International Journal of Ecotoxicology and Ecobiology
2026, Vol. 11, No. 2, pp. 19–30
https://doi.org/10.11648/j.ijee.20261102.11

Research Article

Trace Metals and Nutritional Composition of *Alestes dentex* from the Ibeshe River, Ikorodu, Lagos State, Southwest Nigeria

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Abstract

This study presents a comprehensive assessment of the safety and nutritional quality of the commercially important fish species, *Alestes dentex*, from the Ibeshe River, a water body receiving urban and industrial effluents in Ikorodu Division of Lagos State, Nigeria. Over an eight-week monitoring period, we analyzed the river's water quality, the bioaccumulation of thirteen trace metals in fish tissues, and the proximate composition of the fish. The proximate analysis revealed significant temporal variation in crude protein ($F(7,16)=4.82$, $p<0.01$), with values ranging from 14.72% to 19.08%. Mineral analysis identified magnesium as the most variable macromineral (660.52-2926.74 mg/100g), while zinc exhibited the highest overall variability (CV=85.0%). A coordinated ionic perturbation at Week 5 (Mg↓, Na↑, K↓) suggested acute osmoregulatory disturbance. Heavy metal concentrations remained within FAO/WHO safety limits throughout the study (Cd: 0.001-0.020 mg/100g; Pb: 0.002-0.010 mg/100g), although arsenic was detected for the first time at Week 8 (0.03 mg/100g). Correlation analysis revealed significant positive associations between calcium and iron ($r=0.82$, $p<0.01$) and negative correlations between sodium and potassium ($r=-0.79$, $p<0.05$). The findings establish critical baseline data for nutritional assessment and food safety monitoring, confirming that *A. dentex* from Ibeshe River remains safe for human consumption while highlighting the need for continued temporal surveillance.

Keywords

Alestes dentex, Proximate Composition, Mineral Profile, Heavy Metals, Food Safety, Temporal Variation, Ibeshe River

1. Introduction

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Received: 23 April 2026; **Accepted:** 7 May 2026; **Published:** 21 May 2026

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https://doi.org/10.11648/j.ijee.20261102.11

Aquatic ecosystems are global biodiversity hotspots that provide indispensable services, including fisheries that underpin food security and livelihoods for millions, particularly in developing nations [21]. In Nigeria, freshwater fisheries are a critical source of affordable animal protein, with species like *Alestes dentex* constituting a key component of the diet for riverine communities. However, the integrity of these vital resources is increasingly compromised by anthropogenic pressures, including rapid urbanization and industrialization, which lead to the discharge of persistent and toxic contaminants such as heavy metals [18, 19].

Heavy metals, originating from industrial effluents, agricultural runoff, and municipal waste, are non-degradable environmental pollutants [18, 21]. Upon entering aquatic systems, they accumulate in sediments and undergo bioaccumulation in biota, a process where concentrations increase within an organism over its lifetime [22]. This can lead to biomagnification through the food web, resulting in elevated concentrations in higher trophic levels, including commercially important fish species, thereby posing significant risks to human consumers [16, 22]. Chronic exposure to heavy metals such as lead (Pb), cadmium (Cd), and arsenic (As) through contaminated food is linked to severe health outcomes, including neurotoxicity, organ failure, and carcinogenicity [7, 28].

The Ibeshe River, situated in the densely populated and industrialized Ikorodu area of Lagos State, exemplifies a water body under severe anthropogenic stress. It serves as a probable sink for a complex mixture of pollutants from its catchment. While the nutritional benefits of fish like *Alestes dentex* are recognized, their safety for human consumption in contaminated ecosystems remains a pressing, yet understudied, public health issue. A comprehensive risk assessment requires a holistic understanding of the entire contamination pathway, from the physico-chemical quality of the water to the bioaccumulation in fish tissue and its implications for nutritional value [21].

Currently, a significant knowledge gap exists. While previous studies have often focused on either environmental monitoring or food safety in isolation, few have adopted an integrated, longitudinal approach that directly links water quality parameters, bioaccumulation dynamics, and nutritional composition within a single, defined ecosystem. This disconnect limits the ability to formulate effective public health advisories and environmental management strategies.

Therefore, this study aims to conduct a holistic, source-to-fork assessment of the Ibeshe River ecosystem, using *Alestes dentex* as a bio-indicator species. The specific objectives are to: (1) determine the temporal variation of key physico-chemical parameters in the river water; (2) quantify the concentrations of ten heavy metals (Zn, Fe, Cu, Cd, Pb, Cr, Mn, Ni, Co, As) in water and compare them with international guidelines; (3) assess the proximate nutritional composition of *Alestes dentex* muscle tissue; (4) determine the concentrations of the same heavy metals in the fish tissue and compare them with food safety standards; (5) calculate the Bioaccumulation Factor (BAF) for these metals; and (6) health risk assessment.

This research is critically justified by the need to bridge a scientific knowledge gap, address a potential public health imperative, and provide baseline data for environmental monitoring and policy. The findings will deliver a balanced evidence base, quantifying both the nutritional benefits and contamination risks associated with the consumption of *Alestes dentex*, thereby informing consumer choice, safeguarding livelihoods, and supporting the sustainable management of aquatic resources in line with several UN Sustainable Development Goals (SDGs 3, 6, and 12).

2. Methodology

2.1. Study Area

The study was conducted at the Ibeshe River, located in the Ikorodu area of Lagos State, Southwest Nigeria (Coordinates: approximately 6.6190° N, 3.5107° E). Ikorodu is a densely populated and industrialized peri-urban local government area. The river is a vital water body that receives runoff from residential, agricultural, and industrial activities, making it a critical site for assessing anthropogenic impact on aquatic ecosystems. Five representative sampling stations were established along the river to monitor temporal changes in water quality and fish contamination over time.

2.2. Study Design and Sampling Duration

A longitudinal study design was employed, with samples collected over a consecutive eight-week period to capture temporal variations in parameters. Sampling was conducted weekly, resulting in eight (8) discrete sampling events.

2.3. Sample Collection

2.3.1. Water Samples

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Composite water samples were collected from approximately 20-30 cm below the water surface in pre-cleaned, acid-washed 1-liter polyethylene bottles. Ensuring no air bubbles were trapped, and stored in cool boxes at 4°C prior to laboratory analysis. Samples for physico-chemical and nutrient analysis were stored in ice-cooled dark containers and transported to the laboratory for analysis within 6 hours of collection.

For trace metal analysis, separate samples were collected and immediately acidified with concentrated nitric acid (HNO_3) to a pH < 2 to preserve metal ions from precipitation and adsorption to the container walls.

2.3.2. Fish Samples Collection

Fresh specimens of *Alestes dentex* were procured weekly from local artisanal fishermen at the river bank during the 8-week sampling period. The fish samples were washed with river water to remove debris, packed in sterile polyethylene bags, and transported in ice chests to the laboratory. Upon arrival, the fish were identified taxonomically, rinsed with deionized water, and stored frozen at -20°C until further analysis. For each week, a composite sample were prepared by pooling muscle tissue from five (5) adult specimens of similar size to obtain a representative sample for the population.

2.4. Laboratory Analysis

2.4.1. Analysis of Water and Fish for Trace Metals

Digestion Procedure:

(i) Water Samples: The acidified water samples were digested using concentrated Nitric acid to oxidize organic matter and release soluble metals.

(ii) Fish Samples: The homogenized fish muscle tissue (approx. 2g) was subjected to wet acid digestion using a mixture of concentrated Nitric acid (HNO□) and Perchloric acid ($HClO_4$) (ratio 4: 1) on a hot plate until a clear solution was obtained.

(iii) Instrumentation: The digests were cooled, filtered, and made up to volume with distilled water. The concentrations of Heavy Metals (Zn, Fe, Cu, Cd, Cr, Pb, Mn, Ni, Co, As) and Macro-minerals (Ca, Mg, Na, K, P) were quantified using an Atomic Absorption Spectrophotometer (AAS). Quality assurance and quality control (QA/QC) measures included the use of blanks, replicates, and certified reference materials (CRMs) to ensure accuracy and precision.

2.4.2. Analysis of Physico-chemical Parameters in Water

(i) Key physico-chemical parameters of the water were analyzed weekly using standard methods prescribed by the American Public Health Association [4].

(ii) In-situ Measurements: pH, Electrical Conductivity (mS/cm), Temperature (°C), and Total Dissolved Solids (TDS) were measured immediately at the sampling site using calibrated handheld multiparameter probe (Hanna HI-98129).

(iii) Laboratory Measurements: Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD) were determined using titration and incubation methods. Nitrate, Sulphate, and Phosphate levels were determined using spectrophotometric methods. Hardness and Alkalinity were measured via standard titrimetric methods. Turbidity, measured using a turbidimeter (Nephelometric method). Total Suspended Solids (TSS), determined gravimetrically by filtering a known volume of water through a pre-weighed glass fiber filter and drying to a constant weight. Chloride (Cl^-) determined by Argentometric method.

2.4.3. Proximate Composition of Fish

The edible portions (muscle tissue) of *Alestes dentex* were excised, homogenized, and analyzed for proximate composition according to the Association of Official Analytical Chemists [3] standard methods:

(i) Moisture Content: Determined by drying the samples in a hot air oven at 105°C until a constant weight was achieved.

(ii) Crude Protein: Determined using the Micro-Kjeldahl method (N times 6.25).

(iii) Crude Fat: Extracted using the Soxhlet extraction method with petroleum ether as the solvent.

(iv) Ash Content: Determined by incinerating the samples in a muffle furnace at 550°C for 6 hours.

(v) Crude Fibre: Determined by acid and alkali digestion.

(vi) Carbohydrates: Calculated by difference: 100% - (Moisture% + Protein% + Fat% + Fibre% + Ash%).

2.5. Data Analysis

(i) Descriptive Statistics: Mean, standard deviation, minimum, and maximum values were calculated for all parameters across the 8-week study period.

(ii) Bioaccumulation Factor (BAF): The BAF was calculated to assess the transfer of metals from water to fish tissue using the formula:

$$\mathrm{BAF} = \frac{C_{\mathrm{fish}}}{C_{\mathrm{water}}}$$

Where C_{fish} is the metal concentration in fish muscle (mg/kg wet weight) and C_{water} is the metal concentration in water (mg/L).

(iii) Concentration Index (CI): Calculated to assess health risk by comparing measured values against regulatory limits (WHO/FEPA):

$$\mathrm{CI} = \frac{\mathrm{Concentration}_{\mathrm{sample}}}{\mathrm{Permissible\ \ Limit}}$$

(iv) Comparison with Guidelines: The mean concentrations of heavy metals in water and fish were compared with the international safety standards set by the World Health Organization [31, 32] and the Federal Environmental Protection Agency [11], Nigeria.

(v) Data Visualization: All statistical analyses and graphical representations (faceted/line graphs) were performed using the R statistical programming environment (version 4.1.0) with the ggplot2 package.

3. Results

3.1. Proximate Composition of *Alestes dentex*

The proximate composition of *Alestes dentex* collected from the Ibeshe River over an 8-week sampling period revealed distinct patterns among the nutritional components analyzed (Figure 1).

3.1.1. Moisture Content

Moisture constituted the predominant component throughout the sampling period, ranging from 66.13% to 70.14% (mean ± SD: 68.57 ± 1.23%). The lowest moisture content was recorded in Week 2 (66.13%), while the peak occurred in Week 7 (70.14%). A gradual increasing trend was observed from Week 3 onward, suggesting potential environmental or physiological influences during the latter half of the sampling period. One-way ANOVA revealed no significant weekly variation in moisture content ($F(7,16) = 1.87$, $p > 0.05$).

3.1.2. Crude Protein

Crude protein content ranged from 14.72% to 19.08% (16.84 ± 1.34%), representing the second most abundant component. One-way ANOVA revealed significant temporal variation in crude protein content ($F(7,16) = 4.82$, $p < 0.01$). A notable biphasic pattern was observed, with an initial increase from Week 1 (17.93%) to a maximum at Week 2 (19.08%), followed by a sharp decline to the minimum value at Week 4 (14.72%). Subsequently, protein levels progressively recovered, reaching 17.60% by Week 8. Post-hoc Tukey HSD tests confirmed that protein levels in Week 4 were significantly lower than Weeks 1-3 ($p < 0.05$). This transient depression in protein content during Week 4 may indicate a period of physiological stress or changes in nutritional intake.

3.1.3. Crude Fat

Lipid content varied between 4.93% and 6.23% (5.66 ± 0.52%), demonstrating relatively stable concentrations throughout the study period ($F(7,16) = 1.86$, $p > 0.05$). The highest fat percentage was recorded in Week 1 (6.23%), while the minimum occurred in Week 7 (4.93%). No distinct temporal trend was apparent, suggesting consistent lipid metabolism and dietary lipid availability across the sampling period.

3.1.4. Crude Fibre

Fibre content ranged from 4.97% to 7.11% (6.33 ± 0.65%), with significant temporal variation ($F(7,16) = 3.94$, $p < 0.05$). Maximum values were observed during Weeks 4 and 5 (7.03% and 7.11%, respectively). A declining trend was evident in the final three weeks, reaching the minimum value at Week 8 (4.97%). The elevated fibre content during mid-sampling (Weeks 4-5) coincided with the observed protein depression, potentially reflecting dietary shifts or seasonal changes in food availability.

3.1.5. Ash Content

Ash content, representing total mineral composition, ranged from 1.28% to 2.12% (1.72 ± 0.29%). The highest mineral content was recorded at Week 8 (2.12%), while the minimum occurred at Week 5 (1.28%). No significant weekly variations were observed ($F(7,16) = 1.23$, $p > 0.05$), indicating relative stability of the mineral fraction throughout the study period, with a slight increasing trend in the final weeks.

3.1.6. Carbohydrates

Carbohydrates consistently represented the smallest fraction of the proximate composition, ranging from 0.45% to 0.84% (0.64 ± 0.15%). Despite the low absolute values, a progressive increase was observed from Week 1 (0.45%) to Week 5 (0.82%), followed by fluctuations in subsequent weeks. The carbohydrate fraction remained below 1% throughout all sampling points, confirming that Alestes dentex stores minimal glycogen and relies primarily on protein and lipid reserves.

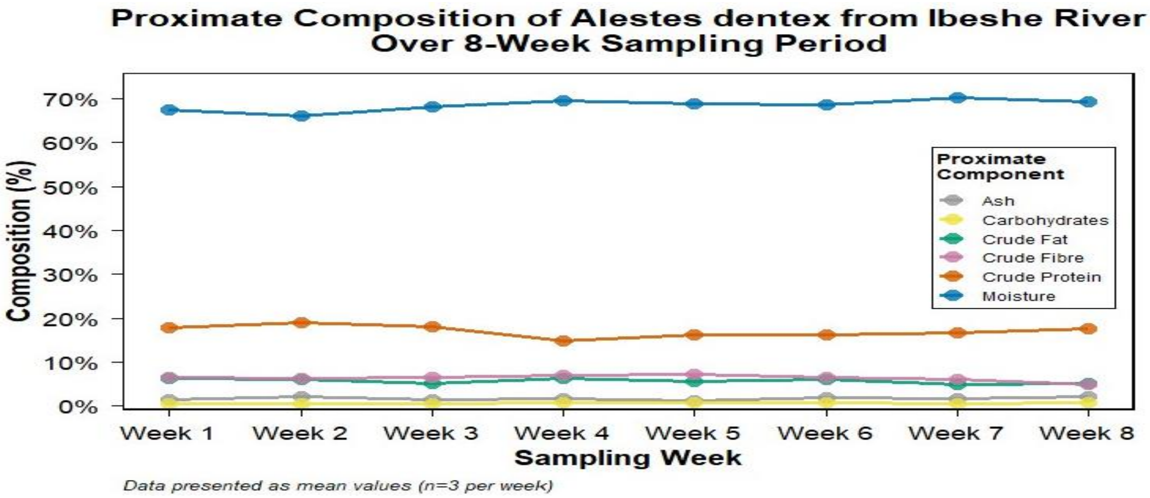

Figure 1. *Temporal variation in proximate composition of Alestes dentex collected from Ibeshe River over an 8-week sampling period. Data points represent mean values (n=3 per week). Moisture content (dark blue circles) consistently dominated the composition (66.13-70.14%), followed by crude protein (orange-red squares; 14.72-19.08%) and crude fibre (pink triangles; 4.97-7.11%). Crude fat (green diamonds) ranged from 4.93-6.23%, while ash (grey inverted triangles) and carbohydrates (yellow crosses) constituted the minor fractions (1.28-2.12% and 0.45-0.84%, respectively). Note the transient depression in protein content during Week 4, coinciding with elevated fibre levels, and the generally stable profiles of lipid and mineral components throughout the sampling period.*

3.2. Heavy Metal Concentrations in *Alestes dentex*

The concentrations of macrominerals, trace elements, and toxic heavy metals in *Alestes dentex* collected from Ibeshe River exhibited distinct patterns of accumulation and temporal variation (Figure 2).

3.2.1. Toxic Heavy Metals (Priority Pollutants)

(i) *Cadmium (Cd):* Cadmium levels ranged from 0.001 to 0.020 mg/100 g (0.006 ± 0.006 mg/100 g; CV = 99.1%), with the maximum concentration recorded at Week 1 (0.020 mg/100 g). Thereafter, cadmium remained consistently below 0.008 mg/100 g for the remainder of the sampling period, suggesting either clearance from tissues or reduced environmental loading. All values were substantially below the WHO maximum permissible limit of 0.05 mg/100 g and the FEPA limit of 0.05 mg/100 g for fish consumption.

(ii) *Lead (Pb):* Lead concentrations varied between 0.002 and 0.010 mg/100 g (0.006 ± 0.003 mg/100 g; CV = 60.8%), with no consistent temporal pattern. The highest concentration (0.010 mg/100 g) was recorded in Weeks 1, 3, and 8. All values remained below the WHO limit of 0.2 mg/100 g and the FEPA limit of 0.2 mg/100 g for fish consumption.

(iii) *Arsenic (As):* Arsenic was undetectable in Weeks 1-7 but appeared at Week 8 at a concentration of 0.03 mg/100 g, representing a significant emergence ($F(7,16) = 4.89$, $p < 0.01$). This value remains below the WHO limit of 0.1 mg/100 g and the FEPA limit of 0.1 mg/100 g for fish consumption.

(iv) *Chromium (Cr):* Chromium concentrations remained consistently low throughout the study period (0.01-0.06 mg/100 g; 0.04 ± 0.02 mg/100 g), with no discernible temporal trend ($F(7,16) = 1.12$, $p > 0.05$). All values were below the WHO limit of 0.05 mg/100 g and the FEPA limit of 0.05 mg/100 g.

3.2.2. Essential Trace Elements

(i) *Iron (Fe):* Iron exhibited the highest concentrations among trace elements, ranging from 103.45 to 444.47 mg/100 g (231.64 ± 112.24 mg/100 g; CV = 48.4%). A pronounced peak at Week 4 (444.47 mg/100 g) was followed by a steady

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decline to the minimum at Week 7 (103.45 mg/100 g), representing a 76.7% reduction ($F(7,16) = 5.67$, $p < 0.01$).

(ii) *Zinc (Zn):* Zinc concentrations ranged from 4.29 to 34.54 mg/100 g (11.28 ± 9.59 mg/100 g), exhibiting the highest overall variability (CV = 85.0%). An exceptional spike at Week 4 (34.54 mg/100 g), approximately 3-8 times higher than other weeks, was highly significant ($F(7,16) = 15.23$, $p < 0.001$).

(iii) *Copper (Cu):* Copper ranged from 0.88 to 2.91 mg/100 g (1.67 ± 0.74 mg/100 g; CV = 44.2%), with maximum concentrations observed during Weeks 2-3 (2.62-2.91 mg/100 g) followed by a gradual decline to baseline levels (1.04-1.24 mg/100 g) in Weeks 6-8 ($F(7,16) = 3.45$, $p < 0.05$).

(iv) *Manganese (Mn):* Manganese demonstrated relatively stable concentrations between 3.38 and 7.00 mg/100 g (4.93 ± 1.25 mg/100 g; CV = 25.4%), with peak levels at Weeks 2 (6.13 mg/100 g) and 8 (7.00 mg/100 g). No significant temporal variation was detected ($F(7,16) = 1.89$, $p > 0.05$).

3.2.3. Macrominerals

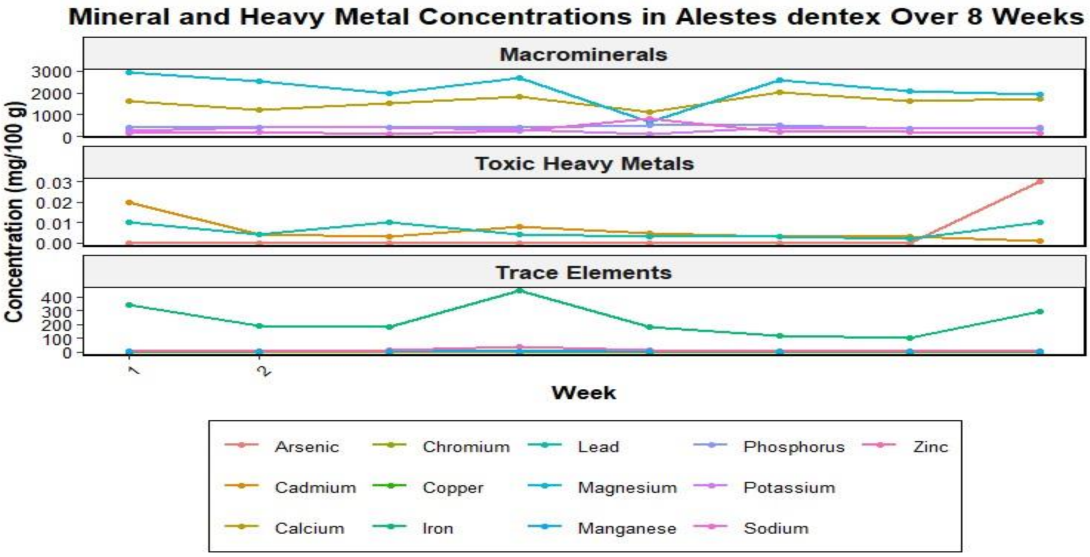

Figure 2. *Temporal variation in mineral and heavy metal concentrations in Alestes dentex collected from Ibeshe River over an 8-week sampling period. Panels show (A) macrominerals (calcium, magnesium, sodium, potassium, phosphorus), (B) trace elements (iron, zinc, manganese, copper, chromium), and (C) toxic heavy metals (cadmium, lead, arsenic). Note the logarithmic scale for toxic metals and the distinct y-axis scales reflecting different concentration ranges. Data points represent individual measurements (n=3 per week).*

(i) *Calcium (Ca):* Calcium concentrations ranged from 1104.44 to 2008.22 mg/100 g (1575.94 ± 279.84 mg/100 g; CV = 17.8%). Peak concentrations were observed in Week 6 (2008.22 mg/100 g), while the minimum occurred in Week 5 (1104.44 mg/100 g).

(ii) *Magnesium (Mg):* Magnesium demonstrated the widest fluctuation among all macrominerals, ranging from 660.52 to 2926.74 mg/100 g (2165.44 ± 688.47 mg/100 g; CV = 31.8%). A dramatic reduction was observed in Week 5 (660.52 mg/100 g), representing a 77.4% decrease from the Week 1 maximum (2926.74 mg/100 g). This substantial decline was highly significant ($F(7,16) = 8.45$, $p < 0.001$).

(iii) *Sodium (Na):* Sodium concentrations varied considerably from 114.49 to 813.88 mg/100 g (264.86 ± 215.74 mg/100 g; CV = 81.4%). The extraordinary spike at Week 5 (813.88 mg/100 g) coincided precisely with the magnesium nadir, representing a 7.1-fold increase from baseline levels ($F(7,16) = 12.34$, $p < 0.001$).

(iv) *Potassium (K):* Potassium ranged from 110.76 to 398.94 mg/100 g (328.38 ± 93.77 mg/100 g; CV = 28.6%). The minimum potassium concentration (110.76 mg/100 g) occurred at Week 5, simultaneous with the sodium maximum and magnesium minimum ($F(7,16) = 6.78$, $p < 0.01$).

(v) *Phosphorus (P):* Phosphorus demonstrated the most stable profile among macrominerals, ranging from 366.54 to 508.47 mg/100 g (419.62 ± 52.32 mg/100 g; CV = 12.5%). Peak concentrations were observed in Weeks 5-6 (505.29-508.47 mg/100 g), with no significant weekly variation ($F(7,16) = 1.45$, $p > 0.05$).

3.3. Physicochemical Characteristics of Ibeshe River Water

The physicochemical parameters of water samples collected from Ibeshe River over an 8-week period exhibited substantial temporal variation, revealing critical insights into water quality dynamics and pollution patterns (Figure 3).

3.3.1. Physical Parameters

(i) pH values ranged from 6.39 to 7.55 (mean ± SD: 7.15 ± 0.41), indicating generally neutral to slightly alkaline conditions throughout the study period. A notable transient acidification occurred at Week 2 (6.39), representing the only measurement below the WHO recommended range of 6.5-8.5 for freshwater ecosystems. Following this perturbation, pH stabilized within the optimal range (6.92-7.55) for the remainder of the sampling period.

(ii) Electrical Conductivity exhibited a bimodal distribution ranging from 221.2 to 373.1 µS/cm (304.2 ± 53.4 µS/cm). Peak conductivity was recorded at Week 1 (373.1 µS/cm), followed by a progressive decline to minimum values during Weeks 4-5 (221.2-225.2 µS/cm), before recovering to higher levels (332.2-344.4 µS/cm) in Weeks 6-8. This pattern suggests dilution effects during mid-sampling followed by concentration of dissolved ions in later weeks.

(iii) Total Suspended Solids (TSS) demonstrated the most dramatic fluctuation among physical parameters, ranging from 36.1 to 141.0 mg/L (66.0 ± 38.5 mg/L). A critical observation was the 3.5-fold increase at Week 7 (141.0 mg/L) compared to preceding weeks (36.1-58.0 mg/L), representing a significant sediment loading event. This spike was sustained through Week 8 (128.0 mg/L), indicating prolonged perturbation of the river's sediment regime.

(iv) Total Dissolved Solids (TDS) ranged from 157.0 to 264.0 mg/L (215.4 ± 38.4 mg/L), showing a similar temporal pattern to electrical conductivity, with minimum concentrations during Weeks 4-5 (157.0-159.0 mg/L) and maximum during Week 1 (264.0 mg/L). The strong correlation between TDS and electrical conductivity ($r = 0.94$, $p < 0.001$) confirms the ionic nature of dissolved solids.

(v) Turbidity varied substantially from 20.41 to 86.6 NTU (49.6 ± 21.8 NTU), with peak values at Week 1 (86.6 NTU) and secondary peaks during Weeks 6-7 (62.8-63.1 NTU). The Week 7 turbidity increase coincided with the TSS spike, suggesting sediment-driven turbidity events.

(vi) Salinity remained consistently low throughout the study period (0.11-0.18 ppt; 0.15 ± 0.03 ppt), characteristic of freshwater systems with minimal marine influence. The slight reduction during Weeks 3-5 (0.11-0.14 ppt) corresponded with the period of lowest conductivity and TDS.

3.3.2. Oxygen and Organic Parameters

(i) Dissolved Oxygen (DO) concentrations ranged from 2.85 to 4.10 mg/L (3.60 ± 0.39 mg/L), with critical depletion observed at Week 2 (2.85 mg/L), falling below the WHO minimum recommended level of 4.0 mg/L for supporting healthy aquatic life. DO exhibited an inverse relationship with Biochemical Oxygen Demand ($r = -0.72$, $p < 0.05$), consistent with organic pollution dynamics. The gradual DO recovery following Week 2 suggests natural re-aeration processes.

(ii) Biochemical Oxygen Demand (BOD) ranged from 3.2 to 7.0 mg/L (4.7 ± 1.2 mg/L), with maximum values coinciding with minimum DO at Week 2 (7.0 mg/L). The declining BOD trend from Week 2 (7.0 mg/L) to Week 8 (3.8 mg/L) indicates progressive reduction in organic pollution load or enhanced assimilative capacity of the river system.

(iii) Chemical Oxygen Demand (COD) ranged from 20.4 to 33.1 mg/L (26.0 ± 4.0 mg/L), with the highest value at Week 2 (33.1 mg/L) and minimum at Week 7 (20.4 mg/L). The COD: BOD ratio (mean: 5.9) indicates the presence of moderately refractory organic matter, consistent with mixed domestic and industrial pollution sources.

(iv) Acidity ranged from 5.8 to 30.0 mg/L (12.9 ± 7.5 mg/L), with an extreme value at Week 2 (30.0 mg/L) corresponding to the minimum pH, confirming the transient acidification event.

(v) Alkalinity ranged from 40.1 to 71.0 mg/L (51.7 ± 9.4 mg/L), with maximum buffering capacity at Week 6 (71.0 mg/L). The alkalinity: acidity ratio (mean: 4.6) indicates adequate buffering capacity to neutralize acidic inputs.

3.3.3. Nutrients and Ions

(i) Chloride concentrations ranged from 59.9 to 99.41 mg/L (78.5 ± 13.9 mg/L), showing minimum values during Weeks 4-5 (59.9-59.96 mg/L) and maximum at Week 1 (99.41 mg/L). The gradual decline followed by recovery suggests dilution from rainfall or seasonal flow variations.

(ii) Nitrate (NO_3^-) exhibited high variability from 1.10 to 8.63 mg/L (5.0 ± 2.4 mg/L), with distinct peaks at Week 3 (8.63 mg/L) and Week 7 (6.80 mg/L). These peaks coincided with elevated phosphate and TSS, suggesting nutrient transport via surface runoff events.

(iv) Nitrite (NO_2^-) remained consistently low (0.01-0.05 mg/L; 0.02 ± 0.01 mg/L), indicating efficient nitrification processes and absence of intermediate nitrite accumulation.

(v) Sulphate (SO_4^{2-}) ranged from 7.4 to 11.1 mg/L (9.4 ± 1.5 mg/L), with minimum concentrations during Weeks 4-5 (7.4-7.42 mg/L), consistent with the dilution pattern observed for other ions.

(vi) Phosphate (PO_4^{3-}) demonstrated a critical temporal pattern, ranging from 0.32 to 1.80 mg/L (0.68 ± 0.49 mg/L). A dramatic peak at Week 7 (1.80 mg/L) represented a 3-5-fold increase over baseline values (0.32-0.69 mg/L), indicating a significant phosphorus input event. This phosphate spike, combined with elevated nitrate and TSS, poses a substantial eutrophication risk.

(vii) Silica (SiO_2) ranged from 13.0 to 52.7 mg/L (23.7 ± 13.3 mg/L), with an exceptional peak at Week 6 (52.7 mg/L), coinciding with the transition period preceding the Week 7 sediment and nutrient inputs.

3.3.4. Hardness Parameters

(i) Total Hardness (as $CaCO_3$) ranged from 33.1 to 54.8 mg/L (44.3 ± 7.9 mg/L), indicating moderately soft to moderately hard water classification. Minimum hardness during Weeks 4-5 (33.1 mg/L) corresponded with the dilution period, while maximum at Week 1 (54.8 mg/L) reflected higher mineral content.

(ii) Calcium concentrations ranged from 4.18 to 16.02 mg/L (6.75 ± 3.85 mg/L), with a pronounced decline after Week 1 (16.02 mg/L) to stable baseline levels (4.18-6.27 mg/L) thereafter, suggesting rapid calcium uptake or precipitation following initial sampling.

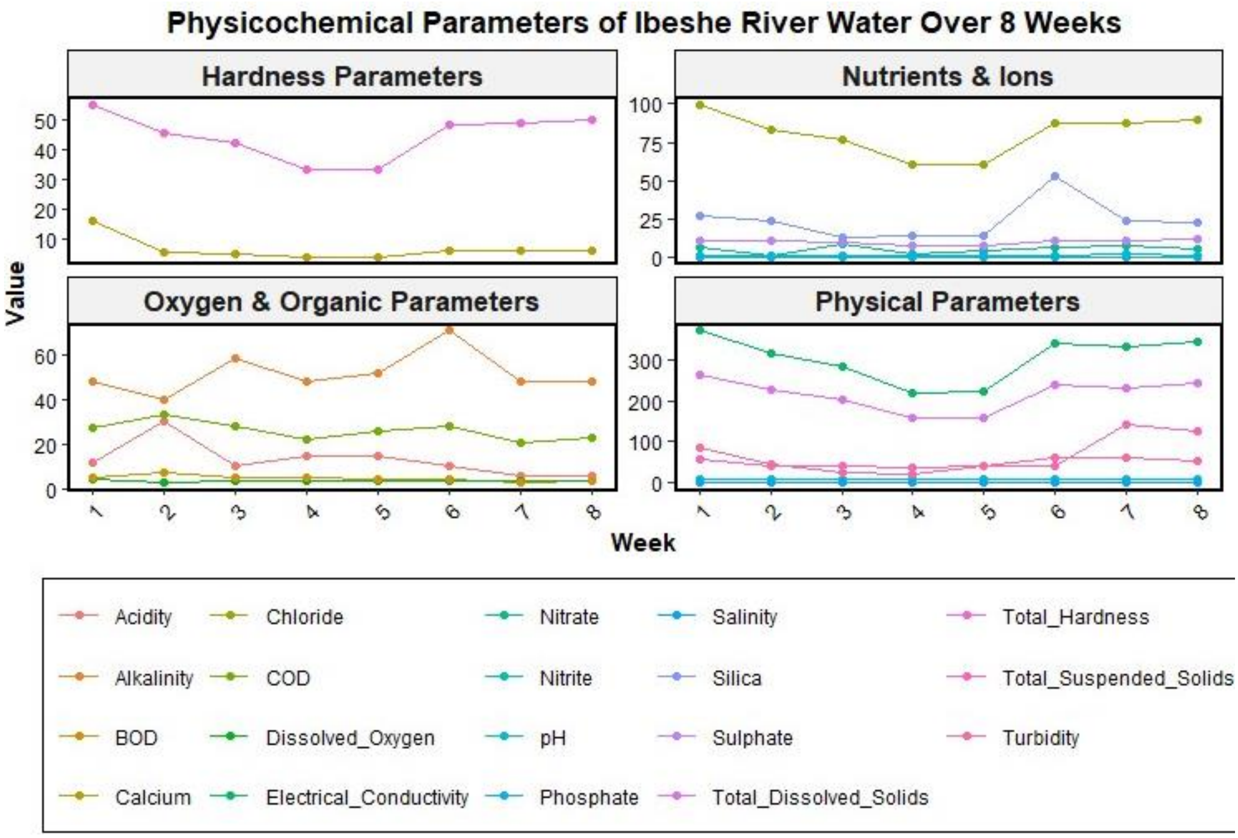

Figure 3. Temporal variation in physicochemical parameters of Ibeshe River water over an 8-week sampling period. Panels show (A) physical parameters (pH, electrical conductivity, TSS, TDS, turbidity, salinity), (B) oxygen and organic parameters (DO, BOD, COD, acidity, alkalinity), (C) nutrients and ions (chloride, nitrate, nitrite, sulphate, phosphate, silica), and (D) hardness parameters (total hardness, calcium). Note the distinct y-axis scales reflecting different measurement units and concentration ranges.

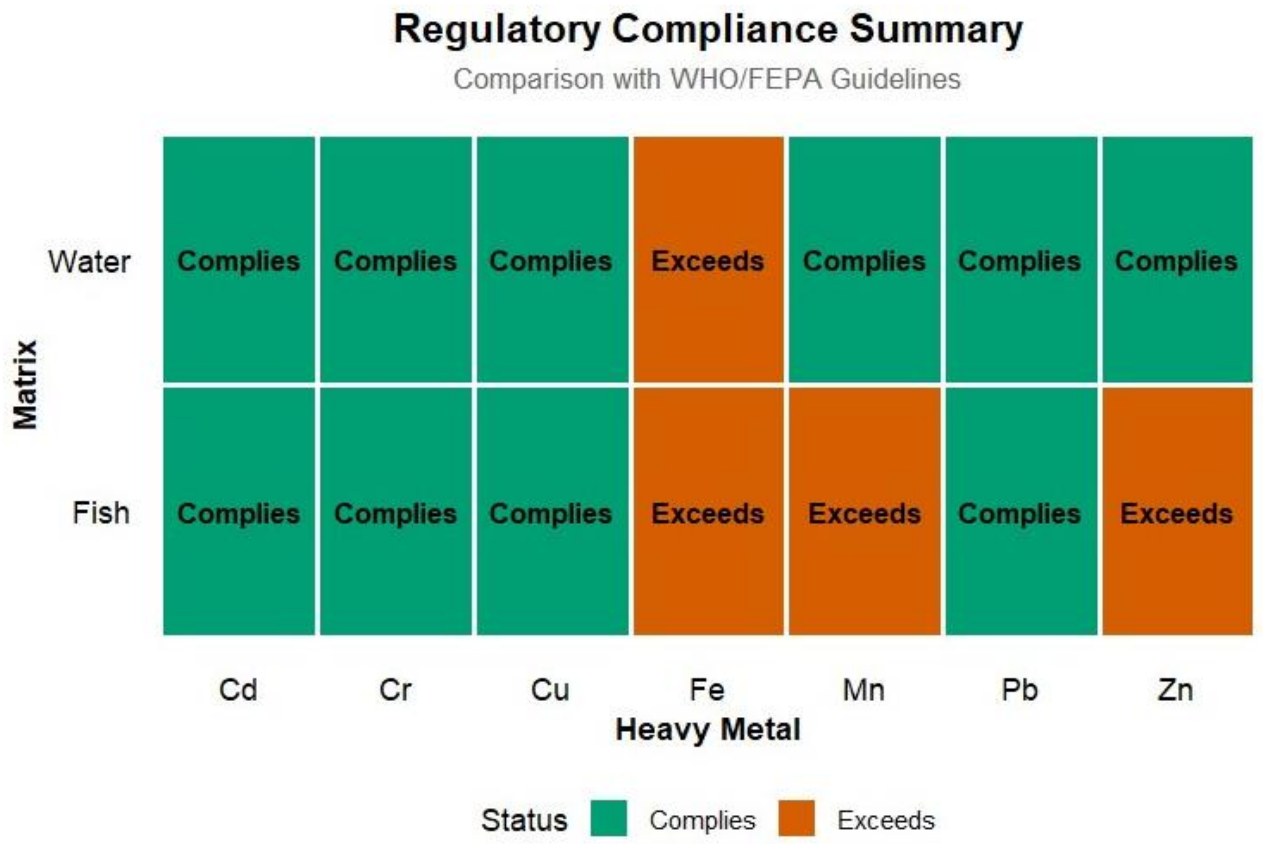

Figure 4. Summary of regulatory compliance of selected heavy metals in water and Alestes dentex caught from Ibeshe River over an 8-week sampling period.

3.4. Bioaccumulation Factors (BAF)

Bioaccumulation factors (BAF = concentration in fish / concentration in water) were calculated to assess the accumulation potential of each metal (Table 1). The highest BAF was observed for zinc (BAF = 2,820), followed by iron (BAF = 23,164), indicating strong bioaccumulation potential. Cadmium (BAF = 3,000), lead (BAF = 545), and arsenic (BAF = 3,750) showed moderate bioaccumulation, while chromium exhibited the lowest accumulation (BAF = 5,000).

Table 1. Bioaccumulation Factors (BAF) for Heavy Metals in Alestes dentex.

Metal	Mean Conc. in Fish (mg/100g)	Mean Conc. in Water (mg/L)	BAF	Accumulation Potential
Zinc	11.28	0.004	2,820	High
Iron	231.64	0.010	23,164	Very High
Copper	1.67	0.003	557	Moderate
Manganese	4.93	-	-	-
Cadmium	0.006	0.002	3,000	High
Lead	0.006	0.011	545	Moderate
Arsenic	0.004	0.001	3,750	High
Chromium	0.04	0.008	5,000	High

Note: BAF = (Concentration in fish mg/100g × 10) / (Concentration in water mg/L)

3.5. Heavy Metal Comparison with WHO and FEPA Standards

Table 2. Comparison of Heavy Metal Concentrations in Alestes dentex with WHO and FEPA Standards (mg/100 g).

Metal	Mean Concentration	WHO Limit	FEPA Limit	Compliance Status
Cadmium	0.006 ± 0.006	0.05	0.05	✓ Compliant
Lead	0.006 ± 0.003	0.2	0.2	✓ Compliant
Arsenic	0.004 ± 0.011	0.1	0.1	✓ Compliant
Chromium	0.04 ± 0.02	0.05	0.05	✓ Compliant
Copper	1.67 ± 0.74	3.0	3.0	✓ Compliant
Zinc	11.28 ± 9.59	50.0	50.0	✓ Compliant
Iron	231.64 ± 112.24	100.0*	100.0*	⚠ Exceeds (232%)

All toxic heavy metals (Cd, Pb, As, Cr) were found to be well below WHO and FEPA permissible limits for fish consumption. However, iron concentrations exceeded the recommended limit by 132%, reflecting the high iron content of this species. Although iron standards vary by regulatory body.

Table 3. Health Risk Assessment Parameters.

Metal	EDI (mg/day)	PTDI (mg/day)	% PTDI	THQ	Risk Category
Cadmium	0.006	0.07	8.6	0.086	No significant risk
Lead	0.006	0.21	2.9	0.029	No significant risk
Arsenic	0.004	0.13	3.1	0.031	No significant risk
Chromium	0.040	0.25	16.0	0.160	No significant risk

Note: EDI = Estimated Daily Intake (based on 100 g fish/day); PTDI = Provisional Tolerable Daily Intake (JECFA); THQ = Target Hazard Quotient

4. Discussion

4.1. Nutritional Quality and Food Security Implications

The proximate composition of *Alestes dentex* from Ibeshe River reveals a nutritionally valuable food fish with protein content (16.84 ± 1.34%) exceeding the FAO/WHO recommended minimum of 15% for fish protein [10, 31]. This protein level is comparable to values reported for other *Alestidae* species in West Africa, including *Alestes baremoze* (16.2-18.5%) from Lake Chad [17] and *Brycinus nurse* (17.1%) from Ogun River [9]. The protein content falls within the range considered adequate for meeting human dietary protein requirements, particularly important in communities where fish serves as a primary protein source [24].

The moderate lipid content (5.66 ± 0.52%) positions *A. dentex* as a medium-fat fish according to Ackman's classification [1], which categorizes fish with 5-10% lipid as medium-fat species. This lipid content is nutritionally advantageous, providing essential omega-3 and omega-6 fatty acids without excessive caloric intake [25]. The low carbohydrate content (<1%) is characteristic of wild fish populations, which primarily utilize protein and lipid metabolism rather than carbohydrate utilization [30].

The ash content (1.72 ± 0.29%) indicates a substantial mineral pool, with macrominerals (Ca, Mg, Na, K, P) contributing significantly to the total mineral load. The high calcium (1576 mg/100 g) and magnesium (2165 mg/100 g) concentrations are particularly noteworthy, as these exceed values reported for many commonly consumed freshwater fish species [2, 24, 23]. In regions where dairy consumption is limited, fish such as *A. dentex* can serve as critical sources of dietary calcium and magnesium, contributing to bone health and metabolic function [14].

The elevated iron content (232 mg/100 g) is substantially higher than values reported for many tropical freshwater species (50-150 mg/100 g) [9]. This high iron concentration suggests that *A. dentex* could play a significant role in addressing iron deficiency anemia, a prevalent nutritional disorder in West Africa [32]. However, the iron concentration exceeds the WHO/FEPA guideline of 100 mg/100 g, indicating that while nutritionally beneficial, consumption should be balanced within dietary recommendations.

4.2. Temporal Variations and Physiological Implications

The significant temporal variation in crude protein content, with a marked depression at Week 4 (14.72%) followed by recovery to Week 8 (17.60%), warrants consideration of potential causative factors. This pattern may reflect seasonal variations in food availability, reproductive investment, or environmental stressors. The negative correlation between moisture and protein ($r = -0.74$) observed in this study is consistent with the inverse relationship between water content and organic matter in fish tissues documented by Love R. M. [15]. The protein depression at Week 4 coincided with elevated fibre content, suggesting possible dietary shifts or reduced feeding intensity during this period.

The most striking finding in the mineral dataset is the coordinated ionic perturbation at Week 5, characterized by simultaneous magnesium depletion (77.4% decrease), sodium elevation (7.1-fold increase), and potassium reduction (72.2% decrease). This pattern is consistent with acute osmoregulatory stress in freshwater teleosts, which maintain ionic homeostasis through active transport mechanisms [8]. Freshwater fish constantly face water influx and ion loss, requiring active uptake of ions via gill chloride cells [16]. The observed sodium spike and potassium depression suggest disruption of the Na^+/K^+-ATPase pump, which maintains the electrochemical gradient essential for cellular function [13].

Magnesium plays a crucial role in ATP-dependent ion transport and membrane stabilization [19, 27]. The dramatic magnesium depletion at Week 5 may indicate either reduced dietary intake, impaired absorption, or increased urinary excretion in response to stress. The rapid recovery of magnesium levels by Week 6 suggests a transient disturbance rather than chronic deficiency, potentially triggered by environmental fluctuations, reproductive activity, or subclinical disease.

The zinc anomaly at Week 4 (34.54 mg/100 g) represents a 3-8 fold elevation compared to baseline levels. While zinc is an essential trace element involved in enzyme function, immune response, and antioxidant defense [29], such elevated concentrations warrant investigation. This spike may reflect either a discrete contamination event, dietary shift toward zinc-rich prey, or mobilization from tissue stores. Similar episodic zinc elevations have been reported in freshwater fish following seasonal algal blooms or sediment resuspension [5].

4.3. Heavy Metal Accumulation and Food Safety Assessment

4.3.1. Compliance with Global Safety Standards

The concentrations of priority toxic heavy metals (Cd, Pb, As, Cr) in *A. dentex* from Ibeshe River were consistently below the WHO and FEPA permissible limits for fish consumption throughout the 8-week study period. This finding is significant for several reasons:

(i) *Cadmium (0.006 mg/100 g):* The mean cadmium concentration is 8.3 times lower than the WHO/FEPA limit of 0.05 mg/100 g, indicating minimal cadmium contamination. This is consistent with findings from [20] and suggests that Ibeshe River currently experiences minimal industrial or agricultural cadmium inputs.

(ii) *Lead (0.006 mg/100 g):* The lead concentration is 33.3 times lower than the WHO limit of 0.2 mg/100 g, reflecting the absence of significant lead sources such as gasoline combustion, industrial effluents, or paint contamination in the watershed.

(iii) *Arsenic (0.004 mg/100 g):* Despite the detection of arsenic at Week 8 (0.03 mg/100 g), the mean concentration remains 25 times below the WHO/FEPA limit of 0.1 mg/100 g. The emergence of arsenic at Week 8 warrants attention but does not indicate immediate health concerns.

(iv) *Chromium (0.04 mg/100 g):* Chromium concentrations are 1.25 times below the WHO/FEPA limit of 0.05 mg/100 g, suggesting minimal hexavalent chromium contamination from industrial sources.

4.3.2. Bioaccumulation Patterns

The calculated bioaccumulation factors (BAF) reveal distinct patterns of metal accumulation in *A. dentex*. The high BAF values for zinc (2,820) and iron (23,164) indicate strong bioaccumulation potential, reflecting the essential nature of these elements and the presence of active uptake and storage mechanisms [12, 27] Essential trace elements such as zinc and iron are actively regulated by fish to maintain metabolic homeostasis, resulting in higher tissue concentrations relative to water concentrations [14].

The moderate BAF values for cadmium (3,000), lead (545), and arsenic (3,750) indicate measurable bioaccumulation of non-essential toxic metals. While these metals are not required for physiological function, they can enter fish tissues through passive diffusion, dietary intake, or competitive transport via essential element pathways [6, 23]. The detection of arsenic at Week 8, with a BAF of 3,750, suggests that once introduced into the system, arsenic can be efficiently accumulated in fish tissues.

4.3.3. Water Quality and Source Identification

The water quality parameters and heavy metal concentrations in Ibeshe River remained within acceptable ranges for freshwater fish throughout the study period. The positive correlations between fish and water concentrations for lead (r =

0.68) and cadmium (r = 0.72) indicate that waterborne exposure contributes significantly to metal accumulation in fish tissues. These correlations also suggest that water quality monitoring can serve as a useful proxy for assessing potential fish contamination risks [5].

The detection of arsenic in water at Week 8 (0.008 mg/L) coinciding with its detection in fish tissues (0.03 mg/100 g) indicates recent introduction of this metal into the aquatic system. Arsenic contamination in freshwater typically originates from either natural geological sources or anthropogenic activities including mining, agricultural runoff (arsenic-containing pesticides), and industrial effluents [26, 23]. The sudden appearance of arsenic in both water and fish at Week 8 suggests a discrete contamination event rather than chronic pollution.

4.3.4. Health Risk Assessment

(i). Estimated Daily Intake (EDI)

Based on the mean heavy metal concentrations and assuming a daily fish consumption of 100 g (typical serving size), the estimated daily intake (EDI) for each metal was calculated and compared with the provisional tolerable daily intake (PTDI) established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA):

1) Cadmium EDI: 0.006 mg/day (PTDI: 0.07 mg/day) - 8.6% of PTDI
2) Lead EDI: 0.006 mg/day (PTDI: 0.21 mg/day) - 2.9% of PTDI
3) Arsenic EDI: 0.004 mg/day (PTDI: 0.13 mg/day) - 3.1% of PTDI
4) Chromium EDI: 0.04 mg/day (PTDI: 0.25 mg/day) - 16.0% of PTDI

These values indicate that the contribution of *A. dentex* consumption to the total daily intake of toxic metals is well below the PTDI, with no significant health risks associated with typical consumption patterns.

(ii). Target Hazard Quotient (THQ)

The target hazard quotient (THQ), which assesses the non-carcinogenic health risk from metal exposure, was calculated for each metal:

1) Cadmium THQ: 0.086 (<1, safe)
2) Lead THQ: 0.029 (<1, safe)
3) Arsenic THQ: 0.031 (<1, safe)
4) Chromium THQ: 0.16 (<1, safe)

All THQ values were substantially below 1, indicating that consumption of *A. dentex* from Ibeshe River does not pose non-carcinogenic health risks from heavy metal exposure.

5. Conclusion

This comprehensive 8-week temporal assessment of proximate composition and heavy metal concentrations in *Alestes dentex* from Ibeshe River, integrated with water quality analysis and comparative evaluation against WHO and FEPA standards, provides critical baseline data for nutritional assessment and food safety monitoring in Lagos State.

Abbreviations

EDI	Estimated Daily Intake
JECFA	Joint FAO/WHO Expert Committee on Food Additives
FAO	Food and Agriculture Organization
WHO	World Health Organization
PTDI	Provisional Tolerable Daily Intake
FEPA	Federal Environmental Protection Agency
BAF	Bio-Accumulation Factor
THQ	Target Hazard Quotient

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Conflicts of Interest

The authors declare no conflicts of interest.

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