NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Impact of Urban Runoff on Benthic and Pelagic Fish Fauna in Ikpoba River: Heavy Metals and Pathology of Liver Tissues

Ozekeke Ogbeide* and Kester Okoduwa
Department of Environmental Management and Toxicology, University of Benin, Nigeria
*Corresponding author: ozekeke.ogbeide@uniben.edu

Article Info

Keywords: *Urban Runoff, Benthic Fish, Pelagic Fish, Heavy Metals, Liver Pathology*

Received 03 March 2024
Revised 22 April 2024
Accepted 30 April 2024
Available online 20 May 2024

https://doi.org/*10.5281/zenodo.11222249*

Abstract

This study investigates the impact of urban runoff on benthic and pelagic fish fauna in the Ikpoba River, focusing on the effects of heavy metals on liver tissues. The research was conducted in Benin City, Nigeria, where the river is central to local livelihoods but faces pollution threats due to proximity to waste disposal and industrial effluent sites. Water, sediment, and fish samples were collected from two sampling stations along the river. The concentrations of heavy metals (Cr, Co, Cd, Ni, Pb) in these samples were analyzed using an Atomic Absorption Spectrophotometer. Histopathological examinations of fish liver tissues were also conducted. Results revealed the presence of heavy metals in the water and sediment samples, with significant concentrations of chromium upstream. Heavy metals were also found in the liver of both benthic and pelagic fishes, indicating potential environmental contamination. Histopathology of the liver tissues showed signs of inflammation and steatosis, common responses to stress or injury, such as that caused by heavy metal exposure. These findings underscore the need for ongoing monitoring and management of the river's health.

1.0. Introduction

Predisposition Urban runoff, originating from impermeable urban surfaces, poses a significant environmental challenge due to its role in contaminating water bodies with various pollutants [1, 2]. This runoff carries a range of contaminants such as heavy metals, toxic chemicals, microplastics, and pathogens, contributing to water quality degradation and ecosystem disruption [3, 4]. Additionally, urbanization alters hydrological processes, leading to increased storm runoff peaks and reduced baseflows, impacting streamflow regimes over time [5]

Urban runoff is a significant source of pollutants that can degrade surface water bodies, such as the Ikpoba River. Studies have shown consistent declines in the richness of algal, invertebrate, and fish communities in urban streams due to the impact of urban runoff [6, 7].

Heavy metals such as lead, cadmium, arsenic, and mercury pose significant risks to both aquatic ecosystems and human health due to their accumulation in fish tissues. Fish, being bio-monitors of pollution, play a crucial role in reflecting the levels of heavy metals in aquatic environments [8]. The liver, a vital organ for heavy metal accumulation, is particularly susceptible to the bioaccumulation of these pollutants [9]. Studies have shown that heavy metal concentrations in fish tissues can vary based on factors like species, climate, and developmental stage, highlighting the complexity of heavy metal accumulation in fish [10].

Urban runoff can have a multifaceted impact on benthic and pelagic fish species, influenced by factors such as water depth, temperature, and food sources. Metals present in runoff can accumulate in fish tissues, posing health risks and inducing oxidative stress [11]. Excessive nutrients like phosphorus and nitrogen from runoff can trigger algal blooms, diminishing oxygen levels and endangering fish [12]. Sedimentation caused by runoff can exacerbate the issue by depleting dissolved oxygen, further impacting fish populations negatively ([6].

The liver of fish plays a crucial role in safeguarding against oxidative stress through essential antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) [13-15]. Heavy metal contamination in aquatic ecosystems poses a significant threat to fish health, particularly impacting the liver tissues. Studies have shown that exposure to heavy metals like zinc, lead, copper, and cadmium can lead to histopathological alterations in fish liver tissues, including vascular congestion, hepatopancreas degeneration, necrosis, and hypertrophy of hepatocytes [16-18]. The accumulation of these toxic heavy metals in fish liver tissues has been well-documented, highlighting the severity of heavy metal pollution in aquatic environments [19].

This research seeks to explore the impact of urban runoff on fish populations in the Ikpoba River, with a particular emphasis on the effects of pollutants, specifically heavy metals and antioxidant enzymes, on benthic and pelagic fish species. The study will involve assessing the concentrations of these substances in fish livers, investigating the implications of urban runoff on the fish populations, evaluating the levels of metals in fish livers as indicators of pollution, and examining the correlation between urban runoff and fish populations by determining the influence of harmful pollutants on the health of the fishes [20].

The Ikpoba River in Nigeria’s Benin-Owena basin is a vital natural resource for the local community, supporting various activities [21, 22]. It serves as an important aquatic ecosystem, providing habitat for diverse fish species and maintaining water quality [23, 24]. Economically, the river sustains fishing activities, offering income and food for residents, and supports waste management and industrial activities [25-27]. Culturally, it is significant for various practices, and its health is valued by the community [25, 27]. However, concerns about pollution from waste and industrial sites threaten its importance, highlighting the need to protect its ecological, economic, and cultural value for sustainable community development [28, 29].

The scope of the research will be focused on the influence of urban runoff on benthic and pelagic fish populations in the Ikpoba River. This will entail the analysis of physicochemical characteristics, the collection of fish samples from both habitats, and the examination of liver samples to assess antioxidant enzymes, oxidative stress, and variations in heavy metal concentrations. The findings from this study will provide valuable insights into the repercussions of urban runoff on the fish fauna in the Ikpoba River, enhance our understanding of the associated health risks, and contribute to the development of strategies for protecting aquatic ecosystems from the adverse effects of urban runoff, identifying potential sources of contamination, and suggesting mitigation measures.

2.0. Materials and Methods

The study took place in Benin City, a southern Nigeria within Edo State, framed by latitudes 6°11’ N to 6°29’ N and longitudes 5°33’ E to 5°47’ E. The city's terrain, perched at roughly 78 meters above sea level, is part of Nigeria's rich and humid tropical rainforest region. The Ikpoba River, a significant natural resource, flows through the Benin-Owena basin, intersecting Egor and Ikpoba-Okha [30]. It is a vital artery for the community, supporting fishing, waste management, recreational activities, and industrial effluent disposal [31].

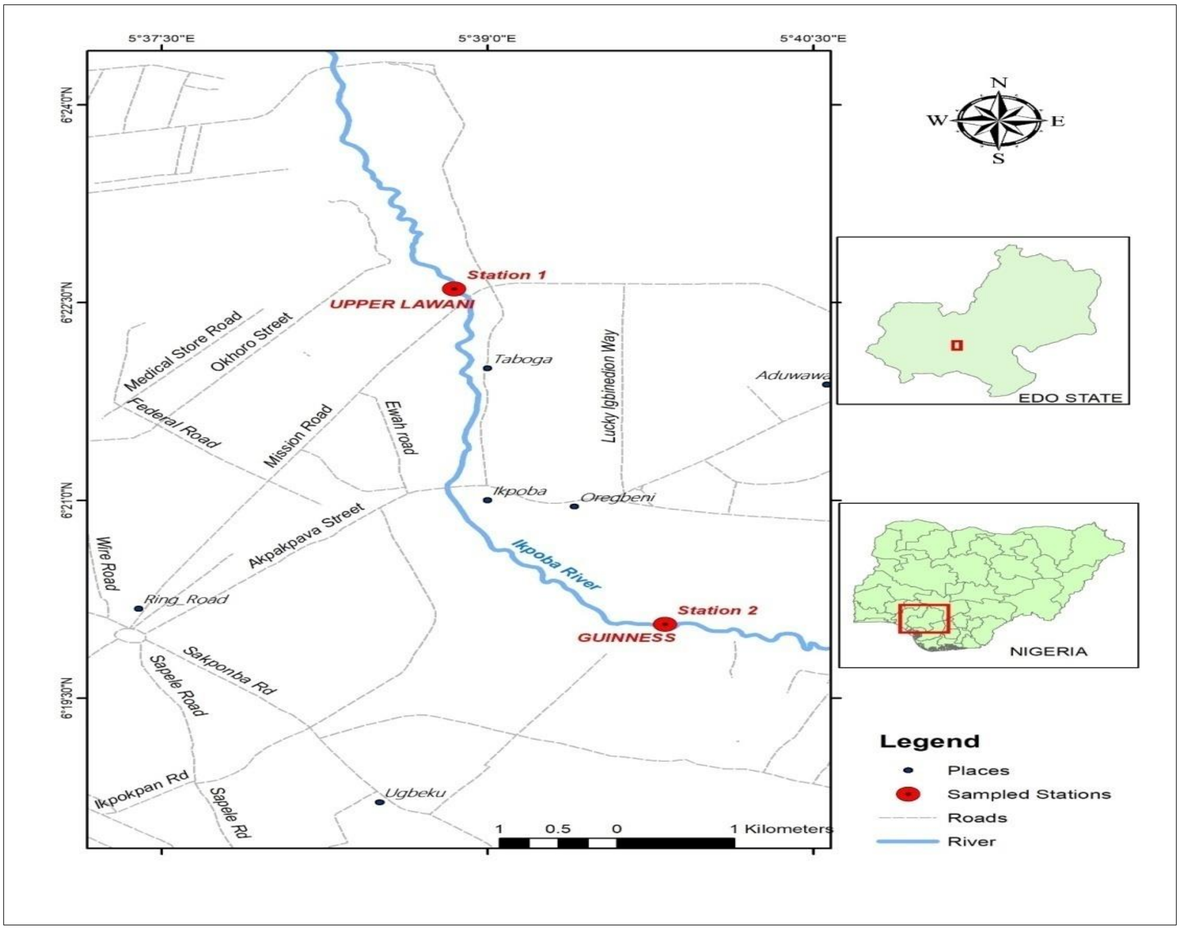
The river is central to the livelihoods of the local populace, facilitating fishing practices and bearing the brunt of human-induced pressures that threaten its water quality and ecosystem vitality health [30, 32]. The proximity of waste disposal and industrial effluent to the river's banks has sparked concerns over pollution and ecological damage. The interplay between human actions and the river's ecological health calls for integrated environmental management approaches that ensure sustainable development while protecting the river's integrity.

2.1. Collection of samples

The study was conducted at two sampling stations along the Ikpoba River, with water, sediment, and fish samples collected for analysis.

2.1.1.Water Samples

Samples were gathered from both the benthic and pelagic zones of the Ikpoba River during regular expeditions from June to August 2023. The method described by Eric, et al. [33] was followed, using thoroughly cleaned 1-liter sampling containers.. After collection, the bottles were immediately sealed, marked, and kept on ice for transport to the lab for further investigation [31].



.

Figure 1: Map showing site locations of the study area

2.1.2. Sediment Sampling

The grab sampling technique was employed for sediment collection. A porcelain crucible was used to weigh ten grams (10 g) of ground and sieved sediment sample. Following this, 25 ml of distilled water, 1 ml of concentrated nitric acid (HNO_3), and 3 ml of concentrated hydrochloric acid (HCl) were added. The sample was then heated on a steam bath for approximately an hour and subsequently cooled. The digested sample was filtered and adjusted to 50 ml with distilled water.

The filtrate was stored in plastic containers for later heavy metal analysis, ensuring consistent treatment procedures for all sediment samples [31].

2.1.3.Fish Sampling: A fishing net was used to randomly collect fish specimens based on the method described by Tongo, et al. [34]. A total of fifty-four (54) fish were collected, with thirty from the pelagic zone and twenty-four from the benthic zone. These specimens were carefully transported to the laboratory for further analysis.

2.1.4. Laboratory Procedure In the controlled laboratory setting, we meticulously cleaned the fish using distilled water. To ensure proper identification and preservation, each fish was stored separately in polyethylene bags at a temperature of -10°C.

2.1.5. Heavy Metal Analysis

The presence of heavy metals in water and sediment samples was ascertained using the techniques outlined by Davies and Ekperusi [35] and Osioma and Iniaghe [36]. A 25ml water sample was placed into a porcelain crucible, followed by the addition of 1ml of concentrated nitric acid (HNO_3) and 3ml of concentrated hydrochloric acid (HCl). The mixture was heated on a steam bath for roughly 30 minutes and then cooled. The resulting digest was diluted to 50ml with distilled water and stored in plastic containers for subsequent heavy metal analysis, ensuring a uniform procedure for all water samples.

In the case of sediment analysis, a 10g sample of ground and sieved sediment was placed into a porcelain crucible. Then, 25ml of distilled water was added, along with 1ml of concentrated nitric acid (HNO_3) and 3ml of concentrated hydrochloric acid (HCl). The sample was heated on a steam bath for about an hour and then cooled. The digested sample was filtered and adjusted to 50ml with distilled water. The filtrate was stored in plastic containers for later heavy metal analysis, ensuring a consistent procedure for all sediment samples.

Fish samples were meticulously measured for length and weight, and the liver was surgically removed, weighed, and set aside for heavy metal determination. The samples were digested with 1ml of concentrated nitric acid (HNO_3) and 3ml of concentrated hydrochloric acid (HCl) until a clear and transparent solution was obtained based on the method described by Jabeen, et al. [37]. The digested samples were diluted to the required volume using double distilled water in a 500 ml volumetric flask. After 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, Pb) was determined using a specific hollow cathode lamp for its analysis. 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 and Ogbeide [31].

2.1.6. Histopathological Examination of Fish Liver

Liver tissues were preserved in a 10% buffer solution for a day, then dissected into small pieces and positioned in a tissue cassette based on the method described by Anyiamuka-Chinedu, et al. [38]. The samples were subsequently washed and subjected to an Automatic Tissue Processing (ATP) machine for an hour, where they stayed in the processing solutions for half a day before being extracted from the ATP machine. The tissue samples were then embedded by situating them in paraffin wax blocks, which offered structural support. Sections of 3 - 5 microns were created through microtomy and made to float on water in a floatation bath at 56oC to eliminate wrinkles, and then relocated to microscopic slides. The tissues underwent a xylene treatment to eliminate the paraffin wax, followed by dehydration using ethanol. They were then stained with haematoxylin and eosin stains and finally scrutinized under a light microscope at a magnification of ×100 [39].

2.2. **Statistical Analysis**

The data gathered from the analysis was processed statistically using the SPSS software, version 21. The analyzed data was displayed in summary tables as Mean ± S.E. For the examination of measurements within each sampling location, a One-way ANOVA and Duncan Multiple Range (DMR) test will be employed.

3.0. Results

3.1. Concentration of Metals in Water from Ikpoba River

The table 1 present data on the monthly concentrations of heavy metals in water samples collected from the Ikpoba River. Over the months of June, July, and August, the concentrations of nickel, chromium, and cobalt showed variations between upstream and downstream locations, while the levels of lead and cadmium remained constant at 0 mg/L. The general concentration of heavy metals, as depicted in Table 1 highlights a significant presence of chromium upstream. The mean difference is significant at $P<0.05$.

Table 1: Monthly concentrations of heavy metals in water

Heavy Metal	June		July		August	
	Upstream	Down stream	Upstream	Down stream	Upstream	Down stream
NICKEL	0.04 ±0.002	0.05 ± 0.002	0.03 ± 0.004	0.05 ± 0.002	0.03± 0.005	0.04 ± 0.002
LEAD	0 ±0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0± 0.0	0.0 ± 0.0
CHROMIUM	0.03 ± 0.003	0.05 ± 0.003	0.04± 0.001	0.04± 0.003	0.04 ±0.004	0.05± 0.003
CADMIUM	0.0 ± 0.0	0.0 ± 0.0	0.0± 0.0	0.0 ± 0.0	0.0 +0.0	0.0± 0.0
COBALT	0.02 ± 0.003	0.02 ± 0.006	0.02 ± 0.003	0.03 ± 0.002	0.03 ±0.004	0.04 ± 0.002

The values are the average standard deviation in three independent analysis. All values are in mg/L. Mean difference is significant at P<0.05

3.2. Concentration of Metals in Sediment from Ikpoba River

Table 2 shows monthly heavy metal concentrations in Ikpoba River sediments. Nickel (Ni) had the highest concentration (7.89 mg/g downstream in July), while Cadmium (Cd) had the lowest (0.177 mg/g upstream in August). Lead (Pb) increased significantly in August (5.827 mg/g upstream, 5.208 mg/g downstream), while Cobalt (Co) and Ni decreased. Chromium (Cr) and Cd concentrations remained stable. Differences in Pb, Co, and Ni concentrations were statistically significant ($P<0.05$), unlike Cr and Cd.

Table 2: Monthly Concentrations(mg/g) of Heavy Metals in Sediments from Ikpoba River

Heavy metal	June		July		August		P value
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	
	Mean±S.E	Mean±S.E	Mean±S.E	Mean±S.E	Mean±S.E	Mean±S.E	
Pb	0.362±0.019	0.474±0.004	0.362±0.019	0.474±0.004	5.827±0.595	5.208±0.348	$P<0.05$
Co	1.718±0.136	2.067±0.058	1.718±0.136	2.067±0.058	0.489±0.019	0.513±0.045	$P<0.05$
Cr	2.568±0.297	2.155±0.021	2.568±0.297	2.155±0.021	1.899±0.149	2.116±0.342	$P>0.05$
Cd	0.181±0.004	0.214±0.002	0.181±0.004	0.214±0.002	0.177±0.036	0.241±0.022	$P>0.05$
Ni	6.125±0.102	7.89±0.193	6.125±0.102	7.89±0.193	1.585±0.061	1.447±0.117	$P<0.05$

The values are the average standard deviation in three independent analyses. All values are in mg/kg. Mean difference is significant at P<0.05

3.3.Concentration of Metals in Fish Liver from Ikpoba River

The monthly concentrations of heavy metals in the liver of benthic fishes showed some fluctuations. In May and June, the concentrations of lead, cobalt, chromium, cadmium, and nickel were 0.0618 mg/g, 0.073 mg/g, 0.348 mg/g, 0.0494 mg/g, and 0.8102 mg/g respectively. However, in July, there was a significant increase in the concentration of lead to 0.864 mg/g, while the concentrations of cobalt, chromium, and nickel decreased to 0.06175 mg/g, 0.4885 mg/g, and 0.0665 mg/g respectively. The concentration of cadmium also decreased slightly to 0.0335 mg/g.

For pelagic fishes, the concentrations of heavy metals in the liver also varied. In May, the concentrations of lead, cobalt, chromium, cadmium, and nickel were 0.0656 mg/g, 0.0736 mg/g, 0.257 mg/g, 0.0532 mg/g, and 0.6782 mg/g respectively. In June, the concentration of lead decreased slightly to 0.0628 mg/g, while the concentrations of cobalt and cadmium also decreased to 0.0708 mg/g and 0.0494 mg/g respectively. The concentration of chromium increased to 0.3904 mg/g, while the concentration of nickel decreased to 0.613 mg/g. In July, there was a further decrease in the concentrations of all heavy metals, with lead, cobalt, chromium, cadmium, and nickel recording concentrations of 0.431 mg/g, 0.0515 mg/g, 0.25425 mg/g, 0.02675 mg/g, and 0.06 mg/g respectively.

Table 3: Monthly Concentrations (mg/g) of Heavy Metals in liver of Benthic fishes

	May	June	July
LEAD	0.0618	0.0618	0.864
COBALT	0.073	0.073	0.06175
CHROMIUM	0.348	0.348	0.4885
CADMIUM	0.0494	0.0494	0.0335
NICKEL	0.8102	0.8102	0.0665

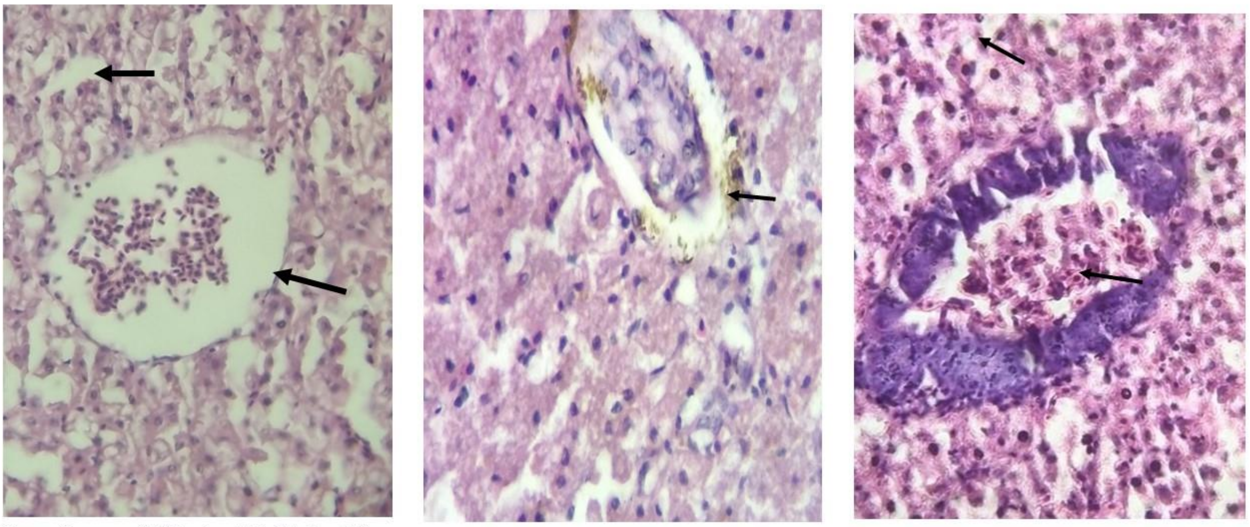
Table 4: Monthly Concentrations (mg/g) of Heavy Metals in liver of Pelagic fishes

	May	June	July
LEAD	0.0656	0.0628	0.431
COBALT	0.0736	0.0708	0.0515
CHROMIUM	0.257	0.3904	0.25425
CADMIUM	0.0532	0.0494	0.02675
NICKEL	0.6782	0.613	0.06

3.4.Pathology of Liver of benthic and Pelagic fishes obtained from Ikpoba River

Histopathology of liver tissues of *Tilapia zilli* obtained from Ikpoba river showed some interesting results: In May, (Fig 2) liver tissues showed a congested central vein with mononuclear cells (long arrow). There are diffused mononuclear infiltrates (short arrow) visible around the central vein. The tissue appears to have a moderate level of cellular congestion, and the structure of hepatocytes is still identifiable. On the other hand, in June (Fig 2), he liver tissue exhibits a congested central vein (long arrow), similar to May but appears more pronounced. Diffused mononuclear infiltrates in the liver parenchyma (short arrow) are visible, indicating an inflammatory response. Marked steatosis is evident, with hepatocytes showing significant fat accumulation. Visible sinusoids can be observed amidst the inflamed tissue. In July (Fig 2), the central vein is not only congested but filled with inflammatory and mononuclear cells (long arrow), indicating an escalated inflammatory response over time. Hepatocytes reveal prominent steatosis (short arrow), suggesting progressive damage or stress to the liver cells. The overall tissue structure appears more disorganized compared to previous months due to increased inflammation and steatosis.

Typically, healthy liver tissues would exhibit clear, unobstructed central veins, absence of mononuclear infiltrate presence indicating no inflammation, and hepatocytes free of marked steatosis showcasing normal metabolic activity [40, 41]



Liver tissues of *Tilapia zilli* obtained from Ikpoba River in May

Liver tissues of *Tilapia zilli* obtained from Ikpoba River in June)

Liver tissues of *Tilapia zilli* obtained from Ikpoba in

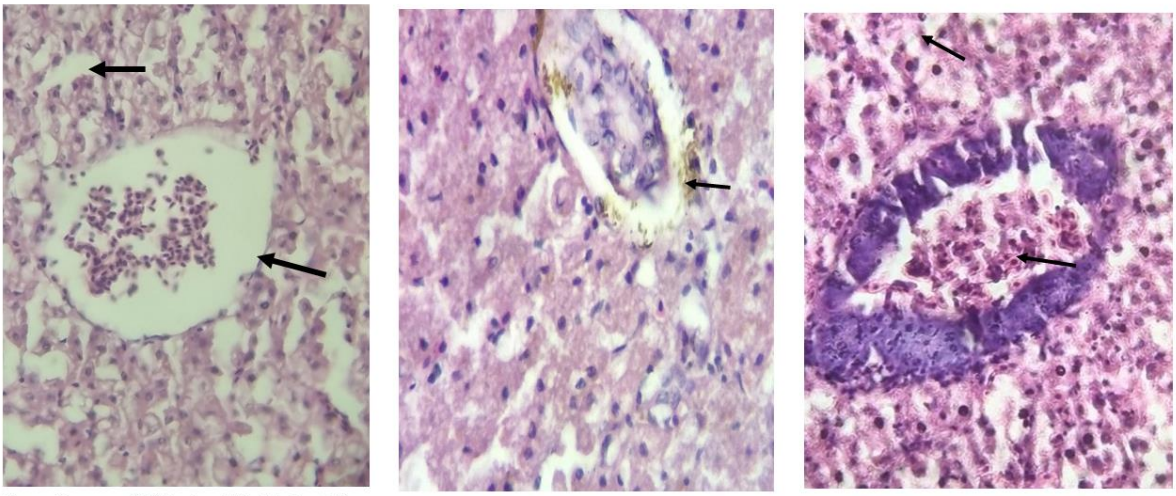
Fig 2: Histopathology of liver tissues in *Tilapia zilli* obtained from Ikpoba river

3.5.Pathology of Liver d Benthic fishes obtained from Ikpoba River

In May, the liver tissue of Carias Sp shows (Fig 3) a congested central vein with mononuclear and inflammatory cells. This suggests an immune response, possibly due to an infection or other form of liver injury. There are also focal mononuclear infiltrates in the liver parenchyma, indicating localized areas of inflammation. The sinusoids are visible, which is normal, but the hepatocytes show marked steatosis. Steatosis refers to the abnormal retention of lipids within cells, suggesting a metabolic imbalance.

In June (Fig 3), the central vein remains congested, which could be due to increased blood flow or blockage. The liver parenchyma shows dispersed mononuclear infiltrates, suggesting a more widespread inflammatory response. The sinusoids and hepatocytes are visible, which is normal. However, there is focal pigmentation, which could indicate localized areas of cell damage or death.

In July (Fig 3), the central vein is still congested, and there are visible mononuclear exudates, suggesting an ongoing immune response. The hepatocytes show prominent fatty changes, indicating metabolic disturbances, possibly due to conditions like non-alcoholic fatty liver disease (NAFLD) or alcoholic liver disease (ALD). There are also diffused mononuclear cells in the sinusoids, suggesting a widespread immune response.



Liver tissues of *Tilapia zilli* obtained from Ikpoba River in May

Liver tissues of *Tilapia zilli* obtained from Ikpoba River in June)

Liver tissues of *Tilapia zilli* obtained from Ikpoba in

Fig 3: Histopathology of liver tissues in Clarias *sp* obtained from Ikpoba river

3.6.Discussion

3.6.1. Heavy metals in water samples

The data presented in Table 1 indicates the presence of heavy metals such as nickel, chromium, and cobalt in the Ikpoba River. The concentrations of these metals vary between upstream and downstream locations over the months of June, July, and August. Notably, the levels of lead and cadmium remained constant at 0 mg/L, suggesting that these metals may not be a significant concern in this context. However, the presence of chromium upstream is significant, which could have implications for the ecosystem and ecological health of the river [42].

Heavy metals in water bodies can pose serious threats to both aquatic life and human health [43, 44]. These metals, such as iron, copper, zinc, lead, cadmium, chromium, and mercury, can contaminate water sources through various sources like industrial effluents, mining waste, and agricultural runoff [45, 46]. These metals can cause a variety of issues in aquatic species, such as decreased hatching rates, physical abnormalities, and bioaccumulation in tissues [47, 48]. Moreover, they can also indirectly impact human health, as humans consume fish and other aquatic organisms that have accumulated these metals [43, 46].

Comparing these findings with other studies, it's evident that heavy metal contamination in water bodies is a global issue [46, 49-52]. For instance, a study conducted on the Pearl River in China found that heavy metals posed elevated ecological risks to certain aquatic organisms due to their presence in the water [53]. Another study by Kumar, et al. [50], highlighted the contamination of water with heavy metals in various water bodies throughout the world from 1994 to 2019. Similarly, Prasad, et al. [54] in another study conducted in the Garhwal Himalaya, India, found varying concentrationss of heavy metals in potable water.

Looking specifically at previous studies conducted on the Ikpoba River, similar findings of heavy metal contamination have been reported. A study conducted in 2012 found that the concentrations of heavy metals were higher in effluents than in the water [55]. Another study conducted on the lower Ikpoba River reported that the concentrations of heavy metals in the water and sediment showed a seasonal pattern of variation [56]. Other studies including Tawari-Fufeyin [57], Igboanugo, et al. [58] and Wangboje and Ekundayo [59] have also reported varying concentrations of heavy metals in waters samples from Ikpoba river. These studies, along with the current data, underscore the ongoing issue of heavy metal contamination in the Ikpoba River.

.

3.6.2. Heavy metals in sediment samples

The heavy metal concentrations in the sediments of the Ikpoba River have significant implications for the ecosystem and ecological health, particularly for aquatic organisms. Heavy metals, even in low quantities, can be harmful due to their toxicity, non-degradability, and high bioaccumulative potential [42, 60]. These metals can lead to various ailments in fish, such as reduced hatching rates and bioaccumulation in tissues [60]. The contamination of sediments with heavy metals can significantly impact the food chain, indirectly affecting human health when individuals consume contaminated fish [61].

The presence of heavy metals in river sediments worldwide has been reported in several studies, indicating that heavy metal pollution in aquatic environments is a global concern. These studies span across various countries. For instance, in Bangladesh, the presence of heavy metals was reported by Ali, et al. [62], Bhuyan, et al. [63], and Islam, et al. [64]. Similar findings were reported in China by Tang, et al. [53], Zheng, et al. [65] and Hoang, et al. [66] reported the same in Taiwan, while Jaskuła and Sojka [67]) and Sojka and Jaskuła [61], did so in Poland. In Southern Africa, Ouma, et al. [68] reported these findings, as did Gupta, et al. [10] in India, Pesantes, et al. [69] in Ecuador, and Rezapour, et al. [70] in Iran. When comparing these findings with other studies, it becomes evident that heavy metal pollution in aquatic environments is indeed a global concern.

Specifically, on the Ikpoba River, there have been numerous studies conducted over the years that have reported on the heavy metal concentrations in its sediments. These studies have provided valuable insights into the environmental health of the river. For instance, the studies by Osa-Iguehide, et al. [28] (2016), Imiuwa, et al. [71], and Oguzie [56] have all contributed to our understanding of this issue. More recent studies by Ogbeide and Edene [72], as well as, Enuneku and Ineh [29], Enuneku and Ineh [73], have continued this important work, further emphasizing the need for ongoing monitoring and management of the river’s health.

3.6.3. Heavy Metal Concentration in Fish Liver from Ikpoba River

The presence of heavy metals in the liver of both benthic and pelagic fishes from Ikpoba River is a clear indication of potential environmental contamination and possess a threat to humans who consume them [74-76]. The fluctuations in metal concentrations over the months in the liver of benthic and pelagic fishes from the Ikpoba River could be attributed to changes in water quality or variations in the fishes' diet and metabolism [77, 78]. These variations may reflect the dynamic nature of metal uptake and accumulation in fish tissues, influenced by environmental factors and biological processes [79]. Studies have shown that heavy metals can exhibit temporal variations in water bodies, affecting the bioavailability and accumulation of metals in aquatic organisms [80, 81]. The bioaccumulation of heavy metals in fish liver tissues can result from prolonged exposure to contaminated environments, leading to potential health risks for both fish and humans consuming these contaminated fish [82, 83].

Research on Clarias gariepinus and Tilapia fish across various global locations has revealed alarming concentrations of metals in fish tissues, exceeding the recommended limits for human consumption. This research spans multiple regions and rivers, each contributing unique insights into the issue.

In Nigeria, studies were conducted in the Elebele River [84], Ona River in Ibadan [85], Ogun River in Ogun State [86],), New Calabar River [87], Asa River in Ilorin, Kwara State [88], Ose River in Ondo State [17] and Ikpoba river [28, 74].

In Egypt, the River Nile was studied [89], as well as other locations [90, 91]. Other studies were conducted in Lake Hayq, South Wollo, Ethiopia [92], and the Lake of Bhopal [93]. These findings indicate significant bioaccumulation of heavy metals in fish tissues, raising concerns about the potential health risks associated with consuming contaminated fish. [17, 74, 84].

When comparing the metal concentrations in benthic and pelagic fishes, it appears that benthic fishes tend to have higher concentrations of certain metals like lead and nickel, especially in July, This is consistent with findings by Odigie, et al. [74]. Benthic fishes, residing closer to the riverbed, tend to accumulate higher concentrations of certain metals like lead and nickel compared to pelagic fishes, which inhabit the water column [94]. This is attributed to the proximity of benthic fishes to the riverbed, where heavy metals often settle, leading to increased metal accumulation in their bodies [95]. The bioaccumulation of heavy metals in fish tissues, including lead and nickel, is influenced by their habitat and feeding behaviour [96]. In aquatic ecosystems, benthic fish species like large-scale tongue sole exhibit higher levels of metal accumulation in their edible tissues due to their benthic lifestyle [97]. Conversely, pelagic fishes may have lower exposure to these contaminants due to their habitat in the water column, potentially resulting in comparatively lower metal concentrations in their bodies [98].

The histopathology of the liver tissues of both tilapia and zebrafish shows signs of inflammation and steatosis, which are common responses to stress or injury, such as that caused by heavy metal exposure [99, 100]. The progression of these conditions over time indicates ongoing exposure to contaminants [101-103]. The histopathological findings in the liver tissues of *Tilapia zilli* and *Clarias species* from Ikpoba River indicate a progressive inflammatory response and steatosis, reflecting ongoing stressors impacting liver health [104]. These observations are crucial as fish liver health serves as a bioindicator for overall aquatic ecosystem health [104]. The liver, being a principal detoxifying organ, is highly susceptible to pollutants, as seen in fish exposed to crude oil pollution [105]. Additionally, dietary exposure to toxic metals like cadmium, chromium, lead, and mercury can lead to liver damage in fish, highlighting the impact of environmental contaminants on aquatic organisms [106]. Therefore, the observed liver pathologies in these fish species could signify broader ecological issues related to water quality and environmental stressors, emphasizing the importance of monitoring and addressing these concerns for ecosystem and ecological health.

3.6.4. Potential Sources of heavy metal in Ikpoba river

The Ikpoba River faces heavy metal pollution from various sources like industrial effluent discharge, waste management, urban runoff, and agricultural activities [28, 107]. Chromium presence in water, sediment, and fish liver samples indicates ecosystem-wide pollution, primarily from industrial effluent disposal, waste management, and urban runoff from Benin City [108]. Agricultural practices using heavy metal-containing fertilizers or pesticides also contribute to the contamination [107][2]. Effective regulation and mitigation of these sources are crucial for safeguarding the river’s ecosystem and the communities dependent on it [28, 29, 109].

4.0. Conclusion

The research on the impact of urban runoff on fish fauna in the Ikpoba River has revealed significant findings, indicating potential environmental contamination from heavy metals in water, sediment, and fish liver samples. Fluctuations in metal concentrations in fish livers suggest changes in water quality or diet metabolism. Liver histopathology of tilapia and zebrafish shows signs of inflammation and steatosis, common responses to heavy metal exposure. These observations are crucial as fish liver health reflects overall aquatic ecosystem health. Recommendations include establishing a long-term monitoring program, identifying and regulating pollution sources, adopting an ecosystem-based approach, implementing policies, engaging stakeholders, conducting broader pollution impact studies, and enhancing local capacity in environmental monitoring and management to protect the Ikpoba River's ecosystem and promote sustainable development.

References

[1] A. Smith, D. Tetzlaff, C. Marx, and C. Soulsby, "Enhancing urban runoff modelling using water stable isotopes and ages in complex catchments," *Hydrological Processes,* vol. 37, no. 2, p. e14814, 2023.

[2] A. Zanoletti and E. Bontempi, "Urban runoff of pollutants and their treatment," *Frontiers in Environmental Chemistry* vol. 4, no. 2023, p. 1151859, 2023.

[3] C. J. Oswald *et al.*, "Integrating urban water fluxes and moving beyond impervious surface cover: A review," *Journal of Hydrology,* vol. 618, p. 129188, 2023.

[4] K. T. Peter *et al.*, "Using High-Resolution Mass Spectrometry to Identify Organic Contaminants Linked to Urban Stormwater Mortality Syndrome in Coho Salmon," *Environmental Science & Technology,* vol. 52, no. 18, pp. 10317-10327., 2018, doi: 10.1021/acs.est.8b03287.

[5] G. Mazzarotto, M. Camporese, and P. Salandin, "Assessing Physical Processes of Permeable Pavements with a Large-Scale Laboratory Model," in *EGU General Assembly Conference* 2022 2022, vol. 2022, pp. EGU22-9353, doi: https://doi.org/10.5194/egusphere-egu22-9353, .

[6] M. J. Paul and J. L. Meyer, "Streams in the Urban Landscape," *Annual Review of Ecology and Systematics,* vol. 32, no. 1, pp. 333-365., 2001, doi: 10.1146/annurev.ecolsys.32.081501.114040.

[7] L. O. Agashua, A. S. Ogbiye, B. D. Oluyemi-Ayibiowu, E. C. Igibah, I. N. Ihimekpen, and J. Wasiu, "Assessment of the Damage Incurred by biodiversity and ecological degradation via HEC-HMS simulations and of Stream Flow Assessment and Analysis (SAAS). A case study," in *IOP Conference Series: Earth and Environmental Science*, 2023 2023, vol. 1178: IOP Publishing, 1 ed., p. 012022.

[8] R. Vinodhini and M. Narayanan, "Bioaccumulation of Heavy Metals in Organs of Fresh Water Fish Cyprinus Carpio (Common Carp)," *International Journal of Environmental Science and Technology,* vol. 5, no. 2008, pp. 179-182, 2008, doi: 10.1007/bf03326011.

[9] E.-S. E. Mehana *et al.*, "Biomonitoring of Heavy Metal Pollution Using Acanthocephalans Parasite in Ecosystem: An Updated Overview," *Animals,* vol. 10, no. 5, p. 811, 2020, doi: 10.3390/ani10050811.

[10] A. Gupta, D. Kumar, R. S. Pandey, and B. Sharma, "Analysis of Some Heavy Metals in the Riverine Water, Sediments and Fish From River Ganges at Allahabad," *Environmental Monitoring and Assessment,* vol. 157, no. 2009, pp. 449-458, 2008, doi: 10.1007/s10661-008-0547-4.

[11] P. Bustamante, P. Bocher, Y. Cherel, P. Miramand, and F. Caurant, "Distribution of Trace Elements in the Tissues of Benthic and Pelagic Fish From the Kerguelen Islands," *The Science of the Total Environment,* vol. 313, no. 1-3, pp. 25-39, 2003, doi: 10.1016/s0048-9697(03)00265-1.

[12] J. D. Allan, "Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems," *Annual Review of Ecology Evolution and Systematics,* vol. 35, no. 2004, pp. 257-284., 2004, doi: 10.1146/annurev.ecolsys.35.120202.110122.

[13] G. Mourente, E. Díaz-Salvago, J. G. Bell, and D. R. Tocher, "Increased Activities of Hepatic Antioxidant Defence Enzymes in Juvenile Gilthead Sea Bream (Sparus Aurata L.) Fed Dietary Oxidised Oil: Attenuation by Dietary Vitamin E," *Aquaculture,* vol. 214, no. 1-4, pp. 343-361., 2002, doi: 10.1016/s0044-8486(02)00064-9.

[14] S. Li *et al.*, "The role of oxidative stress and antioxidants in liver diseases," *International journal of molecular sciences,* vol. 16, no. 11, pp. 26087-26124, 2015.

[15] H. Tayyab, F. Latif, S. Aziz, R. Zubair, and J. Aslam, "TOXICOLOGICAL EFFECTS OF A BINARY MIXTURE OF METALS (Fe+ Mn) ON THE OXIDATIVE STRESS OF MAJOR CARPS," *Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences,* vol. 38, no. 1, pp. 37-45, 2022.

[16] M. M. N. Authman, M. S. Zaki, E. A. Khallaf, and H. H. Abbas, "Use of Fish as Bio-Indicator of the Effects of Heavy Metals Pollution," *Journal of Aquaculture Research & Development,* vol. 6, no. 4, pp. 1-13, 2015, doi: 10.4172/2155-9546.1000328.

[17] J. O. Olayinka-Olagunju, "Heavy metal bioaccumulation and histopathological studies of fish tissues from Ose River, Ondo State, Nigeria," *European Journal of Environment and Earth Sciences,* vol. 3, no. 4, pp. 70-78, 2022.

[18] S. Shahid *et al.*, "Histopathological alterations in gills, liver, kidney and muscles of Ictalurus punctatus collected from pollutes areas of River," *Brazilian Journal of Biology,* vol. 81, pp. 814-821, 2020.

[19] P. Weber *et al.*, "Metals in the Water, Sediment, and Tissues of Two Fish Species From Different Trophic Levels in a Subtropical Brazilian River," *Microchemical Journal,* vol. 106, no. 2013, pp. 61-66, 2013, doi: 10.1016/j.microc.2012.05.004.

[20] N. Topić Popović, L. Čižmek, S. Babić, I. Strunjak-Perović, and R. Čož-Rakovac, "Fish liver damage related to the wastewater treatment plant effluents," *Environmental Science and Pollution Research,* vol. 30, no. 17, pp. 48739-48768, 2023/04/01 2023, doi: 10.1007/s11356-023-26187-y.

[21] C. N. Ezugwu, B. U. Anyata, and E. O. Ekenta, "Estimation of The Life of Ikpoba River Reservoir," *International Journal of Engineering Research & Technology (IJERT),* vol. 2, no. 8, pp. 1170-1186, 2013.

[22] O. C. Izinyon, N. Ihimekpen, and G. E. Igbinoba, "Flood frequency analysis of Ikpoba River catchment at Benin City using log Pearson type III distribution," *Journal of Emerging Trends in Engineering and Applied Sciences,* vol. 2, no. 1, pp. 50-55, 2011.

[23] O. A. Ologbosere and H. S. A. Aluyi, "Microbiological And Physicochemical Qualities Of Ikpoba River Impacted By Piped Treated Brewery Effluent Stream," *Nigerian Journal of Life Sciences (ISSN: 2276-7029),* vol. 6, no. 1, pp. 108-119, 2016.

[24] A. E. Adeleke, S. A. Adegbite, A. P. Onifade, A. A. Sangoremi, and A. A. Adegbite, "Seasonal Variability of Heavy Metals Concentration of Industrial Effluents in Benin City, Edo State, Nigeria," 2023.

[25] N. F. Olele, E. D. Falodun, and O. M. Wangboje, "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, no. 1, pp. 71-79, 2013.

[26] J. C. Ojeah and O. Oriakhi, "Spatial Analysis for Surface Water Quality Assessment of the Ikpoba River Using Geographic Information System," *Nigerian Journal of Environmental Sciences and Technology,* vol. 6, pp. 391-408, 10/01 2022, doi: 10.36263/nijest.2022.02.0374.

[27] O. Wangboje, "Fish stock assessment and potential yield of a reservoir in Benin City, Nigeria," *Dutse Journal of Pure and Applied Sciences,* vol. 7, pp. 55-64, 02/02 2022, doi: 10.4314/dujopas.v7i4a.6.

[28] I. Osa-Iguehide, B. Anegbe, I. G. Okunzuwa, A. Ighodaro, and J. Aigbogun, "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, no. 1, pp. 48-53, 2016.

[29] A. A. Enuneku and F. Ineh, "Assessment of human health risk for surface sediments of Ikpoba River contaminated by heavy metals," *Journal of Applied Sciences and Environmental Management,* vol. 23, no. 11, pp. 2013-2017, 2019.

[30] R. Victor and A. E. Ogbeibu, "Macrobenthic invertebrates of a stream flowing through farmlands in southern Nigeria," *Environmental Pollution Series A, Ecological and Biological,* vol. 39, no. 4, pp. 337-349, 1985.

[31] A. V. Chukwuka and O. Ogbeide, "Riparian-buffer loss and pesticide incidence in freshwater matrices of Ikpoba river (Nigeria): policy recommendations for the protection of tropical river basins," in *River Basin Management-Sustainability Issues and Planning Strategies*, J. Simao and A. D. Carmo Eds.: Intechopen, 2021.

[32] P. Tawari-Fufeyin and S. A. Ekaye, "Fish species diversity as indicator of pollution in Ikpoba river, Benin City, Nigeria," *Reviews in Fish Biology and Fisheries,* vol. 17, pp. 21-30, 2007.

[33] O. H. Eric, I. Rasaq, I. F. Muhammad, and M. A. Muhammad, "concentration and risk evaluation of selected heavy metals in water and African catfish, Clarias gariepinus in river Kaduna, Nigeria," *Green J of Eco & Ecosol,* vol. 1, pp. 1-9, 2017.

[34] I. Tongo *et al.*, "Levels, bioaccumulation and biomagnification of pesticide residues in a tropical freshwater food web," *International Journal of Environmental Science and Technology,* pp. 1-16, 2022.

[35] I. C. Davies and A. O. Ekperusi, "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, no. 3, pp. 207-218, 2021.

[36] E. Osioma and P. O. Iniaghe, "Concentration of heavy metals in water, sediments and tissues of Clarias gariepinus from earthen ponds in Kolo Creek communities in Bayelsa State, Niger Delta, Nigeria," *Asian Journal of Water, Environment and Pollution,* vol. 16, no. 4, pp. 97-106, 2019.

[37] G. Jabeen, M. Javed, and H. Azmat, "Assessment of heavy metals in the fish collected from the river Ravi, Pakistan," *Pakistan Veterinary Journal,* vol. 32, no. 1, pp. 107-111, 2012.

[38] O. K. Anyiamuka-Chinedu, A. P. Ugbomeh, C. C. Amuzie, and I. K. E. Ekweozor, "trace metal concentrations and histopathology of the liver of a gobiid fish from elechi creek, port harcourt, nigeria," *Irish Journal of Environment and Earth Sciences,* vol. 6, no. 3, 2022.

[39] I. E. J. Barnhoorn, J. C. Van Dyk, G. M. Pieterse, and M. S. Bornman, "Intersex in feral indigenous freshwater Oreochromis mossambicus, from various parts in the Luvuvhu River, Limpopo Province, South Africa," *Ecotoxicology and Environmental Safety,* vol. 73, no. 7, pp. 1537-1542, 2010.

[40] O. A. Ajala *et al.*, "Concentrations, bioaccumulation, and health risk assessments of heavy metals in fishes from Nigeria's freshwater: a general overview," *Environmental Science and Pollution Research,* vol. 29, no. 55, pp. 82660-82680, 2022.

[41] R. X. Li *et al.*, "The Adaptive Characteristics of Cholesterol and Bile Acid Metabolism in Nile Tilapia Fed a High-Fat Diet," (in eng), *Aquac Nutr,* vol. 2022, p. 8016616, 2022, doi: 10.1155/2022/8016616.

[42] K. Sharma, R. Gulati, S. Singh, A. Kour, and P. Sharma, "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, 12/19 2022, doi: 10.31018/jans.v14i4.3900.

[43] A. I. Shah, "Heavy metal impact on aquatic life and human health–an over view," in *IA's contribution in addressing climate change 37th annual conference of the international association for impact assessment (* Le Centre Sheraton | Montréal | Canada | 4 - 7 April 2017 2017: International Association for Impact Assessment, pp. 4-7. [Online]. Available: www.iaia.org. [Online]. Available: www.iaia.org

[44] M. Pujari and D. Kapoor, "1 - Heavy metals in the ecosystem: Sources and their effects," in *Heavy Metals in the Environment*, V. Kumar, A. Sharma, and A. Cerdà Eds.: Elsevier, 2021, pp. 1-7.

[45] P. Choudhary, P. Sharma, S. Kaur, and J. Randhawa, "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, no. 2, pp. 395-405, 2023.

[46] K. H. H. Aziz, F. S. Mustafa, K. M. Omer, S. Hama, R. F. Hamarawf, and K. O. Rahman, "Heavy metal pollution in the aquatic environment: efficient and low-cost removal approaches to eliminate their toxicity: a review," *RSC advances,* vol. 13, no. 26, pp. 17595-17610, 2023.

[47] H. Ali, E. Khan, and I. Ilahi, "Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation," *Journal of Chemistry*, vol. 2019*,* p. 14 doi: 10.1155/2019/6730305.

[48] M. A. Yunusa, E. C. Igwe, and A. O. Mofoluke, "Heavy metals contamination of water and fish-a review," *Fudma Journal of Sciences,* vol. 7, no. 1, pp. 110-118, 2023.

[49] Q. Zhou *et al.*, "Total concentrations and sources of heavy metal pollution in global river and lake water bodies from 1972 to 2017," *Global Ecology and Conservation,* vol. 22, p. e00925, 2020/06/01/ 2020, doi: https://doi.org/10.1016/j.gecco.2020.e00925.

[50] V. Kumar *et al.*, "Global evaluation of heavy metal content in surface water bodies: A meta-analysis using heavy metal pollution indices and multivariate statistical analyses," (in eng), *Chemosphere,* vol. 236, p. 124364, Dec 2019, doi: 10.1016/j.chemosphere.2019.124364.

[51] D. Piwowarska, E. Kiedrzyńska, and K. Jaszczyszyn, "A global perspective on the nature and fate of heavy metals polluting water ecosystems, and their impact and remediation," *Critical Reviews in Environmental Science and Technology,* pp. 1-23, 2024, doi: 10.1080/10643389.2024.2317112.

[52] A. Sharma, A. S. Grewal, D. Sharma, and A. L. Srivastav, "Heavy metal contamination in water: consequences on human health and environment," in *Metals in water*: Elsevier, 2023, pp. 39-52.

[53] Z. Tang *et al.*, "Ecological risk assessment of aquatic organisms induced by heavy metals in the estuarine waters of the Pearl River," *Scientific Reports,* vol. 13, no. 1, p. 9145, 2023/06/05 2023, doi: 10.1038/s41598-023-35798-x.

[54] M. Prasad, R. S. Aswal, A. Joshi, G. A. Kumar, and R. C. Ramola, "A systematic study on occurrence, risk estimation and health implications of heavy metals in potable water from different sources of Garhwal Himalaya, India," *Scientific Reports,* vol. 12, no. 1, p. 20419, 2022/11/28 2022, doi: 10.1038/s41598-022-24925-9.

[55] F. Oguzie and G. Okhagbuzo, "Concentrations of heavy metals in effluent discharges downstream of Ikpoba river in Benin City, Nigeria," *African Journal of Biotechnology,* vol. 9, 01/01 2012.

[56] A. Oguzie, "Heavy metals in water and sediment of the lower Ikpoba river, Benin City, Nigeria," *Pakistan Journal of Scientific and Industrial Research,* vol. 46, pp. 156-160, 05/01 2003, doi: 10.4038/sljas.v7i1.7498.

[57] P. Tawari-Fufeyin, "Heavy metal contributions of run-off waters discharging into the Ikpoba Reservoir during rainy season," *Bioscience Research Journal,* vol. 14, no. 3, 2021.

[58] A. C. Igboanugo, L. I. N. Ezemonye, and C. M. Chiejine, "Influence of effluent discharge and runoffs into Ikpoba River on its water quality," *Nigerian Journal of Technology,* vol. 32, no. 2, pp. 294-303, 2013.

[59] O. M. Wangboje and O. T. Ekundayo, "Assessment of heavy metals in surface water of the Ikpoba reservoir, Benin City, Nigeria," *Nigerian Journal of Technology,* vol. 32, no. 1, pp. 61-66, 2013.

[60] P. C. Nagajyoti, K. D. Lee, and T. V. M. Sreekanth, "Heavy Metals, Occurrence and Toxicity for Plants: A Review," *Environmental Chemistry Letters,* vol. 214, no. 1-4, pp. 343-361., 2010, doi: 10.1007/s10311-010-0297-8.

[61] M. Sojka and J. Jaskuła, "Heavy Metals in River Sediments: Contamination, Toxicity, and Source Identification-A Case Study from Poland," (in eng), *Int J Environ Res Public Health,* vol. 19, no. 17, Aug 23 2022, doi: 10.3390/ijerph191710502.

[62] M. M. Ali *et al.*, "Distribution of heavy metals in water and sediment of an urban river in a developing country: a probabilistic risk assessment," *International journal of sediment research,* vol. 37, no. 2, pp. 173-187, 2022.

[63] M. S. Bhuyan, M. A. Bakar, M. Rashed-Un-Nabi, V. Senapathi, S. Y. Chung, and M. S. Islam, "Monitoring and assessment of heavy metal contamination in surface water and sediment of the Old Brahmaputra River, Bangladesh," *Applied Water Science,* vol. 9, no. 5, pp. 1-13, 2019.

[64] M. S. Islam, M. K. Ahmed, M. Raknuzzaman, M. Habibullah-Al-Mamun, and M. K. Islam, "Heavy metal pollution in surface water and sediment: a preliminary assessment of an urban river in a developing country," *Ecological indicators,* vol. 48, pp. 282-291, 2015.

[65] N. A. Zheng, Q. Wang, Z. Liang, and D. Zheng, "Characterization of heavy metal concentrations in the sediments of three freshwater rivers in Huludao City, Northeast China," *Environmental pollution,* vol. 154, no. 1, pp. 135-142, 2008.

[66] H.-G. Hoang *et al.*, "Heavy metal contamination trends in surface water and sediments of a river in a highly-industrialized region," *Environmental Technology & Innovation,* vol. 20, p. 101043, 2020.

[67] J. Jaskuła and M. Sojka, "Assessment of spatial distribution of sediment contamination with heavy metals in the two biggest rivers in Poland," *Catena,* vol. 211, p. 105959, 2022.

[68] K. Ouma, A. Shane, and S. Syampungani, "Aquatic Ecological Risk of Heavy-Metal Pollution Associated With Degraded Mining Landscapes of the Southern Africa River Basins: A Review," *Minerals,* vol. 12, no. 2, p. 225, 2022, doi: 10.3390/min12020225.

[69] A. A. Pesantes, E. P. Carpio, T. Vitvar, M. M. M. López, and J. M. Menéndez-Aguado, "A multi-index analysis approach to heavy metal pollution assessment in river sediments in the Ponce Enríquez Area, Ecuador," *Water,* vol. 11, no. 3, p. 590, 2019.

[70] S. Rezapour, F. Asadzadeh, A. Nouri, H. Khodaverdiloo, and M. Heidari, "Distribution, source apportionment, and risk analysis of heavy metals in river sediments of the Urmia Lake basin," *Scientific Reports,* vol. 12, no. 1, p. 17455, 2022/10/19 2022, doi: 10.1038/s41598-022-21752-w.

[71] M. E. Imiuwa, P. Opute, and E. A. Ogbeibu, "Heavy metal concentrations in bottom sediments of Ikpoba River, Edo State, Nigeria," *Journal of Applied Sciences and Environmental Management,* vol. 18, no. 1, pp. 27-32, 2014.

[72] G. E. Ogbeide and A. O. Edene, "Assessment of Physicochemical Properties of Water and Sediments in Ikpoba and Ogba Rivers, Edo State, Nigeria," *Journal of Applied Sciences and Environmental Management,* vol. 27, no. 6, pp. 1057-1062, 2023.

[73] A. A. Enuneku and F. Ineh, "Assessment of Spatial Variations of Heavy Metals in Superficial Sediments of Ikpoba River and Comparison with Sediment Quality Guidelines," *FUTY Journal of the Environment,* vol. 14, no. 1, pp. 78-86, 2020.

[74] J. Odigie, E. Ogie, and E. Odigie, "heavy metal toxicity and histopathology of select organs of tilapia fish (tilapia zilli) from ikpoba river, benin city," *funai Journal of Science & Technology,* vol. 2, no. 1, pp. 10-22, 08/08 2016.

[75] M. Kumar, S. Singh, A. Jain, S. Yadav, A. Dubey, and S. P. Trivedi, "A review on heavy metal-induced toxicity in fishes: Bioaccumulation, antioxidant defense system, histopathological manifestations, and transcriptional profiling of genes," *Journal of Trace Elements in Medicine and Biology,* vol. 83, p. 127377, 2024/05/01/ 2024, doi: https://doi.org/10.1016/j.jtemb.2023.127377.

[76] P. Garai, P. Banerjee, P. Mondal, and N. C. Saha, "Effect of heavy metals on fishes: Toxicity and bioaccumulation," *J Clin Toxicol. S,* vol. 18, 2021.

[77] O. E. Oriakpono and N. G. V. Ima-Owaji, "Plankton Composition and Heavy Metal Concentrations in Fish From Bundu-Ama Creek, Port Harcourt, Rivers State," *World Journal of Biology Pharmacy and Health Sciences,* vol. 10, no. 1, pp. 008-018., 2022, doi: 10.30574/wjbphs.2022.10.1.0059.

[78] Z. Dragun, B. Raspor, and V. Roje, "The Labile Metal Concentrations in Sava River Water Assessed by Diffusive Gradients in Thin Films," *Chemical Speciation and Bioavailability,* vol. 20, no. 1, pp. 33-46, 2008, doi: 10.3184/095422908x299164.

[79] U. E. Jonah and C. F. Mendie, "heavy metals content and health risk assessment of ikpe ikot nkon river, akwa ibom state, nigeria," *food and environment safety journal,* vol. 21, no. 4, 2023.

[80] M. F. Tlusty, A. Myers, and A. Metzler, "Short- And Long-Term Dietary Effects on Disease and Mortality in American Lobster Homarus Americanus," *Diseases of Aquatic Organisms,* vol. 24;78, no. 3, pp. 249-53, 2008, doi: 10.3354/dao01867.

[81] Y. Yang, Z. He, Y. Lin, E. J. Phlips, P. J. Stoffella, and C. A. Powell, "Temporal and Spatial Variations of Copper, Cadmium, Lead, and Zinc in Ten Mile Creek in South Florida, USA," *Water Environment Research,* vol. 81, no. 1, pp. 40-50, 2009, doi: 10.2175/106143008x296479.

[82] F. Norambuena, A. Estévez, E. L. Mañanós, J. G. Bell, I. Carazo, and N. Duncan, "Effects of Graded Levels of Arachidonic Acid on the Reproductive Physiology of Senegalese Sole (Solea Senegalensis): Fatty Acid Composition, Prostaglandins and Steroid Levels in the Blood of Broodstock Bred in Captivity," *General and Comparative Endocrinology,* vol. 191, no. 2013, pp. 92-101, 2013, doi: 10.1016/j.ygcen.2013.06.006.

[83] E. Juniardi, Sulistiono, and S. Hariyadi, "Heavy Metals (Pb and Cd) Contents in the Seawater and Sediment in Panjang and Pamujaan Besar Islands, Banten Bay, Indonesia," *Iop Conference Series Earth and Environmental Science,* vol. 950, no. 1, p. 012052, 2022, doi: 10.1088/1755-1315/950/1/012052.

[84] O.-O. B. Minaopunye, E. D. V. Chinedum, and E. O. Ebere, "Toxic metal concentrations and exposure risks associated with surface water, seafood (Clarias gariepinus, Oreochromis niloticus, Cottus gobio) and vegetable (Telfairia occidentalis) from Elebele River, Nigeria," *Journal of Global Ecology and Environment,* vol. 17, no. 3, pp. 51-66, 2023.

[85] R. Adebola, G. Olufemi, and A. Iyabode, "Analysis of Fish Samples as a Biomarker of Levels of Pollutants in Ona River, Ibadan, Oyo State, Nigeria," *Iosr Journal of Applied Chemistry,* vol. 2, no. 3, pp. 32-37., 2012, doi: 10.9790/5736-0233237.

[86] D. O. Nwude, J. O. Babayemi, and C. P. Ajibode, "Heavy Metals Level in Clarias Gariepinus (Catfish), Oreochromis Niloticus (Tilapia) and Chrysichthys Nigroditatus (Bagrid Catfish) Collected From Ogun River, Ogun State, Nigeria," *Journal of Applied Sciences and Environmental Management,* vol. 191 no. 2013, pp. 92-101., 2020, doi: 10.4314/jasem.v24i8.19.

[87] M. O. Wegwu and J. O. Akaninwor, "Assessment of Heavy-Metal Profile of the New Calabar River and Its Impact on JuvenileClarias Gariepinus," *Chemistry & Biodiversity,* vol. 3, no. 1, pp. 79-87., 2006, doi: 10.1002/cbdv.200690010.

[88] H. K. Okoro, I. O. Ajibola, S. Isaac, and S. O. Oladipo, "Determination of Heavy Metal Genotoxicity and Their Accumulation Pattern in Different Fish Organs of Selected Fish Species Collected From the Asa River, Ilorin, Kwara State, Nigeria," *Journal of Applied Sciences and Environmental Management,* vol. 20, no. 3, pp. 735-745, 2016, doi: 10.4314/jasem.v20i3.28.

[89] D. T. Mohamed, M. Maha, El, Alem., , A. Marwa, Ibrahim., , and A. Thoria, Hamed. , "Comparison between heavy metal residues and their effect on African Catfish (Clarias gariepinus) and Nile Tilapia (Oreochromis niloticus)." *Egyptian Journal of Animal Health (Print), ,* vol. 3, no. 3, pp. 115-132, 2023, doi: 10.21608/ejah.2023.305223.

[90] S. Khalifa, M. Hassan, R. Amin, and N. M. Marzouk, "Evaluation of Some Heavy Metals' Residues in Tilapia," *Benha Veterinary Medical Journal,* vol. 38, no. 1, pp. 24-28, 2020, doi: 10.21608/bvmj.2020.24269.1166.

[91] Y. A. G. Osman, A. E. W. M, H. Mohamed, and A. Mazen, "The Relationship Between the Bioaccumulation of Heavy Metals in Clarias Gariepinus Tissues and Endoparasitic Helminths at Kafr El Sheikh Governorate, Egypt," *Egyptian Journal of Chemistry and Environmental Health,* vol. 1, no. 2015, pp. 1003-1016., 2015, doi: 10.21608/ejceh.2015.253993.

[92] D. Tibebe, D. Lemma, and G. Teshome, "Determination of Heavy Metals in Tilapia (Oreochromis Niloticus) and Water Samples From Lake Hayq, South Wollo, Ethiopia," *International Journal of Chemistry and Materials Research,* vol. 7, no. 1, pp. 10-19, 2019, doi: 10.18488/journal.64.2019.71.10.19.

[93] N. Malik, A. K. Biswas, T. A. Qureshi, K. Borana, and R. Virha, "Bioaccumulation of Heavy Metals in Fish Tissues of a Freshwater Lake of Bhopal," *Environmental Monitoring and Assessment,* vol. 160, no. 2010, pp. 267-276., 2009, doi: 10.1007/s10661-008-0693-8.

[94] O. Adekolurejo, O. N. R., A. O. S., and F. T. J., "Heavy Metal Concentrations and Distribution in Water, Sediment, and Catfish, Clarias Gariepinus Obtained from Aquaculture Farms in Ondo, Nigeria," *Science View Journal,* vol. 4, no. 1, pp. 279-284, 2023.

[95] R. Gulati, A. Kour, and P. Sharma, "Ecological impact of heavy metals on aquatic environment with reference to fish and human health," *Journal of Applied and Natural Science,* vol. 14, no. 4, pp. 1471-1484, 2022.

[96] A. Haseeb *et al.*, "Ecotoxicological assessment of heavy metal and its biochemical effect in fishes," *BioMed Research International,* vol. 2022, 2022.

[97] F. Mehouel and S. W. Fowler, "A mini-review of toxicokinetics and toxicity of heavy metals in marine and freshwater fish," *Journal of the Hellenic Veterinary Medical Society,* vol. 73, no. 1, pp. 3561-3570, 2022.

[98] N. Shiry, N. Derakhshesh, A. Gholamhosseini, M. Pouladi, and C. Faggio, "Heavy metal concentrations in Cynoglossus arel (Bloch & Schneider, 1801) and sediment in the Chabahar Bay, Iran," *International Journal of Environmental Research,* vol. 15, no. 5, pp. 773-784, 2021.

[99] A. Ahmed, A. Ismail, H. Omar, S. Zulkifli, S. Yusof, and F. Rahman, "Impact of Selected Heavy Metal (Cd, Pb, Cu and Zn) Concentration on Histological Changes of 2 Species of Estuarine Catfish (Small, Medium and Large Size) Arius thalassinus and Plotosus anguillaris," *Journal of University of Shanghai for Science and Technology,* vol. 23, no. 3, p. 234, 2021.

[100] R. Jia *et al.*, "Effects of high-fat diet on steatosis, endoplasmic reticulum stress and autophagy in liver of tilapia (Oreochromis niloticus)," *Frontiers in marine science,* vol. 7, p. 363, 2020.

[101] A. C. Schneider *et al.*, "Chronic exposure to ethanol causes steatosis and inflammation in zebrafish liver," (in eng), *World J Hepatol,* vol. 9, no. 8, pp. 418-426, Mar 18 2017, doi: 10.4254/wjh.v9.i8.418.

[102] K. He *et al.*, "A Freshwater Fish-Based Diet Alleviates Liver Steatosis by Modulating Gut Microbiota and Metabolites: A Clinical Randomized Controlled Trial in Chinese Participants With Nonalcoholic Fatty Liver Disease," (in eng), *Am J Gastroenterol,* vol. 117, no. 10, pp. 1621-1631, Oct 1 2022, doi: 10.14309/ajg.0000000000001885.

[103] Y. Asaoka, S. Terai, I. Sakaida, and H. Nishina, "The expanding role of fish models in understanding non-alcoholic fatty liver disease," *Disease models & mechanisms,* vol. 6, no. 4, pp. 905-914, 2013.

[104] L. Čižmek, S. Babić, I. Strunjak-Perović, and R. Čož-Rakovac, "Fish liver damage related to the wastewater treatment plant effluents," *Environmental Science and Pollution Research International,* vol. 30, no. 17, pp. 48739-48768., 2023.

[105] M. S. George, E. O. Nwaichi, and C. Monago-Ighorode, "Heavy Metals and Hydrocarbon Level in Nile Tilapia (Oreochromis niloticus), Mullet Fish (Liza falcipinus) and Crab (Callinectes amnicola) from Crude Oil Contaminated Jetty Rivers in Port Harcourt, Nigeria," *Journal of Applied Sciences and Environmental Management,* vol. 27, no. 4, pp. 883-891, 2023.

[106] R. A. Elrayess, H. N. G. El-Hak, and M. I. S. El-Din, "Histopathology and Ultrastructure in Liver and Gonads of the Nile Tilapia (Oreochromis niloticus) as a Bio-Monitor for Water Quality Assessment in Lake Manzalah," *Egyptian Journal of Aquatic Biology & Fisheries,* vol. 26, no. 6, 2022.

[107] F. A. Oguzie and G. A. Okhagbuzo, "Concentrations of heavy metals in effluent discharges downstream of Ikpoba river in Benin City, Nigeria," *African Journal of Biotechnology,* vol. 9, no. 3, 2010.

[108] A. C. Igboanugo and C. M. Chiejine, "Pollution Survey of Ikpoba River, Benin City, Nigeria," *Journal of Emerging Trends in Engineering and Applied Sciences,* vol. 3, no. 3, pp. 567-571, 2012.

[109] N. K. Egun and I. P. Oboh, "Surface water quality evaluation of Ikpoba reservoir, EDO State, Nigeria," *International Journal of Energy and Water Resources,* vol. 6, no. 4, pp. 509-519, 2022/12/01 2022, doi: 10.1007/s42108-021-00139-z.