POLISH JOURNAL OF NATURAL SCIENCES
Abbrev.: Pol. J. Natur. Sc., Vol 38(1): 51–63, Y. 2023

DOI: 10.31648/pjns.8093

HEAVY METAL CONCENTRATIONS IN THE WATER AND FISH MUSCLES OF LAKES OGELUBE AND OJII IN SOUTHEASTERN NIGERIA

***Oma Judith Ajanwachukwu*[1], *Ikechukwu Eugene Onah*[2], *Patience Obiageli Ubachukwu*[3]**

[1] ORCID: 0009-0000-6457-9128
[2] ORCID: 0000-0002-2101-7894
[3] ORCID: 0009-0003-8268-3561
Department of Zoology and Environmental Biology
University of Nigeria Nsukka, Enugu State, Nigeria

Key words: Fish, heavy metals, pollution, lake, Nigeria.

Abstract

Heavy metal pollution is one major environmental challenge for aquatic ecosystems. Heavy metal pollution of lakes and subsequent accumulation in the tissues of fish inhabiting the lakes impair use of the lake water and constitute a public health hazard for consumers of fish from the lakes. We investigated the concentrations of Chromium (Cr), Copper (Cu), Iron (Fe), Lead (Pb), and Zinc (Zn) in the water and muscles of fish from the Ogelube and Ojii Lakes of Southeastern Nigeria using an Atomic Absorption Spectrometer (AAS). All the heavy metals tested except Cu were detected in both lakes at concentrations exceeding the permissible limits according to WHO. In the Ojii Lake concentrations of tested elements were not significantly higher than in Ogelube Lake, except for Cu and Zn, which were at similar levels in both lakes. Lead (Pb) was not detected in the fish muscles regardless of the lake. In Ogelebu Lake, the concentrations of Fe were significantly higher in *Hepsetus odoe* than *Coptodon zillii* ($p < 0.05$). In Ojii Lake, the concentrations of Cr were significantly higher in *C. zillii* than *H. odoe* while the concentrations of Fe were significantly higher in *H. odoe* than *C. zillii* ($p < 0.05$). All elements tested in fish muscles were at safe levels for human consumption according to FAO.

Introduction

Industrial revolution across the globe has heightened water pollution and good quality water bodies are scarce (EKUBO and ABOWEI 2011, TIWARI 2015). Water pollution has become a major global problem and is worse in developing nations due to lack of surface water quality protection measures and poor sanitation (LONGE and OMOLE 2008). Among water pollut-

Address: Ikechukwu Eugene Onah, University of Nigeria, Nsukka, Enugu State, Nigeria, phone: +2348064618073, e-mail: ikechukwu.onah@unn.edu.ng

ants, heavy metals are of prime concern due to their toxicity and ability to bioaccumulate in the tissues of fish (CENSI et al. 2006). Heavy metals from industrial, agricultural, and domestic sources constitute serious pollutants in aquatic ecosystems and a threat to fish life globally (DIAGOMANOLIN et al. 2004, STORELLI et al. 2005, VOELZ et al. 2005, AKOTO et al. 2008, JIBIRI and ADEWUYI 2008).

Fish can accumulate heavy metals in their tissues and serve as bioindicators of heavy metal contamination in aquatic ecosystems (RASHED 2001, KARADEDE-AKIN and UNLU 2007, SIVAPERUMAL et al. 2007, YILMAZ et al. 2007, LASHEEN et al. 2012, ZHAO et al. 2012, ANNABI et al. 2013). Fish also form a significant proportion of the human diet (RASHED 2001, SIOEN et al. 2007). In Nigeria, fish constitutes approximately 40% of the animal protein in human diets (ATTA et al. 1997). However, bioaccumulation of heavy metals in fishes impair their values to human nutrition and risk the public health (AL-KHATEEB and LEILAH 2005, CASTRO-GONZALEZ and MENDEZ-ARMENTA 2008, HASHIM et al. 2014, BAWURO et al. 2018).

Ogelube and Ojii Lakes are tropical freshwater habitats located at Opi-Agu in the valley of the Uhere River, north-east of Nsukka, Enugu State, Nigeria. Fishes abound in Ogelube and Ojii Lakes (ONAH et al. 2022) and supply the local residents with food. The lakes are surrounded by agricultural lands and important for pastoral activities and sand mining in and around the lakes (ONAH et al. 2022), all of which constitute sources of heavy metals to the lakes. The lakes are the closest waterbodies to the University of Nigeria Nsukka and as a result have been a centre of research from various disciplines interested in freshwater bodies and their biotic community. Several studies have been conducted to evaluate the heavy metal contents of lakes and their fishes across Nigeria (SAMBO et al. 2014, UMUNNAKWE and AHARANWA 2014, JENYO-ONI and OLADELE 2016, ADEBAYO et al. 2017, AYOADE and NATHANIEL 2018, BAWURO et al. 2018, MATOUKE and ABDULLAHI 2020, UTETE and FREGENE 2020). However, despite the anthropogenic activities in and around Ogelube and Ojii Lakes that supply heavy metals to the lakes and the locals depending on the lakes for fish food, no research to the best of our knowledge has been carried out to determine those elements in the water and fish. These knowledge gaps threaten the public health of the locals who consume the fish from the lakes, irrigate their crops with the lake water, and the herds of cattle that regularly drink the lake water. Lack of this knowledge hampers policy advice and public health campaigns of the lakes. Therefore, the objective of this study was to determine the levels of heavy metals in the lake water and major fishes of the lakes.

Materials and Methods

Study area

Opi-Agu Community is situated north-east of the city of Nsukka in Enugu State, Nigeria, between Latitudes 6°42′–6°47′ N and Longitudes 7°28′–7°33′ E. Lake Ojii (6°42′10.7″ N, 7°32′52.9″ E) and Lake Ogelube (6°45′16.12″ N, 7°29′26.9″ E) (Figure 1) are located in the valley of the Uhere River, north-east of Nsukka, Enugu State (OZOKO 2015). The lakes do not have permanent rivers feeding into them. Sources of water to the lakes are groundwater, rainfall, and runoff from farmlands, and during the wet season the lakes overflow through the sloping northern end.

Collection of water samples

The two lakes were each divided into three stations, based on natural features of the lakes. For Lake Ojii, Station 1 was situated at the shallow end of the lake, with limited vegetation cover and runoff during heavy rainfall. Station 2 had extensive vegetation cover and was located between Station 1 and 3. Station 3 was in the middle of the lake, had no vegetation cover and was exposed to direct sunlight. For Lake Ogelube, Station 1 was situated at the southern or overflow end of the lake with good vegetation cover, shade, and runoff during heavy rainfall. Station 2 was situated in the middle of the lake with less vegetation cover and less shade than Station 1. Station 3 was situated at the northern end of the lake and had no vegetation cover or shade.

Water samples were collected from Ogelube and Ojii Lakes monthly for six months from June to December 2018. Water samples were collected from each sampling station using 150 ml plastic containers. The containers were washed with nitric acid and dried to remove any contaminants. The water samples were transported and analysed separately for heavy metals immediately at the Energy Research Centre Laboratory, University of Nigeria Nsukka. In total eighteen water samples were collected for six months from each lake.

Fish collection and identification

Two species of fish, *Coptodon zillii* and *Hepsetus odoe,* were selected for analysis of heavy metal accumulation in the muscles. *Coptodon zillii* was chosen because it is the most abundant fish in the lakes and an omnivore, while *Hepsetus odoe* was chosen because it is a carnivore and the most preferred fish by consumers, both fishes are of commercial value to the locals.

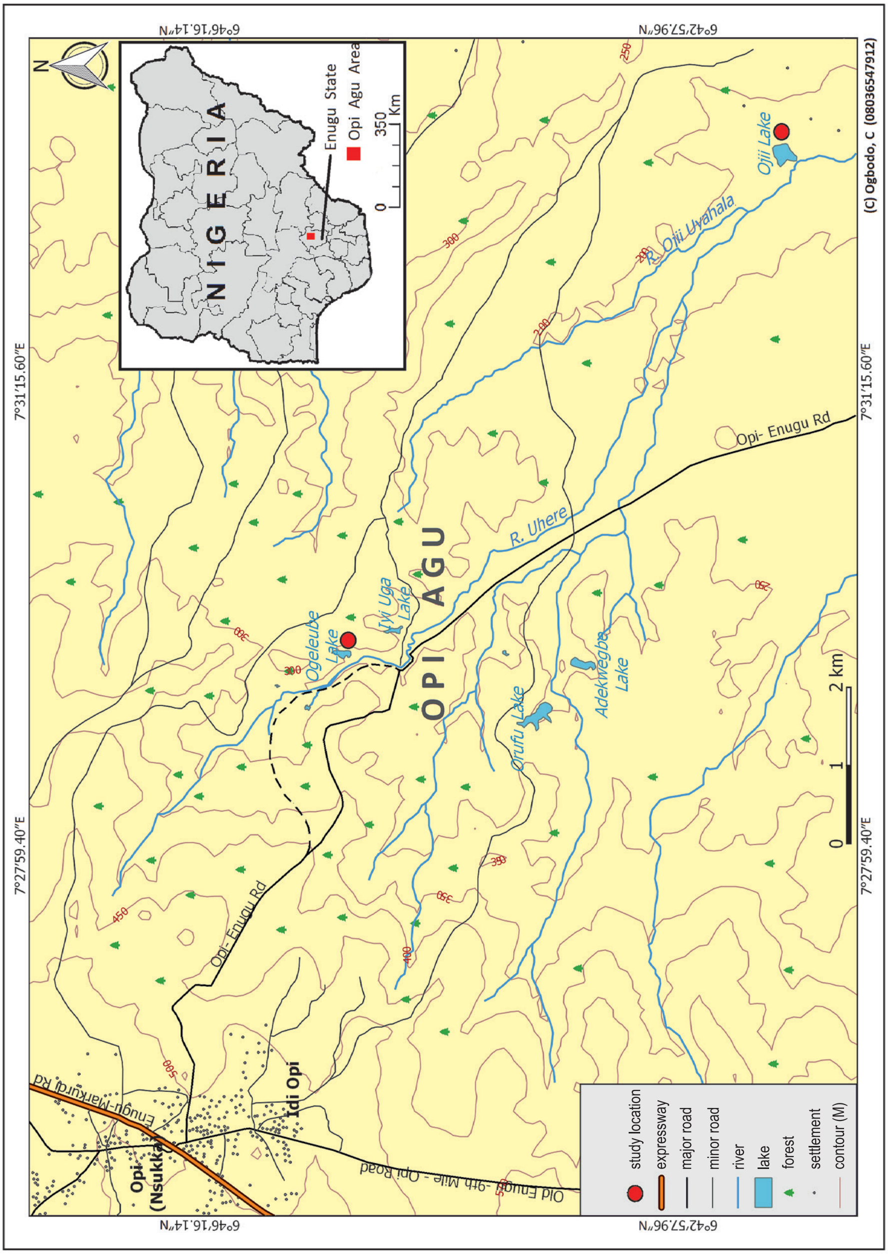

Fig. 1. Map of the Opi Agu Community, showing the study locations – Ogeleube and Oji Lakes

Fishes were collected using a cast net with a 30–80 mm stretched mesh. For each lake, two adult fishes (1 each for *C. zillii* and *H. odoe*) were collected each month for 6 months (June – August; October – December). The mean total length (TL) of the fishes were 14.20 ±2.37 cm for *C. zillii* and 17.57 ±0.74 for *H. odoe*. Twenty-four (24) fishes were analyzed in total, 12 for each species. Thereafter, they were euthanized by severing the spinal cord, labeled, and placed in sealed plastic bags in a cooler pack containing ice and immediately taken to the Energy Research Center Laboratory, University of Nigeria Nsukka for analysis. The fishes were identified using keys by BABATUNDE and AMINU (2004) and the identities further confirmed by a fishery biologist in the Department of Zoology and Environmental Biology, University of Nigeria Nsukka.

Determination of heavy metals in the water

Heavy metals including: Chromium (Cr), Copper (Cu), Iron (Fe), Lead (Pb) and Zinc (Zn) were analyzed in this study. The concentrations of heavy metals in each water sample were determined using an Atomic Absorption Spectrometer (AAS). A sample of 1 ml from each of the water samples was measured into a digestion flask and 30 cm^3 of aqua regia added and digested in a fume-cupboard until a clear solution was obtained. Thereafter, the solution was cooled, filtered, and made up to 50 ml in a standard volumetric flask with deionized water. A blank sample was prepared to zero the AAS; an instrument used for the analysis before re-running other series of samples. Standards (2 ppm, 4 ppm, and 6 ppm) were prepared from a 1000 ppm stock solution of the metals and used to plot the calibration curve. The calibration curve was plotted automatically by the instrument using the formula:

$$C_1 \cdot V_1 = C_2 \cdot V_2,$$

where:
C_1 = 1000 ppm
C_2 = 2 ppm.

A volume of 0.2 ml was pipetted from the 1000 ppm solution, put into a 100 ml flask and diluted to the mark with deionized water. These procedures were used in the preparation of 4 ppm and 6 ppm solutions. High temperatures produced in the ignition chamber provided enhanced reduced settings for atomization of the heavy metals. Each standard was aspirated with an aspirator by nebulizer; converted into an aerosol, mixed with the glass, and converted into atomic form. All the standard solutions were analyzed, and the calibration curve plotted automatically for the metals of interest. Each metal was analyzed with the standard using adequate wavelengths after which its concentration was generated automatically by the instrument. The heavy metal concentrations of the three sampled stations for each month were averaged and the results presented as Mean ± SE.

Determination of heavy metals in fishes

Samples of fresh fishes were washed under tap water and drained. Thereafter, the muscles of the fishes were removed using a sharp knife. The muscles were chosen for heavy metal analysis because they are the most edible part of the fish (Keskin et al. 2007, Hashim et al. 2014). Fleshes were dried to a constant weight in an oven at 105°C, grounded to powder using a ceramic mortar and pestle then sieved through a 20 µm mesh according to Sambo et al. (2014). Thereafter, 1.0 g each of the dry and ground fish samples were digested in 10 cm^3 concentrated nitric acid. The digestates were diluted with 1% HCl. Concentrations of the heavy metals were determined by AAS (APHA 1998). Heavy metal determinations were replicated 3 times for *Coptodon zillii* and *Hepsetus odoe* for each lake. The concentrations of the heavy metals in each fish species were averaged and results presented as Mean ± SE.

Statistical analysis

Data were analysed using Statistical Packages for Social Sciences (SPSS) (version 21.0, IBM Corporation, Armonk, USA) and Paleontological Statistics (PAST) software version 3.21 (Hammer et al. 2001). Heavy metal concentrations of the water bodies were not normally distributed, so the spatiotemporal properties of the water bodies were compared using the Mann–Whitney *U*-tests and Kruskal–Wallis *H*-tests.

Results

Heavy metal concentrations in the Ogelube and Ojii Lakes

Heavy metals fluctuated in water samples across the months studied. In Ogelube Lake, the concentrations of Cu were significantly higher in July than June and October ($p = 0.0112$, $n = 54$, Table 1). Similarly, the concentrations of Fe were significantly higher in July than June, November and December ($p = 0.0045$, $n = 54$, Table 1). In Ojii Lake the concentrations of Fe in July were significantly higher than the rest of the months ($p = 0.0001$, $n = 54$, Table 2). Concentrations of heavy metals were higher in Ojii Lake than Ogelube Lake except for Cu and Zn, which were similar in both lakes. However, detected differences in the concentrations of the studied elements were not statistically significant (Table 3).

Table 1

Monthly variations in heavy metal concentrations in Ogelube, Opi Lake [mg/l]

Metal	June	July	August	October	November	December
Cr	0.04 ±0.03^{a}	0.04 ±0.02^{a}	0.04 ±0.02^{a}	0.05 ±0.02^{a}	0.07 ±0.04^{a}	0.03 ±0.03^{a}
Cu	0.02 ±0.01^{a}	0.06 ±0.01^{b}	0.03 ±0.00^{ab}	0.01 ±0.01^{ca}	0.04 ±0.01^{ab}	0.03 ±0.01^{ab}
Fe	0.38 ±0.07^{a}	0.79 ±0.11^{b}	0.57 ±0.13^{ab}	0.69 ±0.04^{ab}	0.39 ±0.08^{a}	0.40 ±0.08^{a}
Pb	0.06 ±0.04^{a}	0.11 ±0.06^{a}	0.25 ±0.07^{a}	0.08 ±0.04^{a}	0.08 ±0.04^{a}	0.08 ±0.04^{a}
Zn	0.07 ±0.04^{a}	0.06 ±0.01^{a}	0.11 ±0.04^{a}	0.04 ±0.01^{a}	0.03 ±0.01^{a}	0.03 ±0.01^{a}

Means of heavy metals in a row across the months with different superscripts are significantly different ($p < 0.05$).

Table 2

Monthly variations in heavy metal concentrations in Ojii, Opi Lake [mg/l]

Metal	June	July	August	October	November	December
Cr	0.10 ±0.03^{a}	0.02 ±0.01^{a}	0.08 ±0.06^{a}	0.04 ±0.01^{a}	0.22 ±0.11^{a}	0.15 ±0.10^{a}
Cu	0.01 ±0.00^{a}	0.03 ±0.01^{a}	0.05 ±0.01^{a}	0.01 ±0.01^{a}	0.05 ±0.02^{a}	0.03 ±0.02^{a}
Fe	0.32 ±0.07^{a}	1.19 ±0.09^{b}	0.52 ±0.10^{a}	0.51 ±0.09^{a}	0.46 ±0.06^{a}	0.40 ±0.03^{a}
Pb	0.14 ±0.04^{a}	0.22 ±0.05^{a}	0.17 ±0.04^{a}	0.14 ±0.04^{a}	0.08 ±0.04^{a}	0.11 ±0.04^{a}
Zn	0.02 ±0.00^{a}	0.14 ±0.04^{a}	0.08 ±0.04^{a}	0.02 ±0.01^{a}	0.03 ±0.01^{a}	0.09 ±0.05^{a}

Means of heavy metals in a row across the months with different superscripts are significantly different ($p < 0.05$).

Table 3

Mean heavy metal contents in water samples of Ogelube and Ojii Lakes compared with the literature data

Lakes	Cr [mg/l]	Cu [mg/l]	Fe [mg/l]	Pb [mg/l]	Zn [mg/l]	References
Ogelube	0.05	0.03	0.54	0.11	0.06	present study
Ojii	0.10	0.03	0.56	0.14	0.06	present study
Oguta*	0.03–0.87	0.26–1.80	0.30–4.75	0.00–0.05	–	UMUNNAKWE and AHARANWA (2014)
Ibrahim Adamu	3.35	0.75	–	0.81	1.64	SAMBO et al. (2014)
Man-made Ibadan	0.01	0.05	0.81	0.08	–	AYOADE and NATHANIEL (2018)
Asejire	–	–	0.01	0.015	–	JENYO-ONI and OLADELE (2016)
Oguta	–	–	0.17	–	–	ADEBAYO et al. (2017)
Asejire	–	–	0.02	0.05	–	OLADELE et al. (2018)
Permissible values	0.05	2.00	0.50	0.01	0.05	WHO (2011)

* Only ranges are available; (–) not analysed.

Seasonal variations in heavy metal concentrations of Ogelube and Ojii Lakes

The heavy metal contents of Ogelube and Ojii lakes varied between the seasons. In Ogelube Lake, only Zn was significantly higher in the wet season than the dry season ($p < 0.05$, Table 4) while in Ojii Lake, only Fe was significantly higher in the wet season than the dry season ($p < 0.05$, Table 4).

Table 4

Seasonal variations in heavy metal concentrations in the studied Lakes

Element	Ogelube Lake			Ojii Lake		
	wet season [mg/l]	dry season [mg/l]	*p*-value	wet season [mg/l]	dry season [mg/l]	*p*-value
Cr	0.04 ±0.01	0.05 ±0.02	0.64	0.07 ±0.02	0.14 ±0.05	0.21
Cu	0.04 ±0.01	0.03 ±0.01	0.30	0.03 ±0.01	0.03 ±0.01	1.00
Fe	0.58 ±0.07	0.50 ±0.05	0.32	0.67 ±0.09	0.45 ±0.04	**0.02***
Pb	0.14 ±0.04	0.08 ±0.02	0.20	0.18 ±0.03	0.11 ±0.02	0.07
Zn	0.08 ±0.02	0.04 ±0.00	**0.03***	0.08 ±0.02	0.05 ±0.02	0.25

* *p*-values < 0.05 indicate significant difference between wet and dry seasons.

Concentrations of heavy metals in fish muscles

In Ogelube Lake, the concentrations of Fe were significantly higher in *H. odoe* than *C. zillii* ($P < 0.05$, Table 5). In Ojii Lake, the concentrations of Cr were significantly higher in *C. zillii* than *H. odoe,* while the concentrations of Fe were significantly higher in *H. odoe* than *C. zillii* ($P < 0.05$, Table 5).

Table 5

Concentration of heavy metals in fish muscles [mg/kg dry weight]

Element	Ojii Lake			Ogelube Lake			FAO (1989)
	fish species		*p*-values	fish species		*p*-values	
	Coptodon zillii	*Hepsetus odoe*		*Coptodon zillii*	*Hepsetus odoe*		
Cr	0.23 ±0.01	0.06 ±0.00	<0.01*	0.25 ±0.06	0.25 ±0.01	1.00	0.50
Cu	0.20 ±0.01	0.19 ±0.01	0.67	0.14 ±0.01	0.17 ±0.02	0.32	30.00
Fe	0.13 ±0.01	0.24 ±0.00	<0.01*	0.17 ±0.01	0.24 ±0.02	**0.02***	–
Pb	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	0.50
Zn	0.18 ±0.00	0.28 ±0.01	0.15	0.18 ±0.00	0.22 ±0.04	0.30	30.00

***** *p*-values < 0.05 indicate significant difference between *Coptodon zellii* and *Hepsetus odoe*

Discussion

The heavy metals: chromium, copper, iron, lead, and zinc were detected in the Ogelube and Ojii Lakes. The values of 0.05 mg/l and 0.1 mg/l recorded for Cr in Ogelube and Ojii lakes respectively in this study are lower than 0.87 mg/l in Oguta Lake and 3.35 mg/l in Ibrahim Adamu Lake but higher than 0.01 mg/l in Man-made Lake in Ibadan. In the Ogelube Lake Cr was at the WHO (2011) permissible value of 0.05 mg/l, while in the Ojii Lake Cr at a value of 0.10 ± 0.03 mg/l exceeded the permissible value (Table 3). The concentrations of Pb in both lakes are higher than the values recorded in Oguta Lake, Man-made Lake in Ibadan and Lake Asejire but lower than the values recorded in Ibrahim Adamu Lake (Table 3). Both studied lakes were polluted by Fe, Pb, and Zn. The mean values recorded for these elements slightly exceeded the permissible values established by WHO (2011) – Table 3. Heavy metal pollution in the lakes may be the result of agricultural runoff and domestic wastes washed down into the lakes (SIVALINGAM et al. 2021, SOJKA et al. 2022). Runoff during the rainy season from agricultural lands into the lakes probably affected significantly higher concentrations of Fe and Zn, respectively in Lakes Ojii and Ogelube, in the wet than the dry seasons (Table 4).

Concentrations of Cr in the fish muscles ranged from 0.06 mg/kg in *H. odoe* from Ojii Lake to 0.25 mg/kg in *H. odoe* from Ogelube. The values of Cr in the fish muscles were higher than 0.0038 mg/kg recorded by JENYO-ONI and OLADELE (2016) in Lake Asejire, Oyo State, Nigeria from a related species of tilapia (*Oreochromis niloticus*). In Oguta Lake, Imo State, Nigeria, UMUNNAKWE and AHARANWA (2014) did not detect Cr in *Tilapia* sp. However, the values of Cr in the fish muscles were lower than 2.77 mg/kg recorded by SAMBO et al. (2014) in Ibrahim Adamu Lake, Jigawa State, Nigeria for tilapia species (*O. niloticus*). The fish muscles are not considered polluted with Cr because the mean values recorded are lower than the 0.05 mg/kg permissible limit determined by FAO (1989) – Table 5.

The lowest and highest concentrations of Cu were recorded in muscles of *C. zillii* and ranged from 0.14 mg/kg in Ogelube to 0.20 mg/kg in Ojii Lake. These values are visibly higher than 0.07 mg/kg recorded by UMUNNAKWE and AHARANWA (2014) for *Tilapia* sp. in Oguta Lake, Imo State, Nigeria, but lower than 0.30 mg/kg recorded by SAMBO et al. (2014) in tilapia fish (*O. niloticus*) from Ibrahim Adamu Lake, Jigawa State, Nigeria and with ranges of 0.15–11.27 mg/kg recorded by BAWURO et al. (2018) for the flesh of tilapia fish from lake Geriyo, Adamawa State, Nigeria. The values of Cu recorded in the lakes in this study are lower than the maximum permissible value of 30.00 mg/kg given by FAO (1989) – Table 5.

The concentrations of Fe in the fish muscle ranged from 0.13 mg/kg in *C. zillii* from Ojii Lake to 0.24 mg/kg in *H. odoe* from Ojii Lake. These values are lower than 21.17 mg/kg recorded by UMUNNAKWE and AHARANWA (2014) in the muscle of tilapia fish from Oguta Lake, Imo State, Nigeria, and 7.43 mg/kg recorded by JENYO-ONI and OLADELE (2016) and OLADELE et al. (2018) for tilapia fish (*O. niloticus*) from Lake Asejire, Oyo State, Nigeria.

Pb was not found in the muscles of fish from either lake. This observation agrees with the findings of UMUNNAKWE and AHARANWA (2014) who did not detect Pb in the muscles of *Tilapia* sp. from Oguta Lake, Imo State, Nigeria. However, SAMBO et al. (2014), JENYO-ONI and OLADELE (2016), BAWURO et al. (2018) and OLADELE et al. (2018) recorded Pb values of 0.27 mg/kg, 0.05 mg/kg, 0.01–3.78 mg/kg and 0.05 mg/kg, respectively in tilapia (*O. niloticus*) from lakes in different parts of Nigeria.

The concentrations of Zn in the fish muscles ranged from 0.18 mg/kg in *C. zillii* from both lakes to 0.28 mg/kg in *H. odoe* from Ojii lake. These values are lower than 0.87 mg/kg and in the range 4.48–5.06 mg/kg recorded by SAMBO et al (2014) and BAWURO et al. (2018) in the muscles of tilapia (*O. niloticus*) from Ibrahim Adamu Lake, Jigawa State, Nigeria and Lake Geriyo, Adamawa State, Nigeria, respectively. The mean values of zinc recorded in the fishes from both lakes were lower than 30.00 mg/kg, which is the permissible limit recommended by FAO (1989) – Table 5.

Conclusions

This study provides baseline data on the status of several heavy metal elements in the Ogelube and Ojii lakes and fishes inhabiting these lakes. Lakes Ogelube and Ojii are polluted with heavy metals, but the fish are safe for consumption because the concentrations of the heavy metals in the muscles of the fish are lower than the maximum permissible limit as determined by the World Health Organization. Consuming fish from these lakes does not pose a public health risk from heavy metal contamination to the local residents. However, the lakes may be a health risk to herds of cattle that constantly drink the lake water. In addition, the use of the lake water to irrigate crops in the nearby farmlands may lead to accumulation of heavy metals in cultivated crops. Activities that add heavy metals to the lakes such as use of chemical pesticides in the nearby farmlands and dumping of refuse into the lakes should be discouraged to minimize further contamination of the lakes with heavy metals.

Acknowledgements

We wish to express our profound gratitude to Dr Chika Ikele, Mr Godwin Nwosu and Mr Oscar Aguzie of the Department of Zoology and Environmental Biology, University of Nigeria Nsukka for their assistance during field and laboratory work. We are also grateful to Prof. DeMar Taylor for providing the English editing service.

Accepted for print 27.06.2023

References

Adebayo E.T., C-oluwatosin T.J., Nneji P.C. 2017. *Limnological assessment of heavy metals concentration in water and sediment of Oguta Lake, South-East Nigeria.* Nigeria Int. J. Innov. Stud. Aquat. Biol. Fish., 3(3): 18–22.

Akoto O., Bruce T.N., Darko G. 2008. *Heavy metals pollution profiles in streams serving the Owabi reservoir. Afr. J. Environ. Sci. Technol.*, 2(11): 354–359.

Al-Khateeb S.A., Leilah A.A. 2005. *Heavy metals accumulation in the natural vegetation of Eastern province of Saudi Arabia.* J. Biol. Sci., 5: 707–712.

Annabi A., Said K., Messaoudi I. 2013. *Cadmium: bioaccumulation, histopathology and detoxifying mechanisms in fish.* Am. J. Res. Commun., 1(4): 62.

Apha 1998. *Standard methods for the examination of water and wastewater 20th edition.* American Public Health Association, American Water Work Association, Water Environment Federation, Washington, DC.

Atta M.B., Els-Ebale L.A., Naoman M.A., Kassab H. 1997. *The effect of cooking on the content of heavy metals in fish (Tilapia nilotica).* Food Chem., 58: 1–4.

Ayoade A.A., Nathaniel O.G. 2018. *Assessment of heavy metals contamination of surface water and sediment of a tropical manmade lake southwestern Nigeria.* International Journal of Environment and Pollution Research, 6(3): 1–16.

Babatunde D.O., Aminu R. 2004. *Field guide to Nigerian freshwater fishes, 2nd Edition.* Federal College of Freshwater Fisheries Technology, New Bussa, Nigeria.

Bawuro A.A., Voegborlo R.B., Adimado A.A. 2018. *Bioaccumulation of heavy metals in some tissues of fish in Lake Geriyo, Adamawa State, Nigeria.* J. Environ. Public Health, doi: 10.1155/2018/1854892.

Castro-Gonzalez M.I., Mendez-Armenta M. 2008. *Heavy metals: implications associated to fish consumption.* Environ. Toxicol. Pharmacol., 26: 263–271.

Censi P., Spoto S.E., Saiano F., Sprovieri M., Mazzola S. 2006. *Heavy metals in coastal water system, a case study from North Western Gult of Thailand.* Chemosphere, 64(1): 1167–1176.

Diagomanolin V., Farhang M., Jafarzadeh N. 2004. *Heavy metals in the Karoon Waterway River, Iran.* Toxicol. Lett., 15: 63–68.

Ekubo A.T., Abowei J.F.N. 2011. *Aspects of aquatic pollution in Nigeria.* Research Journal of Environmental and Earth Sciences., 3(6): 673–693.

Fao 1989. *Evaluation of certain food additives and the contaminants mercury, lead and cadmium;* WHO Technical Report Series No. 505.

Hammer O., Harper D.A.T., Ryan P.D. 2001. PAST: *Paleontological Statistics Software Package for Education and Data Analysis.* Palaeontol. Electron., 4: 9, http://palaeo-electronica.org/2001_1/past/issue1_01.htm, access: ?

Hashim R., Song T.H., Muslim N.Z.M., Yen T.P. 2014. *Determination of heavy metal levels in fishes from the lower reach of the Kelantan River, Kelantan, Malaysia.* Trop. Life Sci. Res., 25(2): 21–39.

Jenyo-Oni A., Oladele A.H. 2016. *Heavy metals assessment in water, sediments and selected aquatic organisms in Lake Asejire, Nigeria*. Eur. Sci. J., 12(24), doi: 10.19044/esj.2016. v12n24p339.

Jibiri N.N., Adewuyi G.O. 2008. *Radionuclide contents and physico-chemical characterization of solid waste and effluent samples of some selected industries in the city of Lagos, Nigeria*. Radioprotection, 43(2): 203–212, doi: 10.1051/radiopro:2007053.

Karadede-Akin H., Unlu E. 2007. *Heavy metal concentrations in water, sediment, fish and some benthic organisms from Tigris River, Turkey*. Environ. Monit. Assess., 131: 323–337.

Keskin Y., Baskaya R., Ozyaral O., Yurdun T., Luleci N., Hayran O. 2007. *Cadmium, lead, mercury and copper in fish from the Marmara Sea, Turkey*. Bull. Environ. Contam. Toxicol., 78: 258–261.

Lasheen M.R., Abdel-Gawad F.K., Alaneny A.A., El-Bary H.M.H.A. 2012. *Fish as bio indicators in aquatic environmental pollution assessment: a case study in Abu-Rawash area, Egypt*. World Appl. Sci. J., 19(2): 265–275.

Longe E.O., Omole D.O. 2008. *Analysis of pollution status of river Illo, Ota Nigeria*. Environmentalist, 2(3): 34–39.

Matouke M.M., Abdullahi K.L. 2020. *Assessment of heavy metals contamination and human health risk in Clarias gariepinus [Burchell, 1822] collected from Jabi Lake, Abuja, Nigeria*. Sci. Afr. 7 e00292, doi: 0.1016/j.sciaf.2020.e00292.

Oladele A.H., Digun-Aweto O., Jenyo-Oni A. 2018. *The relationship between iron, lead and cobalt content in water, sediments, Nile tilapia and African river prawn of lake Asejire, Nigeria*. Pol. J. Natur. Sc., 33(3): 417–432.

Onah I.E., Ajanwachukwu O.J., Ubachukwu P.O. 2022. *Comparison of physico-chemical parameters with macroinvertebrate and vertebrate fauna of Lake Ogelube and Lake Ojii, Opi-Agu, south-eastern Nigeria*. Afr. J. Aquat. Sci., doi: 10.2989/16085914.2022.2080174.

Ozoko D.C. 2015. *Hydrochemistry of lakes in Opi Agu, Enugu state, southeastern Nigeria*. International Journal of Science and Technology, 4(7): 304–311.

Rashed M.N. 2001. *Monitoring of environmental heavy metals in fish from Nasser Lake*. Environ. Int., 27: 27–33.

Sambo F., Haruna M., Idris S., Moha S., Nasir A. 2014. *Assessment of heavy metals in water and fish from Ibrahim Adamu Lake, Jigawa, Nigeria. Trends Appl. Sci. Res.*, 9(10): 603–606.

Sioen I., De Henauw S., Verdonck F., Thuyne N. van, Camp J. van. 2007. *Development of a nutrient database and distributions for use in a probabilistic risk-benefit analysis of human seafood consumption*. J. Food Compost. Anal., 20: 662–670.

Sivalingam P., Al Salah D.M., Poté J. 2021. *Sediment heavy metal contents, ostracod toxicity and risk assessment in tropical freshwater lakes, Tamil Nadu, India*. Soil Sediment. Contamin., 30(2): 231–252, doi: 10.1080/15320383.2020.1835822.

Sivaperumal P., Sankar T.V., Nair P.G.V. 2007. *Heavy metal concentrations in fish, shellfish and fish products from internal markets of India vis-a-vis international standards*. Food Chem., 102: 612–620.

Sojka M., Jaskuła J., Barabach J., Ptak M., Zhu S. 2022. *Heavy metals in lake surface sediments in protected areas in Poland: concentration, pollution, ecological risk, sources and spatial distribution*. Sci. Rep., 12: 15006, doi: 10.1038/s41598-022-19298-y.

Storelli M.M., Storelli A., D'addabbo R., Marano C., Bruno R., Marcotrigiano G.O. 2005. *Trace elements in loggerhead turtles (Caretta caretta) from the eastern Mediterranean Sea: overview and evaluation*. Environ Pollut., 35(1): 163–70, doi: 10.1016/j.envpol.2004.09.005.

Tiwari S. 2015. *Water quality parameter. A Review*. International Journal of Engineering Science Invention, Research and Development,1(9): 319–324.

Umunnakwe J.E., Aharanwa B.C. 2014. *Assessment of water quality and heavy metal levels of fish species in Oguta Lake, Imo State Nigeria*. J. Nat. Sci. Res., 4(8): 103–112.

Utete B., Fregene B.T. 2020. *Heavy metal concentrations in surface water, sediments and fish and their potential toxicity in highly degraded multipurpose periurban Eleyele Lake, Ibadan City, Oyo State, south-western Nigeria*. Cogent Environ. Sci., 6:1, 1785137, doi: 10.1080/23311843.2020.1785137.

VOELZ J.N., ZUELLIG S.S., WARD J.V. 2005. *Effects of urban areas on benthic macroinvertebrates in two Colorado Plain Rivers*. Environ. Monit. Assess.,101(4): 175–202.

WHO. 2011. *Guidelines for drinking-water quality*. Fourth Edition. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://apps.who.int/iris/bitstream/handle/10665/44584/9789241548151_eng.pdf, access: ?

YILMAZ F., OZDEMIR N., DEMIRAK A., TUNA A.L. 2007. *Heavy metal levels in two fish species Leuciscus cephalus and Lepomis gibbosus*. Food Chem., 100: 830–835.

ZHAO S., FENG C., QUAN W., CHEN X., NIU J., SHEN Z. 2012. *Role of living environments in the accumulation characteristics of heavy metals in fishes and crabs in the Yangtze River Estuary, China*. Mar. Pollut. Bull., 64: 1163–1171.