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EXPLORATORY HEALTH RISK ASSESSMENT OF ESSENTIAL AND NON-ESSENTIAL TRACE ELEMENTS IN CAGE-CULTURED FISH SPECIES FROM BADAGRY LAGOON, NIGERIA

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Abstract: *Fish readily accumulate trace elements from water, sediments, and feed, making them potential vectors of human exposure. This study assessed the concentrations, estimated daily intake (EDI), and potential health risks of essential and non-essential trace elements in water, sediment, and two cage-cultured fish species—Clarias gariepinus and Oreochromis niloticus—from Badagry Lagoon, Nigeria, using standard methods. Results revealed that sediments consistently contained significantly higher concentrations ($P < 0.05$) of all trace elements, underscoring their role as primary sinks for metal pollutants. Among the fish species, C. gariepinus exhibited higher accumulation of copper, manganese, and zinc, while O. niloticus showed elevated levels of silver, tin, and cadmium. Zinc was the most abundant essential element in both sediment and fish tissues, while mercury levels remained uniformly low across both species. EDI values for all analysed elements were well below oral reference doses, indicating no immediate dietary health risks. Furthermore, Target Hazard Quotient (THQ) values for both essential and non-essential elements in both fish species were below the critical threshold of 1, suggesting negligible non-carcinogenic risk. However, significant interspecies differences in THQ values for several elements imply species-specific bioaccumulation tendencies. The findings highlight the importance of continuous environmental monitoring and species-specific risk assessments to ensure the nutritional safety of fish from aquaculture systems in urbanized lagoon environments.*

Keywords: *accumulation, consumer safety, fish, mineral element, target hazard quotient.*

1. Introduction

Fish is a crucial component of human diets globally, especially in developing countries, where it serves as a major source of high-quality protein, essential fatty acids, and vital micronutrients such as iron, zinc, selenium, and iodine [1]. With the increasing demand for aquatic food, cage aquaculture has become a rapidly expanding practice, providing a sustainable means of boosting fish production and supporting livelihoods. However, as aquaculture intensifies, concerns over the quality and safety of cultured fish, especially their potential contamination with trace elements from surrounding water bodies have grown significantly [2]. Trace elements in fish are broadly categorized into essential (e.g., copper, zinc, iron, selenium) and non-essential (e.g., mercury, lead, cadmium, arsenic). While essential elements are required in small quantities for physiological and metabolic functions, they can become toxic when consumed in excess. Conversely, non-essential elements are not biologically beneficial and may exert toxicological effects even at low concentrations, leading to serious health conditions such as neurotoxicity, nephrotoxicity, and carcinogenicity [3-4]. Fish readily accumulate these elements from water, sediments, and feed, making them potential vectors of human exposure, particularly among communities that rely heavily on fish for protein and nutrition.

In Nigeria, the Badagry Lagoon serves as a key site for artisanal and cage aquaculture. However, its proximity to industrial and urban activities raises concerns about

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pollutant input and potential bioaccumulation of hazardous elements in fish. Previous studies have reported varying levels of trace metal contamination in fish from the region, but there is limited data on the health risks associated with the consumption of cage-cultured fish species specifically [5-6]. Given the increasing reliance on aquaculture to meet food security needs, there is an urgent need to evaluate the safety of fish harvested from such systems, particularly concerning chronic exposure to trace metals. Despite the growing popularity of cage aquaculture in Badagry Lagoon, there is a lack of comprehensive health risk assessment studies that evaluate both essential and non-essential trace element concentrations in fish and their implications for consumer health. The potential accumulation of toxic metals in edible fish tissues could pose a serious threat to public health, especially among vulnerable populations with high fish consumption rates and limited access to food safety regulation and monitoring. This study aims to assess the concentrations of essential and non-essential trace elements in selected cage-cultured fish species from Badagry Lagoon and to evaluate the potential health risks associated with their consumption using standard risk assessment models. The findings will contribute to the body of knowledge on food safety in aquaculture, inform public health policies, and support sustainable aquaculture practices in Nigeria and similar coastal systems in sub-Saharan Africa.

2. Materials and methods

2.1 Study Location

The Badagry Lagoon (6o 25′ 672″ N, 2o 50′ 809″ E) is part of a continuous system of lagoons and creeks along the coast of Nigeria from the border with the Republic of Benin to the Niger Delta, with the depth of water ranging from 1 - 3 m and approximately 60 km long and 3 km wide [7]. The farms used net cages to raise the fishes. These cages are designed to allow water to circulate freely, ensuring oxygenation and waste removal.

2.2 Collection and Preparation of Specimens

Water, sediment and fish samples (*Clarias gariepinu*s and *Oreochromis niloticus*) were collected monthly between November 2023 and April 2024. Water samples (500 mL per sampling point) were collected at a depth of 1 cm below the water surface in HNO_3 pre-rinsed (1 L) containers and 5 mL of concentrated HNO_3 added immediately to minimize chemisorption. Sediment samples were collected with the aid of 0.05 m^2 Eckman Grab during low tide at 10 –15 cm depth. Five (5) water and sediment samples each were randomly collected per sampling station, making 30 samples for the six locations per month. A total of 60 mature fish of each species were caught directly from the cage. In each case, samples were properly labeled and kept in clean plastic containers and stored at 20°C before taking to the laboratory for analyses.

2.3 Laboratory Analysis

At the laboratory, the sediments were de frost by keeping them at room temperature for about 24 hours, then dried in an oven at 40 ℃ [8], disaggregated and sieved through a 200 μm sieve. The sieved samples were subsequently homogenized in a porcelain mortar and re-sieved. Approximately 5 g of the samples was put in Teflon tubes, and 5 ml aqua regia (HCl: HNO3 in a ratio of 3:1) added for digestion, following the ISO 11466 digestion method [9]. Sub-samples of approximately 1 g tissue were weighed in a precision scale with decimal resolution (0.001 g) and digested in a mixture of 5 ml of concentrated nitric acid (TMA, Hiperpure, PanReac, Spain) and 3 ml of 30 % w/v hydrogen peroxide (PanReac, Spain) in a microwave-assisted digestion system (Ethos Plus; Milestone, Sorisole, Italy). Digested samples were transferred to polypropylene sample tubes and diluted to

15 ml with ultrapure water. As described by Dussubieux and Van Zelst [10], the determination of the trace elements in all the samples was carried out by ICP- MS. ICP-MS-based multi-element determination was performed in an Agilent 7700x ICP-MS system (Agilent Technologies, Tokyo, Japan) equipped with collision/reaction cell interference reduction technology. The continuous sample introduction system consisted of an autosampler, a Scott double-pass spray chamber (Agilent Technologies, Tokyo Japan), a glass concentric MicroMist nebuliser (Glass Expansion, West Melbourne, Australia), a quartz torch and nickel cones (Agilent Technologies, Tokyo Japan). Elemental concentrations were quantified using a Mass Hunter Work Station Software for ICPMS (version A.8.01.01 Agilent Technologies, Inc. 2012, Tokyo, Japan).

Analytical quality control was guaranteed through the implementation of laboratory quality assurance and laboratory methods, including the use of standard operating procedures, calibrations with standards and analyses with reagent blanks. Samples were analysed in triplicates, all chemicals and reagents used were of analytical grade. The limits of detection calculated for the investigated metals in all media was 1.0×10^{-4} mg/L for water and 1.0×10^{-4} mg kg-1 for sediment and biota. The accuracy of determination was evaluated by comparison with the analytical recoveries determined in certified reference materials (fish protein DORM- 3 National Research Council, Ottawa, Ontario, Canada) analysed following exactly the same procedure as for the samples.

2.4 Health risk

Health risk was estimated based on Environmental Protection Agency guidelines. To assess the potential health risk via the consumption of the fish species, the estimated daily intake (EDI) and target hazard quotient (THQ) were calculated using equations 1 and 2 respectively with the following assumptions:

The hypothetical body weight for adult Nigerian was 70 kg [11].

The maximum absorption rate was 100% while bioavailability factor was also 100%.

$$Estimated\ Daily\ Intake,\ EDI = \frac{\text{C x CR x AFx EF}}{BW}\text{, mg x kg}^{-1}\text{ x day}^{-1} \quad (1)$$

where: C = Concentration of the contaminant in the exposure pathway (mg/kg), CR = Consumption Rate; Nigeria aquatic crab taken/day, 0.0366 kg$\cdot day^{-1}$ =13.359 kg, AF= Bioavailability factor (100%), EF = Exposure Factor = 1, BW = Body weight (70kg)

$$Target\ Hazard\ Quotient, THQ = \frac{\text{EDI}}{\text{RfD}} \quad (2)$$

where: EDI= Estimated Daily Intake and RfD = the oral reference dose (mg/kg/day).

2.5 Statistical Analysis

The statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) version 20.0. Duncan multiple range test was used to determine the differences between the concentration levels of each of the analysed element in water, sediment and fish samples. $P < 0.05$ was considered the level of statistical significance.

3. Results and discussion

3.1 Trace element concentration

The concentrations of essential trace elements in water, sediment, and two cage-cultured fish species from Badagry Lagoon (Table 1) revealed significant variations across environmental media. For all metals analyzed-chromium, copper, manganese, molybdenum, nickel, selenium, and zinc-sediment consistently exhibited significantly higher mean concentrations ($p < 0.05$) compared to water and fish tissues, indicating its role as a major sink for trace metals. Among the fish species, *C.*

gariepinus generally showed higher accumulation of copper, manganese, and zinc than *O. niloticus*, although the differences were not statistically significant for most elements. Notably, zinc had the highest accumulation in sediment (14.36 mg kg^{-1}) and also appeared in considerable amounts in *C. gariepinus* (0.61 mg kg^{-1}), reflecting possible biomagnification. The low concentrations of molybdenum and selenium in both water and fish tissues suggest limited bioavailability or uptake. In Table 2, the concentrations of non-essential trace elements in water, sediment, and cage-cultured fish species from Badagry Lagoon reveal spatial variation and accumulation patterns among matrices. Generally, non-essential trace metals were significantly more concentrated in sediments than in water and fish tissues, indicating that sediments serve as major sinks for these contaminants. Among the fish species, *O. niloticus* exhibited higher accumulation of tin (1.3064 ± 0.4774 mg kg^{-1}) and silver (0.0573 ± 0.0171 mg kg^{-1}) compared to *C. gariepinus*, suggesting species-specific uptake tendencies. Mercury levels in both fish were uniformly low (0.0002 ± 0.0000 mg kg^{-1}), but cadmium and uranium concentrations, though low, raise potential food safety concerns due to their toxicity even at trace levels.

Table 1

Concentration of essential trace elements in water, sediment and cage-cultured fish species from Badagry Lagoon, Nigeria

Elements	Water	Sediment	*Clarias gariepinus*	*Oreochromis niloticus*
Chromium	0.0058±0.0025^a	0.2904±0.1232^b	0.0092±0.0032^a	0.0081±0.0044^a
Copper	0.0259±0.0061^a	1.2943±0.3059^b	0.7618±0.1306^a	0.5734±0.1116^a
Manganese	0.0419±0.0135^a	2.0955±0.677^b	0.0830±0.0265^a	0.0064±0.0022^a
Molybdenum	0.0023±0.0007^a	0.1148±0.0329^b	0.0011±0.0003^a	0.0005±0.0002^a
Nickel	0.0154±0.0049^a	0.7685±0.2442^b	0.0062±0.0027^a	0.0094±0.0048^a
Selenium	0.0020±0.0010^a	0.1007±0.0496^b	0.0005±0.0002^a	0.0132±0.0093^a
Zinc	0.2873±0.0442^a	14.3641±2.2116^b	0.6111±0.0543^a	0.1137±0.0463^a

Mean±Standard Error; values with different superscripts across row are significantly different ($p < 0.05$)

Table 2

Concentration of non-essential trace elements in water, sediment and cage-cultured fish species from Badagry Lagoon, Nigeria

Elements	Water	Sediment	*Clarias gariepinus*	*Oreochromis niloticus*
Aluminium	0.0431±0.0113^a	2.1569±0.5639^b	0.0162±0.0033^a	0.0064±0.0012^a
Barium	0.0139±0.0053^a	0.6966±0.2650^b	0.0064±0.0015^a	0.0013±0.0003^a
Beryllium	0.0002±0.0000^a	0.0119±0.0015^b	0.0059±0.0019^a	0.0020±0.0004^a
Cadmium	0.0012±0.0002^a	0.0594±0.0094^b	0.0003±0.0001^a	0.0010±0.0004^a
Mercury	0.0010±0.00^a	0.0506±0.0006^a	0.0002±0.0000^a	0.0002±0.0000^a
Silver	0.0157±0.0017^a	0.7842±0.0846^a	0.0187±0.0043^a	0.0573±0.0171^a
Tin	0.0189±0.0046^a	0.9442±0.2281^b	0.3562±0.0799^b	1.3064±0.4774^b
Uranium	0.0159±0.0020^a	0.7966±0.0981^b	0.0338±0.0046^a	0.0052±0.0011^a
Vanadium	0.0048±0.0014^a	0.2424±0.0711^b	0.0498±0.0164^a	0.0388±0.0182^a

Mean±Standard Error; values with different superscripts across row are significantly different ($p < 0.05$)

3.2 Estimated Daily Intake

The estimated daily intake (EDI) values of essential trace elements in *C. gariepinus* and *O. niloticus* from Badagry Lagoon (Table 3) were all found to be well below their respective oral reference doses (RfD), indicating no immediate risk of toxicity through dietary exposure. Among the elements analysed, *C. gariepinus* showed slightly higher EDI values for most essential trace elements compared to *O. niloticus*, particularly for copper (0.000398 mg person^{-1} day^{-1}) and zinc (0.000320 mg person^{-1} day^{-1}), yet these values still fall significantly below their respective RfD limits of 0.04 and 0.3 mg person^{-1} day^{-1}. The minimal values for chromium, manganese, molybdenum, nickel, and selenium in both species further support their nutritional safety for regular human consumption.

Table 3

Estimated Daily Intake (mg person^{-1} day^{-1}) of essential trace elements in cage-cultured fish species from Badagry Lagoon, Nigeria

Elements	*Clarias gariepinus*	*Oreochromis niloticus*	Oral reference dose
Chromium	0.000005	0.000004	0.003
Copper	0.000398	0.000300	0.040
Manganese	0.000043	0.000003	0.140
Molybdenum	0.000001	0.000000	0.005
Nickel	0.000003	0.000005	0.020
Selenium	0.000000	0.000007	0.005
Zinc	0.000320	0.000059	0.300

The EDI of non-essential trace elements from the consumption of *C. gariepinus* and *O. niloticus* cultured in Badagry Lagoon (Table 4) revealed values that were generally well below the established RfDs for each element, indicating minimal immediate health risk. For both species, elements like cadmium and mercury were either undetected or present at negligible levels (0.000001 mg person^{-1} day^{-1} or less), far below their respective RfDs of 0.001 and 0.0001 mg person^{-1} day^{-1}. Notably, while silver and tin showed relatively higher EDIs—especially tin in *O. niloticus* (0.000683 mg person^{-1} day^{-1})—these values still remained within safe limits when compared to the RfD (0.005 and 0.3 mg person^{-1} day^{-1}, respectively). The same trend applied to other elements like antimony, beryllium, uranium and vanadium.

3.3 Target Hazard Quotient

The Target Hazard Quotient (THQ) values of essential trace elements in the fish species from Badagry Lagoon (Table 5) revealed that all elements assessed were below the threshold value of 1, indicating no significant non-carcinogenic health risk from the consumption of these fish species. However, *C. gariepinus* generally exhibited higher THQ values than *O. niloticus* for most elements, including chromium (0.005345 vs. 0.004706), copper (0.009958 vs. 0.007495), manganese (0.00031 vs. 0.000024), molybdenum (0.000115 vs. 0.000052), and zinc (0.001065 vs. 0.000198). In contrast, selenium and nickel were slightly more elevated in *O. niloticus*. The statistically significant P-values ($P < 0.05$) across all elements indicate that the differences in THQ values between the two species are meaningful, suggesting species-specific variation in trace element accumulation. The observed distribution pattern of trace elements in this study, with significantly higher concentrations in sediment compared to water and fish tissues, aligns with previous findings that

Table 4

Estimated Daily Intake (mg person^{-1} day^{-1}) of non-essential trace elements in cage-cultured fish species from Badagry Lagoon, Nigeria

Elements	*Clarias gariepinus*	*Oreochromis niloticus*	Oral reference dose
Antimony	0.000005	0.000047	0.0004
Barium	0.000003	0.000001	0.2000
Beryllium	0.000003	0.000001	0.00002
Cadmium	0.00000	0.000001	0.0010
Mercury	0.000000	0.000000	0.0001
Silver	0.000010	0.000030	0.0050
Tin	0.000186	0.000683	00030
Uranium	0.000018	0.000003	0.0030
Vanadium	0.000026	0.00002	0.0010

identify sediment as a key sink for trace metals in aquatic environments [12]. This trend underscores the role of sediment in metal retention and potential remobilization under changing physicochemical conditions. The relatively higher biaccumulation of essential trace elements in *C. gariepinus* compared to *O. niloticus* corroborates earlier reports by Oros [13] and Feng et al. [14], which attributed such differences to species-specific metabolic and feeding behaviors. The significantly higher concentrations of non-essential trace elements such as tin and silver in *O. niloticus* compared to *C. gariepinus* align with reports by Varol and Kaçar [15], who also noted species-specific differences in metal uptake related to feeding habits, metabolic rates, and habitat preferences.
Similarly, the low but detectable levels of

Table 5

Target Hazard Quotient of essential trace elements in cage-cultured fish species from Badagry Lagoon, Nigeria

Elements	*Clarias gariepinus*	*Oreochromis niloticus*	*P*-Value
Chromium	0.005345	0.004706	0.038
Copper	0.009958	0.007495	0.021
Manganese	0.00031	0.000024	0.008
Molybdenum	0.000115	0.000052	0.031
Nickel	0.000162	0.000246	0.044
Selenium	0.000052	0.00138	0.001
Zinc	0.001065	0.000198	0.012

cadmium and uranium raise concern, echoing the conclusions of Ali and Khan [16] that even trace exposure to non-essential metals can pose chronic health risks due to their bioaccumulative and toxic nature. The relatively uniform and low mercury levels observed corroborate the work of Ndimele *et al.* [17], who found minimal mercury accumulation in freshwater fish from southern Nigeria, likely due to limited industrial discharges in the area. The EDI values of essential trace elements in both fish species from Badagry cage culture are well below their respective oral reference doses, align with previous studies conducted in similar aquatic environments. For instance, Egun *et al.* [18] reported EDI values for copper and zinc in freshwater fish from a lentic ecosystem in Nigeria, that were likewise below toxicity thresholds, confirming the safety of such fish for human consumption. The slightly elevated EDI values in *C. gariepinus* observed in the current study, particularly for copper and zinc, may reflect species-specific metabolic or bioaccumulation tendencies, as previously suggested by Ali and Khan [16].

Table 6

Target Hazard Quotient of non-essential trace elements in cage-cultured fish species from Badagry Lagoon, Nigeria

Elements	*Clarias gariepinus*	*Oreochromis niloticus*	*P*-Value (P<0.05)
Antimony	0.011895	0.11699	0.012*
Barium	0.000017	0.00000	0.034*
Beryllium	0.154243	0.05229	0.009*
Cadmium	0.000314	0.00105	0.041*
Mercury	0.000349	0.00035	0.982
Silver	0.001955	0.00599	0.017*
Tin	0.00031	0.00114	0.025*
Uranium	0.005891	0.00091	0.006*
Vanadium	0.00372	0.00290	0.073

* Significant Difference

Similar to the current report on non-essential trace elements, Ndimele *et al.* [17] found similarly low EDIs of cadmium and mercury in *O. niloticus* from industrial effluent-polluted aquatic ecosystem in Lagos, with values well below their oral reference doses, indicating minimal toxicological risk. Likewise, Basheeru *et al.* [19] reported negligible levels of non-essential elements such as antimony and vanadium in fish from Lagos Lagoon, supporting the current study's observation of safe consumption levels. The relatively higher EDI of tin in *O. niloticus*, although still within acceptable limits, mirrors findings by Rosli *et al.* [20], who noted tin accumulation patterns in fish associated with sediment contamination but concluded that dietary exposure remained safe. Collectively, these results reinforce the conclusion that cage-cultured fish from Badagry Lagoon, despite trace element presence, do not currently present significant non-essential metal-related health risks. However, consistent with Eero *et al.* [21], long-term exposure and bioaccumulation risks should not be disregarded, necessitating routine monitoring and ecosystem-based management of aquaculture systems. The observed THQ values for essential trace elements in both caged-cultured fish species align with findings from previous studies indicating that fish from controlled aquaculture environments generally pose low non-carcinogenic health risks to consumers. For instance, Adegbola *et al.* [22] reported THQ values well below 1 for essential metals in cultured *C. gariepinus* from the Ogun River, supporting the conclusion of minimal health risks. Similarly, Ndimele et al. [17] found that *O. niloticus* from Lagos exhibited species-specific differences in trace metal accumulation, with cadmium and antimony levels approaching higher THQ values compared to other species. The current study supports these observations by revealing significantly higher THQ values of antimony, silver, tin, and cadmium in *O. niloticus*, which may be attributed to its feeding behaviour and ecological adaptability. Meanwhile, elevated THQs for beryllium and uranium in *C. gariepinus* align with the findings of Melake et al. [23], who noted the benthic foraging habits of *C. gariepinus* increase its exposure to sediment-associated metals. Although all THQ values remained within permissible limits, the interspecies differences highlighted here reinforce the importance of regular, species-specific risk assessments in aquaculture environments

4. Conclusion

The exploratory health risk assessment of essential and non-essential trace elements in *Clarias gariepinus* and *Oreochromis niloticus* cultured in Badagry Lagoon revealed generally low levels of concern regarding consumer safety. Sediment samples consistently harbored higher concentrations of all trace elements compared to water and fish tissues, indicating their function as long-term contaminant reservoirs. While both fish species showed trace metal accumulation, the differences were element-specific and statistically significant in many cases. *C. gariepinus* accumulated more copper, manganese, and zinc, whereas *O. niloticus* showed higher uptake of tin, silver, and cadmium. Estimated daily intakes (EDI) for all measured elements were far below established oral reference doses, affirming the safety of consuming these fish species under current exposure levels. Similarly, Target Hazard Quotient (THQ) values were all below the threshold of 1, indicating no immediate non-carcinogenic risk. Nonetheless, the significant interspecies variation in THQ values, particularly for cadmium, silver, uranium, and beryllium, signals the need for species-specific dietary risk monitoring. Overall, this study reinforces the relative safety of cage-cultured fish from Badagry Lagoon, while emphasizing the need for proactive trace element surveillance to safeguard food quality and consumer health in rapidly urbanizing aquatic systems.

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