Bioaccumulation of Heavy Metals in water and some fish samples from Onuimo River, Imo State, Nigeria

ABSTRACT

Bioaccumulation of some heavy metals (Cu, Zn, Cd and Cr) was determined in selected fish samples from Onuimo River in Imo State. Concentrations of some heavy metals in water and fish samples were determined using atomic absorption spectrophotometer (AA 500 PG) and the results obtained varied significantly among the fish species. Bioaccumulation of heavy metals were found to follow the sequence as Damsel fish > Cling fish > Dat fish > Tilapia fish > Cat fish. Bioconcentration factor model implored in the study showed a decreasing order as follows; Damsel fish = Cling fish > Cat fish > Dat fish > Tilapia fish and Damsel fish = Cling fish > Tilapia > Dat fish > Cat fish for copper and zinc metals respectively. Those of Cadmium and chromium were not calculated due to the fact that there concentrations in water samples were below detection limits. Results of analyses of heavy metals in selected water samples revealed that concentration of cadmium and chromium was below detection limits of some international regulatory bodies whereas those of zinc and copper were also lower than these permissible limits.

Keywords: Atomic absorption spectrophotometer, bioaccumulation, bioconcentration, fish, heavy metals, Onuimo River, water analysis.

1. INTRODUCTION

Due to geometric increase in human population around the world, the rate at which fish is consumed globally had also increased owing to the fact that fish have both nutritional and therapeutic values. Fish not only serve as good sources of protein but are unsaturated fatty acids richly in various essential minerals and vitamins which nourishes the body when consumed [1].These vital nutrients makes fish a perfect health food which when consumed adequately encourages optimal heart functioning. The American Heart Association (AHA) recommended the consumption of fish for at least twice per week in order to reach the daily intake of omega – 3 fatty acids [1].

However, excess consumption of heavy metal contaminated fish can result in bioaccumulation of these toxic wastes in the body over time. Fish which are relatively situated at the top of the aquatic food chain can accumulate heavy metals in their tissues either from food, water, sediments or all. [2-4]. Bioaccumulation of heavy metals in fish and their subsequent distribution at various organs of the fish are greatly interspecific. Some factors that can influence metal uptake by fish may include the following; metal type, fish species and tissue, sex, size, age feeding behaviour, swimming pattern, reproductive cycle and geographical location etc [2, 5-7]. Entry of heavy metals into the organs of fish mainly takes place by adsorption and absorption along kidney, liver, gut tract walls, muscular and gills surfaces. Thus, the rate of accumulation becomes a function of uptake and depuration rates. This makes fish a good indicator of heavy metal contamination in water [8-10].

Essential heavy metals like zinc, iron, manganese and copper are vital for biological systems like enzymatic activities but they can also be toxic at high concentration [11]. Non essential heavy metals like nickel, chromium, cadmium, mercury, lead, arsenic, silver etc have no known essential role in living organisms. They exhibit extreme toxicity at very low concentration and have been regarded as major threat to life of both organisms and humans. [12-14]. Toxic effect occurs due to inability of excretory, metabolic, storage and detoxification mechanisms to counter metal uptake [15]. This eventually leads to histopathological and physiological changes [16-17]. Heavy metals in fish can invalidate their health benefits to humans. Several adverse effects of heavy metals in fish samples have been extensively studied [18]. Some of the adverse effects are cardiovascular, renal and peripheral vascular diseases, neurologic and non–behavioural disorders, cancer, proteinuria, liver and kidney failure, gastrointestinal toxicity, nephropathy, hematogic disorder, encephalopathy, pulmonary fibrosis, nasopharyngeal tumors, nephrotoxicity, tremor, nausea, damage to fetus among others [19-21]. As a result of these effects, many inter-national monitoring programs have been established in order to assess the quality of fish for human consumption and also to monitor the health of aquatic ecosystem [22-24].

Heavy metals are natural components of earth crust with a relative density greater than 5.0 g/cm^3. The can enter the environment through anthropogenic processes like mining, extraction and refining, combustion and electro wining process, indiscriminate discharge of automobile and industrial wastes, fertilizer, pesticides and herbicides application in farm lands, river run off like hydrothermal vent [26] and volcanic eruptions [27]. Due to great benefits of fish consumption, there is an urgent need for humans to ascertain the level of heavy metals in fish species that are consumed daily by both humans and animals in other avoid health hazards that come with consumption of heavy metals contaminated fishes. Some researchers have reported presence of toxic metals in various fish samples in water bodies in Nigeria [24, 28-35]. Onuimo has been one of the fresh water rivers in the South Eastern part of the country. The river plays important role in water supply (domestic and industrial), flood control and fisheries and agricultural purposes to the rural communities that her tributaries cut across. Presence of massive economic and agricultural activates around the river is believed to be the major sources of pollution through river run offs. Hence presence of contaminants like heavy metals and its bioaccumulation in water, soil, sediments, and aquatic organisms especially fishes in river could cause adverse health risk to people who consume products from the river [36-37]. The main objective of this work is to investigate the bioaccumulation of four heavy metals in selected fish samples from Onuimo River namely; Moon fish (*Citharinus citharus*), Tilapia fish (*Oreochronus niloticus*), Mud fish (*Clarias anguillaris*), Cat fish (*Clarias gariepinus*) and Carp fish (*Labeo coulbie*).

2. EXPERIMENTAL DETAILS

2.1. Site Description

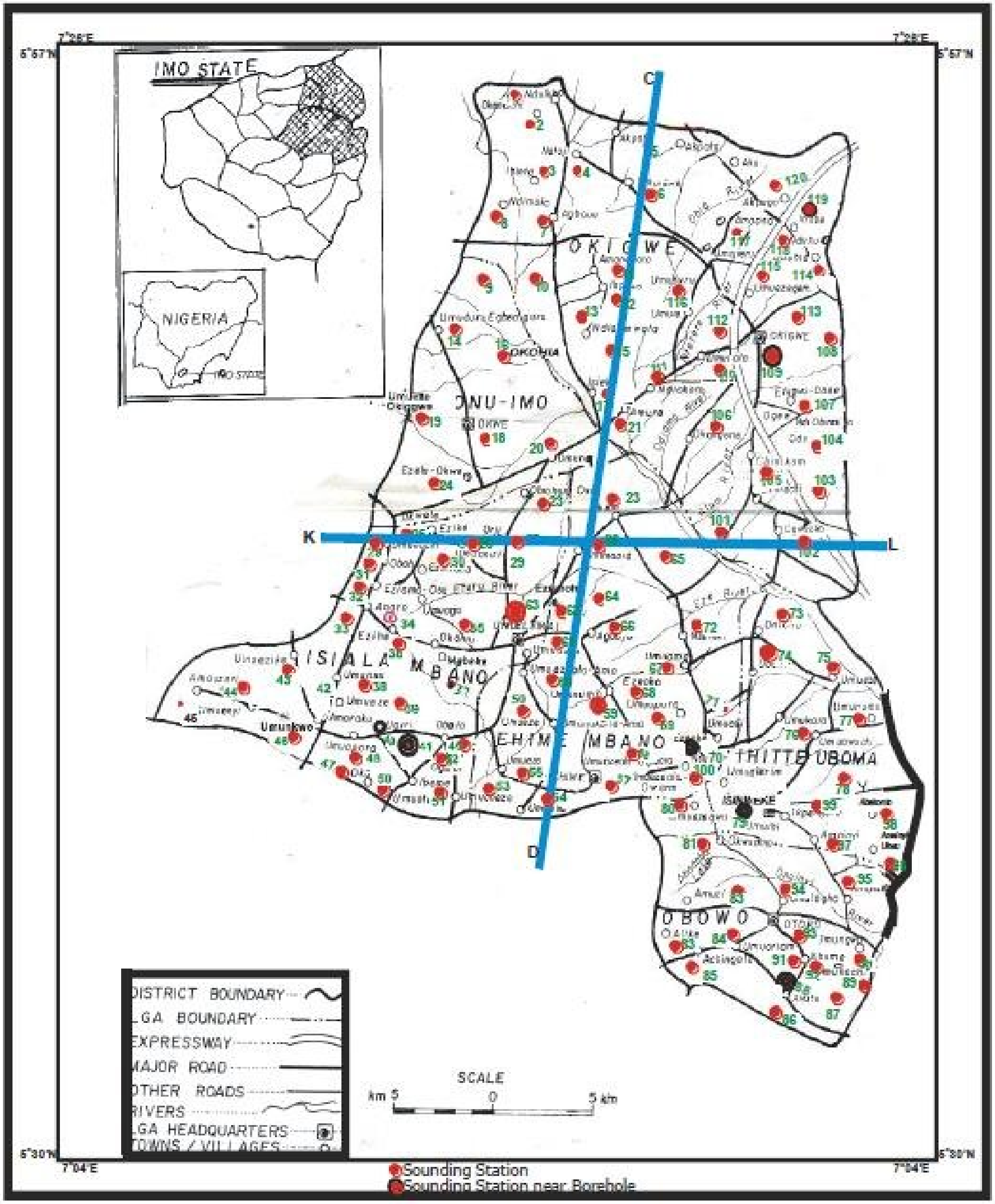

Figure 1. Geological Map Showing Onuimo River

Onuimo River is located in Umungwa Community in Obowo Local Government Area of Imo State, Nigeria and the river lies between Longitude 5°50 '56 N and latitude 7°14 ' 20 W. The River is also linked to Umunachi River which is also in Obowo Local Government Area. The river is located close to Onuimo industrial market and has been seen to be a repository for waste generated in the market. The river runs approximately ten kilometers across Umuahia down to Obowo where it is located.

2.2 Fish and Water Sampling

Fifteen commercial fish samples were harvested with a local made net through the aid of local fishermen at the river. The harvested fish samples were first washed with clean water at the point of harvest, separated according to species and preserved in an ice chest. They were then taken to the laboratory and kept frozen at -20 °C in a refrigerator prior to analyses. On the other hand, water samples were collected alongside where the fishes were harvested with separate acid pre washed water plastic containers, labeled, enclosed in a chest and transported to the laboratory where they were further refrigerated prior to analysis.

2.3 Quality Control

All glass wares used for the analysis were all Pyrex and reagents of analytical grade. The glass wares prior to their various uses, were first washed with 10% nitric acid, 0.5% potassium permanganate and thoroughly with deionized water and air dried. Standard operating conditions were all observed to ensure accurate and precise analysis.

2.4 Determination of Heavy Metal Contents in Fish and Water Samples

The fish samples were brought out of the refrigerator, rinsed thoroughly with deionized water and dried in an electric oven at a temperature range of 70 – 80 °C for three days. After drying, they were all separately brought out and crushed to fine particle size using acid pre-washed mortar and pestle. Exactly 1 g of the grounded fish sample was accurately weighed and transferred into a 250 mL conical flask. 10 mL of digestion mixture in the ration of (1:2:2) of perchloric, nitric and sulphuric acids ware all added to the sample and heated on a hot plate in a fume cupboard at about 200 °C for 30 minutes until white fumes formed disappeared indicating complete digestion. The sample was allowed to cool after which 20 mL of distilled water was added to bring the metals into solution. Sample was later filtered with whatman filter paper under gravity into a 100 mL volumetric flask. The filtrate was made up with deionized water up to the graduated mark of the volumetric flask. The following metal (Cu, Zn, Fe, Pb, Cd and Hg) contents were analyzed using atomic absorption spectrophotometer (AAS) of model AA500PG after selecting the various wavelengths at which the heavy metals were determined. Also an analytical blank was prepared in a similar method which was used in the calibration of the AAS machine. The analyses were validated by diluting the salt solutions of the investigated heavy metals (Zn, Cu, Cr, Cd) in various concentrations of 0.2, 0.4, 0.6, 0.8 and 1.0 ppm to enable the spectrophotometer measure the concentrations of the investigated heavy metals from their sample solutions [30]. The same procedure was also repeated for all the fish samples and all analyses were done in triplicate. Refrigerated water samples were brought out allowed to defrost and transferred into separate beakers. It was followed by digestion of samples according to the procedure stated by Standard Methods for Examination of Water and Waste water, 2^{nd} edition, 2012 (APHA-AWWA-WEF) [38].

2.5 Statistical Analysis

Statistical data analysis was done using SPSS 16.0 software. Descriptive statistics was conducted on the triplicate data to determine the mean, range and standard deviation.

2.6 Bioconcentration of Heavy Metals in Investigated Fish Samples

Bioconcentration is the process by which a chemical substance is absorbed by an organism from the ambient environment only through its respiratory and dermal surfaces. The degree to which bioconcentration occur is expressed as the bioconcentration factor (BCF) and can only be measured under controlled laboratory conditions in which dietary intakes of the chemicals are deliberately not included. The competing uptake and elimination processes resulting in bioconcentration can be represented mathematically by an organism-water-two-compartment model where the organism is considered to be single compartment in which the chemical is homogeneously mixed [39].

$$\frac{dC_B}{dt} = (k_1 C_{WD}) - (k_2 + k_E + k_M + k_G)C_B \qquad \text{Eq. 1}$$

where C_B = chemical concentration in the organism ($g.kg^{-1}$),

t = unit time (d^{-1})

k_1 = chemical uptake rate constant from the water at the respiratory surface ($L.kg^{-1}.d^{-1}$)

C_{WD} = freely dissolved chemical concentration in the water ($g.L^{-1}$)

k_2, k_E, k_M, k_G = rate constants (d^{-1}) representing chemical elimination from the organism via the respiratory surface, fecal egestion, metabolic transformation and ngrowth dilution

when both C_B and C_{WD} no longer vary with exposure duration. That is, $\frac{dC_B}{dt} = 0$, the system has reached a steady state and equation (1) can be rearranged to calculate the BCF as;

$$BCF = \frac{C_B}{C_{WD}} = \frac{k_1}{(k_2 + k_E + k_M + k_G)} \qquad \text{Eq. 2}$$

Bioconcentration can also be calculated as the ratio of the chemical concentration in the organism to the chemical concentration in water at steady state [39].

$$BCF_{ss} = \frac{C_B}{C_{WD}} = \frac{Conc._{Biota}}{Conc._{Water}} \qquad \text{Eq. 3}$$

The steady state calculation also refered to as the "Plateau Method" is only valid if the staedy state actually occur (USEPA 1996a; OECD 1996) [40-41].

BCF can also be determined kinetically as the ratio of the chemical uptake rate constant from water and the total elimination or depuration rate constant k_T (d^{-1}),

$$BCF_k = \frac{k_1}{k_T}, \text{ where } k_T = k_2 + k_E + k_M + k_G \qquad \text{Eq. 4}$$

Table 1. An Overview of Regulatory Bioaccumulation Assessment Endpoint and Criteria [39]

S/No	Regulatory Agency	Bioaccumulation endpoint	Criteria (log values)	Programme
1	Environmental Canada	K_{ow}	≥ 100000 (5)	CEPA (1999)*
2	Environmental Canada	BCF	≥ 5000 (3.7)	CEPA (1999)
3	Environmental Canada	BAF	≥ 5000 (3.7)	CEPA (1999)
4	European Union 'bioaccumulative'	BCF	≥ 2000 (3.3)	REACH+
5	European Union 'very bioaccumulative'	BCF	≥ 5000 (3.7)	REACH

6	United States ‘bioaccumulative’	BCF	1000 – 5000 (3.7)	TSCA ǂ, TRI
7	United States ‘very bioaccumulative’	BCF	≥ 5000 (3.7)	TSCA, TRI
8	United Nations Environment Programme	K_{ow}	≥ 100000 (5)	Stockholm convection §
9	United Nations Environment Programme	BCF	≥ 5000 (3.7)	Stockholm convection

*CEPA , Canadian Environmental Protection Act, 1999 (Government of Canada 2000).
+Registration, Evaluation and Authorization of Chemicals (REACH) Annex XII (European Commission 2001)
ǂCurrently being used by the US Environmental Protection Agency in its Toxic Substance Control Act (TSCA) and Toxic Release Inventory (TRI) Program (USEPA 1976).
§ Stockholm Convention on Persistent organic Pollutants (UNEP 2001).

3.0 EXPERIMENTAL RESULTS AND DISCUSSION

Table 2. Levels of Heavy Metals in fish samples in River Onuimo compared to some International Standards

Sample	Cu	Cd	Cr	Zn
Damsel fish				
A	30.88	2.00	2.61	79.55
B	28.99	1.36	3.20	80.10
C	27.10	0.72	2.10	79.00
Range	27.10 – 30.88	0.72 – 2.00	2.02 – 3.20	79.00 – 80.10
$\bar{X}$ ± SD	28.99 ± 1.89	1.36 ± 0.64	2.61 ± 0.59	79.5 ± 0.55
Tilapia fish				
A	33.56	2.10	1.74	100
B	23.29	1.14	1.40	61.37
C	13.02	0.18	2.08	22.64
Range	13.02 – 33.36	0.18 – 2.10	1.40 – 2.08	22.64 – 100
$\bar{X}$ ± SD	23.29 ± 10.27	1.14 ± 0.96	1.74 ± 0.34	61.37 ± 38.73
Cat fish				
A	30.36	2.15	0.88	40.12
B	27.18	1.24	1.10	45.56
C	24.00	0.33	0.66	51.00
Range	24.00- 30.36	0.33 – 2.15	0.66 – 1.10	40.12 – 51.00
$\bar{X}$ ± SD	27.18 ± 3.80	1.24 ± 0.91	0.88 ± 0.22	45.56 ± 5.44
Dat fish				
A	25.12	1.26	1.27	70.00
B	24.66	1.88	0.53	60.44
C	24.20	2.40	2.01	50.88
Range	24.20 – 25.12	1.36 – 2.40	0.53 – 2.01	50.88 – 70.00
$\bar{X}$ ± SD	24.66 ± 0.46	1.88 ± 0.52	1.27 ± 0.74	60.44 ± 9.56
Cling fish				
A	30.77	0.21	0.41	79.35
B	29.10	1.12	0.32	80.20
C	27.10	2.03	0.23	79.10
Range	27.10 – 30.77	0.12 - 2.03	0.23 – 0.41	79.10 – 80.20
$\bar{X}$ ± SD				

	28.99 ± 1.89	1.12 ± 0.91	0.32 ± 0.09	79.55 ± 0.55
[42]FEPA(2003)	1.3	-	0.15	-
[43]WHO(2006)	3.0	-	0.15	-
[44]EU (2001)	1.0	-	1.0	-
[45]EU (2008)	0.5 – 1.0	0.5 – 1.0	2.0	-
[46]Indonesia	80	-	-	200
[47]FAO (1983)	-	2.0	1.0	-

[42]Federal Environmental Protection Agency (2003)
[43]World Health organization (2006)
[44]European Union (2001)
[45]European Union (2008)
[46]Indonesia Decree of General Director of Food and Drug Supervision No.03725/B/SK/VII concerning, maximum limits of metals in food.
[47]Food and Agricultural Organization of the United Nation (1983)

Previous research had shown that escalating human population, economic development and poor waste management have affected adversely the ecosystem. This have significantly contributed to the current worldwide deterioration of water quality including seasonal accumulation of heavy metals like Cr, Cu, Zn, Cd, As, Hg, Fe, etc [23,24]. An insight on the levels of these heavy metals in aquatic organism especially fishes are of paramount important to basically for consumption by human and nature management. This research work documents results of bioaccumulation of some heavy metals in some fish samples together with their bioconcentration factor.

Results of the study conducted as shown in Table 2 above reveals that copper level in the investigated fish samples ranges as follows; Damsel fish (27.10- 30.88) mg/kg, Cat fish (24.00- 30.36) mg/kg, Tilapia fish (13.02-33.56) mg/kg, Dat fish (24.20-25.12) mg/kg and Cling fish (27.10-30.77) mg/kg. A trend of mean concentrations of copper in mg/kg can be written as Tilapia (23.29) $<$ Dat (24.66) $<$ Cat (27.18) $<$ Damsel = Cling (28.99) mg/kg. These mean values were found to have been higher than some standard permissible limits like WHO (3.0mg/kg), FEPA (1.3 mg/kg), EU (2008) (1.0 mg/kg) and those reported in *Cyprinus Carpio* and *Pelteobagrus Fluridraco* [23], *L.Coubie* and *M. Tapirus* [31]. Indo-pacific king Mackerel and Tiger tooth Crocker [48]. Although copper is recognized as an essential element, excessive intake of it can lead to poisoning, nausea, nausea, diarrhea and fever, acute stomach pain and death [23].

Cadmium is an environmental pollutant and a highly toxic metal which has no biological function in both human system and aquatic organisms. Bioaccumulation of cadmium can remain in human system for decades and cannot be efficiently metabolized. It can cause kidney damage, lung cancer, ostemalacia, testicular tissue destruction, high blood pressure, proteinuria, red blood destruction and non-descended testes in young males [19, 48-49]. Recent research has it that exposure to cadmium at even low concentration can increase the risk to hormonal cancer [50]. Another research on Long Island also estimated about 40% of breast cancer cases recorded in the United States might be associated with elevated cadmium levels [51]. Results of various levels of cadmium as shown in Table 2 depicts that cadmium recorded highest mean value of 1.88 mg/kg in Dat fish and least value of 1.12 mg/kg in Cling fish. The various mean values as shown in Table 2 were also higher than permissible limits of EU (2008) but lower than that of FAO (1983).

Chromium another environmental pollutant showed an increasing trend in mg/kg as follows, Cling fish (0.32) $<$ Cat fish (0.88) $<$ Dat fish (1.27) $<$ Tilapia fish (1.74) $<$ Damsel fish (2.61). Mean values of chromium in Cling and Cat fishes (Table 2) were observed to be lower than permissible limit of FAO

(1983), EU (2008) and some literature values [52-53]. Chromium level in the remaining fish samples were higher than the permissible limits above and those reported in *Balistoides Vridiscens* [19]. Bioaccumulation of chromium in human can lead to the following health diseases; pulmonary fibrosis, lung cancer (inhalation), cardiovascular, renal, gastrointestinal, hematological and neurological effects [19].

Levels of zinc in the investigated fish recorded least minimum value of 45.56 mg/kg in Cat fish and highest value of 79.55 mg/kg in Damsel and Cling fishes. A trend of decrease in mean values of zinc in the investigated fish samples can be seen as; Cat fish (45.56) $<$ Dat fish (60.44) $<$ Tilapia fish (61.37) $<$ Damsel fish = Cling fish (79.55). These mean values are also higher than some permissible limits of Indonesia maximum limits of metals in food (Table 2) and some literature studies [30, 31].

Table 3. Level of Heavy Metals in Water, Bioconcentration Factor (BCF) of Investigated Fish Samples

								Bioconcentration Factor				
Metal	Conc. of water (mg/L)	[54] WHO (2011) limits (mg/L)	[55] UNEP (2007) limits (mg/L)	[56] USEPA (mg/L)	[57] ECE (1998) (mg/L)	[58] FTP-CDW (mg/L)	[59] ADWG (mg/L)	Damsel	Tilapia	Cat	Dat	Cling
Cu	0.065	2.000	2.000	1.300	2.000	1.000	2.000	446	358	418	379	446
Cd	BDL	0.003	0.003	0.005	0.005	0.005	0.002	-	-	-	-	-
Cr	BDL	0.050	0.050	0.010	0.050	0.005	0.050	-	-	-	-	-
Zn	0.112	3.000	3.000	0.500	-	50.00	3.000	710	548	407	540	710

[54]World Health Organization (WHO, 2011)
[55]United Nation Environmental Programme (2007)
[56]United States Environmental Protection Agency (USEPA, 2011)
[57]European Commission Environment (ECE, 1998)
[58]Federal-Provincial-Territorial Committee on drinking Water (CDW), Health Canada (FTP-CDW, 2010)
[59]Australian Drinking Water Guidelines (2011)

Results of heavy metals in investigated water samples as shown in Table 3 depicts that levels of copper (0.065 mg/L) and zinc (0.112 mg/L) were lower than permissible limits of World Health Organization(2011). Cadmium and chromium levels were observed to be below detection limit (BDL). Results of Bioconcentration Factor (BCF) implored showed that copper has an increasing BCF values of Tilapia fish (358) < Dat fish (379) < Cat fish (418) < Damsel = Cling (446). Also zinc has an increasing BCF values of Cat fish (407) < Dat fish (540) < Tilapia (548) < Damsel = Cling (710). These values were found to be lower than the criteria (log value) of $\leq$ 2000 (3.3) for European Union bioaccumulative and criteria (log values) of 1000 (3) – 5000 (3.7) for United States bioaccumulative and other international regulatory assessment endpoints and criteria as shown in Table 1. Bioconcentration factors of chromium and cadmium were not calculated because there levels in water samples were below detection limits.

Levels of heavy metals in water samples were also investigated and reported (Table 3). The results showed that mean concentration of copper in the investigated water samples had a value of 0.0065 mg/L which was observed to be lower than the permissible limits of World Health Organization (WHO, 2011) (2.0 mg/L), United States Environmental Protection Agency (USEPA) (1.3 mg/L), European Commission Environment (2.0 mg/L) and Federal-Provincial-Territorial Committee on Drinking Water, Health Canada (FTP-CDW, 2010) (1.0 mg/L). Mean concentration of zinc (0.112 mg/L) was also lower than permissible limits of WHO (3.0 mg/L), USEPA (0.5 mg/L), FTP-CDW (50 mg/L) and UNEP (3.0 mg/L). Values of cadmium and chromium were observed to be below detection limit.

4. CONCLUSION

The results of the study provide valuable information on levels of heavy metals in water samples and their bioaccumulation in some selected fish samples from Onuimo River, Imo State. The result also showed heavy metals sorption and bioaccumulation by fish varied with respect to species of fish and other specific factors like feeding pattern, weight and age. A trend of bioaccumulation of heavy metals by fish samples can be deduced as follows; Damsel fish > Cling fish > Dat fish > Tilapia fish > Cat fish. Bioconcentration factor model implored in the study showed a decreasing order as follows; Damsel fish = Cling fish > Cat fish > Dat fish > Tilapia fish and Damsel fish = Cling fish > Tilapia for copper and zinc metals respectively. Also bioconcentration (BCF) values obtained were lower than the standards of some International regulatory bodies. Levels of heavy metals in investigated water samples were also lower permissible limits of WHO, USEPA, UNEP and FTP-CDW. These results imply that River Onuimo having little contamination by heavy metals is safe for human, agricultural and industrial uses. Also rate of disposal of heavy metal containing waste into the river and other anthropogenic activities which can contaminants the water should be discouraged. Better still, they should be adequately recycled before disposal to avoid loading of heavy metals and other contaminants into the river.

COMPETING INTEREST

The authors have declared that there is no conflict of interest regarding the publication of this research work.

REFERENCES

1. Kris – Etheron P., Haris W., Appel L., Fish consumption, fish fish oil, omega – 3 fatty acids and cardiovascular disease circulation 2002; 106 (21): 2747 – 2757.
2. Zhao S., Feng C., Quan W., Chen X., Niu J., Shen Z., Role of living environments in the accumulated characteristics of heavy metals in fishes and crabs in the Yangtze River Estuary, China. Marine Poll. Bull. 2012; 64 (6):1163 – 1171
3. Yilmaz F., Özdemir N., Demirak A., Tuna A.L., Heavy metals levels in two fishes species Cephalus and Lepomis gibbosus. Food Chemistry 2007; 100 (2): 830 – 835.
4. Oguzie FA., Heavy metals in fish water and effluents of lower Ikpoba River, Benin City. Park J. Sci. Ind. Res. 2003; 46 (30): 156 – 160.
5. Mustafa C., Guluzar A., The relationship between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. Environmental Poll. 2003; 121 (1): 129 – 136.
6. Korkmaz Gorur F., Keser R., Akcay N., Dizman S., Radioactivity and heavy metal concentrations of some commercial fish species consumed in the Black Sea Region on Turkey. Chemosphere 2012; 87: 356 – 361.
7. Petrovic Z., Teodrovic V., Dimitrijevic M., Borozan S., Beukovic M., Milicevic D., Environmental Cd and Zn concentration in liver and kidney of Erupean hare from different Serbian Region: Age and Tissue Difference. Bulletin of Cont. Toxicol. 2013; 90: 203 – 207.
8. Oliveira Ribeiro CA., Vollaire Y., Sanchez-Chardi A., Roche H., Bioaccumulation and the effects of Organochlorine pesticides PAH and heavy metals in the eel (Anguilla Anguilla) at the Camargue Nature Reserve, France. Aquatic Toxicol 2005; 36: 243 – 252.

9. Voegborlo RB., Atta A., Agorku ES., Total mercury distribution in different tissues of six species of freshwater fish from the Kpong hydroelectric reservoir in Ghana. Environmental modeling and Assessment 2012; 184 (5): 3259 – 3265.
10. Annabi A., Said K., Messooudi I., Cadmium: bioaccumulation, histopathology and detoxifying mechanisms in fish. Am. J. Res. Commun. 2013; 1: 60 – 70.
11. Tüzen M., Determination of heavy metals in fish samples of the MidDame Lake Black Sea (Turkey) by graphite furnace atomic absorption spectrometry. Food Chem.2003; 80: 19 – 123.
12. Järup L., Hazards of heavy metal contamination. British Med. Bull. 2003; 68: 167 – 182
13. Eisler r., Cadmium hazard to fish, wildlife and invertebrates: A Synoptic Review, U.S fish wild L. Serv. Biol. Rep. 1985; 85: 1 – 30.
14. Fernandes C., Fontainhas – Fernendes A., Cabral D., Salgado M.A., Heavy metal in water, sediments and tissues of Liza Saliens from Esmoriz- paramos lagoon, Portugal. Environmental monitoring Assessment. 2008; 136: 267 – 275
15. Obasohan E.E., Oronsaye JAO, Eguavoen OI., A comparative assessment of heavy metal loads in the tissues of a common Catfish (*Clrias gariepinus* from Ikpobaand Ogba River in Benin City, Nigeria. Journal of African Science. 2018; 9: 13 – 23.
16. Vinodhini R., Narayanan M., Heavy metal induced histopathological alterations in selected organs of the Cyprinus Carpio nL., (common Carp). Int'l. J. Envioron. Res. 2009; 3:95 – 100.
17. Gorgiera E., Velcheva i., Yancheva V., Stoyanova S., Trace metal effects on gill epithelium of common carp *Cyprinus Carpio L. (Cyprinitae).* Acta Zool. Bulgarica. 2014; 66: 277 – 282.
18. Castro-González MI., Mendez-Armenta M., heavy metals: implications associated to fish consumption: Environ. Toxicol. Pharmacol. 2008; 26: 263 – 17.
19. Hakami MO., Risk assessment of heavy metals in fish in Saudi Arabia. American J. Environ. Sci. 2016; 12 (6) :341 – 357.
20. Al-Busaidi M., Yesudhasan P., Al-Rhini WAK., Al- Harthy KS., Al-Mazooei NA., Al-Habsi S.H., Toxic metals in commercial marine fish in Oman with reference to National and International Standards. Chemosphere 2011; 85: 67 – 73 Doi: 10.3844/ajessp.2016.341.357
21. Rahman MS., Molla AH., Saha N., Rahman A., Study on heavy metals levels and its risk assessment in some eligible fishes from Bangshi River Savar, Dhaka, Bangladesh. Food Chem. 2012; 134: 1847 – 1854.
22. Meche A., Martins MC., Lofrano BESN., Hardaway CJ., Merchant M., Verdade L., Determination of heavy metals by inductively coupled plasma – optical emission spectrometry in fish from the Piracicaba River in Southern Brazil. Micro J. 2010; 94:171 – 174.
23. Rajeshkumar S., Li X., Bioaccumulation of heavy metals in some tissues of fish species from the Meiliang Bay, Taihu lake China. Toxicology Reports 2018; 5: 288 – 295. https://doi.org/10.1016/j.toxrep.2018.01.007
24. Bioaccumulation of heavy metals in some tissues of fish in Lake Geriyo, Adamawa State, Nigeria. Journal of Environmental and Public Health Vol 2018, Article ID 1854892, 7 pages https://doi.org/10.1155/2018/1854892 (2018)

25. Ekeocha CI., Nwoko CI., Onyeke LO., Impact of automobile repair activities on Physicochemical and microbial properties of soils in selected automobile repair sites in Abuja, Central Nigeria. Chemical Science Int'l J. 2017; 20 (2): 1 – 15 Doi: 10.9734/CSJI/2017/36065
26. Minic Z., Serre V., Herve G., Adaptation of organisms' to extreme conditions of deep – sea hydrothermal vents. Comptes Rendus Biol. 2016; 329: 527 – 540 Doi: 10.1016/j.crvi.2006.02.001
27. Calabrese S., D'Alessandro W., Bellomo S., Brusca L., martin R.S., Characterization of the Etna Volcanic emissions through an active biomonitoring technique (moss-bags): Part 1 – Major and trace element composition. Chemosphere. 2015; 119; 1447 – 1455
28. Olaifa FE., Olaife AK., Adelaja AA., Owolabi AG., Heavy metal contamination of *Claris gariepinus* from a lake and fish farm in Ibadan, Nigeria. African J. Bio. Res. 2004; 7: 145 – 148
29. Obot OI., Isangedighi AI., David GS., Heavy metal concentration in some commercial fishes in the lower Cross River Estuary, Nigeria. J. Agricult. Food & Environ. 2016; 12(4): 218 - 223
30. Adeosun F.I Akinyemi AA., Idowo AA., Taio IO., Omoike A., Ayomide BJO., The effect of heavy metals concentration on some commercial fish in Ogun River, Opeji, Ogun State, Nigeria. African Journal of Environ. Sci. Tech. 2005; 9(4):365 – 370 Doi:10.5897/AJEST
31. Nwani CD., Nwoye VC., Eyo JE., Assessment of heavy metal contamination in the Tissue (Gills and Muscles) of six commercially important fresh water fish species of Anambra River South – Environ. Sci. 2009; 11(1): 7 – 12.
32. Ojutiku R.O., Okojevoh FI., Bioaccumulation of some heavy metals in three selected fish species from Chanchaga River, Minna, Niger State. Nigeria. Nigerian Journal of Fisheries and Aqua culture 2017; 50(10):44 – 49.
33. Ujah II., Okeke DO., Okpashi VE., Determination of heavy metals in fish Tissues, water and sediments from the Onitsha segment of the River Niger, Anambra State, Nigeria. J. Environ. Anal. Toxicol. 2017; 7(5):507 – 509. Doi:10.4172/2161-0525.1000507
34. Olowu RA., Ayejuyo OO., Adewuyi IA., Denloye AAB., Babatunde AO., Ogundajo AL., determination of heavy metals in fish tissues, water and sediments from Epe and Badagry Lagoons, Lagos State , Nigeria E – Journal of Chemistry 2010; 7(1): 215 – 221.
35. Wangboje OM., Ekome PC., Efendu UI., Heavy metal concentration in selected fishes and water from Orogodo River, Agbor, Delta State in Nigeria. Asia J. Environ. Ecol. 2017; 3(1): 1-10. Doi:10.9734/AJEE/2017/33608
36. Tao Y., Yuan Z., Xiaona H., Wei M., Distribution and bioaccumulation of heavy metals in aquatic organisms of different tropic levels and potential health risk assessment from Taihu Lake, China. Ecotoxicol. Environ. Saf. 2012; 81:56 – 64.
37. Bao L., Wang D., Li Y.,, Zhang G., Wang G., Zhang S., Accumulation and risk assessment of heavy metals in water sediments: and aquatic organisms in rural rivers in the Taihu lake Regions of China. Environ. Sci. Pollut. Res. 2015; 22:6721 – 6731.
38. Standard Method for the Examination of Water and Wastewater, 22nd Edition, Edited by Rice EW., Baird RB., Eaton AD., Clesceri LS., American Public health Association

(APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF), Washington D.C, USA (2012)

39. Arnot JA., Gobas FAPC. A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. Environ. Rev. 2006; 14:257 – 297. Doi:10.1139/A06-005
40. USEPA 1996a. Fish BCF. US Environmental protection Agency, Washington D.C., USA.
41. OECD 1996. Bioconcentration: Flow- through fish test. OECD guidelines for the testing of chemicals N0. 305 E. Organizations for Economic Co-operation and Development, Paris, France. Pp 23
42. Federal Environmental Protection Agency (FEPA). Guidelines and Standards for Environmental Pollution Control in Nigeria, Page 238.
43. World Health organization (WHO) Guidelines for Drinking Water Quality, Recommendation volume 1, WHO, Geneva, page 130, (1985).
44. European Union (EU), Commission Regulation as Regards Heavy metals, Directive, 2001/22/EC, No: 466, (2001)
45. European Union (EU), Commission regulation (EC) No: 629/2008. Setting maximum levels for certain contaminants in food stuffs. Official journal of the European Union L 173 (2008)
46. Indonesia Decree of General Director of food and Drug Supervision N. 03725/B/SK/VII/89 Concerning maximum limits of metals in food.
47. Food and Agriculture Organization (FAO), 1983. Compilation of legal limits for harzadous substances in fish and fishery products. FAO fishery circular 1983; 463: 5 - 100
48. Dobaradaran S., Naddafi K., Nazmanra S., Ghaedi H., Heavy metals (Cd, Cu, Ni, Pb) content in two fish species of Persian Gulf in Bashehr Port, Iran. African J. Biotech. 2010; 9(37): 6191 – 6193.
49. Gupta BN., Mathur AK. Toxicity of heavy metals. Ind. J. Med. Sci. 1983; 37:236 – 270.
50. Larson Sc., Orsini N., Wolk A., Urinary cadmium concentration and risk of breast cancer. A systematic review and dose- response meta-analysis. Am. J. Epidemol. 2015; 182 (5): 375 – 380 Doi:10.1093/aje/kwv085.
51. Gallagher CM., Chen JJ., Kovach JS. Environmental cadmium and breast cancer risk. Aging 2: 804 – 814 PMID: 21071816
52. Sekar CK., Chang NS., Kamala TC., Raj DSS., Rao AS., Fractionation studies and bioaccumulation of sediment-bound heavy metals in Kolleru lake by edible fish. Environ. Int. 2003; 29: 1001 – 1008.
53. Mendil D., Uluozlu OD., Determination of trace metal levels in sediment and five fish species from lakes in Tokat, Turkey. Food Chem. 2007; 101: 739 – 745.
54. Rahmanian N., Ali SHB., Homayoonfarrd M., Ali NJ., Rehan M., Sadef Y., Nizami AS. Analysis of physiochemical Parameters to Evaluate the Drinking Water Quality in the State of Perak, Malaysia. Hindawi Publishing Corporation. Journal of Chemistry volume 2015, Article ID 716125, http://dx.doi.org/10.1155/2015/716125
55. Khan SL., Din ZU., Ihsanullah, Zubair A., Levels of selected Heavy Metals in Drinking water of Peshawar City. Int'l J. Sci. Nat. 2011; 2(3): 648 – 652.

56. United Nation Environmental programme (UNEP), Global drinking Water Quality Index Development and Sensitivity Analysis Report, 2007
57. Total dissolved solids (Guidelines for drinking-water quality). Health criteria and other supporting information. World Health organization, Geneva, 1996, 2nd edition, volume 2.
58. World Health organization (WHO). Guidelines for drinking water quality, 4th edition, WHO, Geneva, Switzerland, 2011.
59. Mahugija JAM. Levels of heavy Metals in Drinking Water, Cosmetics and Fruits Juices from selected Areas in Dar ES Salam, Tanzania. Tanzania J. Sci. 2018; 44 (1): 1-11,
60. United States Environmental Protection Agency (2011). National primary Drinking Water Regulations. Retrieved from http://water.epa.gov/drink/contaminats/index.cfm#List (Verified January, 2019)
61. European Commission Environment (1998). Council Directive 98/83/EC of 3rd November, 1998. Retrieved from http://eur-lex.europa.eu./lexUriServ/LexUriServ.do? Uri = OJ:L1998:330:0032:0054:EN PDF (verified January, 2019).