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Bioaccumulation of Toxic Heavy Metals in Tilapia Fish Species *Oreochromis niloticus* in River Riana Kisii County Kenya

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Abstract: *Aquatic pollution with toxic heavy metals is currently a global threat to the survival of humanity. These metals may be bioaccumulated and biomagnified in aquatic food chains and food webs and eventually become toxic to human beings via consumption of aquatic resources such as fish. This study was carried out on the biological analysis of heavy metals in Tilapia Oreochromis niloticus from the Riana River. The fish samples were collected monthly using plastic nets from three sampling sites in the River. The fish samples were dissected in the laboratory using plastic knives to obtain gills and intestines. The fish organs were digested for heavy metal analysis using HNO3 according to the method used by Meche et al (2010). Toxic heavy metal analysis was done using the inductively coupled plasma optical emission spectroscopy (ICP-OES-Shimadzu ICPE 9000). The data collected was analyzed using t-tests and one-way ANOVA where significant differences were accepted at p<0.05. Turkey's HSD post hoc tests were used to separate means where ANOVA exposed significant differences. The average metal levels in gills and intestines in dry weight (mg/kg). The toxic metal levels in tilapia fish gills: Pb (.256±0.135), Ni (.279±0.143), Cr (.255±0.131), Mn (1.211±0.986), for Cu (1.265±0.723) and Zn (2.051±0.868). Equally, the levels in the tilapia intestines were: Pb (.235±0.089), Ni (.162±.058), Cr (.250±.102), Mn (.172±0.138), Cu (.343±0.142) and Zn (.395±0.175). The heavy metals in tilapia fish under study met the recommended WHO/FAO threshold limits except for Cr. The elevated Cr level was attributed to industrial pollution and agricultural application of Cr containing chemicals. Enhanced ecosystem management approaches were recommended for sustainable biodiversity conservation and protection of human health.*

Keywords*— Bioaccumulation: toxic heavy metals: tilapia fish species: Oreochromis niloticus : River Riana: Kisii County Kenya.*

I. INTRODUCTION

Fish are nutritionally essential because they contain minerals, vitamins, proteins and omega-3 and the complex polyunsaturated fatty acids (PUFAs) which are important for the control of body cholesterol levels and reduction of neurodegerative disorders, circulatory disorders including coronary heart disease such as cardiac arrest, high blood pressure and premature delivery (Omara et al., 2018). In the aquatic ecosystem, fish are strategic bioindicators of toxic metal contamination because fish a major food source from water bodies and forms an important part of human food due its numerous nutritional advantages and may pose hazardous effects on human health (Korkmaz et al., 2019). Furthermore, toxic heavy metal pollution in fish may occur through bioaccumulation and biomagnification in aquatic food chains and food webs and may eventually be toxic to human beings via consumption of aquatic resources including fish. Fish are a regular portion of human diet due of their many nutritional and health benefits hence form a cheap source of exposure to toxic heavy metals because fish have the ability to bioaccumulate and biomagnify the toxic heavy metals in aquatic food chains (Õzparlak *et al*., 2012; Jiang *et al*., 2014).
Recently, the tilapia fish species *Oreochromis niloticus* has been widely investigated for toxic metal contamination because it is an important freshwater fish species commonly consumed worldwide (Ahmad *et al*., 2016). Equally, scientists use tilapia fish species as bioindicators in ecotoxicological studies because these metals are deposited in certain organs of the fish and have the capacity to undergo bioaccumulation and biomagnification in food chains (Bedassa, 2020). In a many of these assessments, evaluations and analyses the tilapia fish species *Oreochromis niloticus* has been widely used as a bioindicator species in aquatic contamination because of its ability to bioaccumulate and biomagnify toxic metals from their diet and the surrounding aquatic ecosystem in aquatic food chains. In addition, the tilapia fish species is an excellent bioindicator of toxic heavy metals because this fish has a worldwide distribution (Zhong et al., 2018).

This amplifies the urgent need of judiciously and regularly screening fish for human ingestion to ascertain no hazardous metals passed on to humans via ingestion of fish or fish products. This is because fish constantly forms an essential share of human food due to the discussed nutritional values but toxic heavy metal pollution through the food chains poses a number of hazards due to heavy metal biomagnification in food chains (Korkmaz *et al*., 2019; Javed and Usman, 2011). The dynamic metabolic changes that occur simultaneously in fish body may be responsible in evaluating the levels of the toxic metals in fish contained or deposited in their organs or tissues (Malik, 2010). Fish exposes people to heavy metals since fish occupy the top trophic levels of the food chains hence and may accumulate large amounts of toxic heavy metals from water and their food. Toxic metals may cause adverse health impacts in humans including liver disorders, kidney failure as well as heart disorders and eventually death. Fish is therefore a suitable bioindicator in the assessment of aquatic pollution by heavy metals (Maury-Brachet *et al*., 2019; Adeyeye and Ayoola, 2013). Equally, fish consumption is riddled with some negative health effects arising from toxic heavy metal contamination (Korkmaz et al., 2019).

The ability of tilapia fish to absorb and accumulate high amounts of heavy metals in their organs makes them valuable bioindicators of hazardous metal contamination in aquatic ecosystems environments. These hazardous heavy metals may be directly absorbed by tilapia fish or they may be indirectly absorbed by other organisms through ingestion via food chains in the aquatic environment. This is because these fish occupy higher trophic levels in food chains and food webs. Equally, tilapia fish are excellent bioaccumulators of large amounts of xenobiotics including toxic heavy metals in different body organs including gills, skin, liver, brain, kidneys and intestines. In addition, the tilapia species Oreochromis niloticus has a worldwide distribution hence suitable species for measuring the aquatic impacts of different aquatic contaminates including heavy metals (Maury-Brachet *et al*., 2019; Zhong, *et al*., 2018). In this regard, fishes are significantly affected by xenobiotics including toxic trace metals in the aquatic ecosystems (Olaifa *et al*., 2004). Once absorbed the toxic heavy metals may follow different routes to enter the fish body. It could happen through direct ingestion of food, immediate absorption of water or intake through the skin or gills. When the toxic heavy metals are absorbed into the fish body these trace elements enter the blood stream and are transported alongside other materials to various fish organs including the liver, kidney, and gills prior to discharge (Hussain *et al.* 2014). Fish plays a significant role in human nutrition and are potential as sources of toxic heavy metal exposure. Based on this observation; it is significant that fish should be regularly screened for toxic heavy metals as a precaution to ensure that levels of toxic heavy metals exceeding the regulatory safe limits are not transmitted to people through consuming aquatic creatures from the river. Fish are susceptible to harmful metal exposure since bioaccumulation and biomagnification of these toxic heavy metals may occur in their muscle, liver, brain, skin, gills and intestines.in the aquatic environment (Korkmaz *et al.*, 2019; Adeniyi, 2007). In this research, the tilapia species *Oreochromis niloticus* was utilized as a bioindicator to assess aquatic toxic heavy metal pollution in the River because this fish species was a resident inhabitant of the ecosystem, resides in the food chains at more advanced trophic levels and were known to be efficient bioaccumulators of xenobiotic including the toxic heavy metals (Maury Brachet *et al.*, 2019; Zhong *et al*., 2018).

The tilapia species Oreochromis niloticus is an outstanding bioindicator because of its survival qualities such as strong immune system with the ability to tolerate aquatic ecosystem stress and its omnivorous, non-predator, surface feeder, behaviour. This makes them extremely vulnerable species for contracting various types of contaminants including heavy metals as opposed to fish that eat on the bottom (Giron-Pérez *et al.*, 2008; Eissa *et al*., 2013). The tilapia fish species Oreochromis niloticus is among the outstanding fish species which is regularly consumed and quite significant in world fisheries (FAO/WHO, 2011). This fish species has the potential to bioaccumulate xenobiotics such as toxic heavy metals many times its real value in the aquatic ecosystem. The tilapia fish species Oreochromis niloticus has the ability bioaccumulate toxic metals in different quantities in its organs including the skin, gills intestines and brain. Human exposure to toxic heavy metals is through feeding on aquatic resources including fish and water resulting in short-term and long-term effects (Dorgan and Yilmaz, 2007).

Lately, investigations of toxic heavy metal contaminations in fish organs have been conducted in a number of locations in different fish species globally. This includes studies by Oguzie (2003) on heavy metal contamination in fish from lower Ikpoba River in Benin City in Nigeria; Investigations by Olojo et al., (2005) on the composition and operation of the African catfish's liver and gill tissue Clarias gariepinus regarding the exposure to lead. In parallel studies by Ahmad and Othman (2010) on hazardous trace metal levels in fishes of Lake Chini, Malaysia; Equivalent investigations were equally carried out on toxic trace metal contamination for fish in the Hunza River and its streams in Pakistan (Muhammad *et al*., 2020). Equivalent studies have been reported on fragile aquatic ecosystems including rivers and lakes in different locations (Baharon and Ishak, 2015; Bedassa, 2020; Izuchukwu Ujah *et al*., 2007). This study therefore aimed at analyzing the levels of toxic heavy metals in gills and intestines of tilapia fish species *Oreochromis niloticus* from the River Riana. This fish species is one of the most common inhabitant’s species in this river and commonly consumed by the local inhabitants

II. MATERIALS AND METHODS

Study Location

The research was carried out in the River Riana, Kisii County of Kenya. The catchment area of this River comprises mainly the densely populated lower section of the Kisii County (Figure 1). The River receives effluents from various sources including wastewater from agricultural, industrial as well as from the sewage treatment ponds at Suneka in Kisii County (Rayori *et al.*, 2022). The locations for collecting the fish samples were in three places including S1 at Nyamataro Bridge (00º39.622′S, 034º45.043’E), S2 at Nyagwekoa Bridge (S00º39.503′S, 034º43.101′E) and S3 at Riana Bridge (00º39.496′S, 34º40.097′E. The global positioning system (Garmin Etrex 10) was used for establishing geographical positions the sampling (Momanyi et al., 2023).

Sampling and storage of fish

Tilapia fish species *Oreochromis niloticus* were caught monthly by use of plastic nets at each of the sampling sites between January 2021 and June 2021. A total of 54 fish samples were caught during the study period which were immediately labeled indicating the site and time. The fish transported in ice boxes to KARLO laboratories in Kericho. In the laboratory, the fish were dissected using plastic knives to obtain the gills and intestines which were homogenized to form composite samples for each site during each sampling period. The gill and intestine samples were frozen at -20ºC before heavy metal analysis.

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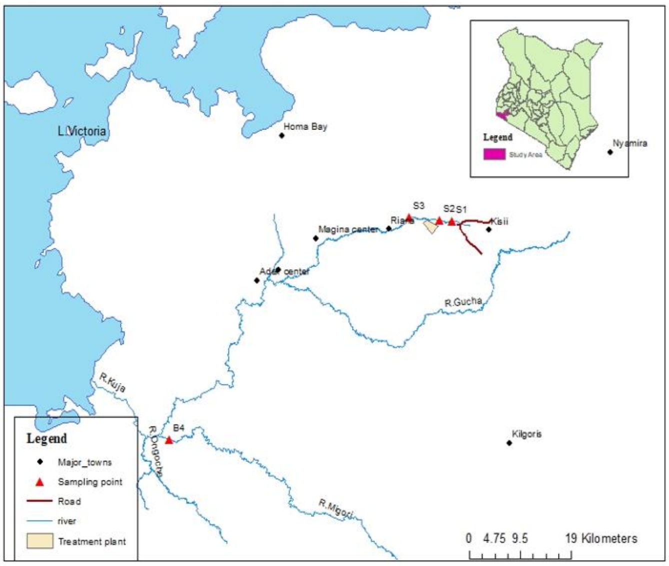

Fig. 1: Map of River Riana joining River Kuja with the three sampling sites

Heavy Metal Analysis

Fish intestines were thawed, dried, and crushed using a cleaned ceramic mortar. Digestion of fish tissues was done according to the method used by Meche *et al.*, (2010) which involved microwave digestion of the gills and intestines using concentrated nitric acid (65 %). The acid was added to a Teflon microwave digestion bomb containing 0.5 grams of each fish sample and placed in a MARS 5 microwave digestion system (CEM, Matthews, NC). This was consecutively allowed to heat up to 180^{0}C for five minutes and another 9.5 minutes respectively. The samples were then placed into clean volumetric flasks and diluted by 10ml using 65 % nitric acid. Samples were stored at 5°C until toxic heavy metal analysis. The samples were analyzed in triplicates using the ICP-OES (Shimadzu ICPE 9000). Each samples was compared with the multielement standard curve to determine heavy metal level in parts per million (ppm) of each analyte in the digested solutions.

Data Analysis

The one-way analysis of variance (ANOVA) was applied to check for significant differences ($p<0.05$). Turkey's (HSD) post hoc test was used to separate means when significant differences were detected.

III. Results and Discussion

Throughout the investigation of all the six toxic metals lead, chromium, nickel, manganese, copper and zinc were detected in the tilapia fish *Oreochromis niloticus* gills and intestines and discussed hereunder.

Lead (Pb) level (mg/kg, DW)

The average lead level (dry weight) in the tilapia fish's intestines and gills was .235±0.089 milligrams per kilogram and .256±.135 milligrams per kilogram respectively for tilapia fish from the River. The Pb level in this investigation met the safety criteria of 2.0 milligrams per kilogram for fish food (FAO/WHO. 2003). ANOVA showed no significant differences in the mean Pb level in both gills and intestines of the tilapia fish species *Oreochromis niloticus* amongst the sites. The comparison of the mean Pb levels obtained for each of the organs investigated using the one sample t-test revealed that the observed mean Pb levels in both gills and intestines were significantly below the permissible safe limit 2.0 mg/kg for fish food. The average lead level in the tilapia fish species *Oreochromis niloticus* from the River during this investigation met fish food permissible criteria of 2.0mg hence the tilapia fish obtained from the river were fit for human consumption with regard to Pb levels (FAO/WHO. 2003). This was because the tilapia fish from the River met the human health safety criteria without any adverse toxic hazards. However, the study suggested that extreme caution ought to be observed through sustained screening of fish from this River for all toxic heavy metals to safeguard the human consumers against hazardous effects. This is because Pb is bioaccumulative and may undergo food chain biomagnification when present even at very low levels. This may cause toxic hazards to the lives of human consumers that depend on the River for fish (Gashkina *et al*,.2020; Muiruri *et al*. 2013)

Recently, Pb levels in fish including the tilapia fish species *Oreochromis niloticus* species have been reported to exceed or meet the permissible threshold criteria of 2,0mg/kg for fish food in different aquatic ecosystems (FAO/WHO. 2003). In a related study, the mean Pb level of .64±.026 mg/kg (dry weight) for the connective tissues of the liver of *Chanos chanous* from Gadilam River in India was reported. This met Pb permissible safe level in fish food of 2.0 mg/kg (FAO/WHO, 2003, Ambedkar and Muniyan, 2012). In similar studies, mean Pb levels exceeding the current study were recorded with the mean Pb level of 2.10±0.07 mg/kg in tilapia fish samples from Lake Hayq, Wollo South in Ethiopia. The Pb level exceeded the fish food criteria and fish from the Lake were not fit for human consumption (Tibebe and Teshome, 2019). Equally, comparable to this research the average lead level of 0.313±0.093 mg/kg was determined for fish from Onitsha Segment in Nigeria. This mean Pb level compared closely with the Pb level observed in the contemporary investigation (Izuchukwu Ujah *et al*., 2017). In another parallel study in the Athi, Galana and Sabaki Rives in Kenya, the Pb levels in fish organs have been recorded with Pb levels ranging from 1.42 mg/kg to 4.48 mg/kg, dry weight (Muiruri *et al*., 2013). This level exceeded the regulatory safe threshold of 2.0 mg/kg for fish food (FAO/WHO. 2003). Equivalent studies recorded higher Pb levels than the current study in tilapia fish species varying between .552 mg/kg and .765 mg/kg (dry weight) from Masinga Reservoir (Nzeve, 2015). Equally, higher levels of lead have been recorded in fish species *Cyprinus carpio* muscles ranging from 0.994 mg/kg to 1.424 mg/kg (dry weight) for fish samples from Masinga Reservoir (Nzeve and Kitur, 2019). The contemporary investigation attributed the Pb levels in the fish organs to water Pb contamination of the River by anthropogenic activities including industrial effluents, agricultural wastes, fossil fuel wastes, pigments and paints from automobile exhaust fumes and wastewater from sewage treatment into the river (Okey Wokeh and Wokeh, 2022). The tilapia fish species

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Oreochromis niloticus acted as an efficient bioindicator of Pb bioaccumulation in the River Riana and the problem may be exacerbated with time because fish is at the top of aquatic food chains. Consuming fish food from the River may pose an imminent threat to human health (Maury- Brachet *et al*., 2019)

Chromium (Cr) level (mg/kg, DW)

The average Cr level (dry weight) in the gills and intestines of the tilapia species taken from the River were .255±.131 mg/kg and .250±.102 mg/kg, respectively. The Cr level in the fish organs did not meet the health safety criteria of .15 mg/kg for fish food (FAO/WHO. 2003). One-way t-test revealed that the average Cr content in fish organs was considerably above the permissible threshold of .15 mg/kg for gills and intestines ($p<.05$), respectively. The Cr level in the tilapia fish organs for fish from the River did not meet the criteria for human consumption. Equally, the ANOVA revealed no substantial variations ($p<.05$) for both the mean Cr level in gills and intestines of the tilapia fish species *Oreochromis niloticus* amongst the sites in study area. The mean Cr level in the investigated fish organs exceeded the permissible safe threshold of .15 mg/kg for fish food. The fish from this River were not appropriate for human consumption due to elevated Cr levels in the fish organs. The elevated chromium levels in the tissues of this tilapia fish species *Oreochromis niloticus* in current investigation was caused by anthropogenic activities including industrial by-products that are pigment-containing, wastewater from sewage treatment lagoons, agricultural wastes containing fertilizers and pesticides and wood preservatives into river (Okey-Wokeh and Wokeh, 2022; Muhammad *et al*., 2011). The observed results confirmed Cr bioaccumulation in the tilapia fish from the River and this was extremely risky due toxic metal contamination of humans via food chain intake of fish from the river (Korkmaz *et al*., 2019)

Recently, studies on Cr levels in fish have been investigated in fish from various aquatic ecosystems worldwide as well as in Kenya. These include investigation on the Cr levels in the tilapia species *Oreochromis niloticus* from Lake Hayq South Wollo in Ethiopia and the study observed a mean Cr level of .745mg/kg in the fish samples. This exceeded the Cr level obtained in the contemporary study as well as the Cr regulatory limit for fish food of .15mg/kg (Tibebe and Teshome, 2019; FAO/WHO, 2003). Equally, other studies, with equivalent findings to the current investigation have reported elevated mean Cr level of 1.18±.042mg/kg (dry weight) in fish species Mugil cephalus. In the same study, the mean Cr level of .34±.016mg/kg (dry weight) in fish species in *Chanos chanous* from the same aquatic ecosystem which exceeded the regulatory threshold. In all these cases fish from the River Gudillam in India were not fit for human consumption because the Cr level exceeded the permissible safe limit of .15mg/kg in fish food (Ambedkar and Muniyan, 2012; FAO/WHO, 2003).

Similar studies observed Cr levels in tilapia fish species *Oreochromis niloticus* gills which also exceeded the optimal safe limit for fish food ranging from BDL to .2 mg/kg in dry weight (Mururi *et al*., 2012). Parallel studies reported elevated Cr levels in muscles of fish species *Cyprinus carpio* varying from .324 mg/kg to .709 mg/kg in dry weight for fish from Masinga Reservoir (Nzeve and Kitur, 2019). Equally, investigations with elevated Cr levels than regulatory safe threshold for fish food and the contemporary study were reported in fish species *Clarius gariepinus* muscles ranging from .516 mg/kg to .858 mg/kg (dry weight) for fish from the Masinga Reservoir (Nzeve, 2015). The elevated Cr levels in the organs of the tilapia fish from River was attributed to human activities which released wastes containing toxic heavy metals such as Cr into the river ecosystem. These activities included industrial effluents, agrochemicals containing fertilizers and pesticides, wastewater from sewage treatment ponds and surface runoffs (Okey-Wokeh and Wokeh, 2022; Muhammad *et al*., 2011).

Nickel (Ni) level (mg/kg, DW)

The mean Ni level (dry weight) in gills and intestines of the tilapia fish from the River were .279±0.143 mg/kg and .162±.058 mg/kg and both met the regulatory limit for fish food of .40 mg/kg accordingly. The reported mean Ni levels in the contemporary study for gills and intestines indicated that the fish obtained from the River were appropriate for human ingestion because the Ni levels met the regulatory safe threshold criteria of .40 mg/kg (FAO/WHO. 2003). The one way t-test exposed that the mean Ni level for both gills and intestines were below the permissible safe limit of .40 mg/kg for both the gills and intestines (FAO/WHO; 2003). Equally, ANOVA confirmed notable differences ($p<.05$) in mean Ni level in the gills of tilapia fish species *Oreochromis niloticus* among the sites in the study area. Tukey's HSD test exposed vital differences in mean Ni level amongst all the sites of the study area; between sites S1 and S2, S1 and S3 as well as S2 and S3. The differences in Ni levels in fish organs at the sites were imputed to wastes from factories and urban waste materials consisting Ni battery wastes and Ni containing fossil fuels where wastes of various types were released into the river (Obosohan and Orosanye, 2004). Equally, ANOVA further exposed that no noticeable variations existed ($p>.05$) in mean Ni levels in the intestines of tilapia fish species *Oreochromis niloticus* amongst the sites. The Ni concentrations found in the organs of the tilapia fish species *Oreochromis niloticus* were related to human-caused pollution of the River. These included industrial effluents with battery wastes, agricultural wastes, surface runoffs and fossil fuels (Okey-Wokeh and Wokeh, 2022; Nwankwoala and Aganya, 2017). There was the possibility of Ni bioaccumulation and biomagnification of toxic heavy metals in food chains and this may adversely affect humans since fish forms a vital portion of human diet. In addition, Ni is persistent and non-biodegradable element in the environment (Gashkina et al, 2020, Korkmaz et al, 2020)

Recent studies on Ni levels in different locations worldwide and in Kenya have been investigated. Ni levels in fish from Galas River in Kalantan met the Ni optimal safe threshold of .40mg/kg (Barahon and Ishak, 2015; FAO/WHO, 2003).. Similarly, Tibebe and Teshome (2019) recorded mean Ni level ranging from 1.61±.018mg/kg to 2.11±.00mg/kg in the fish organs of *Oreochromis niloticus* from Lake Hayq in Ethiopia which exceeded the regulatory threshold of .40 milligrams per kilogram for fish food. In another parallel study, Ni was not detectable in water, but its level in tilapia fish was found ranging from .41µg/gin to .48µg/gin (FAO/WHO, 2003; Bedassa, 2020). Fish may accumulate and biomagnify Ni in different organs when exposed to elevated levels in their environment (Obosohan and Orosanye, 2004). Equally, Ni pollution in fish has been investigated in different aquatic ecosystems and found to exceed or meet the regulatory threshold criteria of .40 mg/kg for fish food (FAO/WHO, 2003). Equivalent studies have investigated Ni levels in fish organs including the mean Ni levels of 2.29 mg/kg (dry weight) in the muscles of tilapia species *Oreochromis niloticus* reported from Lake Hayq in Ethiopia. This evidence confirmed that the fish obtained from the lake Hayq did not meet the health criteria for human consumption as Ni level in fish tissues was above the statutory threshold of .40 mg/kg (Tibebe and Teshome 2019; FAO/WHO, 2003). Parallel studies recorded Ni levels in fish organs for fish from the Athi, Galana and Sabaki Rivers in Kenya ranging from .12 mg/kg to 1.75 mg/kg (dry weight) which exceeded both the Ni level from in contemporary study and the regulatory limit of .40 mg/kg. The fish from these rivers exceeded minimum health criteria for human consumption since the Ni level did not meet the regulatory safe limit of .40mg/kg for fish food (Muiruri *et al*., 2012; FAO/WHO, 2003). This Ni level observed in the tilapia fish from the River Riana was attributed to human activity in the river's vicinity in the catchment including industrial effluents, use of agrochemicals, municipal waste, surface runoffs and wastewater from the sewage treatment ponds at Suneka (Oguzie and Izevbigie, 2009). Other authors have noted that fish accumulate the toxic trace metal Ni in different levels in fish tissues and organs when exposed to contaminants containing the metal in the ecosystem (Obasohan and Orosanye, 2004).

Manganese (Mn) level (mg/kg, DW)

The mean Mn level (dry weight) in gills and intestines of the tilapia fish from the River were 1.211±.986 mg/kg and .172±.138 mg/kg respectively Both of these mean results met the permissible threshold of 2.5 mg/kg for fish food(FAO/WHO, 2003). One way t-test exposed that both the Mn levels in the gills and intestines of the tilapia fish species *Oreochromis niloticus* were significantly lower ($p<.05$) than the regulatory threshold of 2.5 milligrams per kilogram (FAO/WHO, 2003). The fish obtained from the River met the safety criteria for human consumption in relation to the Mn level in the fish organs. The detected low Mn level in fish was a potential toxic hazard because of the water-based food chain and food webs biomagnification. The entry of this toxic metal into fish may occur through absorption from water, sediments and food. This toxic trace metal may be harmful to humans via consumption of aquatic resources especially fish where it undergoes food chain bioaccumulation and biomagnification (Maury-Brachet *et al*., 2019), Mn pollution is extremely hazardous on human health for people consuming aquatic resources including water and fish. Sustainable heath protection of human inhabitants using natural resources from this River requires regular analysis for toxic metal levels to enhance sound biodiversity. In addition, fish from the River should be regularly screened for toxic heavy metals including Mn to ensure there acceptable bioaccumulation of these xenobiotics (Nzeve and Kitur, 2019)

Recently, Mn levels in fish have been investigated in various aquatic ecosystems and have been found to either meet the permissible safety criteria of 2.5 mg/kg or to exceed this threshold limit in fish organs (FAO/WHO, 2003). Comparable studies to the contemporary investigation on Mn level in fish organs have been reported with mean Mn level varying between .02±0.01 mg/kg to 0.36±0.18 mg/kg (dry weight) in muscles of fish species *Channa panctatus* (Ambedkar and Muniyan, 2012). Another parallel study reported agreeable results to the contemporary study with mean Mn in tilapia muscle levels ranging from .183 mg/kg to 1.480 mg/kg (dry weight) for fish obtained from Masinga Reservoir (Nzeve, 2015). Equally, a higher Mn level was recorded in muscles of fish species *Cyprinus carpio* varying between .659 mg/kg to 1.432 mg/kg for fish from Masinga Reservoir (Nzeve and Kitur, 2019). Also, extremely higher Mn levels in tilapia fish gills ranging from 81.50 mg/kg to 132.67 mg/kg (dry weight) for fish obtained from Galana, Athi and Sabaki Rivers was reported. These Mn levels were higher than the observed results in the contemporary investigation and the permissible safe threshold of 2.5mg/kg. The Mn level in these Rivers did not meet the human health safe criteria of 2.5mg/kg for fish obtained from that ecosystem (FAO/WHO, 2003; Muiruri *et al*., 2013). The Mn levels in the tilapia fish organs in this investigation were attributed to anthropogenic activities including fossil fuel contamination, industrial effluents, agricultural wastes from nearby farms using fertilizers and pesticides, wastewater from the sewage treatment lagoons and surface runoffs (ATSDR, 2012; Okey-Wokeh and Wokeh, 2022).

Copper (Cu) level (mg/kg, DW)

The mean Cu level (dry weight) in gills and intestines of the tilapia fish from the River were 1.265±.723 mg/kg and .343±142 mg/kg respectively. The Cu level obtained in the organs of tilapia fish species *Oreochromis niloticus* met the permissible safety criteria of 3.0 milligrams per kilogram for fish food (FAO/WHO. 2003). The one-way ANOVA revealed that there were vital differences ($p<.05$) in average Cu level in gills of tilapia fish species *Oreochromis niloticus* among the sites. Equally, the one-way ANOVA showed no significant differences in intestine average Cu concentration in ($p>0.05$) among the sites. Tukey's HSD test exposed vital differences in mean Cu levels of the fish gills between site S1 and S3. Further statistical analysis using one sample t-test with the 3.0 mg/kg criteria for fish food showed that the observed mean Cu levels observed for the tilapia fish organs were significantly less ($p <.05$) compared to the regulatory limit of 3.0 mg/kg. The tilapia fish obtained from this ecosystem met the regulatory criteria and were fit for human consumption. However, extreme caution should be observed since low levels of trace metals including Cu pose toxicity concerns because they may undergo bioaccumulation and biomagnification in aquatic food chains and food webs. Since fish occupy the higher trophic levels of the aquatic food chains and food webs they may contain concentrations of these dangerous heavy metals than water (Maury-Brachet *et al*., 2019; Zhong *et al*., 2018). The contemporary study suggested regular screening of fish obtained from the River for harmful xenobiotics including toxic heavy metals such as Cu for biodiversity conservation and protection of human health. The bioaccumulation and biomagnification of Cu in the aquatic ecosystem may lead to elevated levels of Cu in different organs fish (Ezemonye *et al*., 2019)

Currently, similar studies to determine Cu levels in fish organs in various aquatic ecosystems have been conducted in different locations in Kenya Africa and globally providing important insights on ecosystem contamination by toxic heavy metals. In related studies, Cu levels lower than the present study were recorded between .007±.002 mg/kg to .010±.001 mg/kg for tilapia fish from river Niger in Nigeria (Izuchukwu *et al.*, 2017). Parallel investigations have determined Cu level of 11.18mg/kg in edible tilapia fish muscle from Lake Hayq in Ethiopia which was higher the Cu level in both gills and intestines in the contemporary study. The Cu level in fish from the Lake met the regulatory safe threshold of 3.0 mg/kg for fish food (Tibebe and Teshome, 2019; FAO/WHO, 2003). The Cu level higher than the current study in the organs of tilapia species *Oreochromis niloticus* ranging from .515 mg/kg to .792 mg/kg for Masinga Reservoir in Kenya have been reported. This Cu level met the regulatory safe limit of 3.0mg/kg for fish food (Nzeve, 2015; FAO/WHO, 2003). Equally, the Cu level was observed in in fish species *Cyprinus carpio* muscles ranging from 0,519 mg/kg to 1.422 mg/kg (dry weight) fish samples from Masinga Reservoir met the permissible limit of 3.0 mg/kg (Nzeve and Kitur, 2019; FAO/WHO, 2003). Equivalent studies observed Cu levels ranging from 7.50 mg/kg to 7.65 mg/kg for tilapia fish organs obtained from Lake Baringo which surpassed the observed Cu level in the contemporary research but met the Cu regulatory threshold of 3.0 mg/kg for fish food (Mbuthia, 2015; FAO/WHO, 2003). The observed mean Cu level in tilapia fish organs in this research were attributed to anthropogenic activities including wastewater from the sewage treatment lagoons at Suneka adjacent to Kisii town, industrial effluents, surface runoffs, pigments, industrial effluents fertilizers and pesticides into the River Riana (Ezemonye *et al.*, 2019).

Zinc (Zn) level (mg/kg, DW)

The observed mean Zn level (dry weight) in gills and intestines of the tilapia fish from the river were 2.051±.868 mg/kg and .395±.175 mg/kg respectively. The obtained mean Zn level in the fish organs met the permissible threshold of 75mg/kg for fish food. The tilapia fish from this ecosystem were fit for human consumption (FAO/WHO; 2003). The one-way ANOVA revealed no vital differences among the sites ($p>.05$). The one-way t-test showed that the mean Zn level in the investigated tilapia fish organs were significantly lower ($p<.05$) than the permissible safe limit of 75 mg/kg (WHO/FAO, 2003). The mean Zn level in tilapia for fish from this ecosystem met the safety criteria threshold of 75 mg/kg hence the fish from the River were fit human consumption. However, the consumption of fish from this River should be done with extreme caution because of the bioaccumulative effects of the hazardous heavy metals including Zn. These metals may cause adverse toxic health effects to people via the food chain and food webs biomagnification (Maury-Brachet et al, 2019; Orosanye *et al*., 2010). This study suggested the need of regular analysis and evaluation for hazardous trace metals in the River because fish may absorb these metals from water, sediments and food. Toxic heavy metal exposure in this aquatic ecosystem raises serious threats which may arise from bioaccumulation and biomagnification through food chains and may adversely increase toxic effects through the consumption of fish (Tibebe *et al*, 2019; Nzeve and Kitur, 2019).

Recently similar studies have been carried out to determine Zn levels in fish organs to provide deeper understanding of various aquatic ecosystems in different locations globally and in Kenya. Parallel studies observed mean Zn level of 55.52±.072 mg/kg in tilapia fish muscles throughout the rainy season for tilapia fish from Lake Hayq in Ethiopia. This Zn level surpassed the contemporary study but met the permissible safe criteria of 75 mg/kg (Tibebe *et al*., 2019). The Zn level obtained in this study closely agreed with the observations of mean Zn level of .48±.013 milligrams per kilogram (dry weight) in the liver of Heteropnustes fossilis and Zn level .10±.003 mg/kg (dry weight) in muscle of *Chanos chanos* from river Gadilam in Tamilnadu India (Ambedhar and Muniyan , 2012). Equivalent investigations reported Zn levels in tilapia fish gills ranging from 28.00 mg/kg to 76.55 mg/kg (dry weight) for fish obtained from the Athi, Sabaki and Galana Rivers. The Zn level in these aquatic ecosystems surpassed both the observed Zn level in the contemporary study and the regulatory safe criteria of 75 mg/kg for fish food. The fish from these rivers were not fit for human consumption (Muiruri et al., 2013; WHO, 2011). Parallel studies recorded average Zn level of 17.10±4.36 mg/kg (wet mass) in tilapia muscles and mean Zn level in the intestines 85.7±4.07mg/kg (wet mass) for fish from Lake Baringo. This Zn level exceeded the contemporary investigation but met the regulatory limit of 75mg/kg for fish food (Nyingi *et al*., 2016; FAO/WHO, 2003). Comparable Zn levels in tilapia muscle ranging from 29.645mg/kg to 37.999 mg/kg (dry weight) in Masinga Reservoir. Equally, Zn level has been reported in fish species *Cyprinus carpio* muscles ranging from 39.466 mg/kg to 63.333mg/kg fish from Masinga Dam (Nzeve and Kitur, 2019). Parallel studies reported Zn levels in *Clarius gariepinus* species muscles which were also higher than the current study ranging from 32.929 mg/kg to 37.205 mg/kg (dry weight) for fish from Masinga Dam Reservoir (Nzeve, 2015). Lately a few authors in related studies have reported Zn concentration ranging 16.65 mg/kg to 20.82 mg/kg in tilapia fish tissues for fish samples obtained from Lake Baringo which met the fish food quality criteria of 75 mg/kg. The zinc level recorded in the tilapia fish organs in the contemporary study was attributed to contaminants from anthropogenic activities including industrial effluents containing toxic heavy metals such as Zn. This hazardous heavy metal may undergo bioaccumulation and biomagnification in food chains and food webs and is gradually deposited different in fish organs (Maury-Brachet *et al*., 2019; FAO/WHO, 2003). This study further suggested that fish obtained from the River require regular screening for hazardous trace metals including Zn to minimize their toxic impacts on the health of human consumers (Nzeve and Kitur, 2019).

IV. CONCLUSIONS AND RECOMMENDATIONS

There was no toxic heavy metal bioaccumulation in both gills and intestines of tilapia fish species *Oreochromis niloticus* from the River Riana except for Cr. The Cr level exceed the permissible threshold of .15 mg/kg in both gills and intestines of the fish. This was through food chains and food web bioaccumulation and biomagnification of this toxic heavy metal. There was a potential toxic threat for people consuming fish from the River as the Cr level exceeded the WHO permissible limit. Therefore, the tilapia fish species *Oreochrimis niloticus* from the river were unfit for human consumption as the fish does not meet the health criteria for human consumption. The study recommends regular screening of fish from the river for hazardous heavy metals. In addition, the regulatory authorities such as the National Environmental and Management Authority in Kenya should ensure that industrial and domestic effluents meet the recommended standards before they are released into water bodies such as rivers.

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