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Environmental degradation of Nike lake: a study on water quality parameters and heavy metal accumulation in fish

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Abstract

Environmental pollution is a pressing global issue, with heavy metal pollution posing a significant threat. This study examined the concentrations of heavy metals (cadmium, nickel, lead, chromium, manganese, iron, zinc, copper, mercury, selenium, and arsenic) in various organs and tissues (blood, gills, intestines, liver) of African Catfish (*Clarias gariepinus*) and Redbelly Tilapia (*Tilapia zillii*) from Nike Lake in Enugu State, Nigeria. Water samples from the lake were also analyzed for heavy metal concentrations, as well as nitrogen and phosphorous content, nitrate, phosphate, and dissolved oxygen levels. The results showed that the fish samples contained varying concentrations of heavy metals, with the highest levels found in the gills. The ranges of metal concentrations were: Cd (0.00-0.033), Ni (0.00-0.002), Pb (0.00-0.072), Cr (0.00-0.039), Mn (0.00-0.041), Fe (0.010-1.363), Zn (0.268-0.604), Cu (0.008-0.084), Hg (0.00-0.147), Se (0.293-0.474), Mo (0.020-0.095), and As (0.00-0.034). The water samples contained similar concentrations of heavy metals, were Cd:0.02, Ni:0.001, Pb:0.034, Cr:0.00, Mn:0.012, Fe:0.037, Zn:0.173, Cu:0.008, Hg:0.147, Se:0.309, Mo:0.027, As:0.004, with the addition of nitrate (4.373), phosphate (4.383), and dissolved oxygen (45.33) levels. The nitrogen and phosphorous content in the fish organs ranged from 2.938-4.987 and 3.089-7.484, respectively. The study highlights the presence of toxic heavy metals in the organs of the fish, emphasizing the need for regulation and monitoring to mitigate the risks associated with heavy metal pollution in aquatic ecosystems.

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Keywords: Pollution, Heavy metals, Nike lake, *Clarias gariepinus*, *Tilapia zillii*

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1. Introduction

Aquatic environments are crucial for human survival, providing food and water for human consumption [1]. Water, which covers over 70% of the earth's surface, is essential for both plants and animals, and it is important to maintain its quality and supply it in

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Email address: `innocent.ujah@esut.edu.ng`, `ujahii812f@gmail.com` (I. I. Ujah) the least contaminated form [2]. However, aquatic environments are currently degraded by environmental toxicants such as heavy metals, pesticides, polyaromatic hydrocarbons (PAH), and insecticides [3]. In developed nations like the USA and China, agriculture is a significant factor in water ecosystem degradation [4], with agrochemicals like fertilizers, pesticides, insecticides, herbicides, fungicides, and nematicides contributing to the problem [5].

Excess nitrogenous and phosphate fertilizers can lead to eutrophication, depleting dissolved oxygen in water bodies [6, 7]. Eutrophication is characterized by excessive algae growth, depleting dissolved oxygen and altering ecosystem balance. When excess nitrogen enters water bodies, it stimulates phytoplankton growth, which consumes dissolved oxygen during decomposition, harming aquatic life. Similarly, excess phosphorous promotes algae growth, leading to algal blooms that reduce sunlight penetration and consume oxygen during decomposition. As a result, oxygen levels decrease, disrupting habitats and potentially producing toxins harmful to aquatic life and humans.

In developing countries like Nigeria, industrial discharges, waste waters, effluents, and oil exploration also contribute to water ecosystem degradation [8, 9], introducing large amounts of toxicants, including heavy metals, into the aquatic ecosystem [10]. The occurrence of toxicants like polyaromatic hydrocarbons, pesticides, herbicides, and metals in aquatic ecosystems can reduce water quality parameters [11]. Heavy metals, naturally occurring elements with high atomic weight and density, are toxic, persistent, and bioaccumulative, increasing in concentration over time in biological organisms [12–14]. While essential in small amounts, they become toxic in large quantities and can build up in biological systems, posing a significant health hazard [15]. Plants and animals utilize various heavy metals as essential micronutrients, including copper, iron,manganese, molybdenum, nickel, zinc, chromium, and selenium [16, 17].

Exposure to toxic heavy metals can have devastating health consequences. Cadmium inhalation, for instance, can cause these issues, as well as gastrointestinal distress and reproductive failure [18–20]. Nickel fumes can also irritate the respiratory system, leading to pneumonitis, lung cancer, and heart disorders [21, 22]. Similarly, lead exposure disrupts hemoglobin production, causing kidney damage, miscarriages, nervous system disruption, and fertility issues [23, 24]. Furthermore, excessive intake of essential metals like chromium(III) can lead to skin issues, respiratory problems, and lung cancer [25]. Moreover, mercury and inorganic arsenic exposure can result in nervous system disruption, DNA damage, reproductive issues, and increased cancer risk [26–28]. The African Catfish (Clarias gariepinus) and Redbelly Tilapia (Tilapia zillii) are valuable fish species that can bioaccumulate toxicants, including heavy metals [29]. These fish can serve as biological indicatorsto monitor and assess the integrity of aquatic ecosystems [9].

Nike Lake in Enugu State, Nigeria, plays a crucial ecological role as a biodiversity hot spot, supporting various plant and animal species and maintaining ecosystem balance [30]. The lake provides numerous benefits to human livelihoods, including flood control, water regulation, food security through fish production, irrigation, drinking water, carbon sequestration, and ecotourism opportunities [31]. Despite its importance, Nike Lake faces significant environmental threats from pollution, overfishing, habitat destruction, and climate change, which jeopardize its ecosystem balance and human benefits [32].

This study thus assessed Nike Lake's environmental degradation via water quality parameters and heavy metal accumulation in fish tissues. Objectives included evaluating water quality, determining heavy metal levels, identifying degradation sources, and providing conservation recommendations. Its findings will inform sustainable management practices to ensure Nike Lake's long-term ecological sustainability.

2. Materials and methods

2.1. Sample collection and preparation

The fishes (African Catfish and Red belly Tilapia) of similar lengths of 12-15 cm and the average size weighed 41.3 g used for this study were caught alive by fisherman using nets from the Nike River. They were thoroughly descaled and then sacrificed conscientiously in order to obtain the blood, tissue, liver and gill. The collected samples were submerged in formalin for preservation purposes. The water sample was gotten from the same freshwater source, the Nike River, which was the natural habitat for the fishes. Both samples were taken to Springboard Laboratories, Awka for Heavy metal Analysis and further analysis of the water.

2.2. Methods

2.2.1. Preparation of reference solution

A series of standard metal solutions in the optimum concentration range was prepared, the reference solutions were prepared daily by diluting the single stock element solutions with water containing 1.5 ml concentrated nitric acid. A calibration blank was prepared using all the reagents except for the metal stock solutions. The calibration curve for each metal was prepared by plotting the absorbance of standards versus their concentrations.

2.2.2. Determination of the heavy metals in the fishes

A quantity, 2 g of the sample was weighed using a weighing balance; each sample was heated in a furnace for 2hrs at 55 ^{0}C, diluted with 20 ml, 20 % H2SO4 and filtered out with a filter paper. The filtrate into a cuvette and was measured using Agilent Atomic Absorption Spectroscopy AAS 2400 FS model.

Table 1: Heavy metal levels in tissues, blood and different organs of African catfish (clarias gariepinus), red belly tilapia (tilapia zillii) and water.

Samples	Cd Ppm	Ni ppm	Pb Ppm	Cr ppm	Mn Ppm	Fe Ppm	Zn Ppm	Cu Ppm	Hg ppm	Se ppm	Mo ppm	As ppm
A/Tissue	0.005	0	0	0.013	0.009	0.01	0.268	0.01	0.035	0.473	0.024	0.032
A/Blood	0.007	0	0.016	0	0.026	0.075	0.604	0.009	0.109	0.293	0.015	0.011
A/Gills	0.033	0	0.029	0.017	0.041	0.01	0.323	0.084	0.147	0.383	0.101	0
A/Intestine	0.001	0	0.027	0.001	0.029	0.072	0.338	0.008	0	0.347	0.022	0
A/Liver	0.004	0	0.01	0	0.003	0.016	0.225	0.01	0.031	0.298	0.095	0
B/Tissue	0.001	0.002	0.05	0.039	0	0.018	0.33	0.011	0.074	0.422	0.029	0.01
B/Blood	0.003	0	0.005	0	0.008	0.122	0.434	0.009	0.108	0.294	0.035	0.034
B/Gills	0	0.002	0.072	0.013	0.003	0.025	0.335	0.011	0.12	0.428	0.02	0.023
B/Intestine	0	0	0.038	0	0.011	1.363	0.507	0.008	0.022	0.385	0.025	0
B/Liver	0	0	0.018	0.018	0.002	0.048	0.286	0.009	0.073	0.474	0.043	0.012
WATER	0.002	0.001	0.034	0	0.012	0.037	0.173	0.008	0.147	0.309	0.027	0.004

Note: A = African catfish; B= Red belly tilapia.

2.2.3. Determination of heavy metals in water

The sample is thoroughly mixed by shaking, and 100 ml of it is transferred into a glass beaker of 250 ml volume, to which 5 ml conc. nitric acid was added and heated to boil. The volume is reduced to about 15-20 ml, by adding conc. nitric acid in increments of 5 ml till all the residue is completely dissolved. The mixture is cooled, transferred and made up to 100 ml using metal free distilled water. The sample is aspirated into the oxidizing air-acetylene flame. When the aqueous sample is aspirated, the sensitivity for 1 % absorption was observed using Atomic Absorption Spectrophotometer.

2.2.4. Nitrate determination

A known volume (50ml) of Sample was pipetted into a porcelain dish and evaporated to dryness on a hot water bath. 2ml of Phenol disulphonic acid was added to dissolve the residue by constantly stirring with a glass rod. Concentrated solution of sodium hydroxide was added with stirring to make it alkaline. This was filtered into a Nessler's tube and made up to 50 ml with distilled water. The absorbance was read at 410 nm using PD303 UV Spectrophotometer after the development of colour. A standard graph was plotted by taking concentration along X-axis and the spectrophotometer readings (absorbance) along Y–axis. The value of nitrate was found by comparing absorbance of sample with the standard curve and expressed in mg/L [33].

2.2.5. Phosphate determination

Exactly 100 ml of the homogenized and filtered sample was pipetted into a conical flask. A volume, 1 ml of 18M H2SO4 and 0.89g of ammonium persulphate were added to the flask and gently boiled for 1½ hrs, keeping the volume of 25-50cm3 with distilled water.It was then cooled; one drop of phenolphtalein indicator was added and after neutralized to a faint pink colour with the 2M NaOH solution.The pink colour was discharged by drop-wise addition of 2M HCl, and the solution made up to 100 ml with distilled water. For the colorimetric analysis, 20 ml of the sample was pipetted into test tubes; 10 ml of the combined reagents was added, shaken and left to stand for 10 mins before reading the absorbance at 690 nm on a spectrophotometer [33].

2.2.6. Determination of dissolved oxygen in water

The stopper was carefully removed from the sample bottle, and then 1cm^3 of manganese sulphate solution was added, followed consecutively by 1cm^3 of alkaline-iodide-azide solution. After each addition, the stopper was carefully replaced to prevent air bubbles from forming. The contents were thoroughly mixed by inversion and rotation until clear supernatant water was obtained. Next, 1cm^3 of concentrated sulphuric acid was added with the pipette tip below the solution level, and the stopper was replaced again. The solution was mixed well by rotation until the precipitation was completely dissolved. Subsequently, a 100cm^3 portion of the sample was pipetted into a 250cm^3 conical flask and immediately titrated against standard sodium thiosulphate (0.0125 moldm^3) using freshly prepared starch solution as the indicator, which was added when the solution turned pale yellow. This titration process was carried out in duplicate [33].

3. Results

The results of the study are shown in Figures 1 - 3, and Tables 1 - 3.

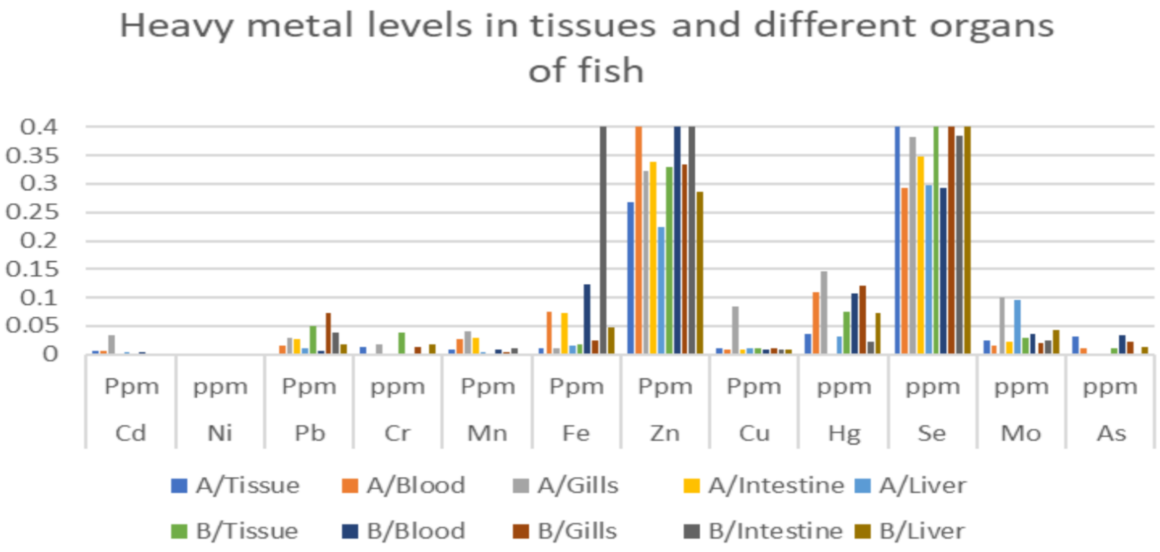

Figure 1: Heavy metal levels in tissues and different organs of the fish.

Table 2: Nitrogen and Phosphorus levels in tissues, blood and different organs of African Catfish(Clarias Gariepinus) and Red belly Tilapia (Tilapia zillii).

Samples	Nitrogen %	Phosphorus mg/kg
A/Tissue	4.073	6.489
A/Blood	3.278	5.473
A/Gills	3.574	3.173
A/Intestine	3.784	5.338
A/Liver	3.984	3.089
B/Tissue	3.944	4.564
B/Blood	4.183	6.933
B/Gills	4.178	6.374
B/Intestine	4.987	7.484
B/Liver	2.938	4.786

Note: A = African catfish; B= Red belly tilapia.

Table 3: Concentration of nitrate, phosphate and dissolved oxygen in water from Nike lake.

Parameters	Concentration (mg/l)
Nitrate	4.373
Phosphate	8.383
Dissolved Oxygen	45.33

4. Discussion

Heavy metal contamination in aquatic ecosystems poses significant health risks to humans and wildlife. This study on water quality, concentrations of some heavy metals in tissues and organs of Clarias gariepinus and Tilapia zillii obtained from Nike Lake revealed varying levels of heavy metals such as lead, mercury, chromium, and arsenic.

Nickel was not detected in Clarias gariepinus, but was present in Tilapia zillii at 0.04 ppm, below the permissible limit of 0.5-0.6 ppm [34]. This suggests species-specific differences in metal accumulation or environmental exposure. Tilapia zillii may have a selective uptake or detoxification mechanism, while Clarias gariepinus may be more sensitive to Nickel pollution or have a different metabolism [35]. Nickel levels in fish vary by location and species, ranging from 0.01 to 0.13 ppm as also reported in these studies [35, 36]. The levels found in this study are consistent with other researches.

Lead levels in Clarias gariepinus and Tilapia zillii were within the safe range (0.082 and 0.183 ppm, respectively), posing no immediate health risk to humans [34]. The gills had the highest lead concentration, followed by the intestine, blood, and liver, indicating that the gills are the most affected tissue as was also observed by Refs. [36, 37]. The lower lead levels in Clarias gariepinus

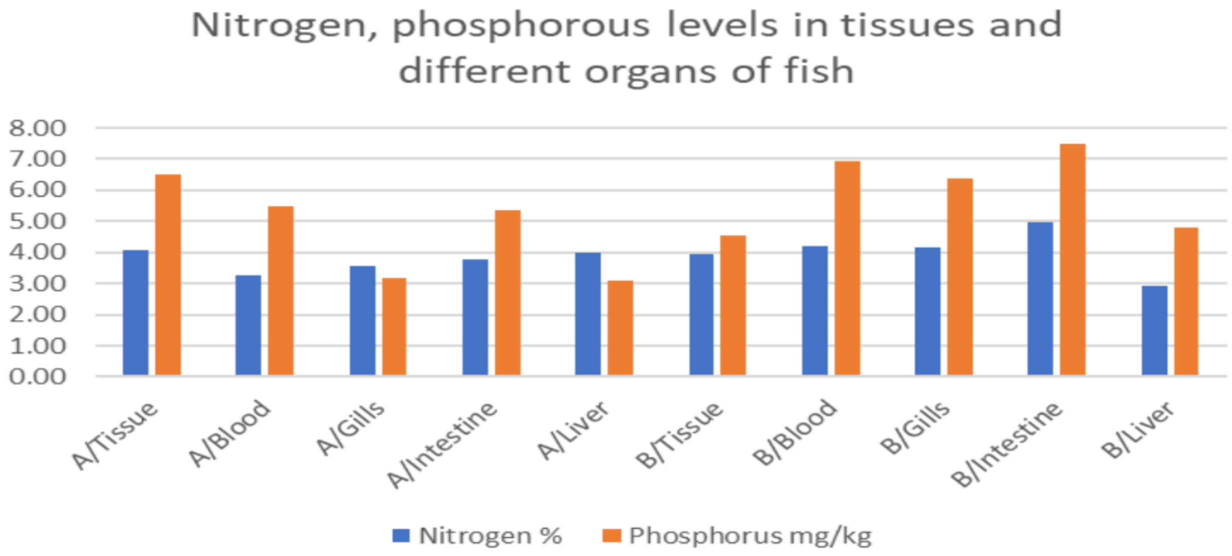

Figure 2: Nitrogen and phosphorous Levels in tissues and different organs of fish.

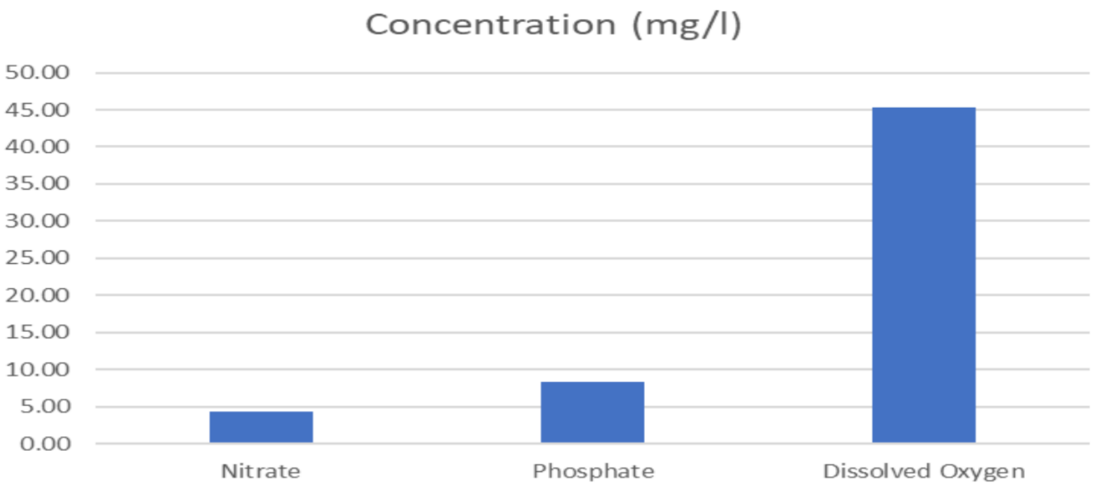

Figure 3: Concentrations of nitrate, phosphate and dissolved oxygen in Nike lake.

suggest differences in habitat, diet, or metabolism. Both species had lead levels below the permissible limit, indicating relatively low lead pollution levels in their environment. Continued monitoring is essential to ensure the long-term safety of the aquatic ecosystems.

Chromium (Cr) levels in Clarias gariepinus and Tilapia zillii were below the maximum permissible concentration (50 mg/kg). The order of Cr concentration varied between species, with gills being the primary site of absorption in Clarias gariepinus and tissue in Tilapia zillii. Both species had relatively low Cr levels, indicating a healthy aquatic environment. The absence of Cr in blood and liver suggests efficient excretion or detoxification mechanisms. The differences in Cr distribution may be due to physiological, habitat, or dietary variations. Similar Cr levels were found in studies in the Nile River [38] and Amazon River [39], but higher levels were reported in a polluted river in China [40].

Manganese (Mn) is an essential trace element that is naturally present in foods and available as a dietary supplement. In Clarias gariepinus, Mn concentration ranged from 0.00-0.049 ppm, occurring in the order of gills >intestine >blood >tissue >liver, while in Tilapia zillii, the order was intestine >blood >gill >liver, with Mn absent in tissue. The different distribution patterns may be due to physiological, habitat, or dietary variations. Manganese is essential for fish nutrition and physiology, and its presence in gills and intestine suggests involvement in absorption and metabolism. Manganese levels in fish can indicate environmental pollution, highlighting the need for ongoing water quality monitoring. Similar Mn levels were found in studies in Lake Victoria [34], the Nile River [37], and the Amazon River [38], while higher levels were reported in a polluted river in China [40]. A global review reported a range of 0.01-0.50 ppm, encompassing the levels found in this study.

Iron (Fe) is an essential heavy metal in the human body, involved in various physiological activities. In Tilapia zillii and Clarias gariepinus, the highest iron concentrations were found in the intestine and blood, respectively, while the lowest concentrations were detected in the tissue. The concentrations ranged from 0.010-1.363 ppm, suggesting differences in iron metabolism and requirements between the species. The presence of iron in the gills and intestine suggests involvement in absorption from water and diet. The study highlights the importance of iron in fish physiology and nutrition, and suggests further research is needed to fully understand its role in fish health and development. The findings also have implications for human health, as iron is an essential nutrient for humans. Similar studies found varying iron levels in fish from different rivers and lagoons, including the Ogun River [41], Owan River [42], and Lagos Lagoon [41].

Zinc (Zn) is an essential trace mineral involved in cellular metabolism, with a permissible limit of 40 ppm set by WHO/FAO (1989) [43]. In Clarias gariepinus and Tilapia zillii, the highest Zn concentrations were found in the blood and intestine, while the lowest concentrations were found in the liver. This suggests that the blood and intestine may be more susceptible to Zn accumulation or have a higher affinity for the substance, while the liver may be less efficient at accumulating or storing Zn. Similar patterns were observed in other studies on Oreochromis niloticus [44], Cyprinus carpio [45], and mussels [46], suggesting a common physiological or biochemical mechanism.

Copper (Cu) is an essential trace metal vital for nervous system function and hemoglobin synthesis in vertebrates, including fish [47]. However, chronic exposure can lead to anemia and liver toxicity. In *Clarias gariepinus* and *Tilapia zillii*, copper concentrations were highest in the gills, followed by tissue, liver, blood, and intestine, with similar distribution patterns in both species [48]. The levels were within the safe range, below the maximum permissible limit of 30 ppm (parts per million) established by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) in 1989, as referenced in [43] study, posing no immediate risk to human consumption or environmental concern. The gills were the primary site of copper accumulation, and the tissue distribution pattern suggested a conserved physiological mechanism. Similar results were found in studies on *Oreochromis niloticus* [48] and shrimp [49], while in humans, copper is primarily stored in the liver and muscles [50].

Mercury (Hg) is the most toxic heavy metal in the environment, and exposure primarily occurs through consuming contaminated fish and shellfish or inhalation [51, 52]. In *Clarias gariepinus* and *Tilapia zillii*, the highest mercury level was 0.147 ppm in the gills of *Clarias gariepinus*, while the lowest level was 0.022 ppm in the intestine of Tilapia zillii. Mercury was not detected in the intestine of Clarias gariepinus. The mercury content in both species did not exceed the FAO's maximum limit of 0.5 ppm. Similar studies found higher Hg levels in *Cyprinus carpio* (up to 0.21 ppm) [53] and similar levels in shrimp (Litopenaeus vannamei, up to 0.15 ppm).

Selenium (Se) is an essential element that can be toxic at high doses. In Clarias gariepinus and Tilapia zillii, the highest Se content was found in the tissue and liver, respectively, while the lowest content was found in the blood of both species. ”The levels of Selenium (Se) in both fish species were higher than the safe limit of 1 part per million (ppm), exceeding the toxicity threshold. Selenium is an important nutrient for humans, particularly in Japan, where fish is the main source [54]. Se-enriched diets have been shown to prevent methylmercury toxicity and reverse its symptoms [55]. Molybdenum is found in legumes, whole grains, nuts, beef liver, dairy products, leafy vegetables, cereal grains, cheese, and meat, making a balanced diet a reliable way to meet daily needs. A balanced diet with adequate molybdenum intake is crucial for maintaining overall health and well-being. Molybdenum (Mo) is an essential micronutrient that can be toxic at high concentrations (>10 mg/kg). Molybdenum is essential for enzyme function, but excessive intake can cause joint pain and high uric acid levels, while deficiency can lead to cardiac and respiratory issues, headaches, and night blindness. However, the Mo levels in both fish samples were below the toxicity limit, and it is considered less toxic than other heavy metals, with potential anticarcinogenic properties [56].

Arsenic, a semi-metal, is known to have adverse effects on aquatic biota and human health, with the liver being a major target organ of arsenic toxicity [57]. Arsenic was only detected in the tissues and blood of Clarias gariepinus, with the highest content found in the blood of Tilapia zillii. According to Ref. [58], the reference dose of arsenic in fish is 0.0003 parts per million (ppm), which was exceeded by both samples. Similar studies found higher arsenic levels in fish from Nigeria's Niger Delta (0.02-0.15 ppm) [59], India's Ganges River (up to 0.24 ppm) [60], and varying levels in the US (generally below 0.01 ppm, but dependent on species and location).

Heavy metal exposure poses a significant threat to human health, causing a range of debilitating effects. Exposure to mercury, lead, and cadmium can lead to neurotoxicity, damaging the nervous system and resulting in cognitive impairment, memory loss, and tremors [61]. Furthermore, heavy metals like chromium, arsenic, and nickel increase the risk of carcinogenicity, or cancer [62]. Additionally, mercury and lead exposure can contribute to cardiovascular disease, including hypertension, cardiovascular disease, and stroke [63]. Cadmium and mercury can also cause renal damage, leading to kidney dysfunction [64]. Moreover, heavy metal exposure can have devastating effects on reproductive health, affecting fertility, fetal development, and birth outcomes [65].

The highest nitrogen levels were found in the intestine of Tilapia zillii and tissue of *Clarias gariepinus*, consistent with [66] research. On average, 25% of nitrogen (ranging from 11-36%) comes from nutrient input [67]. The total nitrogen percentage in Clarias gariepinus (18.693%) and Tilapia zillii (20.23%) falls within the normal range for fish. According to Ref. [68], the maximum allowed levels for nitrate and phosphate in surface water are 50 milligrams per liter (mg/L) for nitrate and 5 milligrams per liter (mg/L) for phosphate. While nitrate levels (4.373 mg/L) were within the limit, phosphate levels (8.383 mg/L) exceeded the limit. Dissolved oxygen (DO) levels, a direct indicator of water quality, were reported at 45 mg/L, exceeding the recommended range of 13-14 mg/L [69]. According to the USEPA, DO levels below 3 mg/L are concerning, and those below 1 mg/L are considered hypoxic.

The statistical analysis results revealed significant variations in Pb, Fe, Zn, and Se concentrations across samples ($p < 0.001$). This suggests that the concentrations of these metals differ significantly between tissues, blood, and water.There was moderate correlations between Pb, Cr, Mn, and Zn (0.32-0.44). This suggest that these metals may have similar sources or mechanisms of accumulation in the environment. There was significant differences in Pb and Fe concentrations between A/Blood and B/Intestine ($p < 0.001$). This suggests that these tissues may have different capacities for metal accumulation or elimination. Also, there was a significant differences in Zn concentrations between A/Tissue and A/Blood ($p = 0.012$). This indicates that Zn may be differentially distributed across tissues.

5. Conclusion

The concentrations of heavy metals in water decreased in a specific order, with most being within WHO guidelines except for Hg, Se, and Pb, while nitrogen levels were highest in the intestine of Tilapia zillii and tissue of Clarias gariepinus, falling within the normal range for fish, but phosphate levels exceeded the permissible limit, although nitrate levels were within the limit, and dissolved oxygen levels were high, exceeding the recommended range, which can harm aquatic life and affect water quality. Overall, the research highlights the importance of monitoring water quality parameters, including heavy metal concentrations, nutrient levels, and dissolved oxygen, to ensure the health and sustainability of aquatic ecosystems. To comprehensively address metal contamination in Nike Lake, further research is necessary to identify pollution sources, assess health risks, and monitor seasonal trends and bioaccumulation in various fish species. Establishing monitoring programs to track metal concentrations over time is also crucial. Remediation efforts should be implemented to mitigate pollution and potential health risks. Additionally, increasing the sample size and validating sampling and analytical methods will enhance the accuracy and generalizability of findings. Seasonal variations in pollution levels should also be taken into account.

Data availability

The datasets generated and analyzed during the current research are available from the corresponding author upon request.

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