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# Assessing the Impacts of Microplastic Pollution in the Andoni River Estuary: From Source to Sink.

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**Abstract:** Microplastic pollution presents serious ecological and socio-economic challenges in aquatic environments globally, with estuaries serving as key sites for the accumulation and transport of these pollutants. This study examines microplastic contamination in the Andoni River Estuary, an ecologically and economically important region in the Eastern Niger Delta, which is under significant pollution stress. Through extensive seasonal and spatial sampling of water, sediments, and biota, the research assesses microplastic distribution, polymer types, and associated environmental risks using the Polymer Hazard Index (PHI) and Pollution Load Index (PLI). Results identify polyethylene (PE) and polystyrene (PS) as the most prevalent contaminants, with specific polymers showing seasonal increases linked to wet season runoff and hydrodynamics. Sediments emerge as long-term reservoirs for microplastic pollution, exhibiting higher hazard indices than water, with contamination hotspots, notably at the Opobo/Ataba Channel, remaining consistent across seasons. The study finds strong correlations between microplastic concentrations in water and sediments, indicating shared transport and accumulation processes. This research provides the first comprehensive baseline for microplastic pollution in the Andoni Estuary and highlights the urgent need for targeted mitigation measures to protect the local ecosystem, fisheries, and public health in the Niger Delta region.

Key words: Microplastic pollution, Andoni River Estuary, Polymer Hazard Index, Pollution Load Index,Niger Delta ecosystem

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## Introduction

Microplastic pollution has emerged as a pervasive contaminant of global significance, encompassing ecological, socio-economic, and potential health ramifications for humans throughout aquatic systems, from source to sink. Estuaries, where fluvial systems converge with marine environments, exhibit particular susceptibility as they serve dual functions as both filters and transient repositories for microplastics, thereby promoting the ingestion of particles by aquatic organisms, the transport of chemical pollutants, and the ultimate incorporation into fisheries and local food webs (Browne *et al.*, 2015; Nel *et al.*, 2024). The Andoni River Estuary in the Eastern Niger Delta is a critical center for biodiversity and a lifeline for local livelihoods; however, it has a well-documented history of contamination from petroleum hydrocarbons, domestic waste, and other pollutants, which have progressively degraded its water quality and ecological integrity (Davies & Abowei, 2009). Although microplastics have been documented across various Nigerian river systems, sediments, and biota, including other estuaries within the Niger Delta, there exists a paucity of site-specific data about Andoni, resulting in uncertainties regarding sources, distribution, seasonal fluctuations, and impacts (Oni *et al.*, 2020; Nworie *et al.*, 2024). In the absence of such baseline and process-oriented data, managers and communities are unable to quantify exposure, identify sources, or formulate effective mitigation strategies. Research deficits encompass spatial and temporal inventories of microplastics along the river estuary coastal continuum; elucidating connections between terrestrial sources and estuarine accumulation zones; evaluating ingestion and accumulation in commercially significant species; assessing hydrodynamic influences on retention and export; and conducting risk assessments for human exposure through seafood consumption (Nel *et al.*, 2024; Odey *et al.*, 2024). The dynamics of estuarine retention and export are regulated by particle size and density, biofouling, flocculation, and tidal energy, underscoring the necessity for multi-compartment, multi-season sampling (Zhao *et al.*, 2022).

From an ecological perspective, microplastics are ingested by fish and invertebrates, possess the potential to traverse food webs, and function as sorbents for persistent organic pollutants and pathogens, thereby raising significant concerns regarding food safety (Wright & Kelly, 2017; Akindele *et al.*, 2020). The communities of the Andoni Estuary depend on fisheries, aquaculture, and mangrove resources for both their livelihoods and daily sustenance. However, plastic pollution is intensified by poorly managed waste, discarded fishing gear, and oil-related activities (Davies & Abowei, 2009). The pressures, combined with pre-existing hydrocarbon contamination and habitat degradation, further heighten the estuary's vulnerability. Therefore, a comprehensive study should endeavor to inventory microplastics in water, sediments, and key biota across seasonal and hydrological gradients; identify and prioritize sources; characterize transport mechanisms and fate; assess ecological exposure and sub-lethal effects; estimate human dietary exposure; and provide actionable recommendations for waste management, fisheries practices, and monitoring. Research will bridge a significant knowledge gap by producing the inaugural systematic microplastic baseline for the Andoni estuary, correlating contamination patterns with hydrodynamics and local pressures, and facilitating interventions aimed at preserving biodiversity, food security, and public health within the Eastern Niger Delta.

**Materials and Methods**

**Study Area**: The Andoni River (4°28′ N, 7°45′ E) is among the longest rivers in Rivers State, located between the New Calabar River to the west and the Imo River to the east, flowing into the Atlantic Ocean under a semi-diurnal tidal regime (Rivers State Ministry of Environment, 2010; Obire & Nwadukwe, 2002). It passes through several towns, including Inyong-orong, Iwoma, Asarama-Ija, Uyeada, and Ataba, and is a part of the lowland Niger Delta's brackish water system, marked by dense mangrove forests and tropical rainforests (Akpan & Ekpenyong, 2015). The river mouth harbors vast mangrove ecosystems, including nipa palms, which provide spawning and nursery habitats for species such as *Sarotherodon melanotheron* and *Penaeus monodon* (Ekundayo, 2003; Ezekiel *et al*., 2011). The region experiences a tropical equatorial climate with distinct wet (April–October) and dry (November–March) seasons, characterized by high humidity and consistently warm temperatures, with wet-season rainfall boosting river discharge and pollutant influx (Ansa *et al*., 2007). The estuary supports more than 300,000 people in coastal and riverside communities, where artisanal fishing is the dominant occupation, along with marine transportation, commerce, subsistence farming, salt production, and boat building (City Population, 2022; Mbikan *et al*., 2022). Geologically, it is situated on the Benin Formation, composed of unconsolidated sands and gravels, renowned for its high permeability and abundant aquifers that provide crucial groundwater resources for the Niger Delta (Ideriah *et al*., 2024).

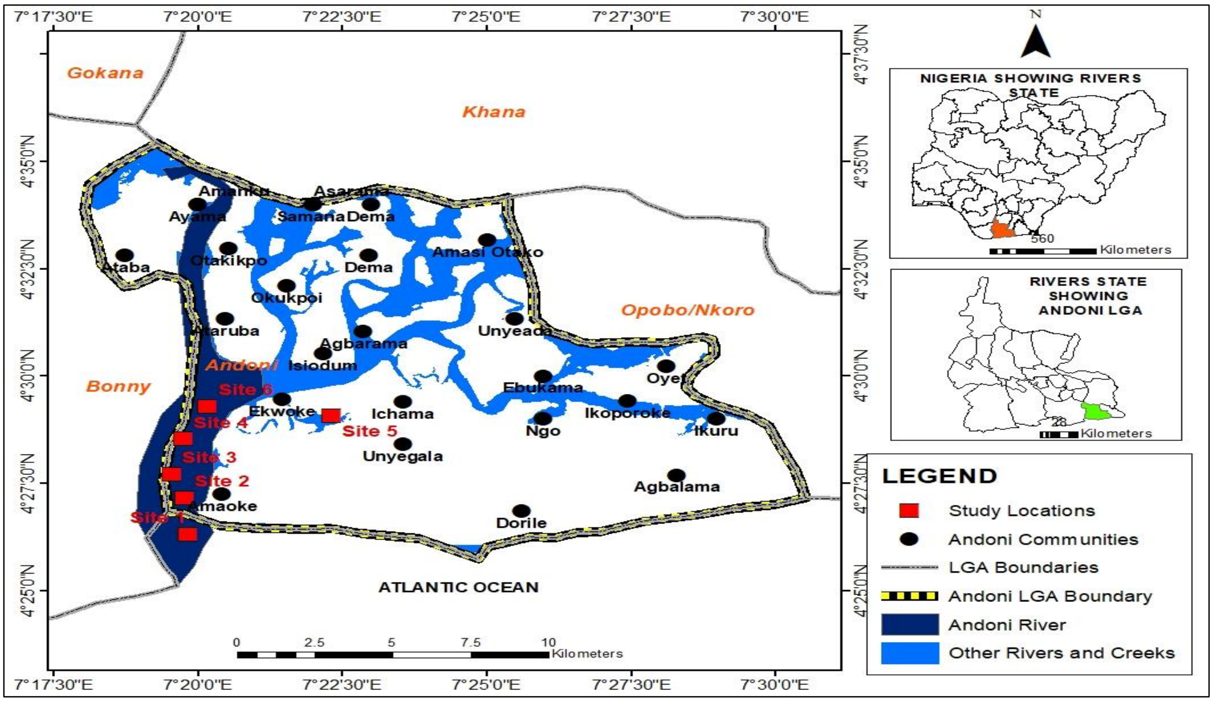


Figure 1: Map of the Study Area

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**Sampling Design:** A stratified random sampling approach was implemented to ensure spatial representation and to capture seasonal variations in microplastic contamination. Six distinct sampling stations were chosen, considering factors such as proximity to potential pollution sources (e.g., urban runoff, industrial effluents), sediment properties, water flow dynamics, and depth. Sampling was conducted during both dry and rainy seasons to assess seasonal changes in the abundance and distribution of microplastics.

**Sample Collection**

**Water Samples:** Surface water was collected using a 5-litre stainless steel bucket, then transferred into pre-cleaned glass containers. Microplastics were extracted by filtering the water through a 0.45 µm stainless steel mesh.

**Sediment Samples:** Sediment samples were obtained from the upper 5 cm layer using a stainless steel grab sampler. At each station, multiple sub-samples were collected and combined into composite samples. These were stored in pre-cleaned glass jars and kept cool with ice packs for transport to the lab within 24 hours.

**Sample Preparation and Microplastic Isolation:** Sediment samples were air-dried and weighed to determine their dry mass. Coarse particles and organic matter were removed using a 5 mm sieve. Density separation was performed using a saturated sodium chloride (NaCl) solution to isolate microplastic particles. Organic material was digested with a 30% hydrogen peroxide ($H_2O_2$) solution, and the resulting residue was filtered through a 0.45 µm mesh.

**Microplastic Identification and Quantification:** Identification was first performed with a stereomicroscope, sorting microplastics by type (e.g., fragments, fibers, beads), size, morphology, and colour. Fourier Transform Infrared Spectroscopy (FTIR) and Raman Spectroscopy were employed to identify polymer types, providing detailed molecular composition analysis.

**Instrument Calibration and Quality Control:** The FTIR and Raman spectrometers were calibrated using certified microplastic standards to ensure accurate measurements. Quality control measures included procedural blanks, sample replicates, and performance evaluations. Instrument parameters, such as spectral resolution and laser intensity, were fine-tuned to effectively detect polymer types and particle sizes.

**Environmental Data and Site Documentation:** GPS coordinates were recorded for each sampling site, alongside environmental data such as water temperature, pH, salinity, and flow rate.

## Results

**Environmental Risk Assessment of Microplastics in the Andoni River Estuary:** The environmental risk assessment, conducted using the Polymer Hazard Index (PHI) and Pollution Load Index (PLI), highlighted both seasonal and spatial variations in microplastic (MP) contamination across water and sediment samples (Figures 2–4).

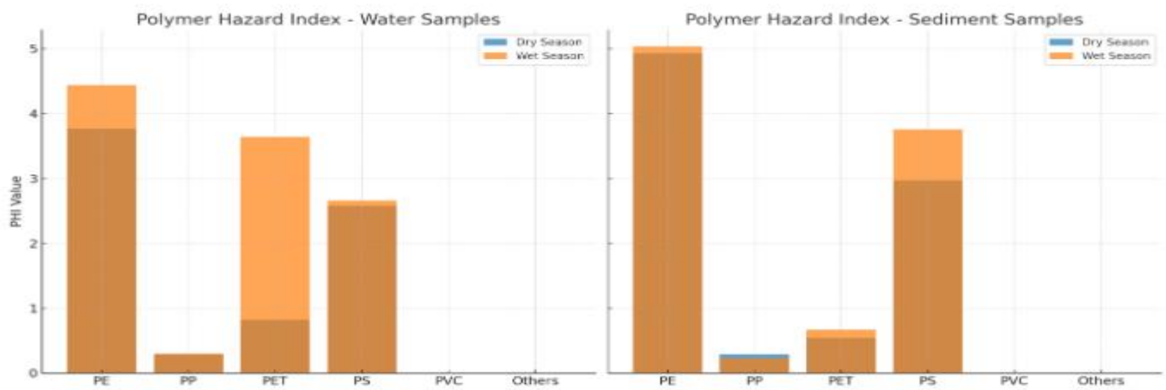


Figure 2: Polymer Hazard Index (PHI) for water and sediment samples across dry and wet seasons

In water samples, polyethylene (PE) exhibited the highest PHI values, followed by polystyrene (PS) and polyethylene terephthalate (PET) (Figure 2). PE's PHI increased from 3.77 in the dry season to 4.44 in the wet season, while PET showed a substantial rise from 0.82 to 3.64. Consequently, the total PHI for water samples rose from 7.46 during the dry season to 11.04 in the wet season. For sediment samples, PE continued to dominate, with a modest increase in PHI from 4.93 to 5.04,

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while PS increased from 2.97 to 3.76. Overall, the sediment PHI values were higher than those in the water samples, increasing from 8.73 in the dry season to 9.70 in the wet season

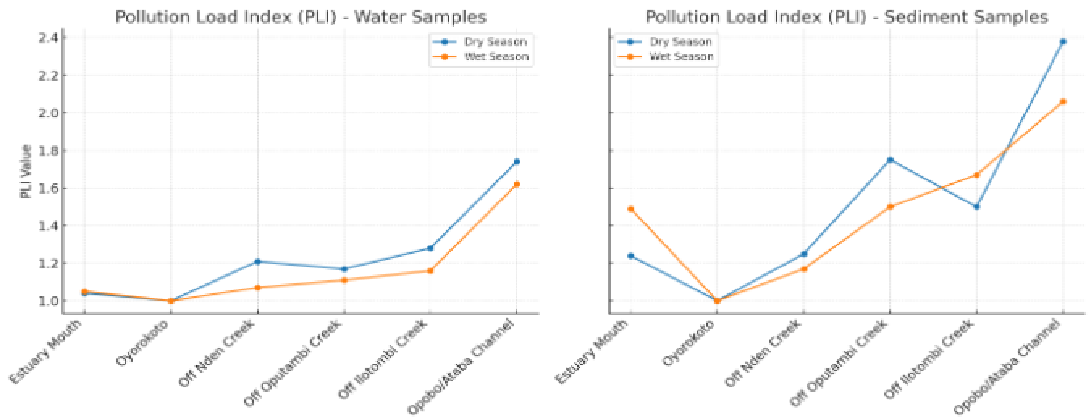


**Figure 3: Site-by-Site PLI plots**

Site-specific PLI analyses revealed moderate to moderately high contamination across the study area, with the Opobo/Ataba Channel consistently recording the highest values in both water and sediments. Most sites exhibited PLI values indicative of moderate contamination; however, the Opobo/Ataba Channel reached 1.74 (dry) and 1.62 (wet) in water, and 2.38 (dry) and 2.06 (wet) in sediments, classifying it as moderately high contamination. The minimal seasonal variation in PLI highlights persistent, site-specific pollution hotspots, underscoring the channel's vulnerability to continuous pollutant inputs.

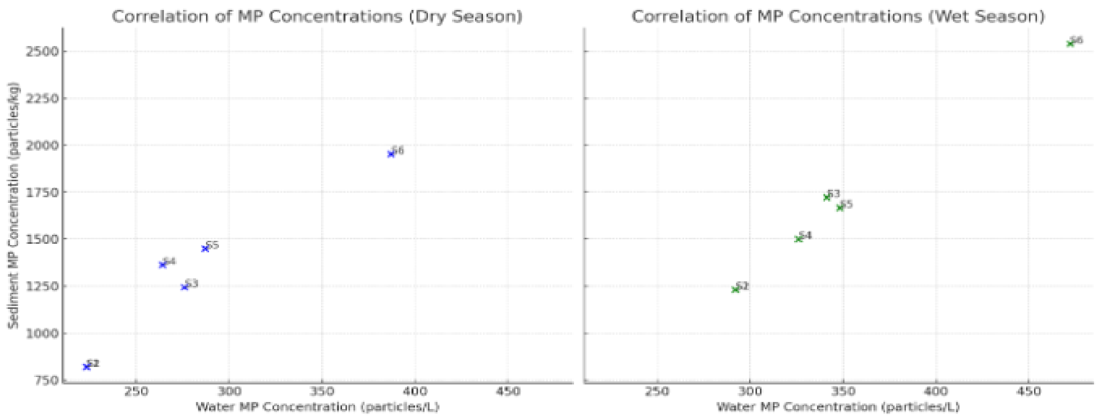


**Figure 4: Correlation Scatterplots**

The correlation scatterplots highlight strong positive relationships between water and sediment microplastic (MP) concentrations in both dry and wet seasons, visually reinforcing the statistical findings. ANOVA results indicated no significant seasonal variation in water MP concentrations ($p = 0.105$), whereas sediment concentrations differed significantly between seasons ($p = 0.044$). Correlation analysis further confirmed strong positive associations between waterborne and sedimentary MPs during the dry ($r = 0.915$) and wet ($r = 0.869$) seasons (Figure 4), suggesting that elevated MPs in the water column contribute to increased sediment accumulation. Microplastic contamination in the Andoni River Estuary is predominantly composed of polyethylene (PE) and polystyrene (PS), with sediments exhibiting higher hazard potential. Contamination is spatially persistent, particularly in the Opobo/Ataba Channel, and sedimentary MP loads display significant seasonal variation, highlighting their role as long-term sinks for estuarine microplastics.

**Discussion**

Microplastic contamination in the Andoni River Estuary exhibits clear polymer-specific patterns and spatial persistence, with sediments functioning as significant long-term hazard reservoirs. Polymer Hazard Index (PHI) analysis indicates that polyethylene (PE) and polystyrene (PS) dominate hazard contributions, consistent with global observations of estuarine microplastic assemblages (Lithner *et al.*, 2011; Ranjani *et al.*, 2021). Seasonal variations, including the increase of PE PHI from 3.77 to 4.44 in water and the marked rise in PET PHI from 0.82 to 3.64 during the wet season, likely reflect enhanced mobilization and transport driven by runoff, tidal forcing, and storm events. Such hydrological processes have been reported to redistribute land-based plastics into estuarine environments (Ranjani *et al.*, 2021; López, 2021).

Sediments recorded higher total PHI values than water (dry: 8.73; wet: 9.70), with a statistically significant seasonal difference (ANOVA, $p = 0.044$), supporting the conceptual model of estuaries acting as filters that capture and accumulate plastic particles in depositional zones (Fulfer *et al.*, 2023). Strong positive correlations between microplastic concentrations in water and sediments ($r = 0.915$ dry; $r = 0.869$ wet) further indicate a tight coupling between transport mechanisms and sedimentary accumulation.

Pollution Load Index (PLI) patterns reveal moderate contamination across most sites; however, the Opobo/Ataba Channel consistently exhibited the highest PLI in both water (dry: 1.74; wet: 1.62) and sediments (dry: 2.38; wet: 2.06), highlighting a persistent hotspot. Such localized contamination likely results from point-source inputs, including urban runoff, artisanal refining, and port activities, combined with hydrodynamic retention (Ranjani *et al.*, 2021; Ebere *et al.*, 2019). From an ecological risk perspective, elevated PHI values in sediments imply increased exposure for benthic organisms, such as detritivores and sediment-feeding fauna. Polymers like PS and PET, particularly those that increase seasonally, are known to sorb hydrophobic contaminants and leach hazardous additives, amplifying ecological risks. Furthermore, the strong coupling between water and sediment concentrations suggests that reducing surface microplastic levels alone may not immediately decrease ecological risks, given the sediment reservoir's capacity to remobilise particles (Fulfer, 2023).

**Conclusion**

This study demonstrates that microplastic contamination in the Andoni River Estuary is both spatially persistent and polymer-specific, with PE and PS comprising the majority of pollutants. Sediments serve as long-term microplastic reservoirs, presenting higher environmental risk than the overlying water column and exhibiting notable seasonal variation. The persistent contamination hotspot at the Opobo/Ataba Channel reflects localized sources and estuarine hydrodynamics favoring particle retention. Strong correlations between water and sediment concentrations underscore the tightly coupled transport and accumulation processes within the estuary. These findings emphasize the critical role of estuaries as natural filters and sinks for microplastics and underscore the need for sustained monitoring and targeted management interventions. Addressing microplastic pollution in the Andoni Estuary is essential for protecting benthic ecosystems, sustaining fisheries, and safeguarding the health and livelihoods of local communities dependent on these resources.

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