

ASSESSMENT OF CADMIUM AND LEAD LEVELS IN SELECTED FISH SAMPLES FROM IKPOBA RIVER, BENIN CITY, NIGERIA

^{1,2}Enuneku, A., ^{1,2}Ogbomida, E., ^{*}¹Izebere, B. and ¹Omeni, E.

¹Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, PMB 1154, Benin City, Nigeria.

²Laboratory for Ecotoxicology and Environmental Forensics, University of Benin, PMB 1154, Benin City, Nigeria.

*Corresponding author Email: izeberebright@gmail.com



ABSTRACT

Heavy metal contamination of aquatic ecosystems poses significant ecological and public health challenges. Hence, this study assessed the concentrations of cadmium (Cd) and lead (Pb) in two fish species (*Clarias gariepinus* and *Parauchenoglanis fasciatus*) collected from Ikpoba River, Benin City, Nigeria, and evaluated the associated health risks from their consumption. Fish samples were measured, weighed, oven-dried, homogenized, and digested using perchloric acid before analysis with Atomic Absorption Spectrophotometry (AAS). The mean concentrations of Cd and Pb in *C. gariepinus* were 0.0025 mg/kg and 0.0125 mg/kg, respectively, while *P. fasciatus* contained 0 mg/kg Cd and 0.01 mg/kg Pb. Statistical analysis revealed no significant difference ($p > 0.05$) in metal concentrations between species. Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Carcinogenic Risk (CR) values for both metals were below the recommended safety limits, indicating no immediate non-carcinogenic or carcinogenic risks to consumers. The concentrations observed were lower than permissible limits set by the World Health Organization (WHO) and Food and Agriculture Organization (FAO) suggesting that fish from Ikpoba River are currently safe for consumption. However, continuous monitoring is essential due to the river's exposure to anthropogenic activities. This study provides valuable baseline data for environmental quality assessment, public health protection, and sustainable management of aquatic resources in Edo State and similar freshwater ecosystems in Nigeria.

Keywords: Heavy metal, Health risk, Fish, Concentration, Hazard quotient, bioaccumulation

INTRODUCTION

The contamination of freshwater systems by heavy metals remains one of the most critical environmental issues globally. Industrialization, urbanization, and agricultural activities have led to the release of toxic elements into aquatic environments, threatening the ecological balance and public health (Ashraf and

Maah, 2012; Ahmed *et al.*, 2015). Heavy metals such as cadmium (Cd) and lead (Pb) are of particular concern because they are non-biodegradable, persistent and capable of bioaccumulating in aquatic organisms (Islam *et al.*, 2015).

Fish species are at the top of the aquatic food chain and heavy metals bioaccumulate in the organs of fish species and are

biomagnified in humans when consumed. Essential elements are required in biological systems for growth and other functions but higher excessive concentrations of these essential elements can become toxic to living organisms and the environment. The non-essential metals such as nickel, cadmium and lead are highly toxic in trace amounts in biological systems (Bassey and Chukwu, 2019).

Fish is a central constituent of balanced diet which provides nutrients to humans who consume them (Parida *et al.*, 2017). Regular consumption of fish can reduce several illnesses such as stroke and asthma (Oyewole and Amosu, 2012). Fish metabolism can accumulate heavy metals from sediments, water and food (Yilmaz *et al.*, 2017). Heavy metals are accumulated in fish by absorption in marine ecosystems through their gills as well as ingestion of contaminated food (Miri *et al.*, 2017).

The accumulation of heavy metals in organs and tissues of fish may cause adverse health effects through consumption of fish (Hao *et al.*, 2013). Therefore, different types of fishes are used as biomarkers to study accumulation of heavy metals in marine environments (Muiruri *et al.*, 2013). Exposure to Cd and Pb poses severe health risks, including renal dysfunction, hematological disorders, neurotoxicity, and carcinogenic effects (Han and Pan, 2021). Therefore, monitoring the levels of these metals in fish consumed by local populations is essential for assessing potential human health risks.

The Ikpoba River in Benin City, Edo State, Nigeria, is a significant inland water body that supports domestic, agricultural and recreational activities. However, the river receives effluents from nearby industrial and residential areas, which may contribute to heavy metal contamination (Ekhaise and

Anyasi, 2005; Tawari-Fufeyin and Ekaye, 2007). Despite its ecological and socioeconomic importance, there is limited current information on the concentration of toxic metals in fish species from this river and their potential health implications for consumers. Therefore, this study aims to determine the concentrations of cadmium (Cd) and lead (Pb) in two commonly consumed fish species; *Clarias gariepinus* and *Parauchenoglanis fasciatus* from Ikpoba River, Benin City; evaluates the potential non-carcinogenic and carcinogenic health risks associated with their consumption.

The findings will provide baseline data on heavy metal contamination in the river ecosystem and contribute to environmental monitoring, food safety policy and public health protection in Edo State and similar aquatic environments in Nigeria.

MATERIALS AND METHODS

Study Area

This study was carried out in Ikpoba River, an inland freshwater River in Benin City, Edo State, Nigeria. It is a fourth order stream surrounded on both sides by the sloppy terrain of Ikpoba slope (Victor and Ogbeibu, 1985). The river flows through dense rainforest and empties into the Benin River (Ekhaise and Anyasi, 2005) where the deposits of organic matter from the surrounding vegetation are derived through run-off from the surface of the soil (Tawari-Fufeyin and Ekaye, 2007). Vegetation around the river comprises of bamboo trees (*Bambusa vulgaris*), rubber plant (*Hevea brasiliensis*), in addition to several herbaceous plants (Tawari-Fufeyin and Ekaye, 2007), most of which have been lost due to massive deforestation for agricultural

activities and other anthropogenic activities.

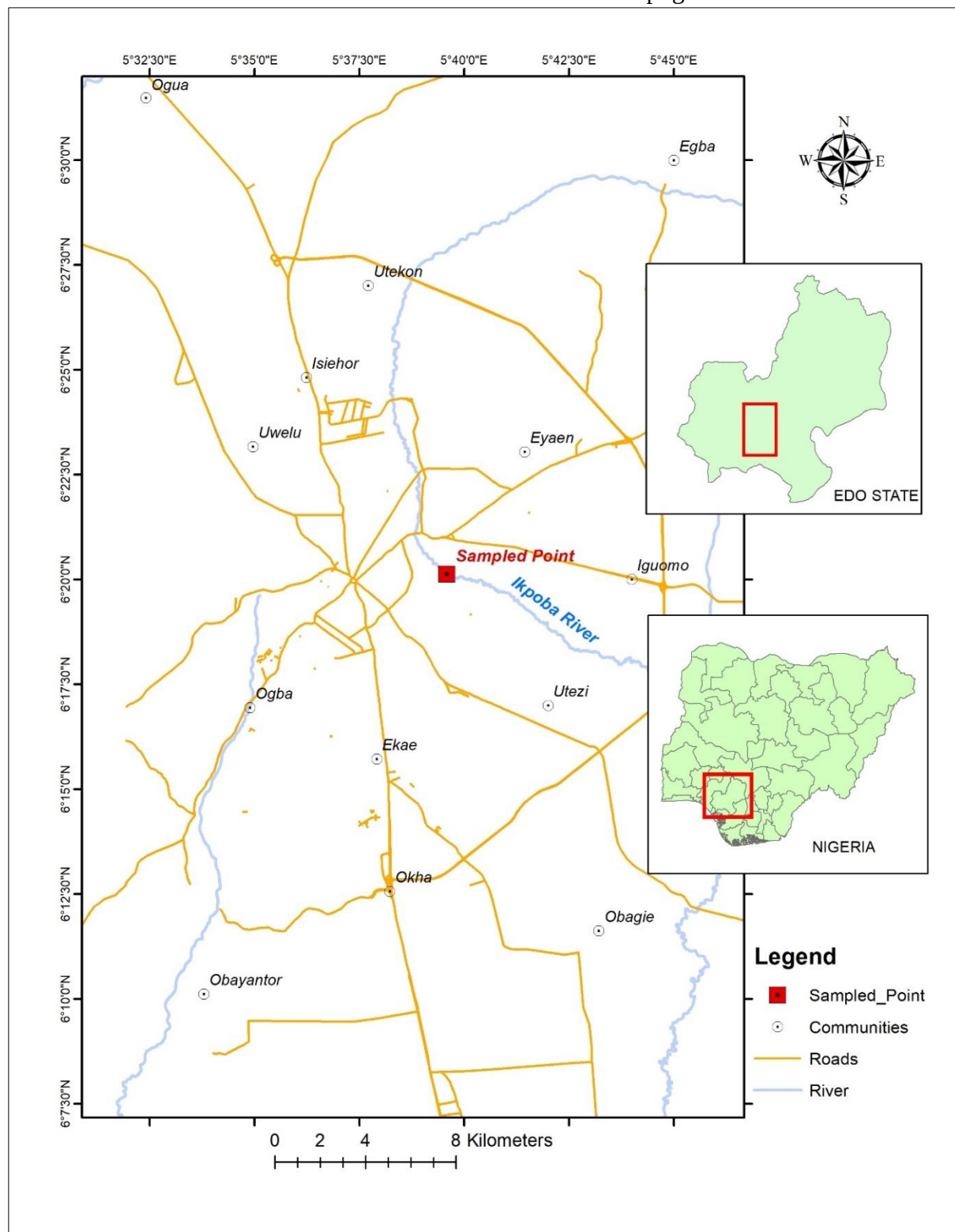


Figure 1: Map of the study area

SAMPLE COLLECTION

Specimens of two fish species; *Clara griepmus* and *Parauchenoglaris fasciulus*

were taken from Ikpoba River, Benin city. Four replicates of each species were collected. The fish samples were measured to take their length and weight.

Table 1: Weight and Length of Fish specimen

Fish specimen	Length	Weight
<i>Parauchenoglaris fasciulus</i> 1	13cm	32.1g
<i>Parauchenoglaris fasciulus</i> 2	11cm	22.6g
<i>Parauchenoglaris fasciulus</i> 3	13cm	18.5g
<i>Parauchenoglaris fasciulus</i> 4	13.5cm	18.1g
<i>Clara griepimus</i> 1	28cm	103.9g
<i>Clara griepimus</i> 2	26cm	44.5g
<i>Clara griepimus</i> 3	19cm	56.1g
<i>Clara griepimus</i> 4	17cm	32.0g

SAMPLE PREPARATION

The weighed samples were taken to the oven for drying. The specimen was rapped with foiled paper properly labelled according to their number. The samples were grinded with mortar and pestle to break the hard pieces. One gram (1g) of the sample was transferred to an acid-wash 250ml extraction bottle and 2ml of perchloric acid were added. The mixture was digested for 5-6hrs on a mechanical shaker hot plate. The samples were analyzed for heavy metals using atomic absorption spectroscopy (AAS).

RESULTS

Table 2 indicates the mean, standard deviation, minimum and maximum values of the heavy metal concentrations of lead (Pb) and cadmium (Cd) in *Clarias gariepinus* and *Parauchenoglaris fasciatus*. The mean values of Pb were greater (0.0125mg/kg) than Cd (0.0025mg/kg). T-test showed that there was no significant difference in Pb and Cd in the two species at the confidence level of 0.05.

In the human health risk estimations, target hazard quotient reveals that populations who consume this species of fish are not exposed to a non-cancer risk as THQ was below 1(0.004 and 0.002). Also,

carcinogenic risk evaluations showed that there will be no occurrence of cancer risk

for individuals that consume this species of fish as shown in table 4.3.

Table 2: Summary of heavy metal concentrations in *C. gariepinus* and *P. fasciatus*

Parameters and units	<i>C. gariepinus</i>	<i>P.fasciatus</i>	P-value
	mean±SD	mean±SD	
	(min-max)	(min-max)	
Pb (mg/kg)	0.0125±0.005	0.01±0	P>0.05
	0.01-0.02	0.01-0.01	
Cd (mg/kg)	0.0025±0.005	0±0	P>0.05
	0-0.01	0-0	

Health risk assessment of heavy metals

To assess the human health risk associated with the ingestion of toxic metals from the fishes, estimated daily intake, target hazard quotient (THQ) and carcinogenic risk were calculated using equation 1, 2 and 3.

Target hazard quotient (THQ): Non-carcinogenic risk estimation of toxic metals

consumption was determined using THQ values. THQ is a ratio of the determined dose of a toxicant to a reference dose considered harmful. If the ratio is equal to or greater than 1, an exposed population is at risk. THQ values were calculated using equation 1.

$$THQ = \frac{\text{concentration of metals} \times \text{Daily fish intake}}{RfD \times \text{average body weight}} \quad (1)$$

Where;

THQ is target hazard quotient

RfD is reference oral dose

Average body weight is 60kg as reported by Di Leo *et al.* (2010)

Average daily fish intake is 0.102mg/kg/day as reported by Nkpaa *et al.* (2016)

Estimated daily intake of heavy metal is depended on the average consumption rate of the fish intake. EDI is calculated using equation 2

Estimated Daily Intake (EDI)

$$EDI = \frac{\text{concentration of metal} \times \text{Daily fish intake}}{\text{Average body weight}} \quad (2)$$

Where;

EDI is estimated daily intake

Average body weight is 60kg as reported by Di Leo *et al.* (2010)

Daily fish intake is 0.102mg/kg/day as reported by Nkpaa *et al.* (2016)

Carcinogenic risk (CR)

The probable cancer risk due to exposure to a specified dose of heavy metal in fish can be imputed. The ILCR is defined as the incremental probability of a person developing any type of cancer over a lifetime as a result of exposure to a given daily amount of a carcinogenic element for 70 years (Mohammadi *et al.* 2019). The following equation is commonly used for the calculation of the life time cancer risk.

$$\text{Carcinogenic risk} = EDI \times CSF_{ing}$$

Where;

EDI is estimated daily intake

Average body weight is 60kg as reported by Di Leo *et al.* (2010)

Daily fish intake is 0.102mg/kg/day as reported by Nkpaa *et al.* (2016)

USEPA 2011 states that 10^{-6} (1 in 1,000,000) to 10^{-4} (1 in 10,000) indicates a range of permissible predicted lifetime risks for carcinogens. Chemicals for which the risk factor falls below 10^{-6} may be eliminated from further consideration as a chemical of concern.

Table 3: Reference dose (RfD) and Cancer slope factor (CSF) for different metals

Metals	RfD	CSF _{ing}
Pb	0.004	0.0085
Cd	0.001	6.1

Table 4: Health risk assessment of heavy metals

Metals	THQ		EDI		CR	
	<i>Pb</i>	<i>Cd</i>	<i>Pb</i>	<i>Cd</i>	<i>Pb</i>	<i>Cd</i>
	0.004	0.002	0.0002	0.00002	0.000002	0.0001

DISCUSSION

In this study, cadmium (Cd) and lead (Pb) were detected in both *Clarias gariepinus* and *Parauchenoglanis fasciatus* from Ikpoba River, although no significant differences were observed between the two species. The higher mean concentrations of Pb compared to Cd indicate greater environmental input or stronger bioaccumulation potential of Pb in the study area. The relatively low levels of both metals suggest minimal contamination but also point to potential localized sources of pollution that warrant continuous monitoring.

In contrast to this study, Mensoor and Said (2018) reported higher levels of Cd in the muscles of *B. sharpeyi* and *B. xanthropterus* caught from different stations of the Tigris River in Baghdad, which ranged from (0.80 – 1.20) ug/h. Similar to this study, Sallam *et al.* 2019 reported lower Cd levels (0.006-0.024) ug/g from Tok Bali Port, Kelantan, Malaysia. The observed variations across regions may be attributed to differences in industrial discharges, wastewater inputs, and geological background. Bilandzic *et al* (2011) reported that acute exposure to high doses of cadmium can lead to respiratory irritation while prolonged exposure to cadmium may cause chromilpulmonary disease and testicular degeneration. It may also cause hyperactivity and learning difficulties in children (Wang and Du, 2013).

The concentrations of Cd and Pb in this study was lower than WHO permissible limits. Cadmium, though present in trace amounts, is known to cause chronic toxicity in aquatic organisms. It can induce hematological changes, impair enzymatic function, and disrupt essential trace element metabolism (Wang & Du, 2013). Prolonged human exposure to Cd through dietary intake may also lead to renal dysfunction and skeletal damage (Bilandžić *et al.*, 2011). Similarly, Pb accumulation in fish can lead to physiological stress and behavioral changes (Authman *et al.*, 2015), while human exposure is associated with neurological and cardiovascular disorders (Han and Pan, 2021). The relatively low Cd and Pb concentrations found in the present study therefore suggest limited toxicological risk to both fish and consumers.

Non-Carcinogenic Risk and Carcinogenic Risk

The non-carcinogenic risk assessment showed that the Target Hazard Quotient (THQ) values for Cd and Pb were below 1, indicating that there is no significant health concern from consuming these fish species. Furthermore, the calculated carcinogenic risk (CR) values for both metals were within the acceptable range specified by the U.S. Environmental Protection Agency (USEPA, 2011), confirming the absence of potential lifetime cancer risk. Comparable findings were reported by Ahmed *et al.* (2016) and Gbogbo *et al.* (2018), who also

observed THQ values below unity in fish from moderately impacted aquatic systems. Besides comparing the mean concentration of heavy metals with maximum standards set by USEPA, the daily and weekly intakes of metals through fish consumption were determined and compared with the estimated daily intake. Acceptable values of cadmium and lead in fish were established by FAO as follows: (Cd 0.05ug/g and Pb 0.5ug/g regulation of the European commission (EC) NO. 1881/2006 (Cd 0.05ug/g, Pb 0.3ug/g): FAO/WHO (Cd 0.1ug/g, Pb 0.5ug/g). In this study, the average concentrations of cadmium and lead in the two species of fish does not exceed the maximum allowable limits specified by FAO/WHO. For the estimated daily intakes (ug/kg/body weight) from heavy metals in comparison to standard PTWIs and TWIs, Cd EDI values through consumption of the two species of fish does not exceed the TDIs proposed by JECFA and EFSA. Also, for Pb the EDI values through consumption of the two species of fish does not exceed the TDI proposed by JECFA and EFSA.

Fish species as Bioindicators of Trace metal contamination

Fish species are widely recognized as reliable bioindicators for monitoring aquatic pollution because they integrate contaminant exposure over time through respiration, ingestion, and sediment contact (Kaba *et al.*, 2023). The relatively low concentrations observed in *C. gariepinus* and *P. fasciatus* in this study may reflect the current moderate pollution status of Ikpoba River. Nevertheless, given the river's proximity to industrial and residential areas, the risk of increased contamination remains. Continuous monitoring and enforcement of effluent discharge regulations are therefore essential to prevent bioaccumulation of heavy metals in aquatic organisms and protect public health.

CONCLUSION

In this study the heavy metal concentrations in *C. gariepinus* were below the WHO and FMEnv guideline values. The estimation of non-carcinogenic risk (THQs and HI) conducted in this study indicated no adverse health effects from the consumption of fish. Also, the heavy metal concentrations in *P. fuciatus* were below the WHO/FMEnv guidelines values. The estimation of non-carcinogenic risk (THQ and HI) conducted for *P. fuciatus* indicated no adverse health effects from the consumption of the fish. Overall, this study demonstrates that the concentrations of Cd and Pb in fish from Ikpoba River are within safe limits for human consumption. However, given the persistence of heavy metals and their tendency to bioaccumulate, periodic assessment of both water and biota is crucial to detect early signs of contamination and ensure the long-term ecological integrity of the river.

Acknowledgements

We acknowledge the technical assistance provided by the Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin.

DECLARATIONS

Declaration of Conflict of Interest: The authors declare that no known conflict of interest or personal relationships that could have influence the work reported in this paper

Declaration of Data Availability: Data are available upon request from the corresponding author.

REFERENCES

- Ahmed, M.K., Baki, M.A., Islam, M.S., Kundu, G.K., Habibullah-Al-Mamun, M., Sarkar, S.K. and Hossain, M.M., 2015. Human health risk assessment of heavy metals in tropical fish and shellfish collected from the river Buriganga, Bangladesh. *Environmental science and pollution research*, 22(20), pp.15880-15890. <https://doi.org/10.1007/s11356-015-4813-z>.
- Anim-Gyampo, M., Kumi, M. and Zango, M.S., 2013. Heavy metals concentrations in some selected fish species in Tono Irrigation Reservoir in Navrongo, Ghana. *Journal of Environment and Earth Science*, 3(1), pp.109-119.
- Ashraf, M. A. and Maah, M. J. (2012). *International Journal of Environmental Research*. 6(1), pp. 209-218.
- Authman, M.M., Zaki, M.S., Khallaf, E.A. and Abbas, H.H., 2015. Use of fish as bio-indicator of the effects of heavy metals pollution. *Journal of aquaculture research & development*, 6(4), pp.1-13. <http://dx.doi.org/10.4172/2155-9546.1000328>.
- Bassey, O.B. and Chukwu, L.O., 2019. Health risk assessment of heavy metals in fish (*Chrysichthys nigrodigitatus*) from two lagoons in south-western Nigeria. *Journal of Toxicology and Risk Assessment*, 5(2), p.027. <https://doi.org/10.23937/2572-4061.1510027>.
- Bilandžić, N., Đokić, M. and Sedak, M., 2011. Metal content determination in four fish species from the Adriatic Sea. *Food chemistry*, 124(3), pp.1005-1010. <https://doi.org/10.1016/j.foodchem.2010.07.060>.
- Canli, M. and Atli, G., 2003. The relationships between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. *Environmental pollution*, 121(1), pp.129-136. [https://doi.org/10.1016/S0269-7491\(02\)00194-X](https://doi.org/10.1016/S0269-7491(02)00194-X).
- Di Leo, A., Cardellicchio, N., Giandomenico, S. and Spada, L., 2010. Mercury and methylmercury contamination in *Mytilus galloprovincialis* from Taranto Gulf (Ionian Sea, Southern Italy): risk evaluation for consumers. *Food and Chemical Toxicology*, 48(11), pp.3131-3136. <https://doi.org/10.1016/j.fct.2010.08.008>.
- Egborge, A.B.M., 1994. Water pollution in Nigeria: Biodiversity and chemistry of Warri River. *Ben-Miller Books Nigeria Ltd*, pp.27-59.
- Ekhaise, F. O. and Anyasi, C. C. (2005). Influence of breweries effluent discharge on the microbiological and physico-chemical quality of Ikpoba River Nigeria. *African Journal of Biotechnology*, 4(10), pp. 1062–1065. <https://doi.org/10.4314/ajb.v4i10.71272>.
- Ezeonyejiaku, Chigozie Damian, Nwuba Lucy Afulenu, Obiakor Maximilian Obinna and Okonkwo Chidumeje Ndidi (2014). Bioaccumulation of heavy metals in fish sourced from environmentally stressed axis of River Niger: Threat to ecosystem and public health. *International Journal of Environmental Protection and Policy*, 2(4), pp. 126-131. <https://doi.org/10.11648/j.ijep.20140204.11>
- FAO/WHO (1989). Evaluation of certain food additive and the contaminants mercury, lead and cadmium. WHO Tech. Rep. Ser. No. 505.
- Gbogbo, F., Arthur-Yartel, A., Bondzie, J.A., Dorleku, W.P., Dadzie, S., Kwansa-Bentum, B., Ewool, J., Billah, M.K. and Lamptey, A.M., 2018. Risk of heavy metal ingestion from the consumption of two commercially valuable species of fish from the fresh and coastal waters of Ghana. *Plos*

one, 13(3), p. e0194682.
<https://doi.org/10.1371/journal.pone.0194682>.

Han, J.L., Pan, X.D., Chen, Q. and Huang, B.F., 2021. Health risk assessment of heavy metals in marine fish to the population in Zhejiang, China. *Scientific reports*, 11(1), p.11079. <https://doi.org/10.1038/s41598-021-90665-x>.

Hao, Y., Chen, L., Zhang, X, Zhang, D., Zhang, X. and Yu Y, Fu. J. (2013). Trace elements in fish from Taihu Lake, China: Levels associated risks, and trophic transfer. *Ecotoxicology Environmental safety*, 90, pp. 89-97. <https://doi.org/10.1016/j.ecoenv.2012.12.012>.

Islam, M. S., Ahmed, M. K., Raknuzzaman, M., Hubibullah-Al-Mamun, M. and Masunaga, S. (2015). Metal speciation in sediment and their bioaccumulation in fish species of three urban rivers in Bangladesh. *Arch Environmental Contamination Toxicology*, 68(1), pp. 92-106. <https://doi.org/10.1007/s00244-014-0079-6>.

Kaba, P., Shushi, S., Gyimah, E., Husein, M. and Abomohra, A., 2023. Multivariate Analysis of Heavy Metals and Human Health Risk Implications Associated with Fish Consumption from the Yangtze River in Zhenjiang City, China. *Water*, 15(11), p.1999. <https://doi.org/10.3390/w15111999>.

Mensoor, M. and Said, A., 2018. Determination of heavy metals in freshwater fishes of the Tigris River in Baghdad. *Fishes*, 3(2), p.23. <https://doi.org/10.3390/fishes3020023>.

Micheline, G., Rachida, C., Céline, M., Gaby, K., Rachid, A. and Petru, J., 2019. Levels of Pb, Cd, Hg and As in fishery products from the Eastern Mediterranean and human health risk assessment due to their consumption. *International Journal of*

Environmental Research, 13(3), pp.443-455. <https://doi.org/10.1007/s41742-019-00185-w>.

Miri, M., Akbari, E., Amrane, A., Jafari, S.J., Eslami, H., Hoseinzadeh, E., Zarrabi, M., Salimi, J., Sayyad-Arbabi, M. and Taghavi, M., 2017. Health risk assessment of heavy metal intake due to fish consumption in the Sistan region, Iran. *Environmental monitoring and assessment*, 189(11), p.583. <https://doi.org/10.1007/s10661-017-6286-7>.

Muiruri, J.M., Nyambaka, H.N. and Nawiri, M.P., 2013. Heavy metals in water and tilapia fish from Athi-Galana-Sabaki tributaries, Kenya. *International Food Research Journal*, 20(2), pp. 891-896. <http://www.ifrj.upm.edu.my/>.

Nkpaa, K.W., Patrick-Iwuanyanwu, K.C., Wegwu, M.O. and Essien, E.B., 2016. Health risk assessment of hazardous metals for population via consumption of seafood from Ogoniland, Rivers State, Nigeria; a case study of Kaa, B-Dere, and Bodo City. *Environmental Monitoring and Assessment*, 188(1), p.9. <https://doi.org/10.1007/s10661-015-5006-4>.

Ogbeibu A. E. and Edutie L.O. (2002). Impact of Brewery effluent on the water quality and Rotifiers of Ikpoba Rivers Southern Nigeria. *African Journal of Environmental Pollution and Health*, 1(1), pp. 1-12. <https://doi.org/10.4314/jas.v17i1.19908>.

Oronsaye, J.A.O., Wangboje, O.M. and Oguzie, F.A., 2010. Trace metals in some benthic fishes of the Ikpoba river dam, Benin City, Nigeria. *African Journal of Biotechnology*, 9(51), pp.8860-8864. <https://doi.org/10.4314/ajb.v9i51>.

Oyewole, O.E. and Amosu, A.M., 2012. Nutritional considerations and benefits associated with consumption of catfish in

South-West Nigeria. *Annals Biological Research*, 3, pp.4094-4098.
<http://scholarsresearchlibrary.com/archive.html>.

Parida, S., Barik, S.K., Mohanty, B., Muduli, P.R., Mohanty, S.K., Samanta, S. and Pattanaik, A.K., 2017. Trace metal concentrations in euryhaline fish species from Chilika lagoon: human health risk assessment. *International Journal of Environmental Science and Technology*, 14(12), pp.2649-2660.
<https://doi.org/10.1007/s13762-017-1334-y>.

Sallam, Khalid Ibrahim, Samir Mohammed Abd-Elghany, and Mahmoud Ahmed Mohammed. "Heavy metal residues in some fishes from Manzala Lake, Egypt, and their health-risk assessment." *Journal of Food Science* 84, no. 7 (2019): 1957-1965.
<https://doi.org/10.1111/1750-3841.14676>.

Serdar, D., Filiz K. G. and Recep, K. (2017). Assessment of human health risk from heavy metals levels in water and tissues of two trout species (*Oncorhynchus mykiss* and *Salmo coruhensis*) from Firtina and Guneyisu Rivers in Rize. *Toxin Reviews*, 36(4), pp. 306-312.
<https://doi.org/10.1080/15569543.2017.1312452>.

Tariq, J., Ashraf, M., Jaffar, M. and Afzal, M., 1996. Pollution status of the Indus River, Pakistan, through heavy metal and macronutrient contents of fish, sediment and water. *Water research*, 30(6), pp.1337-1344. [https://doi.org/10.1016/0043-1354\(95\)00300-2](https://doi.org/10.1016/0043-1354(95)00300-2).

Tawari-Fufeyin, P. and Ekaye, S.A., 2007. Fish species diversity as indicator of pollution in Ikpoba river, Benin City, Nigeria. *Reviews in Fish Biology and Fisheries*, 17(1), pp.21-30.
<https://doi.org/10.1007/s11160-006-9015-9>.

Tawari-Fufeyin, P. and Ekaye, S.A., 2007. Fish species diversity as indicator of pollution in Ikpoba river, Benin City, Nigeria. *Reviews in Fish Biology and Fisheries*, 17(1), pp.21-30.
<https://doi.org/10.1007/s11160-006-9015-9>.

USEPA (2011). USEPA Regional Screening Level (RSL) Summary Table: November 2011. Available at: <http://www.epa.gov/regshwmd/risk/human/Index.htm>. Accessed 25th February, 2025

USEPA (U.S. Environmental Protection Agency). United State Environmental Protection Agency, Washington, DC. (1989). Risk Assessment Guidance for superfund, Volume I. Human Health Evaluation Manual Part A, Interim Final. (EPA/540/1-89/002).

Victor, R. and Tetteh, J.O., 1988. Fish communities of a perturbed stream in Southern Nigeria. *Journal of Tropical Ecology*, 4(1), pp.49-59.
<https://doi.org/10.1017/S0266467400002492>

Wany and Du, (2013). Cadmium and it's neurotoxic effects. *Oxidative Medicine and Celular. Longevity*, 13, pp. 1-12.
<https://doi.org/10.1155/2013/898034>.

Yılmaz, F., Özdemir, N., Demirak, A. and Tuna, A.L., 2007. Heavy metal levels in two fish species *Leuciscus cephalus* and *Lepomis gibbosus*. *Food chemistry*, 100(2), pp.830-835.
<https://doi.org/10.1016/j.foodchem.2005.09.020>.