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SPATIAL VARIABILITY OF HEAVY METAL BIOACCUMULATION IN TILAPIA (*Tilapia guineensis*) AND ITS CORRELATION WITH WATER AND SEDIMENT QUALITY IN RIVER STATE

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ABSTRACT

This study examines the spatial variability of heavy metal bioaccumulation in Tilapia guineensis and its correlation with water and sediment quality across Akuku Toru, Asari Toru, and Degema in Rivers State, Nigeria. Heavy metals such as cadmium (Cd), lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), copper (Cu), and nickel (Ni) were analyzed in water, sediment, and fish samples collected from the region. Results indicate significant variations in heavy metal concentrations across stations. Asari Toru recorded the highest cadmium concentration in fish (0.027 mg/kg), while Degema had the highest lead (0.05 mg/kg) and chromium (0.052 mg/kg) concentrations. The bio-sedimentation factor (BSF) showed that arsenic had the highest bioaccumulation in tilapia, with BSF values ranging from 0.182 to 0.700 across stations. Furthermore, the bioaccumulation factor (BAF) demonstrated considerable arsenic bioaccumulation in fish tissues, with values ranging from 0.366 to 2.333. Copper and zinc were two other metals with minor bioaccumulation. This study's findings also suggest a correlation between heavy metal levels in water and sediments and the bioaccumulation of heavy metals by fish. Although most metal concentrations are under regulatory limits, the potential health risks associated with long-term heavy metal ingestion from fish diets raise concerns, particularly in sensitive regions.The findings emphasise the need of ongoing monitoring and stricter environmental regulations in reducing the risks posed by heavy metal contamination in the Niger Delta's aquatic environment.

Keywords: Metal, Bioaccumulation, Tilapia, Sediment, Water Quality

INTRODUCTION

Seafood offers a high-quality source of protein, critical vitamins, minerals, and omega-3 fatty acids, all required for maintaining good health, making it more significant for human nutrition (Tacon et al., 2020; Jamioł-Milc et al., 2021). Regular seafood consumption has been connected to various health benefits, including enhanced cardiovascular health, cognitive development, and higher immune function (Cuparentcu et al., 2019; Liu and Ralston, 2021). Particularly fatty fish are well-known for their high omega-3 fatty acid content, which has anti-inflammatory properties and promotes brain function and heart health (Drenjančević and Pitha, 2022). Moreover, seafood gives critical vitamins, selenium, and iodine—key nutrients required for the body to function generally (Jayasekara et al., 2020).

Fish species include *Tilapia guineensis* flourish in the Niger Delta region of Nigeria, which is defined by its complex river system, wetlands, and various aquatic conditions. Apart from its high biodiversity, this area is also significant for the livelihoods of neighbouring people who depend on aquaculture and fishing for subsistence (Adekola and Mitchell, 2011). Nonetheless, the region faces substantial environmental concerns, largely connected to heavy metal pollution brought on by industrial operations including urbanisation, agriculture, and illicit crude oil refining, including unlawful crude oil refinery, agriculture, and urbanisation. This investigation seeks to explore the geographical variability of heavy metal bioaccumulation in tilapia and its relationship with water and sediment quality in Rivers State, hence highlighting the repercussions for both environmental health and food safety.

A significant concern impacting water quality and aquatic life in the Niger Delta is heavy metal contamination. In the region, sources of heavy metals include wastewater from industrial activities, pesticide and fertiliser runoff from agricultural areas treated, and oil leaks (Kalio, 2024). Lead, cadmium, mercury, and arsenic are among elements that may build up in aquatic life and induce biomagnification and bioaccumulation along the food chain. Particularly for communities that depend largely on fish as a protein source, the bioaccumulation of hazardous chemicals in fish offers considerable health dangers (Damian et al., 2014; Mutlu, 2021). Understanding the degree of pollution and its environmental repercussions relies on measuring the spatial variability of heavy metal concentrations in fish, water, and sediments (Ali et al., 2021). Because of their feeding behaviours and habitat preferences, West African freshwater fish *Tilapia guineensis*often consumedare especially prone to heavy metal bioaccumulation (Ajala et al., 2022; Garai et al., 2021). Being an omnivorous species, tilapia feeds benthic invertebrates and detritus, which frequently contain heavy metals from polluted sediments and therefore expose them to accumulation in their tissues (Chinedu and Chukwuemeka, 2018). This study presents crucial new insights on the bioaccumulation of heavy metals in tilapia, which is vital for evaluating the health dangers to human consumers as well as aquatic ecosystems (Agbugui and Abe, 2022).

Factors including proximity to pollution sources, river flow patterns, and sediment characteristics (Moiseenko and Gashkina, 2020) may impact geographic variability in heavy metal concentrations. These factors may alter the degree to which fish like tilapia acquire heavy metals (Attah et al., 2021; Agbugui and Abe, 2022). This research attempts to discover high-contamination locations by studying several sites in Rivers State and analyse the connection between these concentrations and water and sediment quality. Development of effective management methods to minimise pollution and preserve public health relies on a knowledge of these developments (Zhang et al., 2017).

Fish, particularly tilapia, contain significant metal contamination that raises severe public health concerns. Eating contaminated fish could induce neurological abnormalities, developmental issues, and a greater risk of chronic diseases (Attah et al., 2021; Umeoguaju et al., 2023). Particularly at risk are vulnerable populations like children and pregnant women, which highlights the significance of continued heavy metal level monitoring in commercially relevant fish species (Alipour and Banagar, 2018). This study examines the spatial variability of heavy metal bioaccumulation in *Tilapia guineensis* and its correlation with water and sediment quality across Akuku Toru, Asari Toru, and Degema in Rivers State, Nigeria. It therefore, provides vital information for environmental management in the Niger Delta (Ehiemere et al., 2022).

Study Area

Figure 1 shows the study area is a tidal soft-bottom mangrove swamp with wide-ranging exposed mudflats. It is located between the following coordinates: 4°45'41.566"N, 6°45'30.448"E (Degema LGA), 4°44'52.365"N, 6°46'56.573"E (Asari Toru LGA), and 4°44'9.758"N, 6°46'11.764"E (Akuku-Toru LGA). Due to regular and strong tidal action, pollutants from various sources are believed to be uniformly distributed throughout the ecosystem. The main fish families present are Lutjanidae, Clupeidae, Cichlidae, and Claroteidae. Tidal mudflats host mudskippers, gobies, crabs, and periwinkles.

Each sample station, except for station 1, which serves as a primary landing site for artisanal bunkering materials (according to anecdotal reports by residents), has distinct characteristics. Station 1 is a hub for crude oil bunkering supplies and firewood collection from mangroves. Activities such as sand mining, fishing, and seafood harvesting are reported at this location. The sample sites were intentionally chosen to capture a range of locations and activities within the Creek for comprehensive data collection and analysis.

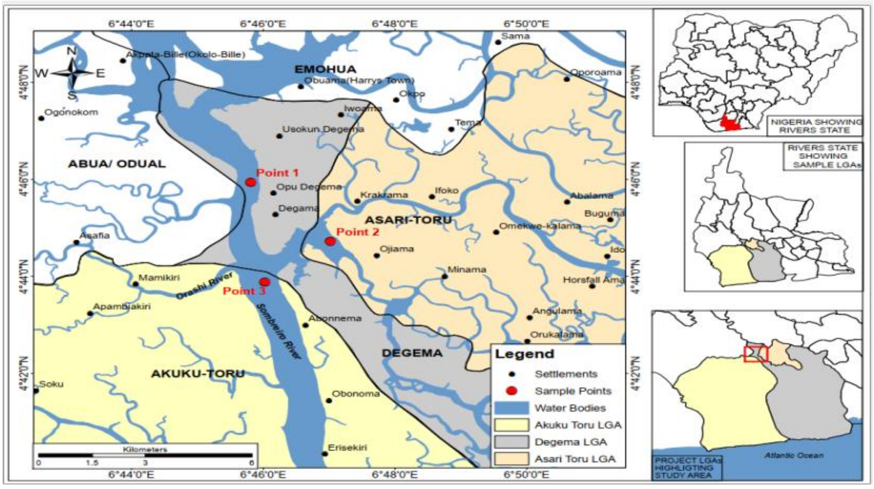

Figure 1: shows a map of the research region in Rivers State, Nigeria, with three sites sampled: Akuku Toru, Asari Toru, and Degema Local Government Areas.

Sample and Sampling Procedure

Buguma Creek's vegetation is predominantly red mangrove, white mangrove, black mangrove, and Nypa palm. The local community relies on the creek for recreation, transportation, open defecation, spiritual practices, and livelihood purposes. In order to represent various activities in catchments and their importance as important pollution sites, the sampling stations were chosen based on characteristics found in the study region. The study focuses on the presence of heavy metals like Cadmium (Cd), Lead (Pb), Chromium (Cr), Arsenic (As), Zinc (Zn), Copper (Cu), and Nickel (Ni) in the Buguma Creek catchment due to their high prevalence in the area due to industrial effluents. Sampling stations were chosen based on their characteristics and activities in the vicinity. Samples collected include sediments, surface water, tilapia (*Tilapia guineensis*). All sites were geo-referenced using a handheld GPS receiver unit.

Data Collection of Samples

The surface water's physicochemical parameters, namely electrical conductivity, temperature, dissolved oxygen, biological oxygen demand, and salinity, were assessed on-site using handheld ExtechEC500 and Extech DO multimeters. Meanwhile, BOD was collected using a BOD bottle and sent to a laboratory for examination. For the purpose of heavy metal analysis, water and sediment samples were aseptically collected in clean, fresh screw-capped bottles, acidified, and properly labelled, at a depth of about 20 cm below the water's surface near shore during both high and low tide. The purpose of the sampling distance from the bank was to guarantee that the sediment and water samples accurately reflected the distinct and real pollution pockets within the research region. For a period of six months, local fishermen's catch at each sample site was used to gather live, freshly caught tilapia (*Tilapia guineensis*). To account for statistical variance, a total of twenty representative fish samples (ten each sample) were gathered for each sampling campaign across a six-month period (March to August 2023) of sampling. Because the fish sample was easily obtainable and represented both benthic and pelagic environments, it was selected. These fish species are among of the Niger Delta's most valuable commercial fisheries. To protect the samples' integrity, each one was properly marked before being brought to the lab that same day on an ice chest. After that, the samples were chilled while they were analysed. Standard procedures were used in the analysis of the heavy metal content (APHA 2000).To make sure the monitoring apparatus was charged accurately and using the proper charger, precautions were taken. Before the test, the relevant gas sensor (probe) was fixed. In cases where there were environmental hazards, protective apparel was employed. Every sample was examined three times.

Heavy metal analysis

APHA3111B was utilised for the heavy metal analysis (Chris et al., 2024). Cd, Pb, Cr, As, Zn, Cu, and Ni were the heavy metals that were tested (mgkg-1 and mgL-1 for water samples). The operating conditions and instrument setup were accomplished in line with the manufacturer's instructions.

Heavy Metal Analytical procedure and Methods

Fish Samples collection and Total Digestion for Heavy Metals

At each sampling location, tilapia (*Tilapia guineensis*) samples were collected from the streams using fishing nets that had been thrown and left overnight. During the sampling periods, three primary fishing locations along the streams provided samples of fin and shellfish. As soon as the fish samples were received, they were placed in ice chests for transit to the laboratory, sealed, labelled and cleaned polythene bags. The samples were stored in a deep freezer in the lab until the muscle tissues were taken out for examination. Since muscle tissues represent the portion of the fish that is most often ingested, they were selected for analysis in this research. The majority of the fin and shellfish species that are eaten year-round by the residents of this River State local government region are those that have been examined. Higher risks to human health are associated with the presence of substantial levels of heavy metals in muscle tissues.

The tilapia (*Tilapia guineensis*)] samples were ground into granules using a blender. The extraction process was carried out utilising the full digestion technique (APHA 3030I modified) of nitric acid, perchloric acid, and sulphuric acid. In a 250 ml Pyrex conical flash, one gramme of granulated fish samples was weighed, and 20 ml of digestion solution was added. The samples were heated to 250 degrees Celsius in the fume hood using an electrical mantle to assure full digestion by causing the granule colour to shift from black to grey. The digested solution was heated, taken out of the fume hood, and set aside to cool on the workstation. Once further cooling was achieved, 20 millilitres of distilled water was added. Using a Whatman 42 filter with ashless filter paper, the digested solution was sieved into a 100 ml glass volumetric flask. The volumetric flash was filled with the digested filtrate to the 100 ml mark on the flask. This was then put into a sanitised 100 ml plastic container and marked. AAS analysis of the sample extracts for Cd, Pb, Cr, As, Zn, Cu, and Ni was prepared. To provide quality control and assurance, the findings were checked for consistency using spiked sample recovery, reagent blanks, and standard operating procedures.

Sampling and Digestion of Sediment

During the sampling periods (March to August 2023), sediment samples were collected from the bottom surface of the mud flat (0 to 5 cm thick) using an Eckman grab in accordance with Chris and Davies, (2024). Three randomly selected sediment grabs were collected from the stream banks for every sample, organised, and sealed in sterile polythene bags. Because it controls the movement of metals from sediments into water and acts as a sink for metals that are exposed to benthic organisms, the surface layer was selected for this study (Georgeet al., 2016). Next, the date and sample location were inscribed on the polythene bags. While being transferred to the laboratory, the samples were kept cold in an ice box. Before the samples were ready for heavy metal analysis, they were kept in a freezer at -20°C in the lab. Before being put in pre-acid washed evaporating beakers for digestion, the sediment samples were cooled to room temperature (25 to 28° C). The sediments were then dried to a consistent weight at 50°C in an oven. The samples of dried sediment were crushed using a ceramic mortar and pestle and then filtered through a 2 mm mesh polypropylene sieve. Hydrochloric acid (aqua regia) and concentrated nitric acid (analytical grade) were used in a 1:3 ratio for digestion. Two grammes of dry sediment were weighed out and placed into a 50-millilitre beaker that had been acid-washed using an electronic weighing scale. After adding the silt, 9 mL of a newly prepared HNO3 and HCl solution was heated gradually over a water bath until the volume dropped to 20 mL. The digested sample was filtered using a Whatman 0.42 m filter paper and then transferred into a 50 mL volumetric flask that was completely filled with distilled, deionised water. The filtrate's heavy metal content was examined using AAS. The same process was used to make a blank solution using distilled water.

Sampling and Digestion of Water

Following the protocol outlined by Kumolu-Johnson and Ndimele (2012), surface water samples were collected. At three different random locations, about 0.3 meters below the surface of the river, water samples were taken from the stream. Throughout March through August of 2023, samples from all three sites were combined, then placed into three 500 ml plastic bottles. Using 10% nitric acid and distilled water as a rinse, the sample vials were prepared for sampling. During the sample process, the bottles were then cleaned three times using the creek's water. Using a sampling vial submerged directly in the surface water, samples were obtained. 2 mL of AR-grade nitric acid was added to the water samples right away after sample collection in order to lessen the adsorption of metals onto the plastic bottle walls. Samples were taken in an ice box to the laboratory and kept there for analysis at 4˚C until their labels with the date and location of sampling were applied. The concentrated nitric acid (Analytical Grade) technique of **Zhang et al. (2017**) was used to distil the water samples in triplicate.

Quality assurance and control

To create a calibration curve, the analytical apparatus was calibrated using atomic absorption standards for many heavy metals that were buck-certified. To prevent equipment drift, reagent blanks were initially run per ten samples analysed. The range of recoveries was 82–110%. AAS (Model 210 VGP, Buck Scientific) was used to evaluate the metal contents in samples of biota and sediments. Every sample was tested twice, and the average results were given.

Statistical analysis

The variations in heavy metal concentrations in sediment and benthic fauna between the wet and dry seasons were determined using oneway analysis of variance (ANOVA) at a significant threshold of 0.05. Additionally, standard errors were calculated. IBM SPSS Statistics 20 and Microsoft Excel 2010 were used to do all statistical analyses on the computer.

Evaluation of Heavy Metals in Fish Tissue

Bioaccumulation Factor (BAF) for Water

Bioaccumulation Factor was calculated to determine the level of heavy metal accumulation in the tissue of the fish using the formula below:

The tissue concentration of heavy metals through the water was calculated using simple form, BAF, by dividing the heavy metal concentration in fish tissue by that in the water;

BAF = Concentration of metals in fishes (mg/kg) /Concentration of metals in water (mg/kg).

Bio-sediment Accumulation Factor (BSAF)

The tissue concentration of heavy metals through the sediment forms BSAF and is obtained by dividing the heavy metal concentration in fish tissue by that in the sediment.

BSAF = Concentration of metals in fishes (mg/kg) /Concentration of metals in sediment (mg/kg).

RESULTS

Concentration of Heavy Metals in Sediment Samples Across Stations

Results from table 1 shows that sediment samples inAkuku Toru recorded the highest concentration of Cd (0.453 mg/kg), which was significantly higher than the values in Asari Toru (0.172 mg/kg) and Degema (0.108 mg/kg). Similarly, Cu concentration was highest in sediments from Akuku Toru (27.724 mg/kg) and was significantly higher than sediment samples from Asari Toru (8.386 mg/kg) and Degema (2.659 mg/kg). Ni also showed the highest concentration in Akuku Toru (13.18 mg/kg) compared to Asari Toru's sediment (5.34 mg/kg) and that of Degema (4.003 mg/kg).

In sediments from Asari Toru, Pb exhibited the highest concentration (1.803 mg/kg), significantly higher than Akuku Toru's sediment (1.138 mg/kg) and that of Degema(0.932 mg/kg). Zn concentration was also highest in sediment sample from Asari Toru (26.25 mg/kg), significantly higher than sediment from Akuku Toru (20.125 mg/kg) and sediment from Degema (15.314 mg/kg).

For Degema's sediment, Cr had the highest concentration (0.988 mg/kg), significantly higher than sediment from Akuku Toru (0.183 mg/kg) and Asari Toru (0.228 mg/kg). As was also highest in Degema's sediment (0.225 mg/kg), significantly higher than sediment from Akuku Toru (0.01 mg/kg) and Asari Toru (0.018 mg/kg).

Table 1: The concentration of heavy metals found in sediment samples across the stations

Heavy metals (mg/kg)	**Akuku Toru**	**Asari Toru**	**Degema**	**DPR**Standard
Cd	0.453±0.053a	0.172±0.011b	0.108±0.005b	0.8
Pb	1.138±0.133b	1.803±0.164a	0.932±0.097b	85
Cr	0.183±0.009b	0.228±0.007b	0.988±0.09a	100
As	0.01±0.001b	0.018±0.002b	0.225±0.033a	1.0
Zn	20.125±1.039b	26.25±0.852a	15.314±0.602c	140
Cu	27.724±0.503a	8.386±0.441b	2.659±0.17c	36
Ni	13.18±0.564a	5.34±0.376b	4.003±0.257c	3.5

Concentration of Heavy Metals in Surface Water Samples Across Stations

Table 2 shows that surface water samples in Asari Toru recorded the highest concentration of Cd (0.117 mg/l), significantly higher than water sample from Akuku Toru (0.06 mg/l) and Degema (0.058 mg/l). Zn concentration was also highest in water from Asari Toru (17.42 mg/l), significantly higher than Akuku Toru's surface water (13.472 mg/l) and Degema's surface water (10.708 mg/l). In water from Degema, Pb exhibited the highest concentration (0.63 mg/l), significantly higher than water from Akuku Toru (0.131 mg/l) and Asari Toru (0.124 mg/l). Cr concentration was also highest in water from Degema (0.137 mg/l), significantly higher than water from Akuku Toru (0.04 mg/l) and Asari Toru (0.067 mg/l). As was highest in water from Degema (0.112 mg/l), significantly higher than water from Akuku Toru (0.003 mg/l) and Asari Toru (0.005 mg/l). Akuku Toru's water recorded the highest concentration of Cu (15.463 mg/l), significantly higher than water from Asari Toru (6.424 mg/l) and Degema (3.178 mg/l).

Table 2: The Concentration of Heavy Metals found in Surface Water Samples across the stations

Heavy metals (mg/l)	**Akuku Toru**	**Asari Toru**	**Degema**	**DPR**Standard
Cd	0.06±0.006b	0.117±0.005a	0.058±0.003b	0.8
Pb	0.131±0.015b	0.124±0.006b	0.63±0.076a	85
Cr	0.04±0.002c	0.067±0.004b	0.137±0.008a	100
As	0.003±0b	0.005±0.001b	0.112±0.017a	1.0
Zn	13.472±0.584b	17.42±0.74a	10.708±0.443c	140
Cu	15.463±0.453a	6.424±0.305b	3.178±0.21c	36
Ni	8.422±0.338a	3.541±0.17c	5.654±0.265b	3.5

Concentration of Heavy Metals in Tilapia (*Tilapia guineensis*) Samples Across Stations

In table 3, tilapia (*T. guineensis*) samples for Asari Toru recorded the highest concentration of Cd (0.027 mg/kg), significantly higher than tilapia from Akuku Toru (0.013 mg/kg) and Degema (0.015 mg/kg). While Degema's tilapia exhibited the highest concentrations for Pb (0.05 mg/kg), Cr (0.052 mg/kg), and As (0.041 mg/kg). These concentrations were significantly higher than those in tilapia from Akuku Toru (Pb: 0.021 mg/kg, Cr: 0.017 mg/kg, As: 0.007 mg/kg) and Asari Toru (Pb: 0.036 mg/kg, Cr: 0.014 mg/kg, As: 0.004 mg/kg).

However, tilapia from Akuku Toru recorded higher concentrations of Zn (8.5 mg/kg) and Cu (9.394 mg/kg), with Zn not significantly different from Degema's tilapia (8.979 mg/kg) but significantly higher than Asari Toru (7.545 mg/kg). Cu concentration in Akuku Toru was significantly higher than tilapia from Asari Toru (4.664 mg/kg) and Degema (1.651 mg/kg).

Table 3: The Concentration of Heavy Metals found in Tilapia Samples across the stations

Heavy metals (mg/kg)	**Akuku Toru**	**Asari Toru**	**Degema**	**DPR**Standard
Cd	0.013±0.002b	0.027±0.004a	0.015±0.002b	0.8
Pb	0.021±0.002c	0.036±0.004b	0.05±0.005a	85
Cr	0.017±0.001b	0.014±0.002b	0.052±0.006a	100
As	0.007±0.001b	0.004±0.001b	0.041±0.008a	1.0
Zn	8.5±0.213ab	7.545±0.448b	8.979±0.355a	140
Cu	9.394±0.347a	4.664±0.299b	1.651±0.143c	36
Ni	6.357±0.244a	0.871±0.052c	2.771±0.144b	3.5

Bio-sedimentation Factor (BSF) of Heavy Metals for Tilapia

In Table 4, the Tilapia Bio-sedimentation Factor (BSF) reflects the ratio of heavy metal concentrations in tilapia to that in sediments. The BSF values for various heavy metals across different stations are as follows: Arsenic (As) shows the highest BSF across all stations, with values ranging from 0.182 to 0.700. This indicates that arsenic accumulates in tilapia at significantly higher levels compared to sediment. However, Copper (Cu) follows, with BSF values between 0.339 and 0.621, suggesting a notable accumulation in tilapia relative to sediment.

Nickel (Ni) is also considerably bioaccumulated, with values ranging from 0.163 to 0.692. While Chromium (Cr) and Zinc (Zn) have intermediate BSF values, with chromium ranging from 0.053 to 0.093 and zinc from 0.287 to 0.586. However, Cadmium (Cd) and Lead (Pb) exhibit lower BSF values, with cadmium ranging from 0.029 to 0.157 and lead from 0.018 to 0.054. This suggests less bioaccumulation relative to sediment compared to the other metals. 4.1.5 Pearson

Table 4:Bio-sedimentation factor (BSF) of heavy metals for Tilapia

Heavy metals	Akuku Toru	Asari Toru	Degema
Cd, mg/kg	0.028698	0.156977	0.138889
Pb, mg/kg	0.018453	0.019967	0.053648
Cr, mg/kg	0.092896	0.061404	0.052632
As, mg/kg	0.70000	0.222222	0.182222
Zn, mg/kg	0.42236	0.287429	0.586326
Cu, mg/kg	0.33884	0.556165	0.62091
Ni, mg/kg	0.482322	0.163109	0.692231

Bioaccumulation Factor (BAF) of Heavy Metals for Tilapia

The Bioaccumulation Factor (BAF) for tilapia indicates the concentration of metals in tilapia compared to their concentration in water is represented in table 5. Arsenic (As) has the highest BAF, ranging from 0.366 to 2.333, reflecting significant bioaccumulation in tilapia tissues. While Zinc (Zn) follows with BAF values between 0.434 and 0.839. However, Copper (Cu) and Nickel (Ni) show moderate BAF values, ranging from 0.608 to 0.727 for copper and 0.490 to 0.755 for nickel. Chromium (Cr) and Cadmium (Cd) have lower BAF values, with chromium ranging from 0.209 to 0.425 and cadmium from 0.217 to 0.259. While lead (Pb) has the lowest BAF values, ranging from 0.079 to 0.290.

Table 5:Bioaccumulation factor (BAF) of heavy metals for Tilapia

Heavy metals (mg/kg)	Akuku Toru	Asari Toru	Degema
Cd	0.216667	0.230769	0.258621
Pb	0.160305	0.290323	0.079365
Cr	0.425	0.208955	0.379562
As	2.333333	0.8	0.366071
Zn	0.630938	0.433123	0.838532
Cu	0.607515	0.726027	0.519509
Ni	0.754809	0.245976	0.490096

DISCUSSION

Heavy Metal Concentrations in Tilapia (*Tilapia guineensis*) Samples Across Stations

The analysis of *Tilapia guineensis* samples from Akuku Toru, Asari Toru, and Degema reveals varying concentrations of heavy metals, which pose potential health risks for human consumption. The highest cadmium (Cd) concentration was recorded in Asari Toru (0.027 mg/kg). Although this concentration was significantly higher than in Akuku Toru (0.013 mg/kg) and Degema (0.015 mg/kg), is still far below the DPR standard of 0.8 mg/kg. Cd exposure through fish consumption can lead to kidney dysfunction, bone damage, and cancer (Peanaet al., 2022). Though below regulatory limits, chronic exposure, particularly in children, may still pose health risks.

Lead (Pb) levels were highest in Degema (0.05 mg/kg), higher than in Asari Toru (0.036 mg/kg) and Akuku Toru (0.021 mg/kg). These levels are significantly lower than the DPR standard of 85 mg/kg. Lead is particularly dangerous for children, causing developmental delays, lower IQ, and attention deficits. For adults, it can result in hypertension and kidney issues (Olufemi et al., 2022). Even at these low concentrations, prolonged exposure to Pb in seafood could contribute to cumulative health risks, particularly in communities reliant on fish as a staple protein source.

Degema also exhibited the highest chromium (Cr) (0.052 mg/kg) and arsenic (As) (0.041 mg/kg) concentrations, compared to significantly lower levels in Akuku Toru (Cr: 0.017 mg/kg, As: 0.007 mg/kg) and Asari Toru (Cr: 0.014 mg/kg, As: 0.004 mg/kg). While these levels are below the DPR limits (Cr: 100 mg/kg, As: 1.0 mg/kg), Cr and As are known carcinogens. Chronic exposure to Cr can lead to respiratory issues, while arsenic is associated with various cancers and cardiovascular diseases (Adelakun et al., 2023; McGrath et al., 2022).

Zinc (Zn) levels were highest in Degema (8.979 mg/kg) and Akuku Toru (8.5 mg/kg), with Asari Toru showing the lowest levels (7.545 mg/kg). Although these concentrations are below the DPR limit of 140 mg/kg, excessive zinc intake can disrupt immune function and interfere with nutrient absorption (Ogwu and Izah, 2023). Similarly, copper (Cu) levels were highest in Akuku Toru (9.394 mg/kg), significantly higher than in Asari Toru (4.664 mg/kg) and Degema (1.651 mg/kg). Cu is an essential nutrient, but elevated levels can cause gastrointestinal disturbances, liver damage, and neurological effects (Nduka and Orisakwe, 2011).

Nickel (Ni) concentrations were also highest in Akuku Toru (6.357 mg/kg), surpassing the DPR limit of 3.5 mg/kg, indicating a potential risk for consumers. Chronic exposure to Ni can cause respiratory issues and increase cancer risks, particularly in communities that frequently consume fish (Peana et al., 2022). Ni's toxicity is especially concerning as it can accumulate in fish tissues and pose long-term risks to both human health and the environment.

These results highlight the presence of heavy metals in tilapia across the three stations, albeit at concentrations generally below regulatory limits, except for Ni. Long-term exposure, particularly in places where fish consumption is high, has implications, however, which should not be disregarded. Although the levels of heavy metals like Pb, Cr, and As are modest, their tendency to build up in the body with frequent intake can have detrimental health repercussions, especially in sensitive groups including kids and pregnant women.

Moreover, it is hard to neglect the consequences on ecosystem of heavy metal contamination. Increased levels of Cu, Zn, and Ni in aquatic settings may disturb aquatic ecosystems, so altering the survival and reproduction of fish and other species, so leading in biodiversity loss and imbalance of the ecosystems (Izah et al., 2016). To halt the spread of heavy metal contamination in these aquatic systems, the study advises more regular monitoring and tighter environmental rules.

Heavy Metal Concentrations in Sediment Samples

Children and adults are greatly in risk from heavy metal concentrations reported in sediment from Akuku Toru, Asari Toru, and Degema. In aquatic ecosystems, metals including cadmium (Cd), lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), copper (Cu), and nickel (Ni) may have dangerous impacts on both living organisms and the environment (Asonye et al., 2007; Zhang et al., 2017).

Comparatively to Asari Toru (0.172 mg/kg) and Degema (0.108 mg/kg), Akuku Toru had the largest Cd concentration (0.453 mg/kg). Particularly in youngsters (Zhang et al., 2017; Ehiemere et al., 2022), Cd exposure may induce renal, bone, and respiratory damage. Cu concentrations were also highest in Akuku Toru (27.724 mg/kg), and although essential in small amounts, high levels can damage the liver and kidneys (Asonye et al., 2007). Ni concentrations were highest in Akuku Toru (13.18 mg/kg), which can cause respiratory issues and increase cancer risks in humans and impair aquatic organisms' growth and reproduction (Peana et al., 2022).

Asari Toru had the highest Pb concentration (1.803 mg/kg). Pb is particularly harmful to children, affecting cognitive development and behavior, and can cause kidney damage in adults (Talayero et al., 2023). Zn concentrations were also highest in Asari Toru (26.25 mg/kg); although essential, excessive exposure can impact immune function and disrupt aquatic ecosystems (Frydrych et al., 2023). Degema recorded the highest Cr (0.988 mg/kg) and As (0.225 mg/kg), both known carcinogens that affect the liver, kidneys, and respiratory systems (Snodgrass et al., 2022; McGrath et al., 2022).

Studies in Rivers State and the broader Niger Delta region, such as those by Asonye et al. (2007) and Isotuk et al. (2023), have consistently reported high levels of Cd, Pb, Ni, and Cu in sediments, aligning with findings in this study. Similar contamination patterns have been observed globally, with heavy metal pollution in sediments leading to significant health and ecological risks (Zhang et al., 2017).

Heavy Metal Concentrations in Surface Water Samples

The analysis of surface water samples from Akuku Toru, Asari Toru, and Degema revealed significant concentrations of cadmium (Cd), lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), and copper (Cu), posing serious health and ecological risks. These contaminants may affect both children and adults who rely on the water for drinking, cooking, and other domestic uses, while also having detrimental effects on aquatic ecosystems.

The highest concentration of Cd was observed in Asari Toru (0.117 mg/l), which poses risks such as kidney damage, bone demineralization, and developmental issues, particularly in children. Chronic exposure in adults can lead to kidney dysfunction, fractures, and cancer. Ecologically, Cd could bioaccumulate and disrupt higher trophic levels by changing development, reproduction, and survival of aquatic life (Izah et al., 2016). In Degema, Pb levels reached 0.63 mg/l. For children, Pb is a neurotoxin, linked to cognitive deficits and behavioral problems, while adults may face hypertension, kidney issues, and reproductive problems. Pb also disrupts aquatic life, causing neurological damage in fish and impairing reproductive success (Olufemi et al., 2022).

Cr levels in Degema were 0.137 mg/l. In children, exposure can result in skin and respiratory issues, while for adults, prolonged exposure can cause cancer and respiratory problems. Cr also negatively affects aquatic organisms, reducing growth and reproductive rates and disrupting microbial communities (Adelakun et al., 2023). Arsenic (As) levels in Degema (0.112 mg/l) pose serious health risks, including developmental issues, cardiovascular diseases, and various cancers.

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In aquatic environments, As leads to reduced growth, reproductive failure, and increased mortality among organisms (Igbinosaet al., 2021).

Asari Toru exhibited the highest Zn levels (17.42 mg/l). While Zn is an essential nutrient, excessive intake can cause gastrointestinal issues and affect immune function. Ecologically, high Zn levels disrupt fish growth and the balance of aquatic ecosystems (Ogwu and Izah, 2023). Akuku Toru had elevated Cu concentrations (15.463 mg/l), which may result in gastrointestinal and neurological issues in humans. In aquatic systems, Cu exposure can impair reproductive success and damage microbial communities (Nduka and Orisakwe, 2011).

Research from the Niger Delta, including studies by Izah et al. (2016) and Olufemi et al., 2022, often reveal identical difficulties with heavy metal contamination in surface water, hence echoing findings from other countries such India and China (Suku et al., 2023; Zhang et al., 2017). These studies raise attention to public health as well as ecological dangers associated to heavy metal poisoning of water systems.

Tilapia Bio-sedimentation Factor (BSF) of Heavy Metals

The BSF for heavy metals in fish across sites is examined to identify differing degrees of bioaccumulation in fish compared to sediments. Potential health concerns associated to fish consumption are highlighted by the BSF values for arsenic (As), copper (Cu), nickel (Ni), chromium (Cr), zinc (Zn), cadmium (Cd), and lead (Pb). With BSF values ranging from 0.182 to 0.700, arsenic displayed the highest values implying considerable deposition in fish tissues. Fish ingestion of arsenic over extended periods of time may cause substantial health concerns including cardiovascular illnesses (Chen et al., 2019; Salam et al., 2019). The varying BSF values hint to different degrees of pollution across stations, which begs for concentrated action in severely contaminated places.

Copper appeared next, with BSF values ranging from 0. 339 to 0. 621, hence exhibiting considerable buildup. While copper is important in low amounts, overly high levels may affect the liver and gastrointestinal tract (Burger et al., 2015). Preventing health concerns from copper in water bodies relies on continual monitoring of it. With high BSF values of 0. 163 to 0.692 nickel demonstrated its endurance in aquatic conditions. Control of nickel presence in the environment is vital as exposure to it might cause cancer (Chen et al., 2019) and respiratory issues.

Chromium's lower BSF values of 0.053 to 0.093 showed negligible bioaccumulation. Chromium still causes non-cancer health concerns such skin irritation and respiratory issues even with decreased deposition (Salam et al., 2019). With a BSF ranging from 0.287 to 0.586, zinc showed negligible bioaccumulation. Although zinc is crucial for health, overly high amounts could trigger immune system dysfunction and nausea (Zhang et al., 2017). Safe levels rely on monitoring.

With ranges from 0.029 to 0.157 and 0.018 to 0.054, cadmium and lead demonstrated correspondingly lower BSF values. Though their levels are lesser, both metals are highly hazardous; cadmium has been associated to kidney damage and cancer, while lead effects brain development (Burger et al., 2015; Chen et al., 2019).

The differences in BSF between metals and places attract attention to diverse risks; arsenic, copper, and nickel represent the largest ones. To prevent health hazards, even metals with lower BSF such as cadmium and lead require rigorous supervision. Previous study in the Niger Delta congruent with our findings indicate serious health risks from heavy metal contamination in seafood (Chen et al., 2019; Salam et al., 2019). Reducing health dangers associated to these pollutants rely largely on regulatory efforts like warnings and monitoring campaigns (Zhang et al., 2017; Burger et al., 2015).

Tilapia Bioaccumulation Factor (BAF) of Heavy Metals

The BAF helps to assess the prospective health consequences of fish consumption by presenting vital new insights on how heavy metals build up in fish compared to their levels in water. BAF values for arsenic (As), zinc (Zn), copper (Cu), nickel (Ni), chromium (Cr), cadmium (Cd), and lead (Pb) demonstrate substantial diversity across sites, hence exposing changes in metal accumulation patterns.

With a range from 0.366 to 2.333, arsenic (As) displays the largest BAF values, hence implying considerable bioaccumulation in fish tissues. Skin difficulties, cardiovascular illnesses, and a greater cancer risk are just a few of the primary health concerns this provides (Mitra et al., 2020; Salam et al., 2019). The large variance in BAF levels across diverse areas refers to variable degrees of arsenic contamination, which calls for specific therapies to minimise exposure via fish consumption.

Following arsenic with BAF values ranging between 0.434 and 0.839, zinc (Zn) follows Although zinc is necessary for biological processes, too high accumulation may induce nausea, vomiting, and weakened immune system (Perrelli et al., 2022). The moderate to high BAF findings underscore the necessity of keeping an eye on zinc levels to prevent detrimental repercussions for health. Copper (Cu) has moderate BAF values ranging from 0.608 to 0.727. Although copper is necessary for health, too much of it may harm livers and induce gastrointestinal issues (Wei et al., 2015). regular BAF measurements across sites indicate how vital regular monitoring is to keeping safe copper levels in fish.

Additionally demonstrating low BAF values, nickel (Ni) falls between 0. 490 and 0.755. Increased cancer risks, allergic reactions, and respiratory difficulties may all ensue from prolonged nickel exposure (Salam et al., 2019). This underscores how urgently regulation and continual monitoring are required to defend human health from nickel contamination. Though it has less accumulation, chromium (Cr) nonetheless causes health risks including skin irritation and respiratory difficulties (Salam et al., 2019). Its BAF levels vary from 0.209 to 0.425. Regular monitoring is needed to decrease chromium-related dangers even if bioaccumulation is less than for other metals.

With 0.217 to 0.259, cadmium (Cd) has fairly low BAF values. Cadmium is exceedingly hazardous even with decreased bioaccumulation; this damages kidneys, causes bone demineralisation, and promotes cancer (Zhang et al., 2022). The findings underscore the significance of stringent pollution control to limit exposure dangers. Lead (Pb) has the lowest BAF values between 0.079 and 0.290. Lead remains harmful despite minor bioaccumulation, particularly for children who experience developmental delays and neurological damage (Lanphear et al., 2019). Continuous legislative actions are required to address lead exposure problems.

Different bioaccumulation potentials and concomitant health concerns are illustrated by the differences in BAF values between metals and stations. Given their significant health impacts, elevated BAF values for arsenic, zinc, copper, and nickel especially raise concerns. Even metals with mild or low bioaccumulation such as lead, cadmium, and chromium require constant supervision to prevent detrimental implications for health. Consistent with the elevated BAF levels identified in this study, earlier studies as those by Mitra et al. (2020) and Salam et al. (2019) have also underscored the health dangers of arsenic and other heavy metals in fish. Reducing health dangers in Nigeria also rely on legislative initiatives to address heavy metal pollution, as proven in the United States (Choose et al., 2023).

CONCLUSION

The present study for the selected heavy metals in *Tilapia guineensis* across Akuku Toru, Asari Toru, and Degema revealed varying harmful metal concentrations where nickel surpasses permissible limits in Akuku Toru. Although certain contaminants still fall short of DPR guidelines, normal consumers and children particularly face potential health problems from cadmium, lead, and arsenic. The bioaccumulation findings from this studyhighlight the requirement of ongoing monitoring and tighter restrictions to safeguard human health. Additionally, the ecological effects of heavy metals, such as zinc and copper, may disrupt aquatic ecosystems, calling for environmental interventions.

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