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Preliminary Ecological Risk Assessment of Toxic Elements in Fish Cage Culture Sites within the Interconnected Epe and Badagry Lagoons, Nigeria

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ABSTRACT

The interconnected Epe and Badagry Lagoons in Nigeria are vital ecosystems supporting fish cage culture, but they may be at risk of toxic element contamination, posing threats to aquatic life and human health. This study conducted a preliminary ecological risk evaluation, focusing on arsenic, boron, selenium, silicon, and sulfur concentrations in water, sediment, and *Heteroclarias* tissues using standard analytical methods. Contamination levels and ecological risks were assessed using contamination factor (CF), enrichment factor (EF), bioaccumulation factor (BAF), and the index of geo-accumulation (Igeo). Sediment consistently showed the highest concentrations of all analyzed elements, with arsenic levels in Badagry Lagoon (0.4426 ± 0.0731 mg kg^{-1}) exceeding those in water and fish tissues, and a sediment-dominant pattern was observed for boron, selenium, silicon, and sulfur. Arsenic bioaccumulation factors in *Heteroclarias* from Epe Lagoon were significantly high (62.29 ± 0.36 for water and 1.26 ± 0.73 for sediment), while EF values for arsenic were highest in Badagry Lagoon (29.80), and selenium showed the highest EF in Epe Lagoon (224.64). Despite negative Igeo values indicating no significant sediment contamination, elevated arsenic concentrations and bioaccumulation in fish tissues raise potential health concerns for aquatic life and human consumers, emphasizing the need for regular monitoring and management strategies to mitigate toxic element contamination in the Lagos Lagoon system.

INTRODUCTION

Aquaculture has emerged as the fastest-growing and most diverse sector in global food production, with its worldwide output increasing over threefold from 34 million tons in 1997 to 112 million tons in 2017 (Naylor et al., 2021). Aquaculture accounts for approximately half of the global fish supply and is recognized as the fastest-growing segment in the food industry. Kaleem & Sabi (2021) highlight its significance as an essential agricultural practice capable of significantly addressing global nutritional deficiencies and effectively alleviating poverty. Consequently, it is positioned as a key solution, as it offers a sustainable and controlled way to produce seafood without putting further pressure on wild fish stocks.

The growing request for fish and its products has driven expansion of aquaculture practices, with cage culture systems being widely embraced for their high efficiency and productivity (Orinda et al., 2021). However, these activities often take place in natural water bodies, such as lagoons and rivers, where anthropogenic inputs, including industrial discharges, agricultural runoff, and urban waste, may introduce toxic elements into the aquatic environment. Despite its significance, aquatic environment is subject to varying degrees of environmental pressure from surrounding human activities, raising concerns about contamination and ecological risks.

Toxic elements, including arsenic, boron, selenium, silicon, and sulfur, pose significant risks because they persist in the environment, have the potential for bioaccumulation, and negatively impact aquatic ecosystems and human health (Raj & Maiti, 2020). Ecological risk assessments are essential tools for evaluating the potential hazards posed by these contaminants to aquatic ecosystems and the organisms within them. Preliminary studies help identify key risks, guide sustainable aquaculture practices, and inform regulatory policies aimed at preserving aquatic ecosystems like Lagoons.

The lagoons in Lagos play a dual role as a critical biodiversity hotspot and a major source of livelihood for communities engaged in fishing and aquaculture (Moruf, 2022). However, the intensification of cage culture activities within the lagoons has coincided with increased anthropogenic pollution. According to Sonone et al. (2020), introduction of toxic elements into the aquatic environment poses significant ecological risks, including bioaccumulation in fish, disruption of food web dynamics, and potential human health hazards by consuming contaminated fish.

Earlier works indicate that different lagoons in Lagos, Nigeria have been contaminated with metals (Taiwo et al., 2019; Mustapha et al., 2021; Lawal-Are et al., 2021; Moruf, 2021). However, there is a paucity of data on the levels and ecological impact of toxic elements in cage culture sites within lagoon system in Nigeria (Ajiboye et al., 2024). This lack of information hinders the development of evidence-based management strategies and threatening region aquaculture sustainability practices. The study aims to conduct a preliminary ecological risk evaluation of toxic element contamination at fish cage culture site in Epe and Badagry Lagoons in Lagos, Nigeria. The study will evaluate selected toxic elements levels in environmental matrices and fish samples and assess their ecological risk levels. The outcomes of this research will promote the understanding of the environmental status of the lagoons in a better way, providing baseline data essential for policymakers, environmental managers, and aquaculture practitioners to implement sustainable practices and pollution control measures.

MATERIAL AND METHODS

Study Area

The Epe Lagoon (6°29′ 6.38″ N and 3° 35′ 40″ E) and Badagry Lagoon (6°25′45″ N and 26°0′43″ E) which are the locations of the study both fall within Lagos State, South Western region of Nigeria as seen in Figure 1. These two lagoons are connected and are part of the estuarine system that spans across the shores of Nigeria with its vast lagoons and creeks. Epe lagoon has an extent of 243 km^2 and an averaged depth of waters of around 1.80 meters (Olopade et al., 2015) to complement the information. The Badagry lagoon is about the same distance from both entrances as we go into the lagoons of Cotonu and Lagos ports. On the southern border side is the Republic of Benin which turns into Niger delta with depth of the watery regions ranging between 1 to 3 m and stretch approximately 60 km in length and 3 km in breadth (Ndimele & Kumolu-Johnson, 2012). These lagoons assist in supporting fishing that is undertaken in Lagos state of the Nigeria and also serve as a transport network for timber logs and even passengers to various regions within the south western Nigeria. In this research each of the locations is around 1.5 km distance from each other.

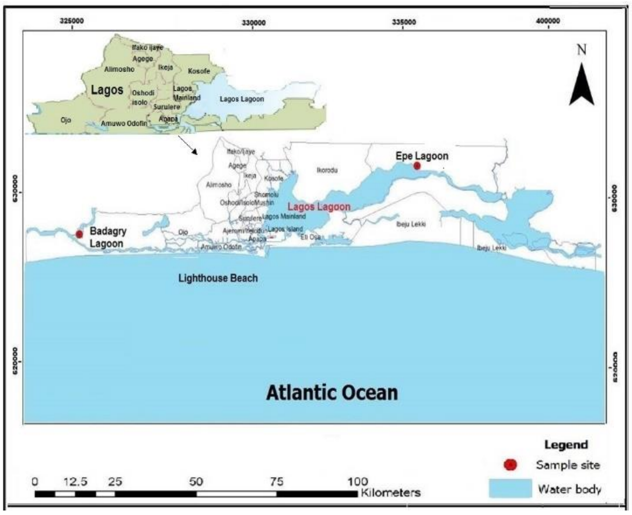

Figure 1. Map of Badagry and Epe Lagoons (adapted from Moruf, 2019)

Collection of Samples

Water, sediment and fish samples (*Heteroclarias*) collected every month from November 2023 to April 2024 which represented dry season. A total of twenty water samples were collected from six fish culture sites/sampling points in both lagoons. During the time of low tides, sediment samples were collected at the depths of 10-15 cm in the dry season. Each of the monthly water samples collected comprised of five 500 L samples collected at a geographical location together with water samples collected using two non-contaminated containers (5 mL) and concentrated hl. Water, sediment and fish were also collected on the sites of the lagoons. All the samples were in good condition, marked and were put in sturdy plastic bottles, then stored at 20°C before being dispatched to the lab for tests.

Sample Preparation

In the laboratory, sediment samples were thawed by allowing them to sit at room temperature for approximately 24 hours. Subsequently, they were dried in an oven set at 40°C, disaggregated, and sieved using a 200 μm mesh sieve, as outlined by Gilli et al. (2018). The sieved material was then homogenized using a porcelain mortar and re-sieved. About 5 g of the homogenized sediment was placed into Teflon tubes, where 5 mL of aqua regia (prepared as a 3:1 mixture of concentrated hydrochloric acid [37%, TraceMetal™, Fisher Scientific, USA] and concentrated nitric acid [69%, TraceMetal™, Fisher Scientific, USA]) was added for digestion in accordance with the ISO 11466 method (Pueyo et al., 2001).

For tissue samples, approximately 1 g was precisely weighed using a scale with a decimal resolution of 0.001 g. These samples were digested with a mixture of 5 mL concentrated nitric acid (65%, TMA, Hiperpure, PanReac, Spain) and 3 mL of 30% hydrogen peroxide (Hiperpure, PanReac, Spain) in a microwave-assisted digestion system (Ethos Plus; Milestone, Sorisole, Italy). The digested solutions were then transferred to polypropylene tubes and diluted to 15 mL with ultrapure water (18.2 MΩ·cm, Milli-Q, Merck, Germany).

Elemental concentrations were quantified using an inductively coupled plasma mass spectrometer (ICP-MS, Thermo Scientific, Germany), following the protocol by Dussubieux & Van Zelst (2004). The ICP-MS settings included a radiofrequency power of 1.3 kW, plasma gas flow rate of 13 L min^{-1}, auxiliary gas flow rate of 0.7 L min^{-1}, nebulizer gas flow rate of 0.87 L min^{-1}, peak jump scan mode, dwell time of 10 ms, and three readings per repetition. Reagent blanks were processed alongside each batch of 10 samples. Stable isotopes such as 72Ge, 103Rh, and 205Tl, at a concentration of 50 μg L^{-1}, were added to both calibration standards and sample solutions as internal standards.

Total mercury content was measured using a cold vapor atomic absorption spectrometer (CVAAS, with Zeeman correction, Lumex RA-915+, Russia). The accuracy of the analysis was assessed with the certified reference material DORM-3 (fish protein certified reference material for trace metals, NRCC, Canada), based on recovery rates of the analyzed elements.

Ecological Risk Assessment

The ecological risk was evaluated by calculating three indices: the contamination factor (CF), the enrichment factor (EF), and the geo-accumulation index (Igeo).

Contamination Factor (CF)

It is based on the method proposed by Hakanson (1980), was determined as the ratio of the concentration of a specific element in surface sediment to its average global concentration in the earth's crust (Eq. 1):

$$CF \frac{C_{pollutant}}{C_{background}} \quad (1)$$

where:

$C_{pollutant}$: Concentration of the pollutant in the environment (sediment).

$C_{background}$: Reference or background concentration of the pollutant.

CF values were categorized as follows:

- Low contamination: CF < 1
- Moderate contamination: 1 ≤ CF < 3
- Considerable contamination: 3 ≤ CF < 6
- High contamination: CF≥6

Enrichment Factor (EF)

It is calculated using the method described by Sinex & Helz (1981), utilized iron (Fe) as the reference element for normalization (Eq. 2):

$$EF = \left(\frac{Cm}{Cref}\right)_{sample} / \left(\frac{Cm}{Cref}\right)_{background} \quad (2)$$

where:

C_m: Concentration of the metal of interest in the sediment sample.

C_{ref}: Concentration of a reference element i.e., Fe.

$\left(\frac{Cm}{Cref}\right)_{sample}$: Ratio of the metal to the reference element in the sample

$\left(\frac{Cm}{Cref}\right)_{background}$: Ratio of the metal to the reference element in a background (uncontaminated) environment, often using pre-industrial levels or a reference site.

Interpretation of EF values:

- EF ≈ 1: Indicates primarily natural origins.
- EF > 1: Suggests anthropogenic influence, classified as:
  - Minor enrichment: 1 ≤ EF < 2
  - Moderate enrichment: 2 ≤ EF < 5
  - Significant enrichment: 5 ≤ EF < 20
  - Very high enrichment: 20 ≤ EF < 40
  - Extremely high enrichment: EF ≥ 40

Geo-accumulation Index (Igeo)

The Geo-accumulation Index, developed by Müller (1969), was employed to assess sediment contamination relative to global shale values (Eq. 3):

$$I_{geo} = \log_2\left(\frac{C_n}{1.5B_n}\right) \quad (3)$$

where C_n: the measured concentration of the element in the sediment;

B_n: the geochemical background value; and the constant 1.5 is introduced to analyze natural variations of the background values in the environment and to detect a minimal human-made impact.

Igeo values were categorized as follows:

- Igeo ≤ 0: Uncontaminated
- 0 < Igeo ≤ 1: Uncontaminated to moderately contaminated
- 1 < Igeo ≤ 2: Moderately contaminated
- 2 < Igeo ≤ 3: Moderately to heavily contaminated
- 3 < Igeo ≤ 4: Heavily contaminated

- 4 < Igeo ≤ 5: Heavily to extremely contaminated
- Igeo > 5: Extremely contaminated

Data Analysis

Statistical analyses were conducted using SPSS software (version 20.0). Differences in element concentrations among water, sediment, and fish samples were evaluated using Duncan's multiple range test. Statistical significance was established at P<0.05.

RESULTS

Toxic Elemental Level in Water, Sediment and Cage-Cultured Fish

Toxic element levels in water, sediment, and *Heteroclarias* harvested from a caged culture system in Epe Lagoon is presented in Table 1. The sediment exhibited the highest concentrations of arsenic (0.3537 ± 0.1318 mg kg⁻¹), which were significantly greater than those found in water (0.0071 ± 0.0026 mg L⁻¹) and *Heteroclarias* (0.2390 ± 0.0902 mg kg⁻¹). Similarly, boron levels were most pronounced in sediment (0.1375 ± 0.0242 mg kg⁻¹), whereas concentrations in water (0.0027 ± 0.0005 mg L⁻¹) and *Heteroclarias* (0.0038 ± 0.0008 mg kg⁻¹) were considerably lower. Selenium was also predominantly concentrated in sediment (0.1540 ± 0.0446 mg kg⁻¹), surpassing the amounts observed in water (0.0031 ± 0.0009 mgL⁻¹) and *Heteroclarias* (0.0015 ± 0.0006 mg kg⁻¹). In the case of silicon, sediment showed markedly elevated levels (22.4595 ± 6.0508 mg kg⁻¹) compared to water (0.4492 ± 0.1210 mg L⁻¹) and *Heteroclarias* (2.0699 ± 0.6158 mg kg⁻¹). Sulfur concentrations, although relatively low across all samples, were still highest in sediment (0.0333 ± 0.0105 mg kg⁻¹), significantly exceeding those in water (0.0007 ± 0.0002 mg L⁻¹) and *Heteroclarias* (0.0006 ± 0.0004 mg kg⁻¹).

Table 2 presents the concentrations of the five toxic elements in water, sediment, and *Heteroclarias* from a caged culture system in Badagry Lagoon. Arsenic concentrations were highest in sediment (0.4426 ± 0.0731 mg kg⁻¹) and comparatively lower in water (0.0089 ± 0.0015 mg L⁻¹) and fish tissues (0.3001 ± 0.0589 mg kg⁻¹). Boron levels followed a pattern similar to arsenic, with the highest concentrations in sediment (0.1830 ± 0.0372 mg kg⁻¹) and lower levels in water (0.0037 ± 0.0007 mg L⁻¹) and fish tissue (0.0047 ± 0.0007 mg kg⁻¹). However, the differences between sediment and other matrices were not significant (P > 0.05). All other elements exhibited highest significant level in sediment.

Table 1. Concentration of toxic elements in water, sediment and farmed fish harvested from caged culture site in Epe Lagoon

Elements	Water (mg L⁻¹)	Sediment (mg kg⁻¹)	*Heteroclarias* (mg kg⁻¹)
Arsenic	0.0071±0.0026ᵃ	0.3537±0.1318ᵇ	0.2390±0.0902ᵃ
	(0.0015-0.0159)	(0.0735-0.7946)	(0.0359-0.5702)
Boron	0.0027±0.0005ᵃ	0.1375±0.0242ᵇ	0.0038±0.0008ᵃ
	(0.0012-0.0043)	(0.0615-0.2145)	(0.0013-0.0065)
Selenium	0.0031±0.0009ᵃ	0.1540±0.0446ᵇ	0.0015±0.0006ᵃ
	(0.0010-0.0070)	(0.0500-0.3486)	(0.0003-0.0042)
Silicon	0.4492±0.1210ᵃ	22.4595±0.0508ᵇ	2.0699±0.6158ᵃ
	(0.0983-0.8065)	(4.9141-40.3237)	(0.2746-4.7177)
Sulfur	0.0007±0.0002ᵃ	0.0333±0.0105ᵇ	0.0006±0.0004ᵃ
	(0.0000-0.0010)	(0.0000-0.0500)	(0.000-0.0018)
WHO (2017) recommended level in water	As (0.01 mg L⁻¹) B (2.4 mg L⁻¹) Si (0.04 mg L⁻¹), Se and S (Not available)		

Note: Mean±Standard Dev.; values with different superscripts across row are significantly different at P < 0.05. Arsenic (As), Boron (B), Selenium (Se), Silicon (Si), Sulfur (S)

Table 2. Concentration of toxic elements in water, sediment and farmed fish harvested from caged culture site in Badagry Lagoon

Elements	Water (mg L^{-1})	Sediment (mg kg^{-1})	*Heteroclarias* (mg kg^{-1})
Arsenic	0.0089±0.0015[a]	0.4426±0.0731[b]	0.3001±0.0589[b]
	(0.0036-0.0139)	(0.1817-0.6935)	(0.0819-0.4977)
Boron	0.0037±0.0007[a]	0.1830±0.0372[ab]	0.0047±0.0007[a]
	(0.0025-0.0073)	(0.1260-0.3638)	(0.0027-0.0075)
Selenium	0.0020±0.0010[a]	0.1007±0.0496[b]	0.0008±0.0003[a]
	(0.0010-0.0070)	(0.0500-0.3486)	(0.0003-0.0021)
Silicon	1.2441±0.5842[a]	62.2032±0.208[b]	4.8635±0.4987[a]
	(0.3623-4.1333)	(18.113-206.667)	(1.0123-11.550)
Sulfur	0.3512±0.3502[a]	17.5587±17.5087[b]	0.0012±0.0004[a]
	(0.0010-2.1020)	(0.0500-105.102)	(0.0000-0.0018)
WHO (2017) recommended level in water	As (0.01 mg L^{-1}) B (2.4 mg L^{-1}) Si (0.04 mg L^{-1}), Se and S (Not available)		

Note: Mean±Standard Dev.; values with different superscripts across row are significantly different at P < 0.05. Arsenic (As), Boron (B), Selenium (Se), Silicon (Si), Sulfur (S)

Table 3. Bio-water accumulation factor (toxic elements) of *Heteroclarias* harvested from caged culture system in Lagos, Nigeria

Elements	Epe Lagoon	Badagry Lagoon	*P-value*
Arsenic	62.29±0.36	33.41±0.42	0.02*
Boron	1.50±0.35	1.35±0.12	0.18
Selenium	0.65±0.28	0.46±0.08	0.06
Silicon	5.37±0.65	5.03±0.24	0.10
Sulfur	0.60±0.38	0.90±0.40	0.50

Note: Mean±Standard Dev.; * significantly different at P < 0.05

Table 4. Bio-sediment accumulation factor (toxic elements) of farmed fish species harvested from caged culture system in Lagos, Nigeria

Elements	Epe Lagoon	Badagry Lagoon	P-value
Arsenic	1.26±0.73	0.67±0.08	0.06
Boron	0.03±0.01	0.03±0.00	0.52
Selenium	0.01±0.01	0.01±0.00	0.56
Silicon	0.11±0.03	0.10±0.02	0.60
Sulfur	0.01±0.01	0.02±0.00	0.50

Note: Mean±Standard Dev.; * significantly different at $P < 0.05$

Table 5. Ecological risk assessment (toxic elements) of caged culture system in Lagos, Nigeria

Elements	Contamination Factor		Enrichment Factor		Index of Geo-accumulation	
	Epe	*Badagry*	*Epe*	*Badagry*	*Epe*	*Badagry*
Arsenic	0.02721	0.03405	23.8123	29.7973	-5.784804	-5.461327
Boron	0.00138	0.00183	1.2034	1.6016	-10.091315	-9.678903
Selenium	0.25667	0.16783	224.6356	146.8884	-2.546995	-3.159861
Silicon	0.00031	0.00085	0.2693	0.7458	-12.251317	-10.781654
Sulfur	0.00001	0.00732	0.0121	6.4031	-16.722115	-7.679667

Bio-Accumulation Factors of Toxic Elements in Caged-Culture Fish

The bio-water accumulation factor (BWAF) and bio-sediment accumulation factor (BSAF) for the five toxic elements in *Heteroclarias* are shown in Tables 3 and 4, respectively. Only the BWAF for arsenic was significantly higher in *Heteroclarias* from Epe Lagoon (62.29 ± 35.79) compared to Badagry Lagoon (33.41 ± 4.24) (P = 0.02). The BSAF for arsenic was higher in Epe Lagoon (1.26 ± 0.73) than in Badagry Lagoon (0.67 ± 0.08), with the difference approaching statistical significance (P = 0.06). The BSAF values for boron, selenium, silicon, and sulfur were consistently low across both lagoons.

Ecological Risk Assessment of Toxic Elements in Sediment from Cage Culture

Table 5 provides the ecological risk indices, including the contamination factor (CF), enrichment factor (EF), and index of geo-accumulation (Igeo), for the five elements. Arsenic had the highest CF values, with 0.03405 in Badagry Lagoon and 0.02721 in Epe Lagoon. Boron, selenium, silicon, and sulfur exhibited much lower CF values (<0.26), indicating minimal contamination. Selenium had the highest EF in both lagoons, particularly in Epe Lagoon (224.64). Arsenic also showed substantial enrichment, with EF values of 23.81 in Epe Lagoon and 29.80 in Badagry Lagoon. Boron, silicon, and sulfur demonstrated much lower EF values (<7). All the elements had negative Igeo values across both lagoons, indicating no significant sediment contamination. Arsenic exhibited the highest Igeo values among the elements (-5.46 in Badagry Lagoon and -5.78 in Epe Lagoon), while sulfur in Epe Lagoon had the lowest Igeo value (-16.72).

DISCUSSION

The findings on the toxic elemental concentration reveal clear distinctions between environmental compartments and the farmed fish. The concentration in sediment is substantially higher than in water and *Heteroclarias*. The significantly elevated levels in sediment (P < 0.05) align with sediment's role as a sink for metals, binding metal through adsorption and precipitation (Usese et al., 2018). While boron, selenium, silicon, and sulfur are essential for the human body in trace amounts, exceeding their recommended limits in water or diet can pose health risks (WHO, 2017). Arsenic is purely toxic and should be strictly monitored. The low elemental concentrations in water imply limited mobility, and hence, minimal risk of immediate bioavailability, except in circumstances where environmental changes might release these metalloids into the water (Hauser-Davis & Wosnick, 2022). Similar trends have been reported by Usese et al. (2020), who observed elevated arsenic accumulation in sediments from contaminated tropical Lagoon in Nigeria. Sediments serve as a reservoir for heavy metals because of their strong association with organic matter and fine particles (Moruf et al., 2022).

Only the bio-water accumulation factor (BAF) for arsenic was significantly higher in *Heteroclarias* from Epe Lagoon compared to Badagry Lagoon, indicating a greater propensity for bioaccumulation in fish from Epe Lagoon. The elevated BAF values observed at both locations reflect arsenic's strong affinity for biological tissues, consistent with findings by Usese et al. (2019) and Zhang et al. (2022), who documented similar trends in aquatic systems influenced by anthropogenic pollution. The higher arsenic bioaccumulation in Epe Lagoon can be attributed to environmental factors influencing arsenic mobility and bioavailability. Sediment composition, particularly the organic matter content, plays a critical role in arsenic binding and release. Sediments with higher organic matter content, such as those found in Epe Lagoon, can adsorb arsenic under oxidizing conditions but release it under reducing conditions, enhancing bioavailability (Usese et al., 2020). This is compounded by the redox potential in the lagoon, which can shift between oxidizing and reducing states due to variations in water flow and oxygen levels, thereby influencing arsenic speciation and its subsequent uptake by aquatic organisms (Hussain et al., 2019).

Additionally, trophic interactions may further explain the elevated arsenic levels in *Heteroclarias*. As an omnivorous species, *Heteroclarias* may consume both benthic prey and particulate organic matter from sediments, which are primary reservoirs of arsenic. Studies have shown that arsenic biomagnifies in food webs where sediments act as a significant source of contamination, particularly in ecosystems impacted by anthropogenic activities such as agriculture, wastewater discharge, and industrial runoff (Sarker et al., 2022). The higher anthropogenic pressure on Epe Lagoon compared to Badagry Lagoon may explain the elevated arsenic concentrations in the biota. The lack of significant differences in the bio-sediment accumulation factor (BSAF) for arsenic and other elements between the two lagoons suggests that arsenic bioaccumulation in *Heteroclarias* is primarily driven by direct uptake from the water column rather than sediment ingestion alone. This aligns with findings by Verma et al. (2023), who highlighted the importance of aqueous arsenic speciation and its interactions with organic and inorganic ligands in determining bioaccumulation patterns.

Arsenic had the highest contamination factor (CF) values among the elements. These values, though relatively low, indicate a slight contamination. Similar low CF values for arsenic have been reported in other tropical aquatic systems (Ahamad et al., 2020), where natural sources contribute predominantly to arsenic levels. The low CF for sulfur in Epe Lagoon suggests negligible sediment contamination, likely due to sulfur's reduced mobility under anaerobic conditions, as noted by Rahim et al. (2021). Selenium had the highest enrichment factor (EF) in both lagoons, particularly in Epe Lagoon, highlighting significant anthropogenic inputs. High selenium enrichment is often linked to industrial discharges and agricultural runoff. Boron, silicon, and sulfur demonstrated much lower EF values, indicating their concentrations are primarily influenced by natural geochemical processes rather than human activities. All the elements had negative index of geo-accumulation (Igeo) values across both lagoons, indicating no significant sediment contamination. Arsenic exhibited the highest Igeo values among the elements, suggesting minimal arsenic accumulation in sediments. The negative Igeo values for all elements differ from the findings of Audu et al. (2022) with positive Igeo values in sediment pollution indices from Niger State water bodies in Nigeria.

CONCLUSION

This study aimed to evaluate the ecological risks associated with toxic elements, including arsenic, boron, selenium, silicon, and sulfur, in fish cage culture sites within the interconnected Epe and Badagry Lagoons, Nigeria. The objective was to assess their concentrations, enrichment levels, and potential ecological impacts using contamination factor (CF), enrichment factor (EF), and the index of geo-accumulation (Igeo). The findings highlight selenium as the most ecologically significant element, with higher anthropogenic contributions, particularly in Epe Lagoon. While the ecological risk assessment reveals notable enrichment for selenium and arsenic, the low CF and negative Igeo values indicate that sediment contamination remains minimal in both lagoons. However, the high EF for selenium underscores the importance of addressing potential anthropogenic sources to prevent long-term ecological risks. To mitigate potential ecological and public health threats, it is recommended to implement regular monitoring programs for selenium and other elements, particularly in regions with high anthropogenic activities. These efforts will help manage contamination sources and safeguard the ecosystems and communities reliant on the lagoons.

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Compliance with Ethical Standards

Authors' Contributions

ORA: Conceptualization, Conducted the survey, Writing – review & editing.

AOL: Supervision, Investigation,

AIO: Investigation, Methodology.

ROM: Manuscript design, Writing – original draft, Formal Analysis.

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Data Availability

The data that support the findings of this study are available from the corresponding author on request.

AI Disclosure

The authors confirm that no generative AI was used in writing this manuscript or creating images, tables, or graphics.

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