# A~~Bio~~accumulation of Heavy Metals in W~~w~~ater and some F~~f~~ish S~~s~~amples from Onuimo River, Imo State, Nigeria


## ABSTRACT

A~~Bioa~~ccumulation of some heavy metals (Cu, Zn, Cd and Cr) was determined in selected fish, Moon fish (*Citharinus citharus*), Tilapia fish (*Oreochronus niloticus*), Mud fish (*Clarias anguillaris*), Cat fish (*Clarias gariepinus*) and Carp fish (*Labeo coulbie*) and water samples from Onuimo River in Imo State in Nigeria. ~~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. Bioa~~Accumulation order of heavy metals in fish samples comprised of ~~were found to follow the sequence as~~ Damsel fish > Cling fish > Dat fish > Tilapia fish > Cat fish.~~-~~ Bioconcentration factor model used~~implored~~ in the present study showed the following ~~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. The concentration of ~~Those of c~~Cadmium and chromium ~~were not calculated due to the fact that there concentrations in water samples~~ were below detection limits in all water samples. ~~Results of analyses of heavy metals in selected water samples revealed that~~ C~~c~~oncentrations of Cu, Cd, Zn and Cr ~~cadmium and chromium~~ were~~as~~ below permissible~~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, Nigeria~~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 rich in unsaturated fatty acids basically as~~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,~~ E~~e~~xcess 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, and sediments ~~or all.~~ [2-4]. Bioaccumulation of heavy metals in fish and their subsequent distribution to~~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].

**Comment [b1]:** Metals do not bioaccumulate in water and sediments but rather in fish so the title here is misleading see my suggestions

**Comment [b2]:** Be consistent with the use of capilaisation in the title

**Comment [b3]:** No check the metals that you said you digested in the methods section:

**Comment [b4]:** Name them here please and put their scientific names also

**Comment [b5]:** I think you are using the term detection limits incorrectly

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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~~,~~ and 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]. Toxicity ~~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]. Excessive h~~H~~eavy metals in fish tissues can invalidate their health benefits to humans who consume the fish. 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, hematologic disorder, encephalopathy, pulmonary fibrosis, nasopharyngeal tumors, nephrotoxicity, tremor, nausea, and 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 elements with a relative density greater than 5.0 g/cm$^3$ occurring~~are~~ naturally as components of the earth's crust ~~with a relative density greater than 5.0 g/cm$^3$~~. Metals~~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 levels of heavy metals in fish species that are consumed daily by both humans and animals to minimise~~in other avoid~~ health hazards associated with ~~that come with~~ consumption of ~~heavy metals~~ contaminated fishes. Some researchers have reported presence of toxic metals in various fish samples in water bodies such as Onuimo in Nigeria [24, 28-35]. ~~Onuimo has been one of the fresh water rivers in the South Eastern part of the country~~. Onuiom River~~The river~~ plays an 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 activities~~ates~~ 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 was~~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*) as well as to assess the levels of Cu, Cd, Cr and Zn in the water phase of the same river.

## 2. EXPERIMENTAL DETAILS

### 2.1. Site Description

Onuimo River is located in Umungwa Community in Obowo Local Government Area of Imo State, Nigeria and the river lies between Longitude 5$^{\circ}$50 '56 N and latitude 7$^{\circ}$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.

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**Comment [b16]:** You describe the area with the aid of the map not the other way around

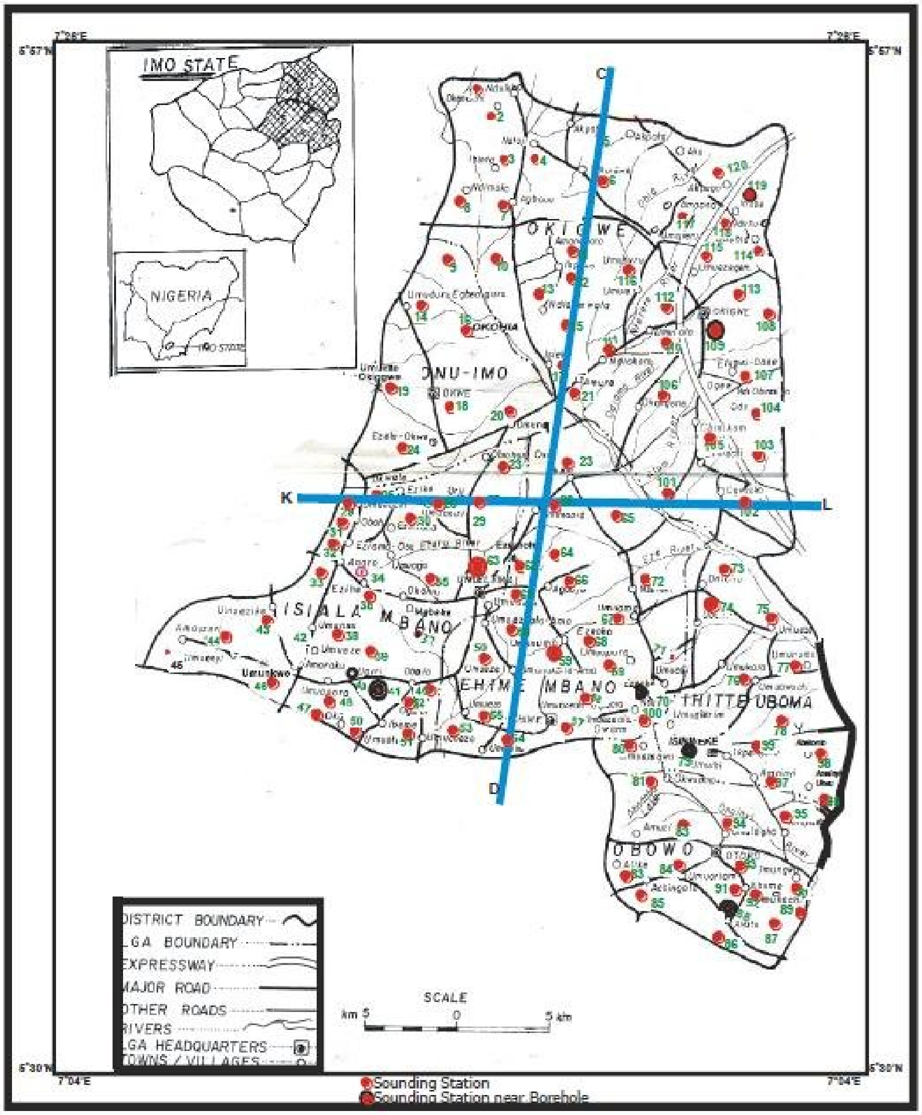


**Figure 1. Geological Map Showing Onuimo River**

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 of the Moon fish (*Citharinus citharus*), Tilapia fish (*Oreochronus niloticus*), Mud fish (*Clarias anguillaris*), Cat fish (*Clarias gariepinus*) and Carp fish (*Labeo coulbie*) were harvested with a locally made gill net in the Onuimo River ~~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 ℃ in a refrigerator prior to analyses. On the other hand, water samples were collected alongside ~~where~~ the fishes. Water samples were harvested with separate acid pre washed water plastic 250ml containers, labelled, enclosed in a chest and transported to the laboratory where they were further refrigerated for a maximum of 48 hours prior to analysis.

**Comment [b17]:** For how many hours before analysis

**Comment [b18]:** See my suggestions

## 2.3 Quality Control

All glass wares used for the analysis were ~~all~~ Pyrex, and the reagents used were of analytical grade. The glass wares were washed in 10% nitric acid, 0.5% potassium permanganate and thoroughly rinsed with deionized water and air dried 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

In the laboratory, t~~T~~he fish samples ~~were brought out of the refrigerator, rinsed thoroughly with deionized water and~~ were dried in an electric oven at a temperature range of 70 – 80 ℃ for three days. After drying, fish samples~~they were all~~ s~~eparately brought out and~~ were 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 ratio~~n~~ 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 ℃ for 30 minutes until white fumes ~~formed disappeared~~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 W~~w~~hatman 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 metals ~~(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 and allowed to defrost and were 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, 2nd edition, 2012 (APHA-AWWA-WEF) [38].

**Comment [b19]:** Check my comments on the abstract which metals did you actually analyse?

## 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 $k_T$ ($d^{-1}$),

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

**Comment [b20]:** This is unnecessary at most just tell us what you did and show us the formula

**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 ‡, 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)
‡Currently 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**

Comment [b21]: Format these tables for them to make sense

| 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 |
| $\bar{X} \pm$ SD | 24.66 $\pm$ 0.46 | 1.88 $\pm$ 0.52 | 1.27 $\pm$ 0.74 | 60.44 $\pm$ 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 |
| $\bar{X} \pm$ SD | 28.99 $\pm$ 1.89 | 1.12 $\pm$ 0.91 | 0.32 $\pm$ 0.09 | 79.55 $\pm$ 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~~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 show~~has it~~ that exposure to cadmium at

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even low concentration can increase the risk of~~to~~ hormonal cancer [50]. Another research on Long Island also estimated that about 40% of breast cancer cases recorded in the United States might be associated with elevated cadmium levels [51]. Results of cadmium~~various~~ levels ~~of cadmium as~~ shown in Table 2 depict~~s~~ that cadmium recorded highest mean value of 1.88 mg/kg in Dat fish and the 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 levels in the remaining fish samples were higher than the permissible limits above and those reported in *Balistoides Vridiscens* [19]. Bioaccumulation of chromium in humans 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 the 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**

| 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) | Bioconcentration Factor 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 ar~~es~~ shown in Table 3, and these depict~~s~~ that levels of copper (0.065 mg/L) and zinc (0.112 mg/L) were lower than permissible ~~limits of~~ World Health Organization limits~~(2011)~~. Cadmium and chromium levels were observed to be below detection limit (BDL). Results of Bioconcentration Factor (BCF) ~~implored~~ showed that copper levels have an increasing~~has an increasing~~ BCF order as follows~~values of~~ ;Tilapia fish (358) < Dat fish (379) < Cat fish (418) < Damsel = Cling (446). Also zinc has an increasing BCF order which comprised; ~~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 ≤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 ther~~re~~ levels in water samples were below detection limits.

Levels of heavy metals in water samples were also investigated and are reported in ~~(~~Table 3~~)~~. The results showed that the 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 WHO 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 that heavy metal~~s~~ sorption and bioaccumulation by fish varied with respect to fish species ~~of fish~~ and other specific factors like the feeding pattern, weight and age. In this study the ~~A~~ trend of bioaccumulation of heavy metals in~~by~~ fish samples was ~~can be deduced as follows~~; Damsel fish > Cling fish > Dat fish > Tilapia fish > Cat fish. The b~~B~~ioconcentration factor model used~~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, the 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 than the permissible ~~limits of~~ WHO, USEPA, UNEP and FTP-CDW limits. These results imply that River Onuimo is relatively less contaminated by heavy metals, thus the water ~~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.~~

**Comment [b25]:** Poor recommendations start again please

## COMPETING INTEREST

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

## REFERENCES

**Comment [b26]:** Follow the format of the journal


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