Assessing Concentrations of Microplastics as Emerging Environmental Pollutants, A Case Study of Otuoke River

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Abstract

This study looks into characteristics, seasonal variations, and spatial distribution of microplastic concentrations in sediment and surface water along the Otuoke River in Nigeria's Niger Delta. Samples were taken every month at three specific locations (STA-1, STA-2, and STA-3) for a six-month period from December 2022 to May 2023. Microplastics in surface water and sediments were sampled following standard procedures. A long hollow and cylindrical sampling apparatus (approximately 6L) was employed in the sampling of surface water microplastics and samples obtained were subsequently allowed to pass through a 50µm steel sieve where the microplastics collected alongside the water were trapped and subjected to further analysis. Samples of collected sediment were transferred to the chemical laboratory, where density floatation and hydrogen peroxide digestion techniques were used to extract microplastics from sediment matrices. The samples were then analyzed for microplastic abundance, shape, and composition. The separated microplastics were examined for number, type, size, and color via a dissecting microscope, In the dry and wet seasons, the mean microplastic concentrations in surface water (MCPW) ranged from 15 to 32 particles L^{-1}, whereas in sediment (MCPS), they ranged from 102 to 346.4 particles kg^{-1}. No significant spatial variability was found among the locations ($P > 0.05$) according to statistical analysis; however, seasonal changes indicated significantly greater concentrations during the dry season ($P < 0.05$). MCPS samples were consistently greater than MCPW, suggesting that sediments serve as sinks for these contaminants. The primary microplastic types observed were fragments and fibers, suggesting inputs from local garbage and textile products. The results emphasize the necessity of enhanced waste management and continuous monitoring to reduce microplastic pollution in this environmentally sensitive region.

***Key words**: Microplastics, Otuoke River, spatial and seasonal variation*

1. Introduction

Microplastics, which are plastic particles smaller than 5 mm, are ubiquitous in aquatic ecosystems and have become a significant environmental concern. The growing frequency of these particles in different environmental compartments, such as sediments and surface waters, presents serious dangers to human and ecological health. Numerous studies conducted worldwide have confirmed the existence of microplastics in freshwater and marine environments, emphasizing their potential to devastate ecosystems, endanger aquatic life, and act as carriers of dangerous substances (Wagner *et al.*, 2014; Barboza *et al*., 2018; Li *et al.*, 2018). Studies conducted in developed nations have revealed concerning quantities of microplastic pollution in urban rivers, coastal regions, and even remote locations. The concentrations of the pollution vary according to factors like land-use patterns, hydrological conditions, and the proximity to sources of pollution (Browne *et al.*, 2011; Eriksen *et al.*, 2014). The study of microplastic pollution in Africa has accelerated recently. Research conducted in South Africa's estuaries and coastal waterways has shown that there are significant amounts of microplastics in the sediments and surface water, which is consistent with worldwide trends (Naidoo *et al.*, 2015; Verla *et al.*, 2019). Similarly, studies conducted in Ghana and Kenya have revealed notable degrees of microplastic pollution in urban river systems, which have been linked to insufficient waste management and untreated wastewater discharges directly (Munyaka et al., 2020; Besseling *et al*., 2017). Studies on microplastics are rather scarce in Nigeria, especially in the Niger Delta area, when compared to international research endeavors. Due to its enormous oil exploration activities, thick network of rivers and creeks, and large human population, the Niger Delta is particularly vulnerable to environmental pollution. The extent of microplastic contamination in the local aquatic systems is beginning to become clearer thanks to recent research conducted in the area. In the Bonny and Cross Rivers, for instance, Auta et al. (2017) found that the amounts of microplastics ranged from 100 to 300 particles per kilogram of soil and from 15 to 50 particles per liter of surface water. Similarly, Ogwo et al. (2020) observed microplastic concentrations in the Nun River to be considerably lower, ranging from 5 to 20 particles per liter in surface water. Despite these initiatives, there are still questions about the distribution, seasonal change, and possible ecological effects of microplastic contamination in the Niger Delta. Inadequate waste management techniques, lax legislation, and low public awareness all contribute to the problems caused by microplastic pollution (Thompson *et al*., 2009). Microplastic contamination increases the hazards that populations and ecosystems confront in areas like the Niger Delta, where environmental degradation from gas flaring and oil spills is already a significant problem (Oribhabor & Ogbeibu, 2010). Larger plastic objects break down into smaller pieces, which, when combined with direct emissions into water bodies and river traffic, causes microplastics to accumulate in sediments. There, they can linger for a long time and act as a sink for other contaminants (Andrady, 2011).

In addition to endangering benthic organisms, this contamination puts fish at higher trophic levels—including fish that humans eat—at risk (Setälä *et al*., 2014; Lusher *et al.*, 2017). Comprehending the microplastic contamination dynamics in the Niger Delta is crucial, considering its ecological vulnerability and function as a center of biodiversity. The scope and ramifications of microplastic pollution in Niger Niger Delta region have not received much attention, despite the fact that the problem is becoming more well acknowledged worldwide. The region is essential for researching the dynamics of microplastic contamination because of its intricate hydrological network and distinctive socioeconomic activities, which include artisanal fishing, agriculture, and oil production (Ilechukwu *et al*., 2021; Ebere *et al*., 2019). Microplastics have been found in surface waters and sediments, according to some studies, but full information about their sources, distribution, seasonal variations, and effects on nearby communities and ecosystems is still lacking (Bank & Hansson, 2019). Effective mitigation methods are challenging to establish because of the lack of baseline data, which hampers efforts to quantify the dangers to the environment and human health associated with microplastic contamination. By examining the quantity, distribution, and properties of microplastics in surface water and sediment along the Otuoke River in the Niger Delta, the current study seeks to close this knowledge gap. The study examines changes in microplastic concentrations over the course of two seasons, concentrating on three specific sample stations. This analysis offers important insights into the temporal and spatial dynamics of microplastic pollution in the area. The goal is to measure the amount of microplastics present in surface water and sediment samples taken from the Otuoke River. Additionally, it aims to evaluate the spatial distribution of microplastic pollution at three different sampling stations along the river. Additionally, the research assesses the seasonal differences in microplastic abundance between the dry and wet seasons and characterizes the morphological traits (size, shape, and color) of microplastics in the studied region (Teng *et al.*, 2020; Park *et al*., 2021).

2. Methodology

2.1 Study Area

This study was conducted at Otuoke, a semi-urban hamlet in Ogbia Local Government Area, Bayelsa State, Nigeria, situated at approximately 5°12'59.6" N and 6°19'10.1" E. The town of Otuoke, which is home to the Federal University of Otuoke, is a socio-political and educational center situated along the Otuoke River in the Niger Delta region (Tamuno, 2005). Due to its advantageous location, which connects Yenagoa, the state capital, to neighbouring settlements, it has experienced considerable development in recent years. The town experiences two distinct seasons in its climate: a dry season that lasts from November to March and a rainy season that runs from April to October. This study was focused on the Otuoke River, which is essential to the local economy and communal activities. Three designated locations, labelled, STA-1, STA-2, and STA-3) along the major river in the town, known as Otuoke River, were earmarked for this study. The stations were separated 3 km along the river. STA - 1 is located close to the major bridge connecting the major road in Otuoke and Yenagoa via a neighbouring town, Onuebom. STA - 2 was situated at the extreme end of the one of the roads (Azikel road) inside the community where most university staff and students reside which is densely populated. The location of STA - 3 was also situated at the end of another road (Hospital Road) in the community, which also connects the same river with almost similar population.


Fig. 1 Sample collection at the study location

2.2 Sample Collection

Samples were taken every month from December 2022 to May 2023 at three designated locations (STA-1, STA-2, and STA-3) along Otuoke River separated 3 km from each point, during low tide. Collection of samples of microplastics in surface water was carried out following the method described by Wang et al. (2017); Qu *et al*., (2018) and Zhu *et al*. (2019) with slight modification to suit the environment of study. Five liters of surface water sample (0–20 cm in depth) was collected using a one-sided open-ended cylindrical sampling device and made to pass through a 50µm size steel sieve. Three replicates were collected at each station. The residue on the sieve was rinsed with distilled water into a 100 mL glass jar and kept at 4 °C before analysis. Three sediment samples were collected transversely from each station along the creeks using two sets of shovels (plastic and steel), to collect the top layer soft sediment (≈10 cm in depth). The samples were taken approximately 1m from the shore at each station with a steel and a plastic shovel, each marked differently to differentiate sediments sampled for microplastics and metals respectively. Samples were put into well-labelled foil bags (indicating sampling point information and time of sampling) and placed into ice chest coolers at 4 ^{0}C and transferred to the laboratory. Photo plates of field samples collection are shown in Fig. 1.

2.2 Extraction of Microplastics from Sediments and Water Samples

In the laboratory, separation of microplastics from water and sediment matrices was carried out following standard procedures adopted by Mohsen *et al.* (2019) and Li *et al*. (2021) but with slight modifications. The density floatation method as described by the authors was adopted in separation of microplastics from sediments. The sediment samples were dried in an oven at 60 °C for 72 hours to obtain a dry weight. Exactly 50 g of dried sediment were placed in a beaker and mixed with 400 mL of zinc chloride solution of density, 1.60 g/mL The solution was thoroughly stirred with a clean glass rod, covered with tin foil and left to stand for 2 hours of precipitation. Further, the supernatant was transferred to another clean 500 mL beaker. This was repeated thrice to enhance recovery rate of microplastics. Finally, 15 mL of 30 % hydrogen peroxide solution (H_2O_2) were added to the supernatant to digest the organic matter. The supernatant was filtered through an 8-μm glass microfiber filter paper (Whatman, diameter: 45 mm, pore size: 0.3 μm) with vacuum filtration, and transferred to a new petri dish for later inspection by a dissecting microscope to identify colour, size and number of microplastics in each sample. Photo plates of lab analysis of samples are shown in Fig. 1.

2.3 Identification of Microplastics in Water and Sediment Samples

The separated microplastics on the filter membrane were placed under a dissecting microscope (Model: Fisher Scientific) to determine the abundance, shape, size and colour of microplastics in samples. The categories of microplastics based on the morphological characteristics were fibers, fragments, films and pellets. Average concentration of microplastics in each matrix was determined as particles kg^{-1} and particles L^{-1} for microplastics in sediment (MCPS) and microplastics in water (MCPW) respectively.

3. Results and Discussion

3.1 Results

The abundance (concentrations) and other basic properties of microplastics obtained during dry and wet seasons, via visualization technique, in the study areas are presented in Table 1. Study showed relative abundance of microplastics in the dry season ranging from 10 particles L^{-1} to 56 particles L^{-1} in surface water and 95 particles kg^{-1} to 430 particles kg^{-1} in sediment at STA-3, 25 particles L^{-1} to 72 particles L^{-1} in surface water and 69 particles kg^{-1} to 504 particles kg^{-1} in sediment at STA-2 and 12 particles L^{-1} to 26 particles L^{-1} in surface water and 71 particles kg^{-1} to 210 particles kg^{-1} in sediment at STA-1. It further showed that during wet season, abundance of microplastics ranged from 12 particles L^{-1} to 23 particles L^{-1} in surface water and 120 particles kg^{-1} to 196 particles kg^{-1} in sediment at STA-3, 17 particles L^{-1} to 32 particles L^{-1} in surface water and 111 particles kg^{-1} to 317 particles kg^{-1} in sediment at STA-2 and 12 particles L^{-1} to 18 particles L^{-1} in surface water and 42 particles kg^{-1} to 143 particles kg^{-1} in sediment at STA-1. Data revealed no statistical ($p > 0.05$) spatial variability, even though the MCP concentrations followed the order: STA-2 > STA-1 > STA-3 and temporally: dry season > wet season at $P < 0.05$. Study showed that generally, microplastics at various study sites had various shapes (appearances): STA-3 (44 % fragments, 22 % fibers, 24 % pellets and 10 % films), STA-2: 51 % fragments, 18 % fibers, 15 % pellets and 16 % films and STA-1: (22 % fragments, 41 % fibers, 24 % pellets and 13 % films). The colours associated with the microplastics were mostly tint, milky white and brown. The sizes ranged from less than 2 mm to 5 mm. result of spatial distribution of microplastic abundance between dry and wet season is presented in Fig. 2.

Table 1: Abundance/properties of microplastics obtained via visualization technique in study locations

S/N	Origin/Study location	MPs size	Abundance (Dry Season)	(Wet Season)	Colour	Common Appearance
1	STA-1, Otuoke fresh water (particles L^{-1})	< 2mm – 4mm	32 ± 20.8 (19 – 56)	18.67 ± 5.87 (12–23)	milky white, brown,	Fragments, pellets and films
2	STA-2, Port Otuoke fresh water (particles L^{-1})	1.5 – 3.5mm	31 ± 6.5 (25 – 72)	24 ± 7.55 (17 - 32)	tint	Fragments, fibers, pellets
3	STA-3, Otuoke fresh water (particles L^{-1})	2 - 4 mm	18.67 ± 7.02 (12 – 26)	15 ± 3.00 (12 - 18)	Milky, white	Fragments and Fibers
4	STA-1, Otuoke sediment (particles kg^{-1})	1 - 4 mm	292 ± 175.12 (95 – 430)	151 ± 39.89 (120 - 196)	Black, tint, milky white	Fragments and Films
5	STA-2, Otuoke sediment (particles kg^{-1})	< 2 - 5 mm	346.33 ± 240.93 (69 – 504)	234.67 ± 109.04 (111 - 317)	Black, tint, brown	Fragments, fibers and films
6	STA-3, Otuoke sediment (particles kg^{-1})	1 - 5 mm	173.67 ± 90.17 (71 – 240)	102 ± 53.11 (42 – 143)	Black, tint, brown	Fragments and Fibers
	H factor		2.87			
	P value		P > 0.05			

3.2 Discussion

The study conducted on microplastic abundance (concentrations) in the Niger Delta reveals significant insights into the presence and distribution of these pollutants in both surface water and sediment across three sampling stations (STA-1, STA-2, and STA-3). The observed variations, influenced by seasonal changes, highlight the complexity of microplastic contamination in this ecologically sensitive region. With recorded microplastic mean concentrations ranging from 15 to 32 particles L^{-1} in surface water during the dry season and sediment levels from 102 to 346.4 particles kg^{-1} (Fig. 2), these findings necessitate a critical evaluation in comparison with studies conducted in Niger Delta and elsewhere.

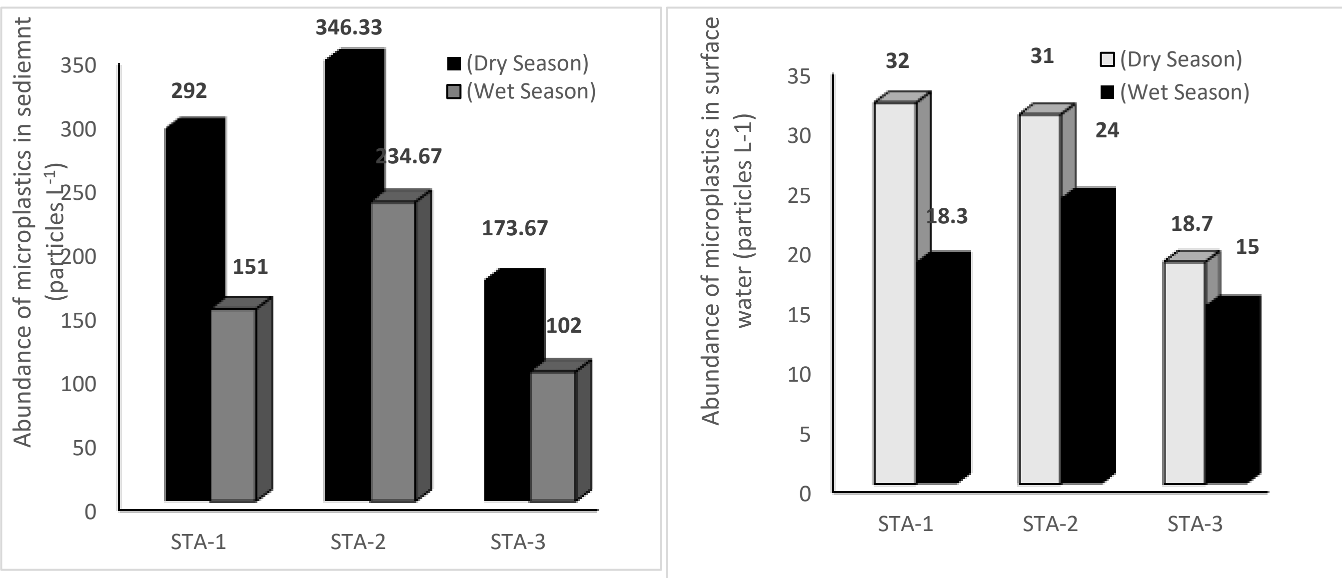

Fig. 2: Spatial distribution of microplastic abundance in sediment and surface water along Otuoke river - study site

Diverse aquatic ecosystems exhibit varying quantities of microplastics, as revealed by studies conducted in the Niger Delta. For example, Okeke *et al.* (2022) found that sediment concentrations in the Bonny and Calabar Rivers ranged from 100 to 300 particles kg^{-1}, whereas surface water microplastic levels varied from 15 to 50 particles L^{-1}. These results, especially at sampling sites STA-2 and STA-3, are in good agreement with the findings of this study. On the other hand, Iheanacho *et al*. (2023) discovered surface water values between 5 and 20 particles L^{-1} in the Nun River, indicating lower microplastic concentrations. This heterogeneity could be the result of variations in sampling techniques or localized environmental conditions. Furthermore, larger silt concentrations—up to 600 particles kg^{-1}—were reported by Oduor *et al*., (2021) in the Forcados and Brass Rivers, two Niger Delta regions. These results highlight the need for extensive monitoring and research to fully comprehend the dynamics of microplastic distribution and its environmental implications throughout the Niger Delta region. They also point to substantial hotspots of microplastic accumulation.

From our data, the difference in abundance of MCPs with respect to location was not statistically significant ($P > 0.05$). However, the difference in the values of MCP in dry season was statistically significant at $P < 0.05$. More so, the difference in concentrations of MCPs in surface water was statistically significantly lower than that of sediment. Our data indicate that the difference in the abundance of MCPs concerning location was not statistically significant ($P > 0.05$). This finding suggests that microplastic concentrations across the different sampling stations (STA-1, STA-2, and STA-3) did not show considerable variability, implying that local environmental conditions might be relatively uniform regarding microplastic pollution. Variability in microplastic concentrations can depend on multiple factors, including environmental dynamics, local pollution sources, and hydrological conditions. Studies have shown that microplastic pollution can be influenced by factors such as river flow, urban runoff, and proximity to industrial areas. Work conducted by González-Fernández *et al.,* (2020) showed that microplastic abundance varied significantly in urban versus rural locations, indicating that local sources play a critical role in microplastic distribution. This is particularly so because Otuoke is a bubbling township being a university environment where students are evenly distributed across these locations where they live and generate almost similar volume of wastes on daily basis.

The data showed that the difference in microplastic concentrations during the dry season was statistically significant at $P < 0.05$. This finding implies that the conditions during the dry season contributed to higher microplastic levels. The increase in concentrations during the dry season may be attributed to lower water levels, lower sediment transport and reduced dilution, leading to localized accumulation. Studies have reported that reduced rainfall can result in concentrated pollutants as water levels recede, leading to elevated readings. Khalil *et al*. (2021) noted that microplastic concentrations were significantly higher in seasons with lower precipitation due to the accumulation of waste in stagnant water bodies. In contrast, the wet season may facilitate greater dispersion due to increased runoff, potentially distributing microplastics more widely throughout the aquatic environment. Our results in the Niger Delta region in comparison to international studies, gives even further insight to microplastic contamination of the aquaculture. Lusher *et al.* (2017) recorded levels ranging from 50 to 150 particles L^{-1} in their investigation of microplastic concentrations in coastal waters of the North Atlantic, particularly near the UK. While not exactly equivalent to the dry season findings seen in the Niger Delta, these concentrations are obviously greater than those found during the wet season in our study. The study revealed that the concentrations of MCPs in surface water were statistically significantly lower than those found in sediment. This aligns with the common understanding that sediments act as a sink for microplastics due to their higher density and settling characteristics. Microplastics tend to aggregate and settle in sediments due to gravitational forces and their larger size in many cases. Studies have demonstrated that sediments in aquatic environments often contain much higher concentrations of microplastics than the overlying water. Report of Mason *et al.* (2016) revealed that sediments collected from various aquatic systems had concentrations of microplastics that were orders of magnitude higher than those found in surface water, supporting our findings. In Indonesia, Rochman *et al*. (2015) found sediment microplastic concentrations exceeding 800 particles kg^{-1}.

This study which was conducted in Southeast Asia highlights the extreme nature of the microplastic problem by pointing to unusually high pollution levels in that area.

These results draw attention to a critical facet of the study of microplastics: the regional variations in concentrations. Population density, waste management techniques, and regional industrial activity are some of the elements that affect this variability, highlighting the necessity of focused initiatives and policies to reduce microplastic contamination worldwide. Such pollution has a wide range of effects. Many aquatic species can consume microplastics, which can have toxicological and physical impacts. Studies have shown that consumption can cause decreased rates of growth, problems with reproduction, and even death in marine animals (Browne *et al*., 2011; Wright *et al.*, 2013). The existence of microplastics in sediments presents further hazards, as these particles have the potential to function as carriers for detrimental substances, intensifying their influence on benthic creatures.

Evidently, from our results, there is a threat posed by microplastic pollution. The ecological implications of microplastic pollution in the Niger Delta extend beyond aquatic organisms. As microplastics accumulate in sediments, they may enter the food web, potentially affecting higher trophic levels, including fish that are critical to local fisheries and communities. The consumption of contaminated seafood poses a direct risk to human health, particularly in regions where fish is a primary dietary component. Furthermore, the diverse shapes and colors of microplastics found in this study indicate a wide range of sources, from local waste mismanagement to global pollution trends. The predominance of fragments and fibres suggests a significant contribution from textile waste and packaging materials, which are often poorly regulated in developing regions like Nigeria.

Conclusions and Recommendations

Critical examinations of microplastic concentrations in three (3) locations and at wet and dry seasons have revealed the intricate and complex dynamics of microplastic pollution. Even while MCP abundance may not be greatly impacted by location, seasonal changes and the diverse ways that MCP accumulate in sediments point to substantial consequences for environmental management and monitoring. To effectively reduce microplastic contamination in aquatic ecosystems, it has become imperative to understand these patterns. From the observed concentrations of MCPs, which raise concerns about human and ecological health, it is imperative that waste management strategies be put into place and that public awareness of the negative effects of plastic pollution be increased. This suggests that government agencies, local communities, and researchers should work together to develop a comprehensive plan to reduce the effects of microplastics in this environmentally sensitive area. Further research is recommended to fully understand the long-term effects of this type of pollution and to help guide policy decisions meant to protect the environment and public health.

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