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Concentration of Heavy Metals in Water, Sediments and Tissues of *Clarias gariepinus* from Earthen Ponds in Kolo Creek Communities in Bayelsa State, Niger Delta, Nigeria

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Abstract: Concentrations of heavy metals (HMs - Pb, Mn, Fe, Cu and Cd) in water and sediments, and their bioaccumulations in gill and muscle tissues of *Clarias gariepinus* from four earthen fish ponds in communities around Kolo Creek area of Bayelsa State, Nigeria, were evaluated. The HMs were extracted with acid mixtures, quantified using atomic absorption spectrophotometry and characterized in terms of metal pollution index (MPI). Furthermore, pond waters' physicochemical properties were determined using standard methods. The pH values of pond waters indicated slight alkalinity. Biochemical oxygen demand indicated significant pollution of the ponds. Range of HMs concentrations are: water (mg/L) – Fe: 0.013 - 0.30, Cu: 0.002 - 0.96; Mn: 0.20 - 0.83; Pb: 0.01 - 0.15, Zn: 0.67 - 2.72; sediment (mg/kg) – Fe: 67.8 - 200.3, Cu: 0.98 - 2.95; Mn: 4.06 - 17.1; Pb: 0.73 - 10.6, Zn: 1.90 - 96.9 and tissues (mg/kg) – Fe: 0.001-1.97, Cu: 0.98-17.2, Mn: 0.001-33.9, Pb: 0.001-8.13, Zn: 0.16-36.9. All HMs in pond waters were below drinking water limits except Pb and Mn. Gills and muscles showed high Fe and Pb concentrations respectively. The MPI values revealed that the bioaccumulation capacity of a fish tissue for HMs depended on several factors. The results generally suggest significant HMs bioaccumulation in tissues of *Clarias gariepinus*, which can be risky to consumers over time.

Key words: Heavy metals, *Clarias gariepinus*, earthen fish ponds, gill tissue, muscle tissue, bioaccumulation.

Introduction

Over the years, there has been an increase in the number of chemical contaminants identified to be present in surface water, many of which originate from increasing urbanisation and several industrial activities, including oil exploration and mining (Olusola and Festus, 2015). The aquatic ecosystem has been particularly disturbed by such activities, being one of the major recipients of such contaminants (Negi and Maurya, 2015). Although heavy metals (HMs) contamination of aquatic ecosystems is less noticeable compared to other types of aquatic impurities due to high solubility, the HMs' low metabolic rate implies that they cannot be removed through self-purification (Harikumar and Nasir, 2010). Thus, they can accumulate in water, sediments, tissues and organs of aquatic organisms, including fish, before entering the food chain (Edem et al., 2008; Khanipour et al., 2018).

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Aquatic animals are desirable for biomonitoring purposes, since they are in direct contact with contaminated water and sediments in their habitats (Andral et al., 2004; Viarengo et al., 2007; Negi and Maurya, 2015). Fish can bioaccumulate HMs in their internal organs, gills and muscles to concentrations higher than those present in their surrounding habitat in water, sediment and microflora (Yehia and Sebaee, 2012). This bioaccumulation ability is an indirect measure of the availability of HMs in fish tissues and could serve as an indicator of water quality or sediment contamination (Mansour and Sidky, 2002; Kucuksezgin et al., 2006). Although gill and kidney tissues have been reported to bioaccumulate more HMs than muscle tissues due to the physiological roles of the former (Dural et al., 2007; Fatima and Usmani, 2013; Asante et al., 2014; Ugbomeh and Akani, 2016), bioaccumulation of HMs have also been reported in the latter, which is the most commonly consumed part of fish (Hashim et al., 2014; Khanipour et al., 2018).

Clarias gariepinus is a fish species commonly reared in earthen fish ponds in communities around Kolo Creek in Bayelsa State, Nigeria. Proximity of many of these ponds to oil exploration activities as well as increasing urbanisation of the surrounding communities can lead to contamination of these ponds by HMs. The fact that fish is in high demand by the populace as an important source of protein, essential minerals, vitamins and omega-3 fatty acid implies that consumption of contaminated fish presents an important route for metals toxicity in human, thereby invalidating the fishes' beneficial effects. In this study, therefore, the concentration of some selected HMs, i.e. lead (Pb), copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe) in water, sediments and fish tissues (gills and muscles) of *C. gariepinus* from earthen fish ponds around Kolo creek in Bayelsa State was determined. Furthermore, the metal pollution index and bioaccumumation factors were computed.

Materials and Methods

Study Area

The study area comprises three communities/towns (Otuoke, Emeyal and Imiringi) in the environs of Kolo Creek oil and gas field in Ogbia Local Government Area (LGA) of Bayelsa State. Ogbia LGA has an area of approximately 695 km^2 and a population of about 179,926. The study area is well known for its historic value to the mainstay of Nigeria's economy i.e. the oil industry. The Kolo Creek oil and gasfield operated by the Shell Petroleum Development Company (SPDC) is located within Imiringi and Emeyal towns and situated about 5 km from Otuoke. Many of the inhabitants of the study area engage in fishing on a subsistence and commercial level.

Collection and Preparation of Samples

Triplicate samples of water, sediment and *C. gariepinus* were collected from earthen fish ponds from the Otuoke, Emeyal and two locations in Imiringi (designated as Imiringi I and Imiringi II). Water samples were collected at 0.5 m below the water surface into pre-cleaned 1L plastic containers. Approximately 100 g of sediment samples were collected using a grab sampler into aluminum foil, while samples of *C. gariepinus* were collected using cast net.

Collected water samples were stored in a refrigerator until analysis. On-site fixation of water was carried out to measure the dissolved oxygen (DO), pH was determined using a pocket-sized pH meter (pHep®, Hanna Instrument, USA), total dissolved solids (TDS) was measured using a pocket-sized conductivity meter (DiST 1, Hanna Instrument, USA), while sulphates, phosphates and biochemical oxygen demand were determined using methods described by APHA (2006).

Sediment samples were air-dried in the open for three weeks, ground using agate mortar and pestle and sieved using 2 mm mesh size while fish samples were dissected using sterile knife to separate the gills and muscle tissues.

Digestion of Samples

Water Samples

Digestion was carried out as follows: 100 mL of water samples was placed in a 250 mL conical flask, 10 mL of 1M HNO_3 was added, placed in a digestion block and heated at 150°C until the mixture reduced to about 25 mL. The mixture was removed from the block, cooled, filtered using a Whatman No. 40 filter paper, transferred to a 100 mL volumetric flask and made up to mark with 1M HNO_3 (Csuros and Csuros, 2002).

Digestion of Sediment and Fish Tissues (Gills and Muscles)

Wet digestion of tissues was carried out as follows: 2.00 g sample of sediment, fish gill and muscle from each pond were separately placed in 50 mL conical flasks. 10 mL of aqua regia (1:3 HNO_3:HCl) mixture was added, followed by 5 mL of perchloric acid and covered with a dish. This mixture was then placed in a digestion block and heated at 150°C until the acid mixture reduced to about 5 mL. The mixture was removed from the block, cooled, filtered using a Whatman No. 40 filter paper, transferred to a 100 mL volumetric flask and made up to mark with 1M HNO_3 (Csuros and Csuros, 2002).

Instrumental Analyses

The filtrates obtained from digestion of water, sediment, fish gills and muscles were analyzed using an Atomic Absorption spectrophotometer (Varian spectrAA100, USA) for the following metals: Pb, Cu, Zn, Mn and Fe. After appropriate dilution of the stock solution for each metal to be analyzed, a calibration graph was prepared using five different concentrations.

Quality Control Measures

All laboratory glass wares used were initially washed with detergent and tap water, then soaked in 5% nitric acid for twenty-four (24) h, then washed and rinsed with deionized water. Samples were prepared and analyzed in triplicates to check for precision of the results obtained. Reagents blanks were also included in analysis.

Bioaccumulation Factor

The bioaccumulation factor (BAF) is the ratio of the concentration of a contaminant in the tissue of an organism to the concentration of the contaminant in the ambient environment at a steady state, where the organism can take in the contaminant through ingestion with its food as well as through direct content (USEPA, 2010). This ratio was calculated according to Asante et al. (2014) as follows:

$$\text{BAF} = \frac{\text{Concentration of metals in fish tissue}}{\text{Concentration of metals in abiotic media}}$$

where the abiotic media represents water and sediment, respectively.

Metal Pollution Index

The metal pollution index (MPI) compares the total metals accumulated in various tissues of fish when the metals are beyond five in number (Javed and Usmani, 2013). The values were calculated using the equation (Usero et al., 1997):

$$(C_1 \times C_2 \times \ldots \times C_n)^{1/n}$$

where C_n is the concentration of metal n in a sample.

Statistical Analysis

Data were expressed as Mean ± standard deviation. One-way Analysis of Variance (ANOVA) was used to determine whether the concentrations of metals varied significantly across the various sites with p-value less than 0.05 ($p < 0.05$) considered to be statistically significant. The statistical calculations were performed with SPSS 11.5 version.

Results and Discussions

Physicochemical Properties of Pond Water

The physicochemical properties of water samples from the studied fish ponds are shown in Table 1. The pH values ranging from 8.07–8.47 indicates that all pond water samples were slightly alkaline, and were within the range of the World Health Organisation (WHO, 2008) standard limits of 6–9. Boyd and Lichtkoppler (1979) reported that a pH range of 6.09–8.45 is ideal for supporting aquatic life including fish while pond waters with a pH less than 6.0 may result in stunted, reduced or even absent fish population (Swistock, 2015). Since the bioavailability and subsequent toxicities of many contaminants are pH-based, the slightly alkaline pH values obtained in this study indicates that contaminants such as heavy metals are not expected to be readily available in soluble forms for uptake

Table 1: Physicochemical properties of pond water

	Ponds			
Parameters	*Otuoke*	*Emeyal*	*Imiringi I*	*Imiringi II*
pH	8.13±0.06	8.07±0.06	8.3±0.1	8.47±0.05
TDS (mg/L)	111.7±2.89	471.7±2.90	244.3±4.04	51.7±2.89
DO (mg/L)	4.11±0.10	3.19±0.02	3.78±0.03	2.46±0.02
BOD (mg/L)	9.59±0.09	14.2±0.03	12.6±0.11	18.3±0.25
PO_4^{3-} (mg/L)	6.63±0.03	3.87±0.06	8.57±0.04	2.18±0.02
SO_4^{2-} (mg/L)	1.04±0.05	1.77±0.03	2.18±0.03	1.01±0.08

Values expressed as Mean±SD of triplicate determinations by aquatic organisms, rather, they will be present as complexes/hydroxides, which are of insignificant toxicities (Weigner, 2007).

The concentration (mg/L) of total dissolved solid (TDS) ranged from 51.7–472. The TDS is normally controlled by the natural source of the pond water and by nearby land use activities. Generally, TDS measurements higher than 1000 mg/L could be indicative of a pond that has an existing water problem (Swistock, 2015). On this basis, the results of this study do not indicate any existing water problem of the studied ponds.

The dissolved oxygen (DO) levels (ranging from 2.46–4.11 mg/L) in pond water were found to follow the order: Otuokepond > Imiringi I pond > Emeyal pond > Imiringi II pond. The generally accepted minimum DO levels that support a large population of fish is from 4–5 mg/L, and DO level below 3 mg/L can lead to fish mortality (Oram, 2014a). The DO level was thus moderately low in Otuoke, Emeyal and Imiringi I ponds but was below normal for fish level in Imiringi II pond. Low DO levels between 4 – 5 mg/L can impair fish growth and reproduction and subsequently, fish may become more susceptible to diseases and attacks, and prolonged exposure can lead to stress and eventually, death of fish (Ovie and Adeniji, 1990).

Biochemical oxygen demand (BOD) levels in pond water was found to follow the order: Imiringi II pond > Emeyal pond > Imiringi Ipond > Otuoke pond. As expected, BOD levels were greater than their corresponding DO levels in all ponds because organic wastes generally reduce DO by increasing BOD, and this could inhibit aquatic flora and fauna. Vowels and Connel (1980), Mara (1983) and Adakole et al. (1998) classified aquatic pollution with respect to BOD values as follows: unpolluted (BOD < 1.0 mg/L), moderately polluted (BOD ≥ 2 ≤ 9 mg/L) and heavily polluted (BOD > 10 mg/L), while the maximum permissible limits set by the Department of Petroleum Resources (DPR, 2002) and WHO (2005) are 10 mg/L and 5.0 mg/L, respectively. Based on these classifications, all studied ponds can be classified as being heavily polluted and exceeded the WHO permissible limit, while Otuoke pond had values slightly below the DPR permissible limit. The consequence of high BOD are same for low DO, and aquatic organisms can become stressed, suffocate and die from prolonged exposure to depleted oxygen.

The nutrient levels (mg/L) ranged from 2.18–8.57 and 1.01–2.18 for phosphate and sulphates, respectively. Phosphates can stimulate the growth of aquatic plants which provide food for fish, thereby causing an increase in fish population. However, an excess of phosphates can lead to eutrophication and consequently, depleted oxygen levels. According to Oram (2014b), phosphate concentration of 0.025–0.1 mg/L can stimulate plant growth in water. The observed concentration in this study thus indicates the possibility of accelerated plant growth in water from all ponds.

Heavy Metal Concentrations in Water and Sediment of Studied Ponds

Table 2 shows the concentration of HMs in water samples from the various studied ponds. Metal concentrations (mg/L) ranged as follows – Fe: 0.013–0.30, Cu: 0.002–0.96; Mn: 0.20–0.83; Pb: 0.01–0.15 and Zn: 0.67–2.72. Zinc was found to be highest in all studied ponds. The metal concentrations did not vary significantly ($p > 0.05$) within and across the studied ponds for each of the studied metals but were all below the WHO (2008) limit for metals in drinking water except Pb and Mn. The generally low metal levels can be attributed to the alkaline nature of the waters because most metals are soluble under acidic media (i.e. low pH).

Table 2: Concentrations of heavy metals in pond water

	Concentration (mg/L)				
Ponds	*Fe*	*Cu*	*Mn*	*Pb*	*Zn*
Otuoke	0.30 ± 0.20^{a}	0.24 ± 0.00^{a}	0.20 ± 0.02^{a}	0.02 ± 0.00^{a}	0.74 ± 0.01^{b}
Emeyal	0.03 ± 0.00^{b}	0.002 ± 0.0^{b}	0.55 ± 0.05^{b}	0.04 ± 0.00^{a}	0.67 ± 0.03^{a}
Imiringi I	0.17 ± 0.00^{c}	0.96 ± 0.01^{c}	0.83 ± 0.04^{c}	0.15 ± 0.05^{b}	2.72 ± 0.15^{b}
Imiringi II	0.01 ± 0.00^{b}	0.25 ± 0.00^{a}	0.61 ± 0.03^{b}	0.02 ± 0.00^{a}	2.50 ± 0.04^{b}
WHO (2008) limit	0.3	1	0.1	0.01	3

Values expressed as Mean±SD of triplicate determinations
Means with different superscript letters on same vertical column differ significantly at $p < 0.05$.

Table 3 shows the concentration of HMs in sediment samples from the various studied ponds. Metal concentration (mg/kg) ranged as follows – Fe: 67.8–200, Cu: 0.98–2.95; Mn: 4.06–17.1; Pb: 0.73–10.6 and Zn: 1.90–96.9. Metals concentration were found to follow the order: Fe > Zn > Mn > Pb > Cu for Otuoke pond; Fe > Zn > Mn > Pb > Cu for Emeyal pond; Fe > Mn > Pb > Cu > Zn for Imiringi I pond and Fe > Mn > Zn > Cu > Pb for Imiringi II pond. Sediments in aquatic environments are generally known to be good reservoirs for contaminants such as HMs, with holding capacity up to 90% of the total HMs in such environments (Aremu et al., 2011). They are thus used for assessing the impact of anthropogenic activities to aquatic environments by providing historical information on metal inputs in such locations and also serve as a means of identifying heavy metals contamination (Boran and Altinok, 2010). This metal holding ability is evident in results presented in Figures 1a-d where all studied metal levels in sediments were significantly ($p < 0.05$) greater than their corresponding levels in water samples except Zn in Imiringi I pond. Such significant variability has been previously reported (Aremu et al., 2011; Iderial et al., 2012; Upadhi et al., 2013). The elevated concentrations of heavy metals in sediments compared to water thus indicates that sediments are the major depository of HMs in aquatic systems (Chinda and Braide, 2003), and high metal concentrations in sediments may in turn, affect water quality and bioaccumulation of metals in aquatic organisms.

Heavy Metal Concentrations in Tissues of *C. gariepinus* from Studied Ponds

Tables 4 and 5 show the concentrations of heavy metals in gill and muscle tissues respectively of *C. gariepinus* obtained from the studied ponds. The average metal concentration across the studied ponds were shown to

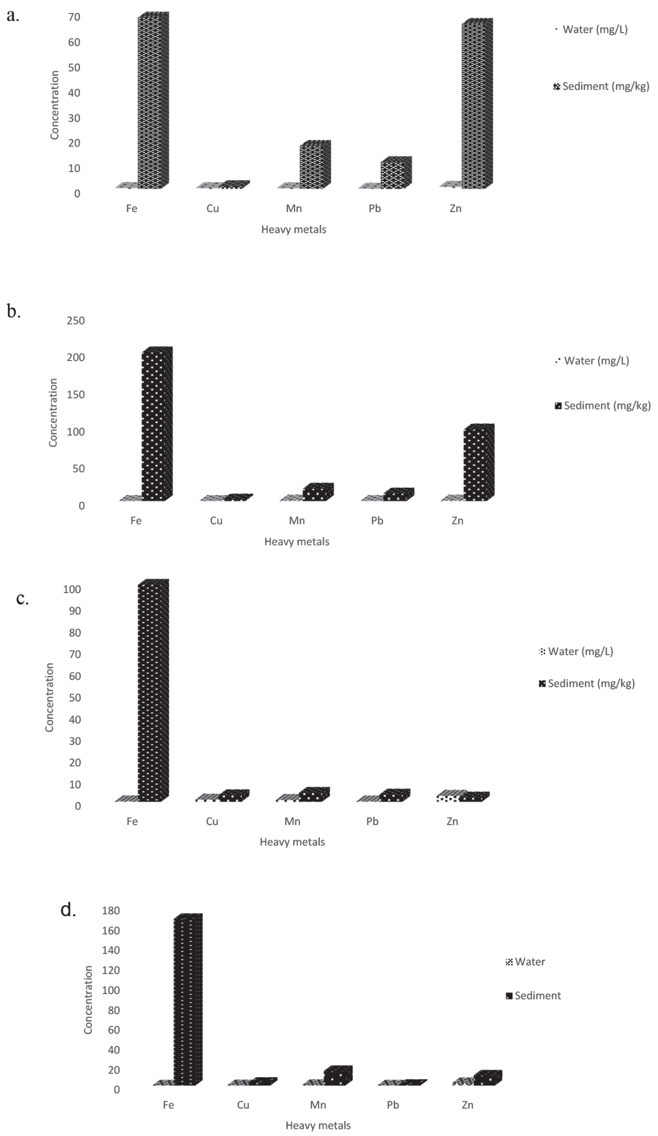

Figure 1: Comparing the metal levels in water and sediments of studied ponds (a – Otuorke; b – Emeyal; c – Imiringi I; d – Imiringi II).

Table 3: Concentrations of heavy metals in pond sediments

	Concentration (mg/kg)				
Ponds	*Fe*	*Cu*	*Mn*	*Pb*	*Zn*
Otuoke	67.8±0.14^{a}	0.98±0.02^{a}	17.1±0.04^{a}	10.6±0.51^{a}	65.3±0.04^{a}
Emeyal	200.3±0.42^{b}	1.99±0.02^{b}	16.7±0.04^{a}	10.1±0.16^{a}	96.9±0.07^{b}
Imiringi I	99.9±0.23^{c}	2.95±0.05^{c}	4.06±0.08^{b}	3.26±0.04^{b}	1.90±0.02^{c}
Imiringi II	167.1±1.75^{d}	2.78±0.02^{c}	14.6±0.08^{a}	0.73±0.04^{c}	10.1±0.05^{d}
WHO (2008) limit	30	20	10	0.05	40

Values expressed as Mean±SD of triplicate determinations
Means with different superscript letters on same vertical column differ significantly at $p < 0.05$.

follow the order: Mn > Zn > Cu > Fe > Pb for gills and Mn > Cu > Zn > Pb > Fe for muscles.

The gill and muscle tissues of *C. gariepinus* generally had high concentrations of Mn, Cu, Zn and Pb and minimal concentrations of Fe. The concentrations of Fe and Zn was shown to be higher in gills than muscles in all but Imiringi II pond (for Zn); Mn was higher in Imiringi ponds; Pb was higher in Imiringi I pond while Cu was higher in muscles tissues except Imiringi II pond. The generally high concentrations of metals in the gill tissue could be attributed to the fact that metal ions are first absorbed through the gill, since the gills are in direct contact with the medium of contamination (i.e. water and sediment) and also, they have very thin epithelium when compared with other organs of fish (Bebianno et al., 2004).

High concentrations of HMs in gill tissues have also been attributed to the binding of metals to gill tissues, and the metal-mucus complex is usually difficult to remove during tissue analysis (Karadede-Akin and Unlu, 2007). Lower concentrations of some metals in muscle tissues could be attributed to low levels of binding proteins in muscles (Negi and Maurya, 2015). Furthermore, since the muscle is an active site for detoxification and is not in direct contact with the metals, penetration of trace metals may be limited, which may further decrease its metal content (Dural, 2007). Similar high bioaccumulation of some HMs in gill tissue relative to muscle tissues have been previously reported (Murtala et al., 2012; Akintujoye et al., 2013; Fatima and Usmani, 2013; Javed and Usmani, 2013; Akpanyung et al., 2014; Asante et al., 2014).

The average concentration of Mn was greatest in both gill and muscle tissues for all studied ponds and exceeded its permissible limit set by WHO (2005). Although Mn is an essential element required by a range of enzymes in living organisms, very high intake can interfere with the central nervous system of vertebrates, thereby leading to adverse health effects (Das et al., 2017).

The average concentration of Zn across the studied ponds exceeded the Turkish Food Codex limit of 5 mg/kg for gills except Imiringi II pond. However, only Otuoke pond exceeded this limit in muscle tissues. This result is similar to previous reports on gill and muscle tissues in different species of fish (Farombi et al., 2007; Akpayung et al.; Etesin and Benson, 2007; Javed and Usmani, 2013). The high concentration of Zn in both gill and muscle tissues could be attributed to its high demand as an essential element in blood haemoglobin (Kambole, 2002). However, it has been reported to be neurotoxic and causes neuronal cell death at high concentrations (Chen-Jung and Su-Lan, 2003).

The Pb concentration in gill and muscle tissues across all studied ponds exceeded the Turkish Food Codex (2002) permissible limit of 0.2-0.4 mg/kg except gills in Emeyal pond. The observed high concentration of Pb in fish tissues could be detrimental to human health through consumption, since Pb is toxic even at low concentrations. Furthermore, the replacement of calcium ions by Pb can result in toxicity of many vital enzymes in the central nervous system, which could impair development and functions of enzymes involved in the production and transport of neurotransmitters (NAS/NRC, 1993). Like Pb, Cu concentration in gill and muscle tissues was also higher than its permissible limit of 0.5 mg/kg across all studied ponds. Although Cu is an essential trace nutrient needed for haemoglobin and haemocyanin formation, high concentrations can be toxic, and toxicity is largely attributed to its cupric (Cu^{2+}) form (Olaifa et al., 2004). Its toxicity can however be mitigated by the presence of naturally occurring organic matter through complexation.

The MPI values in Tables 4 and 5 show that muscle tissues from Otuoke pond had the highest metal load (4.05), followed by gill tissues from Imiringi I pond (3.71), while muscle tissues from Imiringi II pond was least influenced by HMs. This indicates that the capacity of a fish tissue to bioaccumulate heavy metals depends on several factors, including the physiological role of each tissue (Bahnasawy et al., 2009), total amount and bioavailability of each metal in the environmental medium, the route of uptake, storage and excretion mechanisms (Sanker et al., 2018), feeding activities, species and age of fish (Romeo et al., 1999). Since the muscle tissue is edible, its quality therefore needs to be monitored especially in ponds from Otuoke and Imiringi I, which recorded high metal index values. Increasing urbanisation of the environs of Otuoke pond and proximity of Imiringi I pond to the oil facility may be attributed to the high metal load recorded in this study.

Bioaccumulation Factors of Heavy Metals in Tissues of *C. gariepinus*

The bioaccumulation factors (BAF) for the gill and muscle tissues of *C. gariepinus* are shown in Tables 6 and 7, respectively. The results indicate that the bioaccumulation factors of HMs from pond water were greater than their corresponding factors in sediments by several folds, which suggests that bioaccumulation of metals occurred mainly from the pond waters from where the fish were caught rather than sediments (Kalfakakou

Table 4: Concentrations of heavy metals in gill tissues of *C. gariepinus*

Heavy metals	*Concentration (mg/kg)*				**Limit*
	Otuoke	*Emeyal*	*Imiringi I*	*Imiringi II*	
Fe	0.70±0.02[a]	1.53±0.12[b]	1.97±0.03[b]	0.001±0.00[c]	30
Cu	1.71±0.04[a]	2.70±0.05[b]	8.92±0.08[c]	1.78±0.03[a]	0.5
Mn	28.9±0.06[a]	0.47±0.03[b]	30.9±0.20[a]	6.10±0.10[c]	10
Pb	1.03±0.04[a]	0.001±0.00[b]	8.13±0.15[c]	0.66±0.04[d]	0.2-0.4
Zn	18.6±0.24[a]	5.88±0.12[b]	36.9±0.34[c]	1.97±0.04[d]	5
MPI	3.66	0.65	3.71	0.42	

Values are expressed as Mean±SD of triplicate determinations
* – Turkish Food Codex (2002)
Means with different superscript letters on same horizontal row differ significantly at $p < 0.05$.
MPI – metal pollution index

Table 5: Concentrations of heavy metals in muscle tissue of *C. gariepinus*

Heavy metals	*Concentration (mg/kg)*				**Limit*
	Otuoke	*Emeyal*	*Imiringi I*	*Imiringi II*	
Fe	0.12±0.021[a]	0.25±0.015[a]	1.03±0.03[b]	0.001±0.00[c]	30
Cu	1.97±0.03[a]	8.99±0.04[b]	17.2±0.06[c]	0.98±0.03[d]	0.5
Mn	33.9±0.06[a]	30.2±0.26[a]	30.1±0.36[a]	0.001±0.00[b]	10
Pb	7.58±0.16[a]	0.78±0.02[b]	5.25±0.04[a]	0.73±0.03[b]	0.2-0.4
Zn	18.1±0.29[a]	2.85±0.16[b]	0.16±0.02[c]	2.99±0.02[b]	5
MPI	4.05	2.70	3.39	0.07	

Values expressed as Mean±SD of triplicate determinations
* – Turkish Food Codex (2002)
Means with different superscript letters on same horizontal row differ significantly at $p < 0.05$.
MPI – metal pollution index

Table 6: Bioaccumulation factors (BAF) of heavy metals from water in the gill and muscle tissues of *C. gariepinus*

Tissues	*Gill*				*Muscle*			
	BAF				*BAF*			
Heavy metals	*Otuoke*	*Emeyal*	*Imiringi I*	*Imiringi II*	*Otuoke*	*Emeyal*	*Imiringi I*	*Imiringi II*
Fe	2.33	51.0	11.5	0.07	0.40	8.33	6.05	0.008
Cu	7.13	1350	9.29	7.12	8.20	4495	17.9	3.92
Mn	144.5	0.85	37.2	10.0	169.5	54.9	36.2	0.002
Pb	51.5	0.03	54.2	47.1	379	19.5	35.0	52.1
Zn	25.1	8.78	13.6	0.78	24.5	4.25	0.05	1.20

Table 7: Bioaccumulation factors (BAF) of heavy metals from sediment in the gill and muscle tissues of *C. gariepinus*

Tissues	*Gill*				*Muscle*			
	BAF				*BAF*			
Heavy metals	*Otuoke*	*Emeyal*	*Imiringi I*	*Imiringi II*	*Otuoke*	*Emeyal*	*Imiringi I*	*Imiringi II*
Fe	0.01	0.007	0.02	$1x10^{-5}$	0.002	0.001	0.01	1×10^{-5}
Cu	1.74	1.35	3.02	0.64	2.01	4.52	5.86	0.35
Mn	1.70	0.03	7.61	0.42	1.98	1.82	7.41	0.001
Pb	0.10	0.0001	2.49	0.90	0.71	0.07	1.61	1.00
Zn	0.28	0.06	19.4	0.20	0.27	0.03	0.08	0.30

and Adrida-Demertzi, 2000). The BAF values were greatest for Cu and Mn and least for Fe in both tissues and abiotic media. The minimal bioaccumulation of Fe in muscle tissue could be attributed to the fact that Fe is an essential element needed for production of haemoglobin while the high bioaccumulation of Pb in both gill and muscle tissue could be as a result of the non-essentiality of Pb.

Conclusion

This study showed that heavy metal concentrations in pond waters were generally low but were relatively high in sediments. For fish tissues, the average metal concentrations were high and exceeded their permissible limits for Mn, Zn and Pb, which indicates significant bioaccumulation from the abiotic media. Upon consumption of such contaminated fish, these metals contaminants could be transferred to man via the food chain. Although the results do not explicitly indicate a manifestation of the metals' toxic effects, the possibility that deleterious effects could manifest after prolonged periods of consumption of fish in the studied earthen fish ponds by metals contamination cannot be ruled out.

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