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Heavy Metal Accumulation and Nutrient Composition in *Erpetoichthys calabaricus*: Environmental and Human Health Implications

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ABSTRACT

Background and Objective: Despite the ecological and economic significance of *Erpetoichthys calabaricus* in West Africa, limited research has been conducted on its nutritional value and potential as a bioindicator of heavy metal pollution. Additionally, human activities and environmental degradation threaten its habitats, yet its ecological role remains poorly understood. This study investigated the heavy metal content and proximate composition of *Erpetoichthys calabaricus* from the Iba-Oku Stream in Southeastern Nigeria, evaluating potential ecological and human health risks. **Materials and Methods:** Samples were collected and analyzed using Atomic Absorption Spectrophotometry (AAS) to determine metal concentrations and standard methods for nutritional profile. The proximate composition analysis included moisture, protein, fat, and ash content, providing insight into the nutritional value of the fish. Data were analyzed using one-way ANOVA ($p \leq 0.05$) and Duncan's multiple range test, with IBM SPSS version 20. **Results:** The findings revealed that Ni levels exceeded those reported in comparable studies, with mean concentrations ranging from 1.123 to 3.450 mg/kg, while the concentrations of other heavy metals fell within the ranges observed in similar studies. The proximate composition indicated high protein, lipid, and moisture content, aligning with the nutritional profile of freshwater fish but raising concerns about metal toxicity. **Conclusion:** These findings highlight potential health risks associated with consuming *E. calabaricus* due to elevated heavy metal levels, emphasizing the need for regular monitoring of heavy metals in aquatic ecosystems, particularly in regions impacted by industrial and agricultural runoff. It advocates for stringent regulatory measures to mitigate metal contamination in water bodies and ensure the safety of fish for human consumption.

KEYWORDS

Erpetoichthys calabaricus, heavy metal accumulation, proximate composition, ecological risk, human health risk, nutritional analysis, environmental contamination, food safety

INTRODUCTION

Metals pose significant threats to aquatic ecosystems and human health due to their potential to enter and accumulate in food chains[1-3]. Anthropogenic activities, such as industrialization and urbanization contribute to metal pollution, affecting fish species differently in the same habitat[4]. Organ-specific accumulation of essential trace metals like iron, zinc, copper, manganese, and cobalt further complicates the issue[1-3].

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Heavy metals, characterized by high density and toxicity, including chromium, cadmium, arsenic, lead, zinc, nickel, mercury, selenium, and copper are present in aquatic habitats, posing significant risks to fish and shellfish[5]. Essential metals like iron, cobalt, and zinc, as well as probably non-essential ones like nickel, play crucial roles in biochemical processes. However, toxic metals such as cadmium, lead, and mercury can cause severe health issues, with concentrations exceeding recommended limits[6].

Fish serve as vital indicators of heavy metal pollution due to their tendency to accumulate metals in various organs, posing risks to human health through consumption[7,8]. Heavy metal toxicity in fish can disrupt food sources, leading to habitat degradation and ultimately impacting ecosystems[9,10]. Consumption of toxic metals beyond recommended limits can severely impair bodily functions and even lead to death[11].

Nutrients sourced from foods, including water, carbohydrates, proteins, fats, vitamins, and minerals, are crucial for maintaining human health[12]. Fish, supplied through capture fisheries, aquaculture or imports[13], offer essential nutrients beneficial to human health[14], especially the vulnerable[15]. Fish, known for their high-quality proteins and medicinal value, undergo evaluation based on factors like color, texture, and nutritional composition[16]. Proximate analysis of fish, focusing on constituents like water, protein, lipid, and ash, is vital for food product development and quality control[17].

Erpetoichthys calabaricus, also known as the Reedfish or Ropefish, is a unique species found in West and Middle Africa, valued for both food and commercial ornamental purposes[18]. *Erpetoichthys calabaricus*, is a member of the family Polypteridae, recognized for its elongated, snake-like body[19], and unique dorsal fin structure. They are a rare species of freshwater fish in the bichir group first described 149 years ago after *Polypterus senegalus*. They usually inhabit slow-moving waters with a lot of vegetation[20]. *Erpetoichthys calabaricus* employs a foraging strategy that emphasizes invertivory, indicating a narrow trophic spectrum focused on available invertebrate prey[21]. The species' feeding habits may vary with environmental conditions, as seen in other fish species that adapt their diets based on habitat changes[22]. Though not endangered, its restricted habitat range may pose a risk. Nonetheless, human activities and limited research efforts have placed *E. calabaricus* under threat, contributing to its perceived scarcity and insufficient cultivation[23,24]. *Erpetoichthys calabaricus* is popular in the aquarium trade, thrives on a high-protein diet and is known for its adaptability and unique appearance[25]. It is frequently collected from West Africa for the aquarium trade due to its distinctive appearance, engaging behaviors and hardy nature, making it popular among aquarists[24]. This species serves as an indicator for monitoring heavy metal pollution in aquatic environments[26].

Studies on the proximate composition and heavy metal analysis of *E. calabaricus* in the Iba Oku stream have not been reported previously, highlighting the novelty and importance of this research. By assessing the nutritional status and potential health risks associated with consuming these fishes, this study fills a significant gap in the existing literature[15,27-38]. Despite its near-threatened status, studies on the proximate composition and heavy metal content of *E. calabaricus* in southern Nigeria, particularly regarding its nutritional status and potential health implications for consumers, remain scarce. Therefore, this study aims to assess the heavy metal content and proximate composition of this commercially important fish, providing valuable insights for nutritionists, dieticians, and policymakers concerned with ensuring accessible sources of low-fat, high-protein foods in the region.

This study examined the nutritional composition and heavy metal content of *E. calabaricus* in the Iba Oku stream, providing baseline data to inform sustainable fisheries management, food safety, and public health policies. The findings address critical gaps in understanding potential health risks and support food security initiatives in West Africa.

MATERIALS AND METHODS

Sample location: The study area, Iba-Oku stream, lies within the Oku Clan of Uyo Local Government Area in Akwa Ibom State, Southeastern Nigeria. Positioned between Latitude 5°02-5°04 N and Longitude 7°56'-7°58'E, it sits at an altitude of approximately 15 m above Mean Sea Level (M.S.L.). Characterized by a sub-equatorial climate, the area experiences a mean annual rainfall of 2500 mm, with the rainy season typically lasting from March to early November. Relative humidity remains consistently between 70 and 80% throughout the year, except during brief periods of harmattan. Iba-Oku stream is prone to flooding for most of the year, except during particularly dry months (Meteorological Station, University of Uyo, 2019).

The sampling site features muddy terrain with brownish water, abundant in both coarse and fine particulate organic matter. Dominated by riparian vegetation such as *Hevea brasiliensis*, *Oxytenanthera abyssinica*, and various types of grass, the area also hosts a variety of macrophytes like *Raphia hookeri*, *R. vinifera*, *Elaeis guineensis*, *Pandanus candelabrum*, and *Musa* species. Hydrophytes such as *Wolffia* species and *Nymphaea lotus*, along with *Commelina* species, constitute the most prevalent bank macrophyte. Soil types range from clay to clayey-loam to laterite, supporting subsistence-level riparian agriculture and the cultivation of crops like *Talinum triangulare*, *Telfairia occidentalis*, and *Dioscorea* spp. during dry months.

Sample collection: Monthly samples of *E. calabaricus* were collected from subsistence catches in Nduetong Village at Iba-Oku Stream from July to September, 2019. Non-return valve traps were employed for sampling, with a total of 120 samples collected throughout the study period. Following collection, the fish were transported to the Department of Biochemistry and Chemistry Laboratory, University of Uyo, Uyo, in 15 L buckets for analysis.

Determination of metal composition: Digest solutions of the samples were prepared by digesting 1 g of each sample in aqua regia (HCl and HNO_3 at a 3:1 ratio) at 130 for 30 min. The resulting solutions were filtered and made up to 100 mL after filtration. Standard solutions of the metals to be analyzed were prepared, and an Atomic Absorption Spectrophotometer (AAS) was calibrated using these standard solutions. The concentrations of metals in the samples were determined using AAS.

Proximate analysis of the samples: The chemical composition of the samples was determined using standard methods. Moisture, crude protein, crude lipid, carbohydrate, and ash contents were analyzed using the following procedures[39]:

- **Moisture determination:** Five grams of the ground sample was placed in an oven at 105 for 24 hrs. The moisture content was calculated using the weight loss after drying
- **Crude protein determination:** One gram of the ground sample was digested using a Kjeldahl flask and titrated to determine nitrogen content, which was then converted to crude protein content
- **Lipid determination:** Five grams of the ground sample was refluxed with petroleum ether for 6 hrs, and the resulting crude lipid content was calculated based on weight loss
- **Crude fiber determination:** Two grams of the sample were subjected to acid and alkali treatments to determine crude fiber content
- **Total ash determination:** Two grams of the dried sample were ignited in a muffle furnace to determine the total ash content
- **Total carbohydrate content:** Available carbohydrate content was calculated as the difference between total dry matter and the sum of lipid, ash, and fiber values

Statistical analysis: Data were subjected to One-way Analysis of Variance (ANOVA) at a 0.05 level of significance, followed by Duncan's New Multiple Range tests to assess differences between mean values. Further analysis was conducted using IBM SPSS version 20 software.

RESULTS AND DISCUSSION

The results of heavy metal analysis, comparison of monthly mean metal concentration with similar studies in fish, and the proximate composition are presented below in Table 1-3, respectively.

From the current study, metal concentrations followed the order: Zn>Ni>Pb>Fe>Cd>Cr, with all metals detected in the analyzed samples (Table 1). The comparison of mean concentrations of Zn, Pb, Ni, Cd, Cr, and Fe in *Erpetoichthys calabaricus* from Iba Oku Stream (based on monthly assessments over three months) with values reported in other studies are shown in Table 2. The mean concentrations of Zn ranged from 3.443±0.001 to 4.370±0.002 mg/kg, with the highest in July and the lowest in August. The Pb peaked in August (2.680±0.002 mg/kg) and was lowest in July (0.002±0.001 mg/kg). The Ni showed the highest mean concentration (3.450±0.003 mg/kg) in July and the lowest (1.123±0.001 mg/kg) in August. The Cd showed the highest mean concentration (1.070±0.001 mg/kg) in July and the lowest (0.022±0 mg/kg) in August. The Cr recorded the highest mean concentration (0.711±0.003 mg/kg) in July and the lowest (0.116±0 mg/kg) in August. The Fe exhibited the highest concentration (2.020±0.001 mg/kg) in July and the lowest (0.254±0.001 mg/kg) in September. Significant differences ($p<0.05$) were observed in the mean concentrations of Zn, Pb, Ni, Cd, Cr, and Fe between months, with Ni concentrations exceeding international standards for food fish.

Results show that significant differences ($p<0.05$) were observed in moisture, protein, lipid, carbohydrate, fiber, ash, and calorie content (Table 3). The moisture content of *E. calabaricus* in this study ranged from 46.98 to 74.67%, with the highest value observed in September and the lowest in August. Ash content

Table 1: Heavy metal (Mean±SD) concentration (mg/kg) of *E. calabaricus* obtained from Iba-Oku stream

Parameter	July	August	September
Zinc	4.370±0.002[a]	3.443±0.001[b]	3.660±0.002[b]
Lead	2.680±0.002[a]	0.002±0[b]	1.580±0.002[b]
Nickel	3.450±0.003[a]	1.123±0.001[b]	3.200±0.005[b]
Cadmium	1.070±0.001[a]	0.022±0[b]	0.061±0.001[b]
Chromium	0.711±0.003[a]	0.116±0[b]	0.144±0.003[b]
Iron	2.020±0.001[a]	1.804±0[b]	0.251±0.001[c]

Means within same row with same superscript are not significantly different ($p>0.05$)

Table 2: Comparison of mean concentrations of heavy metals (mg/kg) in *Erpetoichthys calabaricus* from Iba Oku Stream (based on monthly assessments over three months) with values reported in other studies

		Other studies mean concentration (mg/kg)		
Heavy metal	Obtained mean concentration (mg/kg)	Elinge *et al.*[35]	Ojaniyi *et al.*[37]	Resma *et al.*[40]
Zn	3.443-4.370	0.15-0.60	0.245	16.205-22.270
Pb	0.002-2.680	ND	0.276	NA
Ni	1.123-3.450	1.27-1.90	0.419	NA
Cd	0.022-1.070	0.06-0.12	0.022	0.0035-0.0067
Cr	0.116-0.711	0.13	0.001	0.577-0.623
Fe	0.25-2.020	0.65-1.17	1.755	NA

Zn: Zinc, Pb: Lead, Ni: Nickel, Cd: Cadmium, Cr: Chromium, Fe: Iron, ND: Not detected and NA: Not assessed

Table 3: Proximate composition (Mean±SD) of *E. calabaricus* (wet weight) obtained from Iba-Oku Stream, Uyo

Parameter	July	August	September
Moisture (%)	55.610±0.003[b]	74.667±0.333[a]	46.980±0.005[c]
Ash (%)	12.410±0.002[a]	3.546±0.856[b]	13.620±0.002[a]
Fiber (%)	9.890±0.001[a]	4.861±0.286[b]	10.110±0.003[a]
Protein (%)	43.753±0.009[a]	22.254±1.359[b]	44.530±0.030[a]
Lipid (%)	16.270±0.002[a]	12.958±0.621[c]	14.941±0.001[b]
Carbohydrate (%)	17.680±0.001[b]	56.382±2.928[a]	16.800±0.004[b]
Caloric value (Kcal)	392.150±0.002[b]	431.163±2.823[a]	379.780±0.095[c]

Means within same row with same superscript are not significantly different ($p>0.05$)

ranged from 3.55 to 13.62%, with the highest observed in September and the lowest in July. Fiber content varied between 4.86 and 10.11%, with the highest in September and the lowest in August. Lipid content peaked in July (16.27%) and was lowest in August (12.96%). Carbohydrate content ranged from 16.80 to 56.38%, with the highest in August and the lowest in September. Caloric values ranged from 379.78 to 431.16 kcal, with the highest in July and the lowest in September.

Assessment of heavy metal concentrations in *Erpetoichthys calabaricus* from the Iba-Oku stream revealed variable levels, with some exceeding thresholds reported in comparable studies, indicating potential health risks. Additionally, the species exhibited significant nutritional value, particularly in its protein and fat content, reinforcing its importance as a dietary resource. Zinc is an essential element in humans, serving as a cofactor for important enzymes and involved in various metabolic pathways[41]. Deficiency can lead to loss of appetite, growth retardation, skin changes, and immunological abnormalities[42,43]. However, at high concentrations, Zn becomes toxic, causing poisoning, diarrhea, and fever[44]. The observed Zn range in *E. calabaricus* (3.443-4.370 mg/kg) was higher than values reported in muscle tissue of *Synodontis membranaceus* (0.28 mg/kg) and *Synodontis schall* (0.15 mg/kg) from River Zamare, Nigeria[35]. However, lower Zn levels were reported in *Clarias gariepinus*, *Heterotis niloticus*, and *Anguilla labiata* from Ogbaru axis of River Niger, Anambra State, Nigeria[37]. The recorded Zn levels are lower than those reported in comparable studies, suggesting that consumption of fish from the Iba-Oku stream is unlikely to pose Zn-related health risks. Lead (Pb) is a well-known hazardous heavy metal, with no known beneficial physiological role in humans[40,45]. Chronic exposure can lead to a multitude of health complications, including developmental problems in children, impaired cognitive function, and cardiovascular diseases[46-48]. The Pb concentrations detected in *E. calabaricus* from the Iba-Oku stream (0.002-2.680 mg/kg) were within the threshold values reported in comparable studies, aligning with the generally recognized safety limits for fish consumption. These findings are consistent with the report by Ojaniyi *et al.*[37], who found Pb levels ranging from 0.276 to 0.394 mg/kg in *Clarias gariepinus*, *Heterotis niloticus*, and *Anguilla labiata* from the Ogbaru axis of River Niger, Nigeria. Similarly, comparable Pb levels of 0.1-0.27 mg/g were reported by Abidemi *et al.*[49] in *Chrysichthys nigrodigitatus* and *Oreochromis niloticus*; 0.1028 µg/g for *Barbonymus schwanefeldii* from Kelantan River[50]; 0.50 and 0.025 mg/kg for *Pomadasys jubelini* and *Monodactylus sebae*, respectively[36]. The observed disparities in Pb concentrations necessitate further investigation into potential sources of Pb contamination in the Iba-Oku Stream.

Nickel (Ni) is an essential element in humans at low concentrations, but excessive intake can be detrimental[51]. Potential health effects of high Ni exposure include respiratory problems, skin allergies, and certain cancers[52,53]. The Ni levels detected in E. calabaricus (1.123-3.450 mg/kg) exceeded both the thresholds reported in comparable studies, indicating potential health concerns. Findings from this study are higher than those reported by Ojaniyi *et al.*[37] for *Heterotis niloticus* (0.514 mg/kg) and *Anguilla labiata* (0.322 mg/kg) from the Ogbaru axis of River Niger, Nigeria. Cadmium (Cd) is a highly toxic heavy metal with no known essential function in humans and chronic exposure can lead to kidney dysfunction, bone problems, and an increased risk of certain cancers[52,54]. The Cd concentrations detected in *E. calabaricus* from Iba-Oku Stream (0.022-1.070 mg/kg) were lower than those reported in comparable studies, suggesting that consumption of fish from the Iba-Oku stream is unlikely to pose Cd-related health risks. This is encouraging as it suggests minimal Cd accumulation in the fish muscle tissue. Ojaniyi *et al.*[37] reported comparable Cd levels (0.020-0.028 mg/kg) in *H. niloticus*, and *A. labiata* from the Ogbaru axis of River Niger, Nigeria. In contrast to previous findings, the observed Cd concentrations in this study differ from those reported in other research. Njinga *et al.*[34] found higher levels in *Tilapia brevimanus* (101.71 µg/L) and *Euthynnus alletteratus* (177.43 µg/L) from coastal waters in Southwestern Nigeria.

Chromium (Cr) exists in several forms, with trivalent chromium (Cr(III)) being an essential element for humans, while hexavalent chromium (Cr(VI)) is highly toxic and carcinogenic[55]. The Cr concentrations detected in *E. calabaricus* (0.116-0.711 mg/kg) were within the range reported in comparable studies, suggesting that the levels of chromium in fish from the Iba-Oku Stream are within acceptable limits. Zaghloul *et al.*[56] reported similar Cr levels 0.15 mg/kg in *Hepsetus odoe* from Ureje water Reservoir, Ado Ekiti. The current study found lower chromium concentrations compared to previous reports. Njinga *et al.*[34] found lower concentrations in *Euthynnus alletteratus* and *Tilapia brevimanus* (65.12-284.71 µg/L) from coastal waters in southwestern Nigeria. Notably, this study's chromium levels were significantly higher than the 0.001 mg/kg[37] for *C. gariepinus* and *A. labiate* in the Niger River, Nigeria. Iron (Fe) is an essential element for humans, playing a crucial role in oxygen transport and various metabolic processes, but excessive iron intake can be detrimental, leading to oxidative stress and organ damage[57-59]. The Fe concentrations detected in *E. calabaricus* (0.25-2.02 mg/kg) were within the range reported in comparable studies, indicating that the levels of iron in fish from the Iba-Oku Stream are within acceptable limits. Findings from this study are consistent with Ojaniyi *et al.*[37] reported Fe levels ranging from 1.23 to 1.93 mg/kg in *C. gariepinus*, *H. niloticus*, and *A. labiata* from the Ogbaru axis of River Niger, Nigeria. In contrast, the iron concentrations in *E. calabaricus* from the current study were lower than reports of Aljabryn[45], who reported a wider range in *Pterygoplichthys pessuliferus* (3.50 mg/kg) and *Epalzeorhynchos sumatranus* (9.09 mg/kg).

The moisture content of *E. calabaricus* in this study ranged from 46.98 to 74.67%. This aligns with the established inverse relationship between moisture and lipid content in fish, where the sum of both often approaches 80%[60]. The findings from the current study compare favorably with Isangedighi *et al.*[15], who reported that cultured and wild African catfish *C. gariepinus* contained 73.23 and 75.06% moisture respectively. However, Krishna *et al.*[16] reported higher moisture levels: 80.2-83.8% for females and 80.4-84.2% for males of *Channa striata* from India. The ash content, representing the mineral content, ranged from 3.55 to 13.62%. This range is higher than what some studies reported, Mahjoub *et al.*[61] documented 1.0 to 3.92% for anchovies in Malaysia. Krishna *et al.*[16] reported 1.61-2.19% (females) and 1.65-2.25% (males) in *Channa striata* muscle. Conversely, results from the present research are in line with Isangedighi *et al.*[15], who reported 9.13 and 17.34% in cultured and wild African catfish (*C. gariepinus*). The fiber content ranged from 4.86 to 10.11%, indicating *E. calabaricus* as a good fiber source for consumers. The research at hand concur with Isangedighi *et al.*[15], who reported 6.58-11.33% for cultured and wild African catfish. The protein content observed in this study (22.25-44.53%) for *E. calabaricus* indicates it is a good dietary protein source. The observed range in *E. calabaricus* aligns well with the findings of Jolaoso *et al.*[36], who reported a range of 0.80 to 31.55% protein in nine fish species from Ologe and Lagos Lagoons. Conversely, di Lena *et al.*[29] reported protein contents of 18.1-18.8% in red mullet (*Mullus barbatus*) from the Central Tyrrhenian and Central Adriatic seas. The lipid content in *E. calabaricus* ranged from 12.96 to 16.27%, significantly higher than what other studies reported for various fish species. Pèlèbè *et al.*[13] documented 3.39-8.73% for *Clarias gariepinus*. The work conducted aligns with Isangedighi *et al.*[15], reporting 18.01 and 19.44% lipid for cultured and wild African catfish. *Erpetoicthys calabaricus* from this study exhibited a good lipid content, and according to Taşbozan and Gökçe[62], *E. calabaricus* can be classified as a high-fat fish (>10%) due to its observed lipid range. *Erpetoicthys calabaricus* exhibited a relatively high carbohydrate content (16.80-56.38%) compared to other reported values for various fish species[13,15]. The calculated gross energy content (379.78-431.16 Kcal/100 g) was at variance than some studies by Kasozi *et al.*[63] documented 547-576 Kcal/100 g for *Alestes baremoze*, while Alemu *et al.*[64] reported 60.2 Kcal/100 g for Nile tilapia.

This study reveals factors influencing metal uptake in fish, including metal availability in water, feeding habits, and the fish's position in the food web. Variations in heavy metal accumulation between this study and previous research are likely due to differences in fish physiology, behavior, and diet. The study emphasizes that different metals accumulate in various fish organs, and factors such as feeding habits, trophic level, metal source, and environmental elements contribute to these variations[65]. Diet is highlighted as a key factor, with pelagic and benthic fish species accumulating metals differently[66]. Additionally, larger fish tend to accumulate metals more rapidly as they grow[67]. The overall proximate composition varies across months due to environmental and biological factors. Understanding these variations is crucial for optimizing fish farming practices and ensuring consistent nutritional quality for consumers. Monitoring metal pollution in the Iba-Oku stream is crucial due to fish's importance in human diets and the population's reliance on the stream for water. This study's nutrient profiles can inform dieticians, nutritionists, marketing industries, and fisheries stakeholders regarding the potential use of *E. calabaricus* as a low-cost food source in human nutrition.

CONCLUSION

The study highlights the presence of trace amounts of heavy metals in *E. calabaricus*, suggesting potential environmental contamination from nearby anthropogenic activities in Iba-Oku. While some metal concentrations were higher than those reported in comparable studies, bioaccumulation levels remained within observed ranges. These findings underscore the importance of continuous biological monitoring, given the reliance of downstream communities on this water source for both aquatic resources and consumption. The proximate composition analysis revealed significant variations in protein, moisture, lipids, fiber, carbohydrates, and caloric values, with *E. calabaricus* showing favorable protein and fat levels, making it a viable and cost-effective dietary option. These findings, combined with the assessment of heavy metal concentrations, highlight the species' nutritional and ecological significance. However, the presence of metals like lead, cadmium, and zinc raises concerns about environmental contamination and human health risks. Continued research is needed to investigate the sources and impacts of heavy metal contamination, as well as its implications for ecosystem health and human well-being.

SIGNIFICANCE STATEMENT

This study examines both essential nutrients and toxic metals in *Erpetoichthys calabaricus* (reed fish) from Nigeria's Iba-Oku Stream, a commonly consumed species in West Africa. The research identifies safe levels of essential nutrients like zinc and iron, which are vital for health, yet also detects high concentrations of nickel, a toxic metal surpassing recommended safety limits. This dual focus on nutrients and toxins provides a more comprehensive understanding of the health risks and benefits of consuming this fish. The findings underscore the impact of pollution on local aquatic life and highlight the importance of regular monitoring to protect both ecosystem health and food safety. This work provides critical data for guiding sustainable fisheries and food policies, which can improve dietary health and support environmental stewardship in West Africa.

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