ABUAD INTERNATIONAL JOURNAL OF NATURAL AND APPLIED SCIENCES
ISSN: 2955-1021
AIJNAS Volume 3, Issue 1, April 2023 pp 1–15
https://doi.org/10.53982/aijnas.2023.0301.01-j

https://journals.abuad.edu.ng/index.php/aijnas

Assessment of metal contamination in *Oreochromis niloticus* from Ekiti State's major Dams, Southwest, Nigeria and its human health Implications

Peter Taiwo Olagbemide[1, 2]*, Olufemi David Owolabi[1]
[1]Department of Zoology, University of Ilorin, Ilorin; Nigeria; [2]Department of Biological Sciences, Afe Babalola University, Ado-Ekiti, Nigeria
*Corresponding author: olagbemidept@abuad.edu.ng

Abstracts
Agricultural and domestic activities around dams in Nigeria involve the use of agrochemicals and insecticides to boost production and combat insect pests respectively. The study aimed to ascertain metals contents and assess the hazards associated with heavy metals in Oreochromis niloticus in three major dams in Ekiti State. Fish samples were collected for 24 months. Metal concentrations in fish samples were determined using spectrometry. The metals concentrations in the tissues were at lower concentrations compared to the maximum acceptable limits in food by Food and Agricultural Organization (FAO) and World Health Organization (WHO). Metals accumulation pattern revealed that the accumulation of the essential metals were higher than those of the non-essential metals in the fish tissues. There were significant seasonal variations in the concentrations of metal in fish tissues within the dam and among the dams. Significant relationships existed at $P < 0.05$ or $P < 0.01$ between some of the metals and the fish body weight and body length in the different dams while in others the relationships were not significant. Human health risk assessment showed no significant non-carcinogenic adverse health risk. Carcinogenic health assessment indicates that the utilization of the species as a protein source does not currently pose public health risk to consumers. However, the discovery of cadmium and lead in fish muscle is of great concern because of their toxic effects on human. Therefore, there is a need for close monitoring of these toxic metals contamination to prevent their excessive accumulation in the human food chain.
Key words: *Heavy metals, target hazard quotient, incremental lifetime cancer risk, dams, Ekiti State.*

INTRODUCTION

Aquatic ecosystems have been grossly polluted by heavy metals in recent times and metal bioaccumulation is a major route through which increased levels of pollutants are transferred through food chains, creating public health problems for humans in the food chain (Otitoloju and Don-Pedro, 2004; Tuzen, 2003). Pollution of the aquatic environment with heavy metals has become a global colossal problem because metals are indestructible, persistent and bio-accumulate and most have toxic effects on organisms (Zeitoun and Mehana, 2014). The increase in aquatic metal pollution is as a result of population growth, urbanization and expansion of industrial activities, exploration and exploitation of natural resources, modern agricultural practices in addition to the lack of environmental regulation (Idowu *et al*., 2004). Metals are essential for normal functioning in organisms. For instance, many enzyme constituents in key proteins that are needed for metabolic pathway are metals. However, they are also an important group of pollutants of water bodies due to their persistent and non-biodegradable properties. Metals vary extensively in their harmfulness, certain metals have low toxicity whilst others are extremely lethal even at low concentrations (Hellawell, 1986). Essential metals are used for ionic balance and as vital measures of amino acids and nucleic acids. Non-essential metals, in addition to being lethal above certain or threshold level, may also affect organisms by inducing deficiencies of essential metals through competition at active sites in biologically important molecules (Walker *et al*., 2006). The increasing need for food that are safe has resulted in fast growth of research regarding the hazard connected with ingestion of food polluted by toxic metals (Saha and Zaman, 2013). Aquatic biota has been used to observe heavy metal contamination in aquatic environments for many years (Kamaruzzaman *et al*., 2011) and among the aquatic organisms, fishes occupy an important position in the field of aquatic toxicology (Akan *et al*., 2012). Resident fish have been shown in studies as good indicators of aquatic ecosystem health and environmental change, especially in the case of toxic water pollution (Baby *et al*., 2010; Ibemenuga, 2013). Metals tend to accumulate in fish through bio-magnification effects in the food chain and they can enter into human body and accumulate in the human tissues to pose prolonged harmfulness, which may disturb growth, development, reduce hemoglobin, create cancer, damage the body tissues and the nervous system, and in extreme case, may also cause fatality of living organisms (Latifah and Met, 2014). Thus, monitoring and evaluation programs as well as intensive research on heavy metals contamination of fish tissue are important as early predictors of water quality contaminations (Mansour and Sidky, 2002) and

are useful in taking right actions in the interest of public health and the environment. Fish caught from Egbe, Ero and Ureje dams were widely consumed by fishermen and the people in the State. There are several severe health hazards that threaten fish consumers by the consumption of metal accumulated fish. Several methods have been proposed for estimation of the potential risks to human health of heavy metals in fishes. These methods typically are based on the target hazard quotient (THQ). The THQ-based risk assessment method, though does not provide a quantitative estimate of the probability of an exposed population experiencing an adverse health effect, but it does provide an indication of the risk level associated with pollutant exposure. This method of risk estimation has been used by many researchers (*Chien et al*., 2002; *Wang et al*., 2005, Ayantobo *et al*., 2014; Orosun *et al*., 2016; Uche *et al*., 2017) and has been shown to be valid and useful and may be divided into carcinogenic and non-carcinogenic effects (Yujun *et al*., 2011). However, such public health risks associated with consumption of fish in surface waters with heavy metals have not been reported in *O. niloticus* from Egbe, Ero and Ureje dams in Ekiti State, southwest, Nigeria, despite their economic importance. *Oreochromis niloticus* was selected for this study because it is one of the most abundant species of fish found in the dams; that is readily available in the dams throughout the year and is the major source of income available to the rural dwellers around Egbe, Ero and Ureje dams. In addition, it is intensively consumed by human throughout Ekiti State. This study was therefore designed to assess the levels of heavy metals in the tissues of *O. niloticus* in three major dams in Ekiti State with the aim of ascertaining whether the concentrations of these metals constitute health hazards to consumers. Furthermore, the result of this study will provide additional information on the heavy metals pollution of the aquatic ecosystems of southwest, Nigeria.

MATERIALS AND METHODS

Study Area

Ekiti State is situated at the east of the Greenwich Meridian between longitudes of 4° 45' and 5° 45' east and the latitudes of 7° 15' and 8° 5' north of the equator. It is bordered on the north by Kwara State, on the east by Kogi State, and on the south and east by Osun State. Ekiti State dams lie within the southwestern basement complex of Nigeria. This study involves the three major dams in the state: Egbe Dam, situated at Longitude 5° 36.91 E and Latitude 7° 37.11 N; Ero Dam, situated at Ikun-Ekiti, Moba Local and Ureje Dam, located at Longitude 5° 141 E and Latitude 7° 38.21 N (Figure 1). Defecation, washing, recreation (boating, swimming/ bathing, and fishing), agricultural operations, and garbage disposal are all common, particularly where human communities occur near dams. Agricultural-based chemicals and insecticides are regularly used in the dams' diverse agricultural and domestic operations to improve production and battle insect pests respectively. Villages and families in the dams' vicinities dump domestic solid and liquid wastes straight into the dams without treatment, while farm runoff is carried directly into the dams.

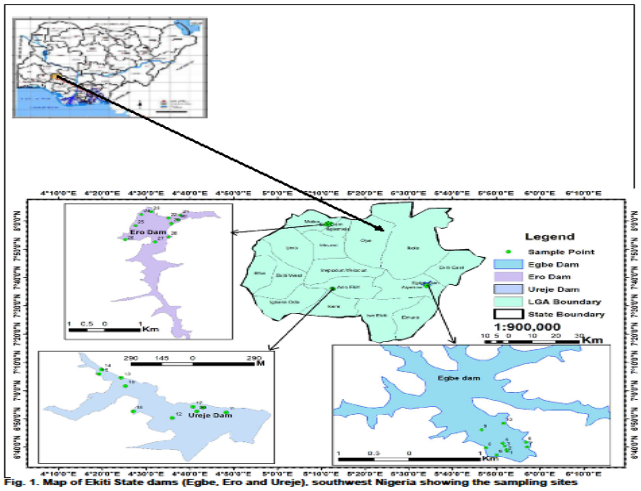

Figure 1: Map of Ekiti State dams (Egbe, Ero and Ureje), Ekiti state, southwest Nigeria

Sample Collections, Identification and Laboratory procedures

Samples of *O. niloticus* were collected from the various landing sites at Egbe, Ero and Ureje dams during both dry (November-March) and (April-October) seasons from November, 2017 to October, 2019. Specimens of *O. niloticus* were collected from each of the dams (Egbe, Ero and Ureje) with the assistance of fishermen operating on the dams. The fishermen used gill nets which were left overnight with surface marker buoys for them to be easily located. Fish were labeled, numbered and transported in ice packed container to the laboratory where further procedures were carried out. In the laboratory, the fish samples were identified using the standard identification key by FAO, (2009); Olaosebikan and Raji (2013) and this was subsequently confirmed by fish scientists at the Department of Zoology, Ekiti State University, Ado-Ekiti, Nigeria. Moisture was removed from the fish with blotting paper. Total length (TL) of each fish was taken from the tip of the snout (mouth closed) to the extended tip of the caudal fin using a measuring board, to the nearest 0.1 cm. The fish body weight was measured to the nearest g using a digital top loading balance (Ohaus CS 5000 model).

The fish samples were dissected using sterilized dissecting utensils to avoid contamination of samples and the gills, liver and muscle were removed. 2 g of each of the macerated fish tissues was weighed out and placed into a clean borosilicate 250 ml beaker for digestion and a mixture of hydrochloric acid (HCl) and nitric acid

(HNO3) in ratio 3:1 was added to the sample in the beaker and placed on a hot plate for digestion in a fume cupboard. The digested solutions of the fish samples were filtered using Whatman No. 42 filter paper and made up to 25 mL (Thomas and Mohaideen, 2015) using distilled water. All chemical reagents were analytical reagent grade (Merck). The glassware and plastic containers were acid washed with nitric acid 10% and rinsed twice with distilled water before use. The various digested tissues were analyzed for Na, Mg, K, Ca, Mn, Fe, Cu, Zn, Cd and Pb using atomic absorption spectrophotometer (Bulk Scientific Model 211 VGP and Flame Photometric FP 902 PG) according to APHA (2005); Baharom and Ishak (2015). The determination of metal contents in the fish entails three steps. (i) The production of standard solutions, (ii) apparatus calibration, and (iii) sample analysis. The stock solution was used to make standard solutions of each element in concentrations of 0.2, 0.4, 0.6, 0.8, and 1.0 mgL^{-1}. The Atomic Absorption Spectrophotometer (AAS) was utilized to analyze each processed metal's filtrate as well as a series of reference solutions. The metal discovery limits in each sample were 0.0001 using the AAS model. Magnesium, calcium, manganese, iron, copper, zinc, cadmium, and lead ions were measured in the sample filtrate and standard solutions using cathode lamps at wavelengths of 285.21, 422.67, 279.48, 248.00, 324.75, 213.86, 228.80, and 217.00, respectively. The AAS was auto-zeroed with distilled water before standard solutions were put in from the lowest to the highest concentrations to assess each element. The AAS gave the matching absorbance to the concentrations of the various solutions and the graph of various concentrations against the absorbance was designed. The metal concentrations in the sample were calculated in parts per million using the standard graph as a guide (Greenberg et al. 1985).

Human Health Risk Assessment Indices

(i) Non-carcinogenic Health Effects

The Human risk assessment from the level of exposure resulting from oral consumption of metals in the edible tissues of *O. niloticus* was expressed by calculating the average daily dose (ADD; average daily intake of a specific metal over a lifetime) using the following equation (USEPA, 2000) and the ensuing assumptions were made in this study to estimate the hazard of heavy metals from fish consumption; the ingested dose was equal to the absorbed pollutant dose (USEPA, 1989); cooking had no effect on the pollutants (Chien *et al*., 2002); the average Nigerians' adult body weight was 70 kg (Abubakar *et al.,* 2015).

$$ADD\ (mg/kg/day) = Cm \times FIR \times EF \times ED/BW \times AT \quad \ldots (1)$$

where Cm is the mean metal concentration in fish muscle, FIR is the fish ingestion rate, daily intake of fish/protein per age group ($kg\ day^{-1}$): 0.051 kg for 18 and above and 0.016 kg for 1-6years (IMNA, 2005). EF is the exposure frequency (365 days/year), ED is the exposure duration over a lifetime (assumed as 70 years), BW is the body weight- assumed as average body weight per age group: 70 kg for 18 years and above and 19 kg for 1-6 (Abubakar *et al.,* 2015), and AT is the average lifetime for non-carcinogens (70 years × 365 days/year).

The Target Hazard Quotient (THQ) is defined as the ratio of the exposure and the reference doses, it expresses the risk of non-carcinogenic effects or is the ratio of a toxic metal exposure level over a period of time to a recommended or reference dose (contamination) for that toxic metal derived from a similar exposure (Addo *et al*., 2013). A THQ value less than 1 means the level of exposure is less than the reference dose, implying that there will not be any obvious risk.

$$THQ = ADD/\ Oral\ RfD \quad \ldots\ldots (2)$$

For the risk assessment of multiple metals containing in fish, a Hazard index (HI) was employed by summing all the calculated THQi values of metals as described in Eq. (3) (USEPA 1989).

$$HI = \sum_{i=1}^{n} THQi \quad \ldots\ldots (3)$$

where THQi is the target hazard quotient of an individual element of metals, HI is the total hazard quotinets for all the five metals examined in the present study, and n is 5.

(ii) Carcinogenic Health Effects

The possibility of cancer risks in the studied *O. niloticus* through intake of carcinogenic heavy metals was estimated using the Incremental Lifetime Cancer Risk (ILCR) (Liu *et al.,* 2013).

$$ILCR = CDI \times CSF \quad \ldots\ldots (4)$$

$$ILCR = \frac{C \times EF \times ED \times FIR \times \left(\frac{kg}{1000g}\right)}{\left(365\frac{days}{years}\right) \times LT \times BW} \times (CSF)$$

(Pepper *et al*., 2012).

where:

SF = slope factor, expressed in [$(mg/kg\text{-}day)^{-1}$]

CDI = chronic daily intake for the toxicant expressed in mg/kg-day

C = Concentration of heavy metal in fish ($mg\ kg^{-1}$)

BW = Body Weight (kg)

ED = Exposure Duration (years)

EF = Exposure frequency (days/year)

IRF= Fish ingestion Rate (g/day)

LT = Lifetime (average) (years)

The USEPA cancer risk considered acceptable for regulatory purposes is within the range of 1×10^{-6} to 1×10^{-4} (Li and Zhang, 2010).

The cumulative cancer risk as a result of exposure to multiple carcinogenic heavy metals due to consumption of fish was assumed to be the sum of the individual heavy metal increment risks and calculated by the following equation (Liu et al., 2013).

$$\sum_1^n ILCR = \text{ILCR}_1 + \text{ILCR}_2 + \cdots + \text{ILCR}_n \quad \ldots\ldots (5)$$

where n = 1, 2, …, n is the individual carcinogenic heavy metals.

Statistical Analysis

The means metal contents in tissues and evaluation of significant differences between different metal concentrations in the tissues and dams were determined using descriptive statistics and analysis of variance (ANOVA) respectively. T-test was used to determine the seasonal variations in the metal contents in the tissues of fish in the different dams. Results of the test were considered significant if the *P* values were ≤ 0.05.

RESULTS

The results of heavy metals in the tissues of *O. niloticus* in the dams during the dry season are shown in Table 1. The Table reveals that the concentrations of the metals in fish tissues (gill, liver and muscle) were in the order of K > Ca > Na > Mg > Fe > Zn > Mn > Cu > Pb > Cd in Egbe, Ero and Ureje dams except in fish muscle in Ero dam where the order was K > Ca > Na > Mg > Fe > Zn > Mn > Cu > Pb, Cd. Cd was not detected in the muscle of fish from Ureje dam and from gill, liver and muscle of fish from Ero dam while Pb was not detected in the muscle of fish from Ero and Ureje dams. In Egbe dam, the highest concentrations of Na, Mg, Cu, Zn, Cd and Pb during the dry season were recorded in the gills and the lowest values in the muscle except for Na and Zn in which the lowest values were recorded in the liver. For K, Mn and Fe the highest values were recorded in the liver and the lowest value in the gills while the highest value of Ca was recorded in the muscle and the lowest value in the gill. In Ero dam, the highest values of Mg, Cu and Pb were observed in the gills and the lowest values were recorded in the muscles except Cu that had the lowest value in the liver. The highest values of K and Zn were recorded in the muscles and the lowest values were observed in the gills for K and in the liver for Zn. The highest value of Na, Ca, Mn and Fe were recorded in the liver and the lowest value in the gill for Mn and Fe and in the muscle for Ca and Na while Cd was not detected in any of the tissues in Ero dam. In Ureje dam, the highest concentrations of K, Ca, Mn, Fe, Cu, Zn, Cd and Pb were recorded in the gills while the lowest concentrations were recorded in the muscle except for Ca and Mn in which the lowest values were recorded in the liver. In Egbe dam, Pb was significantly higher in the gills than what was obtained in the muscle. In Ero dam, none of the metals was significantly higher in the gills than the other tissues. In Ureje dam, Mn and Pb in the gills were significantly higher than in the liver and the muscle while Na and Mg were significantly higher in the liver than in the muscle. Cd is significantly higher in the gills than in the muscle.

The results of heavy metals in the tissues of the fish in the dams during the rainy season are shown in Table 2. The Table reveals that the concentrations of the metals in fish tissues (gill, liver and muscle) were in the order of K > Ca > Na > Mg > Fe > Mn > Zn > Cu > Pb > Cd for gills; K > Ca > Na > Mg > Fe > Mn > Zn > Cu > Pb > Cd for liver and K > Ca > Na > Mg > Fe > Zn > Mn > Cu > Pb, Cd in Egbe dam. In Ero dam, the concentrations of the metals in fish tissues (gill, liver and muscle) were in the order of K > Ca > Na > Mg > Fe > Zn > Mn > Cu > Pb > Cd for gill and liver while in the muscle the order was K > Ca > Na > Mg > Fe > Mn > Zn > Cu > Pb, Cd. In Ureje dam the concentrations of the metals in fish tissues were in the order of K > Ca > Na > Mg > Fe > Zn > Mn > Cu > Cd, Pb except for gill in Ureje dam where the order was K > Ca > Na > Mg > Fe > Zn > Mn > Cu > Pb > Cd. In Egbe dam, the highest concentrations of Na, Mg, K, Ca, Fe, Cu, Zn, Cd and Pb during the rainy season were recorded the gills and the lowest values were recorded in the muscle except Zn that recorded the lowest value in liver while Cd and Pb were not detected in liver and muscle. Mn had the highest value in the liver and the lowest value in the muscle. In Ero dam, the highest concentration of K, Ca, Fe, Zn, Cd and Pb were recorded in the gills while the lowest values were in the liver but Cd was not detected in the liver. The highest value of Na was in the liver and lowest value in muscle while the highest values of Mg, Mn and Cu were in the muscle and the lowest values in the liver. In Ureje dam, the highest concentrations of Na, K, Ca and Zn during the rainy season were recorded in the muscle and the lowest concentrations were recorded in the liver while the highest concentrations of Mg, Mn and Fe were recorded in the gills and the lowest concentrations were recorded in the liver for Mg and Fe and muscle for Mn. The highest value of Na, K, Ca, Zn were recorded in the muscle and the lowest value in the liver while Cd and Pb were not detected in liver and the muscle. Generally, the accumulation of metals in fish tissues showed intra-specific variations in the organs and the dams. There were significant seasonal variations in the concentrations of Na and Ca in the gills of fish from Egbe dam; concentration of Cu in muscle of fish from Ero dam and concentration Mn and Zn in gills and Zn in liver and muscle in fish from Ureje dam. However, the metals were found at lower concentrations compared to the maximum acceptable limits in food by Food and Agricultural Organization (FAO, 1983) and World Health Organization (WHO, 1989).

In Egbe dam during the rainy season, Na, Mg, K, Mn and Cu were significantly higher in the gills than what were obtained in the muscle. During the rainy season in Ero dam, K and Fe were significantly higher in gills than liver and muscle for K and liver only for iron while Cu and Mn were significantly higher in muscle than in the liver. In Ureje dam, Mg was significantly higher in the gills and liver than in the muscle. Ca was significantly higher in the liver than in the muscle. There was no significant seasonal difference ($P < 0.05$) in the metal concentrations in the tissues of the fish from the dams except in Na and Ca in the gills of fish from Egbe dam; Cu in the muscle of fish from Ero dam and Mn and Zn in the gills and Zn in the muscle and liver of fish from Ureje dam.

Table1: Mean Concentration of Metals in the Various Ttissues of *Oreochromis niloticus* in the Dams during the Dry Season

Dam	Tissue	Metals (ppm)									
		Na	Mg	K	Ca	Mn	Fe	Cu	Zn	Cd	Pb
Egbe	Gill	22.40 ± 1.18^a	10.70 ± 0.63^a	27.57 ± 15.12^a	37.22 ± 1.72^a	0.32 ± 0.03^a	0.54 ± 0.03^a	0.26 ± 0.03^a	0.45 ± 0.05^a	0.0003 ± 0.0002^a	0.0093 ± 0.004^a
	Liver	19.47 ± 1.75^a	9.38 ± 0.62^a	30.55 ± 8.66^a	37.88 ± 4.92^a	0.34 ± 0.02^a	0.68 ± 0.08^a	0.22 ± 0.05^a	0.43 ± 0.05^a	0.0002 ± 0.0001^a	0.0024 ± 0.001^a
	Muscle	19.60 ± 1.25^a	9.04 ± 0.57^a	27.17 ± 22.08^a	38.51 ± 1.74^a	0.33 ± 0.02^a	0.58 ± 0.05^a	0.20 ± 0.03^a	0.44 ± 0.05^a	0.0001 ± 0.0001^a	0.0002 ± 0.0001^b
Ero	Gill	17.2 ± 1.86^a	9.67 ± 0.60^a	24.45 ± 12.29^a	50.63 ± 4.18^a	0.38 ± 0.04^a	0.76 ± 0.04^a	0.10 ± 0.02^a	0.54 ± 0.03^a	ND^a	0.0003 ± 0.0002^a
	Liver	18.01 ± 2.21^a	9.07 ± 0.63^a	25.64 ± 10.03^a	54.84 ± 2.83^a	0.41 ± 0.05^a	0.81 ± 0.04^a	0.06 ± 0.01^a	0.53 ± 0.02^a	ND^a	0.0002 ± 0.0002^a
	Muscle	17.04 ± 1.74^a	8.44 ± 0.42^a	25.58 ± 12.33^a	49.95 ± 3.09^a	0.41 ± 0.02^a	0.77 ± 0.06^a	0.07 ± 0.02^a	0.56 ± 0.03^a	ND^a	ND^a
Ureje	Gill	18.36 ±1.74	9.38± 0.26	27.93± 23.76^a	39.89 ± 2.89^a	0.50 ± 0.05^a	0.80 ± 0.12^a	0.18 ± 0.03^a	0.56 ± 0.04^a	0.0004 ± 0.0002^a	0.0045 ± 0.002^a
	Liver	19.57 ± 2.20^a	9.72 ± 0.36^a	25.60 15.70^a	31.64 ± 2.76^a	0.32 ±0.03^b	0.68 ± 0.12^a	0.15 ± 0.03^a	0.48± 0.05^a	0.0001 ± 0.0001	0.0007± 0.0003^b
	Muscle	14.41 ± 1.19^b	8.33 ± 0.48^b	24.02 ± 15.74^a	36.32 ± 3.79^a	0.36 ± 0.05^b	0.66 ± 0.11^a	0.14 ± 0.03^a	0.49 ± 0.06^a	ND^b	ND^b

*Mean with different superscripts along column are significantly different ($P < 0.05$). ND = Not detected, Number of fish sample from each dam = 12

Table 2: Mean Concentration of Metals in the Various Tissues of *Oreochromis niloticus* in the Dams during the Rainy Season

Site	Tissue	Metals (ppm)									
		Na	Mg	K	Ca	Mn	Fe	Cu	Zn	Cd	Pb
Egbe dam	Gill	26.43 ± 1.56^a	9.94 ± 0.48^a	32.58 ± 9.84^a	43.85 ± 3.20^a	0.50 ± 0.05^a	0.766 ± 0.14^a	0.33 ± 0.07^a	0.45 ± 0.07^a	0.0003 ± 0.0002^a	0.0033 ± 0.0022^a
	Liver	21.85 ± 2.25	9.44 ± 0.06	31.63 ±12.27	43.77 ± 3.58^a	0.53 ± 0.06^a	0.626 ± 0.08^a	0.26 ±0.05	0.39 ± 0.05^a	ND^a	ND^a
	Muscle	20.08 ± 1.06^b	7.441 ± 0.96^b	26.95 ± 12.10^b	39.48 ± 3.37^a	0.36 ± 0.02^b	0.505 ± 0.07^a	0.16 ±0.02^b	0.40 ± 0.03^a	ND^a	ND^a
Ero dam	Gill	16.48 ± 1.34^a	10.52 ± 0.65^a	29.42 ± 6.07^a	45.68 ± 1.75^a	0.42 ± 0.04	0.790 ± 0.08^a	0.13 ± 0.02	0.53 ± 0.04^a	0.0001 ± 0.0001^a	0.002 ± 0.001^a
	Liver	17.20 ± 1.50^a	10.31 ± 0.57^a	23.27 ± 11.60^b	40.02 ± 4.29^a	0.34 ± 0.05^a	0.557 ± 0.06^b	0.08 ± 0.02^a	0.48 ± 0.05^a	ND^a	0.001 ± 0.0001^a
	Muscle	15.08 ± 1.32^a	11.01 ± 1.02^a	25.31 ± 15.62^b	42.37 ±3.43^a	0.50 ± 0.05^b	0.622 ± 0.06	0.14 ± 0.01^b	0.49 ± 0.04^a	ND^a	ND^a
Ureje dam	Gill	18.30 ± 1.79^a	10.19 ± 0.88^a	21.52 ± 14.88^a	30.18 ± 2.37	0.28 ± 0.04^a	0.621 ± 0.09^a	0.15 ± 0.02^a	0.30 ± 0.03^a	0.0001 ± 0.0001^a	0.0001 ± 0.0001^a
	Liver	19.05 ± 1.45^a	9.42 ± 0.51^a	22.84 ± 8.42^a	34.17 ± 1.29^a	0.21 ±0.02^a	0.510 ± 0.07^a	0.14 ± 0.02^a	0.31 ± 0.02^a	ND^a	ND^a
	Muscle	16.03 ± 1.19^a	7.33 ± 0.51^b	19.23 ± 12.93^a	26.79 ± 0.89^b	0.22 ± 0.63^a	0.457 ± 0.07^a	0.16 ± 0.04^a	0.26 ± 0.02^a	ND^a	ND^a

*Mean with different superscripts along column are significantly different ($P < 0.05$). ND = Not detected, Number of fish sampled from each dam = 16

Table 3: Concentration of Metals in the Tissues of *Oreochromis niloticus* among the Dams during the Dry Season

		Metals (ppm)									
Tissue	Dam	Na	Mg	K	Ca	Mn	Fe	Cu	Zn	Cd	Pb
Gill	Egbe	22.40 ± 1.18^a	10.70 ± 0.63^a	27.57 ± 15.12^a	37.22 ± 1.72^a	0.32 ± 0.03^a	0.54 ± 0.03^a	0.26 ± 0.03^a	0.45 ± 0.05^a	0.0003 ± 0.0002^a	0.0093 ± 0.004^a
	Ero	17.2 ± 1.86^a	9.67 ± 0.60^a	24.45 ± 12.29^a	50.63 ± 4.18^a	0.38 ± 0.04^a	0.76 ± 0.04^a	0.10 ± 0.02^b	0.54 ± 0.03^a	ND^a	0.0003 ± 0.0002^a
	Ureje	18.36 ±1.74^a	9.38± 0.26^a	27.93± 23.76^a	39.89 ± 2.89^a	0.50 ± 0.05^a	0.80 ± 0.12^a	0.18 ± 0.03	0.56 ± 0.04^a	0.0004 ± 0.0002^a	0.0045 ± 0.002^a
Liver	Egbe	19.47 ± 1.75^a	9.38 ± 0.62^a	30.55 ± 8.66^a	37.88 ± 4.92^a	0.34 ± 0.02^a	0.68 ± 0.08^a	0.22 ± 0.05^a	0.43 ± 0.05^a	0.0002 ± 0.0001^a	0.0024 ± 0.001^a
	Ero	18.01 ± 2.21^a	9.07 ± 0.63^a	25.64 ± 10.03^b	54.84 ± 2.83^b	0.41 ± 0.05^a	0.81 ± 0.04^a	0.06 ± 0.01^b	0.53 ± 0.02^a	ND^a	0.0002 ± 0.0002^a
	Ureje	19.57 ± 2.20^a	9.72 ± 0.36^a	25.60 15.70^a	31.64 ± 2.76^a	0.32 ± 0.03^a	0.68 ± 0.12^a	0.15 ± 0.03	0.48 ± 0.05^a	0.0001 ± 0.0001^a	0.0007± 0.0003^a
Muscle	Egbe	19.60 ± 1.25^a	9.04 ± 0.57^a	27.17 ± 22.08^a	38.51 ± 1.74	0.33 ± 0.02^a	0.58 ± 0.05^a	0.20 ± 0.03^a	0.44 ± 0.05^a	0.0001 ± 0.0001^a	0.0002 ± 0.0001^a
	Ero	17.04 ± 1.74^a	8.44 ± 0.42^a	25.58 ± 12.33^a	49.95 ± 3.09^a	0.41 ± 0.02^a	0.77 ± 0.06^a	0.70 ± 0.02^b	0.56 ± 0.03^a	ND^a	ND^a
	Ureje	14.41 ± 1.19^a	8.33 ± 0.48^a	24.02 ± 15.74^a	36.32 ± 3.79^b	0.36 ± 0.05^a	0.66 ± 0.11^a	0.14 ± 0.03	0.49 ± 0.06^a	ND^a	ND^a

The mean concentrations of metals in each tissue in the dams with similar superscripts along the column are not significantly different at 0.05 levels. Not detected, Number of fish sample from each dam = 12.

Table 4: Metals Concentrations in the Tissues of *Oreochromis niloticus* among the Dams during the Rainy Season

		Metals (ppm)									
Tissue	Dam	Na	Mg	K	Ca	Mn	Fe	Cu	Zn	Cd	Pb
Gill	Egbe	26.43 ± 1.56^a	9.94 ± 0.48^a	32.58 ± 9.84^a	43.85 ± 3.20^a	0.50 ± 0.05^a	0.77 ± 0.14^a	0.33 ± 0.07^a	0.45 ± 0.07^a	0.0003 ± 0.0002^a	0.0033 ± 0.0022^a
	Ero	16.48 ± 1.34^b	10.52 ± 0.65^a	29.42 ± 6.07^b	45.68 ± 1.75^a	0.42 ± 0.04	0.79 ± 0.08^a	0.13 ± 0.02^b	0.53 ± 0.04^a	0.0001 ± 0.0001^a	0.0019 ± 0.001^a
	Ureje	18.30 ± 1.79^b	10.19 ± 0.88^a	21.52 ± 14.88^b	30.18 ± 2.37^b	0.28 ± 0.04^b	0.62 ± 0.09^a	0.15 ± 0.02^b	0.30 ± 0.03^b	0.0001 ± 0.0001^a	0.0001 ± 0.0001^a
Liver	Egbe	21.85 ± 2.25^a	9.44 ± 0.06^a	31.63 ±12.27^a	43.77 ± 3.58^a	0.53 ± 0.06^a	0.63 ± 0.08^a	0.26 ±0.05^a	0.39 ± 0.05^a	ND^a	ND^a
	Ero	17.20 ± 1.50^a	10.31 ± 0.57^a	23.27 ± 11.60^b	40.02 ± 4.29^a	0.34 ± 0.05^b	0.56 ± 0.06^a	0.08 ± 0.02^b	0.48 ± 0.05^a	ND^a	0.0008 ± 0.0001^a
	Ureje	19.05 ± 1.45^a	9.42 ± 0.51^a	22.84 ± 8.42^b	34.17 ± 1.29^a	0.21 ± 0.02^b	0.51 ± 0.07^a	0.14 ± 0.02^b	0.31 ± 0.02^b	ND^a	ND^a
Muscle	Egbe	20.08 ± 1.06^a	7.44 ± 0.96^b	26.95 ± 12.10^a	39.48 ± 3.37^a	0.36 ± 0.02	0.51 ± 0.07^a	0.16 ±0.02^a	0.40 ± 0.03	ND^a	ND^a
	Ero	15.08 ± 1.32^a	11.01 ± 1.02^a	25.31 ± 15.62	42.37 ±3.43^a	0.50 ± 0.05^a	0.62 ± 0.06^a	0.14 ± 0.01^a	0.49 ± 0.04^a	ND^a	ND^a
	Ureje	16.03 ± 1.19^a	7.33 ± 0.51^b	19.23 ± 12.93^b	26.79 ± 0.89^b	0.22 ± 0.63^b	0.46 ± 0.07^a	0.16 ± 0.04^a	0.26 ± 0.02^b	ND^a	ND^a

*The mean concentrations of metals in each tissue in the dams with similar superscripts along the column are not significantly different at 0.05 levels. ND = Not detected, Number of fish sample from each dam = 16

Table 3 shows the concentrations of metals in fish tissue among the dams during the dry season. Na, Mg, K, Ca, Mn, Fe, Zn, Cd and Pb concentrations in the gills were not significantly different at $P < 0.05$ in the fish obtained from the three dams. Only Cu in the gills showed significant difference at $P < 0.05$ between Egbe and Ero dams. Only K, Ca and Cu showed significant differences in the liver of fish among the dams. K and Ca showed significant difference at $P < 0.05$ in the liver of fish between Egbe and Ero dams and Ero and Ureje dams while Cu showed difference in liver of fish between Egbe and Ero dams. Na, Mg, K, Mn, Fe, Zn, Cd and Pb concentrations in the muscles were not significantly different at $P < 0.05$ in the fish obtained from the three dams but Cu showed significant difference in fish between Egbe and Ero dams while Ca showed significant difference in fish between Ero and Ureje dams.

The concentrations of metals in fish tissue among the dams during the rainy season were shown in Table 4. Mg, Fe, Cd and Pb concentrations in the gills were not significantly different at $P < 0.05$ in the fish obtained from the three dams. However, Na, K and Cu in fish gills showed significant difference between Egbe and Ero dams and between Egbe and Ureje dams; Ca, Zn (between Egbe and Ureje dams and between Ero and Ureje dams); Mn (between Egbe and Ureje dams). Na, Mg, Fe, Cd, Pb and Ca levels in the liver were not different significantly at $P < 0.05$ in the fish obtained from the three dams. K, Mn and Cu in liver showed significant differences between Egbe and Ero dams and between Egbe and Ureje dams while Zn showed significant difference between Ero and Ureje dams and between Egbe and Ureje dams. Na, Fe, Cu, Cd and Pb in the muscle showed differences that were not significant at $P < 0.05$ in fish obtained from the three dams. But among the dams, Mn and Zn in muscle showed significance differences at $P < 0.05$ between Ero and Ureje dams, K (between Egbe and Ureje dams); Mg (between Egbe and Ero dams and between Ero and Ureje dams) and Ca (between Egbe and Ureje dams and between Ero and Ureje dams).

Metals in Tissues and Fish Body Weight of *O. niloticus*

The Pearson's correlation coefficients between fish body weight and metals in fish tissues during the dry season are shown in Table 5 while the correlation coefficients between fish body weight and metals in fish tissues during the rainy season are indicated in Table 6. In the tissues and the dams, metals recorded different correlations coefficients in relation to body weight.

During the dry season, Pb in gills of fish from Egbe dam and Ca in the muscle of fish from Ero dam showed negative significant correlation to fish body weight at $P < 0.05$ while Na and Cu in gills of fish from Ero dam showed strong positive significant correlation to fish body weight at $P < 0.05$. During the rainy season, Cd in gills and Ca in muscle of fish from Ero dam; Ca in gills of fish from Ureje dam showed strong positive significant correlation to the body weight at $P < 0.05$ while K in muscle of fish from Ero dam showed strong negative correlation to the body weight at $P < 0.05$. Though not significant, other metals in the different tissues showed moderate, weak and negligible positive or negative correlations with the body weight.

Table 5: Correlation Coefficient between Fish Body Weight and Metal Accumulation in Tissues during the Dry Season

		Metals									
Dam	Tissue	Na	Mg	K	Ca	Mn	Fe	Cu	Zn	Cd	Pb
Egbe	Gill	0.77	-0.36	0.25	0.30	-0.22	0.40	-0.28	0.49	-0.66	-0.84*
	Liver	0.08	0.52	-0.72	0.21	0.39	0.16	0.57	0.26	0.12	-0.19
	Muscle	0.14	0.14	-0.19	0.30	0.16	0.37	-0.45	-0.10	-0.77	-0.40
Ero	Gill	0.83*	-0.03	-0.09	-0.69	0.06	0.30	0.93**	-0.37	-	-0.53
	Liver	-0.55	-0.25	0.001	-0.08	-0.15	0.32	-0.72	0.02	-	-0.002
	Muscle	0.33	-0.37	0.40	-0.89*	-0.25	0.17	0.26	-0.14	-	-
Ureje	Gill	-0.69	-0.10	0.73	0.01	-0.12	0.53	-0.47	0.26	0.32	0.80
	Liver	0.18	0.73	0.10	-0.76	-0.41	-0.59	0.24	-0.41	-0.26	-0.61
	Muscle	-0.06	0.60	0.67	0.19	0.66	0.45	-0.45	0.59	-	-

Correlation is significant at the 0.05 level (2-tailed).*
Correlation is significant at the 0.01 level (2-tailed). **

Table 6: Correlation Coefficient between Fish Body Weight and Metal Accumulation in Tissues during the Rainy Season

		Metals									
Dam	Tissue	Na	Mg	K	Ca	Mn	Fe	Cu	Zn	Cd	Pb
Egbe	Gill	0.77	-0.10	0.58	0.52	0.02	-0.004	0.53	0.11	0.09	0.09
	Liver	0.03	0.60	0.53	-0.03	-0.02	0.20	-0.37	0.30	-	-
	Muscle	0.45	-0.29	-0.72	0.49	-0.38	-0.41	0.68	-0.17	-	-
Ero	Gill	-0.50	0.32	0.19	0.05	0.15	0.79	0.03	0.55	0.86*	0.86
	Liver	0.47	-0.05	0.71	0.26	0.19	-0.18	0.31	0.67	-	0.24
	Muscle	-0.45	0.64	-0.88*	0.88*	-0.18	-0.17	0.02	0.58	-	-
Ureje	Gill	0.01	-0.17	0.61	0.85*	0.43	0.66	-0.09	0.64	-0.47	-0.32
	Liver	-0.23	0.29	0.53	-0.24	-0.04	0.53	0.39	0.10	-	-
	Muscle	0.09	-0.46	-0.68	0.55	0.09	0.52	-0.07	0.35	-	-

Correlation is significant at the 0.05 level (2-tailed).*
Correlation is significant at the 0.01 level (2-tailed).**

Metals in Tissues and Fish Body Length

Table 7 shows the Pearson's correlation coefficients between fish body length and metals in fish tissues during the dry season while Table 8 shows the Pearson's correlation coefficients between fish body length and metals in fish tissues during the rainy season. During the dry season, Pb in gills of fish from Egbe dam and Ca in the muscle of fish from Ero dam showed strong negative significant correlations to fish total length at $P < 0.05$. Na and Cu in gills and Cu in liver in fish from Ero dam showed strong positive significant correlations to fish total length at $P < 0.05$. In the rainy season, K in gills of fish from Egbe and Pb in liver of fish from Ero dam showed strong positive significant correlation with fish total length while Pb in gills of fish from Ureje dam showed strong negative significant correlation with fish total length at $P < 0.05$. Other metals in the different tissues, though not significant, showed moderate, weak and negligible positive or negative correlations with the body length.

Table 7: Correlation Coefficient between Fish Total Length and Metal Accumulation in Tissues during the Dry Season

		Metals									
Dam	Tissue	Na	Mg	K	Ca	Mn	Fe	Cu	Zn	Cd	Pb
Egbe	Gill	0.75	-0.47	0.10	0.47	-0. 25	0.37	-0.24	0.50	-0.67	-0.87*
	Liver	0.17	0.47	-0.67	0.34	0.47	0.23	0.56	0.25	0.17	-0.04
	Muscle	-0.05	0.24	-0.37	0.37	0.14	0.32	-0.35	-0.14	-0.80	0.40
Ero	Gill	0.82*	0.19	-0.27	-0.62	-0.04	0.50	0.93**	-0.28	-	-0.68
	Liver	-0.67	-0.42	-0.35	0.18	-0.44	0.17	0.90*	-0.26	-	0.32
	Muscle	0.44	-0.37	0.01	-0.87*	-0.29	-0.27	0.50	-0.05	-	-
Ureje	Gill	-0.79	-0.11	0.76	0.16	-0.30	0.56	-0.68	0.43	0.47	0.69
	Liver	0.36	0.60	-0.10	-0.78	-0.45	-0.66	0.35	-0.54	-0.16	-0.60
	Muscle	-0.26	0.46	0.59	0.27	0.56	0.55	-0.58	0.67	-	-

Correlation is significant at the 0.05 level (2-tailed).*
Correlation is significant at the 0.01 level (2-tailed).**

Table 8: Correlation Coefficient between Fish Total Length and Metal Accumulation in Tissues during the Rainy Season

		Metals									
Dam	**Tissue**	**Na**	**Mg**	**K**	**Ca**	**Mn**	**Fe**	**Cu**	**Zn**	**Cd**	**Pb**
Egbe	Gill	0.69	-0.45	0.83*	0.75	0.22	0.48	0.11	0.45	-0.16	-0.16
	Liver	0.33	0.17	0.27	0.22	-0.43	-0.10	-0.13	-0.19	-	-
	Muscle	0.09	-0.39	-0.56	-0.23	-0.04	-0.40	0.23	0.40	-	-
Ero	Gill	-0.67	0.42	-0.28	0.20	0.27	-0.19	-0.34	-0.30	-0.16	-0.16
	Liver	0.13	0.58	-0.43	0.65	-0.08	-0.37	0.28	0.64	-	99**
	Muscle	-0.26	-0.06	0.50	-0.14	-0.21	-0.24	-0.79	-0.48	-	-
Ureje	Gill	0.70	0.46	0.54	0.94	0.61	0.25	0.52	0.60	-0.32	-0.85*
	Liver	0.22	-0.02	-0.12	0.36	-0.65	0.500	0.09	0.66	-	-
	Muscle	0.185	0.08	-0.35	-0.49	0.55	0.52	0.46	0.55	-	-

Correlation is significant at the 0.05 level (2-tailed).*
Correlation is significant at the 0.01 level (2-tailed). **

3.3 Assessment of Human Health Hazard

(i) Non-Carcinogenic Health Hazard

Public health hazard connected with intake of *Oreochromis niloticus* from the dams was evaluated by calculating the hazard quotient (THQ) and the Hazard Index (HI) for children (1 – 6 years) and adults (19 years and above) utilizing the fish as a protein source. Table 9 indicates the average concentrations of metals measured in *Oreochromis niloticus* muscles from the Egbe, Ero and Ureje dams in both seasons. The oral reference doses of the measured metals are shown in Table 10 Estimated THQ for individual metal and HI from consumption of *Oreochromis niloticus* are shown in Table 11.

The hazard quotients for Pb, Cd, Cu, Zn, Fe and Mn in muscle of fish from Egbe, Ero and Ureje dam during both dry season and rainy season are less than 1. Likewise, HI, which is the summation of hazard quotients for the metals found in the dams during the dry season and rainy season for adults and children is less than 1 in each of the dams and in both dry and rainy periods. Total THQ values of Pb, Cd, Cu, Zn, Fe and Mn for adults during the dry season were 7.06×10^{-3}, 5.56×10^{-3} and 6.27×10^{-3} for Egbe, Ero and Ureje dams respectively while for children, they were 8.16×10^{-3}, 6.43×10^{-3} and 7.25 × in Egbe, Ero and Ureje dams respectively (Table 11). In rainy period, the total values of THQ for Pb, Cd, Cu, Zn, Fe and Mn for adults were 6.22×10^{-3}, 6.92×10^{-3} and 5.05×10^{-3} in Egbe, Ero and Ureje dams respectively. For children, the total THQ values were 7.19×10^{-3}, 8.00×10^{-3} and 5.84×10^{-3} in Egbe, Ero and Ureje dams respectively (Table 11). There was no seasonal effects. These metals occurred at lesser concentrations related to the maximum acceptable limits in food by Food and Agricultural Organization (FAO, 1983).

Table 9: Mean Metal Concentrations in the Muscle of O. niloticus from Egbe, Ero and Ureje Dams during the Dry and Rainy Season

	Metal concentrations in *O. niloticus* muscle					
	Dry season			Rainy season		
Metal	Egbe dam	Ero dam	Ureje dam	Egbe dam	Ero dam	Ureje dam
Mn	0.33 ± 0.02	0.41 ± 0.02	0.36 ± 0.05	0.36 ± 0.02	0.50 ± 0.05	0.22 ± 0.63
Fe	0.58 ± 0.05	0.77 ± 0.06	0.66 ± 0.11	0.51 ± 0.07	0.62 ± 0.06	0.46 ± 0.07
Cu	0.20 ± 0.03	0.07 ± 0.02	0.14 ± 0.03	0.16 ±0.02	0.14 ± 0.01	0.16 ± 0.04
Zn	0.44 ± 0.05	0.56 ± 0.03	0.49 ± 0.06	0.40 ± 0.03	0.49 ± 0.04	0.26 ± 0.02
Cd	0.0001 ± 0.0001	ND	ND	ND	ND	ND
Pb	0.0002 ± 0.0001	ND	ND	ND	ND	ND

*ND – Not detected, Number of fish sample (Dry season) = 12 and (Rainy season) = 16

Table 10: The Oral Reference Dose of Heavy Metals in Tissues of *Oreochromis niloticus*

Heavy metal	Fe	Mn	Zn	Cu	Pb	Cd
RfDo ($mgkg^{-1}day^{-1}$)	7.0×10^{-1}	1.4×10^{-1}	3.0×10^{-1}	4.0×10^{-2}	4.0×10^{-3}	1.0×10^{-3}

The oral RfD for Cu, Zn, Mn, Cd, and Fe (USEPA, 2015), Pb (Khan *et*., 2008).

(ii) Carcinogenic Risk Assessment

Among the metals analysed, only Cd and Pb are confirmed "Class A" human carcinogen through the oral route of exposure. Cd and Pb were only found in the muscle of fish from Egbe while they were not detected in fish from Ero and Ureje dams.

The incremental lifetime cancer risk (ILCR) = CDI × CSF

For Adults, ILCR (Cd) = Conc. of Cd in fish muscle × FIR/BW × CSF (Cd)

$= (0.0001 \times 0.051)/70 \times 6.1$

$= 4.44 \times 10^{-7}$

For Children, ILCR (Cd) = Conc. of Cd in fish muscle × FIR/BW × CSF (Cd)

$= (0.0001 \times 0.016)/18 \times 6.1$

$= 5.42 \times 10^{-7}$

For Adults, ILCR (Pb) = Conc. of Pb in fish muscle × FIR/BW × CSF (Pb)

$= (0.0002 \times 0.051)/70 \times 8.5$

$= 1.24 \times 10^{-6}$

For Children, ILCR (Pb) = Conc. of Pb in fish muscle × FIR/BW × CSF (Pb)

$= (0.0002 \times 0.016)/18 \times 8.5$

$= 1.51 \times 10^{-6}$

The carcinogenic human health assessment revealed that cadmium and lead in the fish from Egbe dam during dry season were below the range for relatively negligible cancer risk for both adults and children. During the rainy season, the values of Pb and Cd were below detection level.

Table 11: Target Risk Quotients (THQ) and Hazard index (HI) from Consumption of *Oreochromis niloticus* in Egbe, Ero and Ureje Dams during the Dry and Rainy seasons.

	Target Hazard Quotients (THQ)											
	Dry season						Rainy season					
	Egbe dam		Ero dam		Ureje dam		Egbe dam		Ero dam		Ureje dam	
Metal	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children
Mn	1.71×10^{-3}	1.98×10^{-3}	2.13×10^{-3}	2.46×10^{-3}	1.85×10^{-3}	2.14×10^{-3}	1.90×10^{-3}	2.19×10^{-3}	2.59×10^{-3}	3.00×10^{-3}	1.12×10^{-3}	1.29×10^{-3}
Fe	5.99×10^{-4}	6.92×10^{-4}	7.98×10^{-4}	9.23×10^{-4}	6.84×10^{-4}	7.90×10^{-4}	5.25×10^{-2}	6.07×10^{-4}	6.48×10^{-4}	7.49×10^{-4}	4.75×10^{-4}	5.50×10^{-4}
Cu	3.59×10^{-3}	4.15×10^{-3}	1.28×10^{-3}	1.48×10^{-3}	2.54×10^{-3}	2.94×10^{-3}	2.83×10^{-3}	3.28×10^{-3}	2.49×10^{-3}	2.88×10^{-3}	2.82×10^{-3}	3.26×10^{-3}
Zn	1.06×10^{-3}	1.22×10^{-3}	1.36×10^{-3}	1.57×10^{-3}	1.20×10^{-3}	1.38×10^{-3}	9.62×10^{-4}	1.11×10^{-3}	1.19×10^{-3}	1.38×10^{-3}	6.35×10^{-4}	7.34×10^{-4}
Cd	7.29×10^{-5}	8.42×10^{-5}	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pb	3.64×10^{-5}	4.21×10^{-5}	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HI	7.06×10^{-3}	8.16×10^{-3}	5.56×10^{-3}	6.43×10^{-3}	6.27×10^{-3}	7.25×10^{-3}	6.22×10^{-3}	7.19×10^{-3}	6.92×10^{-3}	8.00×10^{-3}	5.05×10^{-3}	5.84 x 103

*ND – Not detected

DISCUSSION

A bio-indicator of environmental impact on organisms that is useful in assessing the potential health risks to people associated with consuming fish from contaminated catchments is the assessment of heavy metals in fish from contaminated areas. This process helps us to better understand how the aquatic ecosystem adapts or changes in response to changes in the surrounding environmental conditions (Ahmad and Al-Mahaqeri, 2015). In this study, the mean concentrations of Mn, Fe, Cu, Zn, Cd and Pb in tissues of *O. niloticus* in the three dams were lower than the limits of permissible levels introduced by WHO (1989) and FAO (1983). Hence, the metal concentrations in *O. niloticus* in the dams are not yet injurious to life. The significant seasonal variations in the concentrations of Na and Ca in the gills of fish from Egbe dam; concentration of Cu in muscle of fish from Ero dam and concentration Mn and Zn in gills and Zn in liver and muscle in fish from Ureje dam are similar to the observations made by Saeed (2013) and Younis *et al.* (2014) in the muscles of *O. niloticus* from lake Edku Egypt and drainage canals in Ah-Ahsa, Suadi Arabia respectively. The seasonal variations in metal concentrations in fish tissues within aquatic ecosystem have been reported to depends on physical and chemical parameters of water, feeding, age (Sauliute and Svecevicius 2017), reproductive cycle of fish (Zyadah, 1999), the rise in water level of the dams due to rainfall and decrease in water level caused by evaporation and absence of rainfall (Varol and Sünbül, 2018) and the fluctuations in the amount of untreated domestic sewage and agricultural drainage water into the ecosytem (Authman *et al*., 2008). However, the seasonal variations in accumulation of metals in the tissues observed in this study are likely to be due to the fluctuations of the amount of runoffs, untreated domestic sewage and agricultural drainage water into the dams during the different seasons.

The observed significant differences in some of the metals concentrations in the tissues of *O. niloticus* among the dams could be due to chemical make-up of the metals,

their concentrations, water quality and parasitic activities which differ among the dams (Olagbemide and Owolabi, 2019; Olagbemide and Owolabi, 2022). However, the variations in the levels of metals in the tissues of fish in aquatic environments were attributed to the proximity of the tissues to metals, the concentration of the metals in the media, the age of the fish, the presence of molecules that have an affinity for metals in the fish, and the roles of the tissues in detoxification in the ecosystems (Adhikari *et al*., 2009) while Weber et al. (2013) and Bashir *et al.* (2013) ascribed them to the type of pollutant, fish species, sample location, trophic level, and method of feeding and changes in the physiological functions of each tissue.

The liver or the gills often have the highest concentrations of the majority of the metals in the dams. Similar situations were reported by other researchers (Türkmen *et al*., 2010, Bawuro *et al*., 2018). This may be because of various factors, including the presence of metallothionein proteins in the liver and gills, which aid in their roles as detoxifying organs (Jobling, 1995; Kent, 1998) and the gills' highly vascularized and sizable surface areas; and their roles in excretion (Mayer et al., 1991; Matthiessen and Brafield, 1977). As seen in this study, the skin and muscle passage often only contributes a modest amount to exposure due to the external epithelium's efficient barrier function (Kir and Tomantozle, 2012). However, due to its significance for human consumption and its health implications on humans, various research on metal accumulation in the muscle have been published (Tekin-zan and Aktan, 2012; Asante *et al*., 2014; El-Moselhy *et al*., 2014; Rajeshkumar and Li, 2018). The buildup of metals in the gills and liver provides a flawless representation of the interactions between fish and their environment by reflecting the concentrations of those metals in the environment where the fish species resides (Monroy et al., 2014). The metal accumulation pattern in the fish tissues in the dams showed that accumulation of necessary metals was larger than that of non-essential elements (Pb and Cd). This might be because necessary metals play important biochemical and physiological roles in fish, but non-essential metals have no biological function but are nevertheless hazardous to fish even at very low doses. Adeyeye and Ayoola (2013) and Aladesanmi *et al.* (2014) reported similar findings on *Clarias gariepinus* organs from the Eko-Ende dam, Ikirun, and from selected fish ponds in Osun state.

It has also been discovered that aquatic animals' propensity for metal buildup is influenced by their size and ecological needs (Kalay and Canli, 2000). In this study, some of the metals and the fish body weight and body length in the various dams were highly correlated whereas other relationships were not significant. This is consistent with the findings of De Wet *et al*. (1994), who reported an inverse relationships between metal concentrations and body weight in the bioaccumulation of Fe, Mn, Zn, Cu, Ni and Pb by *Pseudocrenilabrus philander* from a mine-polluted impoundment. Al-yousuf *et al*. (2000) observed a positive association between the concentration of Zn, Cu, Hg, and Cd in *Lethrinus Lentjan* and the fish length and weight while Canli and Atli (2003) reported a negative relationships between fish length and metal (Cr, Pb, and Cu) concentrations. Astani *et al*. (2018) reported a strong and significant negative correlation between body weight and Cd absorption in the gill of *Alosa braschinkowi* along the Caspian Sea coast, and between body length and Cu absorption of the gonads while there was no significant relationship in the muscle tissues. According to Rakocevic *et al*. (2018), there are no significant correlations between Fe, Cr, Pb, Cd, and Hg with age or size (length and weight) in any of the analyzed fish species, but there are significant correlations between essential elements and fish age and size. However, none of these investigations found a direct connection between fish size (body weight and body length) and heavy metal concentration. Thus, several factors such as age, feeding habits of fish, their retention time in polluted waters (Schuhmacher *et al*., 1992) and the sediment accumulation of each area (Yi and Zhang, 2012) in addition to length and weight can be inferred to affect the heavy metals accumulation in fish.

Consumption of fish has many health benefits on humans such as protein-energy supplementation, a supply of some essential fatty acids as well as vitamins and minerals. However, the presence of lethal substances in the fish, can make their consumption to have detrimental consequences (Kortei *et al*., 2020). For both adults and children, the hazard quotients for Mn, Fe, Cu, Zn, Cd, and Pb in the muscular tissues of fish from the dams were less than 1, and they could be regarded as having low risk. Çulha *et al*. (2016) revealed that scorpion fish from the Black Sea had THQ values for heavy metals (Al, Cu, Ni, As, Cd, Hg, Pb) that were below 1. Fish from the Yangtze River in China were deemed safe for ingestion by Yi *et al*. (2011) since the THQ of the metals was under 1. According to Amirah *et al*. (2013), all metals examined in a particular river in Kuantan, Pahang, Malaysia have THQs of less than 1. Similar findings on the metals in fish from Nigeria's Kiri Dam and River Gongola were made by Orosun *et al.* (2016). The Hazard index (HI), which is the total of the hazard quotients for the metals found in the dams during the dry and rainy seasons for adults and children, was also less than 1 in each of the dams and during both of the seasons, meaning the absence of non-carcinogenic combined effects and thus, indicating that using the species as a protein source currently does not pose a risk to the public's health for consumers over the course of 70 years.

Cadmium and lead, according to the carcinogenic human health assessment, show no evidence of a negative impact on either adults' or children's health when consumed with

fish. However, due to the harmful effects of cadmium and lead on both fish and humans, as well as the fact that any carcinogenic substance, such as Pb and Cd, carries a risk of cancer development at any dose other than zero, the discovery of cadmium and lead in fish muscle is concerning. Long-term exposure to cadmium has been linked to renal failure and obstructive lung disease, and it has also been documented to produce ita-itai disease in fish eaters (Cheung *et al*., 2008; Baby *et al*., 2010). Pb has been linked to long-term neurological damage in children (hyperactivity, inability to focus, low IQ), decreased male fertility, and suppression and alteration of the manufacture of hemoglobin, which results in inadequate oxygen delivery and anemia in man (Landis and Yu, 2003; Bradl, 2005). In order to prevent an excessive buildup of these metals in the human food chain and to reduce the risk to the health of the population that relies on fish from the dams as a major source of their fish supply, it is therefore advised that the relevant environmental and health authorities perform close monitoring of toxic metals contamination as well as the assessment of the potential risks of consumption of fish and other aquatic organisms in the dams.

CONCLUSION

Although heavy metals were detected in the tissues of *O. niloticus* from Egbe, Ero and Ureje dams, their concentrations in the tissues are still at lower concentrations compared to the maximum acceptable limits in food by Food and Agricultural Organization and WHO. In addition, the carcinogenic human health assessment revealed that cadmium and lead indicate no adverse health effect of fish intake, thus indicating that the utilization of the species as a protein source does not currently pose public health risk to consumers. However, the detection of cadmium and lead in fish muscle is of great concern because of their toxic effects on human. Therefore, there is a need for close monitoring of these toxic metals contamination to prevent their excessive accumulation in the human food chain.

Declarations

Ethical approval and consent to participate: Permissions were acquired from the Ekiti State Water Corporation and the University of Ilorin's ethical committees, and the research was conducted in accordance with ethical norms.

Consent for publication: Not applicable

Competing interests: Authors have no conflict of interest to declare.

Availability of Data and Materials: All data generated and analyzed during this study are included in this published article

Funding: No financial assistance was received from local or international organization

Authors' contributions: **OPT** conceived and designed the experiment; data collection, analysis and interpretation; drafting of the article, designed figures and wrote the manuscript in consultation with **OOD**. **OOD** supervised the project; critical review of the article and final approval of the version to be published.

ACKNOWLEDGEMENT

The authors would like to thank Ekiti State Water Corporation for granting the permission to carry out this research work on the three dams. The assistance of the local fishermen working on the dams in the collection of fish species is gratefully acknowledged. Profound thanks to Mr. Samson Mabayoje who assisted in the metal analysis of the tissues of the fish samples.

REFERENCES

Abubakar, A., Uzairu, A., Ekwumemgbo, P. A. and Okunola, O. J. (2015). Risk assessment of Heavy Metals in Imported Frozen Fish Scomber scombrus Species sold in Nigeria: A Case Study of Zaria Metroplolis. *Advances in Toxicology*. 2 0 1 5:11pp.doi:/10.1155/2015/303245. http://dx.doi.org/10.1155/2015/303245

Addo, M. A., Darko, E. O., Gordon, C. and Nyarko, B. J. B. (2013). Heavy Metal Contaminations in soil and cassava harvested near cement processing facility in the Volta Region, Ghana: Implications of Health risk for the Population living in the Vicinity. *e-journal of Sci. Tech*. 3(8):71-83. https://ugspace.ug.edu.gh/handle/123456789/6266

Adeyeye, A. and Ayoola, P. B. (2013). Heavy metal concentrations in some organs of African Catfish (Clarias gariepinus) from Eko-Ende dam, Ikirun, Nigeria. *Continental J. Applied Sciences* 8 (1): 43 – 48. https://zenodo.org/record/2573154#.YxzDc3bMLIU

Adhikari, S., Ghosh, L., Giri, B. S. and Ayyappan, S. (2009). Distributions of metals in food web of Kolleru Lake, India. *Ecotoxicol. Environ. Safety*, 72: 1242-1248. https://doi.org/10.1016/j.ecoenv.2008.10.011

Ahmad, A. K. and Al-Mahaqeri, S. A. (2015). Human Health Risk Assessment of Heavy Metals in Fish Species Collected from Catchments of Former Tin Mining. *International Journal of Research Studies in Science, Engineering and Technology*, 2(4): 9-21. http://www.ijrsset.org/pdfs/v2-i4/2.pdf

Akan, J. C., Mohmoud, S., Yikala, B. S. and Ogugbuaja, V. O. (2012). Bioaccumulation of some heavy metals in fish samples from river Benue in Vinikilang, Adamawa state, Nigeria. *Am J Analyt Chem*., 3(11):727. https://sci-hub.ru/10.1155/2018/1854892

Aladesanmi, O. T., Adeniyi, I. F. and Adesiyan, I. M. (2014). Comparative Assessment and Source Identification of Heavy Metals in Selected Fishpond Water, Sediment and Fish Tissues/Organs in Osun State, Nigeria. *Journal of Health and Pollution*, 4(7): 42-53. https://meridian.allenpress.com/jhp/article/4/7/42/67476/Comparative-Assessment-and-Source-Identification

Al-Yousuf, M. H., El-Shahawi, M. S. and Al-Ghais, S. M. (2000). Trace metals in liver, skin and muscle of *Lethrinus lentjan* fish species in relation to body length and sex. *Science of the Total Environment*, 256: 87-94. https://doi.org/10.1016/s0048-9697(99)00363-0

Amirah, M. N., Afiza, A. S., Faizal, W. I. W., Nurliyana M. H. and Laili, S. (2013). "Human health risk assessment of metal contamination through consumption of fish." *Journal of Environment Pollution and Human Health* 1(1): 1-5. http://www.sciepub.com/JEPHH/abstract/494

APHA (2005). *Standard Methods for the Examination of Water and Waste Water*, American Public Health Association, 2005.

Astani, Z. F., Jelodar, H. T. and Fazli, H. (2018). Studying the accumulation of heavy metals (Fe, Zn, Cu and Cd) in the tissue (muscle, skin, gill and gonad) and its relation with fish (Alosa braschinkowi) length and weight in Caspian Sea coasts. *J Aquac Mar Biol*., 7(6): 308–312. https://doi.org/10.15406/jamb.2018.07.00226

Asante, F., Agbeko, E., Addae, G. and Quainio, A. K. (2014). Bioaccumulation of Heavy Metals in Water, Sediments and Tissues of Some Selected Fishes from the Red Volta, Nangodi in the Upper East Region of Ghana. *British Journal of Applied Science & Technology*, 4(4): 594-603. https://doi.org/10.9734/BJAST/2014/5389

Authman, M. M. N.; Bayoumy, E. M. and Kenawy, A. M. (2008). Heavy metal concentrations and liver histopathology of Oreochromis niloticus in relation to aquatic pollution. Global Veterenaria, 2 (3): 110-116. https://www.researchgate.net/publication/313551801_Heavy_metal_concentrations_and_liver_histopathology_of_Oreochromis_niloticus_in_relation_to_aquatic_pollution

Ayantobo, O. O., Awomeso, J. A., Oluwasanya, I. G. O., Bada, B. S. and Taiwo, A. M. (2014). Non-cancer human health risk assessment from exposure to heavy metals in surface and groundwater in Igun Ijesha, southwest Nigeria. *American Journal of Environmental Sciences* 10 (3): 301-311. https://doi.org/10.3844/ajessp.2014.301.311

Baby, J., Raj, J. S., Biby, E. T., Ankarganesh, P., Jeevitha, M. V., Ajisha, S. U. and Rajan, S. S. (2010). Toxic effect of heavy metals on aquatic environment. *Int. J. Biol. Chem. Sci*. 4(4): 939-952. https://doi.org/10.4314/ijbcs.v4i4.62976

Baharom, Z. S. and Ishak, M. Y. (2015). Determination of heavy metal accumulation in fish species in Galas River, Kelantan and Beranang mining pool, Selangor. *Procedia Environmental Sciences*, 30: 320 – 325. https://doi.org/10.1016/j.proenv.2015.10.057

Bashir, F. Othman, M. Mazlan, A. Rahim, S. Simon, K. (2013). Heavy Metal Concentration in Fishes from the Coastal Waters of Kapar and Mersing, Malaysia, *Turkish Journal of Fisheries and Aquatic Sciences*, 13: 375-382. https://www.researchgate.net/publication/323999478_Heavy_Metal_Concentration_in_Fishes_from_the_Coastal_Waters_of_Kapar_and_Mersing_Malaysia

Bawuro, A. A., Voegborlo, R. B. and Adimado, A. A. (2018). Bioaccumulation of Heavy Metals in Some Tissues of Fish in Lake Geriyo, Adamawa State, Nigeria. *Journal of Environmental and Public Healt*h Volume 2018, Article ID 1854892, 7 pages https://doi.org/10.1155/2018/1854892

Bradl H. (2005). Heavy Metals in the Environment: Origin, Interaction and Remediation. Elsevier/Academic Press. London. p:269.

Canli, M. and Atli, G. (2003). The relationships between heavy metals (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. *Environ. Pollution*, 121: 129-136. https://doi.org/10.1016/S0269-7491(02)00194-X

Chien, L. C., Hung, T. C., Choang, K. Y., Yeh, C. Y., Meng, P. J., Shieh, M. J. and Han, B. C. (2002). Daily intake of TBT, Cu, Zn, Cd and As for fishermen in Taiwan, *Sci. Total Environ*., 285: 177–185. https://doi.org/10.1016/S0048-9697(01)00916-0

Cheung, K., Leung, H. and Wong, M. (2008). Metal concentrations of common freshwater and marine fish from the Pearl River Delta, South China, *Archives of Environmental Contamination and Toxicology*, 54: 705-715. https://doi.org/10.1007/s00244-007-9064-7

Culha, S. T., Yabanli, M., Baki, B., Yozukmaz, A. (2016). Heavy metals in tissues of scorpion fish (*Scorpaena porcus*) caught from Black Sea (Turkey) and potential risks to human health. *Environmental Science and Pollution Research*, 23: 20882–20892. https://doi.org/10.1007/s11356-016-7337-2

De Wet, L. M., Schoonbee, H. J., De Wet, L. P. D. and Wiid, A. J. B. (1994). Bioaccumulation of metals by the southern mouthbrooder, *Pseudocrenilabrus philander* (Weben, 1987) from nine-polluted

impoundment. *Water SA*, 20: 119- 126. https://hdl.handle.net/10520/AJA03784738_1910

El-Moselhy, K. M., Othman, A. I., Abd El-Azem, H., and El-Metwally, M. E. A. (2014). Bioaccumulation of heavy metals in some tissues of fish in the Red Sea, Egypt. *Egyptian Journal of Basic and Applied Sciences,* 1(2): 97–105. https://doi.org/10.1016/j.ejbas.2014.06.001

FAO (1983). Compilation of legal limits for hazardous substances in fish and fishery production," *FAO Fishery Circular*, 764: 5–100. https://www.fao.org/3/q5114e/q5114e.pdf

FAO (2009). *Oreochromis niloticus*. In Cultured aquatic species fact sheets. Text by Rakocy, J. E. Edited and compiled by Valerio Crespi and Michael New. https://www.fao.org/fishery/docs/DOCUMENT/aquaculture/CulturedSpecies/file/en/en_niletilapia.htm

Greenberg, A. E., Trussell, R. R., Clesceri, L. S. (1985). Standard methods for the examination of water and waste water, 16th edition. American Public Health Association, Washington, DC, pp. 146-150.

Hellawell, J. M. (1986). *Biological indicators of freshwater pollution and environmental management.* Elsevier Applied Science Publishers Ltd., London, England. 546 pp.

Ibemenuga, K. N. (2013). Bioaccumulation and toxic effects of some heavy metals in freshwater fishes. *Animal Research International*, 10(3): 1792 – 1798. https://www.ajol.info/index.php/ari/article/view/102740

Idowu, R. T., Inyang, N. M. and Ezenwanji, H. M. G. (2004). Heavy metal concentrations in a west African Sahel Reservoir. *Animal Research International*, 1(1): 12 – 15. https://www.ajol.info/index.php/ari/article/view/40733

IMNA (Institute of Medicine of the National Academics) (2005). Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. National Academic Press. Washington DC. pp 589.

Jobling M. (1995). *Environmental Biology of Fishes*. 1st ed. Printed in Great Britian. Chapman and Hall, London.

Kalay, M. and Canli, M. (2000). Elimination of essential (Cu, Zn) and nonessential (Cd, Pb) metals from tissues of a freshwater fish *Tilapia zillii* following an uptake protocol. *Tr J Zoology*, 24: 429–36. https://journals.tubitak.gov.tr/cgi/viewcontent.cgi?article=2684&context=zoology

Kamaruzzaman, B. Y., Rina, Z., Akbar, B., and Jalal, K. C. A (2011). Heavy metal accumulation in commercially important fishes of southwest Malaysian Coast. *Res. J. Environ. Sci*., 5: 595 – 602. https://scialert.net/abstract/?doi=rjes.2011.595.602

Kent, C. (1998). John Wiley and Sons, New York, USA, Pages: 402. *Basic Toxicology*

Khan, S., Cao, Q., Zheng, Y. M., Huang, Y. Z. and Zhu, Y. G. (2008): Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environmental Pollution*, 152: 686–692. https://doi.org/10.1016/j.envpol.2007.06.056

Kir, I. and Tumantozlu, H. (2012). Investigation of Some Heavy Metal Accumulation in Water, Sediment and Carp (Cyprinus carpio) Samples of Karacaoren-II Dam Lake. *Ekoloji*, 21: 65-70. https://www.semanticscholar.org/paper/Investigation-of-Some-Heavy-Metal-Accumulation-in-Kir-Tumantozlu/d4acb72eb3d4a47d067796406a30a2c69885e0d1

Kortei, N. K., Heymann, M. E., Essuman, E. K., Kpodo, F. M., Akonor, P. T., Lokpo, S. Y., Owusu Boadi, N. O., Ayim-Akonor, M. and Tettey, C. (2020). Health risk assessment and levels of toxic metals in fishes (Oreochromis noliticus and Clarias anguillaris) from Ankobrah and Pra basins: Impact of illegal mining activities on food safety. *Toxicology Reports* 7: 360-369. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7038584/

Landis, W. G. and Yu, M. (2003). Introduction to Environmental Toxicology: Impacts of chemicals upon ecological systems. CRC Press. Boca Raton. Florida. 2003.

Latifah, A. M., Met, L. (2014). An ecological evaluation approach for dam project development in Malaysia. *Life Sci. J.* 11(7): 225–237. http://www.lifesciencesite.com/lsj/life1107/028_23487life110714_225_237.pdf

Li, S. and Zhang, Q. (2010). Risk assessment and seasonal variations of dissolved trace elements and heavy metals in the Upper Han River, China. *Journal of Hazardous Materials*, 181: 1051–1058. https://doi.org/10.1016/j.jhazmat.2010.05.120

Liu, X., Song, Q., Tang, Y., Li, W., Xu, J., Wu, J., Wang, F. and Brookes, P. C. (2013). *Human health risk assessment of heavy metals in soil–vegetable system: A multi-medium analysis. Science of the Total Environment,* 463-464: 530–540. https://doi.org/10.1016/j.scitotenv.2013.06.064

Mansour, S. A. and Sidky, M. M. (2002). Ecotoxicological studies. 3. Heavy metals contaminating water and fish from fayoum Governorate, Egypt. *Food Chem*., 78: 15-22 https://doi.org/10.1016/S0308-8146(01)00197-2

Matthiessen, P. and Brafield, A. E. (1977). Uptake and loss of dissolved zinc by the stickleback *Gasterosteus aculeatus* (L.). *J. Fish Biol*. 10: 399-410. https://doi.org/10.1111/j.1095-8649.1977.tb04071.x

Mayer, W., Kretschmer, M., Hoffmann, A. and Harish, G. (1991). Biochemical and histochemical observations on effects of low level heavy metal load (Lead, Cadmium) in different organ systems of the freshwater crayfish, *Astacus astacus* L. (Crustacea: Decapoda). *Ecotoxicol. Environ. Safe.*, 21: 137-156. https://doi.org/10.1016/0147-6513(91)90016-I

Monroy, M., Maceda-Veiga, A. and de Sostoa, A. (2014). Metal concentration in water, sediment and four fish species from Lake Titicaca reveals a large-scale environmental concern. *Science of the Total Environment*, 487: 233–244. https://doi.org/10.1016/j.scitotenv.2014.03.134

Olagbemide, P. T. and Owolabi, O. (2019). Determination of Water Quality Index and suitability of three major dams in Ekiti State, Nigeria. *Open Access Library Journal, 6: e5719.* https://www.researchgate.net/publication/335742224_Determination_of_Water_Quality_Index_and_Suitability_of_Three_Major_Dams_in_Ekiti_State_Nigeria

Olagbemide, P. T. and Owolabi, O. D. (2022). Prevalence, intensity and influence of size and seasons on parasites of Oreochromis niloticus in Ekiti State Dams, southwest, Nigeria. *ABUAD International Journal of Natural and Applied Sciences*, *2*(2): 123-131. https://doi.org/10.53982/aijnas.2022.0202.010-j

Olaosebikan, B. D. and Raji, A. (2013). *Field guide to Nigerian freshwater fishes*. Revised Edition. Federal College of Freshwater Fisheries Technology. New Bussa. Nigeria. 2013; p. 144.

Orosun, M. M., Tchokossa, P., Orosun, R. O., Akinyose, F. C., Ige, S. O. and Oduh, V. O. (2016). Determination of selected heavy metals and human health risk assessment in fishes from Kiri Dam and River Gongola, Northeastern Nigeria. *J. Phys Chem Biophys*, 6:5 DOI: 10.4172/2161-0398.1000229. https://www.ajol.info/index.php/jonamp/article/view/206938

Otitoloju, A. A. and Don-Pedro, K. N. (2004). Integrated laboratory and field assessments of heavy metals accumulation in edible periwinkle, *Tympanotonus fuscatus* var radula (L.). *Ecotoxicol Environ Saf.*, 57(3): 354-362. https://doi.org/10.1016/j.ecoenv.2003.09.002

Pepper, I. L., Gerba, C. P., and Brusseau, M. L. (2012). Environmental and pollution Science (Pollution Science Series) (pp. 212–232). Academic Press.

Rajeshkumar, S and Li, X. (2018). Bioaccumulation of heavy metals in fish species from the Meiliang Bay, Taihu Lake, China. Toxicology Reports, 5: 288–295. https://doi.org/10.1016/j.toxrep.2018.01.007

Rakocevic, J., la Sukovic, D. and Maric, D. (2018). Distribution and Relationships of Eleven Trace Elements in Muscle of Six Fish Species from Skadar Lake (Montenegro). *Turkish Journal of Fisheries and Aquatic Sciences*, 18: 647-657. https://www.trjfas.org/uploads/pdf_1205.pdf

Saeed, S. M. (2013). Impact of environmental parameters on fish condition and quality in Lake Edku, Egypt. *Egypt. J. Aquat. Biol. Fish*. 17 (1): 101–112. https://www.readcube.com/articles/10.21608%2Fejabf.2013.2160

Saha, N. and Zaman, M. R. (2013). Evaluation of possible health risks of heavy metals by consumption of foodstuffs available in the central market of Rajshahi City, Bangladesh. *Environ Monit Assess*., 185(5): 3867-3878. https://doi.org/10.1007/s10661-012-2835-2

Sauliute, G.and Svecevicius, G. (2017). Heavy metals (Zn, Cu, Ni, Cr, Pb, Cd) in Water and Body Tissues of Young Atlantic SALMON Salmo salar in Two Rivers of Different Pollution Level: A Comparison with Fish Condition Parameters. Fresenius Environmental Bullet, 26(1a): 666673. https://www.researchgate.net/publication/313058145_HEAVY_METALS_Zn_Cu_Ni_Cr_Pb_Cd_IN_WATER_AND_BODY_TISSUES_OF_YOUNG_ATLANTIC_SALMON_Salmo_salar_IN_TWO_RIVERS_OF_DIFFERENT_POLLUTION_LEVEL_A_COMPARISON_WITH_FISH_CONDITION_PARAMETERS

Schuhmacher, M., Domingo, J. L., Corbella, J. and Bosque, M. A. (1992). Heavy metals in marine species from the Terragona Coast, Spain. *J Environ Sci Health*; 27(7): 1939-1948. https://doi.org/10.1080/10934529209375833

Tekin-Ozan, S. and Aktan, N. (2012). Relationship of heavy metals in water, sediment and tissues with total length, weight and seasons of Cyprinus carpioL., 1758 from Isikli Lake (Turkey). *Pakistan journal of zoological*, 44(5): 1405-1416. https://www.zsp.com.pk/pdf44/1405.pdf

Thomas, S. and Mohaideen, J. A. (2015). Determination of some heavy metals in fish, water and sediments from Bay of Bengal. *Int J Chem Sci*., 13: 53-62. https://www.tsijournals.com/articles/determination-of-some-heavy-metals-in-fish-water-and-sediments-from-bay-of-bengal.pdf

Türkmen A, Türkmen M, Tepe Y, Çekiç M (2010) Metals in tissues of fish from Yelkoma Lagoon, northeastern Mediterranean. *Environ Monit. Assess*., 168: 223–230. https://doi.org/10.1007/s10661-009-1106-3

Tuzen, M. (2003). Determination of heavy metals in fish samples of the middle Black Sea (Turkey) by graphite furnace atomic absorption spectrometry. *Food Chem*., 80(1): 119-23. https://doi.org/10.1016/S0308-8146(02)00264-9

Uche, A. O., Sikoki, F. D., Babatunde, B. B., Konya, R. S. and Ifeh, M. O. (2017). Assessing Carcinogenic and other Health Risks Associated with Consuming a Food Fish, *Labeo pseudocoubie*, from the Niger-Benue/Imo River Systems, Nigeria. *J Fisheries Livest Prod* 5: 216 doi: 10.4172/2332-2608.1000216. https://www.omicsonline.org/peer-reviewed/assessing-carcinogenic-and-other-health-risks-associated-with-consuming-a-food-fish-labeo-pseudocoubie-from-the-nigerbenueimo-riv-87636.html

USEPA (1989). Risk Assessment Guidance for Superfund Volume 1 Human Health Evaluation Manual (Part A) (PDF) (EPA/540/1-89/002, 291 pp, 12/1989).

USEPA (2000). Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures. EPA/630/R-00/002. Washington, DC: U.S. Environmental Protection Agency,
Risk Assessment Forum, Office of Research and Development.

USEPA (2015): United States, Environmental Protection Agency, *Integrated Risk Information System*.

Varol, M. and Sünbül, M. R. (2018). Multiple approaches to assess human health risks from carcinogenic and non-carcinogenic metals via consumption of five fish species froma large reservoir in Turkey. Science of the Total Environment, 633: 684–694. https://doi.org/10.1016/j.scitotenv.2018.03.218

Walker, C. H., Hopkin, S. P., Sibly, R. M. and Peakall, D. B. (2006). *Principles of ecotoxicology* (3rd Ed.). New York: Taylor & Francis.

Wang, X., Sato, T., Xing, B. and Tao, S. (2005). Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish, Sci. *Total Environ*. 350: 28–37. https://doi.org/10.1016/j.scitotenv.2004.09.044

Weber, P, Behr, E. R., Knorr, C. D. L., Vendruscolo, D. S., Flores, E. M. M., Dressler, V. L. and Baldisserotto, B. (2013). Metals in the water, sediment and tissues of two fish species from different trophic levels in a subtropical Brazilian river. *Microchem J.*, 106: 61–66. https://doi.org/10.1016/j.microc.2012.05.004

WHO (1989). Heavy metals-environmental aspects. Environment Health Criteria. No. 85. Geneva, Switzerland.

Yi, Y. J. and Zhang, S. H. (2012). The relationships between fish heavy metal concentrations and fish size in the upper and middle reach of Yangtze River. *Procedia Environmental Sciences*, 13: 1699 – 1707. https://doi.org/10.1016/j.proenv.2012.01.163

Yi, Y., Yang, Z. and Zhang, S. (2011). Ecological risk assessment of heavy metals in sediment and: human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin. *Environmental Pollution*, 159, 2575-2585. doi: 10.1016/j.envpol.2011.06.011. https://doi.org/10.1016/j.envpol.2011.06.011

Younis, E. M., Al-Asgah, N. A., Abdel-Warith, A.-W. A., & Al-Mutairi, A. A. (2015). *Seasonal variations in the body composition and bioaccumulation of heavy metals in Nile tilapia collected from drainage canals in Al-Ahsa, Saudi Arabia. Saudi Journal of Biological Sciences,* 22(4): 443–447. **doi:10.1016/j.sjbs.2014.11.020.** https://doi.org/10.1016/j.sjbs.2014.11.020

Yujun, Y., Zhifeng, Y., Shanghong, Z. (2011). Ecological risk assessment of heavy metals in sediment and, Basin. *Journal of Environmental Pollution*, 159: 2575-2585. https://doi.org/10.1016/j.envpol.2011.06.011

Zeitoun, M. M. and Mehana, E. E. (2014). Impact of Water Pollution with Heavy Metals on Fish Health: Overview and Updates. *Global Veterinaria*, 12(2): 219-231. https://www.idosi.org/gv/gv12(2)14/12.pdf

Zyadah, M. A. (1999). Accumulation of some heavy metals in Tilapia zilli organs from Lake Manzalah. Egypt. *Turkish Journal of Zoology*, 23: 365–372. https://journals.tubitak.gov.tr/cgi/viewcontent.cgi?article=2745&context=zoology