ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26sep070

Spatio-Temporal Assessment of Heavy Metal Contamination and Associated Human Health and Ecological Risks in the Ona River, Ibadan, Nigeria

Praise Adenike Alli[1*]; Samuel Opeyemi Kayode[2]; Oyewumi Tolulope Ajao[3]; Oluwatunmise Peter Abolarin[1]; Joseph Dare Adekunle[3]

[1]Department of Civil Engineering, Faculty of Engineering and Technology Lead City University, Ibadan, Nigeria.
[2]Department of Civil Engineering, Faculty of Engineering and Technology Ajayi Crowther University, Oyo, Nigeria.
[3]Department of Civil Engineering, Faculty of Engineering and Technology the Polytechnic Ibadan, Ibadan, Nigeria

Corresponding Author: Praise Adenike Alli[1*]

Publication Date: 2026/09/19

Abstract: Freshwater rivers are critical for human livelihoods, agriculture, industry, and ecosystem services, yet they face increasing pressure from urbanization, industrialization, and agricultural runoff. The Ona River in Ibadan, Nigeria, serves multiple domestic, industrial, and ecological functions but is increasingly compromised by anthropogenic inputs, including industrial effluents, untreated sewage, and urban runoff. This study assessed spatio-temporal variations in heavy metal concentrations along the Ona River at three sampling stations during wet and dry seasons. Water samples were analyzed for potentially toxic elements (Fe, Zn, Cu, Cr, As, Cd, Ni, Pb, and Mn) using Atomic Absorption Spectrophotometry, and pollution indices (Geo-accumulation Index, Enrichment Factor, Contamination Factor, Pollution Load Index) and health risk assessments (carcinogenic and non-carcinogenic) were computed. Results indicated seasonal variations, with higher concentrations of Cr, Pb, Cd, and Ni during the dry season exceeding WHO and Nigerian drinking water standards at certain sites. Pollution indices and health risk metrics revealed moderate to high contamination levels, particularly near industrial and urban discharge points. The findings highlight significant ecological and public health risks, emphasizing the urgent need for targeted pollution management strategies to safeguard water quality and community well-being.

Keywords: *Ona River, Heavy Metals, Water Quality Assessment, Pollution Indices, Spatio-Temporal Variation, Ecological Risk, Human Health Risk, Urbanization Impact.*

How to Cite: Praise Adenike Alli; Samuel Opeyemi Kayode; Oyewumi Tolulope Ajao; Oluwatunmise Peter Abolarin; Joseph Dare Adekunle (2026) Spatio-Temporal Assessment of Heavy Metal Contamination and Associated Human Health and Ecological Risks in the Ona River, Ibadan, Nigeria. *International Journal of Innovative Science and Research Technology,* 11(9), 463-473. https://doi.org/10.38124/ijisrt/26sep070

I. INTRODUCTION

Freshwater rivers are vital for human livelihoods, agriculture, industry, and ecosystem services, particularly in rapidly urbanizing regions. Access to clean and safe water is essential for human survival and the functioning of ecosystems. Water quality challenges are complex, diverse, and demand urgent global attention (Adelagun et al., 2021). Over the past decade, population growth, rapid urbanization, and intensification of agricultural activities have significantly impacted the environment, contributing to the progressive degradation of surface water resources. Polluted water remains a major conduit for disease transmission, with approximately 1.8 million deaths annually in developing countries, primarily among children, due to waterborne diseases. Water quality is generally defined by its chemical, physical, and biological characteristics relative to its intended use (Adelagun et al., 2021). In many developing regions, inadequate waste management, industrial effluents, and agricultural runoff introduce physico-chemical pollutants, heavy metals, and microbial contaminants, posing risks to human health, aquatic life, and overall environmental integrity.

Water is fundamental to human survival, yet global demand continues to rise. The 2021 UNESCO World Water

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26sep070

Development Report indicates that freshwater use has increased sixfold over the past century and has grown by roughly 1% annually since the 1980s. As consumption climbs, water quality is increasingly threatened. Industrial activities, agricultural practices, and urban expansion have contributed to significant environmental degradation, impairing vital aquatic systems and posing risks to human health and sustainable development (Xu et al., 2022). In Nigeria's South-West region, rapid urbanization and expanding industrial activities have placed substantial pressure on river systems. The Ona River, which traverses the Ibadan metropolis in Oyo State, is one of the city's three principal drainage channels and supports various community needs, including domestic water use, fisheries, recreation, and waste disposal. Evidence indicates that portions of the river are degraded by industrial effluents, untreated sewage, and runoff from residential and commercial areas, among other anthropogenic inputs (Iroye and Igbozurike, 2018). The Ona River in Ibadan, Nigeria, is an important water source supporting domestic use, agriculture, fisheries, and ecosystem functions. However, its quality has been increasingly compromised by rapid urban expansion, industrial effluents, untreated sewage, and diffuse runoff. Previous research reports elevated levels of heavy metals including Cd, Cr, Ni, and As exceeding WHO guidelines, as well as microbial contamination in nearby shallow wells, highlighting substantial risks to both human and ecological health (Iroye and Igbozurike, 2018).

Recent investigations report significant contamination within the Ona River catchment. Using Simple Fuzzy Classification, a 2024 study showed that concentrations of several potentially toxic elements (Fe, Pb, Cd, Cr, Mn) exceeded guideline thresholds at numerous sites in both dry and wet seasons, pointing to anthropogenic inputs. Although many locations were still classified as "pristine," a considerable number exhibited moderate to high pollution, particularly those situated near known sources of discharge (Akintola et al., 2024). Given the widespread use of the Ona River and concerns about its contamination, a systematic assessment of heavy metal concentrations across multiple stations and seasons is urgently required. This should include calculating indices such as the Pollution Load Index (PLI), Enrichment Factor (EF), Geo-accumulation Index (Igeo), health risk metrics (carcinogenic and non-carcinogenic), Ecological Risk, and Contamination Factor (Cf), alongside mapping spatial and temporal patterns. Such comprehensive data are critical for pinpointing pollution hotspots, evaluating risks to human and ecological health, benchmarking conditions against permissible limits, and informing management and policy actions to safeguard water quality and community well-being.

II. MATERIAL AND METHOD

➢ *Study Area*

The study was carried out in Ona River which is one of the major Rivers in Ibadan south western, Nigeria. The Ona River flows through Ibadan, Oyo State, Nigeria, serving both domestic and industrial purposes but receiving untreated effluents and stormwater runoff from surrounding communities. The selected study stretch extends from University College Hospital (UCH) to Dandaru River, covering an area of intense urban and industrial activity that may influence water quality. Ona River has a length of 55km2 an area of 81.0km2 and it flows through the low-density western part of Ibadan. The river flows in a north-south direction from its source at Ido Local Government Area where it is dammed and also flows through Apata Genga (Ibadan south-west Local Government Area) to Oluyole Local Government. Companies located along this river include 7up Nigeria Plc, Zartech, Sumal and Interpac a paper mill industry (not in operation). Channeled effluents from these industries are connected by a network of canals channeled directly into Ona River. Ona River receives allochthonous input of organic matter from the surrounding vegetation, derived through run-offs from the surface of the soil.

The study focuses on two locations along the Ona River in Ibadan, Nigeria: UCH (University College Hospital) and Agodi. UCH represents a midstream section where the river receives discharges from medical, residential, and stormwater sources. Agodi, a downstream area, accumulates more pollutants from government offices, markets, and residential runoff. Both areas are urbanized and experience high human activity, making them key points for assessing pollution levels.

The University College Hospital (UCH), Ibadan has a Latitude of 7.4040° N and a Longitude: 3.9275° E. It Located in Ibadan North LGA, UCH is near the Ona River, which runs behind the hospital. It is a critical urban site with potential effluent discharge into the river. Agodi Area (Near Agodi Gardens and Secretariat) has a Latitude: 7.3930° N and Longitude: 3.9105° E. It is downstream from UCH, the Agodi area includes Agodi Gardens, the Oyo State Government Secretariat, and dense residential settlements. It is a known location for urban runoff and pollution input into the Ona River.

➢ *Research Design*

This study employed an experimental and analytical research design, involving field sampling of river water during both wet and dry seasons, followed by laboratory analysis of heavy metals. Pollution indices and risk assessments were subsequently computed to evaluate spatio-temporal variations in water quality along the Ona River.

➢ *Sampling Design and Collection*

The study aimed to assess spatio-temporal variations in heavy metal of Ona River. A total of three sampling stations were identified within the stretch (UCH 1, UCH 2, and Agodi). Exact positions were marked to ensure reproducibility (Table 2.1–2.3). Sampling was conducted in both wet and dry seasons, in the morning hours (8:00 – 11:00 am) to minimize diurnal variations in water quality. The equipment and material used for sample collection is given on Figure 1.

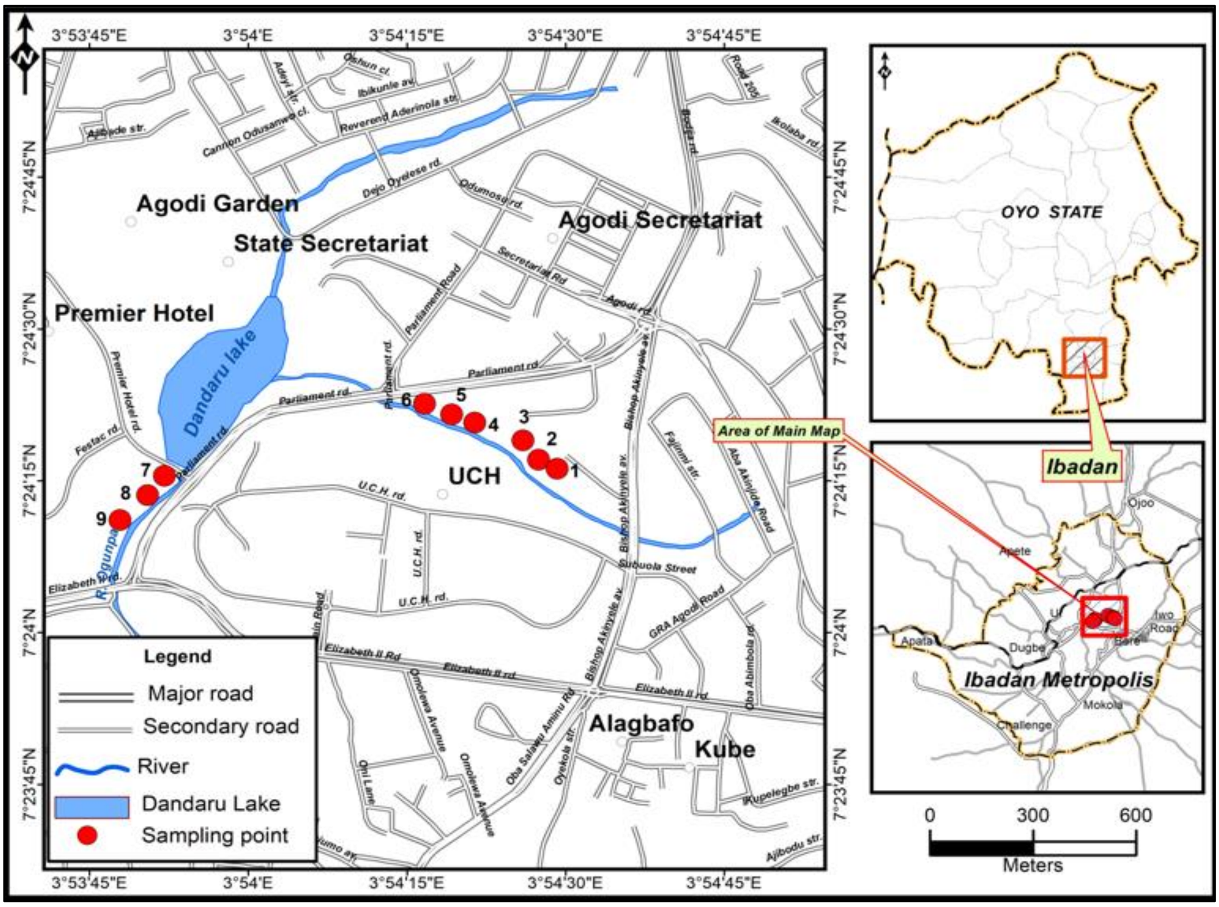

Fig 1 Map of Agodi and Its Environs Showing Sampling Points
Source: Autor's Findings.

- *Sample Collection Procedure*

Water samples were collected following standard field procedures. Each sample bottle was clearly labeled prior to collection, and gloves were worn throughout the process to ensure hygienic handling. During sampling, the collector stood facing upstream to avoid disturbing sediments around the feet. Samples were taken at mid-depth, approximately 30 cm below the surface, while avoiding surface scum and bottom debris. Before final collection, each bottle was rinsed two to three times with river water. Bottles were then filled carefully to minimize aeration and the formation of bubbles.

Immediately after collection, all samples were placed in a cooler containing ice packs to maintain a temperature below 4°C. They were also kept away from direct sunlight to prevent algal growth and photosynthetic changes. Samples for heavy metal parameters were analyzed within twenty-four hours of collection. A field data sheet was maintained for proper documentation during each sampling exercise. This included information such as the sample ID and code, sampling location with corresponding GPS coordinates, date and time of collection, prevailing weather conditions.

➢ *Laboratory Analysis and Procedures*

The laboratory analyses were carried out in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, WEF, 24th edition, 2022). Heavy metal analysis was performed to determine the concentration of toxic trace elements in the river water.

- *Heavy Metal Analysis*

Heavy metal analysis was performed to determine the concentration of toxic trace elements in the river water. Samples were first subjected to acid digestion using concentrated nitric and perchloric acid mixtures to break down organic matter and release bound metals into solution. The digested samples were then analyzed using Atomic Absorption Spectrophotometry (AAS) for heavy metals including lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), zinc (Zn), nickel (Ni), manganese (Mn), iron (Fe), and arsenic (As).

These metals were chosen due to their environmental and public health relevance. Lead (Pb) is a potent neurotoxin, cadmium (Cd) causes kidney toxicity, arsenic (As) is carcinogenic, chromium (Cr) occurs in industrial discharges such as electroplating and tanning, mercury (Hg) bioaccumulates in aquatic systems, and nickel (Ni) is a potential carcinogen. Concentrations were quantified and compared with permissible limits set by the World Health Organization (WHO) and Nigerian Standards for Drinking Water Quality (NSDWQ).

➢ *Data Analysis and Indices Computation*

- *Geo-Accumulation Index (Igeo)*

The Geo-Accumulation Index (Igeo) is used to assess the degree of heavy metal contamination in sediments or soils

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26sep070

by comparing current concentrations with pre-industrial background levels. It is calculated using Equation (1).

$$I_{geo} = log_2 \left(\frac{C_n}{1.5\ x\ B_n}\right) \quad (1)$$

Where,

- ✓ C_n = measured concentration of the metal in the sample
- ✓ B_n = geochemical background concentration of the metal

The constant 1.5 accounts for possible variations in background values due to lithogenic effects.

Interpretation of Igeo Values (Müller, 1969):

Igeo	≤	0	→	Uncontaminated		
0	<	Igeo	<	1	→	Uncontaminated to moderately contaminated
1	≤	Igeo	<	2	→	Moderately contaminated
2	≤	Igeo	<	3	→	Moderately to heavily contaminated
3	≤	Igeo	<	4	→	Heavily contaminated
4	≤	Igeo	<	5	→	Heavily to extremely contaminated
Igeo	≥	5	→	Extremely contaminated		

The Igeo provides a clear indication of anthropogenic influence. Higher values in the Ona River would suggest that industrial, agricultural, or domestic discharges are contributing significantly to metal enrichment.

- *Contamination Factor (CF)*

The Contamination Factor is a measure used to assess the degree of contamination of individual heavy metals in environmental media such as soil, sediment, or water. It was calculated using Enn. 2:

$$CF = \frac{C_i}{C_n} \quad (2)$$

Where:

- ✓ Ci = Measured concentration of the element in the sample
- ✓ Cn = Background concentration or reference value (e.g., WHO standard or local baseline)

Interpretation of CF Values

CF	<	1	→	Low contamination (no significant pollution)		
1	≤	CF	<	3	→	Moderate contamination
3	≤	CF	<	6	→	Considerable contamination
CF	≥	6	→	Very high contamination		

A high CF for elements like lead (Pb), chromium (Cr), or cadmium (Cd) in water or soil indicates potential anthropogenic inputs and environmental health hazards. In this study, the CF will help pinpoint which metals are present at concentrations far above acceptable limits, suggesting pollution from industrial or urban activities.

- *Enrichment Factor (EF)*

The Enrichment Factor (EF) is used to evaluate the degree of anthropogenic contribution of heavy metals in sediments or soils relative to natural (crustal) sources. It normalizes heavy metal concentrations against a reference element, typically Fe, Al, or Ti, using Equation (3):

$$EF = \frac{(C_x/C_{ref})sample}{(B_x/B_{ref})background} \quad (3)$$

Where:

- ✓ Cx = concentration of the target heavy metal in the sample
- ✓ Cref = concentration of the reference element in the sample
- ✓ Bx = background concentration of the target heavy metal
- ✓ Bref = background concentration of the reference element

Interpretation of EF Values

EF	≈	1	→	Metal originates mainly from crustal materials (no enrichment)		
1	<	EF	<	3	→	Minor enrichment
3	≤	EF	<	5	→	Moderate enrichment
5	≤	EF	<	10	→	Significant enrichment
10	≤	EF	<	25	→	Very high enrichment
EF	>	25	→	Extremely high enrichment		

An EF greater than 5 in Ona River samples would suggest that the metals are largely from anthropogenic inputs such as industrial effluents, vehicular emissions, or agricultural runoff.

- *Pollution Load Index (PLI)*

The Pollution Load Index provides a cumulative indication of the overall level of heavy metal pollution at a site. It is calculated as the nth root of the product of n contamination factors (Eqn. 4):

$$PLI = \sqrt[n]{CF_1\ x\ CF_2\ x\ CF_3\ x\ ....x\ CF_n} \quad (4)$$

Where;

- ✓ $CF_1, CF_2, ..., CF_n$ = contamination factors for n different metals

Interpretation of PLI Values

PLI	=	1	→	Baseline level of pollutants (no pollution)
PLI	<	1	→	No or low pollution
PLI	>	1	→	Pollution exists and its severity increases with the value

The PLI allows comparison between locations or samples. A PLI greater than 1 in the Ona River water samples would suggest cumulative pollution, warranting immediate attention for source identification and remediation.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26sep070

- *Human Health Risk Assessment (HHRA)*

Human Health Risk Assessment (HHRA) evaluates the potential health risks associated with human exposure to heavy metals through ingestion, dermal contact, and inhalation. It is divided into non-carcinogenic risk and carcinogenic risk.

✓ *Non-Carcinogenic Risk (HQ)*

The Average Daily Dose (ADD) for each exposure pathway is calculated using standard USEPA (1989, 2011) models as shown in Eqn 5.

$$ADD = \frac{C\ x\ IR\ x\ EF\ x\ ED}{BW\ x\ AT} \quad (5)$$

Where;

- ✓ C = concentration of metal in water/soil (mg/L or mg/kg)
- ✓ IR = ingestion rate (L/day or mg/day)
- ✓ EF = exposure frequency (days/year)
- ✓ ED = exposure duration (years)
- ✓ BW = body weight (kg)
- ✓ AT = averaging time (days)

The Hazard Quotient (HQ) is then derived ass shown in Eqn. 6.

$$HQ = \frac{ADD}{RfD} \quad (6)$$

Where;

- ✓ RfD = Reference dose (mg/kg/day)

The Hazard Index (HI) is the sum of HQs across all metals and pathways;

$$HI = \sum HQ_i \quad (7)$$

Interpretation of HL Values

HI	<	1	→	No significant non-carcinogenic health risk
HI	≥	1	→	Potential adverse health effects

✓ *Carcinogenic Risk*

Carcinogenic risk is assessed using the Cancer Risk (CR) mode

$$CR = ADD \times SF \quad (8)$$

Where;

- ✓ SF = Slope factor $(mg/kg/day)^{-1}$

The cumulative cancer risk (TCRTCRTCR) is calculated by summing CR across metals and pathways:

$$TCR = \sum CR_i \quad (9)$$

Interpretation (USEPA guidelines)

1×10^{-6}	to	1×10^{-4}	→	Acceptable risk range
TCR	>	1×10^{-4}	→	Potentially unacceptable cancer risk

In the context of Ona River, elevated HQ or HI values would suggest potential non-carcinogenic risks (e.g., kidney or neurological damage), while high CR or TCR values would indicate long-term cancer risks due to chronic exposure to toxic metals such as arsenic, cadmium, or chromium.

- *Ecological Risk Index (Er)*

The Ecological Risk Index assesses the potential ecological risk posed by individual heavy metals. It combines the contamination factor with the toxic response factor (Tr) of each metal (Eqn. 10):

$$ERI = CF \times Tr \quad (10)$$

Where:

- ✓ Tr = Toxic response factor, which varies by metal

(e.g., Cd = 30, As = 10, Pb = 5, Cu = 5, Cr = 2, Zn = 1, Ni = 5)

Interpretation of ERI Values

ERI	<	40	→	Low potential ecological risk		
40	≤	ERI	<	80	→	Moderate risk
80	≤	ERI	<	160	→	Considerable risk
160	≤	ERI	<	320	→	High risk
ERI	≥	320	→	Very high risk		

When ERI is calculated for each metal in the samples, it shows which pollutants are not just present in high concentrations but also pose significant ecological harm based on their toxicity. For example, cadmium and arsenic, even in low concentrations, can have high ERI values due to their strong toxicity.

III. RESULTS AND DISCUSSIONS

➢ *Tests and Results*

This chapter presents the results of heavy metal analyses of water samples collected from Ona River during the wet and dry seasons, from three sampling stations between University College Hospital (UCH) and Dandaru River. A total of 9 samples (3 samples from 3 locations) were analysed for selected potentially toxic elements (PTEs) including Fe, Zn, Cu, chloride, Cr, As, Cd, Ni, and Pb. The findings are discussed in relation to national and international drinking water quality standards, particularly those of the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ), to assess contamination levels, ecological risks and public health implications. The analyses were further subjected to pollution

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26sep070

indices such as the Geo-accumulation Index (Igeo), Enrichment Factor (EF), Contamination Factor (CF), and Pollution Load Index (PLI). Health risk assessments (non-carcinogenic and carcinogenic risks) were also conducted to evaluate potential public health implications of heavy metals exposure.

➢ *Heavy Metals and Potentially Toxic Elements (PTEs)*

- *Chromium (Cr)*

Chromium levels in the dry season ranged from 0.09 ± 0.03 to 0.10 ± 0.02 mg/L across the sites, exceeding both WHO and Nigerian limits (0.05 mg/L) but remaining below the EPA threshold of 0.1 mg/L. In contrast, chromium was below detection limits in all wet-season samples, indicating that its presence in the river is strongly influenced by seasonal conditions. The higher chromium levels observed in the dry season may be due to concentration effects caused by reduced river volume and limited dilution making trace metals easier to detect. In contrast, heavy rainfall in the wet season likely increases water volume and enhances dispersion, driving chromium concentrations below detection thresholds. Similar patterns have been documented in Nigerian rivers, where heavy metal levels in dry season are often greater attributed to reduced flow and accumulation than in the wet season. Long-term consumption of water contaminated with chromium has been associated with skin irritation, respiratory problems, digestive disturbances, damage to the kidneys and liver, and an increased risk of cancer (Joseph et al 2022).

Table 1 Average Concentration of Heavy Metals in Water Samples Collected at Ona River

S/N	Dry Season			WHO Guideline	Nigerian Standard	EPA Maximum Contaminant Level	Wet Season		
	Loc 1	Loc 2	Loc 3				Loc 1	Loc 2	Loc 3
Chromium	0.09 + 0.03	0.10 + 0.03	0.10 + 0.02	0.05	0.05	0.1	BDL	BDL	BDL
Cadmium	BDL	BDL	BDL	0.005	0.003	0.005	BDL	BDL	BDL
Arsenic	0.07 + 0.03	0.06 + 0.05	0.03 + 0.02	0.05	0.01	0.01	0.03 + 0.01	0.02 + 0.02	0.02 + 0.01
Magnesium	13.27 + 2.40	12.73 + 2.08	13.33 + 1.26				10.60 + 1.28	12.73 + 1.36	14.00 + 1.50
Mn	1.50 + 0.29	1.41 + 0.48	1.09 + 0.18	0.4	0.1	0.05	2.54 + 0.64	1.66 + 0.21	1.51 + 0.22
Zinc	0.11 + 0.03	0.14 + 0.06	0.07 + 0.01	5	3	5	0.24 + 0.10	0.27 + 0.06	0.15 + 0.02
Nickel	0.04 + 0.02	0.03 + 0.02	0.04 + 0.01	0.07	0.02	0.07	0.04 + 0.01	0.02 + 0.01	0.04 + 0.01
Lead	0.04 + 0.01	0.03 + 0.01	0.03 + 0.01	0.01	0.01	0.01	BDL	BDL	BDL
Iron	0.05 + 0.01	0.08 + 0.04	0.08 + 0.01	0.3	0.3	0.3	0.08 + 0.01	0.11 + 0.04	0.09 + 0.01
Copper	0.01 + 0.01	0.01 + 0.01	0.02 + 0.00	1.0	1	1.3	0.10 + 0.02	0.15 + 0.07	0.18 + 0.05

- *Cadmium (Cd)*

Cadmium concentrations were below detection limits at all three stations during both seasons, remaining far lower than the WHO (0.005 mg/L), Nigerian Standard (0.003 mg/L), and EPA (0.005 mg/L) guideline values (Table 1). This absence of detectable cadmium indicates that the Ona River is not presently subjected to notable cadmium inputs from industrial, agricultural, or domestic activities. Cadmium, a non-essential and highly toxic metal, typically enters aquatic environments through activities such as battery production, electroplating, fertilizer use, pigment manufacturing, mining, and improper waste disposal. Because it has no biological role and tends to bioaccumulate, cadmium can transfer through the food chain. Even at very low levels, long-term exposure is associated with kidney damage, bone disorders (such as Itai-Itai disease), anemia, and elevated cancer risk (WHO, 2017).

The consistent absence of detectable cadmium in both seasons suggests that the Ona River currently poses minimal risk of cadmium-related toxicity. Neither dry-season concentration effects nor wet-season dilution influenced its non-detectable status, indicating that cadmium is unlikely to be a major pollutant in this section of the river. From an ecological standpoint, this is important because cadmium contamination can inhibit photosynthesis in aquatic plants, reduce reproductive success in fish, and disrupt microbial processes that regulate nutrient cycling. (Agbam et al., 2025).

- *Arsenic (AS)*

Arsenic concentrations in the Ona River varied by location and season. In the dry season, levels ranged from 0.03 ± 0.02 mg/L at Location 3 to 0.07 ± 0.03 mg/L at Location 1, exceeding WHO (0.05 mg/L), Nigerian (0.01 mg/L), and EPA (0.01 mg/L) (Table 1) standards at Locations 1 and 2. During the wet season, concentrations were lower

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26sep070

(0.02 ± 0.01 to 0.03 ± 0.01 mg/L), generally approaching or slightly exceeding Nigerian and EPA limits but remaining below the WHO threshold, indicating that rainfall and increased river flow likely dilute arsenic levels. Elevated arsenic levels in the dry season may result from lower river flow, higher evaporation, and pollutant concentration, whereas wet-season reductions likely reflect dilution from increased water volume. Arsenic poses serious health risks, with chronic exposure linked to skin lesions, cardiovascular and neurological disorders, and cancers of the skin, lung, bladder, and liver (WHO, 2017). Ecologically, arsenic can harm aquatic plants, impair fish growth and reproduction, and disrupt microbial communities that support nutrient cycling. The measured concentrations, particularly during the dry season, suggest potential stress on the river's aquatic organisms.

- *Magnesium (Mg)*

Magnesium concentrations in the Ona River exhibited moderate spatial and seasonal variation, ranging from 12.73 ± 2.08 mg/L at Location 2 to 13.33 ± 1.26 mg/L at Location 3 in the dry season, and from 10.60 ± 1.28 mg/L at Location 1 to 14.00 ± 1.50 mg/L at Location 3 in the wet season (Table 1). All values were well below national and international guidelines. Both WHO and Nigerian standards recommend total hardness ($Ca^{2+} + Mg^{2+}$) below 200 mg/L and magnesium below 50 mg/L to prevent health effects such as laxative responses (WHO, 2017). The U.S. EPA does not set a primary standard for magnesium, as it is generally non-toxic at natural concentrations, although elevated levels may cause aesthetic issues such as scaling or taste changes.

Slightly lower concentrations at Location 1 during the wet season likely reflect dilution from rainfall and runoff, whereas the highest wet-season value at Location 3 may result from magnesium-rich geology or agricultural inputs. Magnesium is essential for neuromuscular function and enzymatic activity, and the observed concentrations are non-toxic ecologically, supporting nutrient balance and aquatic productivity (Liu et al., 2025). Overall, levels remain within safe limits, though ongoing monitoring is recommended to detect potential increases from anthropogenic inputs.

- *Manganese (Mn)*

Manganese levels in the Ona River exceeded recommended limits in both seasons. Dry-season concentrations ranged from 1.09 ± 0.18 mg/L (Loc 3) to 1.50 ± 0.29 mg/L (Loc 1), while wet-season values were higher, ranging from 1.51 ± 0.22 mg/L (Loc 3) to 2.54 ± 0.64 mg/L (Loc 1) (Table 1), surpassing the WHO guideline of 0.4 mg/L and the Nigerian standard of 0.1 mg/L (WHO, 2017). Although the US EPA does not regulate manganese in drinking water, elevated levels can pose neurotoxic risks and cause aesthetic issues.

The higher wet-season concentrations likely result from surface runoff transporting industrial effluents, urban waste, and leachates from manganese-rich soils and rocks. Slightly lower dry-season levels reflect reduced inputs but increased stagnation. These elevated concentrations pose significant health risks, including neurotoxicity, cognitive impairment in children, and hepatic or renal stress, for populations relying on untreated river water, highlighting the need for continuous monitoring and water treatment interventions.

- *Zinc (Zn)*

Zinc levels in the Ona River remained low compared with regulatory benchmarks. Dry-season concentrations ranged from 0.07 ± 0.01 mg/L (Loc 3) to 0.14 ± 0.06 mg/L (Loc 2), rising modestly in the wet season to 0.15 ± 0.02 mg/L and 0.27 ± 0.06 mg/L, respectively. All values were far below international standards including the WHO limit of 5 mg/L, the Nigerian limit of 3 mg/L, and the US EPA limit of 5 mg/L (Table 1) indicating negligible health risk from zinc. Overall, zinc does not pose a major contamination issue in the river, with the slight wet-season increase likely linked to runoff inputs from roofs, vehicles, industry, and agriculture, whereas lower dry-season levels reflect reduced runoff and dilution effects.

Zinc levels in the Ona River were well below guideline limits, indicating minimal human health risk. Although zinc is an essential micronutrient, elevated concentrations can impair growth and reproduction in fish and invertebrates (Lin et al., 2023). The observed concentrations are unlikely to cause ecological harm.

- *Nickel (Ni)*

Nickel concentrations in the Ona River showed moderate spatial and seasonal variability. Dry-season levels ranged from 0.03 ± 0.02 mg/L at Loc 2 to 0.04 ± 0.02 mg/L at Locations 1 and 3, with similar values recorded in the wet season (0.02 ± 0.01–0.04 ± 0.01 mg/L; Table 1). These concentrations complied with the WHO and US EPA drinking-water limits of 0.07 mg/L but exceeded the more stringent Nigerian standard of 0.02 mg/L at Locations 1 and 3, while Loc 2 fluctuated around the permissible threshold.

Potential sources of nickel include industrial effluents, electroplating activities, corrosion of metal infrastructure, vehicular emissions, agricultural inputs, and atmospheric deposition. The similarity in dry- and wet-season concentrations suggests contamination from both continuous point sources and diffuse sources. Toxicologically, nickel is recognized as a hazardous metal: although trace amounts are biologically necessary, excessive exposure can cause dermatological, respiratory, gastrointestinal, and renal effects and increase carcinogenic risk (ATSDR, 2024). Ecologically, elevated nickel levels can accumulate in aquatic organisms, impairing growth, reproduction, and survival. While the recorded concentrations do not exceed WHO or EPA limits, exceedances of the national standard at two sites indicate potential localized health and ecological concerns, particularly for communities that rely directly on untreated river water.

- *Lead (Pb)*

Lead concentrations in the Ona River during the dry season ranged from 0.03 ± 0.01 mg/L at Locations 2 and 3 to 0.04 ± 0.01 mg/L at Loc 1, whereas all wet-season samples were below detection limits (BDL), likely due to increased rainfall and hydrological dilution. Dry-season values

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26sep070

exceeded all major drinking-water guidelines, indicating Pb concentrations approximately 3–4 times higher than permissible limits and rendering the water unsafe for direct consumption. Probable sources of contamination include industrial effluents, battery recycling operations, paint residues, plumbing materials, vehicular emissions, and leaching from solid-waste dumpsites. Elevated dry-season levels reflect pollutant accumulation under reduced flow conditions, while BDL values in the wet season demonstrate effective dilution and flushing. Toxicologically, lead is a non-essential and highly hazardous metal: chronic exposure can cause neurological impairment, developmental deficits in children, renal and hepatic damage, hypertension, anemia, and carcinogenic effects (WHO 2024). In aquatic environments, lead can compromise reproductive capacity, enzyme function, and overall biodiversity (Kim and Kang 2019).

- *Iron (Fe)*

Iron concentrations in the Ona River ranged from 0.05 ± 0.01 mg/L at Loc 1 to 0.08 ± 0.04 mg/L and 0.08 ± 0.01 mg/L at Loc 2 and Loc 3 during the dry season, increasing slightly in the wet season to 0.08 ± 0.01 mg/L, 0.11 ± 0.04 mg/L, and 0.09 ± 0.01 mg/L, respectively. All values were well below the WHO, US EPA, and Nigerian Standard (SON, 2007) guideline of 0.3 mg/L as seen in Table 1, indicating that iron levels are within safe limits for potable water. The minor wet-season increase is likely due to surface runoff, erosion of iron-rich soils, and leaching of minerals into the river, whereas lower dry-season concentrations may result from reduced inflow and dilution. Although these levels do not pose health risks, elevated iron in water can affect taste, stain laundry, and clog distribution systems when exceeding 0.3 mg/L (WHO, 2017).

Ecologically, iron affects the redox chemistry of aquatic systems and can influence the solubility and mobility of other heavy metals. In humans, iron is an essential micronutrient necessary for hemoglobin synthesis and oxygen transport; however, excessive intake may lead to gastrointestinal irritation, oxidative stress, or, rarely, iron overload disorders. Since concentrations in the Ona River were well below guideline values, there is no immediate human health concern related to iron exposure from this water source (Ubuoh et al., 2014).

- *Copper (Cu)*

The concentration of copper in the Ona River during the dry season ranged from 0.05 ± 0.01 mg/L at Copper concentrations in the Ona River were very low during both dry and wet seasons. During the dry season, copper ranged from 0.01 ± 0.01 mg/L at Locations 1 and 2 to 0.02 ± 0.00 mg/L at Location 3, while wet season levels increased slightly to 0.10 ± 0.02 mg/L, 0.15 ± 0.07 mg/L, and 0.18 ± 0.05 mg/L across the three locations. These values are well below the WHO guideline of 1.0 mg/L, the Nigerian standard of 1 mg/L, and the EPA maximum contaminant level of 1.3 mg/L, indicating minimal human health risk.

From an ecological perspective, copper is an essential micronutrient for aquatic organisms, playing a critical role in enzymatic activity and metabolic processes. However, elevated concentrations can cause toxicity, leading to gill damage, impaired growth, reduced reproductive success, and altered behavior in fish and invertebrates (Brix, De Boeck, Baken, & Fort, 2022). The concentrations observed in this study are far below levels associated with such effects, suggesting that copper currently poses negligible ecological risk. The slight seasonal increase during the wet season likely reflects runoff and sediment mobilization but remains well below thresholds known to affect aquatic biota.

Overall, copper in the Ona River is within safe limits for both human and ecological health, and there is no evidence of adverse effects on aquatic organisms under current conditions.

➢ *Heavy Metal Pollution Indices*

- *Geo-Accumulation Index (Igeo) Assessment of Heavy Metals in the Ona River*

The calculated Igeo values for heavy metals in the Ona River across both dry and wet seasons indicate that most elements fall within the unpolluted category (Igeo ≤ 0; Table 2), based on Müller's (1969) classification.

Table 2 Geo-Accumulation Index (Igeo)

Metal	**Dry Season**			**Wet Season**		
	Loc 1	Loc 2	Loc 3	Loc 1	Loc 2	Loc 3
Cr	-10.5507	-10.3987	-10.39874	BDL	BDL	BDL
Cd	BDL	BDL	BDL	BDL	BDL	BDL
As	-8.1219	-8.3443	-9.344296	-9.3443	-9.92926	-9.92926
Mn	-10.7275	-10.7875	-10.72103	-11.0516	-10.7875	-10.6503
Mg	-9.73132	-9.82059	-10.19195	-8.97145	-9.5851	-9.72173
Zn	-10.3392	-9.99132	-10.99132	-9.21371	-9.04379	-9.89178
Ni	-11.3163	-11.7313	-11.31628	-11.3163	-12.3163	-11.3163
Pb	-9.55075	-9.96578	-9.965784	BDL	BDL	BDL
Fe	-20.4334	-19.7553	-19.75532	-19.7553	-19.2959	-19.5854
Cu	-12.7207	-12.7207	-11.72067	-9.39874	-8.81378	-8.55075

Chromium (Cr) concentrations in the dry season ranged from –10.55 to –10.40 and were below detection limits in the wet season, indicating levels far below geochemical background and minimal contamination risk (Okafor et al.,

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26sep070

2024). Cadmium (Cd) was BDL across all sites and seasons; given its high toxicity even at trace levels, including potential impacts on kidney and bone function (WHO, 2017), its absence suggests no cadmium pollution in these waters (Ubuoh, Nwogu, Ofoegbu, & Chikezie, 2023). Arsenic (As) exhibited strongly negative Igeo values (–8.12 to –9.93), confirming concentrations below background levels. Nonetheless, as a known carcinogen with no safe threshold (ATSDR, 2007), its presence warrants continuous monitoring.

Manganese (Mn) showed Igeo values of –10.72 to –11.05, reflecting no contamination, with slightly higher wet season levels likely due to leaching and runoff from Mn-rich soils. Magnesium (Mg) ranged from –8.97 to –10.19, with less negative wet season values attributed to dissolution of dolomitic or calcitic rocks. Zinc (Zn) Igeo values (–9.21 to –10.99) were also below zero, although slightly higher wet season levels may reflect inputs from roofing materials or galvanized pipes, consistent with widespread anthropogenic contributions in river systems (Ding et al., 2024).

Nickel (Ni) remained unpolluted across seasons (Igeo –11.73), aligning with findings from minimally impacted freshwater systems (Okafor et al., 2024). Lead (Pb) was detected only in the dry season (Igeo –9.55 to –9.96) and BDL in the wet season, with seasonal differences likely reflecting dilution and sedimentation; despite low levels, Pb remains a cumulative neurotoxicant (USEPA, 2009). Iron (Fe) exhibited highly negative Igeo values (–20.43 to –19.29), consistent with lithogenic dominance and minimal industrial influence (Ubuoh et al., 2023). Copper (Cu) ranged from –12.72 in the dry season to –8.55 in the wet season, with slight increases during rainfall likely from agricultural runoff or corrosion of metallic infrastructure.

Overall, the Igeo assessment confirms that the Ona River is largely unpolluted, with all metals below geochemical background levels. Nevertheless, the presence of toxic elements such as arsenic and lead, even at low concentrations, indicate the need for continuous monitoring and proactive management to prevent long-term accumulation and potential health or ecological risks.

- *Enrichment Factor (EF) Analysis of Heavy Metals in the Ona River*

Enrichment Factor (EF) analysis showed substantial variability across metals and seasons, reflecting strong anthropogenic influences on water quality (Table 3). During the dry season, arsenic (As) exhibited extremely severe enrichment (1,361–5,083), indicating significant inputs from agriculture, pesticides, or industrial effluents. Manganese (Mn) and magnesium (Mg) also showed elevated EF values (757–1,666 and 501–835, respectively), likely from mixed natural and anthropogenic sources, including soil leaching and fertilizer application. Lead (Pb) demonstrated strong enrichment (885–1,888), suggesting contributions from traffic emissions, battery waste, or urban runoff. Chromium (Cr), zinc (Zn), and nickel (Ni) similarly exceeded the EF threshold of 10, highlighting substantial human influence.

In the wet season, EF values generally decreased but certain metals remained highly enriched. Arsenic continued to show significant enrichment (660–1,362), while Mn maintained consistent levels (838–1,763), likely due to mobilization by runoff. Copper (Cu) and zinc (Zn) EF values increased notably (1,311–2,098 and 828–1,491, respectively), reflecting leaching from corroded materials, agricultural inputs, or diffuse runoff. Iron (Fe), used as the reference element, consistently recorded EF near 1, confirming its lithogenic origin and validating the normalization approach.

Overall, EF results indicate that arsenic, lead, copper, and manganese are strongly influenced by anthropogenic activities, with seasonal rainfall events enhancing metal mobilization. These patterns align with studies linking elevated enrichment factors to urbanization, industrial discharge, and agricultural intensification.

Table 3 Enrichment Factor (EF)

Metal	Dry Season			Wet Season		
	Loc 1	Loc 2	Loc 3	Loc 1	Loc 2	Loc 3
Cr	944	655.5556	655.5556	0	0	0
Cd	BDL	BDL	BDL	BDL	BDL	BDL
As	5083.077	2723.077	1361.538	1361.538	660.1399	806.8376
Mn	1665.882	978.7059	756.5882	1763.059	837.9893	931.6601
Mg	835.1253	500.7133	524.3133	416.9333	364.1552	489.4815
Zn	1093.053	869.4737	434.7368	1490.526	1219.522	828.0702
Ni	555.2941	260.2941	347.0588	347.0588	126.2032	308.4967
Pb	1888	885	885	BDL	BDL	BDL
Fe	1	1	1	1	1	1
Cu	209.7778	131.1111	262.2222	1311.111	1430.303	2097.778

- *Contamination Factor (CF) Analysis of Heavy Metals in the Ona River*

The contamination factor (CF) analysis revealed spatial and seasonal variations in heavy metals across the Ona River (Table 4). *Arsenic (As)* exhibited the highest CF values, peaking at 7.00 during the dry season and remaining above moderate thresholds in the wet season, identifying it as the dominant contaminant. *Manganese (Mn)* also showed elevated CF (2.73–6.35), particularly during the wet season, likely due to mobilization from soils and runoff (Iroye &

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26sep070

Igbozurike, 2018). *Lead (Pb)* and *Chromium (Cr)* showed higher CF during the dry season but were below detection limits in the wet season, reflecting dilution or sedimentation effects. In contrast, Zn, Fe, Cu, Ni, and Mg consistently had CF < 1, indicating minimal contamination (Anate & Abule, 2025). Overall, CF results highlight arsenic and manganese as the primary contaminants, warranting continued monitoring and management.

- *Pollution Load Index (PLI) Assessment*

The Pollution Load Index (PLI), calculated as the geometric mean of contamination factors (CF) for detected metals, is commonly used to assess overall heavy metal burden, with values below 1 indicating low or baseline pollution (Okafor, Omokpariola, Tabugbo, & Okoliko, 2024). Even when overall PLI values are within acceptable limits, individual CFs for metals such as arsenic and manganese may be elevated, highlighting localized pollution hotspots that the composite index can overlook (Ding, Han, Qu, Liu, & Wang, 2024). Seasonal variations can further influence PLI, with dilution during wet periods reducing concentrations of some metals, while persistent contaminants maintain elevated levels and localized risks (Li, Zhang, & Wu, 2023). Thus, although the river's cumulative metal load appears moderate, targeted monitoring and mitigation of specific toxic elements remain essential to protect ecological and human health (Li et al., 2023).

- *Ecological Risk Assessment (ERI)*

The ecological risk index (ERI) results highlight the significant potential risk posed by toxic metals, particularly arsenic and lead, which combine high toxic-response factors with elevated contamination factor (CF) values (Li, Zhang, & Wu, 2023). ERI values peaked at 101.10 at Dry Season Location 1 and 85.64 at Dry Season Location 2, indicating considerable ecological risk at these sites (Table 4). During the wet season, ERI values declined markedly (27.05–40.33), reflecting reduced contributions from chromium and lead due to dilution and sedimentation (Li et al., 2023). Nonetheless, ERI remained above 20 across all locations, largely driven by arsenic and manganese, signaling moderate ecological risk. The seasonal comparison indicates that dry season contamination poses a more significant ecological threat than wet season levels. Overall, while cumulative pollution indices such as the PLI suggest low to moderate contamination, the ERI highlights specific metals arsenic, manganese, and lead as key contributors to ecological risk (Okafor, Omokpariola, Tabugbo, & Okoliko, 2024; Ding, Han, Qu, Liu, & Wang, 2024). These findings emphasize the need for continuous monitoring and targeted management, particularly during the dry season, to prevent potential adverse effects on aquatic ecosystems.

Table 4 Contamination Factor (CF), Pollution Load Index (PLI), Degree of Contamination (DoC), Modified Degree of Pollution (mDoC), and Ecological Risk Index (ERI) of Heavy Metals in the Water Samples

Sample	**Contamination Factor (CF)**										**PLI**	**DoC**	**mDoC**	**ERI**
	Chromium	Cadmium	Arsenic	Magnesium	Manganese	Zinc	Nickel	Lead	Iron	Copper				
	Dry Season													
Loc 1	1.80	0.000	7.00	0.6635	3.75	0.037	0.571	4.00	0.167	0.005	0.506	17.993	1.799	101.10
Loc 2	2.00	0.000	6.00	0.6365	3.525	0.047	0.429	3.00	0.267	0.005	0.506	15.908	1.591	85.64
Loc 3	2.00	0.000	3.00	0.6665	2.725	0.023	0.571	3.00	0.267	0.010	0.472	12.263	1.226	55.59
	Wet Season													
Loc 1	0.00	0.000	3.00	0.5300	6.350	0.080	0.571	0.00	0.267	0.050	0.483	10.848	1.085	40.33
Loc 2	0.00	0.000	2.00	0.6365	4.150	0.090	0.286	0.00	0.367	0.075	0.450	7.604	0.760	27.05
Loc 3	0.00	0.000	2.00	0.7000	3.775	0.050	0.571	0.00	0.300	0.090	0.456	7.486	0.749	28.13

IV. CONCLUSION

The Ona River in Ibadan, Nigeria, is under significant pressure from urbanization, industrial effluents, and untreated sewage, leading to elevated levels of heavy metals such as Cr, Pb, Cd, and Ni, particularly during the dry season. Pollution indices and health risk assessments indicate moderate to high contamination, posing potential ecological and human health risks. These findings highlight the urgent need for regular monitoring, targeted pollution control measures, and sustainable management strategies to protect water quality and ensure the river continues to support domestic, agricultural, and ecological functions.

REFERENCES

[1]. Adelagun, R. O. A., Etim, E. E., & Godwin, O. E. (2021). Application of water quality index for the assessment of water from different sources in Nigeria. In Promising Techniques for Wastewater Treatment and Water Quality Assessment. IntechOpen. https://doi.org/10.5772/intechopen.98696.

[2]. Agbam, E. F., Halimoon, N., Mohamat Yusuff, F., Wan Johari, W. L., & Saba, A. O. (2025). Heavy metals and the community structure of macroinvertebrate assemblages in aquatic ecosystems: a systematic review. AIMS Environmental Science, 12(4), 615–652. https://doi.org/10.3934/environsci.2025028.

[3]. Agency for Toxic Substances and Disease Registry (ATSDR). (2007). Toxicological profile for arsenic. U.S. Department of Health and Human Services. https://www.atsdr.cdc.gov/toxprofiles/tp2.pdf.

[4]. Agency for Toxic Substances and Disease Registry (ATSDR). (2024). Toxicological Profile for Nickel. Atlanta, GA: U.S. Department of Health and Human Services. https://www.ncbi.nlm.nih.gov/books/NBK610341/.

[5]. Akintola, O. A., Agunbiade, F. O., Ariyomo, T. O., Babalola, T. E., Adabembe, B. A., Faloye, O. T., & Sajo, O. S. (2024). Simple fuzzy classification of metal qualities of Ona River, Ibadan, Nigeria, and its implication for fish production and other uses. Discover Water, 4(1), 79. https://doi.org/10.1007/s43832-024-00137-2.

[6]. Anate, S. G., & Abule, E. C. (2025). Anthropogenicity, potential contamination index (Cp) and geo-accumulation index (I-geo) analysis of sediments of Kaani River, Ogoni Axis, Rivers State, South-South, Nigeria. American Journal of Environmental Protection. https://doi.org/10.11648/j.ajep.20251402.16.

[7]. Brix, K. V., De Boeck, G., Baken, S., & Fort, D. J. (2022). Adverse outcome pathways for chronic copper toxicity to fish and amphibians. Environmental Toxicology and Chemistry, 41(12), 2911–2927. https://doi.org/10.1002/etc.5483.

[8]. Ding, Z., Han, G., Qu, R., Liu, J., & Wang, P. (2024). Review on zinc isotopes in river systems: distribution and application. Water, 16(1), 87. https://doi.org/10.3390/w16010087.

[9]. Iroye, K. A., & Igbozurike, J. C. (2018). Assessment of heavy metal in urbanized tropical river in Ibadan, Nigeria. International Journal of Multidisciplinary Studies, 5(2), 42–56.

[10]. Joseph, A. P., Edet, U. O., Iwok, E., & Ekanem, S. (2022). Health implications of the oral and dermal exposure to heavy metals in borehole water from a poorly remediated Ikot Ada Udo community, Akwa Ibom State, South-South Nigeria. Scientific African, 18, e01416. https://doi.org/10.1016/j.sciaf.2022.e01416.

[11]. Lee, J. W., Choi, H., Hwang, U. K., Kang, J. C., Kang, Y. J., Kim, K. I., & Kim, J. H. (2019). Toxic effects of lead exposure on bioaccumulation, oxidative stress, neurotoxicity, and immune responses in fish: A review. Environmental Toxicology and Pharmacology, 68, 101–108. https://doi.org/10.1016/j.etap.2019.03.010.

[12]. Lin, L., Yang, H., & Xu, X. (2022). Effects of water pollution on human health and disease heterogeneity: a review. Frontiers in Environmental Science, 10, Article 880246. https://doi.org/10.3389/fenvs.2022.880246.

[13]. Lin, Y., Wang, J., Dai, H., Mao, F., Chen, Q., Yan, H., & Chen, M. (2023). Salinity moderated the toxicity of zinc oxide nanoparticles (ZnO NPs) towards the early development of Takifugu obscurus. International Journal of Environmental Research and Public Health, 20(4), 3209. https://doi.org/10.3390/ijerph20043209.

[14]. Liu, T., Wang, L., Pei, S., Yang, S., Wu, J., Liu, W., & Wu, Q. (2025). Biological functions and detection strategies of magnesium ions: from basic necessity to precise analysis. Analyst, 150, 2979–2999. https://doi.org/10.1039/D5AN00425J.

[15]. Müller, G. (1969). Index of geoaccumulation in sediments of the Rhine River. GeoJournal, 2(3), 108–118.

[16]. Okafor, V. N., Omokpariola, D. O., Tabugbo, B. I., & Okoliko, G. F. (2024). Ecological and health risk assessments of heavy metals in surface water sediments from Ifite Ogwari community in Southeastern Nigeria. Discover Environment, 2, 93. https://doi.org/10.1007/s44274-024-00098-2.

[17]. Peters, A., Wilson, I., Cooper, C. A., Ryan, A., Van Assche, F., & Winbow, H. (2023). Evaluating the protectiveness of a bioavailability-based environmental quality standard for the protection of aquatic communities from zinc toxicity based on field evidence. Environmental Toxicology and Chemistry, 42(5), 1010–1021. https://doi.org/10.1002/etc.5570.

[18]. U.S. Environmental Protection Agency (USEPA). (2009). Integrated Risk Information System (IRIS) on Lead and Lead Compounds. Washington, DC: USEPA. https://www.epa.gov/iris.

[19]. Ubuoh, E. A., Nwogu, F. U., Ofoegbu, C. C., & Chikezie, P. C. (2023). Environmental pollution loads on surface water chemistry and potentially ecological risks of inland aquatic ecosystem in South-Eastern State, Nigeria. Environmental Systems Research, 12, 22. https://doi.org/10.1186/s40068-023-00302-x.

[20]. United Nations Educational, Scientific and Cultural Organization (UNESCO). (2021). The United Nations World Water Development Report 2021: Valuing Water. UNESCO World Water Assessment Programme. UNESCO. ISBN 978-92-3-100434-6. Available at: https://www.unesco.org/reports/wwdr/2021/en/.

[21]. World Health Organization (WHO). (2017). Guidelines for Drinking-water Quality: Fourth Edition Incorporating the First Addendum. Geneva: World Health Organization. https://www.who.int/publications/i/item/9789241549950.

[22]. World Health Organization (WHO). (2022). Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda. Geneva: World Health Organization.

[23]. World Health Organization. (2024, September 27). Lead poisoning and health [Fact sheet]. Geneva: World Health Organization. https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health.