

ENVIRONMENTAL RISK ASSESSMENT OF PAHS AND HEAVY METALS IN WATER BODIES NEAR BONNY RIVER, NIGERIA

Ibiso Tamunotonye Victor

Institute of Geoscience and Environmental Management, Rivers State University, Port Harcourt, Nigeria.

Abstract: *This study assessed polycyclic aromatic hydrocarbons (PAHs) and heavy metals in the Bonny River by analyzing water, sediment, and biota samples from fifteen strategically selected stations: Jetty to Mguodeya, Eagle Island opposite Emenike waterfront, 107 Emenike Str waterfront by slaughter, Waterfront by Hospital Management Board, Abonnema Wharf Rd, Oil terminal, Wait and Bush Jetty, Nembe Jetty, Old PH Tourist Beach 1, PH Tourist Beach 2, Borokiri Sandfill 1, Fed. Housing Estate (Jetty), Fed. Housing Estate (Abandoned House), Rd 2 Old PH TWP, 42 Eastern Bye-pass, and Amadi Sandfill. The research design adopted in this study was a descriptive approach aimed at analyzing the presence and concentration of polycyclic aromatic hydrocarbons (PAHs) in surface water, sediments, and biota samples from the selected sampling points along the Bonny River. Standard sampling methods were followed. Sample collection involved obtaining 15 surface water samples, 15 sediment samples, and 15 biota samples, ensuring a comprehensive representation of the aquatic environment. The collected samples were preserved and prepared for analysis, with selected physicochemical parameters of the water, sediments and biota measured using suitable laboratory equipment.*

Keywords: *Polycyclic Aromatic Hydrocarbons (PAHs), Heavy Metals, Bonny River, Ecological Risk Assessment, Gas Chromatography-Mass Spectrometry (GC-MS), Principal Component Analysis (PCA).*

1. Introduction

Surface water has been, and is still being used, for many purposes, which include drinking, irrigation, animal farming, recreation and serves as habitat to numerous organisms. The aesthetic properties of most rivers and streams have made them sites for tourist attraction and recreation. It has also served as sources of employment, particularly for the fishing industry. Generally, in most countries of the world, surface water is used as the main source of water for the provision of potable water after necessary treatment. The treatment costs for potable water production are reduced greatly when water of a desirable quality is used as a source. Therefore, freshwater sources like rivers and

streams, need to be protected from contamination with benefits not limited to humans alone, but also to prevent environmental deterioration and reduction in biodiversity. Access to safe water is entrenched in the constitution of the federal republic of Nigeria, as a basic human right of Nigerian citizens (Okukpon & Anozie, 2018), yet, it has been estimated that 60 million people in Nigeria do not have access to safe drinking water, and this problem is more pronounced in rural areas (Atser & Udoh, 2015).

Thus, many residents of the affected rural or disadvantaged communities depend largely on surface water for their domestic water needs.

Contamination with polycyclic aromatic hydrocarbons (PAHs) and Heavy metals in the aquatic environment has attracted global attention owing to its abundance, persistence and environmental toxicity (Ali et al., 2016; Rakib et al., 2022). Both natural and anthropogenic activities are responsible for the abundance of PAHs and heavy metals in the environment (Kabir et al., 2020; Islam et al., 2021). However, anthropogenic activities can effortlessly generate PAHs and Heavy metals in sediment and water that pollute the aquatic environment (Ali et al., 2016). The increasing pollution by PAHs and heavy metals have a significant adverse health effect for invertebrates, fish, and humans (Zaynab et al., 2021). The metal pollution of aquatic ecosystems is increasing due to the effects from urbanization and industrialization (Hu et al., 2013).

The assessment of PAHs and heavy metals in water, sediments, and biota represents a crucial endeavor in environmental science, providing a comprehensive understanding of the interactions between contaminants and different components of aquatic ecosystems. In the context of Bonny River, this multifaceted analysis serves as a fundamental tool for evaluating the impact of anthropogenic activities on the river's environmental health. Water, being a primary medium for the transport of pollutants, was scrutinized for concentrations of PAHs and Heavy metals such as lead, cadmium, arsenic, etc. The results demonstrated discernable contamination levels, reflecting the influence of industrial discharges and urban runoff (Aleru et al., 2019; Akankali et al., 2021). This component of the study not only identifies potential risks to aquatic life but also highlights the implications for human populations relying on the Bonny River for drinking water and agricultural activities.

The comprehensive analysis of PAHs and heavy metals in the Bonny River, prompted by escalating industrialization and urbanization in the Niger Delta region, has provided critical insights into environmental contamination and potential risks to ecosystems and human health (Moslen et al., 2019). Anthropogenic activities, notably oil and gas exploration and industrial discharges, introduce significant quantities of PAHs and heavy metals such as lead, cadmium, mercury, and arsenic into the river (Okogbue et al., 2018). For instance, oil and gas exploration in the Niger Delta releases PAHs and heavy metals into water bodies through drilling fluids and produced water, contributing to the contamination of the Bonny River (Erakhrumen, 2015). The results from the analysis revealed elevated concentrations of these contaminants, with sediments acting as reservoirs for persistent pollutants. Fish and benthic organisms were found to bio accumulate metals like mercury and cadmium, posing potential risks to both the aquatic food web and local communities dependent on the river for sustenance.

This research study therefore is to make available the current status of the potable nature, ecological and health risk of the Bonny River tributaries which have immense uses due to their adjacent sites to residential occupations. Understanding the interactions between river water, sediments, and biota is essential for a holistic assessment of ecological resilience in the Bonny River ecosystem. This research aims to integrate findings from these components to develop a comprehensive understanding of the ecological dynamics in the face of heavy metal contamination.

2. Methodology

The methodology outlines the procedural framework and approach for the investigation, designed to address research questions and reduce disparities (Venkatesh et al., 2016). This study employs an experimental design to evaluate the impact of an intervention on specific variables or a population without random assignment. Focusing on the Bonny River in Rivers State, Nigeria, the research involves analyzing water, sediment, and biota. Samples were systematically collected from multiple locations along the river and assessed in the laboratory for physicochemical properties, microbial content, heavy metals, and polycyclic aromatic hydrocarbons (PAHs). The analysis aims to enhance understanding of the river's quality, contributing valuable insights to existing knowledge.

The Bonny River, situated along the southern border of Rivers State, Nigeria, flanked at latitudes $4^{\circ} 27' 5.76''\text{N}$ to $4^{\circ} 49'\text{N}$ and longitudes $7^{\circ} 00'$ to $7^{\circ} 10' 14.66''\text{E}$. It shares a climate similar to the tropical equatorial latitude, with an average precipitation of 2719mm and a temperature ranging from 22°C to 32°C throughout the year (Gobo, 1998; Gobo et al., 2012). This vital water source serves drinking, commercial, and industrial activities in the Port Harcourt metropolis, contributing to the degradation of water quality over time.

The map of the study area is shown in Figure 3.1 below.



Figure 2.1: Study Area showing the Sampling Stations

(Source: Researcher's Design)

Copyright: © 2025 Continental Publication

Table 2.1: Sample Stations and their Locations

Sample	Co-ordinates	Acronym of Description	Address
Prevalent Human			
Station 1	Lat. 4.78891 (N4°47'19.89") Long. 6.97793 (E6°58'40.2")		
Station 2	Lat. 4.78293 (N4°46'58.572") Long. 6.98682 (E6°59'12.57")		
Station 3	Lat. 4.78537 (N4°47'7.326") Long. 6.98948 (E6°59'22.116")		
Station 4	Lat. 4.78405 (N4°47'2.562") Long. 6.99858 (E6°59'54.8942")		Stations Sought Activities Parameters
Station 5	Lat. 4.77513 (N4°46'30.48") Long. 7.0043 (E7°0'15.684")		
Station 6	Lat. 4.75611 (N4°45'22.008") Long. 7.00452 (E7°0'16.284")		
Station 7	Lat.4.75755(N4°45'27.216") (E7°1'27.87")	Long. 7.02443	
W1 and S1	Jetty to Mgbuodeya (6 Rd E, Eagle Island, PH)		
W2 and S2	14 E1, Rd 27, Eagle Island opposite Emenike waterfront		
W3 and S3	107 Emenike Str waterfront by slaughter		
W4 and S4	(Waterfront by Hospital Management Board		
W5 and S5	Abonnema Wharf Rd, Old PH Rd., PH		
W6 and S6	Oil terminal, Wait and Bush Jetty, PH (Has Naval Base)		
W7 and S7	Nembe Jetty, Borokiri, PH		

Floating waste accumulated through traffic of people travel from Eagle Island to Mgbuodaya.

Station 8

Lat. 4.75794 (N4°45'28.53")

Long. 7.04325 (E7°2'35.754")

W8 and S8

Old PH Tourist Beach 1 (Jetty Area)

W9 and S9

PH Tourist Beach 2 (Residential area)

W10 and S10

P2PG + JJW, New Rd,

Borokiri Sandfill 1

W11 and S11

Fed. Housing Estate, Plot

2, Rd 5, Borokiri, PH

(Jetty)

W12 and S12

Fed. Housing Estate, Plot

2, Rd 5, Borokiri, PH

(Abandoned House)

W13 and S13

Rd 2 Old PH.

W14 and S14

42 Eastern Bye-pass (Opp.

NDDC Perm Site

Complex, PH)

W15 and S15

Amadi-Ama Sandfill, PH

Station 9

Lat. 4.76008 (N4°45'36.288")

Long. 7.04277 (E7°2'33.966")

Station 10

Lat. 4.737(N4°44'13.212")

Long. 7.02521 (E7°1'30.762")

Station 11

Lat. 4.73495 (N4°44'5.826")

Long. 7.02775 (E7°1'39.888")

Station 12

Lat. 4.73412 (N4°44'2.832")

Long. 7.02918 (E7°1'44.988")

Station 13

Lat. 4.73446 (N4°44'3.612") Long.

7.0309 (E7°1'55.35")

Station 14

Lat. 4.7731 (N4°46'23.148")

Long. 7.0208 (E7°1'14.892")

Station 15

Lat. 4.79001 (N4°47'24.178")

Long. 7.02918 (E7°1'45.432")

A newly acquired sandfill environment Demolished/destroyed houses and presence of a meat slaughter using tyres to roast meat Petroleum usage by marine operators Petroleum usage by marine operators Illegal bunkering Illegal bunkering Human activities dues to human actives and boat wrecks cooking with firewook and human waste Human activities: fishing, selling and domestic waste Illegal bunkering Boat wrecks and constructions waste Wrecks and illegal bunkering Activities of ship repair yards, mechanics workshops and illegal bunkering Human waste management, assembling and separation action the study involved collecting samples from 15 strategically selected points along the Bonny River,

with locations identified using a Garmin GPS. Sampling focused on water, sediments, and biota, ensuring representation of the river's diverse environments. Surface water samples were gathered by submerging containers just below the top 1-5 cm layer. They were stored in specific containers based on the type of analysis—plastic containers for physicochemical and heavy metal analyses, amber glass bottles for PAHs, and sterile vials for microbial assessments. Preservation methods, such as acidifying with HNO_3 or H_2SO_4 , ensured sample stability. Sediment samples were collected using a stainless steel Eckman's grab sampler, while biota samples, including oysters, crabs, and periwinkles, were carefully extracted and preserved. Biota tissues were processed and stored at -20°C for subsequent analysis. Samples were transported to the laboratory in coolers to maintain integrity.

Field measurements of unstable parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), salinity, and dissolved oxygen (DO), were conducted onsite using calibrated instruments to ensure data accuracy. Laboratory analyses were carried out at a government-certified facility in Port Harcourt, adhering to guidelines from the Federal Ministry of Environment and established standards like APHA and ASTM. Analytical methods included spectrophotometry for total suspended solids (TSS), direct Nesslerization for ammonia, cadmium reduction for nitrates, and turbidimetric methods for sulfates. These rigorous procedures provided comprehensive insights into the physicochemical, microbial, and contaminant profiles of the Bonny River's ecosystem.

The study employed standardized analytical methods to assess phosphate, biochemical oxygen demand (BOD), chemical oxygen demand (COD), microbial load, and heavy metal concentrations in water, sediment, and biota samples, alongside polycyclic aromatic hydrocarbons (PAHs). Phosphate was quantified via ascorbic acid reaction and spectrophotometry, while BOD and COD were determined using 5-day BOD tests and closed reflux methods, respectively. Microbial analysis employed the spreadplate technique, and heavy metals were assessed post-sample digestion using Atomic Absorption Spectroscopy (AAS). PAHs were extracted through liquid-liquid and sonication-based methods followed by gas chromatography-flame ionization detection (GC-FID). Quality assurance included strict adherence to APHA and EPA protocols, calibration with certified standards, and extensive use of blanks, duplicates, and reference materials, ensuring high accuracy, reproducibility, and reliability of data.

Photo Splash of Field Sampling Exercise



Plate 2.1a: Samples in ice ches**Plate 2.1b: Bonny River****Plate 2.1c: Part of the Bonny River used as waste dumpsite****Plate 2.1d: Author with sample from the Bonny River****Photo Splash of Laboratory Analysis at Endpoint Laboratories, Port Harcourt.****Plate 2.2a: Heavy metals Analyses using the AAS****Plate 2.2b: At Port Harcourt****Tourist Beach Plate****3. Results and Discussion**

The physicochemical parameters of Bonny River water samples from 15 locations were evaluated against NSDWQ (2015) and WHO (2011) standards. The pH ranged from 6.09 to 7.64, aligning with acceptable limits (6.5–8.5), while temperature (26.87–29.30°C) met ambient criteria. Electrical conductivity (5850.7–16490.8 $\mu\text{S}/\text{cm}$) and total dissolved solids (2925.37–8245.38 mg/L) showed significant spatial variation ($p < 0.05$). Salinity ranged from 1.95 to 5.50 PSU, with total suspended solids averaging 23.43 mg/L. Nutrient levels showed nitrate (5.18 mg/L) and sulfate (238 mg/L) within WHO limits, but phosphate (2.88 mg/L) and chloride (2209 mg/L) exceeded guidelines. BOD₅ (2.24–7.41 mg/L) and COD (56.74–112.52 mg/L) indicated organic pollution. Cations such as calcium (220.53–532.76 mg/L) and magnesium (88.35–221.53 mg/L) displayed significant spatial disparities. Microbial counts varied widely (2.0×10^2 to 1.8×10^6 cfu/L), highlighting notable contamination differences across locations.

Table 3.1: Results of Physicochemical Parameters of Surface Water Samples from the different Stations of the Bonny River.

PARAMETERS									
STATION	Temperature pH (°C)	EC (µf/cm)	TDS Salinity (mg/L) (PSU)	TSS Chloride Nitrate (mg/L) (mg/L) mg/L		Sulphate Ammonia Phosphate COD Mg (mg/L) (mg/L) (mg/L) (mg/L)		Microbia BOD5 Ca Count (cfu/mL)	
W1	6.09 ^a ±0.01	9800.50	4900.25 ^{ab} ±	25.87 ^{bc} ±1.81		230.53 ^b ±2.15	1.56 ^c ±0.05	3.6 ^{ab} ±0.5	
	27.56 ^{ab} ±0.30	105.62	3.40	1518.27 ^{ab} ±5.30		2.76 ^{ab} ±0.10	5.72 ^b ±0.28	0.10 ³	
			3.27 ^{ab} ±0.52	5.67 ^b ±0.41		102.85 ^b ±7.57			
						302.83 ^{ab} ±7.120			
W2	6.98 ^{ab} ±0.01	13110.8	6555.40 ^b ±5.83	23.62 ^b ±1.60		272.16 ^b ±2.40		2.8 ^{ab} ±0.31	
	27.88 ^{ab} ±0.14	106.35	4.37 ^b ±0.71	1823.88 ^{ab} ±7.11		1.26 ^{ab} ±0.02	1.88 ^a ±0.08	0.08 ¹⁰⁴	
				3.82 ^{ab} ±0.33		3.56 ^{ab} ±0.14	98.34 ^b ±5.30		
						420.76 ^b ±11.815			
W3	6.91 ^{ab} ±0.01	8680.30	4340.15 ^{ab} ±2.85	19.11 ^{ab} ±1.22		214.82 ^{ab} ±1.74		2.2 ^a	
	329.30 ^b ±0.09	104.51	2.89 ^{ab} ±0.30	1461.62 ^a ±3.89		0.97 ^{ab} ±0.02	2.78 ^{ab} ±0.12	±0.28 ¹⁰²	
				2.97 ^a ±0.25		4.67 ^b ±0.22	76.21 ^{ab} ±3.88		
						370.67 ^{1ab} ±9.630			
W4	7.37 ^b ±0.02	15090.8	7545.40 ^{5.0}	26.81 ^{bc} ±6.36 ^b ±		330.48 ^c ±2.28		1.8 ^b	
	28.54 ^{ab} ±0.07	107.30	6.22	3 ^c ± ±2.43	0.53	0.36 ^a ±0.01		±0.43 ¹⁰⁶	
			1.10	2742.6		3.56 ^b ±0.15	2.24 ^a ±0.17		
				8 ^b ±3.5		90.25 ^b ±4.10			
W5	6.95 ^{ab} ±0.01	16170.5	8085.25 ^{5.3}	29.20 ^c ±8.42 ^c ±		360.30 ^c ±3.10	1.52 ^c ±0.03	3.2 ^{ab}	
	526.87 ^a ±0.025	109.30	8.11	9 ^c ± ±2.30	20.71	4.10 ^b ±0.20	3.89 ^{ab} ±0.12	±0.71 ¹⁰⁴	
			1.52	932.90		68.31 ^a ±3.75			
				5.34		512.67 ^{0c} ±10.310			
W6	6.88 ^{ab} ±0.02	15160.3	7580.15 ^{5.0}	34.95 ^d ±5.88 ^b ±		192.62 ^{ab} ±1.30		2.0 ^a	
	28.10 ^{ab} ±0.08	108.50	7.63	5 ^c ± ±2.75	0.52	0.88 ^{ab} ±0.02		±0.22 ¹⁰²	
			0.9	2608.2		3.75 ^b ±0.18	5.78 ^b ±0.30		
			0	2 ^b ±2.8		82.62 ^b ±4.10			
				5		473.98 ^{0b} ±8.621	165.650		
						±2.840			

W7	6.93 ^{ab} ±0.0	15920.7	7960.34	5.31	23.67 ^b	5.21 ^b ±0	223.78 ^{ab} ±2.41	3.6 ^b
2		0 ^c ±8.12	^c ±5.30	^c ±1.	±1.88	.48	0.52 ^a ±0.03	2.52 ^{ab} ±0.12±0.64x10 ⁵
	28.36 ^{ab} ±0.		60	2884.7			7.32 ^c ±0.35	110.43 ^c ±8.24
15				1 ^c ±6.41			478.520 ^b ±11.330	
							170.431 ^b ±4.211	
W8	6.95 ^{ab} ±0.0	13950.2	6975.11 ^b ±4.	19.28 ^{ab} ±1.75	210.82 ^{ab} ±1.88		4.3 ^a	
4		0 ^b ±7.30	80	2362.93 ^b ±3.92	1.36 ^b ±0.04		±0.32x10 ²	
	27.86 ^{ab} ±0.		4.65 ^b ±0.83	4.27 ^{ab} ±0.35	1.93 ^a ±0.06	4.80 ^b ±0.28		
31					73.71 ^{ab} ±2.90			
					423.882 ^b ±9.530			
					134.621 ^{ab} ±2.870			
W9	7.26 ^b ±0.02	15010.5	7505.26 ^c ±7.	26.70 ^{bc} ±2.30	315.95 ^c ±2.94		2.8 ^{ab}	
	27.28 ^{ab} ±0.	0 ^c ±8.30	22	5.00 ^c ±1.12	51.41 ^b ±4.20	71.22 ^{ab} ±0.03	±0.56x10 ⁴	
18			7	.18 ^c ±0.61	5.30 ^c ±0.24	7.41 ^c ±0.33		
					88.35 ^b ±5.10			
					501.726 ^b ±12.514			
					197.268 ^c ±4.426			
W10	6.92 ^{ab} ±0.0	15760.8	7880.42 ^c ±5.	30.42 ^c ±2.15	294.82 ^c ±2.60		3.2 ^a	
7	26.97 ^a ±0.0	0 ^c ±7.55	28	5.25 ^c ±1.32	716.88 ^b ±7.96	0.89 ^{ab} ±0.03	2.86 ^{ab} ±0.15±0.35x10 ²	
22			4	4.93 ^b ±0.30	5.70 ^b ±0.26	65.48 ^a ±2.70		
					454.128 ^b ±10.130			
					153.672 ^{ab} ±2.832			
W11	6.95 ^{ab} ±0.0	10220.80 ^{ab} ±5.40		5110.39 ^{ab} ±3.35	183.62 ^a ±1.73	0.37 ^a ±0.02	1.7 ^b	
3		3.41 ^{ab} ±0.48		27.89 ^{bc} ±2.80	1.67 ^a ±0.05	3.35 ^{ab} ±0.12±0.21x10 ⁵		
	28.47 ^{ab} ±0.	1640.67 ^{ab} ±4.34	2.75 ^a ±0.18		112.52 ^c ±8.72			
13					382.880 ^{ab} ±7.226			
					137.635 ^{ab} ±3.355			
W12	7.31 ^b ±0.02	14610.6	7305.29 ^b ±5.23		221.88 ^{ab} ±1.50		2.3 ^{ab} ±0.4	
	27.87 ^{ab} ±0.10	0 ^b ±6.87	4.87 ^b ±0.91	18.43 ^{ab} ±1.30	1.20 ^{ab} ±0.03		8x10 ⁴	
2			2303.78 ^b ±5.60	8.22 ^c ±0.90	2.10 ^a ±0.09	6.36 ^c ±0.38		
					82.66 ^b ±5.22			
					462.631 ^b ±9.643			
					150.434 ^{ab} ±2.370			
W13	6.85 ^{ab} ±0.0	16490.8	8245.38 ^c ±7.5	85.50 ^c ±1.80	21195.32 ^{ab} ±1.45		1.5 ^b	
4	26.98 ^a ±0.0	0 ^c ±9.41	.56 ^b ±1.76		1.18 ^{ab} ±0.02		±0.17x10 ⁵	
30			2925.21 ^c ±8.51	5.95 ^b ±0.43	3.42 ^b ±0.13	2.88 ^a ±0.09		
					56.74 ^a ±2.36			
					532.755 ^c ±13.735			
					221.532 ^c ±4.225			

W14	6.85 ^{ab} ±0.07	240.40	3620.18 ^a ±3.57				173.56 ^a ±1.20	97.26	2.6 ^a
	2	5.30 ^a	2.41 ^a ±0.23	13.29 ^a ±0.97	0.88 ^{ab} ±0.03			4 ^a ±1.9±0.25x10 ²	
	28.12 ^{ab} ±0.07		1379.54 ^a ±4.30	3.40 ^{ab} ±0.26	2.73 ^{ab} ±0.11			36	
					4.52 ^b ±0.23				
					60.28 ^a ±3.12				
					289.452 ^a ±5.820				
W15	7.64 ^b ±0.05	5850.73	2925 ^a .37±1.65				156.30 ^a ±0.80	88.35	3.1 ^a
	27.53 ^{ab} ±0.1 ^a	±3.70	1.95 ^a ±0.08	10.63 ^a ±0.50	0.97 ^{ab} ±0.02			1 ^a ±1.7 ±0.69x10 ²	
	8		1287.33 ^a ±3.85	2.67 ^a ±0.20	1.88 ^a ±0.04			05	
					3.65 ^{ab} ±0.18				
					72.72 ^{ab} ±0.34				
					220.530 ^a ±3.753				
P-Value	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05
	P<0.05		P<0.05	P<0.05		P<0.05		5	
						P<0.05			
						P<0.05			
						P<0.05			
NSDW Q Limits	6.5-8.5 Ambient	1000	500	-	-	250 50 100	-	-	0.20 -
							-	-	-
WHO Limits	6.5-8.5	28 1000	500	-	5	250 10 500	-	-	-
							0.4 4 10	-	

NB: p < 0.05 – Significant; p > 0.05 – Not Significant;. Similar superscript indicates no significant difference, Unsimilar superscript indicates significant difference

Table 3.2: Summary of the Results for Physicochemical Parameters of Surface Water.

Parameters	Range		Mean
	Minimum	Maximum	
pH	6.09	7.64	6.87±0.06
Temperature(°C)	26.87	29.3	28.09±0.17
EC (µf/cm)	5850.73	16490.76	11170.75±6.56
TDS (mg/L)	2925.365	8245.38	5585.37±4.62
Salinity (PSU)	1.950	5.50	3.72±0.94
TSS (mg/L)	10.63	34.95	22.79±1.63
Chloride (mg/L)	1287.33	2932.9	2110.12±4.60
Nitrate (mg/L)	2.67	8.42	5.55±0.46
Sulphate (mg/L)	156.3	360.3	258.30±1.95
Ammonia (mg/L)	0.36	1.56	0.96±0.03

Phosphate (mg/L)	1.67	5.30	3.49±0.15
BOD ₅ (mg/L)	2.24	7.41	4.83±0.25
COD (mg/L)	56.74	112.52	84.63±5.54
Ca (mg/L)	220.53	532.755	376.64±8.74
Mg (mg/L)	88.351	221.532	154.94±2.97
Microbial Count (cfu/mL)	2.0 x10 ²	1.8 x10 ⁶	9.0 ±0.33x10 ⁵

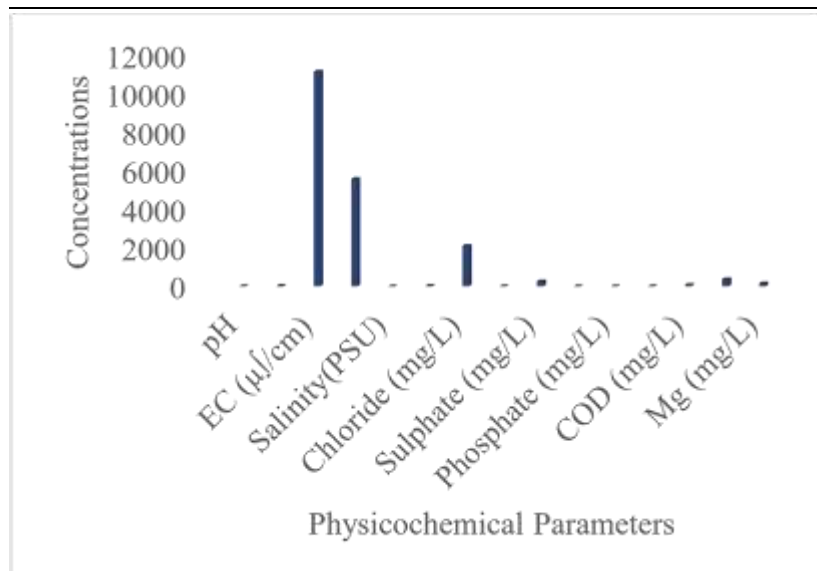


Figure 3.1: Mean Concentrations of Physicochemical Parameters in the Surface Water of the different Stations of the Bonny River

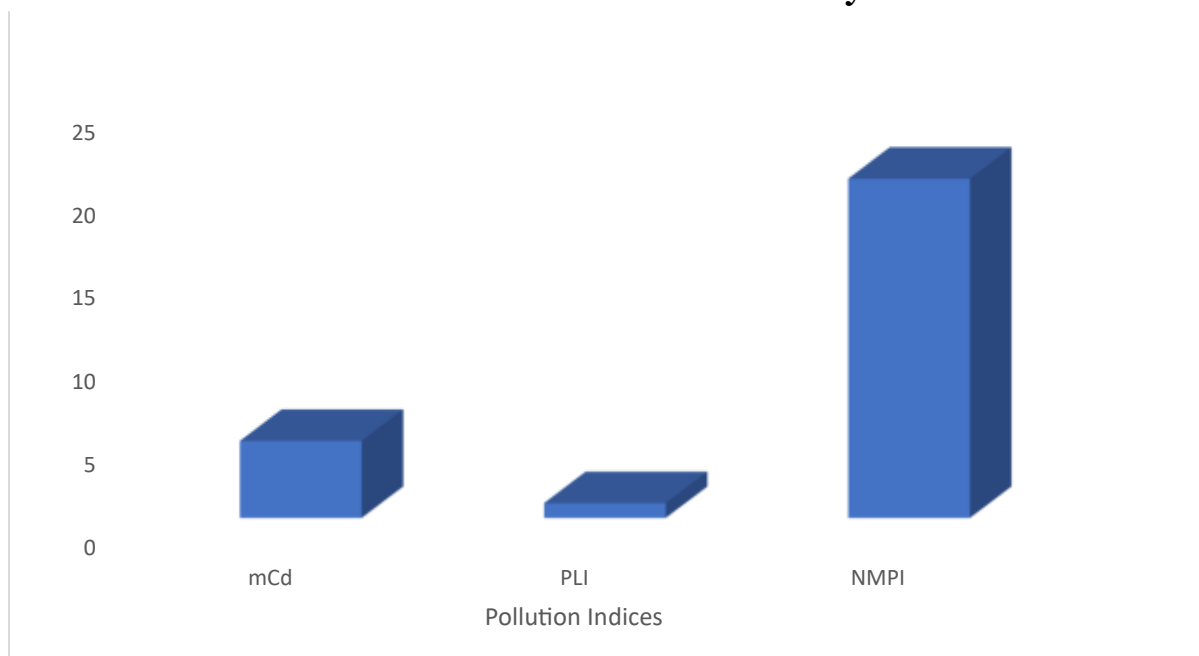


Figure 3.2: Pollution Indices of heavy metals contaminations in water samples

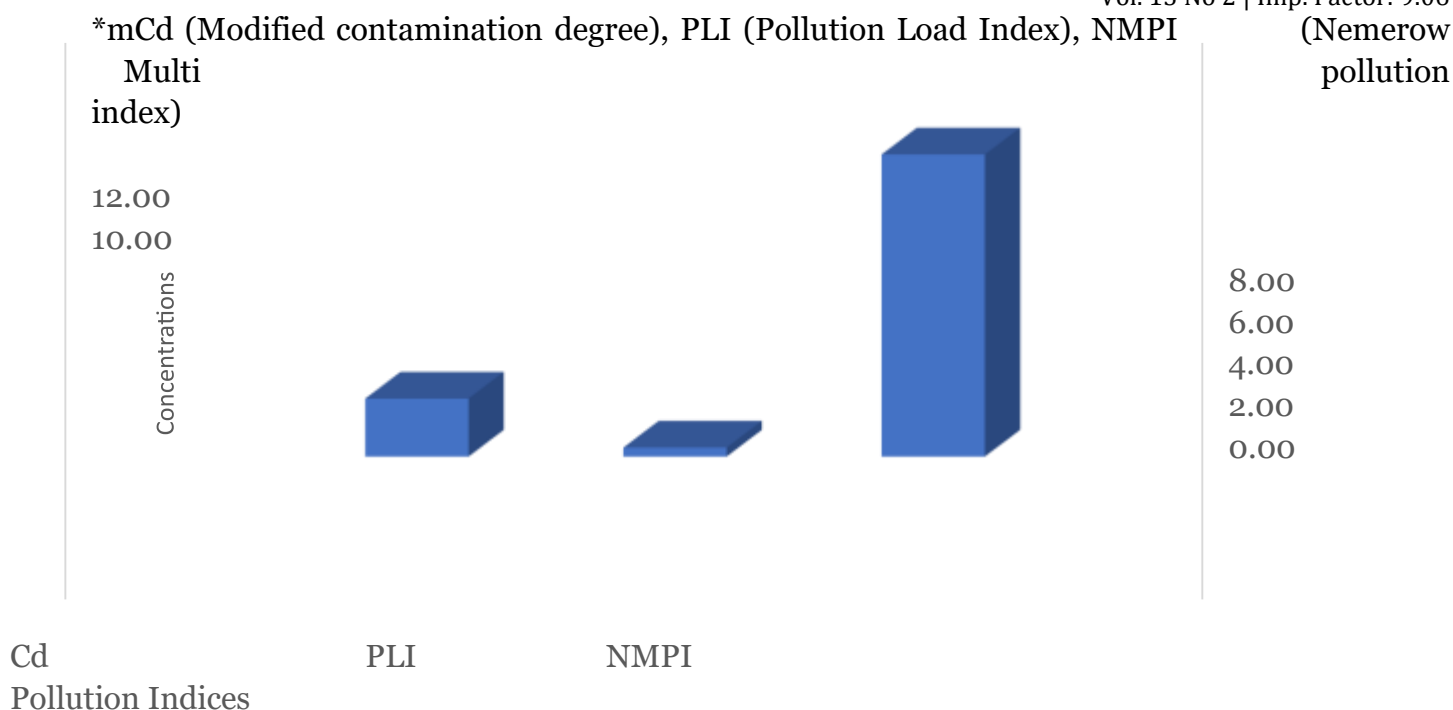


Figure 3.3: Pollution Indices of heavy metals contaminations in sediment samples
 *mCd (Modified contamination degree), PLI (Pollution Load Index), NMPI (Nemerow Multi pollution index)

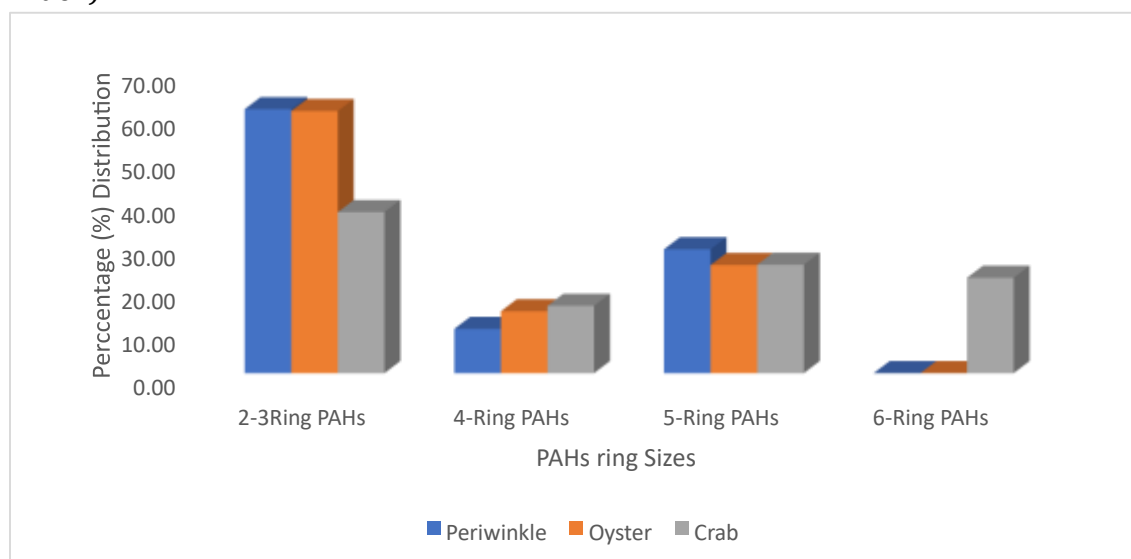


Figure 3.4: The percentage distribution of PAHs ring-size in seafoods

The heavy metal concentrations in Bonny River surface water exhibited significant spatial variability ($p < 0.05$) across sampling points. Arsenic (As) levels ranged from non-detectable to 0.016 mg/L, with a mean of 0.006 mg/L, falling below both WHO (0.05 mg/L) and NSDWQ (0.01 mg/L) limits. Copper (Cu) concentrations varied between 0.022 and 0.045 mg/L, with a mean of 0.035 mg/L, below the WHO (0.5 mg/L) and NSDWQ (1.0 mg/L) limits. Cadmium (Cd) levels ranged from non-detectable to 0.025 mg/L, with a mean of 0.013 mg/L, exceeding the WHO and NSDWQ limit of 0.003 mg/L. Chromium (Cr) concentrations ranged from non-detectable to 0.251 mg/L, with a mean of 0.044 mg/L,

below the WHO and NSDWQ limits. Cobalt (Co) ranged from 0.017 to 0.083 mg/L, with a mean of 0.041 mg/L, below the WHO limit of 0.05 mg/L. Lead (Pb) concentrations ranged from 0.168 to 0.335 mg/L, with a mean of 0.285 mg/L, exceeding both WHO and NSDWQ limits (0.01 mg/L). Iron (Fe) concentrations ranged from 0.873 to 3.518 mg/L, with a mean of 1.894 mg/L, exceeding the WHO and NSDWQ limits of 0.3 mg/L. Manganese (Mn) concentrations ranged from 0.033 to 0.152 mg/L, with a mean of 0.064 mg/L, below both WHO and NSDWQ limits. Zinc (Zn) levels ranged from 0.159 to 0.546 mg/L, with a mean of 0.358 mg/L, well below the WHO and NSDWQ limit of 3 mg/L. Iron had the highest concentration, while arsenic had the lowest among the metals analyzed.

Table 3.3: Summary of Heavy Metal Concentrations in Surface Water Samples Compared with Standard Regulatory Limits.

Range	Heavy metals (mg/L)	Minimum	Maximum	Mean±SD
As (mg/L)	0.000±0.0000	0.016±0.005		0.006±0.002
Cu (mg/L)	0.022±0.005	0.045±0.011		0.035±0.007
Cd (mg/L)	0.000±0.0000	0.025±0.008		0.013±0.004
Cr (mg/L)	0.000±0.0000	0.251±0.005		0.044±0.005
Co (mg/L)	0.017±0.002	0.083±0.018		0.041±0.009
Pb (mg/L)	0.168±0.014	0.335±0.033		0.285±0.019
Fe (mg/L)	0.873±0.037	3.518±0.560		1.894±0.196
Mn (mg/L)	0.033±0.008	0.152±0.017		0.064±0.010
Zn (mg/L)	0.159±0.012	0.546±0.034		0.358±0.018

Table 3.4: Pearson's Correlation Coefficients Analysis of Water Samples

	As	Cu	Cd	Cr	Co	Pb	Fe	Mn	Zn
As	1								
Cu	0.544	1							
Cd	0.641	0.870	1						
Cr	0.356	0.555	0.576	1					
Co	0.361	0.551	0.557	-0.020	1				

Pb	0.582	0.888	0.908	0.458	0.601	1			
Fe	-0.006	0.017	-0.205	-0.074	-0.263	-0.066	1		
Mn	-0.456	-0.139	-0.451	-0.253	0.061	-0.295	-0.102	1	
Zn	0.144	0.300	0.389	0.295	0.446	0.417	-0.618	0.207	1

Table 4.5: PCA Analysis of Water Samples

Components				
Heavy Metals	PC1	PC2	PC3	
As	0.357	0.006	-0.246	
Cu	0.902	0.059	0.046	
Cd	0.813	-0.168	-0.318	
Cr	0.339	-0.037	-0.111	
Co	0.430	-0.145	0.070	
Pb	0.886	0.007	-0.157	
Fe	-0.001	0.963	-0.031	
Mn	-0.144	-0.045	0.956	
Zn	0.221	-0.400	0.147	
Eigen value	4.287	1.793	1.028	
% of Variance	47.64	19.92	11.42	Cumulative % 47.64 67.55 78.98

3.1 Discussion

The physicochemical assessment of the Bonny River highlights concerning pollution levels, with several parameters exceeding WHO and NSDWQ standards. While the pH (6.09–7.64) remained within acceptable limits, suggesting limited acidity or alkalinity alterations, elevated electrical conductivity (up to 16,490.76 $\mu\text{S}/\text{cm}$), total dissolved solids, and salinity indicate substantial seawater intrusion and anthropogenic contributions from industrial and urban runoff (Aghoghovwia et al., 2021; Ajibola et al., 2022). High phosphate levels (1.67–5.30 mg/L) and elevated biochemical oxygen demand (BOD₅: 4.83 mg/L) point to eutrophication and organic pollution, which exacerbate oxygen depletion and harm aquatic life (Onwuchekwa et al., 2023). Furthermore, increased chemical oxygen demand (COD: 84.63 mg/L) and microbial counts signify significant contamination from untreated sewage and industrial discharges, posing severe health risks to water users and the ecosystem (Chukwuocha et al., 2021; Ubah et al., 2023). These findings emphasize the urgent need for robust pollution control policies, improved waste management systems, and consistent water quality monitoring efforts.

The Bonny River in Nigeria is an essential water body supporting human and ecological functions but faces heavy metal contamination posing environmental and health challenges. For arsenic (As), concentrations ranged from non-detectable to 0.016 mg/L, with a mean of 0.006 ± 0.002 mg/L, below WHO and NSDWQ limits, suggesting minimal health risk (Joebolosho et al., 2023; Nubi et al., 2020).

Copper (Cu) levels ranged from 0.022 to 0.045 mg/L, with a mean of 0.035 ± 0.007 mg/L, also below regulatory limits, reflecting minimal contamination (Jolaosho et al., 2023). However, cadmium (Cd) concentrations exceeded permissible levels with a mean of 0.013 ± 0.004 mg/L, highlighting contamination from industrial and anthropogenic activities (Obianefo et al., 2018; Mahdi et al., 2021). Chromium (Cr) levels, averaging 0.044 ± 0.005 mg/L, were below thresholds but demonstrated local industrial influences (Akan et al., 2010). Lead (Pb) concentrations significantly exceeded safe limits, with a mean of 0.285 ± 0.019 mg/L, linked to industrial discharges and oil spills (Nduka & Orisakwe, 2010). Similarly, iron (Fe) and manganese (Mn) levels indicated notable contamination, especially Fe with a mean of 1.894 ± 0.196 mg/L, surpassing WHO limits (Edori & Iyama, 2020). Zinc (Zn) levels remained within acceptable ranges, reflecting moderate impact (Essien et al., 2009). These findings underline the urgent need for stringent pollution control and effective water management strategies to mitigate health and ecological risks.

The assessment of Polycyclic Aromatic Hydrocarbons (PAHs) in water, sediments, and biota from 15 sampling stations along the Bonny River highlighted the significant contamination of these environmental compartments by both pyrogenic and petrogenic sources. Water samples showed high concentrations of carcinogenic PAHs, such as Benzo(a)pyrene, while sediment samples revealed a mixture of PAH sources, indicating contamination from oil spills and industrial activities (Akinmoladun et al., 2021; Oluwaseun et al., 2023). The bioaccumulation of these toxic compounds in biota, particularly in species near pollution sources, suggests a potential risk to the aquatic food chain and human health. These findings align with recent studies in the Niger Delta, confirming both combustion and petroleum-related sources as significant contributors to PAH pollution in aquatic environments (Abah et al., 2023). The persistence and toxicity of PAHs in these ecosystems underscore the need for effective pollution control measures to mitigate health risks associated with long-term exposure (Olajire et al., 2022).

5 Conclusion

This study assessed the levels of polycyclic aromatic hydrocarbons (PAHs) and heavy metals in water, sediment, and biota from fifteen strategically chosen stations along the Bonny River, including 15 sampling points such as Jetty to Mguodeya, Eagle Island opposite Emenike waterfront, and 107 Emenike Street waterfront by Slaughter. Other stations included locations like the Abonnema Wharf Rd, Oil Terminal, Wait and Bush Jetty, Nembe Jetty, Old PH Tourist Beach 1, Port Harcourt Tourist Beach 2, and Borokiri Sandfill 1. These stations were selected to represent various potential sources of pollution, ranging from urban runoff to industrial and oil-related activities. The study revealed that contaminants in water and sediment, such as electrical conductivity, chloride, and chemical oxygen demand, exceeded national and WHO standards, indicating significant pollution. Heavy metals in water samples posed substantial health risks, and sediment analysis showed high levels of cadmium and lead. Biota, including oysters, crabs, and periwinkles, exhibited alarming bioaccumulation of these metals, signaling a serious environmental and public health concern. PAH sources were identified as a mix of pyrogenic (combustion-related) and petrogenic (oil-related) activities, with diagnostic ratios and correlations indicating complex contamination sources. PAH analysis in biota demonstrated elevated carcinogenic potential, especially in oysters and crabs, highlighting the need for stronger pollution control measures and monitoring efforts across the river.

6. Recommendations

Based on the findings, we propose the following actions:

- i. **Strengthen Pollution Control:** Industrial discharges and urban runoff were identified as major sources of PAHs and heavy metals. Tighter regulations on industrial waste and urban runoff are needed to reduce contamination levels, especially in sediments and seafood.
- ii. **Enhance Public Awareness:** The carcinogenic and non-carcinogenic risks associated with seafood consumption, including high B(a)P levels in oysters and crabs, indicate a need for increased community education on the health risks of consuming contaminated seafood.
- iii. **Adopt Bioremediation:** Given the high levels of BOD, COD, and heavy metals, bioremediation strategies should be implemented to restore water and sediment quality and mitigate contamination.
- iv. **Implement Monitoring Programs:** Continuous monitoring is essential to track contamination trends, as identified by PCA and PAH diagnostic ratios, to ensure the effectiveness of pollution control measures and sustain environmental health.
- v. **Incorporate Health Risk Assessments:** The elevated carcinogenic risks from seafood, which exceed safety thresholds, should be integrated into policy frameworks to establish stricter safety measures and provide alternative protein sources for affected communities.

References

- Aghoghovwia, O. A., Uwadi, U. I., & Ajibola, A. A. (2021). Assessment of water quality and heavy metals in surface water of a tropical estuary: Implications for aquatic life. *Journal of Environmental Science and Management*, 24(3), 45–56.
- Ajibola, M. O., Oyeniran, A. A., & Badejo, M. A. (2022). The impact of industrial activities on water quality in coastal regions of Nigeria. *Environmental Monitoring and Assessment*, 194(12), 23–38.
- Akankali, J. A., Olorunfemi, I. D., & Obadele, B. A. (2021). Assessment of heavy metals and polycyclic aromatic hydrocarbons in water, sediment, and biota of the Bonny River, Nigeria. *Environmental Pollution*, 273, 116421.
- Aleru, S. F., Omotayo, O. F., & Idowu, A. B. (2019). Heavy metals and PAHs in aquatic environments: A review. *Environmental Monitoring and Assessment*, 191(10), 611.
- Ali, H., Khan, E., & Sajad, M. A. (2016). Phytoremediation of heavy metals—concepts and applications. *Chemosphere*, 152, 1–13.
- Atser, J., & Udoh, S. A. (2015). Water access challenges in rural Nigeria: An appraisal. *Water Science & Technology*, 72(5), 905–915.
- Chukwuocha, E. O., Ogwuegbu, M. N., & Nwokoro, C. C. (2021). Effects of organic and industrial pollution on river water quality in Nigeria. *African Journal of Environmental Science and Technology*, 15(7), 285–296.

- Erakhrumen, A. A. (2015). Impacts of oil and gas exploration on the Niger Delta environment. *Environmental Monitoring and Assessment*, 187(12), 702.
- Gobo, A. E. (1998). *Meteorology and man's environment*. Ibadan: African-link books, 21-23.
- Gobo, A. E., Ideriah, T. J. K., Francis, T. E., & Stanley, H. O. (2012). Assessment of air quality and noise around Okrika communities, Rivers State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 16(1), 75-83.
- Hu, Z., Zhang, X., & Li, H. (2013). Impact of urbanization and industrialization on heavy metal pollution in aquatic environments. *Environmental Toxicology and Chemistry*, 32(9), 2064-2071.
- Islam, M. A., Rahman, M. M., & Hossain, M. K. (2021). Sources and impact of polycyclic aromatic hydrocarbons in aquatic environments. *Environmental Pollution*, 268, 115833.
- Kabir, H., Khurshid, M., & Rehman, A. (2020). Natural and anthropogenic influences on aquatic PAHs and heavy metals pollution. *Journal of Environmental Chemical Engineering*, 8(3), 103722.
- Moslen, M. K., Samira, A., & Khamis, A. (2019). Ecotoxicological risks of heavy metals and PAHs in the aquatic ecosystems of the Niger Delta. *Marine Pollution Bulletin*, 141, 268276.
- Okogbue, C. O., Chikere, C. B., & Ogunyinka, M. I. (2018). Contamination of water resources in the Niger Delta: Focus on hydrocarbons and heavy metals. *Journal of Environmental Management*, 223, 229-235.
- Okukpon, O. J., & Anozie, M. (2018). Water quality and access in rural Nigeria: Challenges and solutions. *Water Resources*, 44(1), 101-109.
- Onwuchekwa, J. N., Amadi, F. M., & Okoro, P. C. (2023). Nutrient loading and eutrophication in estuarine systems: A Nigerian case study. *Marine and Coastal Ecosystem Science*, 18(2), 134-145.
- Rakib, M. S., Chowdhury, M. J. A., & Hasan, S. M. (2022). Heavy metals and polycyclic aromatic hydrocarbons in aquatic ecosystems: Sources, pathways, and health risks. *Environmental Science and Pollution Research*, 29(24), 36684-36696.
- Ubah, O. C., Ekwe, C. O., & Nwodo, C. O. (2023). Microbial contamination of surface waters in urban regions: Health implications and management strategies. *International Journal of Environmental Health Research*, 33(5), 1125-1138.
- Venkatesh, V., Brown, S. A., & Sullivan, Y. W. (2016). Guidelines for conducting mixed-methods research: An extension and illustration. *Journal of the Association for Information systems*, 17(7), 2.

Zaynab, M., Bae, S., & Lee, Y. (2021). The effects of PAHs and heavy metals on aquatic organisms and human health: A review. *Ecotoxicology*, 30(1), 15-32.