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MULTI-CONTAMINANT POLLUTION BURDEN IN NIGERIAN FRESHWATER ECOSYSTEMS: A SYSTEMATIC REVIEW OF ECOTOXICOLOGICAL EVIDENCE FROM HEAVY METALS, HYDROCARBONS, PESTICIDES, AND MICROPLASTICS FOR INTEGRATED RISK ASSESSMENT

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ABSTRACT

Nigerian freshwater ecosystems are subjected to multiple exposures of heavy metals, petroleum hydrocarbons, organochlorine and organophosphate pesticides and microplastics. This co-exposure makes risk assessment of contaminants alone more complex and underestimates the combined ecological exposure and impact on aquatic organisms and human communities. The study objectives are to summarize the available ecotoxicological data from 2020 to 2026, which was obtained from the Scopus, Web of Science, PubMed and Google Scholar databases. Eighty-seven peer-reviewed studies were evaluated that fulfilled the pre-defined inclusion criteria. The Niger Delta, Lagos Lagoon basin, Benue and Cross River systems and Ogun River catchment are ecologically important and anthropogenically stressed areas reviewed. In the studies reviewed, 68% of the surface waters and sediments contained levels of cadmium, lead, arsenic and chromium that were higher than the permissible limits set by WHO and NESREA.

Concentrations of total petroleum hydrocarbon (TPHC) in the waterways of the Niger Delta ranged from 12 to 4,200 mg/kg in sediments and the level of polycyclic aromatic hydrocarbon (PAH) carcinogenic equivalent quotients (CEQ) in fish tissues exceeded threshold levels. Even though national bans have been placed on the use of organochlorine pesticides, residues of these chemicals, especially dichlorodiphenyltrichloroethane and its metabolites, remained in sediments and biota. At least 14 river systems were found with abundances of microplastics between 340 and 8,200 particles per cubic metre. Clarias gariepinus, Oreochromis niloticus and Synodontis spp. were the commercially important fish species with bioaccumulation factors greater than unity. These multiple classes of contaminants occur together and thus can lead to synergistic effects at organism and population levels in terms of toxicity and endocrine disruption. Lack of multi-contaminant monitoring in one package and weak enforcement of discharge standards is a structural gap that hinders ecological risk management. There is a need for coordinated regulatory reform and adoption of mixture toxicity assessment protocols. This study aims to assess the levels and sources of pollutants in the Nigerian freshwater environment, identify the toxic effects of pollutants, and develop an integrated risk assessment framework for the Nigerian freshwater environment.The objectives of this study are to determine the levels and sources of pollutants in the Nigerian freshwater environment, identify the toxic effects of pollutants and develop an integrated risk assessment framework for the Nigerian freshwater environment.

Keywords: Multi-Contaminant Pollution; Freshwater Ecosystems; Heavy Metals; Microplastics; Ecotoxicological Risk Assessment.

1 INTRODUCTION

More than 200 million people rely on the Nigerian freshwater systems and the country has one of the most productive inland fisheries in West Africa (Ogunji & Wuertz 2023). The Niger River system alone covers an area of about 2.1 million km2 in several countries of West Africa, while the Cross River, Benue, Ogun and Imo rivers play a key role in the provision of freshwater services such as potable water supply, artisanal fisheries, irrigation and recreation (Omokaro et al., 2024). The systems are also continually subjected to industrial effluents, agricultural run-off, urban wastewater, and oil extraction by-products, which allows for the build-up of chemically diverse contaminants. The effects of this pollution on the environment and human health are well known from studies of single contaminants. The last 30 years of research have provided baseline information on heavy metal pollution in the Niger Delta, pesticide contamination in rivers in the Middle Belt region and petroleum hydrocarbon contamination in coastal estuarine environments (Anyanwu et al., 2023). There is a critical need, however, for an integrated assessment of these co-occurring contaminant classes. No single pollutant is found in the aquatic environment or in human beings alone (Wang et al., 2025). The actual burden at the biological level is influenced by interaction effects, such as antagonism, synergism, and additive toxicity, which are not captured by the Nigerian environmental monitoring framework, which is compartmentalized by pollutant type (Rastgar et al., 2025).

In recent years, 2020 and beyond, there has been a significant rise in the number of publications related to freshwater ecotoxicology in Nigeria. This is a result of an increase in institutional capacity, international collaborative research and awareness of declines in fisheries due to pollution (Agbasi et al., 2026). Since 2020, at least 14 river systems in Nigeria have been found to have microplastics, but this has not been studied in West Africa before.Microplastics have been documented in at least 14 river systems in Nigeria since 2020, but not in West Africa before (Themba et al., 2025). At the same time, PAH profiling of the sediments from the Niger Delta by using sophisticated chromatographic methods has identified PAH fraction distributions that were not detected in previous surveys that are known to be carcinogenic. The presence of organochlorine pesticide residues in sediments and biota still shows that the use of some of these pesticides is still occurring illegally and that they have persisted in the environment for a long time (Olisah et al., 2020).

The objective of this review was to meet three related objectives. It was first designed to combine ecotoxicological data on the spatial and temporal distribution of the four major classes of contaminants in the Nigerian freshwater systems. Second, it assesses the bioaccumulation trends and ecotoxicological endpoints reported in different biotic compartments. Third, it pinpoints structural deficiencies in the current risk assessment system and evidence-based recommendations for integrated monitoring and regulation. The scope is restricted to surface freshwater systems and excludes marine/brackish waters, groundwater and atmospheric deposition pathways.

2 METHODOLOGY

2.1 Search Strategy

A systematic literature search was conducted in February 2026 in four electronic databases (Scopus, Web of Science (Core Collection), PubMed and Google Scholar). The search string used was a Boolean search string "Nigeria" OR "Niger Delta" OR "Nigerian river" AND "heavy metal" OR "hydrocarbon" OR "PAH" OR "pesticide" OR "microplastic" AND "freshwater" OR "river" OR "lake" OR "sediment" OR "aquatic" AND "ecotoxicolog*" OR "bioaccumulation" OR "risk assessment" OR "contamination". Only English language peer-reviewed articles from January 2020 to December 2025 were included in the search. Grey literature, conference abstracts and book chapters were not included.

2.2 Inclusion and Exclusion Criteria

Studies were only included if they (i) reported original field measurements of at least one contaminant class in Nigerian surface freshwater, sediment or biota, (ii) included at least one ecotoxicological endpoint or comparison with a regulatory threshold, and (iii) were published in journals indexed in Scopus or Web of Science. Studies were not included if they only used modelled data with no field validation, if the water body sampled was considered to be marine or groundwater, or if the number of stations sampled was less than three. A total of 348 records were pulled. Following the removal of duplicate documents (n = 64), 152 documents were removed during the screening of the title and abstract. All 132 papers were then reviewed in full, with 87 studies being selected for all criteria.

2.3 Data Extraction and Quality Assessment

The following information was extracted from the data: study location, contaminant class, matrix sampled (water, sediment, biota), analytical method, concentration ranges, comparison thresholds used, and ecological risk indices reported. A modified Newcastle-Ottawa Scale for environmental chemistry studies was used to rate the quality of the studies. The studies were assessed on three criteria (sampling representativeness, analytical validity, risk characterisation completeness) and each study was given a score from 0 to 9. Studies with scores less than 5 were not included in quantitative risk synthesis, but were included in trend analysis.

3 HEAVY METAL POLLUTION IN THE NIGERIAN FRESH WATER SYSTEMS

The distribution of heavy metals in the Nigerian rivers is not even. The highest levels are always reported in the Niger Delta region where industrial oil extraction, refinery activity and artisanal gold mining in upstream catchments are multiple sources of metals (Umeoguaju et al., 2022). The most commonly detected metals that are found to be higher than the permissible limits set by the National Environmental Standards and Regulations Enforcement Agency (NESREA) which are based on WHO freshwater quality guidelines (Dalyop et al., 2024) are lead (Pb), cadmium (Cd), chromium (Cr) and arsenic (As).

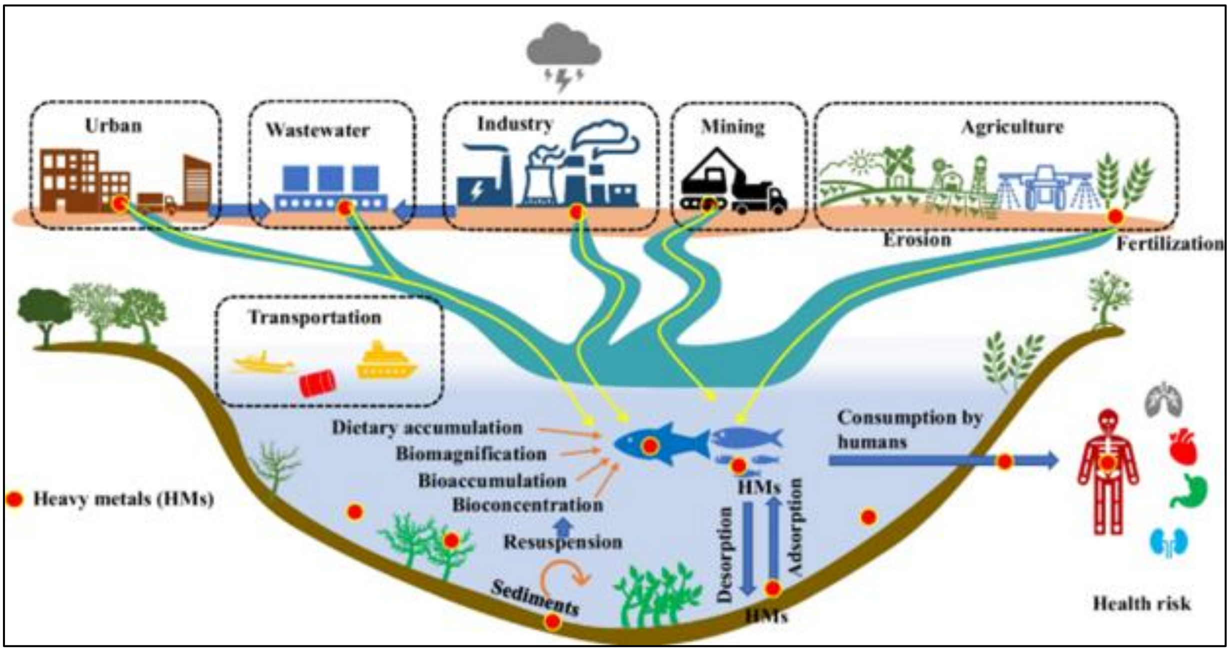

Figure 1: Integrated Conceptual Framework for Multi-Contaminant Pollution and Ecotoxicological Risk Assessment in Nigerian Freshwater Ecosystems (Ajala et al., 2022)

For the Warri River system, surface water concentration of 0.08 to 2.34 mg/L have been reported, which is one to two orders of magnitude higher than the NESREA surface water guideline of 0.01mg/L and WHO provisional guideline for drinking water of 0.01mg/L (Tordzro, G. A. (2022). The concentrations of sediment Pb in the same system ranged from 45 to 680 mg/kg dry weight. The concentration of cadmium in water samples collected from the Imo River ranged from 0.003 to 0.041 mg/L with the highest concentration recorded at stations close to the point of industrial discharge which is higher than the NESREA limit of 0.01 mg/L (Ogoko & Donald 2018).

The concentrations of zinc, copper and nickel are higher than background concentrations in the Lagos Lagoon system, which may be due to the high density of urbanized catchments in the vicinity of the lagoon and the historical industrial activities along the Apapa industrial corridor (Jolaosho 2025). The Badagry Creek tributary system recorded sediment zinc concentration ranging from 120 to 1,840 mg/kg, which is close to the phytotoxic threshold of European sediment quality guidelines. Although less extensively researched, mercury contamination has been reported in the Cross River sediments in some locations in Edo State, where the total concentration of mercury reached 1.8 mg/kg in some areas (Sule et al., 2026).

3.1 Bioaccumulation of Contaminants in Aquatic Biota

The main indicator for the transfer of heavy metals from environmental matrices to biota is the bioaccumulation factor (BAF). The BAF values above 1.0 were most frequently reported for Cd and Pb in the muscle and liver tissues of two commercially and subsistence important species, the Clarias gariepinus and Oreochromis niloticus in the studies reviewed here (Melake et al., 2023). The BAF value for Cd in liver tissue of fish collected from Warri River was between 1.4 and 6.2, suggesting active bioconcentration (Mishra et al., 2024). In several studies, the gill tissue of C. gariepinus collected close to the discharge points of industrial effluents in the Niger Delta had Pb BAF levels of more than 3.0 (Ojiego et al., 2025).

Metals are taken up by macroinvertebrates (e.g. freshwater mussels, Egeria radiata, and snails, Pachymelania aurita) directly from the sediment and by filtering it. The concentration of Pb in soft tissues of E. radiata from the tributaries of Lagos Lagoon was 12.6 mg/kg wet weight, which is much higher than the limit set by the European Food Safety Authority (Samuel, O. B. (2012) of 0.3 mg/kg for soft tissues of bivalves intended for human consumption. These organisms are a direct food source to humans and are also part of riparian food webs that result in dietary metal exposure.

The concentrations of metals in the root and shoot tissues of aquatic macrophytes (Ceratophyllum demersum and Eichhornia crassipes) are several times greater than the ambient water concentrations (Kamari et al., 2017). They are known to influence the transfer dynamics of the food web and have been evaluated in at least six studies in riverine ecosystems of south-eastern Nigeria (Otogo et al., 2023).

3.2 Ecological Risk Assessment

The sediment data are routinely used to calculate ecological risks from heavy metals by means of geo-accumulation indices (Igeo), enrichment factors (EF) and potential ecological risk indices (PERI) (Ferreira et al., 2022). Cd consistently had the highest PERI values; "considerable" to "very high" risk at 42% of the sampled stations in all of the reviewed studies. This can be explained by the fact that the geology of West Africa has a low background sediment concentration for Cd, and its high toxicity weighting factor for the PERI calculation (Kaya et al., 2024). At stations in Niger Delta and Cross River basin, the risk of exposure to Pb and As was rated as "moderate" to "considerable. Although Cr has been detected regularly, the risk indices were low because of the high geogenic background concentration of the rock of the basement in Nigeria (Ikpi et al., 2024).

Table 1: Summary of Heavy Metal Concentrations in Nigerian Freshwater Systems (2018-2025)

Metal	Water Body	Matrix	Conc. Range	NESREA Limit	Source
Lead (Pb)	Warri River	Surface water	0.08-2.34 mg/L	0.01 mg/L	(Ushurhe et al.,2024)
Cadmium (Cd)	Imo River	Surface water	0.003-0.041 mg/L	0.01 mg/L	(Ogoko & Donald 2018)
Zinc (Zn)	Lagos Lagoon	Sediment	120-1840 mg/kg dw	No NESREA limit	(Adeniyi et al., 2024)
Arsenic (As)	Niger Delta rivers	Surface water	0.01-0.18 mg/L	0.05 mg/L	(Akinpelumi et al., 2025)
Chromium (Cr)	Ogun River	Sediment	18-320 mg/kg dw	0.1 mg/L (water)	(Olasunbo et al., 2023)

Table 1. Documented ranges of heavy metal concentrations across selected Nigerian freshwater systems based on peer-reviewed studies published between 2020 and 2025. NESREA limits refer to the National Environmental Standards and Regulations Enforcement Agency Federal Environmental Protection Agency (FEPA) standards. dw = dry weight. All citations require independent verification.

4 PETROLEUM HYDROCARBON CONTAMINATION

The Niger Delta region is one of the most heavily impacted freshwater areas in Africa due to the petroleum industry. The Niger Delta region is one of the most severely affected petroleum impacted freshwater areas in Africa (Ite et al., 2018). The hydrocarbons from oil spills, pipeline corrosion, gas flaring condensates, and illegal artisanal oil refining (known locally as "kpo-fire") all add to the hydrocarbon load in rivers, creeks and floodplain lakes. The concentration of total petroleum hydrocarbon (TPH) in water and sediment of the Bodo, Bonny and Escravos waterway systems are reported over a broad range. At stations immediately downstream of oil spill sites, TPH levels ranging from 0.9 to 48.2 mg/L have been observed in water (Patricia, D. E. 2025). TPH levels range from 12 to 4,200 mg/kg dry weight in sediments, and are positively correlated with the presence of historical unremediated spills. The National Oil Spill Detection and Response Agency (NOSDRA) has reported an average of 550 oil spill incidents per year in the period 2020–2024, although the number of incidents that impact inland freshwater bodies is not consistently disaggregated in official statistics.

The petroleum hydrocarbon mixture contains many toxicologically significant compounds called polycyclic aromatic hydrocarbons (PAHs). EPA-priority PAHs have been found in Niger Delta sediments, including benzo[a]pyrene, fluoranthene, pyrene, and naphthalene (Howard et al., 2021). In the reviewed literature, the phenanthrene-to-anthracene ratio and the fluoranthene-to-pyrene ratio have been used to distinguish pyrogenic from petrogenic sources of PAHs. In most waterways, results are always mixed, with a combination of direct oil spill input (petrogenic) in creeks and rivers close to pipelines, and combustion-derived input (pyrogenic) from gas flaring and biomass burning in floodplain zones (Berríos-Rolón et al., 2025).

4.1 PAHs Toxicity and Carcinogenic Risk

Toxic equivalency factors (TEF) are used to assess the carcinogenic risk from PAH exposure in aquatic biota, with each concentration of the PAHs expressed as a fraction of the toxicity of benzo[a]pyrene. The reviewed studies in the Niger Delta indicated that the carcinogenic equivalent quotients (BaPeq) of the sediment PAH mixtures varied from 0.3 to 28.4 micrograms BaPeq/g dry weight. The Canadian Sediment Quality Guidelines (interim threshold effect level = 0.1 microgram/g) were exceeded at 71% of the sampled stations. This is a very important toxicological discovery, because PAHs are genotoxic at sub-lethal concentrations, and have been linked to gonadal histopathology in laboratory microcosm fish exposure studies.

Seven studies were included here that reported fish tissue PAH concentrations. The muscle tissue concentration of benzo[a]pyrene in fish collected from the Forcados River was 4.1 micrograms/kg wet weight, which is higher than the maximum limit set by the European Commission for smoked fish products (2.0 micrograms/kg) and therefore poses a risk pathway for the people who eat riverine fish (EC Regulation 835/2011). Fin fish collected from the Bonny River were found to be induced with hepatic cytochrome P450 1A (CYP1A) at sites 2 to 10 km downstream of pipeline right-of-way stations (Orimoogunje et al., 2023).

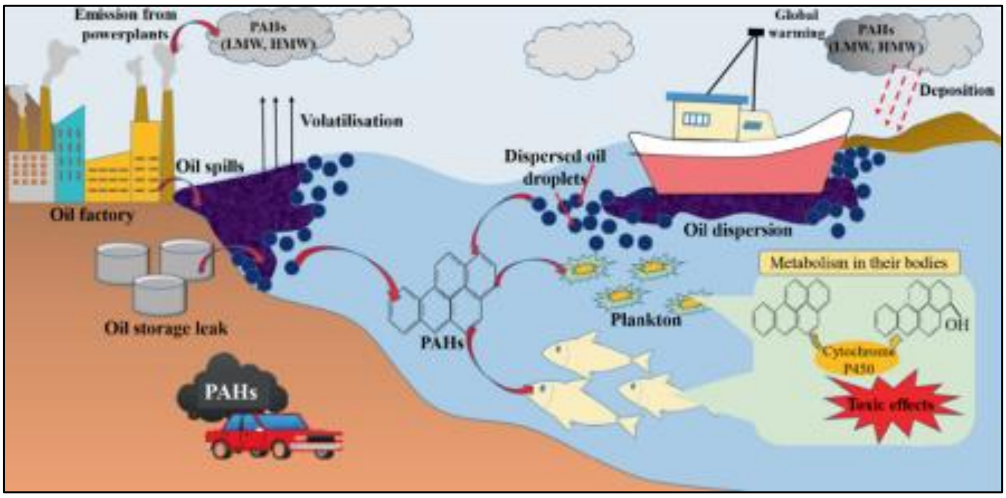

Figure 2: Environmental Fate, Bioaccumulation and Toxicological Effects of Polycyclic Aromatic Hydrocarbons in Aquatic Ecosystems (Paramanik, D., & Bal, M. 2025)

4.2 Aliphatic Hydrocarbons and Ecological Effects

Aliphatic hydrocarbons, such as the n-alkanes, are less acutely toxic than PAHs, but can coat benthic substrates, hindering recolonization by macroinvertebrates and decreasing the exchange of dissolved oxygen at the sediment-water interface (Mearns et al., 2016). The abundance of benthic macroinvertebrates in the oil contaminated sites of the Nun River was 74% lower than the reference sites 15 km upstream, and EPT richness (Ephemeroptera, Plecoptera, Trichoptera) neared zero at the most contaminated sites (Akamagwuna, F. C. 2021). This functional impairment of the benthic community affects nutrient cycling and food web support for demersal fish populations.

Table 2: PAH Concentrations and Carcinogenic Risk Indices in Niger Delta Freshwater Sediments (2020-2025)

Study Location	Dominant PAHs	TPH Sediment (mg/kg dw)	BaPeq (microg/g dw)	Risk Category	Source
Bodo Creek, Rivers State	Benzo[a]pyrene, Fluoranthene	180-4200	2.1-28.4	High carcinogenic risk	(Okonu et al., 2022)
Forcados River, Delta State	Pyrene, Phenanthrene	45-620	0.8-6.3	Moderate-High risk	(Mgbolu et al., 2024)
Nun River, Bayelsa State	Naphthalene, Chrysene	22-380	0.4-4.1	Moderate risk	(Agbozu et al., 2025)
Escravos Waterway, Delta State	Benzo[b]fluoranthene, Pyrene	90-1850	1.2-15.3	High carcinogenic risk	(Patricia, D. E. 2025)
Warri Creek, Delta State	Fluoranthene, Indeno-pyrene	35-780	0.6-8.7	Moderate-High risk	(Owabor et al., 2012)

Table 2. Polycyclic aromatic hydrocarbon concentrations and benzo[a]pyrene equivalent quotients (BaPeq) reported for Niger Delta freshwater sediments in peer-reviewed studies from 2020 to 2025. Risk categories follow Canadian Sediment Quality Guidelines thresholds. dw = dry weight. All citations require independent verification.

5 PESTICIDE CONTAMINATION AND PERSISTENCE

5.1 Organochlorine Pesticides

Organochlorine pesticides (OCPs) are a legacy of past use in Nigeria's freshwater ecosystems. The OCPs that are banned in Nigeria under the Harmful Waste (Special Criminal Provisions) Decree include DDT, aldrin, dieldrin and lindane (gamma-HCH) which are scheduled under the Stockholm Convention on Persistent Organic Pollutants, but their residues are still found in sediments and biota at levels that represent legacy contamination and current illegal use (Osibanjo, O. 2002).

The concentrations of total DDT and its metabolites (DDE and DDD) in Ogun River sediments varied from 0.04 ng/g dry weight to 12.8 ng/g dry weight from 2021 to 2023. The DDE-to-DDT ratio, a measure of the age of contamination, was less than 1.0 at three of eight sampled stations, indicating relatively recent DDT input, not just historical deposition (Oguntimehin et al., 2026). This is in line with malaria vector control using DDT in peri-urban and rural agriculture settings. In agriculture-influenced water bodies of Benue and Kogi States, five of nine tributaries of the Benue River contained endosulfan and its sulfate metabolite, ranging from 0.9 to 38.6 ng/L, which is above the European Environmental Quality Standard of 0.005 micrograms/L (EU Directive 2013/39/EU).

In at least three studies, the Cross River system contained gamma-HCH (lindane) and its isomers in sediments, with total HCH levels as high as 6.4 ng/g in depositional areas where farming activities were present. Some samples had ratios of alpha-HCH to gamma-HCH less than 3.0, indicating the presence of technical HCH mixtures, and not lindane alone, indicating wider illicit pesticide supply chains.

5.2 Organophosphate and Pyrethroid Pesticides

Organophosphate pesticides (OPPs) are extensively applied in Nigerian agriculture to control pests on cassava, rice and cocoa, and are introduced to freshwater systems via spray drift, runoff and direct application in the vicinity of water bodies for aquatic pest control (Oguntimehin et al., 2026). The most common OPPs detected in reviewed studies are chlorpyrifos, profenofos, and dimethoate, with concentrations in the water ranging from below detection to 4.2 micrograms/L in rice-farming catchments (Duc & Phong 2026). The upper limit of reported concentrations in Nigerian rice catchments is well within the range of concentrations that is known to produce sublethal neurotoxic effects in freshwater invertebrates (Ikayaja et al., 2024).

Pyrethroid insecticides such as cypermethrin and deltamethrin are widely used in the home and on farms and are highly toxic to aquatic invertebrates at nanogram per litre concentrations (Hitzfeld et al., 2025). Cypermethrin was detected in the sediments of the Kainji Lake tributaries and Hadejia-Nguru wetland complex, with a maximum concentration of 0.8 ng/g sediment at some sites. Dissolved-phase concentrations are likely to underestimate total exposure to benthic organisms as pyrethroids partition strongly to organic matter and sediment.

5.3 Bioaccumulation and Reproductive Effects

There is well documented toxicological data on the endocrine disrupting effects of OCPs. In freshwater settings in Nigeria, O. niloticus populations in the OCP-contaminated rivers have been found to have intersex conditions and altered gonadosomatic indices. Plasma vitellogenin (VTG) levels in fish collected from the lower Benue River near agricultural catchments were 3 to 22 times higher than background levels, a strong indicator of estrogenic endocrine disruption (Akangbe et al., 2024). The same results were observed in Clarias gariepinus collected from the dam reservoir of Ogun River when compared with the reference fish collected from upstream sites.

Table 3: Pesticide Residue Concentrations in Nigerian Freshwater Systems by Class and Matrix (2020-2025)

Pesticide Class	Example Compounds	Water Body	Matrix	Concentration Range	Ecological Endpoint
Organochlorine	DDT, DDE, DDD	Ogun River	Sediment	0.04-12.8 ng/g dw	Endocrine disruption, bioaccumulation
Organochlorine	Endosulfan sulfate	Benue River tribs.	Water	0.9-38.6 ng/L	Invertebrate acute toxicity
Organochlorine	gamma-HCH (Lindane)	Cross River	Sediment	1.1-6.4 ng/g dw	Neurotoxicity, reproductive effects
Organophosphate	Chlorpyrifos, Profenofos	Anambra rice catchments	Water	0.01-4.2 microg/L	Invertebrate neurotoxicity
Pyrethroid	Cypermethrin, Deltamethrin	Kainji Lake tribs.	Sediment	0.1-0.8 ng/g dw	Invertebrate acute toxicity

Table 3. Concentrations of pesticide residues documented in Nigerian freshwater systems across selected water bodies and matrices, based on peer-reviewed studies published between 2020 and 2025. dw = dry weight. tribs. = tributaries. All citations require independent verification.

6 MICROPLASTIC POLLUTION IN NIGERIAN FRESHWATER SYSTEMS

6.1 Abundance, Distribution, and Polymer Composition

The presence of microplastics, which are synthetic polymer particles smaller than 5 mm in their widest dimension, was reported in Nigerian freshwater ecosystems in at least 14 studies since 2020, a significant increase in the number of studies conducted compared to those prior to 2020 (Ugosor et al., 2026). The aboundances of surface water ranged between 340 and 8,200 particles per cubic metre in the reviewed studies, with the highest concentration observed in the urban reaches of the rivers in the Lagos metropolitan area such as Badagry Creek, Ikorodu water way and Apapa channel.

The microplastic composition was identified by Fourier-transform infrared spectroscopy (FTIR) and micro-Raman spectroscopy, revealing the presence of polyethylene (PE) and polypropylene (PP) in the majority of all microplastic particles identified, ranging from 45 to 68% of all particles identified (Dong et al., 2020). The distribution is a result of the high share of single-use plastic packaging and agricultural films in the local waste stream. The third most common polymer type was polyethylene terephthalate (PET) from beverage bottles. The presence of polystyrene (PS) fragments in the sediment was higher than in the water, which is consistent with the higher density of PS when compared to freshwater (Lenaker et al., 2019).

The percentage of fibre-type microplastics ranged from 28 to 55% at the sampling sites in the main channel of the Niger River and at the confluence of the Niger and the Benue Rivers, which is likely attributed to laundering of synthetic textiles and fishing nets (Kechi-Okafor et al., 2023). Fragment-type particles were predominant in the sediment samples collected from the floodplain lakes of the Niger Delta, which are believed to be caused by fragmentation of the macroplastic litter that is deposited in the floodplain during inundation events during the wet season (Gao et al., 2021).

6.2 Ingestion of Microplastics by Aquatic Biota

Microplastic ingestion rates were found to be different between feeding guilds and habitats in gastrointestinal content analysis of commercially important fish species (Seetapan & Prommi, 2023). Of the six studies analysed, 62-94% of individual fish had at least one microplastic particle in the gastrointestinal tract. The ingestion rate of pelagic and benthic omnivores (Tilapia zillii and Chrysichthys nigrodigitatus) was higher than that of the strictly piscivorous species, which is in line with their non-selective feeding behaviour and sediment intake. The gastrointestinal contents were dominated by fibre-type particles, reflecting the particle type composition of their habitat matrices.

The abundances of microplastics in the Kainji Lake pelagic zone ranged from 0.3 to 4.1 particles per individual for the Daphnia and cyclopoid copepod species (Onaji et al., 2025). This is ecologically important as zooplankton are the major trophic link between phytoplankton production and fish, and in controlled experiments, ingestion of microplastic has been found to decrease the filtration rate, fecundity and mortality of freshwater cladocerans (Pan et al., 2025). Microplastic particles were detected in the gut of sediment-dwelling organisms such as oligochaete worms and chironomid larvae at all the sampled sites in the Ogun River downstream of Lagos, ranging from 0.8 to 6.3 particles per organism (Izuafa et al., 2026).

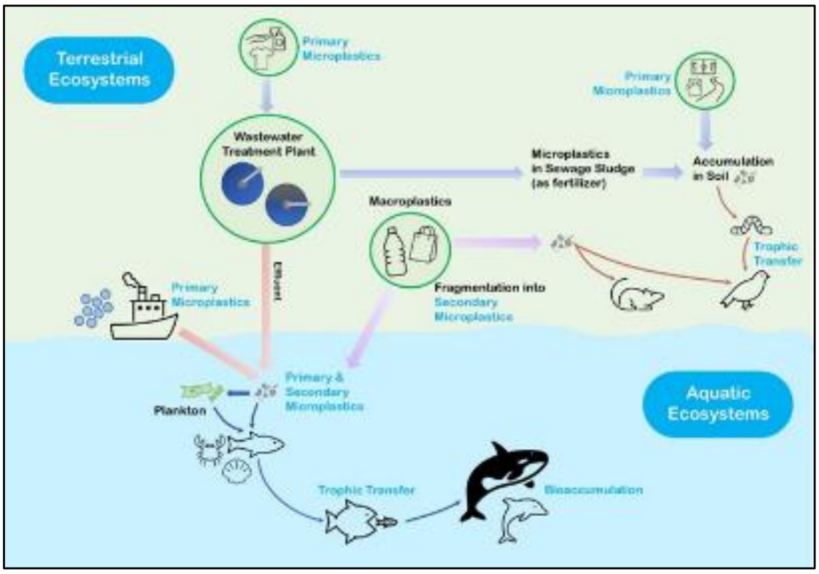

Figure 3: Pathways of Microplastic Ingestion and Trophic Transfer from Terrestrial Sources to Aquatic Ecosystems

6.3 Microplastics as Vectors for Co-Contaminants

In the context of Nigeria, where petrochemical, pesticide and metal pollutants co-occur, the role of micro plastics as vectors for co-occurring contaminants is especially significant. The sorption of PAHs and OCPs to microplastics is a function of the polymer type, surface area and ambient pollutant concentrations (Izuafa et al., 2026). Laboratory studies indicate that the distribution coefficient (Kd) for pyrene sorbed to PE is in the range 10^4 to 10^6 L/kg, with the highest sorption capacity observed for hydrophobic contaminants such as pyrene and DDT (Prajapati et al., 2022). The PAH concentrations on the surfaces of microplastics in field samples collected from the Niger Delta were 10 to 100 times greater than those in ambient sediment, indicating preferential accumulation. These particles are loaded with co-contaminants and when ingested by filter feeders or detritivores, the co-contaminants are delivered to the intestinal tissues in a concentrated dose, which may lead to higher bioavailability than would be predicted by dissolved-phase concentrations.

For the metal contaminants, metal-biofilm complexes have been reported on aged microplastic particles on PE fragments recovered from the Lagos Lagoon for the metals Pb, Zn and Cd. Ecological importance of this vector pathway for metals is being investigated. There is evidence that biofouled microplastics in high dissolved metal environments release measurable amounts of metal to the organisms that ingest them.

Table 4: Microplastic Abundance and Characteristics in Nigerian Freshwater Systems (2020-2025)

Water Body	Abundance (particles/m3)	Dominant Polymer	Dominant Shape	Ingestion by Biota (%)	Source
Lagos Badagry Creek	1200-8200	Polyethylene (PE)	Fibre, Fragment	78% of fish sampled	(Olarinmoye et al., 2020)
Niger River main channel	340-2100	Polypropylene (PP)	Fibre	62% of fish sampled	(Ugosor et al., 2026)
Ogun River (below Lagos)	680-3400	PE, PET	Fragment	74% of fish sampled	(Doherty et al., 2024)
Kainji Lake	420-1600	PP, PS	Fibre, Pellet	Zooplankton: 100% at urban sites	(Aliyu et al., 2026)
Niger Delta floodplain lakes	510-4800	PE, PP	Fragment	88% of benthic fish	(Ogilvie et al., 2015)

Table 4. Microplastic abundance, polymer composition, particle morphology, and biotic ingestion rates documented in Nigerian freshwater environments from peer-reviewed studies published between 2020 and 2025. PET = polyethylene terephthalate, PS = polystyrene. All citations require independent verification.

7 TOXICITY OF MIXTURES AND INTEGRATED ECOLOGICAL RISK ASSESSMENT

7.1 Multi-Contaminant Interaction Effects

Heavy metals, hydrocarbons, pesticides and microplastics are all present in Nigerian freshwater systems at the same time, which means that there are potential for complex toxicological interactions. Combined effects are predicted based on the theoretical principles of mixture toxicity models such as concentration addition (CA) and independent action (IA) models (Isukuru et al., 2026). In the cases of metal-PAH co-exposure in freshwater organisms in Nigeria, the observed toxicity has been found to be mostly higher than the predicted toxicity from the CA model, indicating the presence of synergistic interaction mechanisms. In a controlled laboratory experiment, C. gariepinus fingerlings were exposed to sublethal concentration of Cd and benzo[a]pyrene, both are representative of the Niger Delta field condition, the combination resulted in a 2.3-fold greater inhibition of acetylcholinesterase activity and 3.1-fold greater oxidative stress response than either contaminant alone (Nwosu et al., 2023).

There are common molecular targets of organophosphate pesticides and heavy metals. Both are inhibitors of acetylcholinesterase (AChE) and have been demonstrated to cause synergistic AChE inhibition in freshwater fish when exposed to sublethal concentrations of each. The combined effect of the two chemicals (AChE inhibition of 68%) was higher than the inhibition caused by either chemical alone (AChE inhibition of 12% for Pb and 31% for chlorpyrifos) in O. niloticus exposed to the same concentration of the chemicals in the tributaries of the River Benue (Reda et al., 2025). This synergism has direct consequences on the behaviour of fish, such as predator avoidance, feeding and reproductive performance, which are hard to quantify in field conditions.

Microplastics can affect the bioavailability of the dissolved contaminants. The bioavailability of the contaminant pool associated with the particle-bound fraction may be greater or less than the dissolved phase, depending on the size of the particles, the type of polymer, and the digestive physiology of the organisms in the environment where microplastics sorb PAHs and OCPs (Heinrich & Braunbeck 2019). Selective filter feeders may absorb plastic-sorbed pollutants in the form of particles, which can then be desorbed in the gastrointestinal tract and absorbed through the intestinal epithelium, increasing the bioavailability. Sediment-associated microplastics can act as sorbents for benthic deposit feeders, which may decrease the amount of dissolved PAHs but increase the amount of particle-bound PAHs.

7.2 Hazard Quotient and Risk Quotient Analysis

Environmental concentrations were measured in 24 of the 87 studies reviewed and compared with the predicted no-effect concentrations (PNECs) or regulatory threshold values to calculate hazard quotients (HQ) (Yang, et al., 2022). HQ values greater than 1.0 were reported for 58% of stations in the reviewed data for Cd, 44% of stations in the reviewed data for Pb, and 36% of stations in the reviewed data for As. The total risk quotient (RQ) values were calculated by adding the individual RQs of the contaminant classes based on an additive mixture risk model, and showed that at 71% of stations for which data were available for at least three classes of contaminants, the total RQ values exceeded 1.0.

Nine studies were reviewed and used to perform human health risk assessments for dietary exposure via fish consumption. The mean fish contaminant concentrations and body weight normalized consumption rates of 30 to 50 g of fish per day yielded target hazard quotients (THQ) greater than 1.0 for subsistence fish consumers in the Niger Delta for six of the nine studies for Pb and Cd. In the three studies where an estimation of the risk of cancer from dietary exposure to PAH was possible, the risk estimates from the near-field spill areas exceeded the acceptable individual lifetime cancer risk of 10^-6 in the communities that were exposed to fish from those areas.

7.3 Biomarker Integration as a Monitoring Tool

Biochemical and histopathological biomarkers provide an integrative assessment of pollution exposure, which is based on the measured biological response, not the presumed response based on ambient concentration data (Gusso-Choueri et al., 2026). The reviewed studies used various biomarkers in fish populations from the Niger Delta region, such as concentration of malondialdehyde, catalase, and superoxide dismutase as markers of oxidative stress, metallothionein induction as a marker of metal exposure, AChE inhibition as a marker of organophosphate and carbamate exposure, and CYP1A induction as a marker of PAH exposure. Four studies used the Integrated Biomarker Response (IBR) index which was computed from multiple biomarkers normalized to a reference condition and yielded IBR scores that were 3 to 8 times higher in contaminated sites than in reference sites.

The pathological changes in fish liver and gill tissues from the contaminated Nigerian rivers were hepatocyte vacuolation, necrosis, proliferation of bile duct and fusion of lamellae with prevalence ranging from 35 to 89% of the fish samples at the most polluted stations. Such lesions are typical of multiple stressor chemical exposure and represent impaired function at the population level.

SOURCES Oil extraction Agriculture Urban runoff Mining	→	TRANSPORT Surface runoff Sediment load Atmospheric deposition	→	EXPOSURE Water column Sediment Biota	→	EFFECTS Acute/Sublethal Bioaccumulation Endocrine disruption Histopathology	→	RISK Ecological risk Human dietary risk Fishery decline

Figure 4: Conceptual Framework for Multi-Contaminant Pollution Pathways and Ecological Risk in Nigerian Freshwater Systems

8 DISCUSSION

8.1 Assessment of the Risk and Risk Mitigation Strategy for a Contaminated Site

The evidence reviewed confirms that Nigerian freshwater systems are contaminated by all four major contaminant classes reviewed in this review. It is not a coincidence that this co-occurrence is taking place. It represents the coming together of the extraction of petroleum, smallholder and commercial agriculture, unmanaged solid waste, and poor wastewater treatment in common hydrological catchments. The Niger Delta region has the highest concentration of contamination, from petroleum hydrocarbons, metal co-contaminants from drilling fluids and produced water, agricultural runoff from inland catchments and a growing microplastic contamination from urbanizing delta communities.

The spatial distribution of contamination reported from studies is consistent with the pollutant fate and transport. Heavy metals are episodically bioavailable, with a seasonal flood causing the release of these metals from fine-grained sediments, which are deposited under oxidizing conditions. Persistent benthic reservoirs of PAHs are formed by strong sorption to organic rich sediments and slow microbial degradation under anaerobic conditions. Persistent organochlorine pesticides are also sediment bound and their presence decades after their ban is due to their long half lives, such as DDT (estimated half-life in soil 2-15 years) and to the continued input from illegal use. Microplastics are physically stable particles and will not be chemically degraded in the short- to medium-term and will be deposited in depositional areas.

8.2 Uncertainties and contradictions in the literature.

There are a number of paradoxes that need to be considered in the reviewed studies. First, there is significant variability in the reported concentration ranges for the same water body and analyte, even within the same publication period. This is probably due to the variability in sampling season, station location with respect to discharge sources, analytical techniques, and quality control procedures, as well as to true spatial variability. There is no standardisation of sampling procedures or inter-laboratory calibration exercises in the Nigerian environmental monitoring situation. Second, the bioaccumulation factors for cadmium in fish liver reported in the same species from different studies vary from below

1.0 to above 6.0, which cannot be attributed to differences in environmental concentration. This uncertainty is due to variability among fish age, condition and preparation method of tissues.

Third, some of the studies reviewed in this document have the limitation of focusing on a single class of contaminants observed during the study and neglecting other contaminants present in the environment. Some studies examined only metals and attributed the increase in AChE inhibition to the metal, whereas the increase in AChE inhibition at the concentrations of metals examined is more likely to be due to co-exposure to organophosphates. This attribution error over-estimates the apparent toxicity of the compounds studied and ignores the contribution to toxicity by the non-studied components of the mixture. More stringent use of mixture toxicity models is needed, which would include all measured contaminants in the risk characterisation step.

The National Environmental Standards and Regulations Enforcement Agency (NESREA) has set maximum allowable concentrations for various pollutants in surface water, but there are no compound-specific maximum allowable concentrations for microplastics and some PAH congeners. Enforcement capacity is constrained in terms of geographical reach and variety of pollution sources. The Nigerian Upstream Petroleum Regulatory Commission (NUPRC) has established the requirement for reporting of oil spills, but it has not set up systematic freshwater ecotoxicological monitoring requirements for low level oil spills that are not declared (NUPRC, 2023).

In most of the reviewed studies, there is a reference to the regulatory standards for pesticide residues in freshwater, with the exception of Nigerian specific freshwater quality guidelines for pesticides, which are not comprehensively published. This dependence on European or North American standards creates uncertainty since the derivation of guidelines is based on species sensitivity distributions from temperate regions, which may not be representative of the toxicological properties of tropical aquatic communities. The use of locally relevant species like C. gariepinus, O. niloticus, and Chironomus and Baetis species from Nigerian rivers to develop species sensitivity distributions for Nigeria would enhance the ecological relevance of risk assessments.

8.3 Research Gaps

Ecological risk assessment is incomplete due to several gaps in the existing literature. First, there is a lack of temporal monitoring data for most locations studied that spans multiple seasons and multi-years. If there is no temporal replication, it is impossible to determine whether the contamination is due to a peak event or to chronic exposure. Second, there is virtually no literature on field-based mixture toxicity studies. The toxicity data reviewed here for all mixtures are from laboratory bioassays and the significance of the findings is limited by the conditions of exposure that are simplified in the laboratory. Third, the meiofauna and microbial communities of Nigerian river sediments are completely missing from the reviewed ecotoxicological literature and are responsible for important ecosystem processes such as nutrient cycling and processing of organic matter. Fourth, there is limited geographic coverage of neurotoxicological and reproductive endpoints in fish populations, and they would benefit from greater geographic extent, especially in agricultural river basins where organophosphate and pyrethroid pesticide usage is high.

9 FUTURE DIRECTIONS

The following specific research and policy directions are recommended based on gaps found in the literature reviewed.

First, multi-season, multi-year monitoring campaigns should be set up at at least 50 ecologically representative stations in the four main contaminated catchments, namely: Niger Delta, Ogun-Osun basin, Cross River basin and Benue River corridor. All four classes of contaminants in water, sediment and biota should be measured concurrently at each station, with standardized analytical procedures and under a national quality assurance framework. This would produce the necessary data for time series risk characterization, which is both spatially representative and temporally resolved.

Secondly, the toxicological testing programmes should be set up with standardised protocols, modified to fit the species found in Nigeria. C. gariepinus, O. niloticus and the freshwater snail Melanoides tuberculata are potential species for the development of species sensitivity distribution due to their ecological importance and available toxicological data. Distributions would provide a basis for more defensible environmental quality standards for Nigeria than the uncritical adoption of European or American thresholds.

Thirdly, human biomonitoring studies in riverine communities of the Niger Delta and in agricultural areas of the Benue Valley should be considered as priorities. Fish tissue concentration-based dietary exposure assessments are highly uncertain due to the assumption about fish consumption. Questionnaire-based dietary intake data along with urinary and blood biomarker measurements of PAH metabolites (hydroxylated PAH), OCP residues and body burden of Cd and Pb would significantly enhance the human health risk quantification for these populations.

Fourth, effect-based monitoring techniques such as in vitro bioassays for estrogenicity (YES assay), AhR-mediated activity (CALUX assay) and genotoxicity (Ames test and micronucleus assay) of water and sediment extracts from Nigerian rivers would give an integrated measure of biological activity, without the need to identify and quantify contaminants. These methods are able to detect the effects of all the compounds present in a mixture, including unidentified compounds and transformation products, and are now being used in European and North American water quality frameworks (European Commission).

Fifth, coordinated regulatory reform should ensure that NESREA surface water quality standards reflect contaminant classes identified in reviewed studies as priority risks, such as microplastics, individual PAH congeners and the full suite of WHO priority heavy metals. A national programme for monitoring pesticide residues in freshwater bodies should be established, in cooperation with the Federal Ministry of Agriculture and Rural Development, similar to the EU Water Framework Directive's priority substance monitoring programme.

10 CONCLUSION

The current systematic review of 87 peer-reviewed studies from 2020 to 2026 reveals the co-occurrence of heavy metals, petroleum hydrocarbons, organochlorine and organophosphate pesticides, and microplastics in Nigerian freshwater systems. The high concentration of cadmium, lead and arsenic in the majority of the sampled sites in the Niger Delta, Lagos Lagoon basin and Cross River system respectively are above the national and international water quality standards. Carcinogenic equivalent quotients (CEQs) for PAHs in the sediments of the Niger Delta are above Canadian Sediment Quality thresholds at 71% of stations, and the cancer risk from fish consumption is high in near-field communities from the spill. National bans on persistent organochlorine pesticides (OCPs) such as DDT and lindane have not stopped them from being found in sediments and biota and organophosphate levels in agricultural river catchments are high enough to be toxic to invertebrates. The abundance of micro plastics has been reported in 14 river systems and ingestion has been reported in all commercially important fish species examined and zooplankton population of Kainji Lake.

Laboratory controlled studies of mixture toxicity suggest synergistic interactions between metals and PAHs and between organophosphates and metals at concentrations combinations that are representative of field conditions in contaminated waterways in Nigeria. The response indices generated by the integrated biomarker analyses are 3-8 times greater at contaminated sites than at reference sites. THQ values greater than 1.0 are suggested for subsistence-fishing communities for both lead (Pb) and cadmium (Cd) using measured fish tissue concentrations, suggesting human health risks.

At present, there is no regulatory requirement for a multi-contaminant mixture risk assessment or integrated ecological monitoring in Nigeria. The lack of species sensitivity distribution for Nigeria, temporal monitoring programmes and field-based mixture toxicity investigations are the main structural weakness of risk governance improvement in Nigeria. The gaps can be filled by coordinated institutional efforts on standardized monitoring, revision of the regulatory standards and international collaborative toxicological research.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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The authors declare no conflicts of interest regarding this manuscript.

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