived feed consisting of omena and shrimp were compared for concentrations of the macronutrients Ca (calcium), Potassium (K), Magnesium (Mg), Phosphorus (P) and Sulphur (S). The different feeds contain comparable mineral content in omena, shrimp and formulated feeds (**Fig. 3**).

Higher levels of key minerals of K and Mg and lower concentrations of P, S and Ca were observed in the formulated mixed pellets than in the in-situ feeds i.e. shrimp and omena (**Fig. 3**).

For instance, the mean concentrations of higher level of key minerals of K (16075.15 ± 1299.19 mg/kg). and Mg (2684.38 ± 309.91 mg/kg) were observed in the formulated feed pellet sample. The mean concentrations of key minerals of P (13028.85 ± 845.76 mg/kg), S (9520.15 ± 1092.80 mg/kg) and Ca (11248.92 ± 2318.40 mg/kg) were observed in the omena samples (**Table. 4)**. The *in situ* based feeds contain comparable mineral content to the formulated feeds (pellets) **(Fig. 10).**

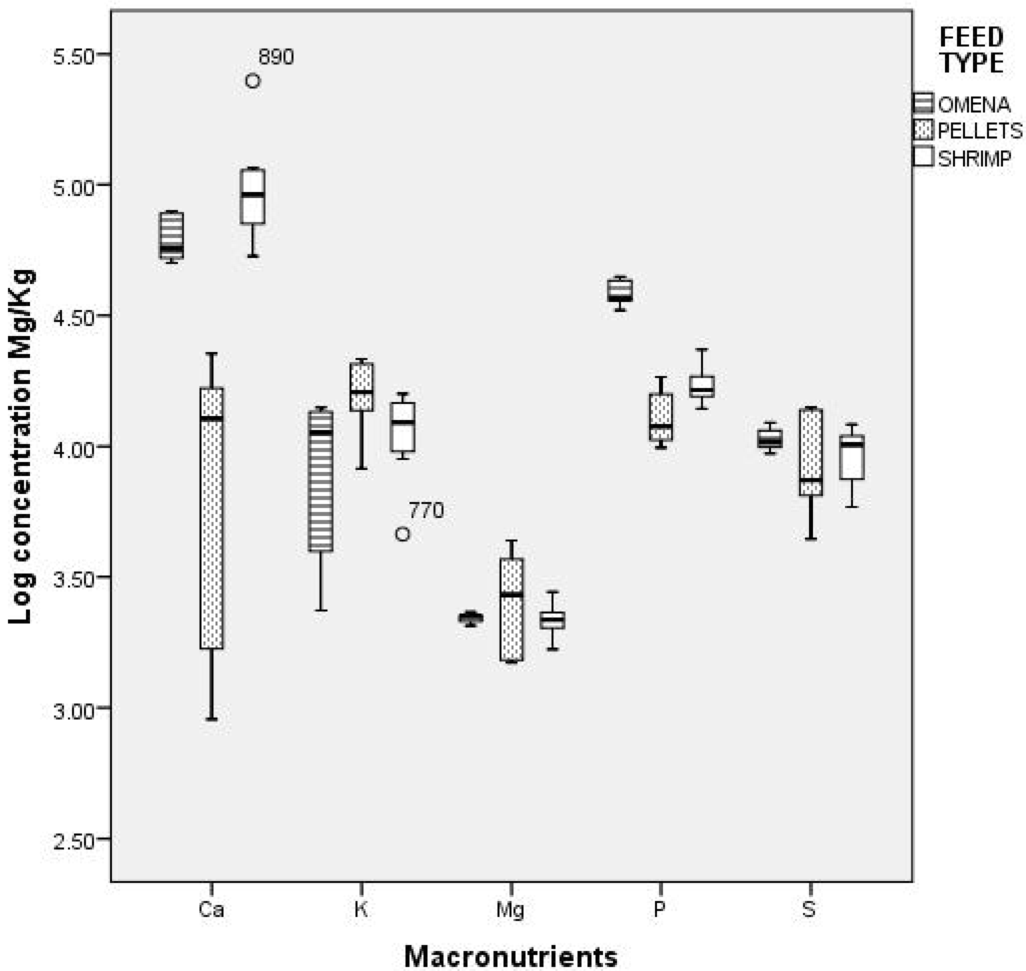

Figure 3: Box plots showing macronutrients concentration in in-situ based feeds and formulated feeds (mg/kg; wet weight).

4.3 Potential toxic elements' concentrations in the different cage aquaculture feeds

The different feeds comprising the commercially formulated pellets (Pellets) and in-situ derived feed consisting of *R argentea* (Omena) and *C nilotica* (Shrimp) were compared for concentrations of the Potential Toxic Elements (PTEs), Aluminum (Al), Barium (Ba), Mercury (Hg), Lead (Pb), Cadmium (Cd), Silver (Ag), Tin (Sn), Arsenic (As), Chromium (Cr) and Lithium (Li).

Caridina niloticus (shrimp) is highly abundant in the Lake and is a key component of *Oreochromis niloticus*, tilapias diet. However, elevated levels of Potentially Toxic Elements (PTEs) of Hg, Al, As, Ba, Cd, Cr, Li, Pb and Sn were observed in shrimp tissue (**Fig. 4**).

For instance, the mean concentrations of PTEs; Ag (0.06 ± 0.02 mg/kg), Al (680.76 ± 0.02 mg/kg), As (0.99 ± 0.17 mg/kg), Ba (98.56 ± 23.69 mg/kg), Cd (0.09 ± 0.01 mg/kg), Cr (9.69 ± 3.21 mg/kg), Li (0.45 ± 0.10 mg/kg), Pb (0.45 ± 0.10 mg/kg) and Sn (0.06 ± 0.02 mg/kg) were observed in the Lake shrimp samples (**Table 5).**

The commercial feed pellets were more variable in Potentially Toxic Elements (PTEs) levels than the in situ feeds (omena and the lake shrimps). For example, the mean concentrations of As (0.35 ± 0.11 mg/kg) in pellets were observed to be lower compared to As (0.73 ± 0.09 mg/kg) and (0.99 ± 0.17 mg/kg) in omena and shrimps respectively. Similarly, Hg (0.01 ± 0.002 mg/kg) in pellets were lower compared to the Hg (0.05 ± 0.01 mg/kg) and Hg (0.03 ± 0.01 mg/kg) concentrations in omena and shrimps respectively (**Table 5**).This could be due to trophic feeding and also mixing processes in pellet manufacture.

The different feeds contain comparable PTEs for omena, shrimp and pellet (**Fig. 4 & 5**).

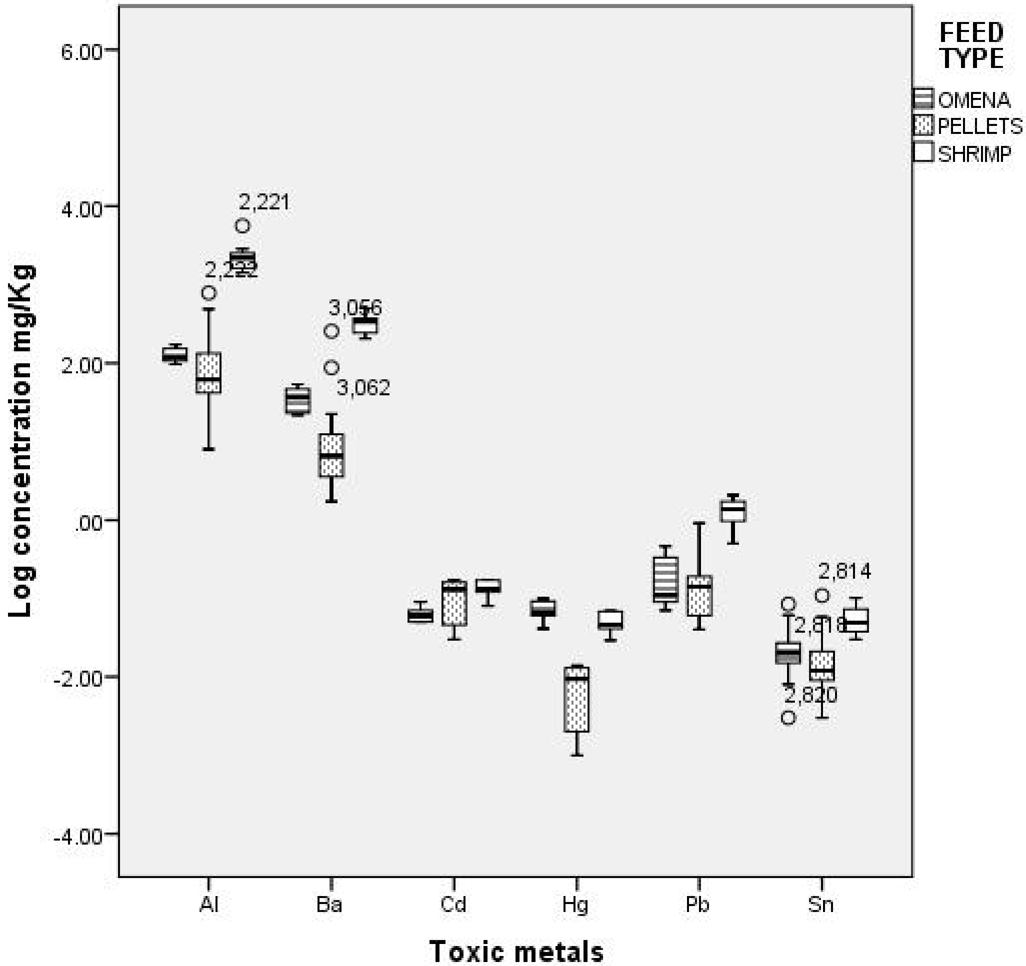

Figure 4: Box plots showing Potential Toxic Elements (PTEs) concentration in mg/kg for in-situ based feeds and formulated feed pellets (mg/kg; wet weight)

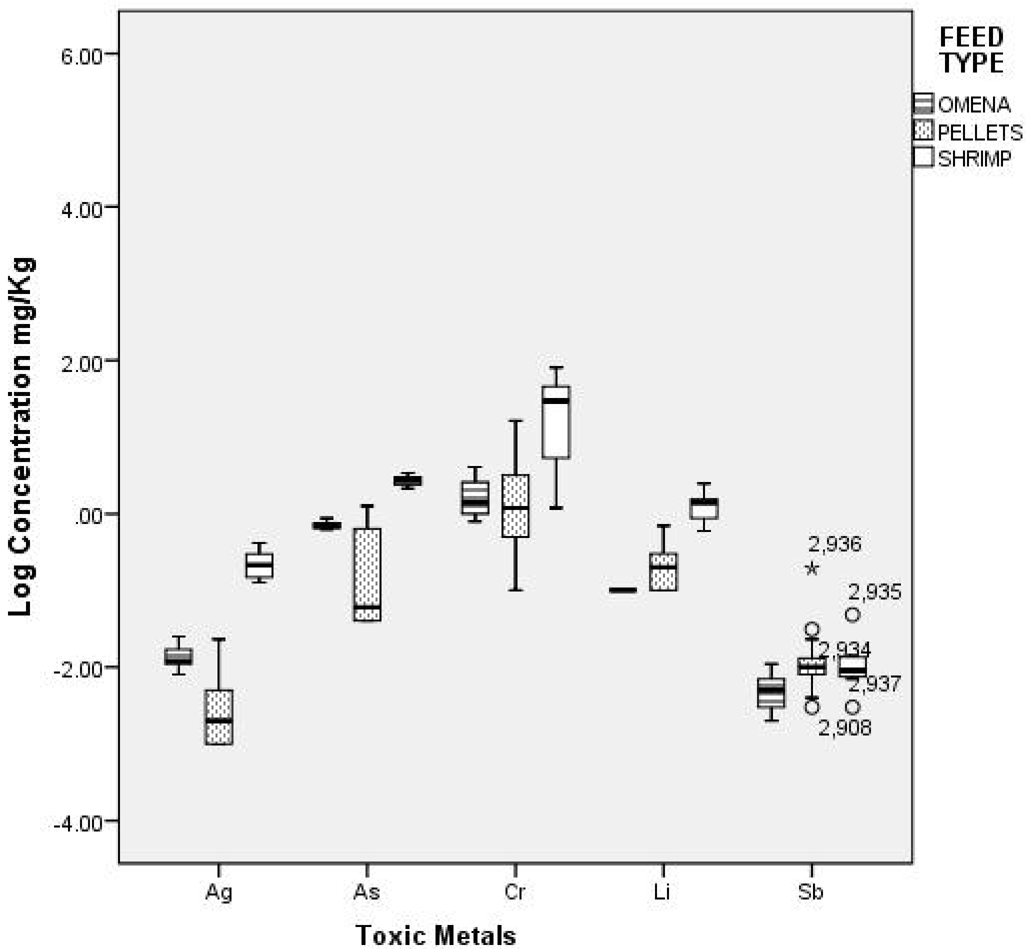

Figure 5: Box plots showing Potential Toxic Elements (PTEs) concentration in mg/kg for in-situ based feeds and formulated feed pellets (mg/kg; wet weight)

4.4 Caged and wild fish muscles of nile tilapia

The different fish comprising the caged fish and wild fish were compared for concentrations of the micronutrients boron (B), iron (Fe), manganese (Mn), silicon (Si), zinc (Zn), molybdenum (Mo), copper (Cu) and selenium (Se). The different fish contain comparable micronutrient in fish muscle for caged/farmed fish and wild fish (**Fig. 6**).

A comparison of caged fish that were fed exclusively on formulated commercial pellet feeds with the wild fish revealed no discernible change in the level of micro-elements in their muscle tissues. The key micro-element concentrations of Cu, Mn, Mo, Si and Zn were significantly higher in the muscle tissue of caged fish than in wild fish except for B and Se (**Fig. 6**).

For instance, the mean concentrations of key micro-elements of Cu (4.39 ± 1.38 mg/kg), Mn (2.96 ± 0.46 mg/kg), Mo (0.08 ± 0.01 mg/kg), Si (42.49 ± 4.80 mg/kg) and Zn (31.57 ± 1.60 mg/kg) were observed in the caged fish muscles samples. The mean concentrations of B (0.59 ± 0.17 mg/kg) and Se (0.61± 0.02 mg/kg) were in lower levels of key minerals of B and Se caged fish samples respectively (**Table 1**).

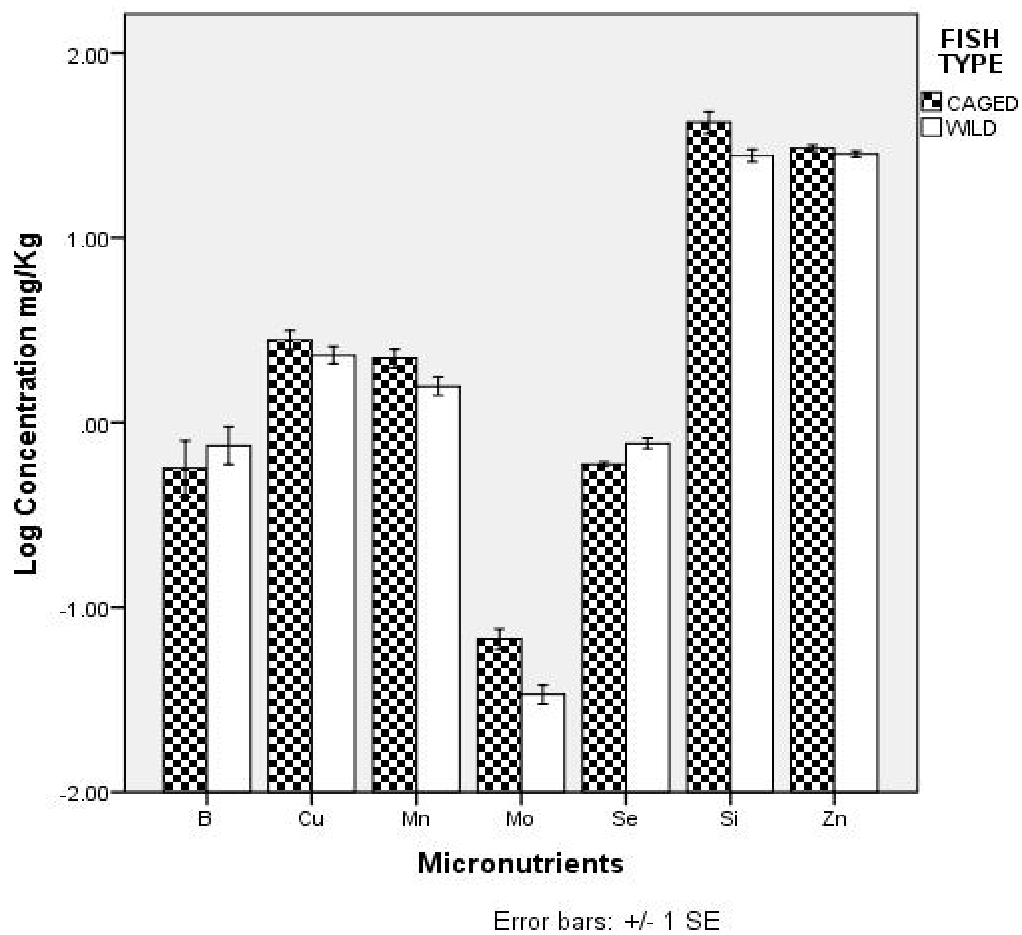

Figure 6: A bar graph showing the concentrations of caged fish and wild fish against essential micronurients in fish muscle (mg/kg; wet weight)

Table 1: A table showing the mean (±SE) concentration of essential nutrients (micronutrients and macronutrients) of caged fish muscles and wild fish muscles in Winam Gulf of Lake Victoria, Kenya (mg/kg; wet weight). SE=Standard error of the mean, means with different letters are significantly different from each other

Nutrient	Elements	Cage fish muscles	Wild fish muscles
Micronutrient	B	0.59 ± 0.17	0.76 ± 0.12
	Cu	4.39 ± 138	3.75 ± 0.83
	Fe	26.57± 1.90	25.28 ± 1.14
	Mn	2.96 ± 0.46	2.57 ± 0.32
	Mo	0.08 ± 0.01	0.07 ± 0.01
	Ni	0.19 ± 0.05	0.19 ± 0.04
	Se	0.61± 0.02	0.68 ± 0.03
	Si	42.49 ± 4.80	34.57 ± 3.52
	Zn	31.57 ± 1.60	30.22 ± 0.98
Macronutrient	Ca	1951.42 ± 434.28	3368.72 ± 518.93
	Co	0.06 ± 0.01	0.05 ± 0.00
	K	23223.55 ± 300.16	23440.15 ± 213.45
	Mg	1574.23 ± 25.08	1592.22 ± 17.33
	Na	2948.58 ± 82.95	2893.06 ± 52.24
	P	11666.65 ± 214.88	12513.26 ± 270.48
	S	14171.87 ± 367.83	14337.68 ± 196.15

The different fish comprising the caged fish and wild fish were compared for concentrations of the macronutrients Ca (calcium), Potassium (K), Magnesium (Mg), Phosphorus (P) and

Sulphur (S). The different fish contained comparable macronutrients in the fish muscle tissue for both the caged fish and wild caught fish (**Fig. 7**).

A comparison of caged fish that are fed exclusively on formulated commercial pellet feeds with the wild fish revealed no discernal change in the level of micro-elements in their muscle tissues. The key macro-element levels of Ca and P were significantly higher in the muscle tissue of caged fish than wild fish (**Fig. 7**).

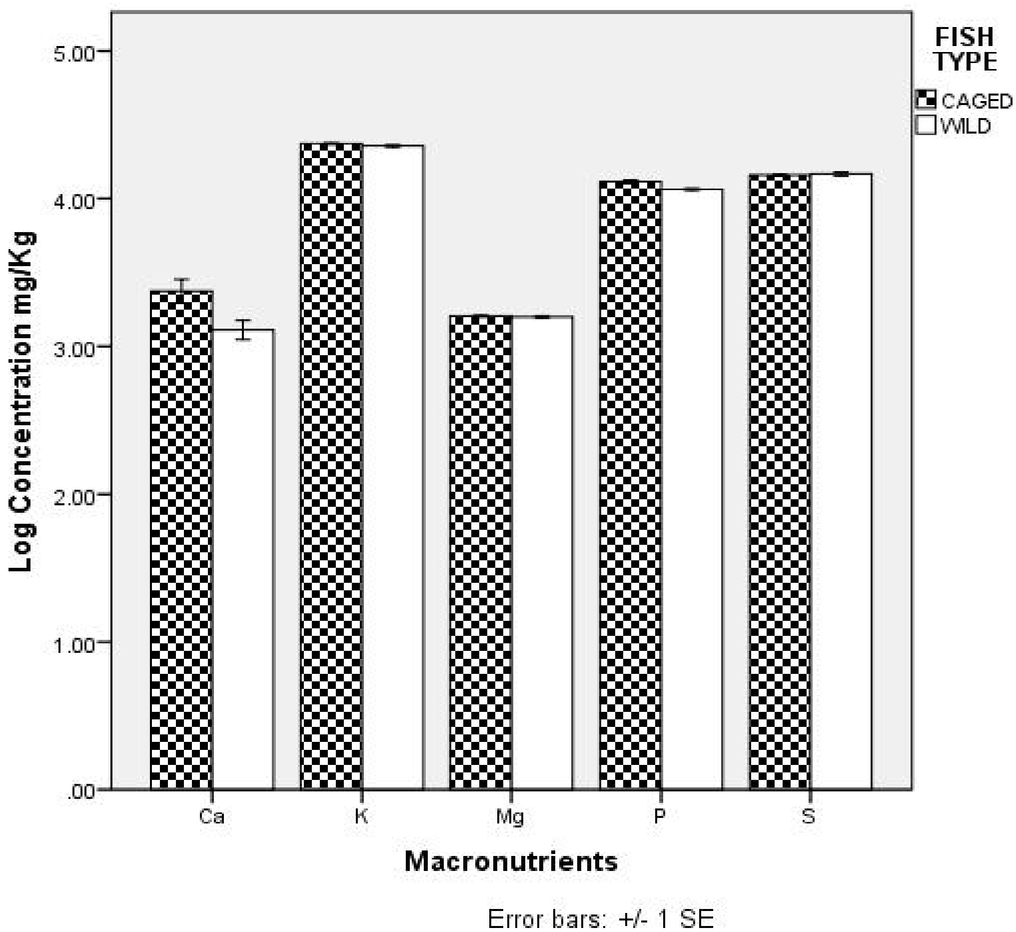

Figure 7: A bar showing the concentrations of caged tilapia fish and wild tilapia fish against essential macronutrients in fish muscle (mg/kg; wet weight)

For instance, the mean concentrations of 1951.42 ± 234.28 mg/kg dry wt. and 11666.65 ± 214.88 mg/kg dry wt. were observed in the key micro-elements of Ca and P in the caged fish muscles samples respectively (**Table 1**). Notably, the latter had relatively empty stomach contents while the former who are fed ad libitum had mostly filled guts. It is possible that the caged fish obtain better nourishment and therefore better quality nourishment to human consumers with regards to macro-elements.

The different fish comprising the *Oreochromis niloticus* (Nile tilapia) farmed fish were compared for concentrations of the Potential Toxic Elements (PTEs), Al, Ba, Cd, Pb, Sn, Ag, As, Cr and Li.The different fish contain comparable micronutrient in fish muscle for caged fish and wild fish (**Fig 16 & 17**).

The mean concentrations of potentially toxic elements in both the; caged & wild tilapia fish muscle were similar but below thresholds i.e. they were comparable even though consistent albeit insignificant higher levels of toxic element were observed in the wild fish.

The PTEs levels of Ag, Cr, Li, Al, Cd, Hg and Pb were elevated in wild fish but were not significantly different (**Fig 8 & 9**).

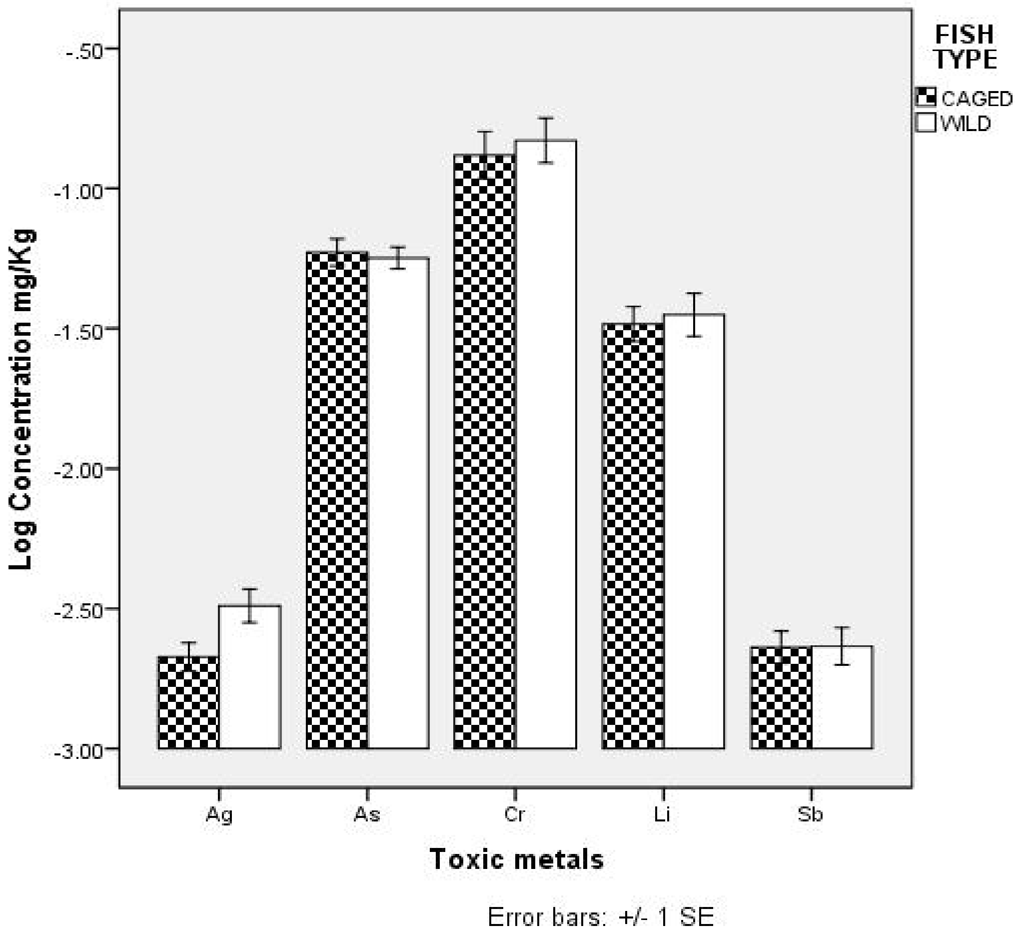

Figure 8: Bar graph showing concentration of caged tilapia fish and wild tilapia fish against Potentially Toxic Elements (PTEs)in Lake Victoria Basin (mg/kg; wet weight)

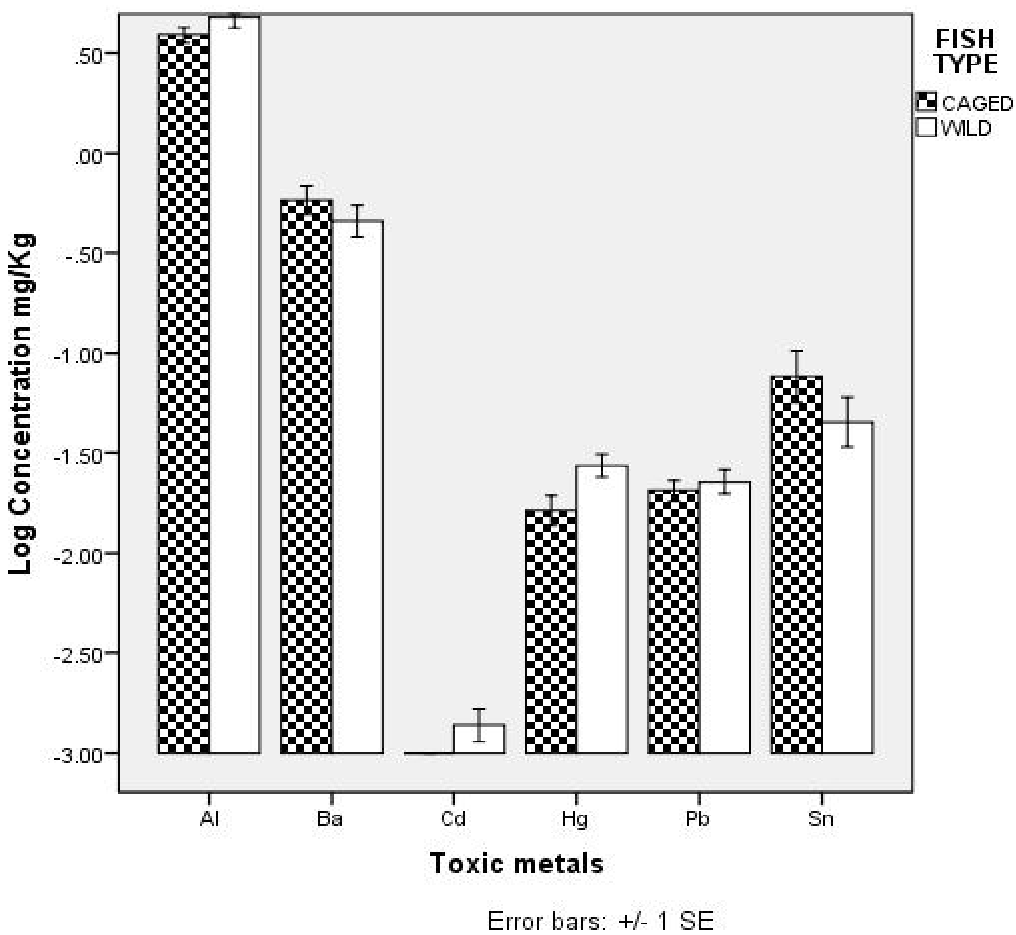

Figure 9: A bar graph showing the concentrations of caged tilapia fish and wild tilapia fish against Potentially Toxic Elements (mg/kg; wet weight)

For instance, the mean concentrations of PTEs of Ag (0.003± 0.0004 mg/kg), Cr (0.34 ± 0.08 mg/kg), Li (0.02± 0.005 mg/kg), Al (5.41± 0.53 mg/kg), Cd (0.0002 ± 0.0001 mg/kg), Hg (0.03 ± 0.003 mg/kg) and Pb (0.03 ± 0.004 mg/kg) were observed in the wild tilapia fish muscles samples (**Table 2**).

The elevated levels in wild tilapia could be the result of a more varied diet, compared to caged tilapia. Another possible explanation for this is that wild tilapia feed on more prey and may be accumulating more of the elements of the water media than the caged fish.

The differences in PTEs and essential mineral element accumulation observed between caged and wild fish were most likely due to environmental variables and dietary element concentrations.

Table 2: Mean (±SE) concentrations of Potentially Toxic Element (PTE) in caged fish muscles and wild fish muscles from Winam Gulf of Lake Victoria, Kenya (mg/kg; wet weight). SE=Standard error of the mean, means with different letters are significantly different from each other

Toxic elements	Caged fish muscle	Wild fish muscle
Ag	0.00 ± 0.00	0.00 ± 0.00
Al	4.62 ±0.63	5.41 ± 0.53
As	0.08 ±0.01	0.07 ± 0.01
Ba	0.99 ±0.20	0.82 ± 0.12
Cd	0.00 ± 0.00	0.00 ± 0.00
Cr	0.33 ± 0.12	0.34 ± 0.08
Hg	0.02 ± 0.00	0.03 ± 0.00
Li	0.02 ± 0.01	0.02 ± 0.01
Pb	0.03 ± 0.01	0.03 ± 0.00
Sb	0.00 ± 0.00	0.00 ± 0.00
Sn	0.35 0.14	0.70 ± 0.09

4.5 Spatial differences in the mineral content

Determining of spatial differences in mineral content, toxic metals and essential metals among the different aquaculture cages on the Winam Gulf of Lake Victoria.

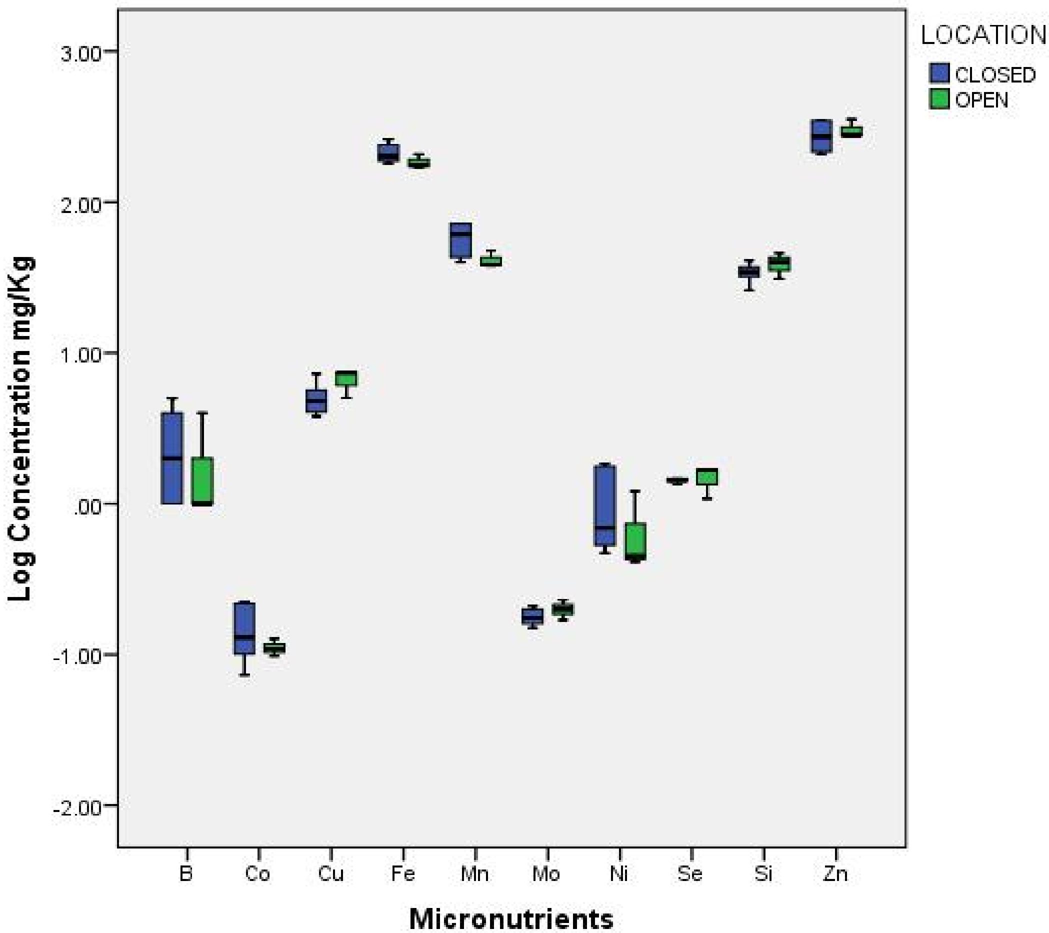

Figure 10: Box plots showing Micronutrient concentration of omena in closed and open Lake Victoria Basin (mg/kg; wet weight)

The analysis of spatial data on micronutrient concentration of omena in closed and open shows that there are areas within Lake Victoria Kenya which have more or less micronutrients concentration than the other. In closed waters of the Lake Victoria Basin, there was higher concentration of B (2.50 ± 0.67 mg/kg), Fe (212.17 ± 13.37 mg/kg) and Mn

(58.22 ± 5.64 mg/kg) as compared to open waters, which had a concentration of B (0.67 ± 1.67 mg/kg), Fe (185.00 ± 11.59 mg/kg) and Mn (41.33 ± 3.24 mg/kg) (**Fig.10 & Table.6**).

In open waters, there was high concentration of omena in Si (39.00 ± 4.36 mg/kg) and Zn (303.33 ± 25.83 mg/kg) as compared to closed water where the concentration were, Si (34.17 ± 2.09 mg/kg) and Zn (277.83 ± 25.35 mg/kg) (**Fig.10 & Table.6**).

There were no big difference between the closed and open lake in the micronutrients concentration of omena in Co, Mo, Ni and Se. In closed lake, the micronutrient concentration of omena were Co (0.15 ± 0.03 mg/kg), Mo (0.18 ± 0.01 mg/kg), Ni (1.00 ± 0.26 mg/kg) and Se (1.42 ± 0.02 mg/kg) whereas in open lake, the micronutrient concentration of omena were; Co (0.11 ± 0.01 mg/kg), Mo (0.20 ± 0.02 mg/kg), Ni (0.69 ± 0.26 mg/kg) and Se (1.47 ± 0.20 mg/kg) (**Fig.10 & Table.6**).

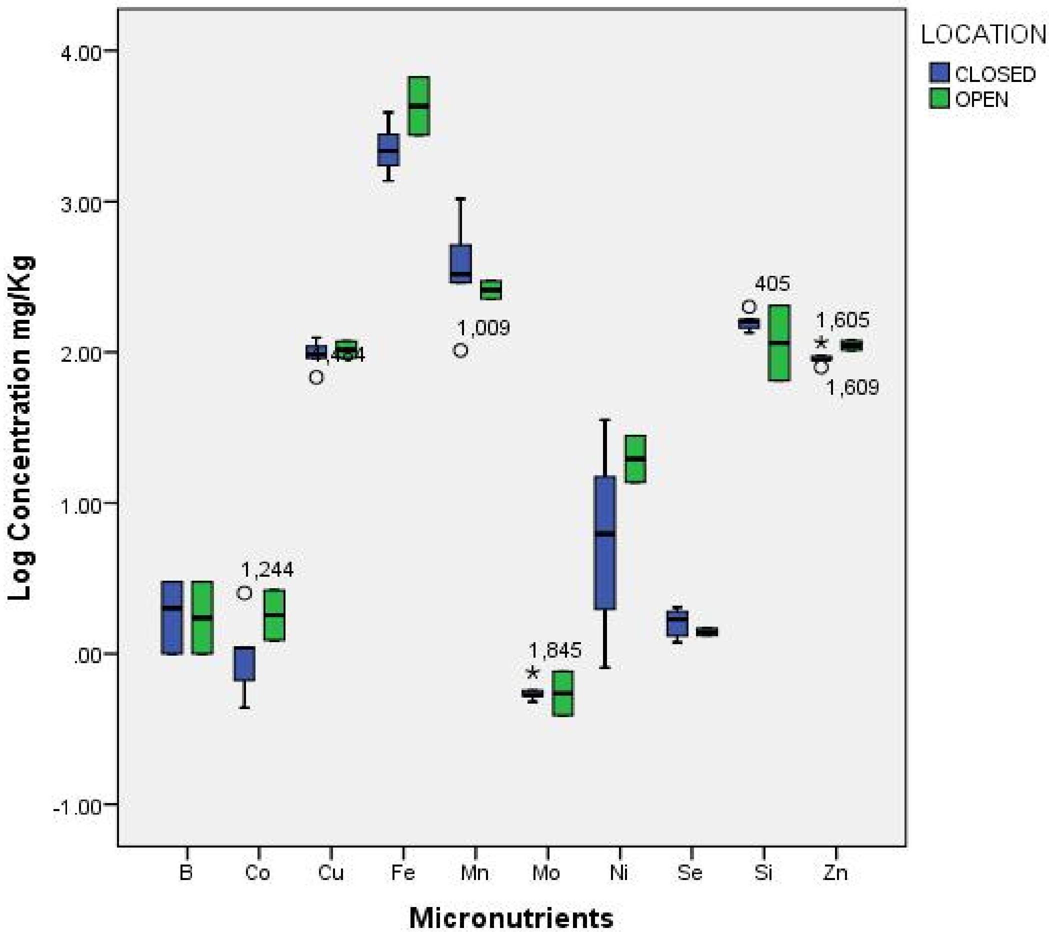

Figure 11: Box plots showing Micronutrient concentration of Lake shrimp in closed and open Lake Victoria Basin (mg/kg; wet weight)

The analysis of spatial data on micronutrient concentration of the Lake shrimp in closed and open shows that there are areas within Lake Victoria Kenya which have more or less micronutrients concentration than the other. In closed waters of the Lake Victoria Basin, there was high concentration of Mn (455.80 ± 160.60 mg/kg) and Si (161.00 ± 11.10 mg/kg) as compared to open waters, which had a concentration of Mn (261.00 ± 35.00 mg/kg) and Si (134.50 ± 69.50 mg/kg) (**Fig.11 & Table.7**).

In open waters, there was high concentration of Co (1.93 ± 0.70 mg/kg), Cu (104.70 ± 13.30 mg/kg), Fe (4723 ± 1960 mg/kg), Ni (20.80 ± 7.10 mg/kg) and Zn (111.00 ± 8.00 mg/kg) as compared to closed water where the concentration were, Co (1.16 ± 0.36 mg/kg), Cu (98.22 ± 9.56 mg/kg) , Fe (2391.20 ± 443.46 mg/kg), Ni (11.88 ± 6.40 mg/kg) and Zn (93.54 ± 6.10 mg/kg) in the Lake shrimp (**Fig.11 & Table.7**).

There were no big difference between the closed and open lake in the micronutrients concentration of Lake shrimp in B, Mo and Se. In closed lake, the micronutrient concentration of Lake shrimp were B (0.80 ± 1.16 mg/kg), Mo (0.57 ± 0.05 mg/kg) and Se (1.62 ± 0.16 mg/kg) whereas in open lake, the micronutrient concentration of Lake shrimp were; B (2.00 ± 1.00 mg/kg), Mo (0.58 ± 0.19 mg/kg) and Se (1.40 ± 0.08 mg/kg) (**Fig.11 & Table.7**).

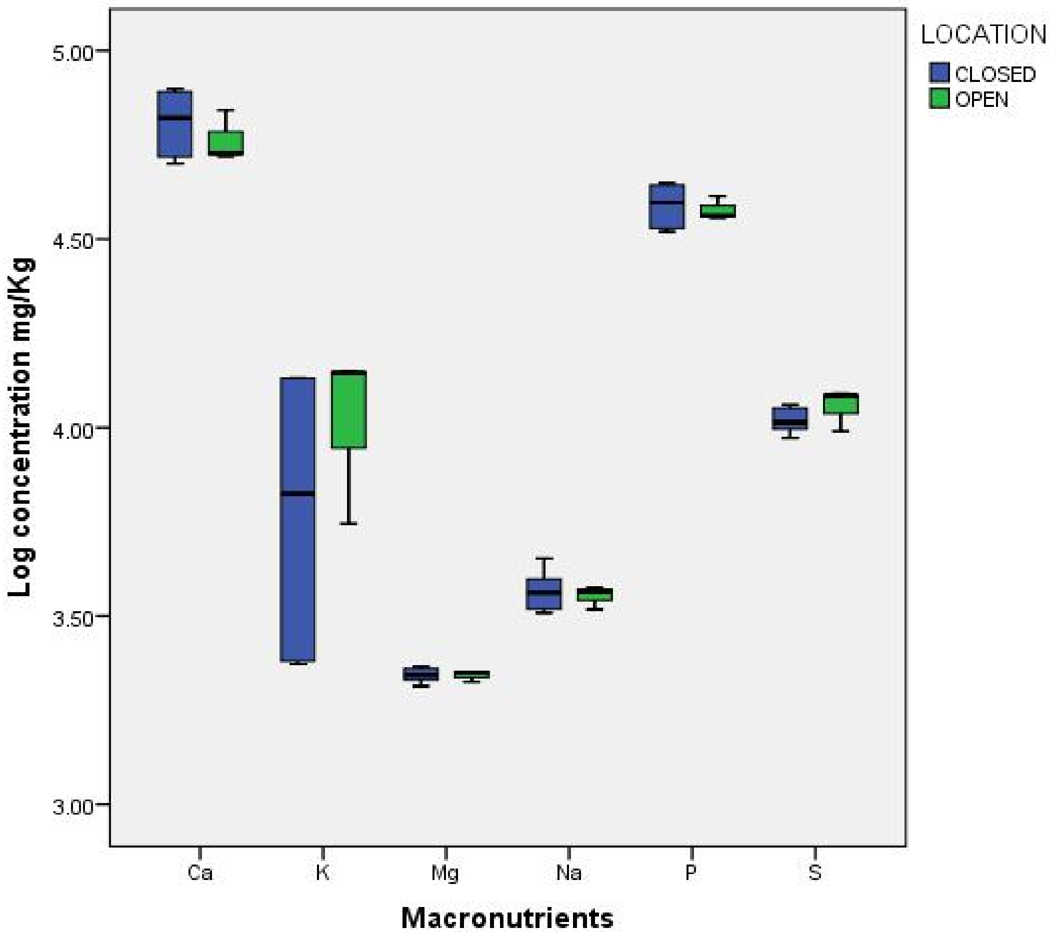

Figure 12: Box plots showing Macronutrient concentration of omena in closed and open Lake Victoria Basin (mg/kg; wet weight)

The analysis of spatial data on macronutrient concentration of omena in closed and open shows that there are areas within Lake Victoria Kenya which have similar or more or less macronutrients concentration than the other. In closed waters of the Lake Victoria Basin, there was high concentration of Ca (65670.50 ± 5691.28 mg/kg) compared to open waters, which had a concentration of Ca (58487.33 ± 5541.29 mg/kg) (**Fig.12 & Table.6**).

In open waters, there was high concentration of K (11213 ± 2824.62 mg/kg) and S (11421.33 ± 825. 96 mg/kg) as compared to closed water where the concentration were, K (7840.33 ± 2245.34 mg/kg) and S (10455.17 ± 328.50 mg/kg)in the omena (**Fig.12 & Table.6**).

There were similar macronutrient concentrations of omena in the closed and open lake in the especially in Mg, Na and P. In closed lake, the macronutrient concentration of Lake shrimp were Mg (2204.17 ± 40.84 mg/kg), Na (3714.33 ± 195.66 mg/kg) and P (39116.83 ± 2168.34 mg/kg) whereas in open lake, the macronutrient concentration of Lake shrimp were; Mg (2198.67 ± 41.88 mg/kg), Na (3574.67 ± 142.23 mg/kg) and P (37916.58 ± 1621.31 mg/kg) (**Fig. 12 & Table.6**).

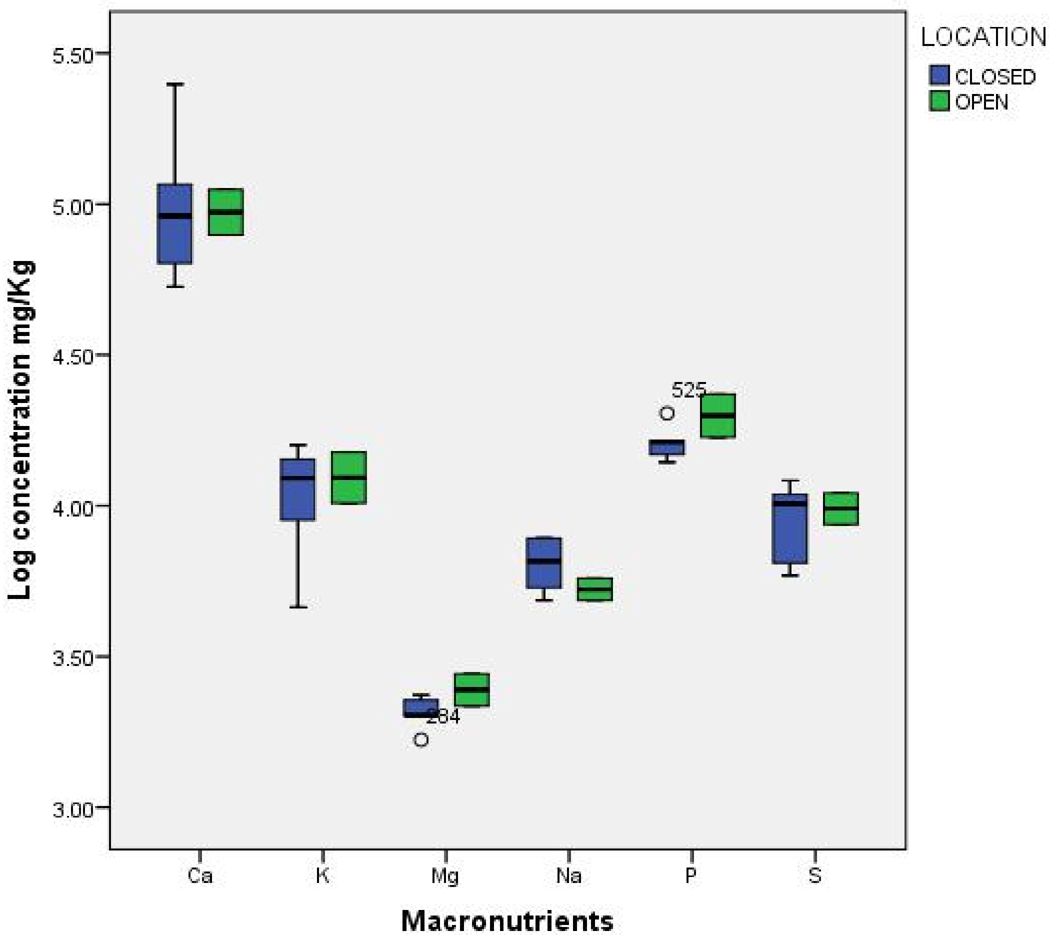

Figure 13: Box plots showing Macronutrient concentration of Lake Shrimp in closed and open Lake Victoria Basin (mg/kg; wet weight)

The analysis of spatial data on macronutrient concentration of omena in closed and open lake shows that the macronutrient levels are more similar than the differences in the micronutrients and Potentially Toxic Elements within the closed and open lake. This is evident in the closed lake where Ca (114944.80 ± 35532.97 mg/kg) , K (11211.00 ± 2014.83 mg/kg)and Na (6478.40 ± 611.79) and S (9097.40 ± 1239.44 mg/kg) were more similar with the open waters, which had a concentration of Ca (95386.00 ± 16454 mg/kg), K (12621 ± 2416 mg/kg) and Na (5296.50 ± 440.50), S(9848 ± 1177) (**Fig.13 & Table.7**).

In open waters, there was high concentration of Mg (2470.00 ± 299.00 mg/kg) and P (20136.50 ± 3295.50 mg/kg)   as compared to closed water where the concentration were, Mg (2066.60 ± 119.34 mg/kg) and P (16343.40 ± 1086.96) in the Lake shrimp (**Fig.13 & Table.7**).

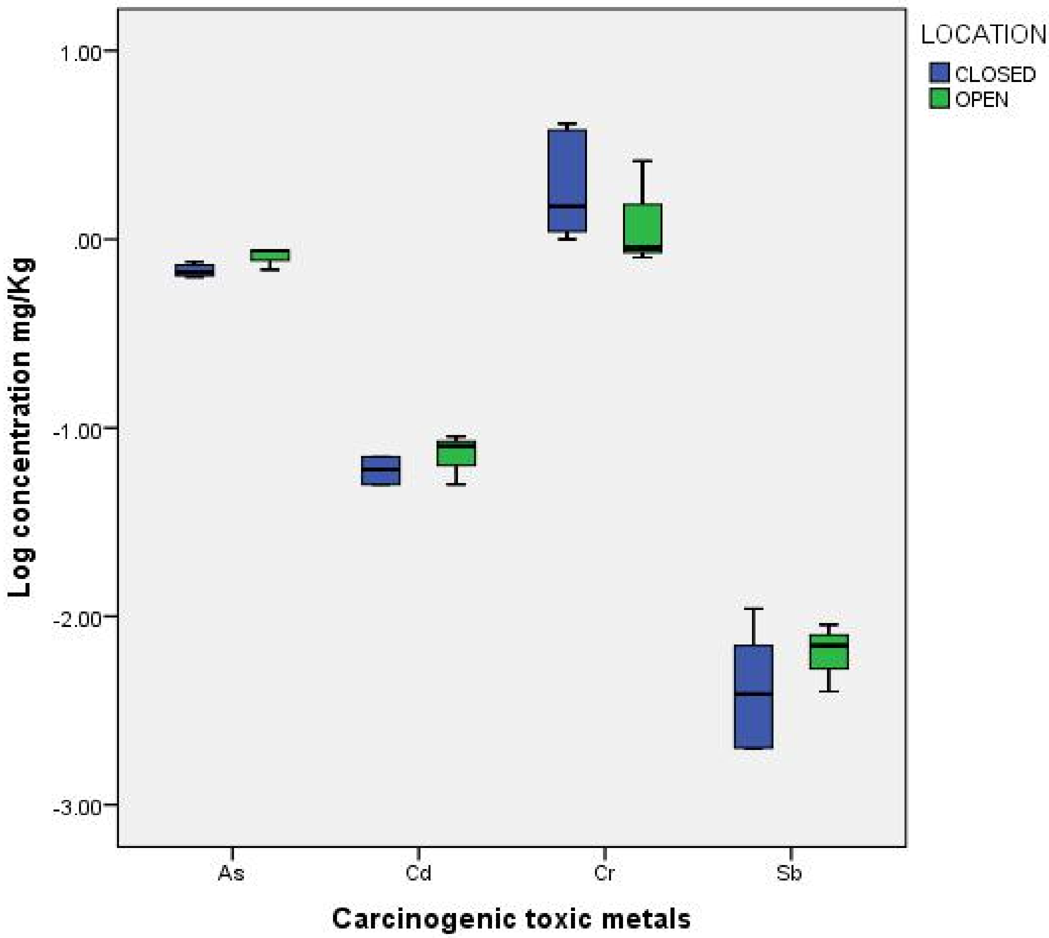

Figure 14:Box plots showing Carcinogenic toxic metals concentration of omena in closed and open Lake Victoria Basin (mg/kg; wet weight)

The analysis of spatial data on Potentially Toxic Elements specifically the carcinogenic toxic metals of omena in closed and open lake shows that there were no big difference between the closed and open lake in the carcinogenic toxic metals concentration of omena in As, Cd, Cr and Sb. In closed lake, the carcinogenic toxic metals of omena were As (0.68 ± 0.02 mg/kg), Cd (0.06 ± 0.00 mg/kg), Cr (2.17 ± 0.57 mg/kg) and Sb (0.01 ± 0.00 mg/kg) whereas in open lake, the carcinogenic toxic metals of omena were; As (0.81 ± 0.06 mg/kg), Cd (0.07 ± 0.01 mg/kg), Cr (1.43 ± 0.58 mg/kg) and Sb (0.01 ± 0.00 mg/kg) (**Fig.14 & Table.8**).

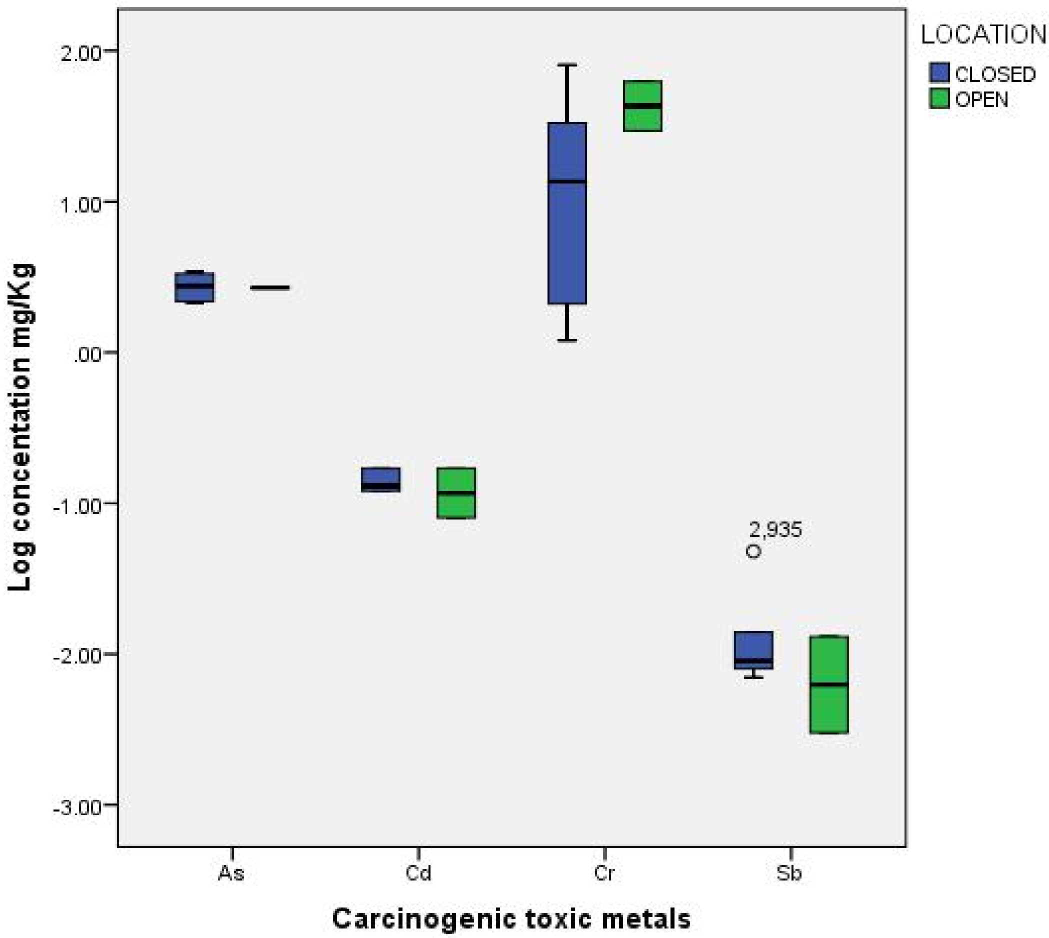

Figure 15: Box plots showing Carcinogenic toxic metals concentration of Lake Shrimp in closed and open Lake Victoria Basin (mg/kg; wet weight)

The analysis of spatial data on Potentially Toxic Elements specifically the carcinogenic toxic metals of the Lake shrimp in closed and open lake shows that there are areas within Lake Victoria Kenya which have more or less carcinogenic toxic metals concentration than the other. In open waters of the Lake Victoria Basin, there was high concentration of Cr (46.20 ± 16.60 mg/kg) compared to open waters, which had a concentration of Cr (26.10 ± 14.77 mg/kg) (**Fig.15 & Table.9**).

There were no big difference between the closed and open lake in the carcinogenic toxic metals concentration of Lake shrimp in As, Cd and Sb. In closed lake, the carcinogenic toxic metals of Lake shrimp were As (2.76 ± 0.27 mg/kg), Cd (0.14 ± 0.01 mg/kg) and Sb (0.01 ± 0.00 mg/kg) whereas in open lake, the carcinogenic toxic metals of Lake shrimp were; As (2.68 ± 0.02 mg/kg), Cd (0.13 ± 0.05 mg/kg) and Sb (0.01 ± 0.00 mg/kg) (**Fig.15 & Table.9**).

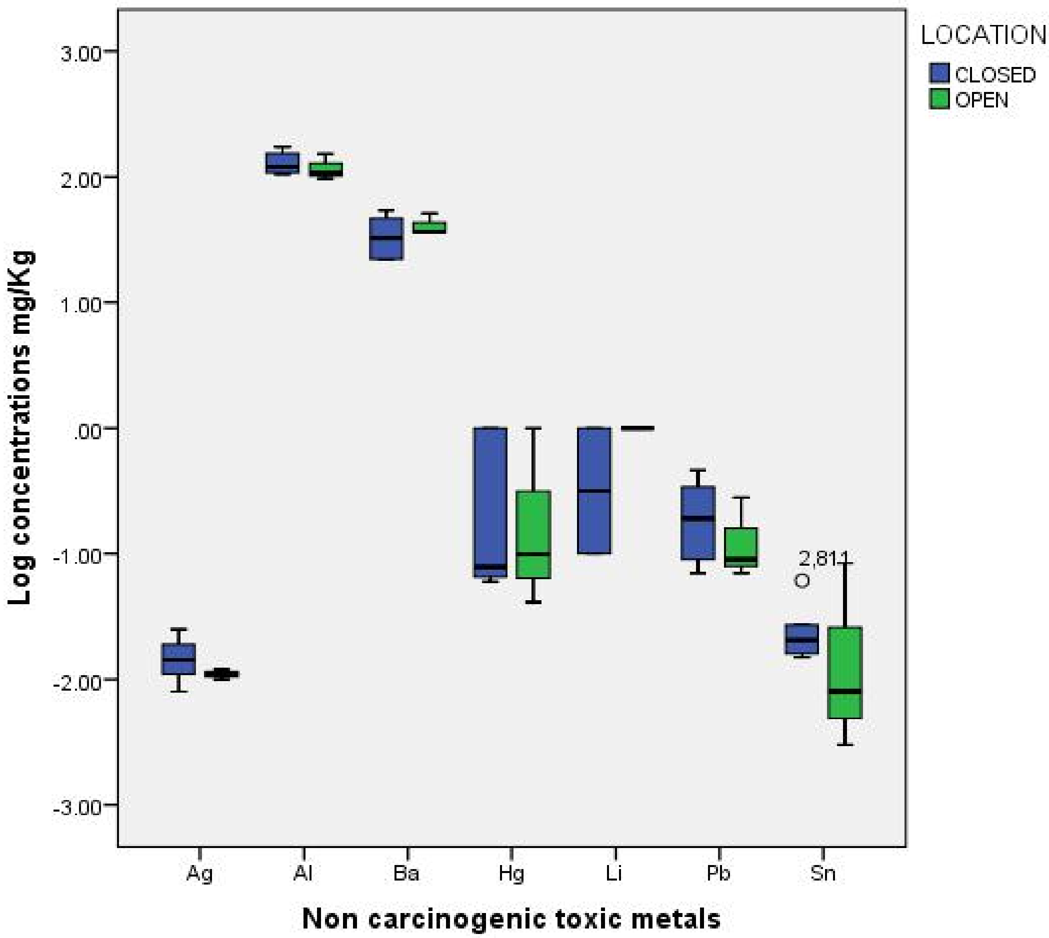

Figure 16: Box plots showing Non-carcinogenic toxic metals concentration of omena in closed and open Lake Victoria Basin (mg/kg; wet weight)

The analysis of spatial data on Potentially Toxic Elements specifically the non-carcinogenic toxic metals of the omena in closed and open lake shows that there are areas within Lake Victoria Kenya which have more or less non-carcinogenic toxic metals than the other. In open waters of the Lake Victoria Basin, there was high concentration of Ba (41.47 ± 4.97

mg/kg) compared to closed waters, which had a concentration of Ba (35.68 ± 4.05 mg/kg) (**Fig.16 & Table.8**).

In closed waters of the Lake Victoria Basin, there was high concentration of Al (130.17 ± 11.15 mg/kg) compared to open waters, which had a concentration of Al (119.00 ± 17.24 mg/kg) (**Fig.16 & Table.8**).

There were no big difference between the closed and open lake in the non-carcinogenic toxic metals concentration of omena in Ag, Hg, Li, Pb and Sn. In closed lake, the carcinogenic toxic metals of omena were Ag (0.02 ± 0.00 mg/kg), Hg (0.05 ± 0.02 mg/kg), Li (0.05 ± 0.02 mg/kg),Pb (0.23 ± 0.07 mg/kg) and Sn (0.03 ± 0.01 mg/kg) whereas in open lake, the carcinogenic toxic metals of omena were; Ag (0.01 ± 0.00 mg/kg), Hg (0.05 ± 0.03 mg/kg), Li (0.00 ± 0.00 mg/kg), Pb (0.15 ± 0.07 mg/kg) and Sn (0.03 ± 0.03 mg/kg) (**Fig.16 & Table.8**).

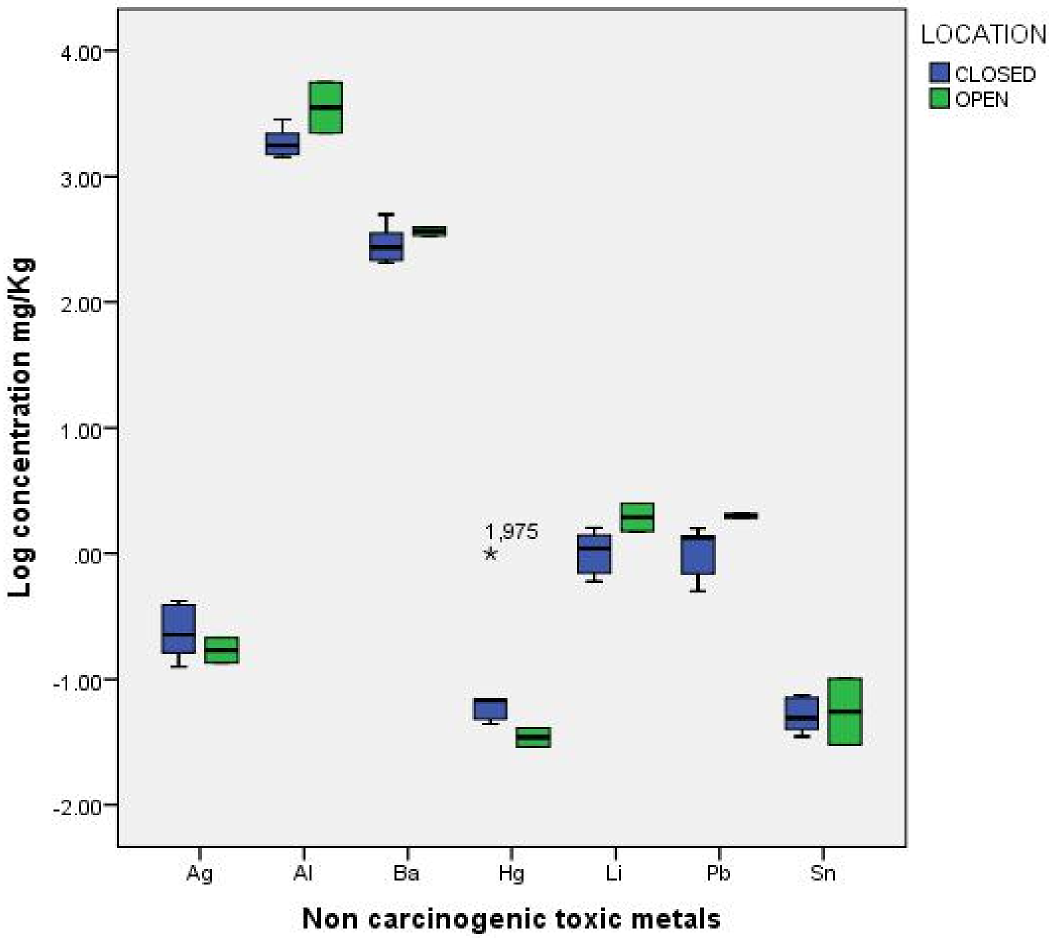

Figure 17: Box plots showing Non-carcinogenic toxic metals concentration of Lake shrimp in closed and open Lake Victoria Basin (mg/kg; wet weight)

The analysis of spatial data on Potentially Toxic Elements specifically the non-carcinogenic toxic metals of the Lake shrimp in closed and open lake shows that there are areas within Lake Victoria Kenya which have more or less non-carcinogenic toxic metals than the other. In open waters of the Lake Victoria Basin, there was high concentration of Al (3919.00 ± 1701.00 mg/kg) and Ba (368.00 ± 28.00 mg/kg) compared to open waters, which had a concentration of Al (1947.80 ± 263.46 mg/kg) and Ba (309.80 ± 54.48 mg/kg) (**Fig.17 & Table.9**).

There were no big difference between the closed and open lake in the carcinogenic toxic metals concentration of Lake shrimp in Ag, Hg, Li, Pb and Sn. In closed lake, the carcinogenic toxic metals of Lake shrimp were Ag (0.26 ± 0.06 mg/kg), Hg (0.05 ± 0.01 mg/kg), Li (1.08 ± 0.19 mg/kg),Pb (1.10 ± 0.21 mg/kg) and Sn (0.05 ± 0.01 mg/kg) whereas in open lake, the carcinogenic toxic metals of Lake shrimp were; Ag (0.17 ± 0.04 mg/kg), Hg (0.04 ± 0.01 mg/kg), Li (2.00 ± 0.50 mg/kg), Pb (2.00 ± 0.09 mg/kg) and Sn (0.07 ± 0.04 mg/kg) (**Fig.17 & Table.9**).

CHAPTER FIVE

DISCUSSION

5.1 Fish feeds concentrations (in-situ based and formulated fish feeds) and fish muscle concentration (wild and caged nile tilapia)

This study was undertaken to determine the difference in feeds on mineral content of the aquaculture fish and effects of diet on their flesh.

5.1.1 Micronutrients mean concentrations in fish feeds and fish muscles

Boron (B) dietary

The present study reveals B accumulated in fish diets examined; the highest mean concentration of (11.62 ± 2.95 mg/kg) was obtained in the formulated feeds (pellets) whereas in in situ based feeds, there was a lower concentration in omena (1.89 ± 0.72 mg/kg) than in shrimp. (**Fig 2 & Table 4**)

On the other hand, the present study also reveals, B accumulated in all fish muscles examined; the highest mean concentration of (0.76 ± 0.12 mg/kg) was obtained in muscle of the wild fish sample in Winam Gulf. Whereas, fish muscle tissue contained the lowest concentration of (0.59 ± 0.17 mg/kg) in caged fish. (**Fig 6 & Table 1**)

It is evident that in comparison on B accumulation in fish feeds were higher than B concentration in fish muscles.

Copper (Cu) dietary

Accumulation of Cu amongst the fish feeds investigated in the current study i.e. *Caridina niloticus,* formulated feed pellets and *Rastrineobola argentea* were in the order (32.96± 6.62 mg/kg), (15.48 ± 3.35 mg/kg) and (5.59 ± 0.50 mg/kg) respectively (**Fig 2 & Table 4**). The increased accumulations of vital metals like Cu in the *Caridina niloticus* could be due to binding proteins like metallothioneins and their role in storage, metabolism, and detoxification, which could increase its ability to store essential metals at higher concentrations. Thus, our findings clearly revealed that Cu concentrations in fish muscles were much lower than the Joint FAO/WHO committee's maximum allowed limits, and greater in the *Caridina niloticus*.

Cu was found in all of the fish muscles investigated in this study, with the greatest mean concentration (4.39 ± 1.38 mg/kg) found in the caged fish muscle sample from Winam Gulf cages. Fish muscle tissue, on the other hand, had the lowest levels (3.75 ± 0.83 mg/kg) among wild fish (**Fig 6 & Table 1).** This could be due to changes in muscle composition as fish grow larger, a decrease in metal absorption in elderly fish's diet, or dilution of growth hormones (Shaw et al., 2011). The concentration of Cu may have been below detection limits, which is a probable scenario. Cu in fish is regulated by the FAO/WHO at 30 mg/kg FAO/WHO (1989). Cu limits in fish in the EU are set at 10 mg/kg EU (2001). The concentration found in fish muscles in this investigation was within permissible limits.

Iron (Fe) dietary

The present study reveals that; Fe accumulated in fish feeds examine where; the highest mean concentration of (942.70 ± 246.01 mg/kg) was obtained in the Lake shrimps and lower concentration (203.11 ± 10.30 mg/kg), (340.92 ± 97.73 mg/kg) in the omena and formulated feeds respectively (**Fig 2 & Table 4**). Dietary iron is required for the regular growth of *Oreochromis niloticus* in a fresh water rearing environment. The current study's findings also suggest that tilapia have an iron requirement that cannot be supplied by the omena's iron concentration, which was lower than that of shrimp..

For fish muscles; our results indicated that highest mean concentration of Fe in fish muscles was (26.57 ± 1.90 mg/kg) in caged fish while lower mean concentration of (25.28 ± 1.14 mg/kg) in wild fish (**Fig 6 & Table 1**). This showed the excessive uptake of iron by fish beyond the optimum level could be detrimental.

Manganese (Mn) dietary

The concentration of Mn varies among the fish feed sample collections in this study. The highest mean Mn content was found to be (137.03 ± 34.13 mg/kg) in *Caridina niloticus*, followed by formulated fish pellets and *Rastrineobola argentea* with a mean concentration of (61.21± 12.97 mg/kg) and (52.59± 4.70 mg/kg) respectively (**Fig. 2 & Table 4**).

Lower development, reduced food consumption, loss of balance, and higher mortality have been observed in Mozambique tilapia fed a less amount of Mn diet (Ambardekar et al., 2007). Mn levels in fishmeal range from 4 to 38 mg/kg, while Mn levels in sea food such as herring and Capelin meals range from 4 to 12 mg/kg. Mn concentrations in grains range from 8 to 50 mg/kg, while corn has 4 to 11 mg/kg. Scientists are still debating the Mn need for tilapia, with some researchers recommending a range of 13 to 15 mg/kg for tilapia (Al-Kahtani et al., 2009).

Mn was found in all of the fish muscles studied in this study, with the caged fish sample in Winam Gulf having the highest mean content (2.96 ± 0.46 mg/kg). On the other hand, the fish muscle tissue contained the lowest concentration of (2.57 ± 0.32 mg/kg) in wild fish (**Fig. 6 & Table 1**). In this study, the mean Mn concentration in the muscles samples from caged and wild fish was similar to some extent.

In Turkey, the Mn standard for fish is stated at 20 mg/kg (Dural et al., 2007). The concentration found in fish muscles in this study was within permissible limits.

In Nile tilapia, a rise in hepatic, bone, and muscle Mn concentration has been seen when the degree of food Mn supplementation increases (Lin et al., 2008). It's crucial to remember that Mn concentrations beyond the optimum range can lead to substantial accumulation in fish tissues, which then bioaccumulates in humans via eating. Age, gender, ethnicity, genetics, and pre-existing medical disorders have all been shown to have a significant impact on Mn exposure in humans (O'Neal & Zheng, 2015).

Molybdenum (Mo) dietary

The present study revealed that Mo accumulated in fish feeds examine; the highest mean concentration of (0.90 ± 0.29 mg/kg) was observed in the formulated feeds, with lower concentration in the in-situ based feeds (0.19 ± 0.01mg/kg), (0.68 ± 0.13 mg/kg) in the omena and shrimps, respectively (**Fig. 2 & Table 4**).

Mo was observed in all of the fish muscles tested, with the caged fish sample in Winam Gulf having the highest mean content of (0.08 ± 0.01) mg/kg. Fish muscle tissue, on the other hand, had the lowest levels (0.07 ± 0.01 mg/kg) in wild fish (**Fig. 6 & Table 1**).

Nickel (Ni) dietary

Ni was found in the fish diets in the present studied, with the highest mean content (5.48 ± 1.41 mg/kg) found in shrimp and lower concentrations (0.90 ± 0.19 mg/kg), (3.16 ± 0.99 mg/kg) found in in-situ based feed i.e. omena and formulated meals, respectively (**Fig. 2 &Table 4**).

Our findings revealed that the mean Ni concentrations in confined and wild fish muscles were comparable. Caged fish had a mean concentration of (0.19 ± 0.05 mg/kg) whereas wild fish had a mean concentration (0.19 ± 0.04 mg/kg) (**Fig. 6 &Table 1**).

The concentration of Ni were below detection limits, which is a likely reason. In fish, the WHO standard for Ni is set at 30.0 mg/kg dry weight WHO (2000). As a result, Ni concentrations in fish feeds and fish muscles from caged and wild fish were significantly lower than the Joint WHO standard committee's maximum allowed limits. Because the concentration of nickel in the fish muscles is within permissible levels, the fish are less dangerous to people, meaning that there is no threat to public health.

Selenium (Se) dietary

The dietary Se requirements of multiple tilapia fish have been published by different researchers. For example, (Ning et al., 2019) found that all tilapia species require Se in the range between 8 mg/kg and 15 mg/kg.

White blood cells (WBC), neutrophils, red blood cells (RBC), and iron levels were found to be significantly higher ($p < 0.05$) in tilapia fed a meal containing 2 mg/kg of Se, and high WBC and RBC were found in tilapia fed an 8 mg/kg Se diet (Iqbal et al., 2017)

The maximum mean concentration of (1.44 ± 0.06 mgk/g) was detected in the omena, while lower concentrations of (1.03 ± 0.10 mg/kg) (0.52 ± 0.08 mg/kg) in shrimp and formulated diets, respectively, were found in the present study (**Fig 2 & Table 4**).

Se accumulated in all fish muscles investigated in this research, with the greatest mean concentration (0.68 ± 0.03 mg/kg) found in the muscle of a wild fish sample from the Winam Gulf. Fish muscle tissue, on the other hand, had the lowest concentration (0.61 ± 0.02 mg/kg) in caged fish (**Fig. 6 & Table 1**).

Silicon dietary

The highest mean concentration of (112.38 ± 34.17 mg/kg) was found in formulated meals, with lower concentrations of (35.78 ± 2.01 mg/kg), (105.49 ± 16.04 mg/kg), and (35.78 ± 2.01 mg/kg) in omena and shrimp, respectively (**Fig 2 & Table 4**).

The present examination also discovered that Si accumulated in all fish muscles investigated; the muscle of the caged fish sample in Winam Gulf had the greatest mean concentration of (42.49 ± 4.80 mg/kg). Fish muscle tissue, on the other hand, had the lowest concentration (34.57 ± 3.52 mg/kg in wild fish) (**Fig. 6 & Table 1**).

Zinc (Zn) dietary

According to the findings of (Barros et al. 2013), the pivotal moment for Zn uptake was 36.29 mg/kg diet, with the highest uptake occurring in the absence of Zn addition and the lowest occurring at 320 mg/kg diet. In Nile tilapia fed an enhanced (327 mg/kg) dietary Zn addition, growth was suppressed, blood glucose levels were higher, cortisol levels were higher, and activated ammonia levels were higher (Evans et al., 2006). The loss of protein and lipid levels in fish exposed to high Zn concentrations above the optimal range has been associated with increased protein oxidation with Zn (Abdel-Tawwab et al., 2016).

The highest mean concentration (286.33 ± 19.05 mg/kg) was recorded in omena, while the lowest concentrations (181.16 ± 18.76 mg/kg) and (151.89 ± 30.76 mg/kg) were recorded in shrimp and formulated diets, respectively (**Fig 2 & Table 4**).

Our findings also revealed significant differences in mean Zn concentrations in the analyzed fish muscle tissues and sample locations. The caged fish had the highest concentration of Zn (31.57 ± 1.60 mg/kg), while wild fish had the lowest concentration (30.22 ± 0.98 mg/kg) (**Fig. 6 & Table 1**). The caged fish may have been fed formulated feeds containing enough zinc nutritional, as opposed to wild fish, which rely on natural feeds such as phytoplanktons and algae. Omena could possibly be their source of food, as the Zn concentration in omena was seen to be greater in this current study when compared to shrimp and pellets.

Zn in fish has an FAO/WHO standard of 40 mg/kg (1989). In this investigation, the concentration in fish muscles was within acceptable limit. As a result, the Zn concentration found in this study was lower than the Joint FAO/WHO committee's maximum acceptable limit.

5.1.2 Macronutrients mean concentrations in fish feeds and fish muscles

Calcium (Ca) dietary

The current study examines the amount of calcium deposited in fish meals; the greatest mean concentration of (63276.11 ± 4181.89 mg/kg) was obtained in the omena and lower concentration of (47307.03 ± 8575.06 mg/kg) and (11248.92 ± 2318.40 mg/kg) in the shrimp and formulated feeds respectively (**Fig. 3 & Table 4**).

Ca was found in all of the fish muscles studied in this study; the highest mean concentrationof (3368.72 ± 518.93 mg/kg) was found in muscle of the wild fish sample in Winam Gulf. Whereas, fish muscle tissue contained the lowest concentration of (1951.42 ± 434.28 mg/kg) in caged fish (**Fig. 7 & Table 1**).

Cobalt (Co) dietary

The current study examines the amount of Co accumulated in fish meals; the lowest mean concentration (0.13 ± 0.02 mg/kg) was obtained in the omena and highest concentration of (0.68 ± 0.12 mg/kg) and (0.61 ± 0.17 mg/kg) in the shrimp and formulated feeds respectively (**Fig 3 & Table 4**).

The current study also indicated that Co accumulated in all fish muscles analyzed; the caged fish sample in Winam Gulf had the highest mean concentration (0.06 ± 0.01 mg/kg). Fish muscle tissue, on the other hand, had the lowest concentration of (0.05 ± 0.00 mg/kg) in wild fish. (**Fig. 7 & Table 1**).

Potassium (K) dietary

The current study discovered that K had accumulated in the fish diets tested; the highest mean concentration of (16075.15 ± 1299.19 mg/kg) was found in the formulated feeds and lowest concentration of (8964.56 ± 1755.42 mg/kg) and (12930.33 ± 906.52 mg/kg) in the in-situ based feeds i.e. omena and shrimp respectively (**Fig 3 & Table 4**).

In comparison to in-situ based feeds, our findings clearly revealed that concentrations of K in fish feeds were available in large quantities in formulated feeds. The shrimp had a higher concentration of K than the omena. The amount of K in a fish's diet has a substantial impact on its growth.

K was found in all fish muscles studied in this investigation, with the highest mean concentration (23440.15 ± 213.45 mg/kg) found in the muscle of a wild fish sample from the Winam Gulf. Fish muscle tissue, on the other hand, had the lowest concentration of (23223.55 ± 300.16 mg/kg) in confined fish (**Fig. 7 & Table 1**).

Magnesium (Mg) dietary

In the present study, the greatest mean concentration of (2684.38 ± 309.91 mg/kg) was achieved in the formulated feeds, whereas the lowest concentrations of (2202.33 ± 29.02 mg/kg) and (2573.64 ± 150.27 mg/kg) were obtained in the in-situ based feeds, namely omena and shrimp, respectively (**Fig 3 & Table 4**).

As a result, our findings clearly revealed that Mg concentrations in fish meals were significantly higher in formulated feeds than in in-situ feeds. The shrimp had a higher concentration of Mg than the omena.

Mg was found in all of the fish muscles studied, with the greatest mean content (1592.22 ± 17.33 mg/kg) found in the muscle of a wild fish sample from the Winam Gulf. Fish muscle tissue, on the other hand, had the lowest levels (1574.23 ± 25.08 mg/kg) in confined fish (**Fig. 7 & Table 1**).

Sodium (Na) dietary

In the present study, the greatest mean concentration of (2684.38 ± 309.91 mg/kg) was acquired in the formulated feeds, whereas the lowest concentrations of (2202.33 ± 29.02 mg/kg) and (2573.64 ± 150.27 mg/kg) were obtained in the in-situ based feeds, namely omena and shrimp, respectively (**Fig. 3 & Table 4**).

Na was found in all fish muscles studied in this study, with the caged fish sample in Winam Gulf having the highest mean concentration of 2948.58 ± 82.95 mg/kg). In wild fish, the lowest concentration was found in the muscular tissue (2893.06 ± 52.24 mg/kg) (**Fig. 7 & Table 1**).

Phosphorus (P) dietary

The maximum mean concentration of (38716.56 ± 1489.35 mg/kg) was found in the omena, with the minimum concentrations of (13028.85 ± 845.76 mg/kg) and (21159.70 ± 2008.51 mg/kg) in the prepared diets and shrimp, respectively (**Fig. 3 & Table 4**).

P was found in all fish muscles studied in this study, with the highest mean concentration (12513.26 ± 270.48 mg/kg) found in the muscle of a wild fish tilapia sample from the Winam Gulf. Fish muscle tissue, on the other hand, had the lowest levels (11666.65 ± 214.88 mg/kg) among confined fish (**Fig. 7 & Table 1**).

Sulphur (S) dietary

The maximum mean concentration of (10777.22 ± 357.41 mg/kg) was found in the omena, with the minimum concentrations of (9520.15 ± 1092.80 mg/kg) and (9536.06 ± 537.23 mg/kg) in the formulated diets and shrimp, respectively (**Fig. 3 & Table 4**).

S was found in all fish muscles studied in this investigation, with the highest mean concentration of (14337.68 ± 196.15 mg/kg). in the muscle of a wild fish sample from the Winam Gulf. Fish muscle tissue, on the other hand, had the lowest concentration (14171.87 ± 367.83 mg/kg) in caged fish. (**Fig. 7 & Table 1**).

5.1.3 Potential Toxic Elements mean concentrations in fish feeds (in-situ based feeds and formulated pellets) and fish muscles (wild and caged fish)

Lead (Pb)

The current study's findings revealed the mean concentrations in in-situ based feeds i.e. omena and Lake shrimp from Winam Gulf were (0.20 ± 0.05 mg/kg) and (0.45 ± 0.10 mg/kg) respectively whereas of the mean concentrations of Pb in formulated fish pellets from Winam Gulf was (0.21 ± 0.07 mg/kg) (**Fig. 4 & Table 5**).

Whereas the mean concentration of Pb in the fish muscle of caged fish was (0.03 ± 0.01 mg/kg) and for the wild fish from Winam Gulf was (0.03 ± 0.00 mg/kg) (**Fig. 8 & Table 2**). Pb concentrations in fish should not exceed 2 mg/kg on a fresh weight basis, according to recognized guidelines. Correspondingly, the Australian National Health and Medical Research Council (ANHMRC) has established a maximum acceptable level of Pb of 2.0 mg/kg on a wet weight basis. In addition, Spanish law sets a limit of 2 mg/kg for Pb concentrations. The amount of Pb in wild fish obtained from the Winam Gulf was (0.03 ± 0.004 mg/kg), which was lower than the proposed maximum tolerable limit of 0.5 mg/kg determined by the Joint FAO/WHO committee. Pb levels in *Caridina niloticus* from Winam

Gulf may be greater due to frequent discharge of industrial effluents from numerous industries, including oil spills.. Another possible explanation for this is that wild tilapia feed on more prey and may be bioaccumulating more of the elements of the water media than the caged fish.

Pb in fish samples could be attributable to human activities such mining, industrial, and steelmaking companies, refineries, and municipal wastewater.

Silver (Ag) dietary

The current study's findings revealed mean Ag concentrations in in-situ based diets, such as omena and Lake shrimp from the Winam Gulf. (0.01 ± 0.00 mg/kg) and (0.06 ± 0.02 mg/kg) respectively whereas of the mean concentrations of Ag in formulated feeds from cages of Winam Gulf was (0.01 ± 0.00 mg/kg) (**Fig. 5 & Table 5**).

Whereas the mean concentration of Ag in the fish muscle of caged fish was (0.00 ± 0.00 mg/kg) and for the wild fish from Winam Gulf was (0.00 ± 0.00 mg/kg) (**Fig. 9 & Table 2**).

Ag was not detectable in the fish muscles from both wild and caged fish samples, according to our findings.

Aluminum (Al)

The present study reveals Al accumulated in fish feeds where the maximum mean concentration of (680.76 ± 203.34 mg/kg) was obtained in the Lake shrimp and minimum mean concentration of (126.44 ± 8.94 mg/kg) and (173.85 ± 65.40 mg/kg) in the omena and formulated feeds respectively (**Fig. 4 & Table 5**).

Our current results revealed that Al was detected in the fish muscles from both wild and caged fish sample collection. The mean concentrations of Al for caged fish and wild fish were (4.62 ± 0.63 mg/kg) and (5.41 ± 0.53 mg/kg) respectively (**Fig. 9 & Table 2**).

Arsenic (As)

The obtained results in the present study showed the mean concentrations of As in in-situ based feeds i.e. omena and Lake shrimp from Winam Gulf were (0.73 ± 0.03 mg/kg) and (0.99 ± 0.17 mg/kg) respectively whereas of the mean concentrations of As in formulated feeds from cages of Winam Gulf was (0.35 ± 0.11 mg/kg) (**Fig. 5 & Table 5**).

Whereas the mean concentration of As in the fish muscle of caged fish was (0.08 ± 0.01 mg/kg) and for the wild fish from Winam Gulf was (0.07 ± 0.01 mg/kg) (**Fig. 9 & Table 2**).

As was detected in the fish muscles from both wild and caged fish sample collection revealed in our results. The mean concentrations of As for caged fish and wild fish were (0.08 ± 0.01 mg/kg) and (0.07 ± 0.01 mg/kg) respectively. The Kenya Bureau of Standards (KEBS) for As in fish is set at 0.2 mg/kg. Because the concentration in muscles obtained in this investigation was within KEBS's permissible limits.

Barium (Ba)

The current study demonstrates that Ba has accumulated in fish diets; the highest mean concentration of (98.56 ± 23.69 mg/kg) was obtained in the Lake shrimp and lowest concentration of (37.61 ± 4.27 mg/kg) and (33.01 ± 1962 mg/kg) in the omena and the formulated feeds respectively (**Fig. 4 & Table 5**).

Ba was not detectable in the fish muscles from both wild and captive fish samples, according to our findings. The mean concentrations of Ba for caged fish was (0.99 ± 0.20 mg/kg) and wild fish was (0.82 ± 0.12 mg/kg) (**Fig. 8 & Table 2**).

Cadmium (Cd)

The obtained results in our present study showed, mean concentrations of Cd in in-situ based feeds from Winam Gulf were omena (0.06 ± 0.01 mg/kg) and Lake shrimp (0.09 ± 0.01 mg/kg) whereas of the mean concentrations of As in formulated feeds from cages of Winam Gulf was (0.07 ± 0.02 mg/kg) (**Fig. 4 & Table 5**).

Whereas the mean concentration of Cd in the fish muscle of caged fish was (0.08 ± 0.01 mg/kg) and for the wild fish from Winam Gulf was (0.07 ± 0.01 mg/kg) (**Fig. 8 & Table 2**).

Cd was not detected in the fish muscles from the wild fish and caged fish sample collection as revealed in our study. The European Community acceptable limits the concentrations for Cd at 0.05 mg/kg EC (2005), the FAO/WHO standard for Cd in fish is set at 0.5 mg/kg FAO/WHO (1989) and 0.02 mg/kg WHO (2001) (**Table 3**)

Mercury (Hg)

The current study's findings indicated mean Hg concentrations in in-situ based foods, such as omena and Lake shrimp from the Winam Gulf were (0.03 ± 0.01 mg/kg) and (0.01 ± 0.00 mg/kg) respectively whereas of the mean concentrations of As in formulated feeds from cages of Winam Gulf was (0.04 ± 0.01 mg/kg) (**Fig. 4 & Table 5**).

Our results revealed that Hg was detected in the fish muscles from both wild and caged fish sample collection. The mean concentrations of Hg for caged fish (0.02 ± 0.00 mg/g) and wild fish (0.03 ± 0.00 mg/kg) (**Fig. 8 & Table 2**). Hg levels are limited to 0.01 mg/kg by NEMA and KEBS, whereas the WHO threshold for Hg in fish is 0.1 mg/kg (**Table 3**). Therefore, The current study's Hg level in muscles was within permissible levels.

Lithium (Li)

The obtained results in the present study showed the mean concentrations of Li in in-situ based feeds i.e. omena and Lake shrimp from Winam Gulf were (0.03 ± 0.02 mg/kg) and (0.45 ± 0.10 mg/kg) respectively whereas of the mean concentrations of As in formulated feeds from cages of Winam Gulf was (0.21 ± 0.07 mg/kg) (**Fig. 5 & Table 5**).

Our results revealed that Li was detected in the fish muscles from both wild and caged fish sample collection. The mean concentrations of Li for caged fish and wild fish were equal/similar i.e. (0.02 ± 0.01 mg/kg) (**Fig. 9 & Table 2**). For comparison, ambient concentrations of Li in the world's major lakes range from (0.014 to 14 mg/kg).

Tin (Sn)

The obtained results in the present study showed the mean concentrations of Hg in in-situ based feeds i.e. omena and Lake shrimp from Winam Gulf were (0.03 ± 0.01 mg/kg) and (0.06 ± 0.02 mg/kg) respectively whereas of the mean concentrations of As in formulated feeds from cages of Winam Gulf was (0.02 ± 0.01 mg/kg) (**Fig. 4 & Table 5**).

Our results revealed that Sn was detected in the fish muscles from both wild and caged fish sample collection. The mean concentrations of Sn for caged fish (0.35± 0.14 mg/kg) and wild fish (0.27 ± 0.09 mg/kg) (**Fig. 8 & Table 2**).

Table 3: Maximum and standard levels in mg/kg; wet weight of essential and toxic elements in tilapia fish described in literature and range of concentrations found in caged fish muscles in Winam Gulf, Lake Victoria Basin

Organization/Country	Cd	Cu	Mn	Ni	Pb	Zn	Sn	Fe	Reference
European Community	0.05	-	-	-	0.2	-			EC (2005)
UK	0.2	20	-	-	2.0	50			MAFF(2000)
FAO(1983)	-	30	-	-	0.5	30			FAO (1983)
Turkish	0.1	20	20	-	1	50			Dural et al. (2007)
FAO/WHO Limits	0.5	30	-	-	0.5	40			FAO/WHO (1989)
WHO Limits									WHO (2001)
EU Limits	0.1	10	-	-	0.1	-			EU(2001)
Saudi Arabia	0.05	-	-	-	2.0	-			SASO (1997)
KEBS						5.0	250	15.0	
Range of metals in the present study (Caged/farmed fish)	Nd-0.00	4.39	2.96	0.19	Nd-0.03	31.57			Present study
Range of metals in the present study (Wild fish)	Nd-0.00	3.75	2.57	0.19	Nd-0.03	30.22			Present study

All tissue concentrations are in mg/kg wet weight

-data were not available in publication or variable was not studied

Nd-Not detected

Spatial distribution of the nutrients

Due to broad non-point and point nutrients inputs, the Lake Victoria ecosystems are undergoing growing eutrophication and prolonged cyanobacteria-dominated algal blooms, which are reducing water quality and ecosystem functioning. The current study used data on nutrient variables (potentially toxic elements and essential elements, both micronutrients and macronutrients) to characterize spatial trends in order to better understand the factors which influence lake conditions of the environment, as well as to ensuring the lengthy ecological stewardship, as well as a deeper understanding of long-term patterns and effects.

Micronutrient concentrations in omena and shrimp of Closed and Open lake zones

Closed lakes were shown to represent zones of greater micronutrient concentrations of B (2.50 ± 0.67 mg/kg), Fe (212.17 ± 13.37 mg/kg) and Mn (58.22 ± 5.64 mg/kg) in omena (**Fig. 10 & Table.6**) and Mn (455.80 ± 160.60 mg/kg) and Si (161.00 ± 11.10 mg/kg) (**Fig.11 & Table.7**) in the Lake shrimps compared to the Open lake zones, with cross correlations that are significant.

Open lake was proven to represent zones of greater micronutrient concentrations of Si (39.00 ± 4.36 mg/kg) and Zn (303.33 ± 25.83 mg/kg) in omena (**Fig.10 & Table.6**) and Cu (104.70 ± 13.30 mg/kg), Fe (4723 ± 1960 mg/kg), Ni (20.80 ± 7.10 mg/kg) and Zn (111.00 ± 8.00 mg/kg) in the Lake shrimp (**Fig.11 & Table.7**) compared to the Closed lake zones, with cross correlations that are significant. This could be owing to nutrient inputs to lake environment, which act upon a crucial role in their production, with consequences for fisheries and water quality aspects. Lake Victoria has been described as eutrophic i.e. contains algal bloom, with significant previous ecosystem alterations caused by fish species invasions, particularly *Lates niloticus* and *Oreochromis niloticus* in the 1950s and 1960s.

Macronutrient concentrations in omena and shrimp of Closed and Open lake zones

Closed lakes were discovered to be zones with the highest concentrations of macronutrients concentrations of Ca (65670.50 ± 5691.28 mg/kg) in omena (**Fig.9 & Table.6**) and Ca (114944.80 ± 35532.97 mg/kg) and Na (6478.40 ± 611.79) (**Fig.10 & Table.7**) in the Lake shrimps compared to the Open lake zones, with cross correlations that are significant.

Open lake was found to represent zones of maximum macronutrient concentrations of K (11213 ± 2824.62 mg/kg) and S (11421.33 ± 825. 96 mg/kg) in omena (**Fig.12 & Table.6**) and K (12621 ± 2416 mg/kg), Mg (2470.00 ± 299.00 mg/kg), P (20136.50 ± 3295.50 mg/kg) and S (9848 ± 1177) in the Lake shrimp (**Fig.13 & Table.7**) compared to the Closed lake zones, with significant inter-parameter correlations. The high macronutrient levels in the lake are thought to support water hyacinth growth, and enhanced management of nutrient cyclic loading to reduce pollution from municipal point source pollution and huge spread emissions along catchments and major agricultural areas is urgently needed.

Generally, mineral concentrations were mostly similar in macronutrient concentration than the levels of the micronutrients concentrations of omena and the Lake Shrimps in both the closed and open lakes. The probable explanaton could be the fact that there may be not big difference in macronutrients concentration of omena and the Lake shrimps in both the open and closed lakes which micronutrients and PTEs offer some subtle difference which are normally hidden away from normal nutritional analyses. According to the KMFRI, the open lake is considered to be the best or ideal for aquaculture as opposed to the closed lake. Also the suspended solids from the agricultural land are more available in the closed lake as opposed to the open lake.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study presents an environmentally sustainable means of solving food security among the rapidly growing human population that suffers malnutrition, hunger, joblessness and diseases. Aquaculture is practiced currently in the lake offers nutritionally fit product that has a potential to address protein and hidden hunger. A potential to exploit the *in-situ* products compromising *Caridina niloticus* and *Rastrineobola argentea* is immense and this may offer an environmentally sustainable feeds sources for aquaculture. This is the first complete investigation of 16 trace elements and 11 PTEs in caged and wild fish species, as well as their diets, from fish farms in Lake Victoria's Winam Gulf. The trace components found in both fish and feed samples revealed a significant degree of similarity. Trace element bioaccumulation trends differed among the fish species studied, although fish retain rather stable trace element concentrations. Hg and other PTE concentrations in fish muscles appear to be low, but more monitoring is needed to confirm the full extent of the problem over the entire Lake Victoria Basin. Future study should concentrate on increasing the nutritional content of aquaculture fish, however the advantages of eating farmed fish in this area are likely to outweigh the disadvantages if excessive intake is eliminated. Open lake and closed section of the lake ppresents diff concentrations of macro and micro element in fish or in omena andlake shrim, for instance there were higher micronutrients concentration of Silicon and Zinc in omena in the open lake and Copper, Iron and Zinc in the Lake shrimp compared to the Closed lake zones.

6.2 Recommendation

This study suggests that more in-depth investigations on the fish and fish feed sectors, as well as at the domestic level, be undertaken in order to fully understand how the numerous aspects addressed in this study interact with one another and the amount of their impact to food insecurity.

Fish consumption in Eastern Africa is expected to increase from 4.80 kg in 2013 to 5.50 kg in 2022. To close the market gap, the Eastern Africa region will require approximately of 2.5

million tonnes of fish due to rising population and economic status. Based on the feed ingredient avalailability and mineral concentration level, the insitu based feeds (i.e. omena and the Lake shrimps) are potential competitors with the formulated fish feeds (commercial fish pellets) as they are the most promising source of animal based protein and also contain essential mictronutrients and macronutrients that add nutritive value to the fish. The local cage farmers are therefore encouraged to use more often the insitu-based feeds together with the formulated feeds to add nutrients to the caged fish for human consumption,

This study also showed that the differences were not quite discernable and that the data indicated are important preliminary findings that indicate that the differences in concentrations of micronutrients were larger/wider than the differences in the concentrations of the macronutrients of the omena and lake shrimps of both closed and open lakes. As a result, a thorough investigation of the Winam Gulf, Lake Victoria's open and closed lake, is required.

In the foreseeable future, aquaculture fish will contribute a bigger share of protein diet in developing countries, and this study has found that fish contain a lot of selenium which is a vital micronutrients. However there was no indication of substantial contamination of potentially harmful components in the fish feed studied, there was evidence of mercury (Hg) bioaccumulation in the fish muscles of *Oreochromis niloticus*, a regularly consumed fish species by Riparian populations in Kenya's Lake Victoria Basin.

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APPENDIX I: TABLES

7.1 Tables

Table 4: Mean (± SE) concentrations of essential nutrients (micronutrient and macronutrient) in In-situ based feeds and formulated feeds from Winam Gulf, Lake Victoria (mg/kg; wet weight). SE=Standard Error of mean, Means with different letters are significantly different from each other

Nutrient	Element	Omena	Lake Shrimp	Formulated feeds
Micronutrient	B	1.89 ± 0.72	6.87 ± 1.49	11.62 ± 2.95
	Cu	5.59 ± 0.50	32.97 ± 6.62	15.48 ± 3.35
	Fe	203.11 ± 10.30	942.70 ± 246.01	340.92 ± 97.73
	Mn	52.59 ± 4.70	137.30 ± 34.13	61.21 ± 12.97
	Mo	0.19 ± 0.01	0.68 ± 0.13	0.90 ± 0.29
	Ni	0.90 ± 0.19	5.48 ± 1.41	3.16 ± 0.99
	Se	1.44 ± 0.06	1.03 ± 0.10	0.52 ± 0.08
	Si	35.78 ± 2.01	105.49 ± 16.04	112.38 ± 34.17
	Zn	286.33 ± 19.05	181.16 ± 18.76	151.89 ± 30.76
Macronutrient	Ca	63276.11 ± 4181.89	47307.03 ± 8575.06	11248.92 ± 2318.40
	Co	0.13 ± 0.02	0.68 ± 0.12	0.61 ± 0.17
	K	8964.56 ± 1755.42	12930.33 ± 906.52	16075.15 ± 1299.19
	Mg	2202.33 ± 29.02	2573.64 ± 150.27	2684.38 ± 309.91
	Na	5200.33 ± 1062.27^{a}	2421 ± 94.46^{b}	3857.15 ± 315.01^{ab}
	P	38716.56 ± 1489.35	21159.70 ± 2008.51	13028.85 ± 845.76
	S	10777.22 ± 357.41	9536.06 ± 537.23	9520.15 ± 1092.80

Table 5: Mean (± SE) concentrations of Potentially Toxic Elements (PTEs) in in-situ based feeds and formulated feeds from Winam Gulf, Lake Victoria (mg/kg; wet weight). SE=Standard Error of mean, Means with different letters are significantly different from each other

Potentially Toxic elements	**Omena**	**Lake Shrimp**	**Formulated feeds**
Ag	0.01 ± 0.002	0.06 ± 0.02	0.0045 ± 0.002
Al	126.44 ± 8.94	680.76 ± 203.34	173.85 ± 65.40
As	0.73 ± 0.03	0.99 ± 0.17	0.35 ± 0.11
Ba	37.61 ± 4.27	98.56 ± 23.69	33.01 ± 19.62
Cd	0.06 ± 0.005	0.09 ± 0.01	0.07 ± 0.02
Cr	1.92 ± 0.42	9.69 ± 3.21	2.71 ± 1.19
Hg	0.03 ± 0.01[a]	0.01 ± 0.00[a]	0.04 ± 0.01[a]
Li	0.03 ± 0.02	0.45 ± 0.10	0.21 ± 0.06
Pb	0.20 ± 0.05	0.45 ± 0.10	0.21 ± 0.07
Sb	0.01 ± 0.001	0.01 ± 0.01	0.03 ± 0.01
Sn	0.03 ± 0.01	0.06 ± 0.02	0.02 ± 0.01

Table 6: Mean (± SE) concentrations of Essential Elements (Micronutrient and Macronutrient) of Omena in Closed and Open Lake Victoria Basin, Kenya (mg/kg; wet weight). SE=Standard Error of mean, Means with different letters are significantly different from each other

Nutrient	Essential element	Omena in Closed Lake	Omena in Open Lake
Micronutrient	B	2.50 ± 0.67	0.67 ± 1.67
	Co	0.15 ± 0.03	0.11 ± 0.01
	Cu	5.08 ± 0.55	6.62 ± 0.80
	Fe	212.17 ± 13.37	185.00 ± 11.59
	Mn	58.22 ± 5.64	41.33 ± 3.24
	Mo	0.18 ± 0.01	0.20 ± 0.02
	Ni	1.00 ± 0.26	0.69 ± 0.26
	Se	1.42 ± 0.02	1.47 ± 0.20
	Si	34.17 ± 2.09	39.00 ± 4.36
	Zn	277.83 ± 26.35	303.33 ± 25.83
Macronutrient	Ca	65670.50 ± 5691.28	58487.33 ± 5541.29
	K	7840.33 ±225.34	11213 ±2824.62
	Mg	2204.17 ± 40.84	2198.67 ± 41.88
	Na	3714.33 ± 195.66	3574.67 ± 142.23
	P	39116.83 ± 2168.34	37916.00 ± 1621.31
	S	10455.17 ±328.50	11421.33 ± 825.96

Table 7: Mean (± SE) concentrations of Essential Elements (Micronutrient and Macronutrient) of Lake shrimp found in Closed and Open Lake Victoria Basin, Kenya (mg/kg; wet weight). SE=Standard Error of mean, Means with different letters are significantly different from each other

Nutrient	Essential element	Shrimp in Closed Lake	Shrimp in Open Lake
Micronutrient	B	0.80 ± 1.16	2.00 ± 1.00
	Co	1.16 ± 0.36	1.93 ± 0.70
	Cu	98.22 ± 9.56	104. 70 ± 13.30
	Fe	2391.20 ± 443.46	4723 ± 1960
	Mn	455.80 ± 160.60	261.00 ± 35.00
	Mo	0.57 ± 0.05	0.58 ± 0.19
	Ni	11.88 ± 6.40	20.8 ± 7.10
	Se	1.62 ± 0.16	1.40 ± 0.08
	Si	161.00 ± 11.10	134.50 ± 69.50
	Zn	93.54 ± 6.10	111.00 ± 8.00
Macronutrient	Ca	114944.80 ± 35532.97	95386.00 ± 16454.00
	K	11211.00 ± 2014.83	12621.00 ± 2416.00
	Mg	2066.60 ± 119.34	2470.00 ± 299.00
	Na	6478.40 ± 611.79	5296.50 ± 440.50
	P	16343.40 ± 1086.96	20136.50 ± 3295.50
	S	9097.40 ± 1239.44	9848.00 ± 1177.00

Table 8: Mean (± SE) concentrations of Potentially Toxic Elements (PTE's) of Omena in Closed and Open Lake Victoria Basin, Kenya (mg/kg; wet weight). SE=Standard Error of mean, Means with different letters are significantly different from each other

Nutrient	Potentially Toxic Elements	Omena in Closed Lake	Omena in Open Lake
Carcinogenic	As	0.68 ± 0.02	0.81 ± 0.06
	Cd	0.06 ± 0.00	0.07 ± 0.01
	Cr	2.17 ± 0.57	1.43 ± 0.58
	Sb	0.01 ± 0.00	0.01 ± 0.00
Non-carcinogenic	Ag	0.02 ± 0.00	0.01 ± 0.00
	Al	130.17 ± 11.15	119.00 ± 17.24
	Ba	35.68 ± 4.05	41.47 ± 4.97
	Hg	0.05 ± 0.02	0.05 ± 0.03
	Li	0.05 ± 0.02	0.00 ± 0.00
	Pb	0.23 ± 0.07	0.15 ± 0.07
	Sn	0.03 ± 0.01	0.03 ±0.03

Table 9: Mean (± SE) concentrations of Potentially Toxic Elements (PTE's) of Lake shrimp found in Closed and Open Lake Victoria Basin, Kenya (mg/kg; wet weight). SE=Standard Error of mean, Means with different letters are significantly different from each other

Nutrient	Potentially Toxic Element	Shrimp in Closed Lake	Shrimp in Open Lake
Carcinogenic	As	2.76 ± 0.27	2.68 ± 0.02
	Cd	0.14 ± 0.01	0.13 ± 0.05
	Cr	26.10 ± 14.77	46.20 ± 16.60
	Sb	0.02 ± 0.01	0.01 ± 0.01
Non-carcinogenic	Ag	0.26 ± 0.06	0.17 ± 0.04
	Al	1947.80 ± 263.46	3919 ± 1701
	Ba	309.80 ± 54.48	368 ± 28
	Hg	0.05 ± 0.01	0.04 ± 0.01
	Li	1.08 ± 0.19	2.00 ± 0.50
	Pb	1.10 ± 0.21	2.00 ± 0.09
	Sn	0.05 ± 0.01	0.07 ± 0.04

APPENDIX II: SIMILARITY REPORT

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