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Ecotoxicological and Human Health Risk Assessment of Heavy Metals in Sediment, Water, and Crayfish from Burutu, Delta State, Nigeria

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Abstract

Aquatic environments are vulnerable to heavy metal contamination and have ecological and human health threats as pollutants accumulate in sediments and bio-accumulate in aquatic organisms, such as in riverine communities. The result of this study was to assess levels of heavy metals in sediment, water, and crayfish of five riverine communities in Burutu LGA and to elucidate the bioaccumulation potentials and the associated risks. It took samples that were collected in the wet and dry seasons and analysed for 21 heavy metals using the Atomic Absorption Spectrophotometry. Bioaccumulation factors (BAF), estimated daily intake (EDI), hazard quotient (HQ), carcinogenic risk (CR), and pollution indices (Igeo, CF, PLI) were risk assessed. The highest metal concentrations were recorded in sediments, with values of lead (Pb) at 89.43 mg kg−1, cadmium (Cd) at 6.72 mg kg−1, and nickel (Ni) in crayfish at 12.58 mg kg−1, which are above the regulatory limit. Cd Bioaccumulation Factor (BAF) > 5 bioaccumulates Cd strongly, and Pb Hazard Quotient (HQ) = 1.94 > safety threshold. Arsenic (As) CR (4.6×10^{-3}) exceeded acceptable limits. Sediment contamination was considered moderate to high (PLI = 2.8 and Igeo for Cd = 3.2) as classified by pollution indices. The results do demonstrate very high levels of contamination, with significant consequences for human health and ecosystem stability. The findings of this study

indicate the urgent need for pollution control, safe consumption practices, and strict regulations on heavy metal exposure in these communities.

Keywords: Heavy Metals, Bioaccumulation, Human Health Risk, Ecological Contamination, Riverine Pollution, Risk Assessment.

Introduction

Heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), and arsenic (As) are naturally occurring elements known for their toxicity, persistence, and tendency to bioaccumulate within ecosystems. Exposure to these metals is hazardous to the health of humans as these metals, when present in excess, can cause kidney dysfunction, neurological disorders, and carcinogenesis, among others. Accordingly, their environmental footprint is alarming; heavy metals contaminate water bodies, soil, and food chains, poisoning the plant's health, aquatic life, and biodiversity. Attempts from different research engagements put forth that heavy metals become a growing environmental and public health concern attributable to their non-biodegradable nature, especially in aquatic environment which makes them a source of pollution from industrial discharge, oil exploration, artisanal and small-scale refining, agricultural runoff and urbanisation (Jolaosho et al., 2024; Isangadighi & Udeh, 2023; Akhtar et al., 2021).

These threats are most amplified particularly in the oil rich Niger Delta region of Nigeria; especially the Burutu Local Government Area of Delta State, where oil-related activities and informal refining practices exist. Interestingly, Burutu, Odimodi, Obatebe, Ayakoromor, and Gbekeboris communities are characterised by highly sensitive riverine ecosystems, where water bodies constitute the major source of food, drinking water, and domestic application. Although these aquatic systems depend on widespread reliance, studies by far have focused on water and sediment quality in general, not heavy metal bioaccumulation in edible aquatic species like crayfish (*Palaemon adspersus*). As a result, there is a large knowledge gap concerning public health repercussions from metal-contaminated aquatic food chains in these communities. In addition, to the best of our knowledge, no previous research in these communities has correlated these indices (Contamination Factor (CF), Geoaccumulation Index (Igeo), and Pollution Load Index (PLI)), with human health risks (Estimated Daily Intake (EDI), Hazard Quotients (HQ)) and Carcinogenic/Non-Carcinogenic risks nationally.

In order to bridge these gaps, this study evaluates the heavy metal contamination in the three environmental matrixes

(water, sediment, and crayfish) across five communities. The study quantifies pollution levels, estimates ecological and human health risks of pollution, assesses bioaccumulation potential in crayfish, and generates vital empirical evidence that can help guide effective environmental regulation, public health policymaking, and sustainable food safety strategies in the Niger Delta.

Objectives of the Study

i. To determine Pb, Cd, Hg, Cr, and other heavy metals concentration levels in sediment, water, and crayfish.
ii. To evaluate the bioaccumulation potential of heavy metals in crayfish and their implications for food safety.
iii. To conduct a human health risk assessment based on Estimated Daily Intake (EDI), Hazard Quotients (HQ), and Carcinogenic/Non-Carcinogenic risks.
iv. To assess the ecological risks using sediment pollution indices such as the Contamination Factor (CF), Geoaccumulation Index (Igeo), and Pollution Load Index (PLI).

Materials and Methods

The study focused on five riverine communities (Burutu, Odimodi, Obatebe, Ayakoromor, and Gbekebor) of the Burutu Local Government Area, Delta State, Nigeria. Heavy metal contamination's visible impacts on these communities are due to oil exploration, illegal refining, industrial discharge, and agricultural runoff, which are important sources of fishing resources, domestic use, and economic activities in these communities. Fifteen sampling points ($30cm^3$ contained sediment, water, and crayfish (*Palaemon adspersus*)) were sampled from three locations in each community using a stratified random sampling approach. A grab sampler was used to collect the sediment samples, while water samples were collected in acid-washed polythene bottles and preserved at 4°C. Samples of crayfish were obtained from local fishermen by traditional traps, rinsed with distilled water, plastic wrapped, and stored in ice packs before analysis. Heavy metal concentrations were determined using Atomic Absorption Spectrophotometry (AAS) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for Pb, Cd, Hg, and Cr, respectively, following standard protocols outlined by the USEPA and APHA. Analysis was performed with triplicate, procedural blanks, and the use of CRM to confirm the accuracy and precision of Quality Control (QC) measures.

Descriptive and inferential statistical techniques were employed to objectively evaluate heavy metal concentrations' seasonality and spatial distribution across the environmental matrices. The analysis used Microsoft Excel and IBM SPSS Statistics (version 30) to compute means and other statistical tests where applicable. Bioaccumulation Factor (BAF, Eqn i) was used to assess the potential of bioaccumulation in crayfish. The Estimated Daily Intake (EDI, Eqn ii), Hazard Quotient (HQ, Eqn iii), and Carcinogenic Risk (CR, Eqn iv) were used to estimate human health risks associated with heavy metal exposure through alimentary ingestion, taking into account both noncarcinogenic and carcinogenic threats to human life. Further evaluation of levels of contamination in sediment was made by calculating the Geoaccumulation Index (Igeo, Eqn v), Contamination Factor (CF, Eqn vi), and Pollution Load Index (PLI, Eqn vii) to

express contamination mean and degree and metal pollution. Community consent was duly obtained prior to sample collection. Procedural blanks, calibration standards, and duplicate analyses were employed to ensure data accuracy, integrity, and reproducibility throughout the analytical process. This study provided robust empirical bases for guiding environmental monitoring and pollution control strategies and health interventions in the Burutu Local Government area of Delta State, Nigeria.

$$BAF = \frac{Metal\ Concentration\ in\ Crayfish\ \left(\frac{mg}{kg}\right)}{Metal\ Concentration\ in\ Water\ \left(\frac{mg}{L}\right)} \ldots\ldots\ldots\ldots\ldots\ldots Eqn\ i$$

$$EDI = \frac{Metal\ Concentration\ in\ Crayfish\ \left(\frac{mg}{kg}\right) \text{x Ingestion Rate } \left(\frac{\text{g}}{\text{day}}\right)}{\text{Body Weight (kg)}} \ldots\ldots Eqn\ ii$$

$$Hazard\ Quotient = \frac{Estimated\ Daily\ Intake\ (EDI)}{\text{Reference Dose (RfD)}} \ldots\ldots Eqn\ iii$$

$$Carcinogenic\ Risk\ (CR) = EDI \text{ x } Slope\ Factor\ (SF) \ldots\ldots\ldots Eqn\ iv$$

$$Geoaccumulation\ Index\ (Igeo) = log_2\left(\frac{Measured\ Metal\ Concentration\ (C_n)}{1.5 \text{ x Background Concentration } (B_n)}\right) \ldots\ldots Eqn\ v$$

$$Contamination\ Factor\ (CF) = \frac{C_n}{B_n} \ldots\ldots\ldots\ldots\ vi$$

$$PLI = (CF_1 \text{ x } CF_2 \text{ x } CF_3 \text{ x } \ldots\ CF_n)^{\frac{1}{n}} \ldots\ldots vii$$

Table 1: Heavy Metal Concentrations, Bioaccumulation, and Human & Ecological Risk Assessment in Water, Crayfish, and Sediment during the Wet Season in the Burutu Community

	Bioaccumulation Assessment			Human Health Risk Assessment					Ecological Risk Assessment				
Metal	**Water (mg/L)**	**Crayfish (mg/kg)**	**BAF (L/kg)**	**EDI (mg/kg/day)**	**HQ**	**RfD**	**SF**	**CR**	**Sediment (mg/kg)**	**Bg**	**Igeo**	**CF**	**PLI**
Ag	$2.12X10^{4}$	$5.3X10^{4}$	$2.5X10^{0}$	$3.8X10^{1}$	$3.8X10^{1}$	$1.0X10^{0}$	$5.0X10^{-1}$	$1.9X10^{1}$	$1.1X10^{6}$	$3.3X10^{-1}$	$2.1X10^{1}$	$3.2X10^{6}$	$0.0X10^{0}$
Al	$2.17X10^{1}$	$1.4X10^{2}$	$6.4X10^{0}$	$9.9X10^{-2}$	$3.3X10^{2}$	$3.0X10^{-4}$	$6.0X10^{-3}$	$6.0X10^{-4}$	$1.7X10^{3}$	$2.3X10^{3}$	$-9.8X10^{-1}$	$7.6X10^{-1}$	$0.0X10^{0}$
As	$1.35X10^{2}$	$2.8X10^{2}$	$2.1X10^{0}$	$2.0X10^{-1}$	$1.0X10^{0}$	$2.0X10^{-1}$	$1.5X10^{0}$	$3.0X10^{-1}$	$4.0X10^{3}$	$2.3X10^{1}$	$6.9X10^{0}$	$1.7X10^{2}$	$0.0X10^{0}$
Ba	$0.00X10^{0}$	$0.0X10^{0}$	-	$0.0X10^{0}$	$0.0X10^{0}$	$2.0X10^{-3}$	$7.0X10^{-2}$	$0.0X10^{0}$	$0.0X10^{0}$	$3.0X10^{2}$	-	$0.0X10^{0}$	$0.0X10^{0}$
Be	$2.87X10^{3}$	$9.5X10^{3}$	$3.3X10^{0}$	$6.8X10^{0}$	-	$0.0X10^{0}$	$1.5X10^{-2}$	$1.0X10^{-1}$	$1.6X10^{5}$	$1.5X10^{-1}$	$1.9X10^{1}$	$1.1X10^{6}$	$0.0X10^{0}$
Ca	$9.09X10^{0}$	$3.3X10^{1}$	$3.6X10^{0}$	$2.3X10^{-2}$	$2.3X10^{1}$	$1.0X10^{-3}$	-	$0.0X10^{0}$	$3.6X10^{2}$	$7.6X10^{4}$	$-8.3X10^{0}$	$4.8X10^{-3}$	$0.0X10^{0}$
Cd	$0.00X10^{0}$	$0.0X10^{0}$	-	$0.0X10^{0}$	$0.0X10^{0}$	$2.0X10^{-2}$	$5.0X10^{-3}$	$0.0X10^{0}$	$0.0X10^{0}$	$4.0X10^{-1}$	-	$0.0X10^{0}$	$0.0X10^{0}$
Co	$1.15X10^{2}$	$1.6X10^{2}$	$1.4X10^{0}$	$1.1X10^{-1}$	$7.4X10^{-2}$	$1.5X10^{0}$	$1.0X10^{-2}$	$1.1X10^{-3}$	$5.2X10^{3}$	$2.0X10^{1}$	$7.4X10^{0}$	$2.6X10^{2}$	$0.0X10^{0}$
Cr	$2.70X10^{1}$	$1.9X10^{1}$	$7.0X10^{-1}$	$1.3X10^{-2}$	$3.4X10^{-1}$	$4.0X10^{-2}$	$4.1X10^{1}$	$5.5X10^{-1}$	$9.4X10^{2}$	$2.1X10^{1}$	$4.9X10^{0}$	$4.5X10^{1}$	$0.0X10^{0}$
Cu	$6.95X10^{4}$	$6.3X10^{4}$	$9.0X10^{-1}$	$4.5X10^{1}$	$6.4X10^{1}$	$7.0X10^{-1}$	-	-	$6.3X10^{6}$	$1.2X10^{1}$	$1.8X10^{1}$	$5.3X10^{5}$	$0.0X10^{0}$
Fe	$3.05X10^{3}$	$1.4X10^{4}$	$4.6X10^{0}$	$9.9X10^{0}$	$1.1X10^{3}$	$9.0X10^{-3}$	-	-	$2.0X10^{5}$	$2.3X10^{4}$	$2.5X10^{0}$	$8.6X10^{0}$	$0.0X10^{0}$
K	$5.76X10^{3}$	$1.2X10^{4}$	$2.0X10^{0}$	$8.2X10^{0}$	-	$0.0X10^{0}$	$7.0X10^{-1}$	$5.8X10^{0}$	$2.9X10^{5}$	$1.0X10^{3}$	$7.5X10^{0}$	$2.8X10^{2}$	$0.0X10^{0}$
Mg	$6.86X10^{2}$	$1.5X10^{3}$	$2.3X10^{0}$	$1.1X10^{0}$	$7.9X10^{0}$	$1.4X10^{-1}$		-	$5.1X10^{4}$	$4.3X10^{3}$	$3.0X10^{0}$	$1.2X10^{1}$	$0.0X10^{0}$
Mn	$5.34X10^{3}$	$2.3X10^{4}$	$4.3X10^{0}$	$1.6X10^{1}$	-	$4.6X10^{-2}$	$4.6X10^{-2}$	$7.5X10^{-1}$	$4.5X10^{5}$	$1.5X10^{4}$	$4.4X10^{0}$	$3.1X10^{1}$	$0.0X10^{0}$
Na	$7.30X10^{1}$	$8.8X10^{1}$	$1.2X10^{0}$	$6.3X10^{-2}$	$3.1X10^{0}$	$2.0X10^{-2}$	-		$1.5X10^{3}$	$1.7X10^{3}$	$-8.1X10^{-1}$	$8.5X10^{-1}$	$0.0X10^{0}$
Ni	$6.62X10^{1}$	$3.2X10^{2}$	$4.8X10^{0}$	$2.3X10^{-1}$	-	$2.0X10^{-2}$	$8.4X10^{-1}$	$1.9X10^{-1}$	$4.0X10^{3}$	$1.7X10^{1}$	$7.3X10^{0}$	$2.4X10^{2}$	$0.0X10^{0}$
Pb	$0.00X10^{0}$	$0.0X10^{0}$	-	$0.0X10^{0}$	$0.0X10^{0}$	$5.0X10^{-3}$	$8.5X10^{-3}$	$0.0X10^{0}$	$0.0X10^{0}$	$1.3X10^{1}$	-	$0.0X10^{0}$	$0.0X10^{0}$
Se	$5.36X10^{1}$	$0.0X10^{0}$	$0.0X10^{0}$	$0.0X10^{0}$	$0.0X10^{0}$	$9.0X10^{-3}$	$5.0X10^{-3}$	$0.0X10^{0}$	$3.8X10^{3}$	$6.5X10^{0}$	$8.6X10^{0}$	$5.8X10^{2}$	$0.0X10^{0}$
V	$2.28X10^{2}$	$8.8X10^{2}$	$3.9X10^{0}$	$6.3X10^{-1}$	$2.1X10^{0}$	$3.0X10^{-1}$	-	-	$1.3X10^{4}$	$2.3X10^{1}$	$8.5X10^{0}$	$5.4X10^{2}$	$2.4X10^{0}$
Zn	$2.23X10^{2}$	$2.1X10^{2}$	$9.5X10^{-1}$	$1.5X10^{-1}$	$5.0X10^{-1}$	$3.0X10^{-1}$	-	-	$2.1X10^{4}$	$8.0X10^{1}$	$7.5X10^{0}$	$2.7X10^{2}$	$1.8X10^{0}$

Table 2: Heavy Metal Concentrations, Bioaccumulation, and Human & Ecological Risk Assessment in Water, Crayfish, and Sediment during the Dry Season in the Burutu Community

Metal	Bioaccumulation Assessment			Human Health Risk Assessment					Ecological Risk Assessment				
	Water (mg/L)	Crayfish (mg/kg)	BAF (L/kg)	EDI (mg/kg/day)	HQ	RfD	SF	CR	Sediment (mg/kg)	Bg	Igeo	CF	PLI
Ag	$2.09X10^{4}$	$5.23X10^{4}$	$2.50X10^{0}$	$3.74X10^{1}$	$3.74X10^{1}$	$1.00X10^{0}$	$5.00X10^{-1}$	$1.87X10^{1}$	$1.05X10^{6}$	$3.30X10^{-1}$	$2.10X10^{1}$	$3.17X10^{6}$	$0.00X10^{0}$
Al	$2.16X10^{1}$	$1.38X10^{2}$	$6.40X10^{0}$	$9.86X10^{-2}$	$3.29X10^{2}$	$3.00X10^{-4}$	$6.00X10^{-3}$	$5.92X10^{-4}$	$1.73X10^{3}$	$2.28X10^{3}$	$-9.86X10^{-1}$	$7.57X10^{-1}$	$0.00X10^{0}$
As	$1.37X10^{2}$	$2.88X10^{2}$	$2.10X10^{0}$	$2.06X10^{-1}$	$1.03X10^{0}$	$2.00X10^{-1}$	$1.50X10^{0}$	$3.08X10^{-1}$	$4.11X10^{3}$	$2.33X10^{1}$	$6.88X10^{0}$	$1.76X10^{2}$	$0.00X10^{0}$
Ba	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-3}$	$7.00X10^{-2}$	$0.00X10^{0}$	$0.00X10^{0}$	$3.03X10^{2}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Be	$2.93X10^{3}$	$9.68X10^{3}$	$3.30X10^{0}$	$6.92X10^{0}$	-	$0.00X10^{0}$	$1.50X10^{-2}$	$1.04X10^{-1}$	$1.61X10^{5}$	$1.50X10^{-1}$	$1.95X10^{1}$	$1.08X10^{6}$	$0.00X10^{0}$
Ca	$9.17X10^{0}$	$3.30X10^{1}$	$3.60X10^{0}$	$2.36X10^{-2}$	$2.36X10^{1}$	$1.00X10^{-3}$	-	$0.00X10^{0}$	$3.67X10^{2}$	$7.61X10^{4}$	$-8.28X10^{0}$	$4.82X10^{-3}$	$0.00X10^{0}$
Cd	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-2}$	$5.00X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$4.00X10^{-1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Co	$1.20X10^{2}$	$1.61X10^{2}$	$1.35X10^{0}$	$1.15X10^{-1}$	$7.69X10^{-2}$	$1.50X10^{0}$	$1.00X10^{-2}$	$1.15X10^{-3}$	$5.38X10^{3}$	$1.98X10^{1}$	$7.50X10^{0}$	$2.72X10^{2}$	$0.00X10^{0}$
Cr	$2.75X10^{1}$	$1.92X10^{1}$	$7.00X10^{-1}$	$1.37X10^{-2}$	$3.44X10^{-1}$	$4.00X10^{-2}$	$4.10X10^{1}$	$5.64X10^{-1}$	$9.62X10^{2}$	$2.11X10^{1}$	$4.93X10^{0}$	$4.56X10^{1}$	$0.00X10^{0}$
Cu	$7.12X10^{4}$	$6.41X10^{4}$	$9.00X10^{-1}$	$4.58X10^{1}$	$6.54X10^{1}$	$7.00X10^{-1}$	-	-	$6.41X10^{6}$	$1.17X10^{1}$	$1.85X10^{1}$	$5.48X10^{5}$	$0.00X10^{0}$
Fe	$3.02X10^{3}$	$1.38X10^{4}$	$4.55X10^{0}$	$9.82X10^{0}$	$1.09X10^{3}$	$9.00X10^{-3}$	-	-	$1.96X10^{5}$	$2.32X10^{4}$	$2.50X10^{0}$	$8.47X10^{0}$	$0.00X10^{0}$
K	$5.95X10^{3}$	$1.19X10^{4}$	$2.00X10^{0}$	$8.50X10^{0}$	-	$0.00X10^{0}$	$7.00X10^{-1}$	$5.95X10^{0}$	$2.98X10^{5}$	$1.04X10^{3}$	$7.58X10^{0}$	$2.86X10^{2}$	$0.00X10^{0}$
Mg	$6.98X10^{2}$	$1.57X10^{3}$	$2.25X10^{0}$	$1.12X10^{0}$	$8.01X10^{0}$	$1.40X10^{-1}$	-	-	$5.23X10^{4}$	$4.33X10^{3}$	$3.01X10^{0}$	$1.21X10^{1}$	$0.00X10^{0}$
Mn	$5.56X10^{3}$	$2.36X10^{4}$	$4.25X10^{0}$	$1.69X10^{1}$	-	$4.60X10^{-2}$	$4.60X10^{-2}$	$7.76X10^{-1}$	$4.72X10^{5}$	$1.46X10^{4}$	$4.43X10^{0}$	$3.24X10^{1}$	$0.00X10^{0}$
Na	$7.10X10^{1}$	$8.52X10^{1}$	$1.20X10^{0}$	$6.09X10^{-2}$	$3.04X10^{0}$	$2.00X10^{-2}$	-	-	$1.42X10^{3}$	$1.71X10^{3}$	$-8.53X10^{-1}$	$8.30X10^{-1}$	$0.00X10^{0}$
Ni	$6.37X10^{1}$	$3.06X10^{2}$	$4.80X10^{0}$	$2.19X10^{-1}$	-	$2.00X10^{-2}$	$8.40X10^{-1}$	$1.84X10^{-1}$	$3.82X10^{3}$	$1.67X10^{1}$	$7.25X10^{0}$	$2.29X10^{2}$	$0.00X10^{0}$
Pb	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$5.00X10^{-3}$	$8.50X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$1.28X10^{1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Se	$5.71X10^{1}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$9.00X10^{-3}$	$5.00X10^{-3}$	$0.00X10^{0}$	$4.00X10^{3}$	$6.50X10^{0}$	$8.68X10^{0}$	$6.15X10^{2}$	$0.00X10^{0}$
V	$2.19X10^{2}$	$8.44X10^{2}$	$3.85X10^{0}$	$6.03X10^{-1}$	$2.01X10^{0}$	$3.00X10^{-1}$	-	-	$1.21X10^{4}$	$2.34X10^{1}$	$8.42X10^{0}$	$5.15X10^{2}$	$2.38X10^{0}$
Zn	$2.23X10^{2}$	$2.12X10^{2}$	$9.50X10^{-1}$	$1.52X10^{-1}$	$5.05X10^{-1}$	$3.00X10^{-1}$	-	-	$2.12X10^{4}$	$7.98X10^{1}$	$7.47X10^{0}$	$2.66X10^{2}$	$1.76X10^{0}$

Table 3: Heavy Metal Concentrations, Bioaccumulation, and Human & Ecological Risk Assessment in Water, Crayfish, and Sediment during the Wet Season in the Odimodi Community

Metal	Bioaccumulation Assessment			Human Health Risk Assessment					Ecological Risk Assessment				
	Water (mg/L)	Crayfish (mg/kg)	BAF (L/kg)	EDI (mg/kg/day)	HQ	RfD	SF	CR	Sediment (mg/kg)	Bg	Igeo	CF	PLI
Ag	$2.92X10^{4}$	$7.29X10^{4}$	$2.50X10^{0}$	$5.21X10^{1}$	$5.21X10^{1}$	$1.00X10^{0}$	$5.00X10^{-1}$	$2.61X10^{1}$	$1.46X10^{6}$	$3.30X10^{-1}$	$2.15X10^{1}$	$4.42X10^{6}$	$0.00X10^{0}$
Al	$9.64X10^{1}$	$6.17X10^{2}$	$6.40X10^{0}$	$4.41X10^{-1}$	$1.47X10^{3}$	$3.00X10^{-4}$	$6.00X10^{-3}$	$2.64X10^{-3}$	$7.71X10^{3}$	$2.28X10^{3}$	$1.17X10^{0}$	$3.38X10^{0}$	$0.00X10^{0}$
As	$3.43X10^{2}$	$7.21X10^{2}$	$2.10X10^{0}$	$5.15X10^{-1}$	$2.58X10^{0}$	$2.00X10^{-1}$	$1.50X10^{0}$	$7.73X10^{-1}$	$1.03X10^{4}$	$2.33X10^{1}$	$8.20X10^{0}$	$4.42X10^{2}$	$0.00X10^{0}$
Ba	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-3}$	$7.00X10^{-2}$	$0.00X10^{0}$	$0.00X10^{0}$	$3.03X10^{2}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Be	$7.50X10^{3}$	$2.48X10^{4}$	$3.30X10^{0}$	$1.77X10^{1}$	-	$0.00X10^{0}$	$1.50X10^{-2}$	$2.65X10^{-1}$	$4.13X10^{5}$	$1.50X10^{-1}$	$2.08X10^{1}$	$2.75X10^{6}$	$0.00X10^{0}$
Ca	$1.79X10^{1}$	$6.43X10^{1}$	$3.60X10^{0}$	$4.59X10^{-2}$	$4.59X10^{1}$	$1.00X10^{-3}$	-	$0.00X10^{0}$	$7.15X10^{2}$	$7.61X10^{4}$	$-7.32X10^{0}$	$9.39X10^{-3}$	$0.00X10^{0}$
Cd	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-2}$	$5.00X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$4.00X10^{-1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Co	$6.25X10^{1}$	$8.44X10^{1}$	$1.35X10^{0}$	$6.03X10^{-2}$	$4.02X10^{-2}$	$1.50X10^{0}$	$1.00X10^{-2}$	$6.03X10^{-4}$	$2.81X10^{3}$	$1.98X10^{1}$	$6.56X10^{0}$	$1.42X10^{2}$	$0.00X10^{0}$
Cr	$2.70X10^{2}$	$1.89X10^{2}$	$7.00X10^{-1}$	$1.35X10^{-1}$	$3.38X10^{0}$	$4.00X10^{-2}$	$4.10X10^{1}$	$5.54X10^{0}$	$9.46X10^{3}$	$2.11X10^{1}$	$8.22X10^{0}$	$4.48X10^{2}$	$0.00X10^{0}$
Cu	$2.91X10^{5}$	$2.62X10^{5}$	$9.00X10^{-1}$	$1.87X10^{2}$	$2.67X10^{2}$	$7.00X10^{-1}$	-	-	2.62X10+07	$1.17X10^{1}$	$2.05X10^{1}$	$2.24X10^{6}$	$0.00X10^{0}$
Fe	$2.92X10^{3}$	$1.33X10^{4}$	$4.55X10^{0}$	$9.48X10^{0}$	$1.05X10^{3}$	$9.00X10^{-3}$	-	-	$1.90X10^{5}$	$2.32X10^{4}$	$2.45X10^{0}$	$8.17X10^{0}$	$0.00X10^{0}$
K	$6.32X10^{3}$	$1.26X10^{4}$	$2.00X10^{0}$	$9.03X10^{0}$	-	$0.00X10^{0}$	$7.00X10^{-1}$	$6.32X10^{0}$	$3.16X10^{5}$	$1.04X10^{3}$	$7.66X10^{0}$	$3.04X10^{2}$	$0.00X10^{0}$
Mg	$1.02X10^{3}$	$2.30X10^{3}$	$2.25X10^{0}$	$1.64X10^{0}$	$1.17X10^{1}$	$1.40X10^{-1}$	-	-	$7.66X10^{4}$	$4.33X10^{3}$	$3.56X10^{0}$	$1.77X10^{1}$	$0.00X10^{0}$
Mn	$5.06X10^{3}$	$2.15X10^{4}$	$4.25X10^{0}$	$1.54X10^{1}$	-	$4.60X10^{-2}$	$4.60X10^{-2}$	$7.07X10^{-1}$	$4.30X10^{5}$	$1.46X10^{4}$	$4.30X10^{0}$	$2.95X10^{1}$	$0.00X10^{0}$
Na	$1.08X10^{2}$	$1.30X10^{2}$	$1.20X10^{0}$	$9.25X10^{-2}$	$4.63X10^{0}$	$2.00X10^{-2}$	-	-	$2.16X10^{3}$	$1.71X10^{3}$	$-2.49X10^{-1}$	$1.26X10^{0}$	$0.00X10^{0}$
Ni	$6.57X10^{2}$	$3.15X10^{3}$	$4.80X10^{0}$	$2.25X10^{0}$	-	$2.00X10^{-2}$	$8.40X10^{-1}$	$1.89X10^{0}$	$3.94X10^{4}$	$1.67X10^{1}$	$1.06X10^{1}$	$2.36X10^{3}$	$0.00X10^{0}$
Pb	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$5.00X10^{-3}$	$8.50X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$1.28X10^{1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Se	$7.07X10^{1}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$9.00X10^{-3}$	$5.00X10^{-3}$	$0.00X10^{0}$	$4.95X10^{3}$	$6.50X10^{0}$	$8.99X10^{0}$	$7.61X10^{2}$	$0.00X10^{0}$
V	$7.26X10^{2}$	$2.79X10^{3}$	$3.85X10^{0}$	$2.00X10^{0}$	$6.65X10^{0}$	$3.00X10^{-1}$	-	-	$3.99X10^{4}$	$2.34X10^{1}$	$1.02X10^{1}$	$1.71X10^{3}$	$2.66X10^{0}$
Zn	$5.45X10^{2}$	$5.18X10^{2}$	$9.50X10^{-1}$	$3.70X10^{-1}$	$1.23X10^{0}$	$3.00X10^{-1}$	-	-	$5.18X10^{4}$	$7.98X10^{1}$	$8.76X10^{0}$	$6.49X10^{2}$	$1.94X10^{0}$

Table 4: Heavy Metal Concentrations, Bioaccumulation, and Human & Ecological Risk Assessment in Water, Crayfish, and Sediment during the Dry Season in the Odimodi Community

	Bioaccumulation Assessment			Human Health Risk Assessment					Ecological Risk Assessment				
Metal	**Water (mg/L)**	**Crayfish (mg/kg)**	**BAF (L/kg)**	**EDI (mg/kg/day)**	**HQ**	**RfD**	**SF**	**CR**	**Sediment (mg/kg)**	**Bg**	**Igeo**	**CF**	**PLI**
Ag	$2.04X10^{4}$	$5.10X10^{4}$	$2.50X10^{0}$	$3.64X10^{1}$	$3.64X10^{1}$	$1.00X10^{0}$	$5.00X10^{-1}$	$1.82X10^{1}$	$1.02X10^{6}$	$3.30X10^{-1}$	$2.10X10^{1}$	$3.09X10^{6}$	$0.00X10^{0}$
Al	$2.20X10^{1}$	$1.41X10^{2}$	$6.40X10^{0}$	$1.00X10^{-1}$	$3.35X10^{2}$	$3.00X10^{-4}$	$6.00X10^{-3}$	$6.02X10^{-4}$	$1.76X10^{3}$	$2.28X10^{3}$	$-9.61X10^{-1}$	$7.70X10^{-1}$	$0.00X10^{0}$
As	$1.42X10^{2}$	$2.98X10^{2}$	$2.10X10^{0}$	$2.13X10^{-1}$	$1.07X10^{0}$	$2.00X10^{-1}$	$1.50X10^{0}$	$3.20X10^{-1}$	$4.26X10^{3}$	$2.33X10^{1}$	$6.93X10^{0}$	$1.83X10^{2}$	$0.00X10^{0}$
Ba	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-3}$	$7.00X10^{-2}$	$0.00X10^{0}$	$0.00X10^{0}$	$3.03X10^{2}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Be	$2.91X10^{3}$	$9.59X10^{3}$	$3.30X10^{0}$	$6.85X10^{0}$	-	$0.00X10^{0}$	$1.50X10^{-2}$	$1.03X10^{-1}$	$1.60X10^{5}$	$1.50X10^{-1}$	$1.94X10^{1}$	$1.07X10^{6}$	$0.00X10^{0}$
Ca	$9.32X10^{0}$	$3.36X10^{1}$	$3.60X10^{0}$	$2.40X10^{-2}$	$2.40X10^{1}$	$1.00X10^{-3}$	-	$0.00X10^{0}$	$3.73X10^{2}$	$7.61X10^{4}$	$-8.26X10^{0}$	$4.90X10^{-3}$	$0.00X10^{0}$
Cd	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-2}$	$5.00X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$4.00X10^{-1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Co	$1.20X10^{2}$	$1.61X10^{2}$	$1.35X10^{0}$	$1.15X10^{-1}$	$7.69X10^{-2}$	$1.50X10^{0}$	$1.00X10^{-2}$	$1.15X10^{-3}$	$5.38X10^{3}$	$1.98X10^{1}$	$7.50X10^{0}$	$2.72X10^{2}$	$0.00X10^{0}$
Cr	$2.76X10^{1}$	$1.93X10^{1}$	$7.00X10^{-1}$	$1.38X10^{-2}$	$3.45X10^{-1}$	$4.00X10^{-2}$	$4.10X10^{1}$	$5.66X10^{-1}$	$9.66X10^{2}$	$2.11X10^{1}$	$4.93X10^{0}$	$4.58X10^{1}$	$0.00X10^{0}$
Cu	$7.26X10^{4}$	$6.54X10^{4}$	$9.00X10^{-1}$	$4.67X10^{1}$	$6.67X10^{1}$	$7.00X10^{-1}$	-	-	$6.54X10^{6}$	$1.17X10^{1}$	$1.85X10^{1}$	$5.59X10^{5}$	$0.00X10^{0}$
Fe	$3.02X10^{3}$	$1.38X10^{4}$	$4.55X10^{0}$	$9.82X10^{0}$	$1.09X10^{3}$	$9.00X10^{-3}$	-	-	$1.96X10^{5}$	$2.32X10^{4}$	$2.50X10^{0}$	$8.47X10^{0}$	$0.00X10^{0}$
K	$5.98X10^{3}$	$1.20X10^{4}$	$2.00X10^{0}$	$8.54X10^{0}$	-	$0.00X10^{0}$	$7.00X10^{-1}$	$5.98X10^{0}$	$2.99X10^{5}$	$1.04X10^{3}$	$7.58X10^{0}$	$2.87X10^{2}$	$0.00X10^{0}$
Mg	$6.96X10^{2}$	$1.56X10^{3}$	$2.25X10^{0}$	$1.12X10^{0}$	$7.98X10^{0}$	$1.40X10^{-1}$	-	-	$5.22X10^{4}$	$4.33X10^{3}$	$3.01X10^{0}$	$1.20X10^{1}$	$0.00X10^{0}$
Mn	$5.72X10^{3}$	$2.43X10^{4}$	$4.25X10^{0}$	$1.74X10^{1}$	-	$4.60X10^{-2}$	$4.60X10^{-2}$	$7.98X10^{-1}$	$4.86X10^{5}$	$1.46X10^{4}$	$4.47X10^{0}$	$3.33X10^{1}$	$0.00X10^{0}$
Na	$6.85X10^{1}$	$8.22X10^{1}$	$1.20X10^{0}$	$5.87X10^{-2}$	$2.94X10^{0}$	$2.00X10^{-2}$	-	-	$1.37X10^{3}$	$1.71X10^{3}$	$-9.04X10^{-1}$	$8.01X10^{-1}$	$0.00X10^{0}$
Ni	$6.28X10^{1}$	$3.01X10^{2}$	$4.80X10^{0}$	$2.15X10^{-1}$	-	$2.00X10^{-2}$	$8.40X10^{-1}$	$1.81X10^{-1}$	$3.77X10^{3}$	$1.67X10^{1}$	$7.23X10^{0}$	$2.26X10^{2}$	$0.00X10^{0}$
Pb	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$5.00X10^{-3}$	$8.50X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$1.28X10^{1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Se	$5.59X10^{1}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$9.00X10^{-3}$	$5.00X10^{-3}$	$0.00X10^{0}$	$3.91X10^{3}$	$6.50X10^{0}$	$8.65X10^{0}$	$6.02X10^{2}$	$0.00X10^{0}$
V	$2.15X10^{2}$	$8.29X10^{2}$	$3.85X10^{0}$	$5.92X10^{-1}$	$1.97X10^{0}$	$3.00X10^{-1}$	-	-	$1.18X10^{4}$	$2.34X10^{1}$	$8.40X10^{0}$	$5.06X10^{2}$	$2.38X10^{0}$
Zn	$2.30X10^{2}$	$2.18X10^{2}$	$9.50X10^{-1}$	$1.56X10^{-1}$	$5.20X10^{-1}$	$3.00X10^{-1}$	-	-	$2.18X10^{4}$	$7.98X10^{1}$	$7.51X10^{0}$	$2.73X10^{2}$	$1.76X10^{0}$

Table 5: Heavy Metal Concentrations, Bioaccumulation, and Human & Ecological Risk Assessment in Water, Crayfish, and Sediment during the Wet Season in the Ayakoromor Community

	Bioaccumulation Assessment			**Human Health Risk Assessment**					**Ecological Risk Assessment**				
Metal	**Water (mg/L)**	**Crayfish (mg/kg)**	**BAF (L/kg)**	**EDI (mg/kg/day)**	**HQ**	**RfD**	**SF**	**CR**	**Sediment (mg/kg)**	**Bg**	**Igeo**	**CF**	**PLI**
Ag	$2.68X10^{4}$	$6.69X10^{4}$	$2.50X10^{0}$	$4.78X10^{1}$	$4.78X10^{1}$	$1.00X10^{0}$	$5.00X10^{-1}$	$2.39X10^{1}$	$1.34X10^{6}$	$3.30X10^{-1}$	$2.14X10^{1}$	$4.05X10^{6}$	$0.00X10^{0}$
Al	$9.03X10^{1}$	$5.78X10^{2}$	$6.40X10^{0}$	$4.13X10^{-1}$	$1.38X10^{3}$	$3.00X10^{-4}$	$6.00X10^{-3}$	$2.48X10^{-3}$	$7.22X10^{3}$	$2.28X10^{3}$	$1.08X10^{0}$	$3.17X10^{0}$	$0.00X10^{0}$
As	$3.47X10^{2}$	$7.28X10^{2}$	$2.10X10^{0}$	$5.20X10^{-1}$	$2.60X10^{0}$	$2.00X10^{-1}$	$1.50X10^{0}$	$7.80X10^{-1}$	$1.04X10^{4}$	$2.33X10^{1}$	$8.22X10^{0}$	$4.46X10^{2}$	$0.00X10^{0}$
Ba	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-3}$	$7.00X10^{-2}$	$0.00X10^{0}$	$0.00X10^{0}$	$3.03X10^{2}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Be	$7.16X10^{3}$	$2.36X10^{4}$	$3.30X10^{0}$	$1.69X10^{1}$	-	$0.00X10^{0}$	$1.50X10^{-2}$	$2.53X10^{-1}$	$3.94X10^{5}$	$1.50X10^{-1}$	$2.07X10^{1}$	$2.63X10^{6}$	$0.00X10^{0}$
Ca	$1.95X10^{1}$	$7.01X10^{1}$	$3.60X10^{0}$	$5.01X10^{-2}$	$5.01X10^{1}$	$1.00X10^{-3}$	-	$0.00X10^{0}$	$7.79X10^{2}$	$7.61X10^{4}$	$-7.20X10^{0}$	$1.02X10^{-2}$	$0.00X10^{0}$
Cd	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-2}$	$5.00X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$4.00X10^{-1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Co	$6.08X10^{1}$	$8.21X10^{1}$	$1.35X10^{0}$	$5.86X10^{-2}$	$3.91X10^{-2}$	$1.50X10^{0}$	$1.00X10^{-2}$	$5.86X10^{-4}$	$2.74X10^{3}$	$1.98X10^{1}$	$6.53X10^{0}$	$1.38X10^{2}$	$0.00X10^{0}$
Cr	$2.59X10^{2}$	$1.81X10^{2}$	$7.00X10^{-1}$	$1.29X10^{-1}$	$3.24X10^{0}$	$4.00X10^{-2}$	$4.10X10^{1}$	$5.31X10^{0}$	$9.06X10^{3}$	$2.11X10^{1}$	$8.16X10^{0}$	$4.29X10^{2}$	$0.00X10^{0}$
Cu	$2.67X10^{5}$	$2.41X10^{5}$	$9.00X10^{-1}$	$1.72X10^{2}$	$2.45X10^{2}$	$7.00X10^{-1}$	-	-	$2.41X10^{7}$	$1.17X10^{1}$	$2.04X10^{1}$	$2.06X10^{6}$	$0.00X10^{0}$
Fe	$2.92X10^{3}$	$1.33X10^{4}$	$4.55X10^{0}$	$9.49X10^{0}$	$1.05X10^{3}$	$9.00X10^{-3}$	-	-	$1.90X10^{5}$	$2.32X10^{4}$	$2.45X10^{0}$	$8.18X10^{0}$	$0.00X10^{0}$
K	$6.97X10^{3}$	$1.39X10^{4}$	$2.00X10^{0}$	$9.96X10^{0}$	-	$0.00X10^{0}$	$7.00X10^{-1}$	$6.97X10^{0}$	$3.49X10^{5}$	$1.04X10^{3}$	$7.80X10^{0}$	$3.35X10^{2}$	$0.00X10^{0}$
Mg	$1.08X10^{3}$	$2.44X10^{3}$	$2.25X10^{0}$	$1.74X10^{0}$	$1.24X10^{1}$	$1.40X10^{-1}$	-	-	$8.13X10^{4}$	$4.33X10^{3}$	$3.65X10^{0}$	$1.88X10^{1}$	$0.00X10^{0}$
Mn	$5.21X10^{3}$	$2.22X10^{4}$	$4.25X10^{0}$	$1.58X10^{1}$	-	$4.60X10^{-2}$	$4.60X10^{-2}$	$7.28X10^{-1}$	$4.43X10^{5}$	$1.46X10^{4}$	$4.34X10^{0}$	$3.03X10^{1}$	$0.00X10^{0}$
Na	$1.16X10^{2}$	$1.39X10^{2}$	$1.20X10^{0}$	$9.93X10^{-2}$	$4.96X10^{0}$	$2.00X10^{-2}$	-	-	$2.32X10^{3}$	$1.71X10^{3}$	$-1.47X10^{-1}$	$1.35X10^{0}$	$0.00X10^{0}$
Ni	$6.90X10^{2}$	$3.31X10^{3}$	$4.80X10^{0}$	$2.36X10^{0}$	-	$2.00X10^{-2}$	$8.40X10^{-1}$	$1.99X10^{0}$	$4.14X10^{4}$	$1.67X10^{1}$	$1.07X10^{1}$	$2.48X10^{3}$	$0.00X10^{0}$
Pb	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$5.00X10^{-3}$	$8.50X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$1.28X10^{1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Se	$6.72X10^{1}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$9.00X10^{-3}$	$5.00X10^{-3}$	$0.00X10^{0}$	$4.70X10^{3}$	$6.50X10^{0}$	$8.91X10^{0}$	$7.23X10^{2}$	$0.00X10^{0}$
V	$6.76X10^{2}$	$2.60X10^{3}$	$3.85X10^{0}$	$1.86X10^{0}$	$6.20X10^{0}$	$3.00X10^{-1}$	-	-	$3.72X10^{4}$	$2.34X10^{1}$	$1.00X10^{1}$	$1.59X10^{3}$	$2.64X10^{0}$
Zn	$5.21X10^{2}$	$4.95X10^{2}$	$9.50X10^{-1}$	$3.53X10^{-1}$	$1.18X10^{0}$	$3.00X10^{-1}$	-	-	$4.95X10^{4}$	$7.98X10^{1}$	$8.69X10^{0}$	$6.20X10^{2}$	$1.93X10^{0}$

Table 6: Heavy Metal Concentrations, Bioaccumulation, and Human & Ecological Risk Assessment in Water, Crayfish, and Sediment during the Dry Season in Ayakoromor Community

Metal	Bioaccumulation Assessment			Human Health Risk Assessment					Ecological Risk Assessment				
	Water (mg/L)	Crayfish (mg/kg)	BAF (L/kg)	EDI (mg/kg/day)	HQ	RfD	SF	CR	Sediment (mg/kg)	Bg	Igeo	CF	PLI
Ag	$2.08X10^{4}$	$5.20X10^{4}$	$2.50X10^{0}$	$3.71X10^{1}$	$3.71X10^{1}$	$1.00X10^{0}$	$5.00X10^{-1}$	$1.86X10^{1}$	$1.04X10^{6}$	$3.30X10^{-1}$	$2.10X10^{1}$	$3.15X10^{6}$	$0.00X10^{0}$
Al	$2.11X10^{1}$	$1.35X10^{2}$	$6.40X10^{0}$	$9.65X10^{-2}$	$3.22X10^{2}$	$3.00X10^{-4}$	$6.00X10^{-3}$	$5.79X10^{-4}$	$1.69X10^{3}$	$2.28X10^{3}$	$-1.02X10^{0}$	$7.41X10^{-1}$	$0.00X10^{0}$
As	$1.34X10^{2}$	$2.81X10^{2}$	$2.10X10^{0}$	$2.00X10^{-1}$	$1.00X10^{0}$	$2.00X10^{-1}$	$1.50X10^{0}$	$3.01X10^{-1}$	$4.01X10^{3}$	$2.33X10^{1}$	$6.84X10^{0}$	$1.72X10^{2}$	$0.00X10^{0}$
Ba	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-3}$	$7.00X10^{-2}$	$0.00X10^{0}$	$0.00X10^{0}$	$3.03X10^{2}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Be	$3.00X10^{3}$	$9.91X10^{3}$	$3.30X10^{0}$	$7.08X10^{0}$	-	$0.00X10^{0}$	$1.50X10^{-2}$	$1.06X10^{-1}$	$1.65X10^{5}$	$1.50X10^{-1}$	$1.95X10^{1}$	$1.10X10^{6}$	$0.00X10^{0}$
Ca	$9.07X10^{0}$	$3.27X10^{1}$	$3.60X10^{0}$	$2.33X10^{-2}$	$2.33X10^{1}$	$1.00X10^{-3}$	-	$0.00X10^{0}$	$3.63X10^{2}$	$7.61X10^{4}$	$-8.30X10^{0}$	$4.77X10^{-3}$	$0.00X10^{0}$
Cd	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-2}$	$5.00X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$4.00X10^{-1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Co	$1.15X10^{2}$	$1.55X10^{2}$	$1.35X10^{0}$	$1.11X10^{-1}$	$7.39X10^{-2}$	$1.50X10^{0}$	$1.00X10^{-2}$	$1.11X10^{-3}$	$5.17X10^{3}$	$1.98X10^{1}$	$7.44X10^{0}$	$2.61X10^{2}$	$0.00X10^{0}$
Cr	$2.68X10^{1}$	$1.87X10^{1}$	$7.00X10^{-1}$	$1.34X10^{-2}$	$3.34X10^{-1}$	$4.00X10^{-2}$	$4.10X10^{1}$	$5.49X10^{-1}$	$9.37X10^{2}$	$2.11X10^{1}$	$4.89X10^{0}$	$4.44X10^{1}$	$0.00X10^{0}$
Cu	$7.02X10^{4}$	$6.32X10^{4}$	$9.00X10^{-1}$	$4.51X10^{1}$	$6.45X10^{1}$	$7.00X10^{-1}$	-	-	$6.32X10^{6}$	$1.17X10^{1}$	$1.85X10^{1}$	$5.40X10^{5}$	$0.00X10^{0}$
Fe	$2.98X10^{3}$	$1.35X10^{4}$	$4.55X10^{0}$	$9.67X10^{0}$	$1.07X10^{3}$	$9.00X10^{-3}$	-	-	$1.93X10^{5}$	$2.32X10^{4}$	$2.47X10^{0}$	$8.34X10^{0}$	$0.00X10^{0}$
K	$5.77X10^{3}$	$1.15X10^{4}$	$2.00X10^{0}$	$8.25X10^{0}$	-	$0.00X10^{0}$	$7.00X10^{-1}$	$5.77X10^{0}$	$2.89X10^{5}$	$1.04X10^{3}$	$7.53X10^{0}$	$2.77X10^{2}$	$0.00X10^{0}$
Mg	$6.82X10^{2}$	$1.53X10^{3}$	$2.25X10^{0}$	$1.10X10^{0}$	$7.83X10^{0}$	$1.40X10^{-1}$	-	-	$5.11X10^{4}$	$4.33X10^{3}$	$2.98X10^{0}$	$1.18X10^{1}$	$0.00X10^{0}$
Mn	$5.51X10^{3}$	$2.34X10^{4}$	$4.25X10^{0}$	$1.67X10^{1}$	-	$4.60X10^{-2}$	$4.60X10^{-2}$	$7.69X10^{-1}$	$4.68X10^{5}$	$1.46X10^{4}$	$4.42X10^{0}$	$3.21X10^{1}$	$0.00X10^{0}$
Na	$7.15X10^{1}$	$8.59X10^{1}$	$1.20X10^{0}$	$6.13X10^{-2}$	$3.07X10^{0}$	$2.00X10^{-2}$	-	-	$1.43X10^{3}$	$1.71X10^{3}$	$-8.42X10^{-1}$	$8.37X10^{-1}$	$0.00X10^{0}$
Ni	$6.61X10^{1}$	$3.18X10^{2}$	$4.80X10^{0}$	$2.27X10^{-1}$	-	$2.00X10^{-2}$	$8.40X10^{-1}$	$1.91X10^{-1}$	$3.97X10^{3}$	$1.67X10^{1}$	$7.31X10^{0}$	$2.38X10^{2}$	$0.00X10^{0}$
Pb	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$5.00X10^{-3}$	$8.50X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$1.28X10^{1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Se	$5.54X10^{1}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$9.00X10^{-3}$	$5.00X10^{-3}$	$0.00X10^{0}$	$3.88X10^{3}$	$6.50X10^{0}$	$8.64X10^{0}$	$5.96X10^{2}$	$0.00X10^{0}$
V	$2.22X10^{2}$	$8.56X10^{2}$	$3.85X10^{0}$	$6.12X10^{-1}$	$2.04X10^{0}$	$3.00X10^{-1}$	-	-	$1.22X10^{4}$	$2.34X10^{1}$	$8.45X10^{0}$	$5.23X10^{2}$	$2.38X10^{0}$
Zn	$2.23X10^{2}$	$2.12X10^{2}$	$9.50X10^{-1}$	$1.52X10^{-1}$	$5.05X10^{-1}$	$3.00X10^{-1}$	-	-	$2.12X10^{4}$	$7.98X10^{1}$	$7.47X10^{0}$	$2.66X10^{2}$	$1.76X10^{0}$

Table 7: Heavy Metal Concentrations, Bioaccumulation, and Human & Ecological Risk Assessment in Water, Crayfish, and Sediment during the Wet Season in Obatebe Community

Metal	Bioaccumulation Assessment			Human Health Risk Assessment					Ecological Risk Assessment				
	Water (mg/L)	Crayfish (mg/kg)	BAF (L/kg)	EDI (mg/kg/day)	HQ	RfD	SF	CR	Sediment (mg/kg)	Bg	Igeo	CF	PLI
Ag	$2.62X10^{4}$	$6.54X10^{4}$	$2.50X10^{0}$	$4.67X10^{1}$	$4.67X10^{1}$	$1.00X10^{0}$	$5.00X10^{-1}$	$2.34X10^{1}$	$1.31X10^{6}$	$3.30X10^{-1}$	$2.13X10^{1}$	$3.97X10^{6}$	$0.00X10^{0}$
Al	$9.28X10^{1}$	$5.94X10^{2}$	$6.40X10^{0}$	$4.24X10^{-1}$	$1.41X10^{3}$	$3.00X10^{-4}$	$6.00X10^{-3}$	$2.54X10^{-3}$	$7.42X10^{3}$	$2.28X10^{3}$	$1.12X10^{0}$	$3.26X10^{0}$	$0.00X10^{0}$
As	$3.48X10^{2}$	$7.30X10^{2}$	$2.10X10^{0}$	$5.21X10^{-1}$	$2.61X10^{0}$	$2.00X10^{-1}$	$1.50X10^{0}$	$7.82X10^{-1}$	$1.04X10^{4}$	$2.33X10^{1}$	$8.22X10^{0}$	$4.48X10^{2}$	$0.00X10^{0}$
Ba	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-3}$	$7.00X10^{-2}$	$0.00X10^{0}$	$0.00X10^{0}$	$3.03X10^{2}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Be	$6.90X10^{3}$	$2.28X10^{4}$	$3.30X10^{0}$	$1.63X10^{1}$	-	$0.00X10^{0}$	$1.50X10^{-2}$	$2.44X10^{-1}$	$3.80X10^{5}$	$1.50X10^{-1}$	$2.07X10^{1}$	$2.53X10^{6}$	$0.00X10^{0}$
Ca	$1.85X10^{1}$	$6.67X10^{1}$	$3.60X10^{0}$	$4.77X10^{-2}$	$4.77X10^{1}$	$1.00X10^{-3}$	-	$0.00X10^{0}$	$7.42X10^{2}$	$7.61X10^{4}$	$-7.27X10^{0}$	$9.75X10^{-3}$	$0.00X10^{0}$
Cd	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-2}$	$5.00X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$4.00X10^{-1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Co	$5.75X10^{1}$	$7.77X10^{1}$	$1.35X10^{0}$	$5.55X10^{-2}$	$3.70X10^{-2}$	$1.50X10^{0}$	$1.00X10^{-2}$	$5.55X10^{-4}$	$2.59X10^{3}$	$1.98X10^{1}$	$6.45X10^{0}$	$1.31X10^{2}$	$0.00X10^{0}$
Cr	$2.56X10^{2}$	$1.80X10^{2}$	$7.00X10^{-1}$	$1.28X10^{-1}$	$3.21X10^{0}$	$4.00X10^{-2}$	$4.10X10^{1}$	$5.26X10^{0}$	$8.98X10^{3}$	$2.11X10^{1}$	$8.15X10^{0}$	$4.25X10^{2}$	$0.00X10^{0}$
Cu	$2.72X10^{5}$	$2.45X10^{5}$	$9.00X10^{-1}$	$1.75X10^{2}$	$2.50X10^{2}$	$7.00X10^{-1}$	-	-	$2.45X10^{7}$	$1.17X10^{1}$	$2.04X10^{1}$	$2.09X10^{6}$	$0.00X10^{0}$
Fe	$3.04X10^{3}$	$1.38X10^{4}$	$4.55X10^{0}$	$9.89X10^{0}$	$1.10X10^{3}$	$9.00X10^{-3}$	-	-	$1.98X10^{5}$	$2.32X10^{4}$	$2.51X10^{0}$	$8.53X10^{0}$	$0.00X10^{0}$
K	$7.11X10^{3}$	$1.42X10^{4}$	$2.00X10^{0}$	$1.02X10^{1}$	-	$0.00X10^{0}$	$7.00X10^{-1}$	$7.11X10^{0}$	$3.55X10^{5}$	$1.04X10^{3}$	$7.83X10^{0}$	$3.42X10^{2}$	$0.00X10^{0}$
Mg	$1.10X10^{3}$	$2.48X10^{3}$	$2.25X10^{0}$	$1.77X10^{0}$	$1.26X10^{1}$	$1.40X10^{-1}$	-	-	$8.25X10^{4}$	$4.33X10^{3}$	$3.67X10^{0}$	$1.91X10^{1}$	$0.00X10^{0}$
Mn	$5.44X10^{3}$	$2.31X10^{4}$	$4.25X10^{0}$	$1.65X10^{1}$	-	$4.60X10^{-2}$	$4.60X10^{-2}$	$7.59X10^{-1}$	$4.62X10^{5}$	$1.46X10^{4}$	$4.40X10^{0}$	$3.17X10^{1}$	$0.00X10^{0}$
Na	$1.15X10^{2}$	$1.38X10^{2}$	$1.20X10^{0}$	$9.84X10^{-2}$	$4.92X10^{0}$	$2.00X10^{-2}$	-	-	$2.30X10^{3}$	$1.71X10^{3}$	$-1.60X10^{-1}$	$1.34X10^{0}$	$0.00X10^{0}$
Ni	$7.27X10^{2}$	$3.49X10^{3}$	$4.80X10^{0}$	$2.49X10^{0}$	-	$2.00X10^{-2}$	$8.40X10^{-1}$	$2.09X10^{0}$	$4.36X10^{4}$	$1.67X10^{1}$	$1.08X10^{1}$	$2.61X10^{3}$	$0.00X10^{0}$
Pb	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$5.00X10^{-3}$	$8.50X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$1.28X10^{1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Se	$6.69X10^{1}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$9.00X10^{-3}$	$5.00X10^{-3}$	$0.00X10^{0}$	$4.68X10^{3}$	$6.50X10^{0}$	$8.91X10^{0}$	$7.20X10^{2}$	$0.00X10^{0}$
V	$6.72X10^{2}$	$2.59X10^{3}$	$3.85X10^{0}$	$1.85X10^{0}$	$6.16X10^{0}$	$3.00X10^{-1}$	-	-	$3.70X10^{4}$	$2.34X10^{1}$	$1.00X10^{1}$	$1.58X10^{3}$	$2.63X10^{0}$
Zn	$4.85X10^{2}$	$4.60X10^{2}$	$9.50X10^{-1}$	$3.29X10^{-1}$	$1.10X10^{0}$	$3.00X10^{-1}$	-	-	$4.60X10^{4}$	$7.98X10^{1}$	$8.59X10^{0}$	$5.77X10^{2}$	$1.92X10^{0}$

Table 8: Heavy Metal Concentrations, Bioaccumulation, and Human & Ecological Risk Assessment in Water, Crayfish, and Sediment during the Dry Season in Obatebe Community

	Metal		Bioaccumulation Assessment						Human Health Risk Assessment				
Metal	**Water (mg/L)**	**Crayfish (mg/kg)**	**BAF (L/kg)**	**EDI (mg/kg/day)**	**HQ**	**RfD**	**SF**	**CR**	**Sediment (mg/kg)**	**Bg**	**Igeo**	**CF**	**PLI**
Ag	$2.00X10^{4}$	$5.01X10^{4}$	$2.50X10^{0}$	$3.58X10^{1}$	$3.58X10^{1}$	$1.00X10^{0}$	$5.00X10^{-1}$	$1.79X10^{1}$	$1.00X10^{6}$	$3.30X10^{-1}$	$2.09X10^{1}$	$3.04X10^{6}$	$0.00X10^{0}$
Al	$2.04X10^{1}$	$1.31X10^{2}$	$6.40X10^{0}$	$9.33X10^{-2}$	$3.11X10^{2}$	$3.00X10^{-4}$	$6.00X10^{-3}$	$5.60X10^{-4}$	$1.63X10^{3}$	$2.28X10^{3}$	$-1.07X10^{0}$	$7.16X10^{-1}$	$0.00X10^{0}$
As	$1.33X10^{2}$	$2.80X10^{2}$	$2.10X10^{0}$	$2.00X10^{-1}$	$1.00X10^{0}$	$2.00X10^{-1}$	$1.50X10^{0}$	$3.00X10^{-1}$	$4.00X10^{3}$	$2.33X10^{1}$	$6.84X10^{0}$	$1.72X10^{2}$	$0.00X10^{0}$
Ba	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-3}$	$7.00X10^{-2}$	$0.00X10^{0}$	$0.00X10^{0}$	$3.03X10^{2}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Be	$3.05X10^{3}$	$1.01X10^{4}$	$3.30X10^{0}$	$7.20X10^{0}$	-	$0.00X10^{0}$	$1.50X10^{-2}$	$1.08X10^{-1}$	$1.68X10^{5}$	$1.50X10^{-1}$	$1.95X10^{1}$	$1.12X10^{6}$	$0.00X10^{0}$
Ca	$8.98X10^{0}$	$3.23X10^{1}$	$3.60X10^{0}$	$2.31X10^{-2}$	$2.31X10^{1}$	$1.00X10^{-3}$	-	$0.00X10^{0}$	$3.59X10^{2}$	$7.61X10^{4}$	$-8.31X10^{0}$	$4.72X10^{-3}$	$0.00X10^{0}$
Cd	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-2}$	$5.00X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$4.00X10^{-1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Co	$1.14X10^{2}$	$1.54X10^{2}$	$1.35X10^{0}$	$1.10X10^{-1}$	$7.32X10^{-2}$	$1.50X10^{0}$	$1.00X10^{-2}$	$1.10X10^{-3}$	$5.13X10^{3}$	$1.98X10^{1}$	$7.43X10^{0}$	$2.59X10^{2}$	$0.00X10^{0}$
Cr	$2.60X10^{1}$	$1.82X10^{1}$	$7.00X10^{-1}$	$1.30X10^{-2}$	$3.25X10^{-1}$	$4.00X10^{-2}$	$4.10X10^{1}$	$5.34X10^{-1}$	$9.11X10^{2}$	$2.11X10^{1}$	$4.85X10^{0}$	$4.32X10^{1}$	$0.00X10^{0}$
Cu	$6.85X10^{4}$	$6.16X10^{4}$	$9.00X10^{-1}$	$4.40X10^{1}$	$6.29X10^{1}$	$7.00X10^{-1}$	-	-	$6.16X10^{6}$	$1.17X10^{1}$	$1.84X10^{1}$	$5.27X10^{5}$	$0.00X10^{0}$
Fe	$2.82X10^{3}$	$1.28X10^{4}$	$4.55X10^{0}$	$9.16X10^{0}$	$1.02X10^{3}$	$9.00X10^{-3}$	-	-	$1.83X10^{5}$	$2.32X10^{4}$	$2.40X10^{0}$	$7.90X10^{0}$	$0.00X10^{0}$
K	$5.58X10^{3}$	$1.12X10^{4}$	$2.00X10^{0}$	$7.98X10^{0}$	-	$0.00X10^{0}$	$7.00X10^{-1}$	$5.58X10^{0}$	$2.79X10^{5}$	$1.04X10^{3}$	$7.48X10^{0}$	$2.68X10^{2}$	$0.00X10^{0}$
Mg	$6.76X10^{2}$	$1.52X10^{3}$	$2.25X10^{0}$	$1.09X10^{0}$	$7.76X10^{0}$	$1.40X10^{-1}$	-	-	$5.07X10^{4}$	$4.33X10^{3}$	$2.96X10^{0}$	$1.17X10^{1}$	$0.00X10^{0}$
Mn	$5.31X10^{3}$	$2.26X10^{4}$	$4.25X10^{0}$	$1.61X10^{1}$	-	$4.60X10^{-2}$	$4.60X10^{-2}$	$7.42X10^{-1}$	$4.52X10^{5}$	$1.46X10^{4}$	$4.37X10^{0}$	$3.09X10^{1}$	$0.00X10^{0}$
Na	$6.74X10^{1}$	$8.09X10^{1}$	$1.20X10^{0}$	$5.78X10^{-2}$	$2.89X10^{0}$	$2.00X10^{-2}$	-	-	$1.35X10^{3}$	$1.71X10^{3}$	$-9.28X10^{-1}$	$7.88X10^{-1}$	$0.00X10^{0}$
Ni	$7.04X10^{1}$	$3.38X10^{2}$	$4.80X10^{0}$	$2.41X10^{-1}$	-	$2.00X10^{-2}$	$8.40X10^{-1}$	$2.03X10^{-1}$	$4.22X10^{3}$	$1.67X10^{1}$	$7.40X10^{0}$	$2.53X10^{2}$	$0.00X10^{0}$
Pb	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$5.00X10^{-3}$	$8.50X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$1.28X10^{1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Se	$5.61X10^{1}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$9.00X10^{-3}$	$5.00X10^{-3}$	$0.00X10^{0}$	$3.92X10^{3}$	$6.50X10^{0}$	$8.65X10^{0}$	$6.04X10^{2}$	$0.00X10^{0}$
V	$2.19X10^{2}$	$8.45X10^{2}$	$3.85X10^{0}$	$6.04X10^{-1}$	$2.01X10^{0}$	$3.00X10^{-1}$	-	-	$1.21X10^{4}$	$2.34X10^{1}$	$8.43X10^{0}$	$5.16X10^{2}$	$2.38X10^{0}$
Zn	$2.21X10^{2}$	$2.10X10^{2}$	$9.50X10^{-1}$	$1.50X10^{-1}$	$5.01X10^{-1}$	$3.00X10^{-1}$	-	-	$2.10X10^{4}$	$7.98X10^{1}$	$7.46X10^{0}$	$2.64X10^{2}$	$1.76X10^{0}$

Table 9: Heavy Metal Concentrations, Bioaccumulation, and Human & Ecological Risk Assessment in Water, Crayfish, and Sediment during the Wet Season in Gbekebor Community

Metal	Bioaccumulation Assessment			Human Health Risk Assessment					Metal				
	Water (mg/L)	Crayfish (mg/kg)	BAF (L/kg)	EDI (mg/kg/day)	HQ	RfD	SF	CR	Sediment (mg/kg)	Bg	Igeo	CF	PLI
Ag	$2.82X10^{4}$	$7.06X10^{4}$	$2.50X10^{0}$	$5.04X10^{1}$	$5.04X10^{1}$	$1.00X10^{0}$	$5.00X10^{-1}$	$2.52X10^{1}$	$1.41X10^{6}$	$3.30X10^{-1}$	$2.14X10^{1}$	$4.28X10^{6}$	$0.00X10^{0}$
Al	$8.76X10^{1}$	$5.61X10^{2}$	$6.40X10^{0}$	$4.00X10^{-1}$	$1.33X10^{3}$	$3.00X10^{-4}$	$6.00X10^{-3}$	$2.40X10^{-3}$	$7.01X10^{3}$	$2.28X10^{3}$	$1.04X10^{0}$	$3.07X10^{0}$	$0.00X10^{0}$
As	$3.29X10^{2}$	$6.90X10^{2}$	$2.10X10^{0}$	$4.93X10^{-1}$	$2.46X10^{0}$	$2.00X10^{-1}$	$1.50X10^{0}$	$7.39X10^{-1}$	$9.86X10^{3}$	$2.33X10^{1}$	$8.14X10^{0}$	$4.23X10^{2}$	$0.00X10^{0}$
Ba	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-3}$	$7.00X10^{-2}$	$0.00X10^{0}$	$0.00X10^{0}$	$3.03X10^{2}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Be	$6.92X10^{3}$	$2.28X10^{4}$	$3.30X10^{0}$	$1.63X10^{1}$	-	$0.00X10^{0}$	$1.50X10^{-2}$	$2.45X10^{-1}$	$3.81X10^{5}$	$1.50X10^{-1}$	$2.07X10^{1}$	$2.54X10^{6}$	$0.00X10^{0}$
Ca	$1.91X10^{1}$	$6.89X10^{1}$	$3.60X10^{0}$	$4.92X10^{-2}$	$4.92X10^{1}$	$1.00X10^{-3}$	-	$0.00X10^{0}$	$7.65X10^{2}$	$7.61X10^{4}$	$-7.22X10^{0}$	$1.01X10^{-2}$	$0.00X10^{0}$
Cd	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$2.00X10^{-2}$	$5.00X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$4.00X10^{-1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Co	$6.24X10^{1}$	$8.42X10^{1}$	$1.35X10^{0}$	$6.01X10^{-2}$	$4.01X10^{-2}$	$1.50X10^{0}$	$1.00X10^{-2}$	$6.01X10^{-4}$	$2.81X10^{3}$	$1.98X10^{1}$	$6.56X10^{0}$	$1.42X10^{2}$	$0.00X10^{0}$
Cr	$2.63X10^{2}$	$1.84X10^{2}$	$7.00X10^{-1}$	$1.32X10^{-1}$	$3.29X10^{0}$	$4.00X10^{-2}$	$4.10X10^{1}$	$5.40X10^{0}$	$9.21X10^{3}$	$2.11X10^{1}$	$8.19X10^{0}$	$4.37X10^{2}$	$0.00X10^{0}$
Cu	$2.63X10^{5}$	$2.36X10^{5}$	$9.00X10^{-1}$	$1.69X10^{2}$	$2.41X10^{2}$	$7.00X10^{-1}$	-	-	2.36X10+07	$1.17X10^{1}$	$2.04X10^{1}$	$2.02X10^{6}$	$0.00X10^{0}$
Fe	$3.05X10^{3}$	$1.39X10^{4}$	$4.55X10^{0}$	$9.91X10^{0}$	$1.10X10^{3}$	$9.00X10^{-3}$	-	-	$1.98X10^{5}$	$2.32X10^{4}$	$2.51X10^{0}$	$8.55X10^{0}$	$0.00X10^{0}$
K	$6.82X10^{3}$	$1.36X10^{4}$	$2.00X10^{0}$	$9.74X10^{0}$	-	$0.00X10^{0}$	$7.00X10^{-1}$	$6.82X10^{0}$	$3.41X10^{5}$	$1.04X10^{3}$	$7.77X10^{0}$	$3.28X10^{2}$	$0.00X10^{0}$
Mg	$1.07X10^{3}$	$2.40X10^{3}$	$2.25X10^{0}$	$1.72X10^{0}$	$1.23X10^{1}$	$1.40X10^{-1}$	-	-	$8.01X10^{4}$	$4.33X10^{3}$	$3.62X10^{0}$	$1.85X10^{1}$	$0.00X10^{0}$
Mn	$5.25X10^{3}$	$2.23X10^{4}$	$4.25X10^{0}$	$1.59X10^{1}$	-	$4.60X10^{-2}$	$4.60X10^{-2}$	$7.33X10^{-1}$	$4.46X10^{5}$	$1.46X10^{4}$	$4.35X10^{0}$	$3.05X10^{1}$	$0.00X10^{0}$
Na	$1.21X10^{2}$	$1.45X10^{2}$	$1.20X10^{0}$	$1.04X10^{-1}$	$5.19X10^{0}$	$2.00X10^{-2}$	-	-	$2.42X10^{3}$	$1.71X10^{3}$	$-8.20X10^{-2}$	$1.42X10^{0}$	$0.00X10^{0}$
Ni	$7.04X10^{2}$	$3.38X10^{3}$	$4.80X10^{0}$	$2.41X10^{0}$	-	$2.00X10^{-2}$	$8.40X10^{-1}$	$2.03X10^{0}$	$4.22X10^{4}$	$1.67X10^{1}$	$1.07X10^{1}$	$2.53X10^{3}$	$0.00X10^{0}$
Pb	$0.00X10^{0}$	$0.00X10^{0}$	-	$0.00X10^{0}$	$0.00X10^{0}$	$5.00X10^{-3}$	$8.50X10^{-3}$	$0.00X10^{0}$	$0.00X10^{0}$	$1.28X10^{1}$	-	$0.00X10^{0}$	$0.00X10^{0}$
Se	$6.61X10^{1}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$0.00X10^{0}$	$9.00X10^{-3}$	$5.00X10^{-3}$	$0.00X10^{0}$	$4.63X10^{3}$	$6.50X10^{0}$	$8.89X10^{0}$	$7.12X10^{2}$	$0.00X10^{0}$
V	$6.78X10^{2}$	$2.61X10^{3}$	$3.85X10^{0}$	$1.86X10^{0}$	$6.21X10^{0}$	$3.00X10^{-1}$	-	-	$3.73X10^{4}$	$2.34X10^{1}$	$1.01X10^{1}$	$1.59X10^{3}$	$2.64X10^{0}$
Zn	$5.25X10^{2}$	$4.99X10^{2}$	$9.50X10^{-1}$	$3.56X10^{-1}$	$1.19X10^{0}$	$3.00X10^{-1}$	-	-	$4.99X10^{4}$	$7.98X10^{1}$	$8.70X10^{0}$	$6.25X10^{2}$	$1.93X10^{0}$

Table 10: Heavy Metal Concentrations, Bioaccumulation, and Human & Ecological Risk Assessment in Water, Crayfish, and Sediment during the Dry Season in the Gbekebor Community

Metal	Bioaccumulation Assessment			Human Health Risk Assessment					Metal				
	Water (mg/L)	Crayfish (mg/kg)	BAF (L/kg)	EDI (mg/kg/day)	HQ	RfD	SF	CR	Sediment (mg/kg)	Bg	Igeo	CF	PLI
Ag	$2.12X10^{4}$	$5.3X10^{4}$	$2.5X10^{0}$	$3.8X10^{1}$	$3.8X10^{1}$	$1.0X10^{0}$	$5.0X10^{-1}$	$1.9X10^{1}$	$1.1X10^{6}$	$3.3X10^{-1}$	$2.1X10^{1}$	$3.2X10^{6}$	$0.0X10^{0}$
Al	$2.17X10^{1}$	$1.4X10^{2}$	$6.4X10^{0}$	$9.9X10^{-2}$	$3.3X10^{2}$	$3.0X10^{-4}$	$6.0X10^{-3}$	$6.0X10^{-4}$	$1.7X10^{3}$	$2.3X10^{3}$	$-9.8X10^{-1}$	$7.6X10^{-1}$	$0.0X10^{0}$
As	$1.35X10^{2}$	$2.8X10^{2}$	$2.1X10^{0}$	$2.0X10^{-1}$	$1.0X10^{0}$	$2.0X10^{-1}$	$1.5X10^{0}$	$3.0X10^{-1}$	$4.0X10^{3}$	$2.3X10^{1}$	$6.9X10^{0}$	$1.7X10^{2}$	$0.0X10^{0}$
Ba	$0.00X10^{0}$	$0.0X10^{0}$	-	$0.0X10^{0}$	$0.0X10^{0}$	$2.0X10^{-3}$	$7.0X10^{-2}$	$0.0X10^{0}$	$0.0X10^{0}$	$3.0X10^{2}$	-	$0.0X10^{0}$	$0.0X10^{0}$
Be	$2.87X10^{3}$	$9.5X10^{3}$	$3.3X10^{0}$	$6.8X10^{0}$	-	$0.0X10^{0}$	$1.5X10^{-2}$	$1.0X10^{-1}$	$1.6X10^{5}$	$1.5X10^{-1}$	$1.9X10^{1}$	$1.1X10^{6}$	$0.0X10^{0}$
Ca	$9.09X10^{0}$	$3.3X10^{1}$	$3.6X10^{0}$	$2.3X10^{-2}$	$2.3X10^{1}$	$1.0X10^{-3}$	-	$0.0X10^{0}$	$3.6X10^{2}$	$7.6X10^{4}$	$-8.3X10^{0}$	$4.8X10^{-3}$	$0.0X10^{0}$
Cd	$0.00X10^{0}$	$0.0X10^{0}$	-	$0.0X10^{0}$	$0.0X10^{0}$	$2.0X10^{-2}$	$5.0X10^{-3}$	$0.0X10^{0}$	$0.0X10^{0}$	$4.0X10^{-1}$	-	$0.0X10^{0}$	$0.0X10^{0}$
Co	$1.15X10^{2}$	$1.6X10^{2}$	$1.4X10^{0}$	$1.1X10^{-1}$	$7.4X10^{-2}$	$1.5X10^{0}$	$1.0X10^{-2}$	$1.1X10^{-3}$	$5.2X10^{3}$	$2.0X10^{1}$	$7.4X10^{0}$	$2.6X10^{2}$	$0.0X10^{0}$
Cr	$2.70X10^{1}$	$1.9X10^{1}$	$7.0X10^{-1}$	$1.3X10^{-2}$	$3.4X10^{-1}$	$4.0X10^{-2}$	$4.1X10^{1}$	$5.5X10^{-1}$	$9.4X10^{2}$	$2.1X10^{1}$	$4.9X10^{0}$	$4.5X10^{1}$	$0.0X10^{0}$
Cu	$6.95X10^{4}$	$6.3X10^{4}$	$9.0X10^{-1}$	$4.5X10^{1}$	$6.4X10^{1}$	$7.0X10^{-1}$	-	-	$6.3X10^{6}$	$1.2X10^{1}$	$1.8X10^{1}$	$5.3X10^{5}$	$0.0X10^{0}$
Fe	$3.05X10^{3}$	$1.4X10^{4}$	$4.6X10^{0}$	$9.9X10^{0}$	$1.1X10^{3}$	$9.0X10^{-3}$	-	-	$2.0X10^{5}$	$2.3X10^{4}$	$2.5X10^{0}$	$8.6X10^{0}$	$0.0X10^{0}$
K	$5.76X10^{3}$	$1.2X10^{4}$	$2.0X10^{0}$	$8.2X10^{0}$	-	$0.0X10^{0}$	$7.0X10^{-1}$	$5.8X10^{0}$	$2.9X10^{5}$	$1.0X10^{3}$	$7.5X10^{0}$	$2.8X10^{2}$	$0.0X10^{0}$
Mg	$6.86X10^{2}$	$1.5X10^{3}$	$2.3X10^{0}$	$1.1X10^{0}$	$7.9X10^{0}$	$1.4X10^{-1}$	-	-	$5.1X10^{4}$	$4.3X10^{3}$	$3.0X10^{0}$	$1.2X10^{1}$	$0.0X10^{0}$
Mn	$5.34X10^{3}$	$2.3X10^{4}$	$4.3X10^{0}$	$1.6X10^{1}$	-	$4.6X10^{-2}$	$4.6X10^{-2}$	$7.5X10^{-1}$	$4.5X10^{5}$	$1.5X10^{4}$	$4.4X10^{0}$	$3.1X10^{1}$	$0.0X10^{0}$
Na	$7.30X10^{1}$	$8.8X10^{1}$	$1.2X10^{0}$	$6.3X10^{-2}$	$3.1X10^{0}$	$2.0X10^{-2}$	-	-	$1.5X10^{3}$	$1.7X10^{3}$	$-8.1X10^{-1}$	$8.5X10^{-1}$	$0.0X10^{0}$
Ni	$6.62X10^{1}$	$3.2X10^{2}$	$4.8X10^{0}$	$2.3X10^{-1}$	-	$2.0X10^{-2}$	$8.4X10^{-1}$	$1.9X10^{-1}$	$4.0X10^{3}$	$1.7X10^{1}$	$7.3X10^{0}$	$2.4X10^{2}$	$0.0X10^{0}$
Pb	$0.00X10^{0}$	$0.0X10^{0}$	-	$0.0X10^{0}$	$0.0X10^{0}$	$5.0X10^{-3}$	$8.5X10^{-3}$	$0.0X10^{0}$	$0.0X10^{0}$	$1.3X10^{1}$	-	$0.0X10^{0}$	$0.0X10^{0}$
Se	$5.36X10^{1}$	$0.0X10^{0}$	$0.0X10^{0}$	$0.0X10^{0}$	$0.0X10^{0}$	$9.0X10^{-3}$	$5.0X10^{-3}$	$0.0X10^{0}$	$3.8X10^{3}$	$6.5X10^{0}$	$8.6X10^{0}$	$5.8X10^{2}$	$0.0X10^{0}$
V	$2.28X10^{2}$	$8.8X10^{2}$	$3.9X10^{0}$	$6.3X10^{-1}$	$2.1X10^{0}$	$3.0X10^{-1}$	-	-	$1.3X10^{4}$	$2.3X10^{1}$	$8.5X10^{0}$	$5.4X10^{2}$	$2.4X10^{0}$
Zn	$2.23X10^{2}$	$2.1X10^{2}$	$9.5X10^{-1}$	$1.5X10^{-1}$	$5.0X10^{-1}$	$3.0X10^{-1}$	-	-	$2.1X10^{4}$	$8.0X10^{1}$	$7.5X10^{0}$	$2.7X10^{2}$	$1.8X10^{0}$

Discussions

A. Seasonal Variation in Heavy Metal Contamination

Table 1 (Wet Season) and Table 2 (Dry Season) show considerable levels of metal concentration fluctuation. Water concentration is higher in the wet season, which Akhtar *et al*. (2021) attributed to an increase in the surface runoff, an increase in leaching from associated soils, and in mobilization of pollutants from industrial and domestic sources. In contrast, sediments have slightly higher metal concentrations during the dry season, implying metal deposition and reduced dilution effects during the time of lower water levels. For example, the Cu concentrations in the water changed from 6.95×10^4 mg/L for the wet season to 7.12×10^4 mg/L for the dry season. On the other hand, Ag concentration varied little (2.12×10^4 mg/L in the wet season and 2.09×10^4 mg/L in the dry season). These results suggest that despite seasonal changes, Cu is still a dominant contaminant since continuous industrial discharges, municipal wastewater effluents, and possibly leaching from agricultural inputs may prevail. Like sediment, Fe and Mn concentrations in sediment increased during the dry season, suggesting that adsorption mechanisms were stronger or could be associated with the signs of hydrologic changes and sediment components.

Table 3 (Wet Season) and Table 4 (Dry Season) reveal that heavy metal concentrations were quite different and significantly seasonal across all different environmental matrices (water, crayfish, and sediment) in the Odimodi community. The data also revealed that some metallic elements, including Silver (Ag), Aluminium (Al), Arsenic (As), Chromium (Cr), and Copper (Cu), have significantly higher concentrations during the wet season, which indicates a seasonal pattern of pollutant dispersion. A reduction in the concentration of Ag in the water was observed from 2.92×10^4 mg/L in Table 3 to 2.04×10^4 mg/L in Table 4. Likewise, Arsenic (As) levels in water are reduced from 3.43×10^2 mg/L in the wet season (Table 3) to 1.42×10^2 mg/L in the dry season (Table 4) due to increased runoff and leaching in the rainy seasons. The higher sediment-bound metal concentrations recorded in Table 4 indicate that accumulation processes dominate in the dry season since water flow reduction favours sedimentation and metal adsorption.

As shown in Table 5 (Wet Season) and Table 6 (Dry Season), there are very large seasonal variations in heavy metal concentrations, and they occur within different environmental matrices (water, crayfish, and sediment) in the Ayakoromor community. Data show that some metals like Silver (Ag), Aluminium (Al), Arsenic (As), and Copper (Cu) have higher concentrations during the wet season rather than the dry season, implying that season has impacted pollutant dispersion. Table 5 and Table 1 show that with the decreasing of hydrological dynamics in sediment, the Ag concentration is 4.52×10^3mg/kg and reaches 1.96×10^3mg/kg in Table 6 (Dry

Season). Similarly, levels of Arsenic (As) found in water in the wet season (Table 5) was reduced to 1.42×10^{2} mg/L in the dry season (Table 6). This indicates that metal transportation in the wet season is dominated by intense surface runoff, while during the dry season, metal retention dominates through sedimentation.

The concentration of heavy metals in water, crayfish, and sediment during the wet season in the Obatebe Community are presented in Table 7 and for the dry season in Table 8. Notably, elevated levels of silver (Ag), aluminium (Al), arsenic (As), and copper (Cu) were found in the two seasons, suggesting anthropogenic sources. Water from the wet season contained Ag concentrations of 2.62×10^{4} mg/L and 2.00×10^{4} mg/L in the dry season, indicating that the contamination was persistent. This sustenance of high levels of Ag in aquatic ecosystems is consistent with previous findings by Aransiola *et al*. (2024), who found increased Ag in industrial zones. Similar to bioaccumulation in crayfish. The bioaccumulation of Ag in wet and dry season Crayfish (Table 7) was respectively 6.54×10^{4}mg/kg and 5.01×10^{4}mg/kg [dry season (Table 8)], which signifies higher bioaccumulation in the wet season. Across both seasons, the highest bioaccumulation factor (BAF) for Ag (2.50) and Cu (9.00) was observed for the bioaccumulation factor. According to Samuel *et al*. (2021), Cu and Ag have a high affinity for aquatic organisms because they bind to their protein.

The concentration of heavy metals in water, crayfish, and the sediment of the Gbekebor Community during the wet season is presented in Table 9 revealed that all three media show significantly high levels of Copper (Cu), Iron (Fe), and Silver (Ag), where Cu records an extremely high concentration of 2.36×10^{7}mg/kg with sediment. The study suggests that the Cu contamination in the water system is presumably due to industrial discharges, mining activities, or agricultural runoff. Table 10, which represents the dry season, has a lower Cu sediment concentration of 6.3×10^{6}mg/kg, suggesting seasonal variations in deposition and sediment retention of metals. Low runoff and dilution effects from decreased rainfall could account for the reduced concentration in the dry season. Also, Nickel (Ni) and Chromium (Cr) respectively had high bioaccumulation potential with the Bioaccumulation Factor (BAF) values in both seasons. These findings corroborate studies by Taka *et al*. (2022) that elsewhere, heavy metal concentrations in aquatic ecosystems are greatly dependent on season due to the dynamics of water flow and rates of precipitation.

B. Comparison with Previous Studies

A review of similar studies from across different aquatic ecosystems indicates that Burutu, Odimodi, Obatebe, Ayakoromor, and Gbekebor are indeed heavily polluted Nigerian water bodies. Cu concentrations in this study (6.95×10^{4} - 7.12×10^{4} mg/L) are significantly high (greater by factors ranging from 2.11 to 4.44) than those reported

in the Niger Delta region (Anyanwu *et al*., 2023; Cu concentrations ranged 1.2 to 5.3 × 10^4 mg/L). Like Agboola (2024) and Chris *et al*. (2024) observed in Nigerian estuaries, Ag concentrations in the Burutu area are more severe than reported for Nigerian estuaries, and it is likely that the more severe Ag contamination arises from uncontrolled effluent discharge and artisanal activities. The Cu and Ag contamination in sediments of Burutu is also confirmed by CF and PLI values to exceed those documented for other places, Lagos Lagoon (Nubi *et al*., 2024). These metals are classified as extreme pollution category (CF > 10^6), which is in line with the concern that these metals have a long-term environmental persistence and may cause ecological damage. These results agree with previous studies conducted in the Warri River (Agori *et al*., 2021; Ekene & Okoro, 2023) that showed Fe concentration below 1.8 × 10^3 mg/L but above 1.8 × 10^5 mg/L in Burutu.

Table 3 and Table 4 show differences from past studies conducted in similarly riverine communities, and likewise, Table 3 and Table 4 show similarities to the previous studies. For example, Chinedu & Chukwuemeka (2018), and other studies in the Niger Delta region (e.g., in Table 3and Table 4) found elevated Cu and Cr in sediment, similar to what is reported in Table 3and Table 4. Nevertheless, the high bioaccumulation of Ag and Be reported in Table 3 and Table 4 is not in accordance with previous studies in other Niger Delta communities, suggesting possibly unique sources of contamination in Odimodi. Furthermore, the values of human health risk assessment in Tables 3 and 4 (HQ >1 for multiple metals) are consistent with the findings of studies in severely polluted freshwater systems (Onyena *et al*., 2024), particularly China's Pearl River Delta, and were determined to present serious non-carcinogenic health risks.

Both similarities and deviations are shown in comparing the results from Table 5 and Table 6 with previous studies. Levels of Cu and Cr in sediment in the Niger Delta region (like (Afolabi & Adesope, 2022; Anyanwu *et al*., 2023 & Ibezim-Ezeani *et al*., 2022) have been reported at higher than studies in Table 5 and Table 6. Nevertheless, these high bioaccumulations of Ag and Be in Table 5 and Table 6 are not known in other Niger Delta communities, which is an indication that Ayakoromor may possibly have specific contamination sources that are connected with local industry. Second, the human health risk assessment values (HQ > 1 for multiple metals in Table 5 and Table 6) are consistent with health risks from research on highly polluted freshwater ecosystems as those located in the China's Pearl River Delta (Jin *et al*., 2023 & Yu *et al*., 2021), where high seafood related heavy metal exposure posed significant non carcinogenic health risks. Unlike studies of the Pb and Cd contamination from industrialised cities, however, Table 5 and Table 6 confirm that Pb and Cd are very

negligible in Ayakoromor, supporting the idea that the pollution sources in Ayakoromor are different from those of urban-industrial areas.

The results of the Obatebe community have some similarities to prior research. However, the contamination levels in this study are more notable, and we reported similar high bioaccumulation of Cu and Ag as was reported in Hussain *et al*. (2021). Al HQ values obtained in the present study (1.41×10^3) are greater than Ighariemu *et al*. (2023) and thus serve as a more severe risk scenario in the Obatebe Community. Similarly, the carcinogenic risk from As ($7.82x10^{-1}$, Table 7) is much higher than Iyorah & Ueezi (2024) reported in a related study on aquatic heavy metal contamination in neritic areas. The seasonal trends observed in Tables 7 and 8 also align with findings from Li *et al*. (2022), who reported greater heavy metal bioaccumulation and pollution load during the wet season due to runoff and increased mobilization of contaminants.

The heavy metal levels in the Gbekebor Community are much higher than previous studies on similar riverine ecosystems. For instance, Ibezim-Ezeani & Ihunwo (2023) found lower Cu sediment concentrations (1.5×10^6mg/kg) in a similar study conducted in the Niger Delta, indicating that Gbekebor Community cannot be as polluted as they are because of anthropogenic activities. Awofolu *et al*. (2017) also report lower As concentrations (1.5×10^2mg/kg) in urban water bodies than 3.29×10^2mg/kg in Table 9. Additionally, according to the findings from Guliyev *et al*. (2024), Ni and Cr have the potential to accumulate strongly in fish and crustaceans. Nevertheless, the increased EDI and HQ values in Tables 9 and 10 indicate a more serious risk to health in GBek10bor, perhaps because of localised industrial pollutions.

Bioaccumulation and Ecotoxicological Implications

The Bioaccumulation Factor (BAF) values presented in Tables 1 and 2 in Burutu show that Cu and Fe are particularly high in bioaccumulation in crayfish, thus having a high impact on aquatic organisms and further up the food chain. Cu BAF values of 9.0 were recorded in this study, which is a lot higher than 5.4 recorded in the Lagos Lagoon (Adeniyi *et al*., 2024 and Jolaosho *et al*., 2024). Since Burutu's aquatic fish are more susceptible to the uptake of metals, it may be merely due to longer exposure duration, availability of metal species, or other ecosystem-specific factors like pH and interactions with organic matter. This is motivated further by the accumulation of Mn (BAF = 4.25 and Fe (BAF = 4.6 through bioaccumulation (BAF), where metals accumulate in higher concentrations with a rise in the food chain. Fe BAF values obtained in this study are higher than those reported in previous studies in the Cross River estuary (Ntinya *et al*., 2023 & da Silver *et al*., 2024) 3.1 and 3.5, suggesting that Burutu's ecosystem has a greater bioaccumulation potential. These findings have

important implications for increased metal retention in aquatic, or potential seafood consumers, leading to higher human exposure risks.

The fact that some metals accumulate strongly in crayfish, as shown in Table 4 (Wet Season) and Table 6 (Dry Season), can lead to serious human consumer risk. For example, Table 3 shows that although Copper (Cu) has a BAF of 0.90 L/kg in the wet season, the BAF remains the same in the dry season in Table 4 (also the among varying seasons itself), indicating that its bioaccumulation is sustained. In Tables 3 and 4, the potential long-term accumulation of As in aquatic organisms and its risks to human consumers are proven further since Arsenic (As) BAF is similarly 2.10 L/kg across both seasons. Table 3 (Wet Season) and Table 4 (Dry Season) show the Risk of human consumption of contaminated seafood by using the Estimated Daily Intake (EDI) values. In Table 7, the EDI for Cu is 1.87×10^{2}mg/kg/day, four times higher than other Table 8 (Dry Season), 4.67×10^{1}mg/kg/day. Thus, results show that the crayfish consumed by Odimodi individuals have a much higher metal intake risk in terms of the wet season. Additionally, the values of the Hazard Quotient (HQ) in Table 3 and Table 4 indicate that the HQ values of Al, Fe, and Cr exceed 1 in both seasons, meaning that they pose noncarcinogenic health risks due to chronic exposure by eating crayfish.

Table 6 (Wet Season) and Table 8 (Dry Season) depict the bioaccumulation assessment factor (BAF) of the crayfish; thus, some metals have lots of tendency to accumulate in crayfish and pose a great risk to human consumers. The data in Table 5 indicates that the BAF of Cu during the wet season is 2.10 L/kg, and in Table 6, it slightly decreases to 1.86 L/kg in the dry season. This indicates that some sort of bioaccumulation persists season after season but is more pronounced during the wet season, as water is more available for metals. Human exposure risks from crayfish exposure are further delineated by the Estimated Daily Intake (EDI) values reported in Table 5 (Wet Season) and Table 6 (Dry Season). Table 5 carries EDI for Cu of 1.87×10^{2}mg/kg/day, which is much higher than that (4.67×10^{1}) in Table 6 (Dry Season). This is a worrisome trend as it indicates that individuals in Ayakoromor are exposed to higher metal concentrations during the wet season. Additionally, the values in Table 5 and Table 6 of the Hazard Quotient (HQ) indicate that the Al, Fe, and Cr are HQ values greater than 1 in both seasons, which implies that these chemicals present non-carcinogenic health risks. The long-term cancer risk from arsenic contamination is also evidenced by the fact that the As Carcinogenic Risk reported in Table 5 and Table 6 also exceeds the acceptable threshold of $1.0x10^{-4}$.

Ecological Risk Assessment, Pollution Load Index, Human Health Risks and Public Health Implications

Hazard Quotient (HQ) and Cancer Risk (CR) suggest long-term Cu, Ag, and As exposure in Burutu is a health hazard to the local population. HQ values for Cu (6.54 in dry season) and Ag (3.74) are very high (>1), indicating major non-carcinogenic risks. The higher HQ values found in Burutu imply that the residents are at greater risk of exposure compared to those in the Warri River (HQ = 4.2) and Lagos Lagoon (HQ = 3.8) described by Jolaosho *et al*. (2024) & Adeniyi *et al*. (2024). Also, As (3.08×10^{-1}) and Ni (1.9×10^{-1}) are above the 1.0×10^{-4} safety threshold, and hence their CR are high, thus heightening the concern for their carcinogenic potential. Studies in the Port Harcourt estuary (Ngoka *et al*., 2021) showed lower CR values of As (1.7×10^{-1}), meaning that residents of Burutu might face higher noxious health impacts in the long run, especially chronic diseases such as cancer, kidney and neurological disorders. Many of the local communities depend largely on seafood for their diet, and it is imperative that we intervene to reduce exposure and prevent problems of bioaccumulation associated with poor health.

Contents of Table 3 (Wet Season) and Table 4 (Dry Season) describe the ecological risk indicators, such as contamination factor (CF), geo accumulation index (Igeo) and pollution load index (PLI). The data also indicate severe Cu contamination in the sediment. Table 3 reveals sediment Cu levels of 2.62×10^{7}mg/kg of the sediment in the wet season and 6.54×10^{6}mg/kg in the dry season, which supports the hypothesis of seasonal variation in sediment-derived contamination. Tables 3 and 4 show that Cu is one of the most significant pollutants with a high ecological risk value. However, Table 3 and Table 4 exhibit relatively lower concentrations of Pb and Cd, implying that industrial emissions and waste discharge to Odimodi are not very affected by these metals as is the case with Cu, Fe, Cr, *et al*. This is further reinforced if the Igeo values for Cr, Mn and Ni in Tables 3 and 4 are classified under moderate to significant pollution categories, which implies that anthropogenic inputs such as industrial runoff and agricultural activities could have contributed to these values.

In Table 5 (Wet Season) and Table 6 (Dry season), the study summarises the ecological risk indicators such as contamination factor (CF), geo accumulation index (Igeo) and pollution load index (PLI). The data indicate that Cu contamination in the sediment is severe. As shown in Table 5, the Cu level of sediment reaches 2.06×10^{6}mg/kg in the wet season and 5.40×10^{5}mg/kg in the dry season (Table 6), which confirms the seasonal variation of sediment contamination. It is also witnessed from Table 5 and Table 6 that Cu is one of the major pollutants, with high ecological risk potential for aquatic organisms at Ayakoromor. Furthermore, Table 5 and Table 6 suggest that Pb and Cd have relatively low concentration levels, implying that industrial emissions

and wastes in Ayakoromor were to a certain extent not affected by these metals as much as other pollutants such as Cu, Fe and Cr. The values of Igeo for Ag, Cr and Fe in Table 5 and Table 6 place them in moderate to significant pollution categories, again indicating the likely anthropogenic inputs from industrial or agricultural sources.

Potential human health risks were evaluated based on the Estimated Daily Intake (EDI) and Hazard Quotient (HQ). They are shown in Table 7 and Table 8 with a value of 1.75×10^{2}mg/kg/day in the wet season and 4.40×10^{1}mg/kg/day in the dry season. EDI values (Table 7: 4.67×10^{1}mg/kg/day and Table 8: 3.58×10^{1}mg/kg/day) of Ag exceeded the percentages shown in Tables B and C, suggesting possible risks to consumers. Haq values more than 1 indicate that the health effects are not likely to be carcinogenic, and metals like Al (HQ=1.41×10^{3} in Table 7) and Cu (HQ=2.50×10^{2} in Table 7) were also greater than safe threshold values, thus indicating possible toxicity in the Obatebe Community. These findings agree with prior research from Saravanan *et al*. (2024), which showed that aquatic resource colonisation of high metals can lead to neurological and renal dysfunctions. Moreover, Table 7 shows the cancer risk (CR) values for arsenic (As) of 7.82×10^{-1}, which is higher than the U.S. EPA limit of 1.00×10^{-4}, indicating significant carcinogenic risks. Changes in human exposure risk were suggested by Table 8, which had a lower CR for As in the dry season (3.00×10^{-1}) compared with the wet season (3.87×10^{-1}).

Tables 9 and 10 provide values of Estimated Daily Intake (EDI) and Hazard Quotient (HQ) and give an indication of potential health risks. Table 9 shows that Copper (Cu) has an EDI of 1.69×10^{2}mg/kg/day and a high HQ of 2.41×10^{2}, denoting a very high health risk. A reduced Cu EDI of 4.5×10^{1}mg/kg/day in the dry season (Table 10) indicates that the rainy season increases metal mobilisation and increases human exposure. Our results are from Ali *et al*. (2016), who found that Cu bioavailability and toxicity are heightened during wet seasons because of their enhanced metal solubility. Arsenous (As) also poses a great health risk in both seasons. Table 9 reports an EDI of 4.93×10^{-1}mg/kg/day with an HQ of 2.46, while Table 10 shows a lower EDI of 2.0×10^{-1}mg/kg/day and an HQ of 1.0. This was consistently present, indicating an ongoing contamination source that could be from industrial effluents or naturally occurring arsenic-bearing minerals. This is consistent with Fatoki & Badmus's (2022) research, which indicates arsenic is a chronic toxicant in aquatic environments and can affect health.

Sediment Contamination and Pollution Load Index (PLI)

Contamination Factor (CF) and Pollution Load Index (PLI) were used to assess the contamination of the sediment. In Table 7 (wet season) and 8 (dry season), the PLI value for Cu is the highest, 2.09×10^{6} and 5.27×10^{5}, respectively, i.e., Obatebe

Community is very heavily polluted by Cu. Ag (PLI = 3.97×10^6 Table 7 and 3.04×10^6 Table 8) was a major ecological concern in a similar manner. The As Geo accumulative Index (Igeo) (Table 7 and Table 8, 2.33×10^1) indicated that the sediments were very polluted, as has been seen in other studies (Adeniyi *et al*., 2024), which also recorded As pollution rates in the order of 2.33×10^1. In general, the dry season had lower contamination values for all metals (Table 8), presumably due to less runoff and dilution as compared to the wet season. Although Cu and Ag remained highly persistent, industrial and agricultural discharges were year-round.

Table 9 shows that there were very high contamination levels for Iron (Fe) and Copper (Cu), with Fe of 1.98×10^5mg/kg and Cu of 2.02×10^6mg/kg. Values of contamination factor (CF) and geoaccumulation index (Igeo) further confirm that there is a high pollution. Cu in Table 9 has an Igeo of 2.04×10^1, thus indicating extreme contamination, for example. Fe and Cu concentrations drop to 2.0×10^5mg/kg and 5.3×10^5mg/kg in the dry season, thus suggesting a lower metal deposition rate (Table 10). This is also supported by the values of the Pollution Load Index of Cu in Table 9 of 4.28×10^6 as opposed to the values of 5.3×10^5 in Table 10, which reflects the impact of the season on pollution levels. These results are comparable to findings by Hossain *et al*. (2023) and Gunes (2022), who documented significant seasonal fluctuations in metal contamination in sediments, with higher values during the wet season due to increased leaching and erosion. The sediment quality data also suggest potential long-term environmental risks, as heavy metals tend to persist in sediments and pose ecological threats to benthic organisms.

Summary of the Discussions on Heavy Metal Contamination Across the Five Study Locations

The assessment of heavy metal contamination across Obatx10Be, Gbekebor, Community A, Community B, and Ayakoromor Community reveals significant spatial and seasonal variations in pollution levels. During the wet season (Tables 7 and 9), Gbekebor and Obatebe recorded consistently the highest concentrations of Copper (Cu), Arsenic (As) and (Ag) in water, crayfish, and sediment. In Gbekebor (Table 9 2.36×10^7mg/kg; highest Cu concentration in sediment); Obatebe (Table 7 2.09×10^6mg/kg~, second highest in sediment… In contrast, the highest Cu levels were found for Burutu Community (Table 1, 9.8×10^5mg/kg), which implied localised pollution sources in the more polluted areas, such as industrial discharge. The highest values of arsenic concentrations were recorded in Obatebe (Table 7; 7.82×10^{-1}mg/kg) and in the Burutu Community (Table 1; 1.09×10^{-1}mg/kg), with low pollution as the trend shown by higher concentrations in industrialised locations. Cu and Ag have the highest Bioaccumulation Factors (BAF) in Gbekebor (Table 9, Cu BAF = 9.10 and Ag BAF

= 8.67) and Obatebe (Table 7, Cu BAF = 9.00 and Ag BAF = 7.32). They are, therefore, bioaccumulating the most. This implies a tendency of heavy metal transfer to the food chain in these locations, in agreement with previous studies by Gumes (2022). The Burutu community (Table 1, Cu BAF = 4.10) showed the lowest bioaccumulation rates and, thus, the least exposure risks. These results suggest that industrial and mining activities at Obatebe and Gbekebor increase the bioavailability of metal into aquatic organisms and thus put human consumers at risk for potential exposure in the environment.

Obatebe (Table 7) had the highest Cu Estimated Daily Intake (EDI = 1.75×10^{2}mg/kg/day, HQ = 2.50×10^{2}) and exceeds safety thresholds for human health risk assessment, thus inducing significant non-carcinogenic risks. The severity of heavy metal exposure in these areas revealed in Table 9 (HQ = 2.41×10^{2}) supports the case made by Gbekebor (HQ = 2.41×10^{2}). Obatebe (Table 7, CR = 7.82×10^{-1}) posed the highest carcinogenic risk by arsenic, while Burutu Community (Table 1, CR = 1.09×10^{-1}) had the lowest health risk. This agrees with the studies of Fatoki & Badmus (2016) that highlight the harmful effects of industrial effluents on riverine heavy metal toxicity.

Further PLI of 4.28×10^{6} (Table 7) and 4.97×10^{6} (Table 9) for Obatebe and Gbekebor, respectively, reinforces the higher contamination levels in these two sites, as the PLI values classify them into highly polluted sites. On the contrary, the Ayakoromor Community (Table 5, PLI = 1.02×10^{6}) and the Burutu Community (Table 1, PLI = 1.51×10^{6}) showed less contamination. All locations showed seasonality with wet season samples (Tables 1, 3, 5, 7, 9) generally having greater metal concentrations than dry season samples (Tables 2, 4, 6, 8, 10), as rainfall and leaching increase. These findings correlate to Sun *et al*. (2022), whose findings in mining-intensive regions are similar to what these findings captured.

Finally, Obatebe and Gbekebor must be remediated urgently as they are extremely contaminated with metal, pose high risks of bioaccumulation, and pose serious health risks to humans. These findings provide essential data for environmental policymakers to implement targeted remediation strategies in the affected communities.

Conclusion

In particular, this study evaluated the sediment, water, and crayfish contaminated with heavy metals across five riverine communities of Burutu LGA. The results show metals in Pb, Cd and Fe at much higher levels than regulatory limits. The accumulated number of metals in sediments was the highest among all effluent systems, acting as long-term pollutant reservoirs. At the same time, crayfish bioaccumulated great amounts of metals and posed serious risks to human consumers. Contamination levels

are also affected by season: dry season samples have higher concentrations because of the reduction in water volume and more pollutant retention. The ecological risk assessment showed that some metals have a high contamination threat, and the human health risk evaluation indicated high levels of non-carcinogen and carcinogen risks for crayfish consumption. These findings have far reached implications as they emphasise the continued degradation of the environment in the Niger Delta due to the discharge from industry, artisanal mining, and from oil exploration work. This is important as the bioaccumulation of metals in aquatic organisms reflects the necessity of continuous environmental monitoring and intervention strategies to reduce exposure risks. If prompt action is not taken, these water bodies will cause health crises and environmental risks in the communities that rely on them for subsistence and economic activity.

Recommendations

i. Regulatory agencies should enforce stricter environmental laws on industrial discharge, mining, and oil exploration activities in riverine communities. The authorities should punish the industries contributing the most to heavy metal pollution with stringent penalties, and effluent treatment systems should not be below set safety standards.
ii. Priority should be given to continuously monitoring heavy metal contamination in sediments, water, and aquatic organisms. Government agencies, research institutions, or environmental NGOs should develop and implement routine assessments of the use of pollutants in industries, which may induce generations of hazardous pollution levels before they escalate and detect them.
iii. Educating the community in the hygienic use of crayfish, which has been recorded to have high bioaccumulation of toxic metals. Public health agencies should run such campaigns to educate people regarding safe levels of consuming heavy metals and guide them about ways to avoid heavy metals.
iv. Authorities should explore remediation techniques like phytoremediation and bioremediation to reduce heavy metal concentrations in contaminated sediments and water bodies. Moreover, adsorption-based water treatment systems will have to be introduced to enhance water quality and protect aquatic ecosystems.
v. Additionally, fishermen in the affected communities should be encouraged not to constantly harvest contaminated aquatic organisms. Government agencies and development partners should also promote alternative economic activities to diminish dependence on fishing in polluted waters.

vi. Organic studies should be conducted over a long period of time to understand the total impact heavy metal exposure has on the affected communities. Policymakers should use these research findings to devise evidence-based approaches for pollution management and reducing pollution-related health risks.

Abbreviations

°C	stands for	degrees Celsius
Ag	stands for	Silver
Al	stands for	Aluminium
As	stands for	Arsenic
AAS	stands for	Atomic Absorption Spectrophotometry
Ba	stands for	Barium
BAF	stands for	Bioaccumulation Factor
Be	stands for	Beryllium
Bg	stands for	Background Concentration
Ca	stands for	Calcium
Cd	stands for	Cadmium
CF	stands for	Contamination Factor
Co	stands for	Cobalt
CR	stands for	Carcinogenic Risk
Cr	stands for	Chromium
CRM	stands for	Certified Reference Materials
Cu	stands for	Copper
EDI	stands for	Estimated Daily Intake
Fe	stands for	Iron
HQ	stands for	Hazard Quotient
ICP-MS	stands for	Inductively Coupled Plasma Mass Spectrometry
Igeo	stands for	Geoaccumulation Index
K	stands for	Potassium
Mg	stands for	Magnesium
Mn	stands for	Manganese
Na	stands for	Sodium
Ni	stands for	Nickel
Pb	stands for	Lead
PLI	stands for	Pollution Load Index
QC	stands for	Quality Control
RfD	stands for	Reference Dose

Se	stands for	Selenium
USAPHA	stands for	American Public Health Association
USEPA	stands for	United States Environmental Protection Agency
V	stands for	Vanadium
Zn	stands for	Zinc

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