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Heavy Metal Concentrations and Distribution in Water, Sediment, and Catfish, Clarias Gariepinus Obtained from Aquaculture Farms in Ondo, Nigeria

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Abstract:

Heavy metal pollution is a serious environmental problem in freshwaters, potentially impacting public health, water quality and ecosystem integrity worldwide. However, the potential public health risks associated with heavy metal accumulation in water, sediment and commercial fish samples remain unclear. Here we assessed the concentrations and distribution of five heavy metal of public health importance (Iron, Copper, Zinc, Lead and Copper) in water, sediment, and edible organs (muscles, liver, gills, and intestines) of the African sharptooth catfish, Clarias gariepinus obtained from aquaculture ponds. Water, sediment, and fish samples were randomly collected from commercial fishponds across different five locations in Ondo. Metal concentrations in water, sediment and fish samples were analyzed using Atomic Absorption Spectrophotometry (AAS, Model AA-680/ Shimadzu). Mean metal levels observed in water, sediment and fish samples were compared with recommended regulatory guidelines for human consumption. Our results showed mean concentrations for all metals in water exceeded recommended permissible limits in freshwater bodies and aquatic biota, presumably suggesting potential risks for human consumers. Heavy metal levels in sediment samples indicated Fe was maximally accumulated, followed by Zn, Cu, Pb, and Cd. The highest and least accumulations for all the metals were recorded in the gills, and in the liver respectively. Higher concentrations of metals observed in gills corroborate the fact that the gill is a major route for heavy metal accumulation in fish whereas the reduced concentration of metals observed in the liver may be associated with enhanced detoxification mechanism in the liver. These results suggest that fish obtained from these aquaculture ponds may be unsafe for human consumption. Hence, we recommend a periodic assessment of heavy metal levels in commercial fish samples as a major regulatory priority.

Keywords: Aquaculture, bioaccumulation, Clarias gariepinus, heavy metals, public health.

I. Introduction

Widespread heavy metal pollution is among the leading water quality threats in surface freshwater systems around the world (Chowdhury et al., 2016; Olaifa et al., 2004; Zhou et al., 2020). The increasing occurrence and persistence of heavy metal contaminants in freshwaters and aquatic biota have been implicated to impact on public health and the sustainability of aquatic systems in the Anthropocene (Stankovic, Kalaba and Stankovic 2014; Hussain et al., 2021). This phenomenon has become exacerbated in rivers and lakes in developing countries, particularly in the Sub-Saharan Africa region (Chowdhury et al., 2016; Zhou et al., 2020), where the mean total concentrations of heavy metal pollution in rivers and lakes have been shown to repeatedly exceed the WHO and USEPA regulatory thresholds (Chowdhury et al., 2016; Zhou et al., 2020). Although there has been increased awareness on the potential sources, impacts, and fates of heavy metal pollution in surface waters, nonetheless, anthropogenic heavy metal inputs from nearby residential, industrial, and agricultural catchments (Islam et al., 2018) is likely to constitute a major threat to public health, biodiversity, and ecosystem integrity in receiving freshwater bodies within these catchments.

Heavy metal contaminants represent a group of hazardous, non-biodegradable chemical substances that possess relatively high density and solubility in water, which enable them to persist for longer period in aquatic systems (Islam et al., 2018; Duman, Aksoy and Demirezen 2007). Several studies have shown that exposure can occur via atmospheric deposition, domestic and industrial effluent, agricultural runoffs, drinking from polluted water sources and uptake through bioaccumulation (Islam et al., 2018; Stankovic, Kalaba and Stankovic 2014). However, among these routes of environmental exposures, bioaccumulation of heavy metal along the aquatic food chain and consumption of contaminated fish potentially poses a greater risk to human health (Ahmed et al., 2019b; Ahmed et al., 2019a; Vu et al., 2017).

Fish is an important, common staple diet among humans, rich in omega-3 polyunsaturated fatty acids, animal proteins, vitamins and minerals required for the maintenance of a normal healthy growth (Olmedo et al., 2013; Taweel et al., 2013; Zhu et al., 2015). In recent decades, FAO statistics have shown a marked rise in human consumption of fish suggesting an average annual consumption of about 115 million tons of fish, primarily supplied from fish stocks reared in commercial aquaculture ponds in fish farms (FAO, 2010; Li et al., 2015). Moreover, there is a growing concern that the dwindling trends in wild fish populations, food safety and food security have continued to drive the fast growth of the aquaculture industry as a major source of food protein in Nigeria and other

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developing countries (WHO, 1999; Orhborbor and Ezenwa, 2005).

Fish fauna are a critical component of the aquatic food chain and may serve as reliable indicators of heavy metal contaminations within aquatic ecosystems (Mason, 2002). Several studies have shown that a variety of fish species can accumulate elevated levels of toxic metals and may serve as important sentinel group of organisms to monitor environmental pollution in aquatic systems (Adefemi et al., 2008; Adeosun, et al., 2015; Authman et al., 2015). The catfish, Clarias gariepinus, is a hardy and highly cultured freshwater omnivore. It is affordable and widely relished by many people across different socio-economic and cultural background (WHO, 1999). C. gariepinus has been widely used in many laboratory studies to assess the toxic effects of chemical contaminants on structure and functions in aquatic systems (Aguigwo 2002; Ogunwole et al., 2021; Adadu and Ochogwu 2020; Eni et al., 2019). However, there is a broad consensus in literature that the safety of food protein obtained from aquaculture and the potential health implications associated with the consumption of contaminated fish on human health remains one of the foremost priorities during risk assessment and public health debates (WHO, 1999; FAO/WHO, 1989).

Heavy metal bioaccumulation in fish samples is a serious environmental problem with potential health risks on human consumers (*Olowu et al.,* 2009; Olowoyo *et al.,* 2012). High levels of heavy metals in water, sediment, and biota, may potentially presents a major risk to public health, because when they enter the food chains, they tend to accumulate and cause serious adverse health effects in higher organisms (WHO, 1999; Li *et al.*, 2015; Zhu *et al.*, 2015). Hence, there is a need to periodically monitor the residual levels of these metals in fish, water and sediment samples obtained from commercial fish farms to safeguard human consumers from the potential health risks associated with consumption. Hence, the present study was designed to assess the levels of five heavy metals of public health importance in fish, water and sediment samples obtained from commercial fishponds within Ondo metropolis in Ondo State.

II. MATERIALS AND METHODS

SAMPLES COLLECTION

Fresh adult catfish, Clarias gariepinus (5), water (5) and sediment (5) samples were randomly sampled from five different commercial earthen aquaculture ponds located across different fish farms within Ondo City. The locations are Shamakinwa, Fagun, Odo-Ayo, Arigbabola and Sabo as shown in Figure 1. For the sake of the readers, these fishponds have been designated as ponds A, B, C, D, and E) within Ondo Town. Briefly, 1000 ml of water samples were collected from each sampling ponds in a prewashed 1litre bottle with 10% HNO3, while 5g of the sediment samples were collected from a depth range of (0-5cm) in a polythene bag and fresh fish samples were obtained in a jar containing water from each pond. All samples were immediately conveyed to the laboratory for further analysis. At the laboratory, individual fish length and weight were determined and recorded. Fish samples were sacrificed and dissected. Gills, liver, muscle, and intestine samples were obtained from each fish after dissection. All fish samples were rinsed thrice in distilled water in preparation for heavy metal analysis.

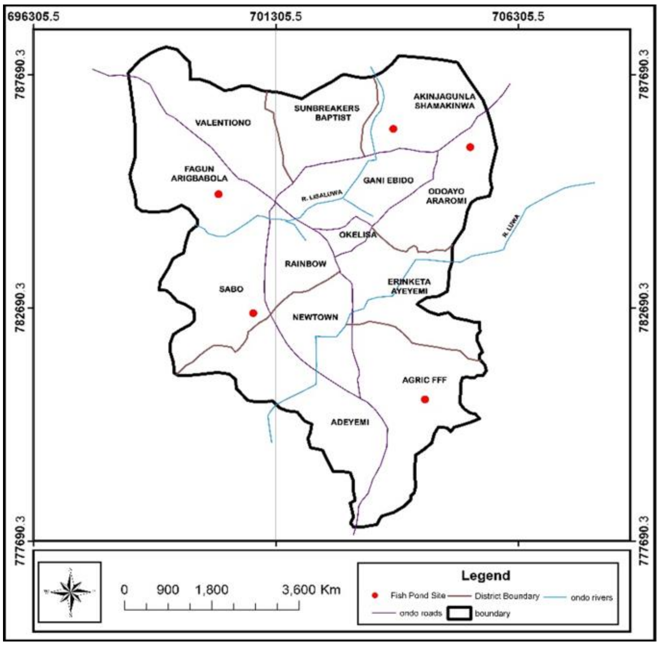

Figure 1: Map of Ondo State, Nigera

HEAVY METAL ANALYSIS

Water, sediment, and fish organ samples were digested according to methods described by (Radojevic and Bashkin, 1999). Digested water, sediment and fish samples for each sampling location were later prepared in triplicates and heavy metal levels in all samples were estimated using a Model AA-680/ Shimadzu Atomic Absorption Spectrophotometer (AAS).

STATISTICAL ANALYSIS

All data obtained were summarized and presented as descriptive statistics (mean± standard error of means or mean± standard deviation). Levels of significance in the concentrations of heavy metals in water, sediment and fish organs across the ponds were tested using one-way analysis of variance (ANOVA) and Duncan's multiple range test at $p<0.05$. All calculations and statistical analysis of data were performed in SPSS Version 22.0, while data visualization was made using the ggplot2 package in R studio version R 3.6.0 (R CoreTeam 2019).

III. RESULTS

HEAVY METALS IN WATER AND SEDIMENT SAMPLES

The results obtained for heavy metals analyzed in water and sediment samples from ponds A-E were compared with national and international water quality guidelines in Table 2. Levels obtained for all the metals in water were higher than the standard permissible limits, in the following order: Iron>Zinc>Copper>Lead>Cadmium. One-way ANOVA and Duncan's multiple range test revealed that metals analyzed in water and sediment varied significantly across the ponds at p-value<0.05 (Table 1). Results for metals in sediment indicated

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Cu (2.67±1.37mg/kg) had its highest concentration in Pond A, Zn (129.53±6.01mg/kg) in Pond D, Pb (6.49±5.24mg/kg) in Pond C, Cd (2.54±0.77mg/kg) in Pond E and Fe (97.22±22.19mg/kg) in Pond C respectively. Accumulation of heavy metals in sediment followed this trend; Zn>Fe>Pb>Cu>Cd, while Zn and Fe were maximally accumulated, Cd had the least concentration.

The results of this study showed that levels of heavy metal in water from all the ponds exceeded the maximum permissible limits, which implied that the ponds are generally polluted and fishes inhabiting them may be unfit for human consumption as they are likely to pose potential health risks for consumers. This is consistent with the findings of Javed and Usmani, (2014), who reported values higher than the permissible limits for heavy metals in rivulet water. In general, deterioration in water quality, such as heavy metal contamination of aquatic ecosystems will have deleterious effects on the biological integrity as well as health of organisms inhabiting them. Heavy metal contamination of the aquatic environment has recently been exacerbated through increasing human population growth, reckless and indiscriminate discharge of domestic and industrial wastes, increased exploration, and exploitation of natural resources as well as lack of stringent environmental regulations (Olowu et al., 2009; Olowoyo et al., 2012).

The present study indicated that levels of heavy metals present in the sediments from all the ponds varied and were significantly higher in comparison with the levels in water. Sediments are the expedient, ultimate sinks of pollutants such as heavy metals in the aquatic environment. Contamination of the aquatic sediment by heavy metals can cause alterations in water quality, bioaccumulation of toxic metals in aquatic organisms, thus pose potential risks for human and ecosystem health (Abdel-Baki et al., 2011). However, the variations observed in across the ponds may be due to the differences in location, topography, and pollution sources for each pond.

HEAVY METALS IN FISH

Trends in the accumulation of heavy metal residues in fish liver, muscle, intestine, and gills respectively are illustrated in Fig 2-5.

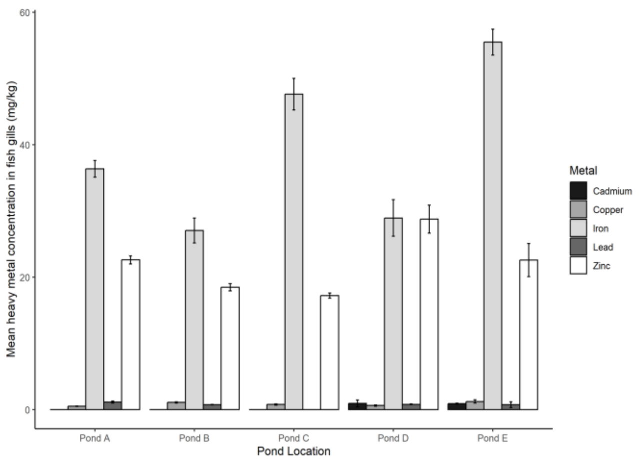

Figure 2: Heavy metal concentration (mean ±SE) in fish liver across Ponds A-E

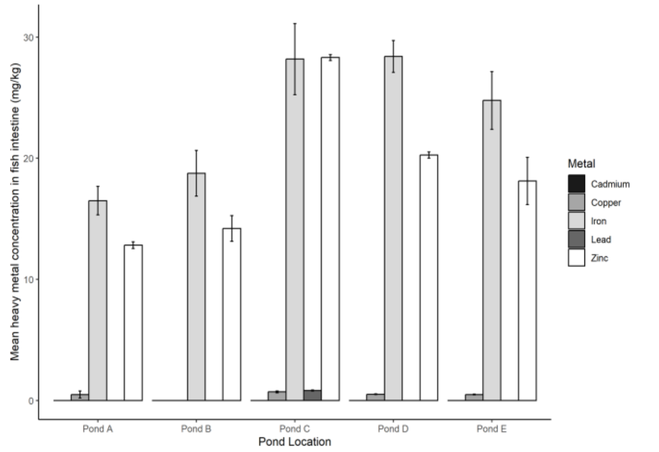

Figure 3: Heavy metal concentration (mean ±SE) in fish muscle across Ponds A-E.

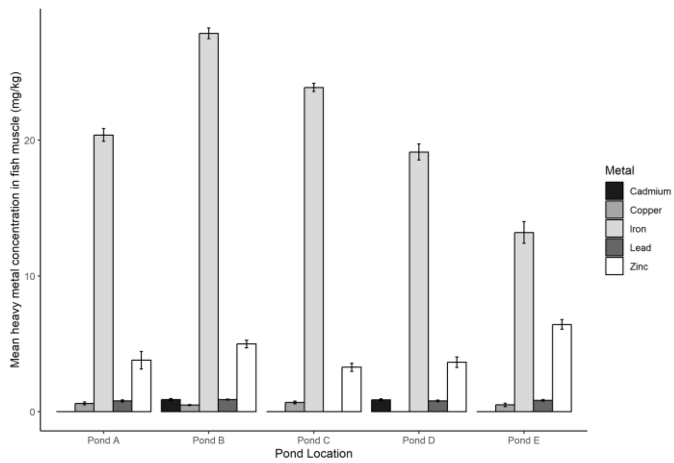

Figure 4: Heavy metal concentration (mean ±SE) in fish intestine across Ponds A-E.

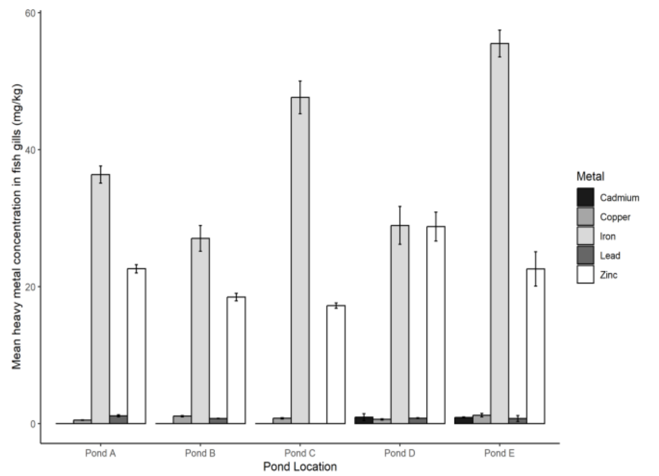

Figure 5: Heavy metal concentration (mean ±SE) in fish gills across Ponds A-E

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TABLE I: MEAN CONCENTRATIONS OF ANALYZED METALS IN WATER AND SEDIMENT SAMPLES ACROSS POND A-E

Metals	Sample	(Mean ±SD) values in Water (mg/L) and Sediment (mg/Kg) Samples						
		Pond A	Pond B	Pond C	Pond D	Pond E	WHO	FEPA
Copper	Water	0.52±0.07[c]	1.13±0.21[b]	0.51±0.08[c]	ND	1.94±0.67[a]	1.00	1.00
	Sediment	1.44±0.51[bc]	2.67±1.37[a]	1.78±0.94[a,b,c]	1.14±0.53[d]	2.15±0.62[a,b]		
Zinc	Water	29.68±6.03[b]	40.29±10.92[a]	20.89±3.05[c]	14.87±7.01[c]	16.88±2.54[c]	5.00	1.00
	Sediment	107.68±12.77[b]	95.05±9.70[c]	49.70±6.11[e]	129.53±6.01[a]	70.03±9.11[d]		
Lead	Water	1.17±0.30[a]	1.09±0.35[a,b]	0.88±0.17[b,c]	0.80±0.13[c]	ND	0.05	0.05
	Sediment	1.79±0.78[b]	2.50±0.93[b]	6.49±5.24[a]	2.97±0.65[b]	2.31±0.58[b]		
Cadmium	Water	ND	0.94±0.10[a]	ND	0.97±0.16[a]	ND	0.05	0.01
	Sediment	0.96±0.14[d]	1.74±0.69[b,c]	1.22±0.37[c,d]	2.04±0.86[a,b]	2.54±0.77[a]		
Iron	Water	44.11±6.46[a]	38.65±4.27[a,b]	44.50±12.92[a]	8.01±9.73[b,c]	27.30±15.53[c]	1.00	1.00
	Sediment	96.73±6.59[a]	71.57±5.45[b]	97.22±22.19[a]	85.34±17.28[a,b]	71.13±11.30[b]		

**** Mean values with different superscripts are significantly different from each other across row* (*$p<0.05$*) *ND means Not detected* WHO (1985) and FEPA (2003)

Accumulation of metals in all the fish parts analyzed across the ponds, followed this order of magnitude; Fe>Zn>Pb>Cu>Cd. The highest values for Cu (1.09±0.25mg/kg), Zn (28.79±4.72mg/kg), Pb (1.14±0.35mg/kg), Cd (0.94±1.13mg/kg) and Fe (55.51±4.41mg/kg) were all recorded in the gills, while the least value for Cu (0.48±0.08mg/kg) was recorded in the muscle, Zn (1.17±0.11mg/kg) in the liver, Pb (0.75±0.99mg/kg) in the gills, Cd (0.88±0.14mg/kg) in the muscle and Fe (3.29±0.88mg/kg) in the liver respectively.

Our results showed the gills had the highest concentrations for all the metals examined among all the other organs. The high values observed for Cu, Zn, Pb, Cd, and Fe in the gills could be due to the fact that bioavailable heavy metal contaminants gain entry into the aquatic organisms by respiration via the gill membrane or by ingestion through feeding. Olowoyo et al., (2012) reported similar elevated concentrations of metals in the gills of Clarias gariepinus obtained from a treated wastewater lake in South Africa. Fe had the highest concentration among all the metal assessed. This is in line with the findings of Olowoyo et al., 2012) who reported Fe concentrations higher than the maximum permissible limits in fish species. Although, iron is a basic requirement in the diet as well as the prevention of anaemic conditions in humans, however its intake may elicit toxic response when certain threshold limits are exceeded. Javed and Usmani, (2014) has recommended that Fe should not exceed the maximum permissible limits of 100pm.

I. Conclusion

The results of this study showed that heavy metal pollution is a problem in the aquaculture industry with serious health implications on human consumers. Fishes reared in these ponds are unfit for human consumption because levels of heavy metal observed were higher than the maximum permissible limits by regulatory agencies. Thus, regular environmental monitoring and regulation of heavy metal contamination in fish should be made a periodic and regulatory priority.

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