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IMPACTS OF GEOGENICALLY DERIVED HEAVY METALS ON CRABS AND SNAILS IN OGUTA LAKE, SOUTH-EASTERN, NIGERIA

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Abstract

Evaluation of the bio-accumulations of heavy metals in some selected benthic invertebrate species specifically crabs and snails from the Oguta Lake is the main focus of this study. Four samples of crabs and juvenile snails were collected from the benthic zone of the Oguta Lake. These samples were analyzed for heavy metals, namely: Arsenic, Cadmium, Chromium, Iron, Nickel, Mercury, Lead and Zinc using Atomic Absorption Spectroscopy AAS. The results of the analysis of crab samples follow in the trend (mg/kg): As 0.22±0.03, Cd 0.49±0.01, Cr 0.23±0.04, Fe 19.90±1.44, Ni 0.12±0.02, Hg 0.03±0.02, Pb 1.62±0.09 and Zn 15.02±1.35. Results of the snail samples indicated that the mean concentrations of these heavy metals are: As 0.20±0.05, Cd 0.10±0.01, Cr 0.11±0.02, Fe 17.03±2.59, Ni 0.11±0.01, Hg 0.02±0.01, Pb 1.52±0.03 and Zn 13.37±1.14. The obtained results were compared with the Food and Agricultural Organization of the United Nations FOA, and the World Health Organization WHO standards. Except for Pb, the other analyzed heavy metals in both crab and snail samples were in conformity with these regulations.

Keywords: Benthic, bio-accumulation, fauna species, heavy metals, invertebrate species.

INTRODUCTION

Problem Statement

Bottom sediment is majorly the main source and ultimate receptor of heavy metals, and it is predominantly the last pathway of both human and naturally induced components to the environment. In specific environmental dynamics like pH, redox potential or even re-suspension, heavy metals held in sediments may become mobile and enter the water or food chain. Some aquatic fauna species, including benthic organisms, bio-accumulate heavy metals in considerable quantity (Ibok et al., 1989, and Burger et al., 2002), hence they are eventually transferred to other animals including humans through the food chain (Etuk and Mbonu., 1999). Apparently, some metals are vital for life, however, toxicity might emerge if an individual's ingestion rate exceeds a certain limit. Ingestion of heavy metals through eating contaminated sea foods and drinking water may bring about various diseases such as neuropsychological effects, anaemia, gastrointestinal pathologies, teratogenic implications and liver

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diseases (Needleman & Bellinger., 1991). Furthermore, it is a known fact that certain heavy metals have the tendency of damaging the DNA of humans which in turn leads to decreased fertility and induction of cancer (Snow, 1992).

Relevance of Study

Nearly all benthic organisms are susceptible to heavy metal contaminants by direct or inadvertent ingestion of sediments and by uptake from pore water or overlying water (Campana et al., 2012; Griscom and Fisher, 2004; Rainbow, 2007; Simpson and Batley, 2007). Benthic communities provide valuable indicators to the overall health of the environment owing to the prevalence of very sensitive species that respond to pollutants. They are for the most part, used in appraising the ecological implications of heavy metal contamination within a lake ecosystem (Clements et al. 1994).

The Oguta Lake has pivotal significance to the local communities of Oguta, Orsu, Mgbidi, Nkwesi, Awo-Omamma and Izombe as a source of water supply, recreation, transportation and tourism development. Over 80% of the local population overly depend on this lake for nearly all of their protein needs. However, natural phenomena such as erosion and flooding; and other events due to human activities like sewage disposal, oil spills, urbanization, local industrial operations, sand mining activities, unsustainable fishing practices, unregulated farming practices and transportation (especially, the regular ferry of timber and palm) within the Oguta Lake may constitute heavy metals pollution in the lake. Consequently, the assessment of heavy metal bioaccumulation in the benthic crabs and juvenile snails in the Oguta lake can give beneficial information of heavy metal pollution and assist in the evaluation of potential environmental risks (detrimental biologic effects on the health of humans) associated with the consumption of seafood from the lake.

REVIEW OF LITERATURE

Various research have recorded the occurrence and concentrations of Pb, Cd, Cr, As, Hg, Fe, Ni, and Zn in the Oguta Lake. For instance, a study by Iwuanyanwu (2020) reported elevated levels of lead and cadmium, particularly near industrial discharge points, with concentrations exceeding the permissible limits set by environmental guidelines, indicating significant pollution. Adaka et al. (2017) recorded 0.21±0.23mg/kg as the lowest mean concentration of Pb measured in the muscle of some fish species in the Oguta Lake, while the highest mean concentration of 1.05±0.84mg/kg was measured in the liver. As discovered in a study conducted by Mgbemena& Obodo (2015), the level of lead accumulated in Channa fish and Catfish were high with bioaccumulation factors of 288.8 and 150 respectively. Also, Ekeanyanwu (2015) derived higher elemental concentration values in bottom sediments

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of Oguta Lake. High levels of Fe and Zn were detected in the gills of fish (Tilapia nilotica) samples by Mgbemena& Obodo (2015), this finding is also in consistent with studies carried out by Davies et al. (2024). In the same manner, Chineze et al. 2024 highlights Pb contamination at 2.96 mg/kg in sediments.

Wirnkoret al. (2021), while working on the Petroleum Hydrocarbons and Heavy Metals Risk of Consuming fish Species from Oguta lake, found that mercury Hg and nickel Ni exceeded permissible limits set by FAO. They opined that the consumption of certain fish species from the Oguta Lake by both adults and children can increase their vulnerability to cancer. Adebayo et al. (2017) documented an elevated concentrations of iron in water sample which exceed NESREA recommendation standard for aquatic life. In a similar way, Uzukwu et al. (2024) noted highest concentrations of iron (1.479±0.003mg/kg) and Pb (1.438±0.015mg/kg) in the gills and intestines of fish samples, indicating potential contamination and threats to aquatic and human health. Though, Ohaturuonye et al. (2024) have reported low concentrations levels of heavy metals in the lake, Green et al. (2023) in their studies detected concentrations higher in both the water, sediment and organs of fishes. Shittu et al. (2021) studied the physicochemical properties and heavy metal Concentration in water and sediment samples from Oguta Lake, their study revealed a gradual but continuous build-up of heavy metals in the lake.

Description of the Study Area

Depending on the season, Oguta Lake has a surface area variation of 180 - 300 hectares. It is largest during rainy season. It has a maximum depth of 8.0m, and an average depth of 5.5m. The water level is Unregulated. Normal range of annual water level fluctuation is 9.3m, while the length of shoreline is 10km (Nfor and Akaegbobi, 2012). Total population within the catchment area is about 50,000 (Herschy, R.W. 2012).

The climate is tropical rain forest with two distinct seasons, a dry season which lasts from October to March, and the rainy season which lasts from April to September (Nnaji, 2011). The area has a relatively high temperature with an average of 27^0C (80.6^0F). Temperature usually peaks within the months of February and March. This region is located within the equatorial rain forest belt with an average annual rainfall of about 10,000mm (1000cm) (Newman, 2002).

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Location of Study Area

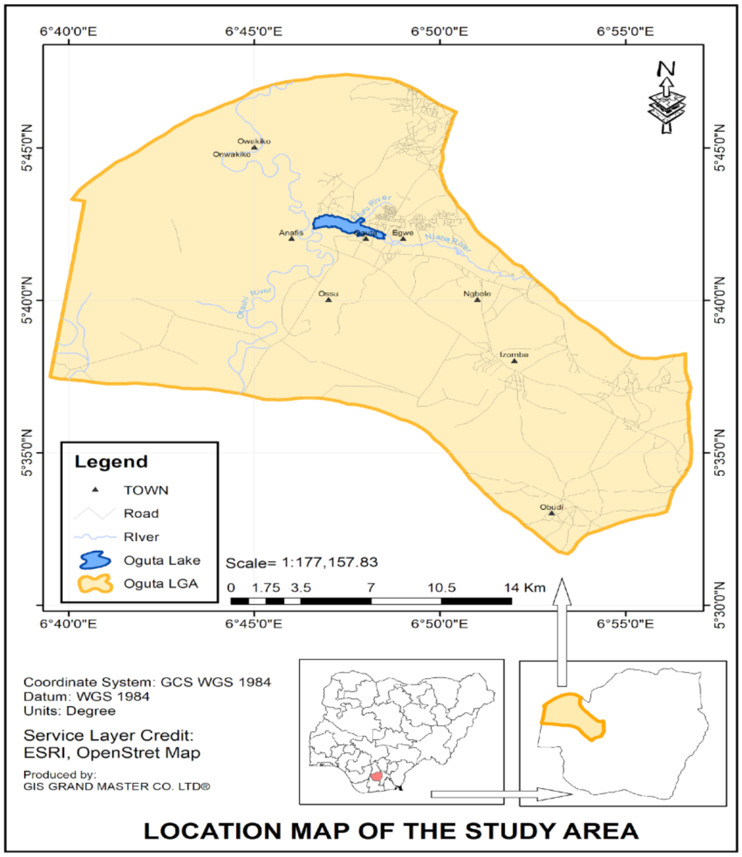

Fig. 1: Location map of the study area.

The location of the Oguta Lake is within coordinates Longitude $05^0$42'474"N, and Latitude $006^0$47'33"E, covering approximately 8.05kmof water area and it is the largest fresh-water lake in the South-eastern part of Nigeria.

Geologic Setting

The study area is underlain by Benin Formation (Onyeagocha, 1980). It is over 90 percent sandstone with minor shale intercalations in some places. The Benin Formation is thus partly marine, partly deltaic, partly estuarine and partly lagoonal and fluviolacustrine in origin (Reyment, 1976).The Benin Formation consists of friable sands with intercalations of shale-clay lenses and it is Pliocene to Miocene in age. The formation also contains some isolated units of gravels, conglomerates, very coarse sands and sandstones (Ananaba et al., 1993). The formation thins out at the contact with the Ogwashi - Asaba and thickens in Owerri area. The average thickness of the Benin Formation around Owerri and environs is 800m (Avbovbo, 1978).

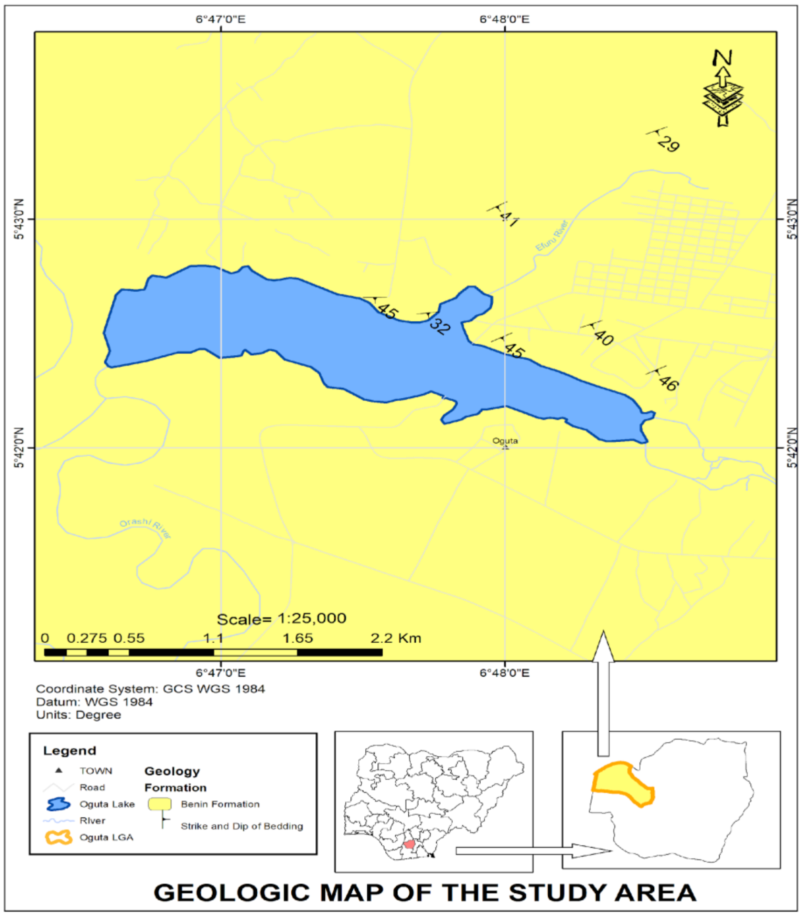

Fig. 2: Geologic map of the study area.

Hydrology

Rivers Njaba and Awbana empty into the Oguta lake. Third River, Utu River flows into the lake only during the rainy season. Apart from the rivers that feed the lake, there is also input from precipitation during the rainy season. The volume of water that flows into the lake as well as the precipitation during the rains are main sources of recharge of the Oguta Lake. Although, the water level of the lake is unregulated, it is relatively higher during the rainy season than the dry season. The total annual outflow from the lake is about 13,476,300m3. The channel outflow from the lakes contributes about 70.2% of total outflow while water withdrawal represents about 24.4% (Ahiarakwem et al. 2012).

MATERIALS AND METHODS

Sampling Method

Since both snail (gastropoda) and crab (brachyuran) are benthic macro-invertebrates, the EPA-recommended Grab Samplers were used in sample collection. Sampling was carried out at the benthic zone of the lake, capturing both the upstream part, the midstream and also the downstream areas of the lake.

Sample Preparation and Analysis

The collected materials were sorted out in a proper manner to separate the macro-invertebrates. Samples were meticulously rinsed using a 15ml glass-distilled water to remove stones, particles, muds and other contaminants in a sieve with a mesh size of 1mm. Identification was carried out using standard taxonomic diagrams and keys, Johannsen (1969). Snail samples were smashed to expose organs (Ibrahim et al., 2023), and dried in the oven using the German-made U27 Memmert oven for seventy-two (72) hours to enable proper drying at temperatures between 80 – 90°C. Thereafter, Silimic mortar was used to grind the specimens of snail and crab separately into powdery form. Weighted (4gm) each of samples in a crucible container were sent into a furnace for 5 hours to obtain the ash. When drying was completed, it was then given some time for cooling to take place. Dissolution of the ash content was carried out through the application of a 10%-unit Hydrochloric Acid HCL to achieve dryness. Next was funnel-filtering into a measuring cylinder and the addition of distilled water to measure-up to twenty milliliters (20ml) for analysis of As, Cd, Cr, Fe, Ni, Hg, Pb and Zn using AAS.

Data Assurance and Quality

For integrity of data, analyses of samples were carried out in triplicate. A GBC AAS (PM 2.02 Avanta) was used in carrying out the determination of metals. Execution of blank analysis was performed just exactly like the samples. Standard solutions which were prepared in the same acid matrix were employed in the determination of concentrations. The certified three-basis mono-element reference solution was deployed for the preparation of instrument calibration standard.

Table 1

Mean values of heavy metal concentration in some selected crab species in Oguta Lake

Crab (*Brachyura)* (mg/kg dry wt)	As	Cd	Cr	Fe	Ni	Hg	Pb	Zn
1	0.29	0.50	0.26	20.80	0.12	0.03	1.68	14.69
2	0.33	0.47	0.20	19.13	0.15	0.01	1.49	12.97
3	0.30	0.49	0.28	17.98	0.12	0.04	1.71	16.54
4	0.26	0.51	0.19	21.69	0.09	0.06	1.59	15.86
Mean	0.22	0.49	0.23	19.90	0.12	0.03	1.62	15.02
SD	0.03	0.01	0.04	1.44	0.02	0.02	0.09	1.35
WHO	0.30	0.20	SILENT	--	0.14	0.05	1.50	--
FAO	0.50	0.50	1.00	48.00	0.14	0.05	0.50	40.00

Table 2

Mean values of heavy metal concentration in some selected juvenile snail species in Oguta Lake

Snail (Gastropoda) (Mg/kg dry wt.)	As	Cd	Cr	Fe	Ni	Hg	Pb	Zn
1	0.28	0.10	0.08	19.45	0.10	0.01	1.52	11.87
2	0.19	0.08	0.11	17.29	0.13	0.03	1.56	13.68
3	0.20	0.12	0.14	12.74	0.11	0.01	1.49	15.01
4	0.14	0.09	0.10	18.63	0.09	0.02	1.50	12.93
Mean	0.20	0.10	0.11	17.03	0.11	0.02	1.52	13.37
SD	0.05	0.01	0.02	2.59	0.01	0.01	0.03	1.14
WHO	0.30	0.20	SILENT	--	0.14	0.05	1.50	--
FAO	0.50	0.50	1.00	48.00	0.14	0.05	0.50	40.00

RESULTS

The results of the analysis of the heavy metal concentration in mg/kg of dry weight of two randomly selected benthic macro-invertebrates (crab and snail) in the Oguta Lake are varied, they are summarized in table 1 and 2. The mean values of As, Cd, Cr, Fe, Ni, Hg, Pb, and Znin Crab sample are 0.22, 0.49, 0.23, 19.90, 0.12, 0.03, 1.62 and 15.02, respectively.The results of the analyzed heavy metal mean concentration in Snail are 0.20, 0.10, 0.11, 17.03, 0.11, 0.02, 1.52, and 13.37, respectively for As, Cd, Cr, Fe, Ni, Hg, Pb, and Zn.

Bioconcentration factors (BCF)

Bioconcentration factors evaluate the quantity of heavy metal conceivably retained in an aquatic organism due to accumulation (Alinnor et al., 2010). The ability for a certain heavy metal accumulated in any benthic specie to become toxic differs from one metal to another. These fauna species can be categorized relatively to their proneness to a particular metal accumulation using the permissible limits as the determinant.

$$\text{Bioconcentration factor (BCF)} = \frac{\text{conc.of metal in organism}}{\text{permissible limit of the metal}} \times 10$$

Table 3

Bio-concentration factor and toxicity index of some selected fauna species in Oguta Lake

Bioconcentration Factors		
Metal	***Crab***	***Snail***
As	44.00	40.00
Cd	38.00	20.00
Cr	23.00	11.00
Fe	41.46	35.48
Ni	85.71	78.57
Hg	60.00	40.00
Pb	324.0	298.0
Zn	37.55	33.42
Toxicity Index		
	0.82	0.70

Heavy Metal Toxicity Index

The HMTI were determined by dividing the average ratios of heavy metal concentration in the fauna species by their assumed allowable limits for each of the analyzed heavy metals. The mathematical expression used is:

Heavy Metal Toxicity Index (HMTI) = $\frac{As}{Pl}+\frac{Cd}{Pl}+\frac{Cr}{Pl}+\frac{Fe}{Pl}+\frac{Ni}{Pl}+\frac{Hg}{Pl}+\frac{Pb}{Pl}+\frac{Zn}{Pl} \div 8$

Where *PL* is the Permissible Limit for each heavy metal.

DISCUSSION

Analysis of heavy metal bioconcentration in the selected benthic macro-invertebrates showed some variations. The results indicate that most of the analysed metals are in conformity with the permissible limits set by the World Health Organization WHO and the Food and Agricultural Organization FAO of the United Nations UN., in the selected fauna species. However, the mean bioconcentration of Pb in the samples of Crab and Snail far exceeds these regulations.Uzukwu et al. (2024) noted Pb concentration values of 1.43mg/kg in the gills and intestines of some fish species in the Oguta lake.

Pb is known to be a systemic toxicant that affects numerous organs which include the brain, bone, reproductive organs and kidney. Studies in human have shown that occupational exposure to Pb decreased sperm count, quality of sperm and chances of fathering a child (Hosni, H. et al., 2013). In adult females, exposures to Pb can mutate hormone production, decreases fertility potentials, alters menstruation, delays conception time and triggers other adverse pregnancy outcomes (De Rosa, M. et al., 2003). Pb has a high reprotoxic effect, this has been linked with its potential to alter the endocrine system, interfere with gene expression and trigger oxidative stress (Dorsun, N. et al., 1999), (Gandhi et al., 2017), (Hosni, H. et al., 2013). It can cause life-long impairment in the cognitive abilities of exposed infants by disrupting the development of their nervous system (FDA, 2023), (Flannery, B.M. et al., 2022).

CONCLUSION AND RECOMMENDATION

The consumption of certain benthic invertebrates such as crabs and snail species from the Oguta lake may constitute a public health risk to the over 30,000 population within the catchment through the food web, due to Pb poisoning.To reduce the susceptibility to specific heavy metals (especially, Pb) and their adverse effects to human, the consumption of crabs and snails from the Oguta lake should be minimized and seeking alternative source of animal protein be encouraged.

References

Adaka, G., Ajima, M., Ezeafulugwe, C., Osuigwe, D &Nlewadim, A. (2017). Assessment of Heavy Metals in Fish Tissues of Some Fish Species in Oguta Lake, South-Eastern Nigeria. Futo Journal Series (FUTOJNLS). Volume-3, Issue-1, pp. 249 – 257.

Adebayo, E.T., Oluwatosin, T.J., & Nneji, P.C. (2017). Limnological Assessment of Heavy Metals Concentration in Water and Sediment of Oguta Lake, South-East Nigeria, Nigeria. International Journal of Innovative Studies in Aquatic Biology and Fisheries. Volume 3, Issue 3, 2017, pp. 18-22.

Alinnor, I.J. (2005). Assessment of elemental contaminants in water and fish samples from Aba River. Journal of Environment Monitoring and Assessment, 102, pp. 15-25.

Ananaba, S. E., Onu, N. N., & Iwuagwu, C. J. (1996). Geophysical study of the gravel deposit in Ihiagwa, Owerri Nigeria. In *International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts*.Vol. 3, No. 33, p. 126A.

Anshumali, Ramanathan, A. L., Singh, G., Singh, G., Ranjan, R., & Tripathi, P. (2009). Chemodynamics of trace metal fractions in surface sediments of the Pandoh Lake, Lesser Himalaya, India. *Environmental geology*, *57*, pp. 1865-1879.

Avbovbo, A.A. (1978). "Tertiary lithostratigraphy of Niger delta." AAPG Bulletin Vol 62 No2, pp. 295-300.

Burger, Henry G. (2002). "Androgen production in women." Fertility and sterility Vol 77, pp. 3-5.

Campana, O., Blasco, J., & Simpson, S.L. (2013). Demonstrating the appropriateness of developing sediment quality guidelines based on sediment geochemical properties. Environmental Science & Technology Vol47, pp. 7483–7489.

Chineze, A., Chibuike, U & Jacinta, A. (2024). Nymphaea lotus Distribution in Oguta Lake: Implications for Heavy Metal Pollution in Surface Water and Sediments.

International Journal of Innovative Science and Research Technology (IJISRT), 2024, pp. 1097-1106.

Clements, William, H & Peter, M. K. (1994). "The influence ofelevation on benthic community responses to heavy metals in Rocky Mountain streams." Canadian Journal of Fisheries and Aquatic Sciences Vol 52 No9, pp. 1966-1977.

Davies, I.C., Evelyn, G.A., & Amarachi, P.O. (2024). Estimation of potential health risks on metals and metalloids contaminants in black goby (Gobiusniger) consumption in selected Niger Delta Coast, Nigeria. Journal of Trace Elements and Minerals 8, p. 100157.

De Rosa M., Zarrilli, S., Paesano, L., Carbone, U., Boggia, B., Petretta, A.,& Colao (2003). Raffic pollutants affect fertility in men Hum. Reprod., Vol18 No (5), p. 1055.

Dursun, N., & Tutus, A. (1999). Chronic occupational lead exposure and thyroid function. *The Journal of Trace Elements in Experimental Medicine: The Official Publication of the International Society for Trace Element Research in Humans*, *12*(1), p. 45-49.

Ekeanyanwu, R. C., Nwokedi, C. L & Noah, U. T. (2015). Monitoring of metals in Tilapia nilotica tissues, bottom sediments and water from Nworie River and Oguta Lake in Imo State, Nigeria. African Journal of Environmental Science and Technology. Vol. 9(8), pp. 682-690.

EPA, ABD. (2004). Risk assessment guidance for superfund. Volume I: human health evaluation manual (Part E, supplemental guidance for dermal risk assessment). Vol. 5.

Etuk, E. U. I. & Mbonu, C. O. (1999). Comparison of trace and toxic metal contamination in periwinkles from qua Iboe River (Ibeno) and Cross River (Oron). Proceeding of the 23rdAnnual conference of the Nigerian Institute of food science and Technology held at Abuja. October 25-27th.

FDA. (2023). Action Levels for Lead in Food Intended for Babies and Young Children: Draft Guidance for Industry. https://www.fda.gov/regulatory-information/search-fda-guidancedocuments/draft-guidance-industry-action-levels-lead-food-intendedbabies-and-young-children

Flannery, B.M & Karlyn, B. (2022). Updated interim reference levels for dietary lead to support FDA's Closer to Zero action planRegulatory Toxicology and Pharmacology, 133, p. 105202.

Food and Drug Administration of the United States. (2023). Action Levels for Lead in Food Intended for Babies and Young Children: Draft Guidance for Industry. https://www.fda.gov/regulatory-information/search-fda-guidanceddocuments/draft-guidance-industry-action-levels-lead-food-intended babies-and-young-children

Gandhi, S., Chen, S., Hong, L., Sun, K., Gong, E., Li, C.,...& Schwalm, J. D. (2017). Effect of mobile health interventions on the secondary prevention of cardiovascular disease: systematic review and meta-analysis. *Canadian Journal of Cardiology*, *33*(2), pp. 219-231.

Green, M.C., Osuala, F.O.U., Okechukwu, R.I., & Abara, P.N. (2023). Bioaccumulation of Heavy Metals in Fish Tissues from Selected Surface Water of the Niger Delta, Nigeria. International Journal of Research Publication and Reviews, Vol 4, no 1, pp. 2196.

Griscom, S.B., & Fisher, N.S. (2004) Bioavailability of sediment-bound metals tomarine bivalve molluscs: An overview. Estuaries Vol27, pp. 826–838.

Herschy, R.W. (2012). World Lake Database: International Lake Environment Committee Foundation (ILEC). In: Bengtsson, L., Herschy, R.W., Fairbridge, R.W. (eds) Encyclopedia of Lakes and Reservoirs. Encyclopedia of Earth Sciences Series. Springer, Dordrecht, *pp. 921–923.*

Hosni, H., Selim, O., Abbas, M., & Fathy, A. (2013). Semen quality and reproductive endocrinal function related to blood lead levels in infertile painters, Andrologia, Vol.45 No. (2), pp. 120.

Hospers, J. (1965)." Gravity field and structure of the Niger delta, Nigeria, West Africa." Geological Society of America Bulletin Vol76. No4, pp. 407-422.

Huang, D. W., Sherman, B. T., & Lempicki, R. A. (2009). Bioinformatics enrichment tools: paths toward the comprehensive functional analysis of large gene lists. *Nucleic acids research*, *37*(1), pp. 1-13.

Ibok, U. J., Udosen, E.D &Udoidiong, O.M. (1989). "Heavy metals in fishes from some streams in Ikot Ekpene area of Nigeria." pp. 61-68.

Ibrahim, A.A., Yahaya, Z.S & Hashim, Z. (2023).Relationship between pH, Water Temperature, Dissolved Oxygen And Parasitic Infestation Of Freshwater Fishes In Temengor, Bersia And Chenderoh Reservoirs, Perak, MalaysiaDepartment of Zoology, Federal University Lokoja, Kogi State, Nigeria. School of Biological Sciences, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia.

Idowu, J. O., & Enu, E. I. (1992). Petroleum geochemistry of some late Cretaceous shales from the Lokoja Sandstone of Middle Niger Basin, Nigeria. *Journal of African Earth Sciences (and the Middle East)*, *14*(3), pp. 443-455.

Iwuanyanwu, P. O. (2020). Assessment of Heavy Metals in Oguta Lake Water and Sediments. International Journal of Environmental Science.

Johansen, H. W. (1969). Morphology and systematics of coralline algae with special reference to Calliarthron. *(No Title)*.

Mgbemena, N.M & Obodo, G. A. (2015). Bioaccumulation of Heavy Metals in Some Fish Samples from Oguta Lake, Imo State, Nigeria. J. Chem. Soc. Nigeria, Vol. 40, No.2, pp. 89-91.

Needleman, H.L & David, B. (1991). "The health effects of low- level exposure to lead." Annual review of public health Vol12 No.1, pp. 111-140.

Newman, A. (2002). The Tropical Rainforest: With a Blueprint for its Survival. New York: Checkmark. (No title).

Nfor, B. N &Akaegbobi, I. M. (2012). Inventory of the Quaternary Geology and the Evolution of the Oguta Lake, in Southeastern Nigeria, Quaternary International, vol.279-280, pg. 351.

Nnaji, O. A. (2011). An assessment of Developmental potential of Oguta Lake as a tourist destination. Review of Tourism Research.9 (6).

Nwachukwu, M. A., Feng, H., &Alinnor, J. (2010). Assessment of heavy metal pollution in soil and their implications within and around mechanic villages. *International Journal of Environmental Science & Technology*, *7*, pp. 347-358.

Ohaturuonye, S.O., Okeke, P.A & Igwe, G.W. (2024). Evaluation of Heavy Metal Levels in Water and Sediment Samples from Oguta Lake, Imo State, Nigeria. International Journal of Water Research. Volume 6. Issue 2.

Okoye, P.A.C., Enemuoh, R.E &Ogunjiofor, J.C. (2002). Traces of heavy metals in marine crabs. Journal Chemical Society Nigeria, 27, pp. 76-77.

Olabaniyi, O.B. &Owoyemi, F.B., 2004, Quality of Groundwater in the Deltaic Plain Sands Aquifer of Warri. Water Resources Journal, Vol.15, pp. 38-45.

Onyeagocha, A. C. (1980). "Petrography and depositional environment of the Benin Formation." J. Min. geol Vol17 No.2, pp. 147-150.

Rainbow, P.S. (2007). Trace metal bioaccumulation: Models, metabolic availability and toxicity. Environment International Vol33, pp. 576–582.

Reyment, R.A. (1976). Geomagnetic reversal data statistically appraised. Tectonophysics, Vol31 No.1-2, pp. 73-91.

Shittu, U. A., Nwachukwu, M. O., & Ofoegbu, P. U. (2021). Studies on Physicochemical Properties and Heavy Metal Concentration in Water and Sediment Samples from Oguta Lake, Imo State Nigeria. *Journal of Environmental Treatment Techniques*, *11*(1), pp. 1-6.

Simpson, S.L., & Batley, G.E. (2007). Predicting metal toxicity in sediments: critique of current approaches. Integrated Environmental Assessment and Management Vol3, pp. 18–31.

Snow, K., Doud, L., Hagerman, R., Hull, C., Hirst, M. C., Davies, K. E., & Thibodeau, S. L. (1992). Analysis of mutations at the fragile X locus using the DNA probe Ox1. 9. *American journal of medical genetics*, *43*(1-2), pp. 244-254.

Sonibare, O. O., &Ekweozor, C.M. (2001). "Distribution of pentacyclic triterpanes and steranes in relation to the origin and thermal maturity of crudes from the Niger Delta, Nigeria." J. Min. Geol Vol37, pp. 37-43.

Uzukwu, E. M., Davies, I. C., Ogueri, C & Sulaiman, Y. (2024). Appraisal on Heavy Metal Contamination In Tissues (Gills, Intestine, Liver, And Fillet) Of Parachanna Obscura And The Physicochemical Properties Of Oguta Lake, South-Eastern Nigeria. Scientia Africana, Vol. 23 (No. 3), pp. 297-310.

Wirnkor, V. A., Iheanyichukwu, O. A., Ebere, E. C., Ngozi, V. E., Natheniel C, O., Kingsley, O. U & Amaka, A. P. (2021). Petroleum Hydrocarbons and Heavy Metals

Risk of Consuming Fish Species from Oguta Lake, Imo State, Nigeria. *Journal of Chemical Health Risks*, *11*(1).

World Health Organization (2017). Guidelines for drinking-water quality: Fourth edition incorporating the first addendum, 10.1016/S1462–0758(00)00006–6.

Zorer, Ö. S., Ceylan, H., & Doğru, M. (2008). Assessment of some trace heavy metals and radioactivity concentration in water of Bendimahi River Basin (Van, Turkey). *Environmental monitoring and assessment*, *147*, pp. 183-190.