https://dx.doi.org/10.4314/dujopas.v10i2c.26
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 10 No. 2c June 2024*

Effects of the Urban Runoff on Fish in the Ikpoba River: Heavy Metal Contamination and Brain Pathology

Ogbeide Ozekeke* and Kanu-Orji Chidera

Department of Environmental Management and Toxicology,
Faculty of Life Sciences,
University of Benin,
Benin City,
Edo State,
Nigeria
.
Email: ozekeke.ogbeide@uniben.edu

Abstract

This study investigated the ecological impact of urban runoff on fish fauna in Ikpoba River, Benin City, Nigeria. In particular, we focused on heavy-metal contamination and its effects on brain tissue pathology. During a three-month period (June–August 2023), water, sediment, and fish samples were collected from two locations with varying effluent attributes. Atomic Absorption Spectrophotometry was employed to determine the heavy metal concentrations (Cr, Co, Cd, Ni, and Pb) in the samples. Our findings revealed fluctuating heavy metal levels in the water and sediment samples. Notably, Ni exhibited the highest concentration in the sediment during July. The brain tissues of Clarias gariepinus and Tilapia 279illi demonstrated metal accumulation, with Nickel, Chromium, and Cobalt being prevalent. Histopathological analysis indicated progressive changes, including mononuclear exudates in the granular layer of the brain tissues of C. gariepinus by August, suggesting an inflammatory response. Urban runoff has emerged as a significant source of heavy metal pollution in the Ikpoba River, leading to bioaccumulation in fish and alterations in the brain tissue. Comprehensive monitoring and management strategies are crucial for mitigating the impact of runoff on aquatic ecosystems and safeguarding fish and human health. These results provide valuable insights into effective water resource management policies and enhance our understanding of the effects of urban pollution on freshwater environments.

Keywords: Ikpoba River, Heavy metals, Fish, Sediment, Antioxidant enzymes.

INTRODUCTION

Urban runoff is a significant environmental concern because it substantially pollutes urban water bodies and carries a variety of contaminants including heavy metals (Lin, 2003; Zanoletti and Bontempi, 2023; Erickson *et al.*, 2013). Pollutants can arise from a range of sources like vehicle emissions, atmospheric deposition, and material wear, posing a threat to the ecosystem and water quality.(Erickson et al., 2013, Geronimo *et al.*, 2014, Zgheib *et al.*, 2012).

The mixture of pollutants originating from various human activities, such as urbanization, industrialization, agricultural practices, and the use of synthetic food dyes and heavy metals,

Author for Correspondence

eventually contaminates water bodies and poses a severe threat to aquatic ecosystems (Isangedighi and David, 2019; Gulati *et al.*, 2022; Javed and Usmani, 2019; Sharma *et al.*, 2024). Sediment runoff harms aquatic ecosystems by smothering aquatic plants that are vital for fish habitats, food, oxygen production, and nutrient cycling (De and Roy, 2019). They can also cover fish eggs, hinder development, cause mortality, and damage fish gills, which are crucial for respiration (Dharmono *et al.*, 2022). Sediments carry pathogens, increase fish stress, and lead to immunosuppression, thereby increasing disease risk (Biggs *et al.*, 2021). River water quality has been a subject of study, with researchers seeking to understand its suitability for human consumption and overall pollution status (Osa-Iguehide *et al.*, 2016, Enuneku and Ineh, 2020, Obasohan *et al.*, 2007).

Heavy metals, which are often present in urban runoff, pose a significant threat to the health of fish (Zhuzzhassarova *et al.* 2024). Studies have shown that heavy metals, such As, Cd, Hg, and Pb, can accumulate in marine and freshwater fish, potentially causing adverse health effects (Zhuzzhassarova et al., 2024, Liu *et al.* 2018; Zhuzzhassarova Khan, 2018). These metals can alter the haemato-biochemical parameters of fish, leading to abnormalities in various blood cells (Shahjahan *et al.*, 2022, Ahmed *et al.*, 2022). Studies have shown that fish residing in contaminated water bodies can suffer from reduced nutritive value and flesh quality owing to the accumulation of these non-essential metals (Abbas *et al.*, 2021). These toxicants can disrupt normal physiology and function of fish, leading to adverse health effects (Gulati et al. 2022, Shahjahan et al. 2022).

Exposure to heavy metals such as Hg, Cu, and Co can induce significant pathological changes in the brain (James *et al.* 2011; Singh and Ansari, 2017; Bose *et al.* 2015; and Nedzvetsky *et al.* 2022; Rehman *et al.* 2021b). Even at low concentrations, these metals have been shown to cause histopathological abnormalities in the brain tissues of various fish species, leading to neurotoxicity, oxidative stress, and genotoxicity (Singh and Ansari, 2017).
In this study, we investigated the ecological effects of urban runoff on benthic and pelagic fish fauna of the Ikpoba River. We investigated the extent of heavy metal contamination and its impact on the brain tissue pathology in fish. This study provides valuable insights into the impact of urban runoff on aquatic ecosystems and contributes to the development of effective strategies for water resource management and conservation.

MATERIAL AND METHODS

Study Area

This research project was conducted in Benin City, which is situated within the humid tropical rainforest belt of Nigeria (Chukwuka and Ogbeide, 2021; Victor and Ogbeibu, 1985). The Ikpoba River, an important feature of the city, supports the activities of local communities but is also impacted by human activities, such as waste disposal and wastewater discharge (Chukwuka and Ogbeide, 2021; Tawari-Fufeyin and Ekaye, 2007; Victor and Ogbeibu, 1985). The proximity of these activities to the river raises concerns regarding possible pollution and environmental degradation.

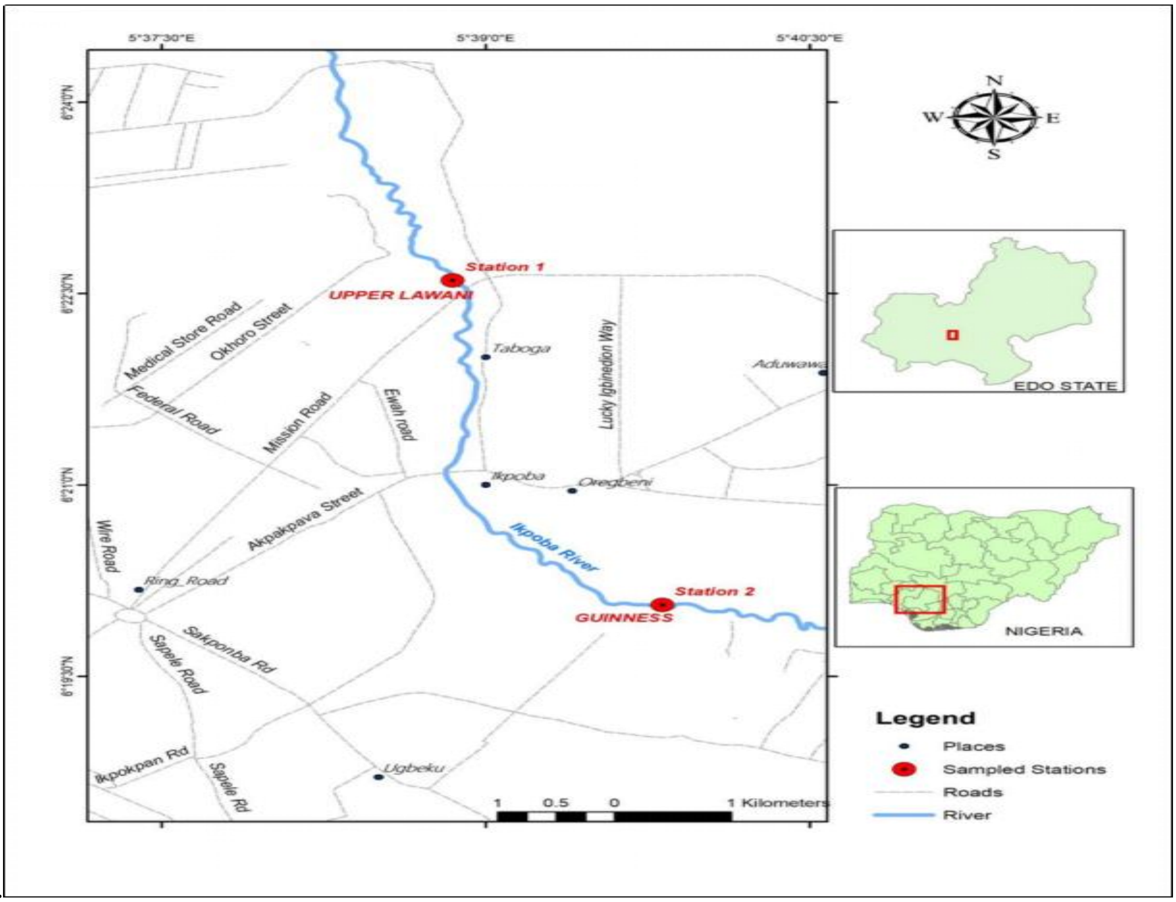


FIG 1: Map of Benin City showing the Ikpoba River and various sampling points.

Sampling and Sample Preparation

Two sites with distinct effluent characteristics were selected for this study. The first site, situated upstream of the effluent outflow point, was considered relatively free from contamination. In contrast, the second site comprised the effluent discharge area from the brewery. From June to August 2023, water samples were procured from both the bottom (benthic) and surface (pelagic) zones of the Ikpoba River during monthly field trips, following the protocol outlined by Onyidoh *et al.* (2017). Sediment samples were collected using a grab sampling method and fish samples were obtained using a fishing net, as per the technique detailed in (Chukwuka. *et al.*, 2019).

Upon arrival at the laboratory, the fish were thoroughly cleaned and individually stored in polyethylene bags at -10°C for subsequent identification and preservation. Heavy metal concentrations in the water, sediment, and fish samples were determined using the procedures outlined by Davies and Ekperusi (2021). A Solar 969 Unicam Series model Atomic Absorption Spectrophotometer (AAS) was utilized to analyze the heavy metals (Cr, Co, Cd, Ni, and Pb), following the method detailed by Zangina *et al.* (2019). Each sample was analyzed in triplicate to ensure that the results were representative. Metal concentrations were computed using a standard calibration plot technique.

Extraction and Analysis of Heavy Metals

The detection of heavy metals in the water and sediment samples was performed using the methods described by Davies and Ekperusi (2021). A 25 mL aliquot of water was transferred to a porcelain crucible and treated with 1 mL of concentrated nitric acid (HNO_3) and 3 mL of concentrated hydrochloric acid (HCl). The mixture was placed in a steam bath for approximately 30 min and then allowed to cool. The digested sample was diluted to 50 mL with distilled water and preserved in plastic containers for subsequent heavy metal analysis, ensuring a standardized procedure across all water samples.

For the analysis of sediments, a 10 g portion of ground and sieved sediment was placed in a porcelain crucible. This was followed by the addition of 25 mL of distilled water, 1 mL of concentrated nitric acid (HNO3), and 3 mL of concentrated hydrochloric acid (HCl). The sample was heated in a steam bath for roughly an hour and subsequently cooled. The digested sample was filtered and the volume was adjusted to 50 mL using distilled water. The filtrate was preserved in plastic containers for heavy metal analysis to ensure uniformity across all sediment samples.

The length and weight of the fish were carefully measured, and their livers were surgically excised, weighed, and reserved for heavy metal determination. The samples were digested with 1 mL of concentrated nitric acid (HNO_3) and 3 mL of concentrated hydrochloric acid (HCl) until a clear and transparent solution was obtained, following the method outlined by Jabeen *et al.* (2012). The digested samples were diluted to the required volume using double-distilled water in a 500 mL volumetric flask. Following wet digestion, fish organ samples were analyzed for heavy metals.

The heavy metals in the water, sediment, and fish samples were analyzed using an Atomic Absorption Spectrophotometer (AAS) Solar 969 Unicam Series model. Each metal (Cr, Co, Cd, Ni, and Pb) was analyzed using a specific hollow cathode lamp. Each sample was analyzed three times to ensure representative results, and the metal concentrations were calculated using a standard calibration plot method, as described by Chukwuka. et al. (2019).

Histopathological analysis

The brain tissue specimens were preserved in 10% formalin to prevent decomposition (Yildirim *et al.*, 2006). This was followed by a sequential dehydration process using graded alcohol concentrations of 50%, 70%, 80%, and 100% for 90 min each (Slaoui and Fiette, 2011). The tissue was then clarified with pure xylene to remove any residual alcohol. This was succeeded by a two-hour impregnation in molten paraffin wax, preparing the tissue for embedding. The embedded tissues were then thinly sliced using a microtome and stained with hematoxylin-eosin (Yildirim *et al.*, 2006). (Yildirim et al., 2006). Finally, histological features, including any histopathological changes within the brain, were examined and documented using a microscope equipped with a digital camera connected to a computer.

Statistical Analysis

The collected data were statistically evaluated using version 21 of the SPSS software. The processed data are presented in summary tables as mean ± S.E. To scrutinize the measurements at each sampling site, we used one-way ANOVA and Duncan's multiple range (DMR) test.

RESULTS AND DISCUSSION

Heavy metals in water samples

Figure 2 illustrates the concentrations of various metals, including Cd, Ni, Co, Pb, and Cr, in mg/l, over three months (June, July, and August). Observations indicated an increase in the concentration of all metals from June to July, with a slight decrease or stabilization in August, except for Cr, which continued to rise. These findings imply potential risks to ecosystem health owing to the toxicity of these metals at high concentrations (Sharma *et al.*, 2023; Jadaa and Mohammed, 2023; Arora *et al.*, 2023). Aquatic life may be adversely affected, leading to a decrease in biodiversity and disruption of aquatic ecosystems (Hama *et al.*, 2023; Sharma et al., 2024). Human life is also at risk, as these metals can contaminate water sources, leading to health issues (Sharma et al., 2023; Izegaegbe *et al.*, 2022).

Possible sources of these metals are industrial discharges, agricultural runoff, or natural geological processes. Sources of heavy metal contamination in the Ikpoba River include mixed effluents from industrial areas, high vehicular traffic density, and runoff water (Oguzie, 2006). Additionally, soil erosion and the Benin Water Storm project have contributed to the presence of heavy metals in sediments (Enuneku and Ineh, 2020). Effluent samples collected from discharge points to the river showed higher concentrations of heavy metals compared to river water itself, indicating direct pollution from these effluents (Oguzie and Okhagbuzo, 2010). Variations in metal concentrations may be attributed to changes in industrial activity levels or environmental conditions, such as rainfall, which can dilute or concentrate pollutants.

The presence and impact of heavy metals in the Ikpoba River have also been assessed in several studies, including that by Imiuwa *et al.* (2014), Wang et al. (2013) and Osa-Iguehide et al. (2016), Obasohan et al. (2007), Igboanugo *et al.* (2013). These studies, along with current findings, underscore the importance of regular monitoring and analysis of metal concentrations in water bodies to safeguard ecosystem health and human life.

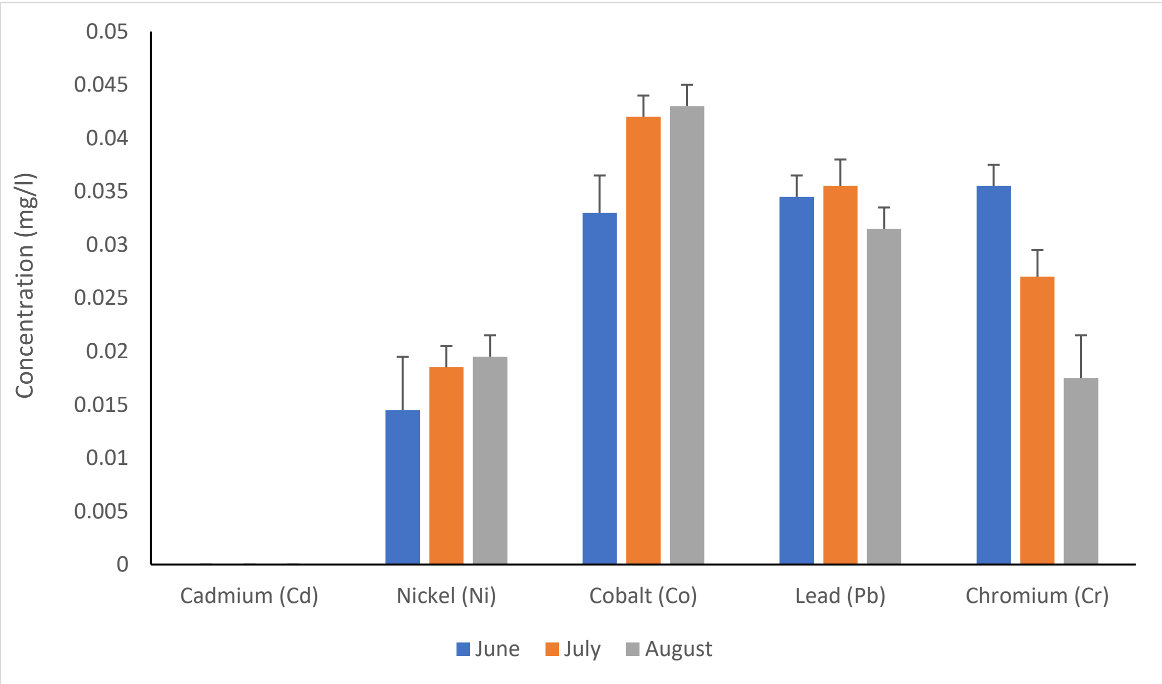


Figure 2: Concentration of Heavy metals in water from Ikpoba River.

Heavy metals in sediment samples

A study on heavy metal concentrations in Ikpoba River sediment revealed fluctuations in Cd, Ni, Co, Pb, and Cr levels over three months similar to reports by Ujah *et al.* (2023). Notably, Ni showed a significantly higher concentration in July than in other months, indicating potential ecological and health risks (Areguamen *et al.*, 2023). Elevated levels of these metals in sediments can lead to toxicity and bioaccumulation, thereby impacting ecosystem, aquatic, and human health (Amqam *et al.*, 2020; Oguzie, 2006; Pandiyan *et al.*, 2021; Ipeaiyeda and Onianwa, 2018). Human exposure to heavy metals, particularly known carcinogens such as Ni, through contaminated water or aquatic organisms poses serious health hazards (Jonah and Mendie, 2023). These findings underscore the importance of monitoring and addressing heavy metal contamination in the Ikpoba River to safeguard both aquatic ecosystems and human well-being. The possible sources of these metals in the sediment of the Ikpoba River could be diverse, ranging from industrial discharge and agricultural runoff to natural geological occurrences, as reported by Areguamen et al. (2023).

The sources of heavy metals in Ikpoba River sediments are diverse, stemming from both anthropogenic and natural origins (Oguzie, 2006). Potential contributors include mixed effluent sources, high vehicular traffic density, and runoff from industrial areas (Odigie, 2014, Oguzie, 2006; Oguzie and Okhagbuzo 2010). Abattoir waste, industrial waste from breweries, agricultural runoff, and wastewater from car washes also play a role (Odigie, 2014). Effluent discharge is a significant source of heavy metals, with higher concentrations found in effluents than in water samples (Oguzie and Okhagbuzo, 2010).

The variations in metal concentrations in the sediment could be attributed to changes in environmental conditions, such as rainfall or temperature, or to anthropogenic activities increasing at certain times (Clark *et al.*, 2014; Caldwell Eldridge and Hornberger, 2023; Kimball, 1999; Guo and Deng, 2022).

The presence of heavy metals in sediments from the Ikopba River was also reported by Osa-Iguehide et al. (2016), Olele *et al.* (2013), Imiuwa et al. (2014), Obasohan et al. (2007) and Enuneku and Ineh (2020),. Contrary to previous findings, the current study revealed a distinct pattern, with nickel exhibiting the highest concentration in July. This variation could be attributed to factors such as varying sampling periods, locations, or fluctuations in environmental and anthropogenic (Egun and Oboh, 2022, Enuneku and Ineh, 2020)

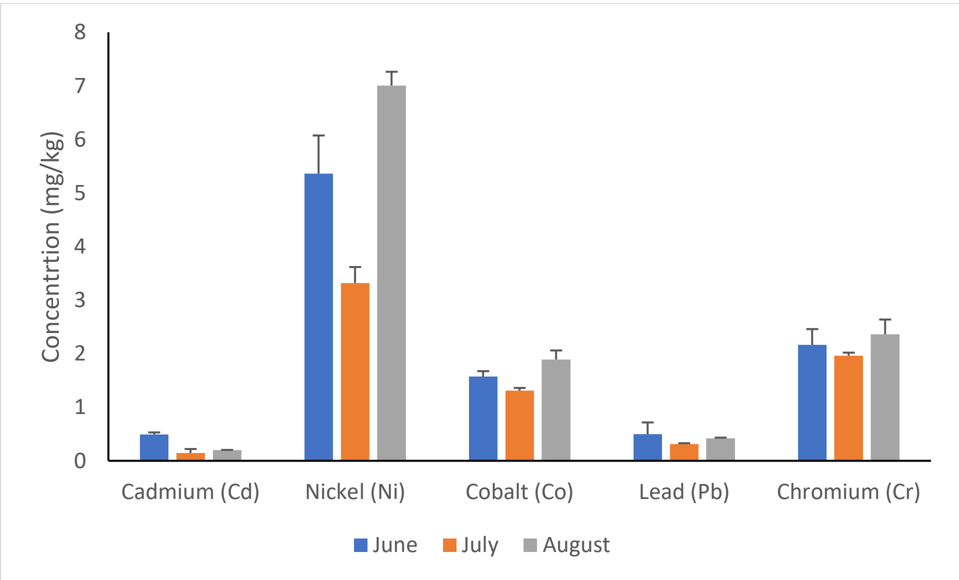


Figure 3: Concentration of Heavy metals in sediments from the Ikpoba River.

The ecological effects of urban runoff on benthic and pelagic fish fauna in the Ikpoba River, Benin City, Edo State have been investigated, with a focus on heavy metal contamination and brain tissue pathology. This study specifically examined the concentrations of heavy metals in the brains of *C. gariepinus* and *T. zilli* collected from the Ikpoba River.

Heavy Metals in Brains of *C. gariepinus*

Table 1 presents the concentrations of heavy metals (Ni, Pb, Cr, Cd, and Co) in the brains of *C. gariepinus* from the Ikpoba River over three months (June, July, and August).

Table 1: Mean Concentration (ug/kg) of heavy metals in brains of *C. gariepinus*

	Ni	Pb	Cr	Cd	Co
June	0.5162	0.0362	0.4324	0.0194	0.039
July	0.3838	0.0332	0.2868	0.015	0.044
August	0.0332	0.00336	0.04368	0.00248	0.00296

The concentrations of all heavy metals decreased from June to August. The highest concentrations of all the metals were observed in June, with Ni being the most prevalent, followed by Cr, Co, Pb, and Cd. By August, the concentrations of all metals had significantly decreased. This decreasing trend in concentrations from June to August may be influenced by seasonal variations, natural sources, and physicochemical parameters, such as water temperature, EC, DO, and pH (Postegal *et al.*, 2022). Such fluctuations in heavy metal concentrations highlight the dynamic nature of metal pollution in waterbodies (Dagdag *et al.* 2023).

Heavy metals pose significant risks to fish health as they can disrupt metabolic processes and mimic essential elements, leading to adverse effects. Exposure to heavy metals has been linked to various health hazards in fish, including changes in growth rate, physiological function, mortality, and reproduction (Chandrapalan and Kwong, 2021; Jamil *et al.*, 2023; Choudhary *et al.*, 2023).

Similarly, studies have shown the presence of heavy metals in fish brains. Heavy metals, such As, Pb, Hg), chromium (Cr), and cadmium (Cd), have been detected in the brains of C. gariepinus, indicating bioaccumulation (Obinna *et al.*, 2021, Okeke *et al.*, 2023). Furthermore, studies have revealed variations in metal concentrations across different organs, including the brain of *C. gariepinus* (Onyidoh *et al.*, 2018). The accumulation of heavy metals in fish brains is concerning because of potential health risks and emphasizes the need for monitoring and control measures to prevent adverse effects on aquatic organisms and human consumers (Hagras *et al.*, 2017, Onyidoh et al., 2018). Other studies that have reported the presence of heavy metals in the brain tissues of *Claris gariepinus* include Fadzil *et al.* (2019), who reported that heavy metals, such as cadmium, can accumulate in the brain of fish and have detrimental effects on neurological function. Similarly, Adeyemo (2008) reported the presence of Pb in C. gariepinus samples, which had detrimental effects on aquatic organisms. Furthermore, Aktas *et al.* (2016) reported trace concentrations of metals in the organs of *C. gariepinus*, including the brain, and reported that the presence of these trace elements in the brain tissue of fish suggests potential exposure to heavy metals, which may be influenced by seasonal variations in habitat conditions.

Heavy Metals in Brains of *T. zilli*

The concentrations of heavy metals (Ni, Pb, Cr, Cd, and Co) in the brains of T. zilli from the Ikpoba River over three months (June, July, and August) were relatively high, with Ni (0.4186), Cr (0.499), and Co (0.043) being the most prevalent. However, in July, there was a significant decrease in the concentrations of all the metals, with values ranging from 0.0018 (Pb) to 0.0173 (Ni). In August, the concentrations increased again but were still lower than the initial values observed in June. (Postegal et al., 2022). The fluctuation in metal concentrations can be attributed to various factors, such as seasonal variations, anthropogenic inputs, and geomorphologic influences (Kamzati *et al.*, 2020). This pattern highlights the dynamic nature of metal pollution in waterbodies (Dagdag et al. 2023).

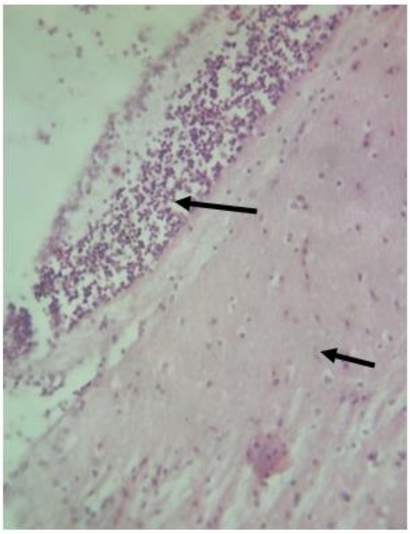
Table 2: Mean Concentration (ug/kg) of heavy metals in brains of *T. zilli*

	Ni	Pb	Cr	Cd	Co
June	0.4186	0.039	0.499	0.0244	0.043
July	0.017	0.002	0.006	0.0027	0.009
August	0.152	0.018	0.13	0.016	0.033

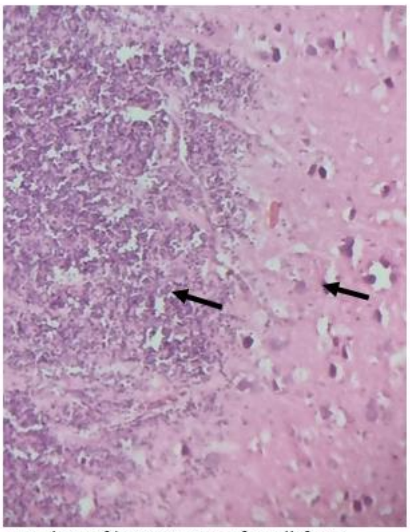
The fluctuating trend in metal concentrations could be attributed to various factors such as changes in water conditions, diet, or exposure to different sources of pollution. These fluctuations in heavy metal concentrations can have significant implications for fish health (Adekolurejo *et al.*, 2023, Mastan *et al.*, 2023). High concentrations of heavy metals can interfere with metabolic processes, impair feeding and breeding, and even cause toxicity (Chandrapalan and Kwong, 2021, Javed and Usmani, 2019, Sharma et al., 2024).

There are similar reports on the presence of heavy metals in *the brain of T. zilli*. Karataş and Kalay (2002) studied lead accumulation in *T. zilli* and found that higher lead concentrations and longer exposure times increased lead levels in the tissues. The brain showed a significant lead accumulation ratio of 25.56%, highlighting the potential neurological impacts on aquatic organisms. Similarly, Akan *et al.* (2012) studied the bioaccumulation of heavy metals in fish samples from the Benue River in Vinikilang, Adamawa State, Nigeria, and reported that the concentration of metals in the brains of tilapia was very significant. Elgaml *et al.* (2019) studied the effects of heavy metal pollutants on the reproduction of Nile tilapia. The research found Significant differences were observed in heavy metal levels, particularly Fe and Cu, in various organs of the fish, including the liver, brain, ovaries, and testes. The concentrations of these metals in the brain of Nile tilapia were notably affected by exposure to heavy metal pollutants, highlighting their potential impact on the reproductive health of fish. These studies, along with those by Eneji *et al.* (2011), Fernö *et al.* (2020a) and Senger *et al.* (2011) have provided valuable insights into the impact of heavy metal concentrations on fish health and the potential risks associated with their bioaccumulation in aquatic ecosystems.

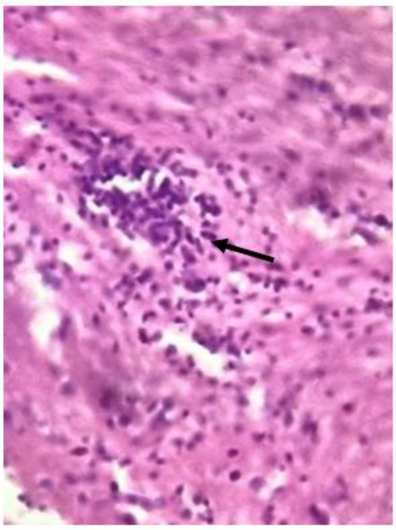
Histopathology of brain issues from Fishes in Ikpoba River



Histology of brain tissues of *T. zilli* Ikpoba river in June

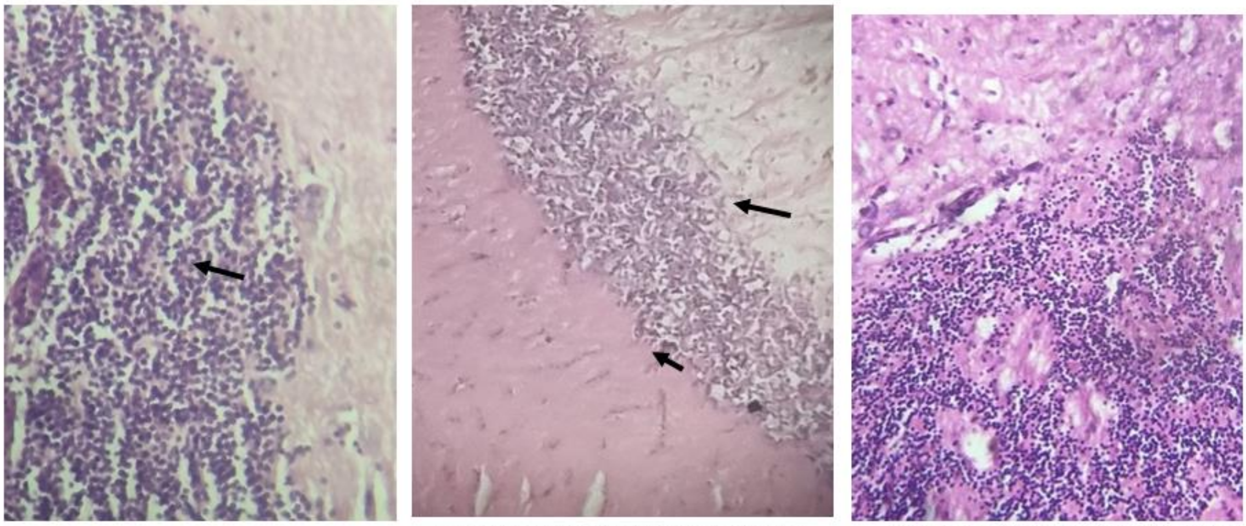


Histology of brain tissues of *T. zilli* from Ikpoba river in July



Histology of brain tissues of *T. zilli* Ikpoba river in August

Figure 4: Histology of brain tissues of *T.zilli* from Ikpoba river



Histology of brain tissues of C. *gariepinus*

Histology of brain tissues of C. *gariepinus* from Ikpoba river in July

Histology of brain tissues of C. *gariepinus* from Ikpoba river in August

Figure 5: Histology of brain tissues of *C. gariepinus* from Ikpoba river

Figure 4 depicts the histological representations of *T. zilli* brains, highlighting the various pathologies. Observations in June revealed a prominent molecular and granular layer with a well-defined Nissl substance. Similar layers were observed in July, although the Nissl substances were less pronounced. In August, the display of lamellae was evident, with primary lamellae appearing longer and having unremarkable rakers but projecting blunt tips and a prominent lacuna, which is likely a capillary lumen.

Histological representations of *T. zilli* brains show varying pathologies across different months. In June, a prominent molecular and granular layer with well-defined Nissl substance was observed. Similar layers were observed in July but with less pronounced Nissl substances. By August, the display of lamellae became evident, with primary lamellae appearing longer and having unremarkable rakers but projecting blunt tips and a prominent lacuna, likely a capillary lumen.

Histopathological changes in fish brains, such as encephalitis, meningitis, and edema, can indicate stress responses and potential health issues (Hc and Sultana, 2014, Matthiessen and Roberts, 1982). Exposure to environmental contaminants such as pesticides and heavy metals can induce such alterations, affecting the brain tissues of fish (Ruiz-Picos *et al.*, 2015; Rehman *et al.*, 2021a). These changes may include inflammatory infiltrates and glial scarring, reflecting the impact of pollutants on fish health (Prakashbansal, 2023; Phrompanya *et al.*, 2021; Tenji *et al.*, 2020). Changes in the Nissl substance, which is crucial for protein synthesis in neurons, can significantly affect neuronal function (Miroyiannis *et al.*, 1963; Sterman, 1984).

Additionally, alterations in the lamellae, such as blunt tips and a prominent lacuna, may suggest changes in the vascular system of the fish brain, potentially affecting the blood flow and oxygen supply (Salamat and Zarie, 2016). Nissl plays a vital role in active protein metabolism within nerve cells, and any disruption in its distribution or composition can lead to functional impairment (Sterman, 1983). Similar trends were observed in other studies. For instance, a study on Nile tilapia (*Oreochromis niloticus*) exposed to temperature shocks showed significant histopathological changes in the brain, indicating that environmental stressors can lead to observable changes in fish brain histology (Phrompanya et al., 2021). Another study on the effects of AgNPs on *T. zilli* and *T. niloticus* also revealed severe degenerative changes in the neuropils of fish exposed to high concentrations of AgNPs (Mansour *et al.*, 2021).

Figure 5 illustrates the evolution of the brain histology of *C. gariepinus* from the Ikpoba River over a period of three months, beginning in June and ending in August. In June, the histology demonstrates an intricate arrangement of molecular and granular layers, characterized by enlarged Nissl substances that are prominently displayed. The tissue exhibited a pale purple hue with darker spots representing Nissl staining. By July, the histology remained largely unchanged from the previous month, featuring the same detailed molecular and granular layers and prominent Nissl substances.

In August, histology revealed a noticeable alteration. Mononuclear exudates were visible within the granular layer, indicating some form of progression or change over time. The tissue also appeared to have a deep purple hue. The general trend observed over these three months suggests a progression in the brain histology of *C. gariepinus,* with the emergence of mononuclear exudates in the granular layer by August. This suggests a possible response to a particular condition or stimulus within brain tissue.

The observed changes in the brain histology of *C. gariepinus* over the three-month period indicate a potential response to environmental or internal stimuli. The emergence of mononuclear exudates within the granular layer by August suggests an inflammatory response, which is often a sign of an underlying issue, such as infection, exposure to toxins, or other stressors (Okogwu *et al.*, 2016; Adedokun *et al.*, 2021). This could potentially impact the health of fish, affecting their behavior, cognitive abilities, and overall well-being (Alexander and Kurt, 2020; Fernö *et al.*, 2020b). Histological studies of various fish species, including *C. gariepinus*, have highlighted the significance of brain histology in health issues. Studies have demonstrated that exposure to pollutants such as lead chloride can lead to severe histological lesions in the brain (Okunade *et al.* 2023). Additionally, studies on the effects of water quality changes due to crude oil exposure have shown histopathological alterations in the brains of *C. gariepinus,* including neuronal necrosis and gliosis (Alkshab and Taha, 2021; Eriegha et al., 2019). These findings emphasize the importance of assessing brain histology in fish health evaluations.

CONCLUSION

This study assessed the ecological consequences of urban runoff on fish species in Ikpoba River, Benin City, Nigeria. The focus was on heavy metal contamination and its impact on the brain tissue pathology. The results indicate fluctuating levels of heavy metals in the water and sediment samples, revealing significant pollution from urban runoff. The brain tissues of *C. gariepinus* and *T. zilli* showed bioaccumulation of these metals, which caused histopathological changes. In August, the brain tissues from *C. gariepinus* showed mononuclear exudates in the granular layer, indicating potential inflammatory responses and neurological effects. To protect fish and human health, it is essential to address the heavy metal pollution in the Ikpoba River. This study provides valuable insights for developing effective water resource management policies and improving our understanding of the effects of urban pollution on freshwater habitats.

REFERENCES

Abbas, K., Alam, M. and Kamal, S. 2021, 'Heavy metals contamination in water bodies and its impact on fish health and fish nutritional value', *International Journal of Fauna and Biological Studies*, vol. 8, pp. 43-49.

Adedokun, R., Aina, O., Akinola, O., Igado, O. and D, T. 2021, 'Histology of selected organs of Clarias gariepinus infected with the metacercaria of a digenean trematode', *Tropical Veterinarian*, vol. 39, pp. 48-56.

Adekolurejo, O., Osungbemiro, N., Adeyem, O. and Falowo, T. 2023, 'Heavy metal concentrations and distribution in water, sediment, and catfish, Clarias gariepinus obtained from aquaculture farms in Ondo, Nigeria', *Science View Journa*l, vol. 4, pp. 279-284.

Adeyemo, O. 2008, 'Histological alterations observed in the liver and brain of Clarias gariepinus exposed to chronic sublethal dose of lead', *Bulletin of the European Association of Fish Pathologists*, vol. 28.

Ahmed, I., Zakiya, A. and Fazio, F. 2022, 'Effects of aquatic heavy metal intoxication on the level of hematocrit and hemoglobin in fishes: A review', *Frontiers in Environmental Science*, vol. 10, 919204.

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,' *American Journal of Analytical Chemistry*, vol. 3, no. 11, p. 10.

Aktas, T., Dayangac, A., Ciftci, H. and Yilmaz, M. 2016, 'Determination of some trace element levels in different seasons in muscle, liver and brain tissues of Clarias gariepinus (Burchell, 1822),' *Journal of FisheriesSciences.com*.

Alexander, K. and Kurt, K. 2020, 'Fish brains: Anatomy, functionality, and evolutionary relationships', The Welfare of Fish.

Ali, H. and Khan, E. 2018, 'Bioaccumulation of non-essential hazardous heavy metals and metalloids in freshwater fish: Risk to human health', *Environmental Chemistry Letters*, vol. 16, pp. 903-917.

Alkshab, A. A. and Taha, A. M. 2021, 'Histological effect of lead chloride on the brain of Gambusia affinis', *Journal of Physics: Conference Series*, vol. 1818, 012024.

Amqam, H., Thalib, D., Anwar, D., Sirajuddin, S. and Mallongi, A. 2020, 'Human health risk assessment of heavy metals via consumption of fish from Kao Bay', *Reviews on Environmental Health*, vol. 35, pp. 257-263.

Areguamen, O.I., Ekwumengbo, P., Omoniyi, I., Okunola, O.J., Abdulkadir, A.T., Nnachi, C., Adanyi, D.N., Elebo, A. and Adeniji, S.E. 2023, 'Evaluation of the source, distribution and risk of metal contaminated stream sediment,' *Case Studies in Chemical and Environmental Engineering,* vol. 8, 100429.

Arora, V., Bithel, N. and Singh, R. 2023, 'A study on heavy metal sources and pollution: Challenge to biological and ecosystem', *Bulletin of Pure & Applied Sciences-Botany*, vol. 42, pp. 44-49.

Biggs, H.J., Haddadchi, A. and Hicks, D.M. 2021, 'Interactions between aquatic vegetation, hydraulics and fine sediment: A case study in the Halswell River, New Zealand', *Hydrological Processes*, vol. 35, e14245.

Bose, M.T.J., Ilavazhahan, M., Tamilselvi, R. and Viswanathan, M. 2015, 'Effect of heavy metals on the histopathology of gills and brain of fresh water fish Catla catla', *Biomedical and Pharmacology Journal*, vol. 6, pp. 99-105.

Caldwell Eldridge, S.L. and Hornberger, M.I. 2023, 'Spatiotemporal variations in copper, arsenic, cadmium, and zinc concentrations in surface water, fine-grained bed sediment, and aquatic macroinvertebrates in the upper Clark Fork Basin, western Montana—A 20-year synthesis, 1996–2016,' *Scientific Investigations Report*, Reston, VA.

Chandrapalan, T. and Kwong, R.W.M. 2021, 'Functional significance and physiological regulation of essential trace metals in fish' *Journal of Experimental Biology*, vol. 224.

Choudhary, P., Sharma, P., Kaur, S. and Randhawa, J. 2023, 'A comprehensive review on the deleterious effects of heavy metal bioaccumulation on the gills and other tissues of freshwater fishes', *Biosciences Biotechnology Research Asia*, vol. 20, pp. 395-405.

Chukwuka, A., Ogbeide, O. and Uhunamure, G. 2019, 'Gonad pathology and intersex severity in pelagic (Tilapia zilli) and benthic (Neochanna diversus and Clarias gariepinus) species from a pesticide-impacted agrarian catchment, south-south Nigeria', *Chemosphere,* vol. 225, pp. 535-547.

Clark, E.V., Odhiambo, B.K. and Ricker, M.C. 2014, 'Comparative analysis of metal concentrations and sediment accumulation rates in two Virginian reservoirs, USA: Lakes Moomaw and Pelham', *Water, Air, & Soil Pollution*, vol. 225, 1860.

Dagdag, O., Quadri, T.W., Haldhar, R., Kim, S.-C., Daoudi, W., Berdimurodov, E., Akpan, E.D. and Ebenso, E.E. 2023, 'An overview of heavy metal pollution and control', Heavy Metals in the Environment: Management Strategies for Global Pollution, pp. 3-24.

Davies, I.C. and Ekperusi, A.O. 2021, 'Evaluation of heavy metal concentrations in water, sediment and fishes of New Calabar River in Southern Nigeria', *Journal of Limnology and Freshwater Fisheries Research*, vol. 7, pp. 207-218.

De, M. and Roy, C. 2019, 'Diverse role of macrophytes in aquatic ecosystems: A brief review', *International Journal of Experimental Research and Review*, vol. 19, pp. 40-48.

Dharmono, D., Mahruddin, M., Irianti, R. and Fajeriadi, H. 2022, 'Aquatic plants as niche for lay eggs and raising juveniles by freshwater fish in three swamp habitats in South Kalimantan, Indonesia', *Biodiversitas Journal of Biological Diversity*, vol. 23.

Egun, N.K. and Oboh, I.P. 2022, 'Surface water quality evaluation of Ikpoba reservoir, Edo State, Nigeria', *International Journal of Energy and Water Resources*, vol. 6, pp. 509-519.

Elgaml, S.A., Saad, T.T., Hamed, M.F. and Zaki, V.H. 2019, 'Effects of heavy metal pollutants on the reproduction of Nile tilapia', no additional information provided.

Eneji, I., Sha'ato, R. and Annune, P. 2011, 'Bioaccumulation of heavy metals in fish (Tilapia zilli and Clarias gariepinus) organs from River Benue, North – Central Nigeria,' *Pakistan Journal of Analytical & Environmental Chemistry*, vol. 12, pp. 25-31.

Enuneku, A. and Ineh, F. 2020, 'Assessment of human health risk for surface sediments of Ikpoba River contaminated by heavy metals', *Journal of Applied Sciences and Environmental Management*, vol. 23, p. 2013.

Erickson, A.J., Weiss, P.T. and Gulliver, J.S. 2013, 'Impacts and composition of urban stormwater', in Optimizing stormwater treatment practices: A handbook of assessment and maintenance, pp. 11-22.

Eriegha, O.J., Omitoyin, B.O. and Ajani, E.K. 2019, 'Water soluble fractions of crude oil deteriorates water quality parameters and alters histopathological components of juvenile Clarias gariepinus', *Animal Research International*, vol. 16, pp. 3308-3318.

Fadzil, N.I., Ahmad, S.A., Yasid, N.A., Sabullah, M.K., Daud, H.M., Khalid, A., Padrilah, S.N. and Shukor, M.Y. 2019, ' Characterization of cholinesterase and histopathological features of brain of Clarias gariepinus following exposure to cadmium,' *Journal of Environmental Biology*, vol. 40, pp. 133-142.

Fernö, A., Folkedal, O., Nilsson, J. and Kristiansen, T.S. 2020a, 'Inside the fish brain: cognition, learning and consciousness', in Kristiansen, T.S., Fernö, A., Pavlidis, M.A. and Van de Vis, H. (eds.) The Welfare of Fish, Cham: Springer International Publishing, pp. 149-183.

Fernö, A., Folkedal, O., Nilsson, J. and Kristiansen, T.S. 2020b, 'Inside the fish brain: cognition, learning and consciousness', The Welfare of Fish, pp. 149-183.

Geronimo, F.K.F., Maniquiz-Redillas, M.C., Tobio, J.A.S. and Kim, L.H. 2014, 'Treatment of suspended solids and heavy metals from urban stormwater runoff by a tree box filter', *Water Science and Technology,* vol. 69, pp. 2460-2467.

Gulati, R., Kour, A. and Sharma, P. 2022, 'Ecological impact of heavy metals on aquatic environment with reference to fish and human health', *Journal of Applied and Natural Science,* vol. 14, pp. 1471-1484.

Guo, Y. and Deng, B. 2022, 'Seasonal variation of heavy metals in suspended sediments downstream the Three Gorges Dam in the Yangtze River', *Environmental Monitoring and Assessment*, vol. 194, p. 660.

Hagras, A.E., El-Gammal, M.I., Abdrabouh, A.E. and El-Bahnasy, H.T. 2017, 'Environmental impact assessment of heavy metals on African catfish (Clarias gariepinus) of some drains in Dakahlia Governorate, Egypt', *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, vol. 11, pp. 39-51.

Hama, A.K., Mustafa, F.S., Omer, K.M., Hama, S., Hamarawf, R.F. and Rahman, K.O. 2023, 'Heavy metal pollution in the aquatic environment: efficient and low-cost removal approaches to eliminate their toxicity: a review', *RSC Advances*, vol. 13, pp. 17595-17610.

Hc, S.V.K. and Sultana, M. 2014, 'Ultra morphological and histopathological studies in liver and kidney of Anabas testudineus collected from Buckingham Canal, at Uppalam area, Chennai, India', *International Journal of Novel Trends in Pharmaceutical Sciences*, vol. 4, pp. 20-25.

Igboanugo, A.C., Ezemonye, L.I.N. and Chiejine, C.M. 2013, 'Influence of effluent discharge and runoffs into Ikpoba River on its water quality', *Nigerian Journal of Technology*, vol. 32, pp. 294-303.

Imiuwa, M.E., Opute, P. and Ogbeibu, E.A. 2014, 'Heavy metal concentrations in bottom sediments of Ikpoba River, Edo State, Nigeria', *Journal of Applied Sciences and Environmental Management*, vol. 18, pp. 27-32.

Ipeaiyeda, A.R. and Onianwa, P.C. 2018, 'Monitoring and assessment of sediment contamination with toxic heavy metals: case study of industrial effluent dispersion in Alaro River, Nigeria', *Applied Water Science*, vol. 8, p. 161.

Isangedighi, I.A. and David, G.S. 2019, 'Heavy metals contamination in fish: effects on human health', *Journal of Aquatic Science and Marine Biology*, vol. 2, pp. 7-12.

Izegaegbe, J.I., Edoreh, J.A. and Onogbosele, C.O. 2022, 'Assessment of heavy metal content and human health risk of Orogodo River, Delta State, Nigeria', *Journal of Aquatic Sciences*, vol. 37, pp. 31-40.

Jabeen, G., Javed, M. and Azmat, H. 2012, 'Assessment of heavy metals in the fish collected from the river Ravi, Pakistan', *Pakistan Veterinary Journal*, vol. 32, pp. 107-111.

Jadaa, W. and Mohammed, H. 2023, 'Heavy metals–definition, natural and anthropogenic sources of releasing into ecosystems, toxicity, and removal methods–an overview study', *Journal of Ecological Engineering*, vol. 24.

James, T.J., Roshini, M.D. and Subramanian, M.V. 2011, 'Heavy metal accumulation in brain of fishes consequent to river pollution', *Asian Journal of Water, Environment and Pollution*, vol. 8, pp. 143-146.

Jamil, E., Rohani, F., M., Sumaiya, N., Tuj Jannat, M.F., Akter, Y., Shahjahan, M., Abdul Kari, Z., Tahiluddin, A.B. and Goh, K.W. 2023, 'Bioaccumulation and bioremediation of heavy metals in fishes—A review', *Toxics*, vol. 11, p. 510.

Javed, M. and Usmani, N. 2019, 'An overview of the adverse effects of heavy metal contamination on fish health', Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, vol. 89, pp. 389-403.

Jonah, U.E. and Mendie, C.F. 2023, 'Heavy metals content and health risk assessment of Ikpe Ikot Nkon River, Akwa Ibom State, Nigeria', *Food and Environment Safety Journal*, vol. 21.

Kamzati, L.L.J., Kaonga, C.C., Mapoma, H.W.T., Thulu, F.G., Abdel-Dayem, S.M., Anifowose, A.J., Chidya, R.C.G., Chitete-Mawenda, U. and Sakugawa, H. 2020, 'Heavy metals in water, sediment, fish and associated risks from an endorheic lake located in Southern Africa', *International Journal of Environmental Science and Technology*, vol. 17, pp. 253-266.

Karataş, S. and Kalay, M. 2002, 'Accumulation of lead in the gill, liver, kidney and brain tissues of Tilapia zilli', *Turkish Journal of Veterinary and Animal Sciences*, vol. 26, pp. 471-477.

Kimball, B.A. 1999, 'Seasonal variation in metal concentrations in a stream affected by acid mine drainage, St. Kevin Gulch, Colorado', The Environmental Geochemistry of Mineral Deposits—Part B, Case Studies and Research Topics, Littleton, Colorado, pp. 467-477.

Lin, H. 2003, Granulometry, chemistry and physical interactions of non-colloidal particulate matter transported by urban storm water, Louisiana State University and Agricultural & Mechanical College.

Liu, Q., Liao, Y. and Shou, L. 2018, 'Concentration and potential health risk of heavy metals in seafoods collected from Sanmen Bay and its adjacent areas, China', *Marine Pollution Bulletin*, vol. 131, pp. 356-364.

Mansour, W.A.A., Abdelsalam, N.R., Tanekhy, M., Khaled, A.A. and Mansour, A.T. 2021, 'Toxicity, inflammatory and antioxidant genes expression, and physiological changes of green synthesis silver nanoparticles on Nile tilapia (Oreochromis niloticus) fingerlings', Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, vol. 247, p. 109068.

Mastan, O.A., Aurel, D., Coroian, A., Longodor, A.L., Ş, M. and Mesaros, D.M. 2023, 'Assessment of heavy metal contamination of certain types of fish meat', in 2023 17th International Conference on Engineering of Modern Electric Systems (EMES), 9-10 June 2023, pp. 1-4.

Matthiessen, P. and Roberts, R.J. 1982, 'Histopathological changes in the liver and brain of fish exposed to endosulfan insecticide during tsetse fly control operations in Botswana', *Journal of Fish Diseases*, vol. 5, pp. 153-159.

Miroyiannis, S.D., Raines, B.A. and Jurczenko, V. 1963, 'Effect of irradiation on Nissl granules in rat spinal cord neurons-A pilot study', Iowa Academy of Science, Inc., pp. 441-453.

Nedzvetsky, V.S., Gasso, V.Y., Novitskiy, R.O. and Herrmann, B. 2022, 'The linkage between mercury-caused neuro-and genotoxicity via the inhibition of DNA repair machinery: fish brain model', *Медичні перспективи*, vol. 27, pp. 4-9.

Obasohan, E.E., Oronsaye, J.A.O. and Eguavoen, O.I. 2007, 'Determination of post-dredging concentrations of selected trace metals in water, sediment and the freshwater mudfish (Clarias gariepinus) from Ikpoba river in Benin City, Edo State, Nigeria', *African Journal of Biotechnology*, vol. 6, p. 470.

Obinna, O., Ibiam, A. and Emmanuel, O. 2021, 'Experimental investigation of some heavy metals in the muscle tissue of cultured African catfish (Clarias gariepinus)', *International Journal of Agriculture and Biology*, vol. 2, p. 5.

Odigie, J.O. 2014, 'Harmful effects of wastewater disposal into water bodies: a case review of the Ikpoba river, Benin city, Nigeria', *Tropical Freshwater Biology*, vol. 23, pp. 87-101.

Oguzie, F.A. 2006, 'Heavy metals in the sediments of the lower Ikpoba River, Benin City, Nigeria', *Sri Lanka Journal of Aquatic Sciences*, vol. 7, pp. 35-44.

Oguzie, F.A. and Okhagbuzo, G.A. 2010, 'Concentrations of heavy metals in effluent discharges downstream of Ikpoba river in Benin City, Nigeria', *African Journal of Biotechnology*, vol. 9.

Okeke, P.A., Evulobi, O.O.C., Adibe, A.C., Onyeche, S.E. and Ohaturuonye, S.O. 2023, 'Studies on some physico-chemical parameters and heavy metals concentration in the tissues of Oreochromis niloticus and Clarias gariepinus from Amansea River of Anambra state, Nigeria', *International Journal of Multidisciplinary Research and Growth Evaluation*, vol. 4, pp. 102-108.

Okogwu, O., Anionwo, Q., Anoke, D.C. and Ugwuezi, P.O. 2016, 'Behavioural, haematological and histopathological changes in the African catfish, Clarias gariepinus exposed to 2,4-dichlorophenoxyacetic acid (2,4-D)', *Nigerian Journal of Biotechnology*, vol. 30, p. 26.

Okunade, O.A., Oladosu, G.A., Ajani, E.K., Adejinmi, J.O. and Adeogun, O.A. 2023, 'Histopathological assessment of infested farmed Clarias gariepinus at various developmental stages in different culture management system', *Alexandria Journal for Veterinary Sciences*, vol. 77.

Olele, N.F., Falodun, E.D. and Wangboje, O.M. 2013, 'Some heavy metals in surface water, sediment and fish (Clarias gariepinus) from Ikpoba River Benin-City, Edo-State, Nigeria', *Journal of Agricultural Science and Environment*, vol. 13, pp. 71-79.

Onyidoh, H.E., Ibrahim, R., Ismail, F.M. and Muhammad, A.M. 2017, 'Concentrations and risk evaluation of selected heavy metals in water and African catfish Clarias gariepinus in River Kaduna, Nigeria', *Greener Journal of Ecology and Ecosolution*, vol. 4, pp. 1-9.

Onyidoh, H.E., Ismail, F.M., Muhammad, A.M. and Idris, J.A. 2018, 'Risk assessment of heavy metals in wild and farmed Clarias gariepinus (Burchell, 1822) in Zaria, Kaduna state, Nigeria', *Greener Journal of Agricultural Sciences*, vol. 8, pp. 12-21.

Osa-Iguehide, I., Anegbe, B., Okunzuwa, I.G., Ighodaro, A. and Aigbogun, J. 2016, 'Levels of heavy metal concentration in water, sediment and fish in Ikpoba River, Benin City, Edo State Nigeria', *International Journal of Chemical Studies*, vol. 4, pp. 48-53.

Pandiyan, J., Mahboob, S., Govindarajan, M., Al-Ghanim, K.A., Ahmed, Z., Al-Mulhm, N., Jagadheesan, R. and Krishnappa, K. 2021, 'An assessment of level of heavy metals pollution in the water, sediment and aquatic organisms: a perspective of tackling environmental threats for food security', *Saudi Journal of Biological Sciences.*

Phrompanya, P., Panase, P., Saenphet, S. and Saenphet, K. 2021, 'Histopathology and oxidative stress responses of Nile tilapia Oreochromis niloticus exposed to temperature shocks', *Fisheries Science*, vol. 87, pp. 491-502.

Postegal, M.K., Noury, M. and Mirbagheri, S.A. 2022, 'Seasonal variation of heavy metal pollution and numerical modeling in the river and dam (Case study: Zarineh river and Bookan dam in Iran)', Copernicus Meetings.

Prakashbansal, O. 2023, 'Effects of potentially toxic metals on fish physiology, histopathology and impact on human health', *Journal of Agricultural Research Advances*, vol. 5, pp. 15-35.

Rehman, T., Naz, S., Hussain, R., Chatha, A.M.M., Ahmad, F., Yamin, A., Akram, R., Naz, H. and Shaheen, A. 2021a, 'Exposure to heavy metals causes histopathological changes and alters antioxidant enzymes in fresh water fish (Oreochromis niloticus)', *Asian Journal of Agriculture and Biology*, vol. 2.

Rehman, T., Naz, S., Hussain, R., Chatha, A.M.M., Ahmad, F., Yamin, A., Akram, R., Naz, H. and Shaheen, A. 2021b, 'Exposure to heavy metals causes histopathological changes and alters antioxidant enzymes in fresh water fish (Oreochromis niloticus)', *Asian Journal of Agriculture and Biology*.

Ruiz-Picos, R.A., Sedeño-Díaz, J.E. and López-López, E. 2015, 'Histopathological indicators in fish for assessing environmental stress', *Environmental Indicators*, pp. 663-675.

Salamat, N. and Zarie, M. 2016, 'Fish histopathology as a tool for use in marine environment monitoring: a review', *Comparative Clinical Pathology*, vol. 25, pp. 1273-1278.

Senger, M.R., Seibt, K.J., Ghisleni, G.C., Dias, R.D., Bogo, M.R. and Bonan, C.D. 2011, 'Aluminum exposure alters behavioral parameters and increases acetylcholinesterase activity in zebrafish (Danio rerio) brain', *Cell Biology and Toxicology*, vol. 27, pp. 199-205.

Shahjahan, M., Taslima, K., Rahman, M.S., Al-Emran, M.D., Alam, S.I. and Faggio, C. 2022, 'Effects of heavy metals on fish physiology–a review', *Chemosphere*, vol. 300, p. 134519.

Sharma, A., Grewal, A.S., Sharma, D. and Srivastav, A.L. 2023, 'Heavy metal contamination in water: consequences on human health and environment', in Metals in Water, Elsevier.

Sharma, M., Kant, R., Sharma, A.K. and Sharma, A.K. 2024, 'Exploring the impact of heavy metals toxicity in the aquatic ecosystem', *International Journal of Energy and Water Resources.*

Singh, C.B. and Ansari, B.A. 2017, 'Biochemical markers of oxidative stress in brain of zebrafish Danio rerio exposed to different heavy metals lead and cobalt', *International Journal of Life-Sciences Scientific Research,* vol. 3, pp. 1484-1494.

Slaoui, M. and Fiette, L. 2011, 'Histopathology procedures: from tissue sampling to histopathological evaluation', in Drug Safety Evaluation: Methods and Protocols, pp. 69-82.

Sterman, A.B. 1983, 'Altered sensory ganglia in acrylamide neuropathy: quantitative evidence of neuronal reorganization', *Journal of Neuropathology & Experimental Neurology*, vol. 42, pp. 166-176.

Sterman, A.B. 1984, 'Hexacarbon neuropathy: cell body changes are early, dynamic, and specific', *Annals of Neurology*, vol. 16, pp. 343-348.

Tenji, D., Micic, B., Sipos, S., Miljanovic, B., Teodorovic, I. and Kaisarevic, S. 2020, 'Fish biomarkers from a different perspective: evidence of adaptive strategy of Abramis brama (L.) to chemical stress', *Environmental Sciences Europe*, vol. 32, pp. 1-15.

Ujah, I.I., Onwurah, I.N.E. and Onovo, O.E. 2023, 'An evaluation of concentrations of arsenic, nickel, cadmium and chromium from the Onitsha segment of the River Niger', *International Journal of Scholarly Research in Science and Technology*, vol. 2, pp. 016-021.

Wangboje, O.M. and Ekundayo, O.T. 2013, 'Assessment of heavy metals in surface water of the Ikpoba reservoir, Benin City, Nigeria', *Nigerian Journal of Technology*, vol. 32, pp. 61-66.

Yildirim, M.Z., Benlı, A.Ç.K., Selvı, M., Özkul, A., Erkoc, F. and Kocak, O. 2006, 'Acute toxicity, behavioral changes, and histopathological effects of deltamethrin on tissues (gills, liver, brain, spleen, kidney, muscle, skin) of Nile tilapia (Oreochromis niloticus L.) fingerlings', *Environmental Toxicology: An International Journal*, vol. 21, pp. 614-620.

Zangina, T., Idris, M., Ummati, L.M.A., Muazu, A., Saadu, I. and Musa, I.M. 2019, 'Atomic absorption spectroscopy analysis of heavy metals in water at Mai-Ganga coal mining village, Gombe State, Nigeria', *FUDMA Journal of Sciences*, vol. 3, pp. 497-500.

Zanoletti, A. and Bontempi, E. 2023, 'Urban runoff of pollutants and their treatment', Frontiers Media SA.

Zgheib, S., Moilleron, R. and Chebbo, G. 2012, 'Priority pollutants in urban stormwater: Part 1–Case of separate storm sewers', *Water Research*, vol. 46, pp. 6683-6692.

Zhuzzhassarova, G., Azarbayjani, F. and Zamaratskaia, G. 2024, 'Fish and Seafood Safety: Human Exposure to Toxic Metals from the Aquatic Environment and Fish in Central Asia', *International Journal of Molecular Sciences*, vol. 25, p. 1590.