

Integrated Assessment of Emerging Contaminants (Microplastics and PFAS) in Nigerian Freshwater Systems: A Review of Implications on Ecotoxicology and Human Health

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ABSTRACT

Microplastics (MPs) and per- and polyfluoroalkyl substances (PFAS) pose more and more risks to freshwater ecosystems and overall human health, especially in Nigeria where communities depend heavily on surface waters, and the available data on these contaminants remain limited. This study reviews existing evidence on the occurrence, eco-toxicological implications, the dangers to health associated with MPs and PFAS in Nigerian freshwater systems. A qualitative narrative review was conducted using peer-reviewed studies, reports, and regional investigations focusing on freshwater organisms, sediments, and water matrices. Emphasis was placed on bioindicator studies, analytical techniques, and exposure pathways. Findings indicate widespread microplastic contamination in Nigerian rivers, with fibers and films of polyethylene, polypropylene, and nylon detected in freshwater invertebrates and water samples at eco-toxicologically significant levels. Transfers to fishes from the affected organisms are made possible because of their position on the cycle of feeding for aquatic organisms. PFAS data are comparatively scarce but confirm detectable concentrations in water, sediments, and wastewater sludge, underscoring their persistence and bioaccumulative potential. Evidence suggests potential sub-lethal ecological effects and plausible human exposure through drinking water and fish consumption. MPs and PFAS represent a growing environmental and public health concern in Nigeria. Despite limited local data, existing evidence supports the need for precautionary management, expanded monitoring, and integrated ecotoxicological and health-focused research to mitigate future risks.

Keywords: Emerging Contaminants; MPs; PFAS; Freshwater Systems; Ecotoxicology; Human Health.

INTRODUCTION

The world has, in the 21st century reached a difficult assessment of its relationship with water, pollution, and the survival of ecological and human species. Over the past five decades, there have been scientific investigations by many international organizations like the UNEP (New York), GGGI (in South Korea), the IPCC (New York) the IUCN (Switzerland), the EEA (Copenhagen), and many others (in Europe, United States, United Kingdom, Germany, Sweden, and Japan) (Athanasios, 2021; Lopez-Claros et al., 2020; Charles et al., 2024). These investigations significantly improved public and institutional awareness of environmental degradation and emphasized the necessity for immediate corrective measures (Athanasios, 2021; Charles et al., 2024). Issues such as air pollution in urban centres caused by vehicle emissions, depletion of the stratospheric ozone layer over Antarctica (Kessenich et al., 2023), contamination of water bodies from agricultural runoff and plastic debris, soil degradation and desert expansion, discharge of toxic industrial and municipal wastewater, acid rain damage to Scandinavian freshwater systems (Ojha, 2021), rapid population growth, unchecked urban expansion, widespread deforestation of tropical forests, biodiversity loss, and climate change were all recognized as serious threats to ecosystems, natural resources, and human well-being (Sulaiman, 2024). Nowhere is this reckoning more urgent than in the freshwater systems of Nigeria; a place where emerging contaminants like PFAS are increasingly detected but scarcely understood. These substances although born of modern convenience and industrial growth now persist in rivers, lakes, and wetlands long after their initial use, ultimately resisting natural degradation and conventional water treatment processes (Isukuru et al., 2024).

Microplastics (MPs) can be fragmented into our ecosystems so small that they evade visibility yet large enough to alter our biological functions, while per- and polyfluoroalkyl substances (PFAS) often called (“forever chemicals”) linger in sediments and living tissues for decades (Alva & Thomas, 2025). With MPs working together with PFAS (especially short-to-long chain carboxylate and sulfonate forms, perfluorooctanoic acid and perfluorooctane sulfonate), they pose a dual threat: i.) disrupting aquatic food webs and ii.) exposing human populations to chronic toxicological risks through drinking water and contaminated fish (Brunn et al., 2023; Alva & Thomas, 2025). These contaminants have been seen many times in smaller subsets selected from the environment for measurement even at low concentrations, these chemicals can be quite lethal on freshwater organisms (Brunn et al., 2023). This is a major concern for Nigeria, in that, beyond freshwater bodies are lifelines for livelihoods and nutrition and so the implications of this threat extends beyond environmental degradation to social and public health vulnerability (Irene et al., 2025).

This paper posits that the central challenge lies not only in the presence of these contaminants but in the absence of comprehensive monitoring, policy frameworks, and especially public awareness. Whenever freshwater systems absorb the byproducts of so called “urbanization”, industrial discharge, and poor waste management, the cost implication is transferred to ecosystems and to human communities least equipped to respond. This assessment reveals an urgent need for integrated research, regulatory reform, and sustainable environmental stewardship to safeguard both ecological integrity and human health.

LITERATURE REVIEW

Scholarly attention for much of the past century with respect to “environmental pollution” was measured by what could be easily seen or smelled ranging from oil slicks, to smoke-filled skies, and even visibly contaminated rivers in Southern Nigeria (Winter, 2024; Ingrao et al., 2023; Siddiqua et al., 2022). But over the last two decades, much of these literatures have begun focusing on a quieter and more complex threat: emerging contaminants that slip beneath the radar of traditional monitoring systems: Chen et al. (2024) took a close look at the latest sensor technologies designed to detect emerging pollutants in water, offering one of the most detailed assessments to date. Their study examined a wide range of detection methods, from biologically based sensors and light-driven optical systems to electrochemical devices and cutting-edge sensors built with nanomaterials. And rather than simply listing technologies they explained how each system works, how sensitive it is to trace levels of pollution, and how well it performs outside the laboratory. Entemake (2024) investigated “emerging contaminant sources, their effects and removal methods” and found that substances such as MPs, residues from personal care products, insecticides, industrial compounds, and pharmaceutical drugs are increasingly being found in water systems around the world. The study points to mounting concerns over the effects of these modern chemicals, particularly those entering rivers and lakes through sewage and wastewater discharges. Although often present in very small amounts, substances like PHACs, PCPs, EDCs and artificial sweepers (ASWs) are chemically diverse and difficult to track, making them challenging to measure using existing monitoring techniques (Entemake, 2024).

In comparison to Bukhari et al. (2025) there is improvement on the investigation of “emerging contaminants in wastewater and how they pose threats to environment and human health.” Endocrine disruptors were among the contaminants investigated not just those from pharmaceuticals, personal care products, and MPs as seen in other literatures. According to Bukhari et al. (2025) new-generation wastewater treatment systems are beginning to show real potential in tackling the growing problem of emerging contaminants. Technologies such as MBB treatment and ACO methods have demonstrated an ability to significantly reduce hard-to-remove pollutants that traditional systems often miss.

A sweeping review of global research has mapped how scientific attention to water contamination causes major stirs around the world in a little over 20 years. Ruiqi et al. (2024) did this mapping which had an analysis of more than 1,600 scientific papers on emerging contaminants in water, drawing from many databases, with the sole aim of tracing how the field has grown and where it is heading. The results show a steady rise in scientific output between 2003 and 2023 which reflects increasing global concern over previously overlooked water pollutants. Studies from the United States, China, and Spain have emerged as the most active contributors collectively driving much of the progress of the field (Ghosh et al., 2023). A closer look at recurring keywords and thematic groupings revealed that most studies concentrate on detecting these contaminants, evaluating their environmental and health risks and also understanding how these substances move and transform within natural water systems.

Lamichhane et al. (2023) argues that MPs have become top on the menu of recent hazards of the last decade and is coldheartedly driven by the explosive growth in plastic manufacturing and everyday use across the globe. According to Lamichhane et al. (2023), early investigations focused largely on oceans and coastal zones where plastic waste is highly visible. And over time, however, attention has shifted to inland regions since rivers and lakes are now understood to play a critical role in storing plastic debris and carrying it across various regions.

Choudhary et al. (2025) also points out that “microplastic pollution” is no longer confined to heavily industrialized or urban regions. Ziani et al. (2023) have reported plastic particles in rivers, reservoirs, and lakes, including freshwater systems far removed from major population centers. These investigations commonly identify fibers, broken fragments, thin films, and tiny pellets as the most prevalent forms. The plastics themselves are typically made from widely used materials such as PEs, PPs, and PETs. Lema (2024) notes that waterways passing through large cities often show the highest concentrations, underscoring the link between human activity and plastic contamination.

Liu et al. (2020) pictures facilities used in processing wastewater as a critical checkpoint in the journey of MPs through the environment. Saravanan et al. (2021) argue that treatment facilities function as both filters and sources of pollution. While modern treatment processes can capture a substantial portion of plastic particles, significant quantities still escape into rivers and lakes with treated effluent. At the same time, Casella et al. (2023) warned that MPs trapped in the sludge of sewages and may be released back into the environment when that material is used in agriculture or disposed off on land.

THEORETICAL FRAMEWORK

This roadmap is theoretically based upon the “Anthropogenic Stress Theory” and the “Ecological Theory in Ecotoxicology” and the “Health Theory”, which together provide a lens for understanding how human activities introduce persistent contaminants into freshwater ecosystems and how these pollutants affect both ecological and human health. Anthropogenic Stress Theory posits that human-driven pressures such as industrialization, urbanization, and unregulated waste disposal and others create cumulative stress on natural systems, often resulting in the accumulation of pollutants that disrupt ecological balance (Mori et al., 2025).

Mori et al. (2025) also iterated that understanding the impact of human-driven stressors on ecosystems requires more than simply identifying individual pollutants. One approach is to assess how similar different stressors are, considering multiple perspectives. Ringwald et al. (2024) suggest that stressors can be compared by examining their traits with what the stressors are, the reasons they are present, the locations they affect, the times they appear, how they act on organisms, and which species are impacted. This multi-dimensional approach provides a more complete picture of environmental pressures. James et al. (2021) notes that certain aspects of stressor similarity relate to the stressors themselves. For instance, their sources and inherent traits (such as their chemical structure, origin, or even their production methods) define their basic characteristics. These intrinsic features help classify stressors according to their origin or composition which is essential for monitoring and regulation. Other aspects of stressor similarity focus on their ecological effects. James et al. (2021) posited that how a stressor interacts with an organism (its mode of action) and which species are sensitive or tolerant to it, are examples of effect-based comparisons.

Eco-toxicological Risk Assessment Theory complements this perspective by focusing on the pathways, bioaccumulation, and toxic effects of chemical contaminants and by so doing provide a framework to predict ecological and human health risks from exposure. Environmental researchers are increasingly blurring the boundaries between once-separate scientific disciplines. Ecologists, who traditionally focused on physical and biological pressures, now routinely include chemical pollutants among the stressors shaping ecosystems (Bundschuh, 2023). At the same time, ecotoxicologists are drawing more heavily on ecological theories and processes to guide their work (Bundschuh, 2023). In response to this gap, a recent special research series set out to foster dialogue between “ecology and ecotoxicology” (Bhagat et al., 2024). The initiative by Bhagat et al. (2024) brings together studies that explore how ecological concepts, models, and theories can strengthen research on chemical contamination and environmental risk assessment and how insights from toxicology can, in turn, inform ecological understanding.

One contribution by Bhagat et al. (2024) to the series argues that research on chemical mixtures and multiple environmental stressors faces shared obstacles, regardless of whether the stressors are chemical or nonchemical in nature. Schafer et al. (2023) suggest that these fields rely on similar analytical tools and predictive approaches, yet continue to operate largely in isolation. Their work calls for stronger integration and cross-disciplinary learning to improve predictions of combined stressor effects.

Another study (Bundshuh, 2023), shifts attention to ecological processes that shape how populations and communities respond during and after contaminant exposure. This examination focuses on concepts such as recovery, recolonization, and adaptation and further on illustrating how these processes unfold simultaneously in natural systems. Olson et al. (2023) argue that understanding their relative importance is essential for improving risk assessment models and developing more effective ecosystem management strategies.

Another group researched on the role of “cryptic species” (which in this study will refer to organisms that appear nearly identical but are genetically distinct) raising questions about whether differences in sensitivity among these species could influence conservation outcomes and regulatory decisions (Jourdan et al., 2023). Although these cryptic species are well studied in ecology and evolution, they have rarely been considered in toxicological assessments (Jourdan et al., 2023).

In that same vein, Grabner et al. (2023) draw attention to parasites as important yet often ignored modifiers of toxicological responses. Parasites, in the view of Grabner et al. (2023), can influence how hosts react to contaminants, complicating interpretations of stressor effects. This introduced key parasite groups commonly found in organisms used for laboratory and field ecotoxicology emphasizing the need to account for these biological interactions (Grabner et al. 2023).

Finally, a literature review by Artigas and Morin (2023) focuses on aquatic microbial communities and the ecological roles they perform, particularly in relation to pesticide exposure. Artigas and Morin (2023) also noted that most existing studies concentrate on bottom-dwelling freshwater organisms, while research on communities dominated by autotrophs and heterotrophs has largely progressed in isolation. This separation persists despite growing evidence that these communities interact closely and jointly influence ecosystem functioning.

Stevenson et al. (2023) have long argued that freshwater systems are particularly vulnerable to MPs and PFAS. In Africa, and Nigeria in particular, these systems receive inputs from domestic wastewater, industrial effluents, agricultural runoff, and stormwater. Rapid population growth, urban expansion, and increasing consumption of plastic products exacerbate the accumulation of MPs in rivers, lakes, and reservoirs. Studies by Stevenson et al. (2023) also indicates that these particles are not confined to sediments and water alone, but can be also ingested by aquatic organisms, which will be eaten by fishes and others and in turn eaten by humans.

A parallel body of research by Krull (2022) reveals PFAS as “a persistent chemical threat.” Characterized by exceptionally strong carbon–fluorine bonds, PFAs resist chemical, thermal, and biological breakdown and this earns them the moniker “forever chemicals.” Their widespread use in industrial processes has led to much faster spread around the world. Once this spreads to freshwater, the short-chain PFAS remain at a place while other compounds move freely and occupy sediments and biota (Krull, 2022).

Environmental scientists (like Olson et al., 2023; Krull, 2022; Stevenson et al., 2023) further argue that MPs and PFAS may interact in more complex ways than what has been seen. MPs can act as vectors for PFAS, transporting them through freshwater systems and into aquatic organisms, potentially amplifying toxic effects. Wastewater treatment plants, although capable of removing some fraction of these pollutants, often fail to eliminate them completely, and the reuse or disposal of contaminated sludge can reintroduce contaminants into the environment (Olson et al., 2023).

Some Nigeria scientists say that, direct data on PFAS contamination in freshwater systems remain limited, leaving major questions unanswered (Guo et al., 2025). Despite this lack of measurement, Alsadik et al. (2025) point to everyday realities that suggest potential exposure. Imported household goods, industrial chemicals, and firefighting foams, many of which are known to contain PFAS are widely used across the country. Pollutants

from city runoff, leaking landfills, and untreated industrial wastewater are believed to carry these chemicals into rivers and lakes, but without routine monitoring, it is difficult to determine how widespread the contamination is or where the most affected areas may be.

Isukuru et al. (2024) reviewed existing studies on the freshwater systems in the country have also identified significant knowledge gaps related to both MPs and PFAS. One major challenge is the absence of uniform sampling and laboratory techniques, which makes it hard to compare findings from different studies or build a reliable national picture.

Another concern raised by Omeka et al. (2024) is the limited attention given to how MPs and PFAS may interact within freshwater environments. Evidence from other regions in Nigeria suggests that plastic particles can act as carriers for chemical pollutants, including PFAS, potentially altering how these substances move through water, how easily organisms absorb them, and how toxic they become. Public health experts (like Hasan et al., 2026; Wang et al., 2024) argue that evaluating emerging contaminants requires looking beyond ecological impacts to consider human exposure and health risks.

METHODOLOGY

To make sense of what is currently known about “MPs and PFAS” in the freshwater systems in Nigeria, this study relies on a qualitative narrative review rather than a data-heavy statistical analysis. The researcher chose this approach because the topic is still emerging, reliable local datasets are limited, and existing studies vary widely in their methods and scope. And by focusing on interpretation rather than numerical aggregation, the review allows findings from different regions and disciplines to be examined within their broader environmental and social contexts. This choice methodology draws together research from environmental science, ecotoxicology, and public health. It considers studies that explore where “MPs and PFAS” come from, how they behave in rivers and lakes, how they affect aquatic life, and what they may mean for human health. A range of targeted search terms was used, covering MPs, PFAS, emerging contaminants, freshwater environments, and geographic references to Nigeria and Africa. Only studies meeting specific standards were considered. These included research focused on “MPs and PFAS” in freshwater settings, peer-reviewed articles, review papers, and authoritative reports published in English. Preference was given to work relevant to Nigeria, Africa, or comparable socio-economic environments.

DISCUSSION

A broad review of scientific studies reveals clear and recurring patterns in how emerging contaminants are affecting freshwater systems, particularly in settings similar to Nigeria. Rather than relying on a single dataset, researchers and scientists have drawn together evidence from multiple investigations to identify shared trends (Schafer et al., 2023; Bundschuh, 2023; Olson et al., 2023; Casella et al., 2023; Athanasios, 2021; Winter, 2024). The limited studies available in Nigeria show that plastic particles are already present, especially in areas shaped by rapid urban growth, industrial activity, and high population density (Irene et al., 2025; Isukuru et al., 2024; Sulaiman, 2024; Omeka et al., 2024). The most frequently observed forms are fibers and fragments, reflecting widespread use of synthetic clothing, packaging, and everyday plastic products (Guo et al., 2025; Charles et al., 2024).

Researchers also note that contamination levels tend to be highest in water bodies receiving untreated sewage, urban runoff, and poorly managed solid waste (Siddiqua et al., 2022; Brunn et al., 2023). Seasonal changes also support these factors, alongside heavier rainfall often washing larger quantities of plastic debris into rivers and lakes through flooding and surface runoff. Although reported concentrations differ widely due to varying sampling methods, the overall picture points to a steady increase in these “slow poisons” (Omeka et al., 2024).

Another recurring finding across studies is how these freshwater organisms consume these contaminants. Some fishes and invertebrates have been shown to consume tiny plastic particles during feeding. This is a pointer to the situation in Nigeria where plastic fibers and fragments are spotted in the valuable fish species. This suggests direct exposure through natural feeding behavior (Isukuru et al., 2024; Choudhary, et al., 2025). Fibers appear most often, likely because they are abundant in the environment and resemble natural food sources. While many

studies stop short of measuring long-term effects, existing laboratory and field evidence indicates that ingesting MPs can disrupt feeding, growth, and energy use (Ruiqi et al., 2024; Chen, et al., 2024; Wang et al., 2024).

Eco-toxicological Implications

Based on observations of the researcher, eco-toxicological risks from MPs can be ascertained even with the scarceness of relevant data on PFAs. Findings from different countries in the continent were studied and one thing is clear – “MPs are not only present in surface waters but are interacting already with aquatic organisms.” And this is steadily raising the concerns of scientists. This concern led to a series of experiments (Verla et al., 2019; Nweke et al., 2024), one of which was carried out in southwestern Nigeria (Osun State) and provided one of the early signals of MPs exposures using a process known as “micro-Fourier Transform Infrared Spectroscopy analysis”.

A number of indicators (freshwater invertebrates) were used to detect and also measure loads of MPs in the tissues of organisms, some of which are: *Lanistes varicus*, *Melanoides tuberculata*, and *Tympanotonus fluviatilis*, resulting in high concentrations ranging from 1.71 to over 6.1 particles per gram (with particles smaller than 0.2 μm). Polymers like nylon, polypropylene and polyethylene which are “mostly in fibre and film forms” are “eco-toxicologically significant.” It was found by Verla et al. (2019) that these invertebrates could easily ingest these MPs due to their shapes, which potentially caused reduced feeding efficiency, altered energy allocation and physical stress.

Other key investigations that revealed the shift from organism-level exposure to system-wide contamination were carried out in both south south and south eastern regions (Verla et al., 2019). For south south (River state), Elechi Creek was chosen, as well as multiple rivers namely Obiaraedu, Nwangele, Okumpi, Ogbajarajaram and Onuezuze all in south east (Imo state). After microscopy-based analysis were completed, reports showed high concentrations of MPs ranging from hundreds to over a thousand particles per liter of freshwater sample. Further investigations identified simple plastics like PPs, PVCs, PEs, and PETs (occurring as fragments, films, and fibres), although there were limitations in some cases due to polymer-specific data. From the researcher’s perspective, especially under the lenses of ecotoxicology, such high loads imply that aquatic organisms have been grossly exposed to MPs, and continuous contact can possibly intensify sub-lethal effects including but not restricted to tissue irritation, higher stress responses, higher vulnerability of organisms to pressures from aquatic environments like low oxygen levels and poor water quality.

In contrast to MPs, a very important investigation by Adeogun et al. (2024) draws the focus to the “ecological workings of freshwater systems” and also warns that pollutants with long-lasting natures can silently build up and spread along the food chain. The effort of this investigation was centered on how PFAs accumulate in aquatic organisms (especially in fishes).

The researcher observes that little concrete data exist on the impact of the presence and spread of Perfluorinated compounds, not just in Nigeria, but also in Africa. Other scientists agree that particular information on PFAS and PFOA in freshwater has been rather sparse (Isaac et al., 2018). Expanded sampling efforts have also been made by Isaac et al. (2018) in major Nigerian rivers, especially to examine how these chemicals move between water and sediment and identifying possible sources of contamination.

Laboratory-based analyses by Sindiku et al. (2023) have added further clarity using advanced techniques such as Ultra-high PLCs paired with spectrometry using tandem mass. PFAS and related compounds are seen in sludge areas from industrial, domestic, and hospital wastewater treatment facilities. More recent developments show that PFAs were identified for the first time in several major rivers in southwestern Nigeria. It was observed that throughout all the locations, there were high concentration ranges of PFAS from 1.71 to 16.19 ngL^{-1} found in freshwater, compared to sedimentary concentrations of 1.64 to 10.30 ng g^{-1} .

Implications on Human Health

In two consecutive freshwater studies (lotic and lentic waters) carried out over the period of three months in Delta state, some aquatic plants were used as indicators for tracking the presence and effects of MPs and PFAS (Esiwo et al., 2024). Changes around plant physiology and the quality of water, especially as they point to

ecological strain, were documented by investigators. This was achieved by monitoring the water bodies during wet or rainy season. Other noticeable changes like unusual high turbidity, acidic condition, altered oxygen levels among others were recorded – changes that could determine the quality of water communities use for cooking, drinking and washing clothes.

A variety of invertebrates that served as indicators for freshwater quality were found among which *Chironomus* species and *Nais* species stood out during the investigations. The *Chironomus* species and *Nais* species are often prey for aquatic organisms especially fishes due to their positions in the food chain. These fishes are also likely to be consumed by humans which once again presents a potential for these contaminants to climb up the food ladder in the ecosystem.

The researcher observes that there is limited scientific investigations as regards PFAS, and this in turn means that healthcare providers may lack the information needed to recognize exposure-related illnesses, increasing the risk of misdiagnosis or delayed treatment.

RECOMMENDATIONS

1. Nigerian environmental agencies should integrate MPs and PFAS into routine freshwater monitoring frameworks. Standardized sampling, extraction, and analytical protocols (such as micro-FTIR and LC-MS/MS) should be adopted nationwide to ensure data comparability.
2. Targeted funding should support laboratory and field-based eco-toxicological studies focusing on organism-level, population-level, and food-web impacts of MPs and PFAS, particularly in freshwater invertebrates and fish.
3. Future studies should prioritize the interaction between MPs and PFAS, given evidence that MPs act as vectors for persistent chemicals, potentially amplifying toxicity and ecological stress.
4. Biomonitoring of fish, drinking water, and vulnerable populations should be conducted to quantify exposure levels and inform public health interventions.
5. Investments in wastewater treatment technologies and plastic waste control are critical to reducing contaminant inputs into rivers and streams.
6. Policymakers should develop regulations addressing emerging contaminants, while public awareness campaigns and partnerships with international research institutions should be strengthened.

CONCLUSION

This review demonstrates that MPs and PFAS represent a growing but underrecognized threat to Nigerian freshwater ecosystems and human health. Evidence from eco-toxicological studies shows that MPs are already present at significant levels in surface waters and within freshwater invertebrates, indicating active biological exposure and the potential for trophic transfer to fish and higher organisms. Although PFAS data remain limited, emerging studies confirm their presence in Nigerian waters, sediments, and wastewater sludge, highlighting their persistence and capacity for bioaccumulation. The combined presence of MPs and PFAS introduces complex ecological pressures, including physical stress, biochemical disruption, and cumulative toxicity. These stressors operate alongside existing challenges such as poor water quality and low oxygen levels, potentially reducing ecosystem resilience. From a human health perspective, reliance on freshwater resources for drinking and food increases exposure risks, while limited research capacity hampers diagnosis, risk assessment, and management. The absence of comprehensive national monitoring should not be mistaken for safety but rather recognized as a critical knowledge gap. Applying precautionary principles, strengthening research infrastructure, and integrating eco-toxicological evidence into policy are essential steps toward safeguarding freshwater biodiversity and public health in Nigeria.

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