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Bioaccumulation of Cadmium in Tilapia (*Oreochromis Niloticus*) from Kangimi Dam and the national water resources institute, Kaduna, Nigeria

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Abstract

The bioaccumulation of cadmium (Cd) in Tilapia fish (*Oreochromis niloticus)* was evaluated between September and October 2024 in Kaduna Metropolis, Nigeria. Fish samples were collected from Kangimi Dam and the National Water Resources Fish Ponds, and cadmium concentrations in the gills, kidneys, and livers were investigated using Atomic Absorption Spectroscopy–High-Performance Liquid Chromatography (AAS-HPLC). ANOVA was used to determine mean concentrations. In Kangimi Dam fish, cadmium levels were 0.045±0.011 mg/kg (gills), 0.056±0.006 mg/kg (liver), and 0.055±0.012 mg/kg (kidneys). In contrast fish from the National Water Resources Fish Ponds, concentrations were higher: 0.098±0.004 mg/kg, 0.107±0.001 mg/kg, and 0.097±0.006 mg/kg, respectively. The liver showed the highest accumulation, though differences across organs were not statistically significant ($p > 0.05$). Cadmium concentrations remained within the WHO/FAO permissible limit (0.05 mg/kg), suggesting no significant health risk. Further studies on other heavy metals and their bioaccumulation factors in the study area are recommended.

Keywords: Bioaccumulation, Cadmium, Heavy metals, Kaduna, *Oreochromis niloticus*, fish.

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Contents

Contribution of this paper to the literature: This study examined cadmium levels in fish (*O. niloticus)* for the purpose of assessing health risks in Kaduna metropolis. Findings compared with global contamination trends, toxicity effects, and mitigation strategies, emphasizing the need for pollution control and monitoring. Also contributed to the existing literature by providing baseline information on heavy metal concentration in Kaduna state, North-western Nigeria.

1. Introduction

Fish play a vital role in the economic development of many fish-producing countries in the world. They serve as an important source of high-quality protein, accounting for approximately 16% of the animal protein consumed worldwide [1]. This contribution is principally significant in counties where livestock is scarce. For example, fish provide less than 10% of animal protein in North America and Europe but contribute 17% in Africa, 26% in Asia, and 22% in China [2]. Overall, nearly one billion people worldwide depend on fish as their primary source of protein [2].

Fish have a superior nutrient profile compared to terrestrial meat and provide highly digestible energy, which is crucial for rural populations [3]. Additionally, fish contain essential fatty acids necessary for human brain and body development, particularly for infants, pregnant women, and lactating mothers [4].

In developing countries like Nigeria, fish farming serves as a source of livelihood, poverty alleviation, and economic stability for rural households engaged in fishing, processing, and retailing fish products [5].

Heavy metals are naturally occurring elements with atomic numbers ranging from 22–34 (Titanium–Selenium), 40–52 (Zirconium–Tellurium), and 72–83 (Hafnium–Bismuth) [6, 7]. Due to anthropogenic activities, fish can accumulate heavy metals, making them key indicators of freshwater pollution [8].

At elevated concentrations, heavy metals such as mercury (Hg), arsenic (As), lead (Pb), and cadmium (Cd) can be toxic to all living organisms. Prolonged exposure to these elements can lead to serious health conditions, including organ failure and death [9]. While trace amounts of metals like cobalt, iron, copper, manganese, molybdenum, and zinc are essential for biological functions; excessive levels can be detrimental [10].

This study investigates the bioaccumulation of cadmium in *O. niloticus* from Kangimi Dam and the National Water Resources Fish Ponds in Kaduna Metropolis. The findings will provide baseline data on the safety of tilapia fish for human consumption in the study area.

2. Materials and Methods

2.1. Study Area

The study was conducted at two locations: Kangimi Dam and the National Water Resources Fish Pond. The National Water Resources facility is located along Mando Road, Kaduna North Metropolis. Kangimi Dam, situated in the savannah region, lies at latitude 10°46′N and longitude 7°E. Constructed in 1972, the reservoir receives agricultural runoff and industrial effluents and supports commercial fishing [11].

2.2. Target Population and Sample Collection

The study targeted adult *O. niloticus*. Fish samples were collected from the two study locations, with each fish measuring 20–25cm in length and weighing 220–240g. Samples were preserved in ice to minimize tissue degradation and transported to the Multi-User Research Laboratory at the Faculty of Science and Technology, Ahmadu Bello University, Zaria, for processing. The samples were washed with deionized water, identified, and deep-frozen at -20°C before processing.

2.3. Sample Processing and Laboratory Procedures

Frozen fish samples were thawed at room temperature, and boneless tissues (liver, gills, and kidneys) were carefully excised using a stainless-steel knife. The samples were then digested using closed-vessel microwave digestion in a Milestone Start D microwave oven (Italy). The digestion process involved adding 7.5 mL of ultra-pure nitric acid and 2.5 mL of hydrogen peroxide, followed by heating at 100–150°C for 20 minutes. After digestion, the samples were allowed to cool for 35 minutes, diluted with deionized water to a final volume of 30 mL, and filtered through 0.45 µm Whatman filter paper [12].

Cadmium concentrations were determined using Atomic Absorption Spectroscopy–High-Performance Liquid Chromatography (AAS-HPLC), with results expressed in parts per million (ppm) or mg/L. To ensure accuracy and avoid contamination, all glassware and plasticware were pre-treated by soaking overnight in 10% nitric acid, followed by rinsing with distilled and deionized water and drying before use [13].

2.4. Data Analysis

Data were subjected to Analysis of Variance (ANOVA), with $p < 0.05$ considered statistically significant.

3. Results

The cadmium concentrations in *Oreochromis niloticus* from Kangimi Dam and the National Water Resources Fish Ponds are summarized in Tables 1 and 2.

In fish from Kangimi Dam, cadmium concentrations were measured at 0.045±0.011 mg/kg in the gills, 0.056±0.006 mg/kg in the liver, and 0.055±0.012 mg/kg in the kidneys. Equally, in fish from the National Water Resources Fish Ponds, cadmium concentrations were 0.098±0.004 mg/kg in the gills, 0.107±0.001 mg/kg in the liver, and 0.097±0.006 mg/kg in the kidneys.

No statistically significant differences were observed among the organs within each location ($p > 0.05$).

Table 1. Cadmium concentration (PPM) in *O.niloticus* from Kangami Dam (n=4).

Organ	Mean ± SME (mg/kg)
Gills	0.045 ± 0.011 NS
Liver	0.056 ± 0.006 NS
Kidney	0.055 ± 0012 NS
P=value=0.478 (p >0.05)	

Table 2. Cadmium concentration (PPM) in *O.niloticus* in national water recourses fish pond (n=4).

Organ	Mean ± SME (mg/kg)
Gills	0.098 ± 0.004 NS
Liver	0.107 ± 0.001 NS
Kidney	0.097 ± 0006 NS
P=value 0.458 (p >0.05)	

4. Discussion

The findings of this work show that cadmium concentrations in Tilafia fish (*Oreochromis niloticus*)from both Kangimi Dam and the National Water Resources Fish Ponds remain below the maximum permissible limits established by the FAO and WHO (0.05 mg/kg). This indicates that, at present, consuming tilapia from these water bodies does not pose an immediate health risk. However, continuous monitoring is necessary due to the bioaccumulative nature of heavy metals, which can lead to long-term envir onmental and health concerns.

Among the three organs analyzed, the liver had the highest cadmium concentration. This aligns with previous studies identifying the liver as the primary organ for metal accumulation in fish [10, 14].

The liver plays a key role in detoxification and metabolism, making it more susceptible to heavy metal accumulation. Cadmium has a strong affinity for metallothionein proteins in hepatic tissues, which contributes to its retention in the liver [15].

The gills also showed notable cadmium accumulation, though at lower levels than the liver. Gills are directly exposed to the aquatic environment and play a crucial role in ion exchange and respiration, making them a primary site for metal absorption [16]. However, not like the liver, which stores cadmium for prolonged periods, gills may show fluctuating metal concentrations due to their ability to excrete certain metals over time [17].

The kidneys, responsible for filtration and excretion, exhibited cadmium concentrations a little lower than those of the liver but comparable to the gills. The ability of the kidneys to accumulate cadmium is attributed to the reabsorption of metal-bound proteins, which can lead to nephrotoxicity in cases of prolonged exposure [18]. While the concentrations in this study were below toxic thresholds, continued exposure could lead to progressive accumulation and potential health effects.

The higher cadmium concentrations observed in fish from the National Water Resources Fish Ponds compared to Kangimi Dam may be related to differences in water quality, anthropogenic activities, and potential sources of contamination. The National Water Resources Fish Ponds are located in an area subject to more human activities, including agricultural runoff and possible industrial waste, which could contribute to elevated metal levels. Kangimi Dam, although exposed to agricultural and domestic waste, may experience a greater degree of dilution due to its larger water volume, reducing the bioavailability of cadmium.

Although cadmium levels in this study were within permissible limits, the potential for bioaccumulation over time cannot be overlooked. Long-term exposure to even low levels of cadmium can lead to chronic health issues such as kidney damage, bone demineralization, cardiovascular diseases etc.[19]. Fish, being at the center of aquatic food chains, can serve as bio-indicators of pollution. Thus, continuous bio-monitoring and assessment of other heavy metals such as lead, mercury, and arsenic are recommended to ensure the long-term safety of aquatic food sources in the study area.

5. Conclusion and Recommendations

This study revealed that cadmium concentrations in *O. niloticus* from Kangimi Dam and the National Water Resources Fish Ponds were within safe limits for human consumption. However, regular monitoring of heavy metal contamination and further studies on the bioaccumulation of other heavy metals are recommended to assess potential long-term environmental and health risks.

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