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Heavy Metal Analysis in Silver Catfish (*Chrysichthys nigrodigitatus*) from Asejire and Erinle Reservoirs in Southwest Nigeria

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ABSTRACT

Background and Objective: Fish tend to accumulate heavy metals from the aquatic ecosystem due to their high trophic position in the food chain. This study was carried out to analyse the concentration of some heavy metals in selected organs of *Chrysichthys nigrodigitatus* collected from Asejire and Erinle Reservoirs. **Materials and Methods:** Measurements of eight morphometric characters were recorded for fish samples from Asejire and Erinle Reservoirs. Heavy metals in the fish and water samples were analysed using atomic absorption spectrophotometer. **Results:** There was a positive correlation between the weight and standard length of the *C. nigrodigitatus* samples from Asejire and Erinle Reservoirs. The liver accumulated the highest level of heavy metals while the muscle had the least bioaccumulation level. A correlation coefficient was observed between fish size and heavy metal concentration in fish. The level of heavy metals in *C. nigrodigitatus* samples from Asejire and Erinle Reservoirs exceeded the safe limit recommended by World Health Organisation (WHO). The water samples had levels of heavy metals within the tolerable range set by WHO. **Conclusion:** Therefore, it is necessary to continuously examine heavy metals in Asejire and Erinle Reservoirs since the reservoirs and their biota serve the surrounding towns.

KEYWORDS

Heavy metal pollution, *Chrysichthys nigrodigitatus,* bioaccumulation, gills, Asejire, Erinle Reservoir

INTRODUCTION

Heavy metals are generally referred to as those metals that possess a specific density of above 5 g cm^{-3} and adversely affect the environment and living organisms[1]. Heavy metals such as mercury, arsenic, chromium, cadmium, lead, iron, nickel and zinc are known to be major sources of environmental pollution. Some of these metals, referred to as essential heavy metals are needed in minute quantities (trace elements) (Copper/Cu, Zinc/Zn, Iron/Fe) while, others are toxic and may be carcinogenic (mercury, lead, cadmium, arsenic, nickel, chromium) even at low concentrations. Heavy metal pollution in aquatic systems arises from numerous sources such as sewage effluent, harbour activities and agrochemicals. They cause a serious threat to the health of various organisms, affecting the central nervous system, kidneys, liver, skin, bones or teeth[2]. Heavy metals are non-biodegradable and are translocated to different components affecting the biota[3]. Most medium and large-scale industries have turned many water bodies into

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dumping sites. This situation has arisen as a result of increasing urbanization and industrialization and a lack of enforcement of environmental regulations in developing countries. Most benthic organisms store toxic chemicals and metals in their tissues through their feeding habits and position in the food chain as secondary consumers[4].

Heavy metal pollution has caused an imbalance in the affected environment and too many species of aquatic organisms. Degenerative changes in the muscular tissues of aquatic animals have been reported as the symptoms of exposure to environmental contaminations such as pesticides or metals[5]. Many histological changes such as gill necrosis and fatty degradation of the liver occur in fish. Metallic compounds could disturb the oxygen level and reproductive processes of aquatic organisms, they cause the inhibition of enzymatic systems involved in protein synthesis and cell division thereby affecting the organisms' growth and development[6]. High mortality of juvenile fish has also been reported[1].

Fish accumulates toxic metals and other contaminants in their internal organs, most especially their edible tissues[7]. They store metals to concentrations many times higher than that present in water or sediment. Among the aquatic fauna, fish is the most susceptible to heavy metal contamination. Heavy metals enter fish through food or non-food particles, gills, oral consumption of water and the skin. These, therefore, have given rise to the use of fishes as biological indicators of metal pollution in aquatic environments[8]. As a result of their feeding habit-being omnivores, catfishes like *Chrysichthys nigrodigitatus,* may be considered indicators of pollution.

Asejire Reservoir located on the boundary of Oyo and Osun States and Erinle Reservoir in Osun state serves as the major source of water supply for industrial and domestic purposes to the surrounding towns. Due to increased urbanization and various anthropogenic activities along these river channels, there is a need for continuous monitoring of their pollution status. Although, various fish species and other aquatic bio-resources have been documented to bioaccumulate heavy metals, there is a paucity of information on the status of *Chrysichthys nigrodigitatus* from these reservoirs as a potential bioindicator of pollution. Therefore, this study assessed the level of accumulated heavy metals in selected organs of *Chrysichthys nigrodigitatus,* investigated relationships between heavy metal concentration in fish organs and fish size, assessed the concentration of heavy metals detected in water samples from the reservoirs and established whether the accumulated heavy metals are within the recommended safe limits for human consumption.

MATERIALS AND METHODS

Study area: Fish and water samples were collected from Asejire Reservoir Oyo State and Erinle Reservoir in Osun State Nigeria between June and September, 2021. Asejire Reservoir is a man-made lake located near Ibadan, Oyo State by the impoundment of River Osun. It is found between latitude 07°59'45"N to 07°36'25"N and longitude 004°08'00"E to 004°13'33"E. Its distance is about 53 km from Ile-Ife along the Ife-Ibadan expressway[9]. The catchment area is 7,800 km^2 and the impoundment area is 23.42 km^2. It provides water to the surrounding communities and industries, fishing activities are carried out on the reservoir by fishermen to meet their daily needs.

The Erinle Reservoir located near Ede Town Osun State has its source from Awon and Erinle Rivers. It has a storage capacity of 94,000 km^3. The reservoir basin extends from longitude 004°24'E to 004°35'E and latitude 07°45'N to 07°58'N. The surface area is about 1.25 km. The reservoir supplies water to inhabitants of Osogbo, Ede, Ifon-Osun, Ilobu, Gbongan, Omu and other towns and villages. Fishing activities are done by peasant fishermen[10].

Fish and water sampling: Thirty *C. nigrodigitatus* samples were captured using a gill net with the assistance of hired fishermen from each reservoir. A water sample from each location was collected in

2 L of the plastic container. The fish collected were stored in an ice-packed container and transported to the Physiology Laboratory in the Department of Zoology, Obafemi Awolowo University, Ile-Ife. The fish samples were identified using keys described by Gbaguidi *et al.*[11].

Morphometric studies: In all the fish samples, eight morphometric parameters which include-total length, standard length, fork length, head length, caudal height, maximum body depth, pre-dorsal length and pre-orbital length were measured to the nearest millimetres using a digital vernier calliper. The body weight of each fish sample was measured using Mettler P1210 digital weighing scale. Specimens were tagged in numerical order in which their morphometric details have been recorded.

Processing and analysis: Individual fish was cut open along the belly to remove the intestine, liver and muscle tissue, the gill was removed from the operculum. The extracted organs of each specimen were kept in their respective well-labelled containers and were analysed for heavy metal concentrations.

Heavy metals analysis: Each of the organs was weighed into a pre-weighed petri dish and dried at 80°C in Gallenkamp hot box oven. The dried samples' weight was recorded at intervals for 4 hrs until a constant weight was obtained. The dried samples were ground separately to fine particles using clean, dried mortar and pestle and then sifted using a sieve of particle size 0.02 mm. The 0.5 g of each sample was measured into a 100 mL beaker and 5 mL of aqua regia HCL and HNO_3 (3:1) was added to the samples for digestion. The samples were evenly distributed in the acid by stirring with a glass rod and the beaker was placed on the heater. The digested samples were filtered into a cylinder and the filtrate was made up to 50 mL using distilled water. The concentration of heavy metals-viz., chromium, cadmium, iron, copper, zinc and lead in the samples (organs and water) was examined using the PG990 model Atomic Absorption Spectrophotometer (AAS).

Bioaccumulation Factor (BAF): The BAF value of the heavy metals was determined by finding the ratio of the concentration of heavy metals in the fish organs to the concentration of heavy metals in the water samples. (https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/kabam-version-10-users-guide-and-technical-3):

$$\text{Bioaccumulation Factor}\left(\text{BAF}\right) = \frac{\text{Concentration of heavy metals in the fish organs (µg/g)}}{\text{Concentration of heavy metals in water (µg/L)}}$$

Statistical study: Data obtained were collated and analysed using One-way ANOVA and Tukey's HSD Test in IBM SPSS Version 25 ($p<0.05$).

RESULTS

The morphometric data of *C. nigrodigitatus* samples from Asejire and Erinle Reservoirs are summarized in Table 1. Fish weight (g) ranged between 59.33 to 183.61 while, the total length and standard length ranged between 99.26 to 328.32 and 155.56 to 224.94 mm, respectively in the samples from Asejire Reservoir. Fish size from Erinle Reservoir ranged between 21.31 to 116.23 g, 123.27 to 223.5 and 97.96 to 184.63 mm in weight, total length and standard length, respectively.

The allometric equation was established between some selected body parts of *C. nigrodigitatus* from Asejire and Erinle Reservoirs as shown in Table 2-3. There was a strong positive correlation between weight (g) and standard length (mm) of *C. nigrodigitatus* from Asejire Reservoir (males: correlation coefficient (r) = 0.9716), females: r = 0.8989). The morphometric relationship of the weight and standard length of *C. nigrodigitatus* obtained from Erinle Reservoir has an r-value of 0.9397, which showed that weight and standard length are strongly correlated.

Table 1: Morphometric characters of *C. nigrodigitatus* samples from Asejire and Erinle Reservoirs

	Asejire Reservoir (N = 30)		Erinle Reservoir (N = 30)	
Parameters	Range (minimum-maximum)	Mean±SE	Range (minimum-maximum)	Mean±SE
Weight(g)	59.33-183.61	107.37±5.933	21.31-116.23	47.41±4.982
TL (mm)	99.26-328.32	236.52±7.246	123.27-223.5	164.02±5.391
SL (mm)	155.56-224.94	186.35±3.208	97.96-184.63	131.58±4.583
FL (mm)	157.82-230.12	192.92±3.463	105.08-192.44	139.33±5.127
HL (mm)	44.88-66.39	55.67±1.047	31.17-61.36	41.57±1.450
CH (mm)	20.24-73.01	38.05±2.103	17.6-45.47	27.19±1.396
MBD (mm)	21.96-36.63	29.31±0.691	16.16-34.99	22.24±1.041
PDL (mm)	54.33-79.35	68.32±1.169	20.57-72.08	47.09±1.906
POL (mm)	12.09-21.45	17.17±0.401	7.91-23.93	12.92±0.696

TL: Total length, SL: Standard length, FL: Fork length, HL: Head length, CH: Caudal length, MBD: Maximum body depth, PDL: Pre-dorsal Length and POL: Pre-orbital length

Table 2: Allometric equations and correlation coefficient (r) values between morphometric variables of *Chrysichthys nigrodigitatus* obtained from Asejire Reservoir

Independent variables (X)	Dependent variables (Y)	Allometric growth equation (Y = A+Bx)	r-value
Male *Chrysichthys nigrodigitatus*			
Standard Length (SL)	Weight (W)	W = 1.687SL-207.3	0.9716
Head Length (HL)	Standard length (SL)	SL = 13.12+3.106HL	0.9737
Maximum Body Depth (MBD)	Weight (W)	W = 9.176MBD-153.0	0.9209
Female *Chrysichthys nigrodigitatus*			
Standard Length (SL)	Weight (W)	W = 1.706SL-210.5	0.8989
Head Length (HL)	Standard length (SL)	SL = 40.41+2.622HL	0.8701
Maximum Body Depth (MBD)	Weight (W)	W = 6.604MBD-88.47	0.7937

Table 3: Allometric equations and correlation coefficient (r) values between morphometric variables of *Chrysichthys nigrodigitatus* obtained from Erinle Reservoir

Independent variable (X)	Dependent variables (Y)	Allometric growth equation (Y = A+Bx)	r-value
Standard Length (SL)	Weight (W)	W = 1.021SL-87.02	0.9397
Head Length (HL)	Standard Length (SL)	SL = 2.886HL-11.59	0.9132
Maximum Body Depth (MBD)	Weight (W)	W = 4.644MBD-55.86	0.9701

The allometric equation was established between some selected body parts of *C. nigrodigitatus* from Asejire and Erinle Reservoirs as shown in Table 2-3. There was a strong positive correlation between weight (g) and standard length (mm) of *C. nigrodigitatus* from Asejire Reservoir (males: correlation coefficient (r) = 0.9716), females: r = 0.8989). The morphometric relationship of the weight and standard length of *C. nigrodigitatus* obtained from Erinle Reservoir has an r-value of 0.9397, which showed that weight and standard length are strongly correlated.

There was a strong positive correlation between the weight (g) and maximum body depth (mm) of males (r = 0.9209) and females (r = 0.7937) gotten from Asejire Reservoir. A high correlation coefficient (r) value of 0.9701 was observed for the weight and maximum body depth morphometric relationship of *C. nigrodigitatus* obtained from Erinle Reservoir indicating a strong positive correlation. The relationship between standard length and head length correlation coefficient (r) was 0.9737 and 0.8701, respectively for male and female *C. nigrodigitatus* sourced from Asejire Reservoir. This indicated a strong positive correlation between the standard length (mm) and head length (mm) of both sexes. The correlation between the standard length and a head length of *C. nigrodigitatus* collected from the Erinle Reservoir was positive (r = 0.9132).

Analysis of heavy metals in selected organs of *C. nigrodigitatus* samples obtained from Asejire and Erinle Reservoirs: Analysis of selected organs of *C. nigrodigitatus* samples obtained from Asejire Reservoir, as summarized in Table 4, revealed that the gill samples contained all the investigated heavy metals, Pb,

Table 4: Heavy metals concentration in selected organs of *Chrysichthys nigrodigitatus* from Asejire Reservoir

Heavy metals	Gills (μg g^{-1})	Intestine (μg g^{-1})	Muscle (μg g^{-1})	Liver (μg g^{-1})
Pb	0.04±0.0111	0.04±0.0111	0.22±0.1612	0.78±0.5001
Zn	0.55±0.4917	0.25±0.1982	0.05±0.0141	0.48±0.2330
Cr	1.08±0.5338	0.45±0.3359	0.44±0.3565	0.81±0.3584
Fe	0.62±0.2505	0.77±0.2358	0.38±0.1734	1.08±0.3535
Cd	0.29±0.1924	0.46±0.2392	0.06±0.0127	0.47±0.2418
Cu	0.04±0.0120	0.66±0.3282	0.61±0.3525	0.34±0.2272

Data are expressed as Mean±SE and no significantly different ($p<0.05$) by Tukey's HSD Test

Table 5: Heavy metals concentration in selected organs of *Chrysichthys nigrodigitatus* from Erinle Reservoir

Heavy metals	Gills (μg g^{-1})	Intestine (μg g^{-1})	Muscle (μg g^{-1})	Liver (μg g^{-1})
Pb	0.20±0.1818	0.21±0.1828	0.24±0.1743	0.76±0.3710
Zn	0.56±0.3553^{ab}	0.25±0.1704^{ab}	0.22±0.1601^{a}	1.27±0.3041^{b}
Cr	0.20±0.1611	0.08±0.0185	0.05±0.0172	0.64±0.2632
Fe	0.44±0.2294	0.92±0.3414	0.05±0.0105	0.82±0.4451
Cd	0.42±0.3393	0.79±0.3503	0.43±0.2066	0.51±0.1505
Cu	0.46±0.2293	0.55±0.2622	0.21±0.1610	0.17±0.0619

Data are expressed as Mean±SE, Mean±SE followed by the same alphabet, within a row, are not significantly different ($p<0.05$) by the Tukey's HSD Test

Table 6: Heavy metal concentration of water samples from Asejire and Erinle Reservoirs

Location	Pb (μg L^{-1})	Zn (μg L^{-1})	Cr (μg L^{-1})	Fe (μg L^{-1})	Cd (μg L^{-1})	Cu (μg L^{-1})
Asejire Reservoir	1.11±0.0310	0.09±0.0101	0.13±0.0304	2.01±0.0710	1.25±0.0127	0.30±0.0100
Erinle Reservoir	1.10±0.0020	0.35±0.0453	0.07±0.020	1.14±0.0301	2.31±0.0631	1.99±0.0321

Data are expressed as Mean±SE

Zn, Cr, Fe, Cd and Cu in the following increasing order, Cu, Pb, Cd, Zn, Fe and Cr ranging from 0.04±0.0120-1.08±0.5338 μg g^{-1}. There was no significant difference in the concentration of heavy metals detected in gills ($F = 1.523$, $df = 71$, $p = 0.212$).

In the intestine, Fe had the highest concentration (0.77±0.2358), followed by Cu (0.66±0.3282) while Pb was the least bio-accumulated metal (0.04±0.0111). Accumulation of heavy metals in intestine showed no significant difference ($F = 1.131$, $df = 71$, $p = 0.365$). Cu (0.61±0.3525) had the highest concentration, while Zn (0.05±0.0141) was the least bio-accumulated metal in the muscle. There was no significant difference in the concentration of heavy metals found in the muscle ($F = 0.978$, $df = 71$, $p = 0.447$). In the liver, Fe had the highest concentration (1.08±0.3535) whereas Cu had the least value (0.34±0.2272). The concentrations of accumulated heavy metals in liver showed no significant difference ($F = 0.677$, $df = 71$, $p = 0.644$).

The examination of selected organs from *C. nigrodigitatus* samples collected from Erinle Reservoir in Table 5 revealed that the liver accumulated the highest concentration of Pb (0.76±0.3710 μg g^{-1}) while gills, intestine and muscle had a similar level (≈ 0.2 μg g^{-1}) of Pb. The build-up of Zn was more in the liver (1.27±0.3041 μg g^{-1}) followed by gills (0.56±0.3553 μg g^{-1}) whereas the intestine and muscle had the minimum bioaccumulation of Zn. Liver had the highest level of Cr (0.64±0.2632 μg g^{-1}) followed by gills (0.20±0.1611 μg g^{-1}), then intestine (0.08±0.0185 μg g^{-1}) and the muscle with the least level of Cr (0.05±0.0172 μg g^{-1}). The intestine had the highest concentration of Fe (0.92±0.3414) while muscle had the lowest amount of Fe (0.05±0.0105). The intestine (0.79±0.3503) and liver (0.51±0.1505) had a higher accumulation of Cd than muscle and gills. However, Cu accumulation in the intestine (0.55±0.2622) and gills (0.46±0.2293) is higher than in the muscle and liver as shown in Table 5. There was no significant difference in the concentration of heavy metals in each of the selected organs. However, Zn concentration was significant different ($F = 3.488$, $df = 47$, $p = 0.035$) across the organs.

Analysis of heavy metals in water samples: Analysis of heavy metals in water samples as shown in Table 6 indicated that the concentration of heavy metals detected in a water sample from Asejire Reservoir

Table 7: Bioaccumulation factor of heavy metals in selected organs of *Chrysichthys nigrodigitatus* from Asejire and Erinle Reservoirs

Asejire Reservoir					Erinle Reservoir				
Heavy metals	Gills	Intestine	Muscle	Liver	Heavy metals	Gills	Intestine	Muscle	Liver
Pb	0.04	0.04	0.20	0.69	Pb	0.18	0.20	0.22	0.69
Zn	5.80*	2.69*	0.48	5.08*	Zn	1.60*	0.72	0.62	3.62*
Cr	8.34*	3.49*	3.41*	6.20*	Cr	2.86*	1.22*	0.78	9.30*
Fe	0.31	0.38	0.19	0.54	Fe	0.38	0.80	0.04	0.72
Cd	0.23	0.37	0.05	1.57*	Cd	0.18	0.34	0.19	0.22
Cu	0.13	2.20*	2.02*	1.14*	Cu	0.23	0.28	0.10	0.09

*Values >1 indicate high bioaccumulation factor while values <1 indicate less bioaccumulation factor

Table 8: Equation, correlation coefficient (r) and the level of significance (P) for the relationship between standard length and heavy metal concentrations in *Chrysichthys nigrodigitatus* from Asejire Reservoir

		Organs			
Heavy metals	Data	Gill	Intestine	Muscle	Liver
Pb	Equation	Pb = 0.051-0.00004SL	Pb = 0.05-0.00004SL	Pb = 0.004SL-0.549	Pb = 0.020SL-2.974
	r-value	-0.028	-0.028	0.196	0.308
	p-value	0.9569	0.9569	0.7099	0.5522
Zn	Equation	Zn = 9.763-0.05SL	Zn = 0.004SL-0.520	Zn = 0.0004SL-0.035	Zn = 0.027SL-4.421
	r-value	-0.772	0.160	0.236	0.865
	p-value	0.0724	0.7615	0.6531	0.0260*
Cr	Equation	Cr = 0.026SL-3.861	Cr = 2.285-0.010SL	Cr = 6.770-0.034SL	Cr = 0.003SL+0.193
	r-value	0.381	-0.224	-0.730	0.071
	p-value	0.4559	0.6691	0.0993	0.8945
Fe	Equation	Fe = 0.012SL-1.644	Fe = 2.282-0.008SL	Fe = 2.193-0.010SL	Fe = 2.85-0.010SL
	r-value	0.138	-0.026	-0.431	-0.207
	p-value	0.4682	0.6138	0.3933	0.6944
Cd	Equation	Cd = 0.011SL-1.657	Cd = 0.007SL-0.838	Cd = 0.144-0.0005SL	Cd = 0.008SL-0.964
	r-value	0.417	0.223	-0.285	0.245
	p-value	0.4113	0.6713	0.5836	0.6405
Cu	Equation	Cu = 0.0004SL-0.037	Cu = 1.148-0.005SL	Cu = 1.702-0.006SL	Cd = 0.009SL-1.323
	r-value	0.272	-0.249	-0.128	0.302
	p-value	0.6016	0.200	0.8093	0.5613

*Significant at p<0.05

is Fe>Cd>Pb>Cu>Cr>Zn. The levels of heavy metals found in a water sample taken from the Erinle Reservoir revealed that Cd and Cu were of higher concentration than Pb, Zn and Cr.

Bioaccumulation Factor (BAF): Generally, for *C. nigrodigitatus* samples obtained from Asejire Reservoir, the liver bio-accumulated more heavy metals than the gills. The rate of bioaccumulation occurred in this order: Liver>gills>intestine>muscle as shown in Table 7. The highest bioaccumulation factor was obtained for Cr in gills (8.34) while, Pb in gills and intestine (0.04) had the lowest bioaccumulation factor. In *C. nigrodigitatus* samples obtained from Erinle Reservoir, the order of bioaccumulation rate is liver>gills >intestine>muscle. Cr in the liver had the highest BAF value of 9.30 whereas, Fe in the muscle had the lowest BAF value of 0.04.

Relationship between heavy metals and standard length of *Chrysichthys nigrodigitatus* from Asejire Reservoir: As shown in Table 8, the concentration of Pb, Fe and Cu concerning fish length showed a very weak correlation (r<0.5) in all the fish organs. However, the concentration of Zn in the gills and Cr in muscle showed a strong negative correlation with fish standard length (r>0.5) while the concentration of Zn in the liver showed a statistically significant positive correlation (r = 0.87). A strong negative correlation was observed between the fish length and level of Zn in fish gill (r = -0.772).

Relationship between heavy metals and weight of *Chrysichthys nigrodigitatus* from Asejire Reservoir: Table 9 showed the relationship between fish weight and concentration of heavy metals in the respective organs. Pb, Cr, Fe and Cu all showed a very weak correlation (r<0.5) with fish weight.

Table 9: Equation, correlation coefficient (r) and the level of significance (P) for the relationship between weight and heavy metal concentrations in *Chrysichthys nigrodigitatus* from Asejire Reservoir

		Organs			
Heavy metals	Data	Gill	Intestine	Muscle	Liver
Pb	Equation	Pb = 0.057-0.0001W	Pb = 0.058-0.0001W	Pb = 0.380-0.002W	Pb = 0.001W-0.68
	r-value	-0.214	-0.214	-0.169	0.033
	p-value	0.6837	0.6837	0.7486	0.9503
Zn	Equation	Zn = 1.999-0.014W	Zn = 0.495-0.002W	Zn = 0.0004W-0.008	Zn = 0.013W-0.873
	r-value	-0.498	-0.205	0.446	0.975
	p-value	0.3152	0.6961	0.3750	0.0009*
Cr	Equation	Cr = 0.006W+0.510	Cr = 1.067-0.006W	Cr = 1.392-0.009W	Cr = 0.006W-0.187
	r-value	0.181	-0.307	-0.448	0.291
	p-value	0.7313	0.5534	0.3727	0.5760
Fe	Equation	Fe = 0.006W+0.553	Fe = 1.183-0.004W	Fe = 0.395-0.0002W	Fe = 1.601-0.005W
	r-value	0.044	-0.294	-0.0173	-0.250
	p-value	0.9344	0.5713	0.9728	0.632
Cd	Equation	Cd = 0.008W-0.515	Cd = 0.005W-0.075	Cd = 0.062-0.0001W	Cd = 0.005W-0.084
	r-value	0.705	0.375	-0.076	0.387
	p-value	0.1180	0.4642	0.8868	0.4479
Cu	Equation	Cu = 0.0002W+0.024	Cu = 1.148-0.005W	Cu = 1.431-0.008W	Cu = 0.350-0.0001W
	r-value	0.252	-0.249	-0.394	-0.006
	p-value	0.6307	0.6336	0.154	0.9917

*Significant at p<0.05

Table 10: Equation, correlation coefficient (r) and the level of significance (P) for the relationship between the standard length and heavy metal concentrations in *Chrysichthys nigrodigitatus* from Erinle Reservoir

		Organs			
Heavy metals	Data	Gill	Intestine	Muscle	Liver
Pb	Equation	Pb = 0.004SL-0.436	Pb = 0.004SL-0.484	Pb = 1.912-0.011SL	Pb = 0.012SL-0.868
	r-value	0.306	0.297	-0.744	0.341
	p-value	0.5560	0.5682	0.0897	0.5085
Zn	Equation	Zn = 0.019SL-2.173	Zn = 1.789-0.010SL	Zn = 0.002SL-0.004	Zn = 2.144-0.006SL
	r-value	0.599	-0.701	0.107	-0.223
	p-value	0.2099	0.1211	0.8396	0.6708
Cr	Equation	Cr = 0.005SL-0.512	Cr = 0.138 -0.0004SL	Cr = 0.129-0.0005SL	Cr = 2.897-0.015SL
	r-value	0.306	-0.228	-0.335	-0.666
	p-value	0.5561	0.6645	0.5160	0.1488
Fe	Equation	Fe = 0.001SL-0.231	Fe = 1.288-0.003SL	Fe = 0.057-0.00005SL	Fe = 3.627-0.019SL
	r-value	0.071	-0.084	-0.056	-0.490
	p-value	0.8944	0.8736	0.9161	0.3234
Cd	Equation	Cd = 0.010SL-1.085	Cd = 0.013SL-1.193	Cd = 1.285-0.006SL	Cd = -0.025SL-2.926
	r-value	0.344	0.439	-0.320	0.567
	p-value	0.5047	0.3837	0.4568	0.2409
Cu	Equation	Cu = 0.003SL-0.027	Cu = 1.247-0.005SL	Cu = 0.004SL-0.439	Cu = 0.005SL-0.457
	r-value	0.163	-0.206	0.311	0.362
	p-value	0.7570	0.6959	0.5487	0.4813

The concentration of Zn in the liver and Cd in the gills showed a strong positive correlation with fish weight (Zn: r = 0.975, Cd: r = 0.705).

Relationship between heavy metals and standard length of *Chrysichthys nigrodigitatus* from Erinle Reservoir: The relationship between fish standard length and concentration of heavy metals in *C. nigrodigitatus* samples obtained from the Erinle Reservoir is summarized in Table 10. Pb in the fish muscle (r = -0.744), Zn in the intestine (r = -0.701) and Cr in the liver (r = -0.666) showed a strong negative correlation. Zn in the gills (r = 0.599) and Cd (r = 0.567) in the liver showed a positive correlation with fish standard length. Cu had a weak correlation with fish standard length (r<0.5).

Table 11: Equation, correlation coefficient (r) and the level of significance (P) for the relationship between the weight and heavy metal concentrations in the gill, intestine, muscle and liver of *Chrysichthys nigrodigitatus* from Erinle Reservoir

		Organs			
Heavy metals	Data	Gill	Intestine	Muscle	Liver
Pb	Equation	Pb = 0.008W-0.251	Pb = 0.008W-0.236	Pb = 0.777-0.009W	Pb = 0.018W-0.328
	r-value	0.468	0.462	-0.575	0.549
	p-value	0.3495	0.3567	0.2323	0.2591
Zn	Equation	Zn = 0.015W-0.318	Zn = 0.735-0.008W	Zn = 0.002W-0.123	Zn = 1.560-0.005W
	r-value	0.464	-0.530	0.111	-0.179
	p-value	0.3542	0.2792	0.8346	0.7349
Cr	Equation	Cr = 0.007W-0.199	Cr = 0.098-0.0002W	Cr = 0.071-0.0003W	Cr = 1.488-0.014W
	r-value	0.461	-0.146	-0.188	-0.603
	p-value	0.3571	0.7821	0.7215	0.2051
Fe	Equation	Fe = 0.556-0.002W	Fe = 1.039-0.002W	Fe = 0.095-0.003W	Fe = 1.721-0.015W
	P-value	-0.095	-0.067	-0.308	-0.380
	p-value	0.8580	0.8993	0.7153	0.4573
Cd	Equation	Cd = 0.015W-0.483	Cd = 0.01W-0.211	Cd = 0.646-0.004W	Cd = 0.032W-1.168
	r-value	0.497	0.308	-0.192	0.715
	p-value	1.3114	0.5529	0.1534	0.1100
Cu	Equation	Cu = 0.003W-0.250	Cu = 0.0003W-0.537	Cu = 0.007W-0.189	Cu = 0.006W-0.003
	r-value	0.168	0.010	0.459	0.369
	p-value	0.7508	0.9828	0.3601	0.4715

Relationship between heavy metals and weight of *Chrysichthys nigrodigitatus* from Erinle Reservoir: As shown in Table 11, the concentration of Pb in the fish organs had a moderate correlation with fish weight, although, the concentration of Pb in muscle showed a negative correlation (r = -0.575). Zn in the intestine had a negative correlation with fish weight. Cr (except in the liver), Fe and Cu in fish organs showed a very weak correlation with fish weight. The concentration of Cd in the liver had a strong correlation with fish weight (r = 0.715).

DISCUSSION

Morphometric information such as total length, standard length, head length, caudal height, maximum body depth and pre-orbital length of fish provides an additional way to describe fish of the same species[12]. This study reflected that there was a positive correlation between the length and weight of *Chrysichthys nigrodigitatus* from Asejire and Erinle Reservoirs (i.e., as the fish length increases, there is a corresponding increase in the weight of individual fish). This agrees with the report given by Rajeshkumar and Li[13]. This study showed that the total length of *Chrysichthys nigrodigitatus* taken from Asejire and Erinle Reservoirs ranged from 99.26 to 328.22 and 123.27 to 223.5 mm, respectively. This result from Erinle Reservoir was lower than the maximum total length, TL = 385 mm reported by Whenu *et al.*[14] and TL = 324 mm reported by Adite *et al.*[15]. The low total length could be that the fishes were not allowed to reach maturity before being captured.

The difference in the concentration of heavy metals observed in the organs could be a result of their roles in the process of bioaccumulation, their method of exposure, ability to modulate or absorb heavy metals as well as the physiological difference in the body part of the fish[16]. The highest concentration of copper was found in the intestine of *C. nigrodigitatus* from Asejire and Erinle Reservoirs. This is in contrast with the report given by Ayotunde *et al.*[17] who reported that the highest concentration of copper was in gills. Fish samples from Asejire and Erinle Reservoirs accumulated high concentrations of essential heavy metals (Zn, Fe, Cu) and low concentrations of ultra-trace metals (Pb, Cr, Cd). A similar result was reported by Abidemi-Iromini *et al.*[18] after observing heavy metal accumulation in catfish species inhabiting Adelakun and Kehinde[7], who observed heavy metal bioaccumulation in *C. nigrodigitatus* from River oli. The metabolic activities of the various parts of the fish could result in the elimination of some of these non-essential heavy metals through excretory organs such as gills and kidneys as they can be very toxic to both fish and man (through consumption of contaminated fish) even at very low concentrations.

Metabolically active organs (liver and gills) store higher concentrations of heavy metals than other organs such as muscle, intestine and skin[19]. It was observed that *C. nigrodigitatus* gotten from Asejire and Erinle Reservoirs had the highest level of heavy metals in the liver while the lowest accumulation was found in the muscle. This result was in line with the reports by Vinodhini and Narayanan[20] and Al-Ghanim *et al.*[21]. The liver having the highest concentration could be because the liver is the main site for metabolism. It carries out the activity of detoxification and could be a result of the presence of metal-binding proteins and metallothioneins which play a vital role in metal detoxification[19,22]. The gills accumulated high heavy metal concentration due to their direct and constant contact with water[23]. The level of heavy metals in gills could indicate the level of heavy metals in the water where the fish lives[19]. Low accumulation of heavy metals in the muscle could show that muscle is a passive organ when it comes to heavy metal bioaccumulation and the presence of low binding proteins in the muscle[24,25].

In this study, the concentration of Pb in the gills, intestine, muscle and liver of *C. nigrodigitatus* from Asejire and Erinle Reservoirs was above the permissible limit -0.0005 and 0.002 μg g^{-1} set by the FAO/WHO[26]. Abdel-Kader and Mourad[27] also detected that the Pb concentration in *Clarias gariepinus* from lake Maryout, Egypt was above the permissible limit given by WHO. Ndimele *et al.*[28] reported that the level of Pb in tissues of *C. nigrodigitatus* was higher than the WHO standard limit. Pb is a very toxic heavy metal that could cause serious damage to fish gills thereby altering the metabolic rate of fish and reducing oxygen consumption. Pb also decreases the protein content in muscles. When fish having a mild concentration of Pb is ingested by humans, it may cause abdominal pain, headache, memory loss and, hand and feet weakness while, a high concentration of Pb can lead to anaemia, kidney and brain damage, and even death[29].

The concentration of Zn found in all the organs analysed in this study was higher than the recommended value of 0.05 μg g^{-1} (Food codex/WHO). Asgedom *et al.*[30] reported that the levels of Pb, Cr, Cd, Co and Zn in the flesh and bone of *Oreochromis niloticus* and *Cyprinus carpio* from Hashenge lake were higher than the recommended standards. Zinc is an important metal which takes part in protein synthesis growth, immunity and energy metabolism in fish[31]. However, increased accumulation of Zn above the tolerance range could impair the rate of respiration, since Zn is mostly concentrated in the gills[32].

The highest concentration of Cd (0.473 μg g^{-1}) in *C. nigrodigitatus* collected from Asejire Reservoir was found in the liver while the intestine obtained from *C. nigrodigitatus* fetched from the Erinle Reservoir stored the highest level of cadmium, Cd (0.786 μg g^{-1})-these values were higher than the maximum consumable values of 0.00001 and 0.00005 μg g^{-1} laid down by WHO. Ayotunde *et al.*[17] reported the highest concentration of Cd to be found in the liver and gills of *C. nigrodigitatus* obtained, respectively from stations I and II of cross river and reported that the metallothionein in the liver is strongly attracted to cadmium.

The highest concentration of Fe (1.075 μg g^{-1}) was found in the liver of *C. nigrodigitatus* obtained from the Asejire Reservoir while, in *C. nigrodigitatus* fetched from the Erinle Reservoir, the liver and the intestine had a high accumulation of Fe. This observation agreed with the study carried out by Abarshi *et al.*[33] on croaker fish fetched from Niger Delta. This could be attributed to the liver functions in the storage of iron which is an important part of haemoglobin required for oxygen transportation in the body[34].

In Asejire and Erinle Reservoirs, the intestine accumulated the highest concentration of Cu. The lowest concentration of Cu was found in the gills of *C. nigrodigitatus* collected from the Asejire Reservoir while in *C. nigrodigitatus* collected from the Erinle Reservoir, the liver stored the lowest level of copper. However, Shah[22] and Abarshi *et al.*[33], on carp (*Labeo rohita*) and croaker fish, reported that the highest mean concentration of copper was found in the gills and liver, respectively.

This present study revealed that all the organs accumulated a certain concentration of Cr. However, the gill had the highest level of Cr in fishes obtained from the Asejire Reservoir while the liver stored the highest amount of Cr in fish samples collected from the Erinle Reservoir.

Six heavy metals: Cd, Cr, Pb, Zn, Fe and Cu were examined and detected in the water samples from Asejire and Erinle Reservoirs. The concentration of Fe was the highest in water samples from Asejire Reservoir while Cd had the highest concentration in water samples from Erinle Reservoir. The levels of the heavy metals in water samples from Asejire and Erinle Reservoirs were lower than the recommended safe limits by WHO[35]: Pb (0.01 mg L^{-1}), Zn (3.0 mg L^{-1}), Fe (0.3 mg L^{-1}), Cd (3.0 mg L^{-1}), Cu (2000 mg L^{-1}) and Cr (50 mg L^{-1}). Ayotunde *et al.*[17] reported that the concentrations of Fe, Zn and Cd were lower than, but Pb had an equivalent value when compared to the WHO standard.

A negative correlation was observed between fish length (and fish weight) and heavy metal concentration in fish muscle except in a few cases. Although, muscle does not reveal the high level of heavy metal bioaccumulation like other fish organs such as the liver and gill, evaluation of heavy metals in muscle is of paramount concern since it is the edible and most consumed part of fish and these heavy metals could have serious implication on human health. Positive correlations exist between heavy metals concentration in gills and fish length (and weight) (except for Pb and Zn concentrations from the Asejire Reservoir which revealed a negative correlation). This outcome could be due to the function of the gill-it is the site for an exchange of dissolved oxygen between the fish and the environment and the gills have a wide surface area which increases the diffusion of metals[36].

CONCLUSION

The rate at which fish organs bio-accumulate heavy metals differ. The gills and liver can store high concentrations of heavy metals while, muscle and intestine have low bioaccumulation capability. *C. nigrodigitatus* got from Asejire and Erinle Reservoirs bio-accumulated high levels of metals and are therefore not safe for consumption. However, the concentration of heavy metals in water was within the permissible limit given by WHO. Generally, the availability of heavy metals could be attributed to indiscriminate dumping of refuse, runoff from operational mines, unmethodical use of agrochemicals in nearby farmlands, bush burning and grasslands. These activities lead to the introduction of heavy metals into the aquatic ecosystem. Heavy metals affect the development of fish embryos and other aquatic organisms and cause organ-system disruption and death in fish and humans when ingested.

SIGNIFICANCE STATEMENT

This study revealed that Asejire and Erinle Reservoirs are gradually being polluted by heavy metals. The pollution has been attributed to the uncontrolled anthropogenic activities along the river banks that feed these Reservoirs. Consequently, the level of heavy metals accumulated in the biota has gradually increased to a status of public health concern. Constant biomonitoring of the reservoirs is essential for the well-being of aquatic organisms and humans. Other biota in these water bodies should be re-evaluated to confirm their safety for human consumption. Buffer zones should be adequately designed to minimize the influx of these metals and protect these water bodies from subsequent disturbances.

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