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Assessment of Microplastics in Water and Sediment of River Benue Troughs, Benue State, Nigeria

Idris Habiba Adam[1*], Ikrimah Usman Mohammed[2], and Isaac John Umaru[3]
Federal University Wukari, Nigeria
habibaidrisdama@gmail.com

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Abstract

Microplastics (MPs) are emerging environmental contaminants with significant ecological and health implications. This study investigates the presence and risks of microplastics (MPs) in the River Benue, Nigeria, using Fourier Transform Infrared (FTIR) spectroscopy. Water and sediment samples were collected from five locations along the river, with FTIR analysis revealing key functional groups such as alcohols, alkenes, amines, and carbonyls. Specifically, water samples from one site showed peaks at 3320 cm^{-1} (O-H stretch, indicating alcohols) and 1640 cm^{-1} (C=C stretch, indicating alkenes), while another site exhibited peaks at 3264 cm^{-1} (N-H stretch, indicating amines) and 1640 cm^{-1} (C=C stretch, indicating alkenes). Sediment samples showed significant peaks at 3622 cm^{-1} (O-H stretch, indicating alcohols and phenols) and 2326 cm^{-1} (C=N stretch, indicating nitriles). The Pollution Load Index (PLI) and Risk Quotient (RQ) analyses confirmed varying levels of microplastic contamination, with potential environmental and health risks due to the leaching of toxic additives. The study underscores the need for continuous monitoring, stricter pollution control, and public education to mitigate microplastic pollution in this vital waterway.

Keywords: Microplastics, Water, Sediment, River Benue, Assessment

INTRODUCTION

Microplastics are classified as "primary" when they are intentionally produced on a small scale, such as the nanoparticles found in consumer products like personal care items and industrial cleaners, often appearing as spherical beads [1]. In contrast, "secondary" microplastics are created from the breakdown of larger plastic objects, such as plastic films, fishing nets, or household items, which results in irregular shapes [1,2]. Textile fibers are also considered secondary microplastics[1,3].

Researchers assess the environmental risks of microplastics by examining their presence and potential harmful effects on ecosystems. While much research has focused on marine environments, significant amounts of microplastics have also been found in freshwater systems. Due to their small size, microplastics can be ingested by organisms across different trophic levels, causing physical harm such as digestive issues, malnutrition, and even death. They can also carry toxic substances like pollutants and metals. As plastic production increases and microplastics degrade slowly, their levels are expected to rise. Therefore, ecotoxicological risk assessments are crucial to understanding their impact on species [4].

Microplastic debris is pervasive in aquatic environments, including coastal, deep-sea, near-shore, and open-ocean habitats. As global plastic production has increased significantly over the past 60 years, so has the accumulation of microplastics in these environments. The risks associated with microplastics stem from their physical properties, chemical makeup, and the toxic substances they absorb, such as persistent bio accumulative and toxic compounds (PBTs) and metals. Fish, acting as bio-indicators, are particularly vulnerable to these microplastic-induced stresses, with studies showing plastic particles in the digestive systems of numerous fish species worldwide [5,6].

The careless disposal of industrial and domestic waste into water bodies is a major environmental issue worldwide, including in Nigeria. This practice contaminates aquatic environments, posing risks to both marine life and human health due to polluted water. Over seven million tons of plastic wastes are added to the environment each year, leading to a rise in microplastics. If current trends continue, plastic may outweigh fish in the oceans, with up to 97% of fish species potentially ingesting microplastics. The presence of microplastics in water poses serious threats to marine ecosystems, creating a significant global concern. To combat this, it is essential to conduct thorough assessments of microplastics in water bodies and promote awareness about effective management techniques. Implementing strict waste disposal and sustainable management practices is crucial for reducing the harmful effects of these pollutants on aquatic ecosystems.

Despite the widespread presence of microplastics as environmental contaminants, there is limited data on their risk assessment in major rivers such as the Benue which are vital to the local communities. These study goals to address this gap by assessing the risks posed by these pollutants in river Benue. The research seeks to provide critical insights that could guide strategies for managing and protecting these essential water resources, given their significant role in the lives of the local population. The study aimed to assess the risks associated with microplastics in the River Benue.

MATERIALS AND METHODS

Description of the Study Area

Benue town has served as the headquarters of Benue Local Government since its establishment in 1970, and presently functions as both the Local Government Headquarters and the State Capital of Benue. The physical coordinates of the location are around 7°45'N latitude and 8°26'E to 8°36'E longitude, situated on both sides of the River Benue. Benue shares borders with Guma Local Government Area to the North, Gwer West Local Government Area to the East, Gwer Local Government Area to the South, and Tarkaa Local Government Area to the West.Benue metropolis, situated in the River Benue valley, experiences a tropical climate characterized by two distinct seasons: the wet and dry seasons. The River Benue is a significant Nigerian river that begins in the Cameroonian highlands and flows westward through Benue until it joins the River Niger at Lokoja in Kogi State.

Figure 1: Map of sampling/study area; Map Showing River Benue and Ibi
Source: Iornenge*et al.* [7].

Collection of Sample

A systematic approach was used to collect water and sediment samples from five distinct locations along the River Benue, with measurements taken at 100-meter intervals. At each site, two liters of water were collected from 0-20 cm below the surface on two consecutive occasions [8]. The water samples were then filtered through a 50 μm stainless steel sieve, with residues washed off using filtered tap water (0.45 μm) and the resulting solution stored in glass containers. To preserve the samples, 5% methylaldehyde was added. Simultaneously, surface sediment samples were collected using a Van Veen grab to a depth of about 5 cm, following the method by Idris *et al.* [8]. Approximately 1.5 kg of wet sediment from each site was placed in labeled aluminum foil bags and transported to the laboratory for further analysis.

Sample Pre-Treatment

As described by Idris *et al.*[8], before laboratory processing, water samples were treated with 15 mL of 30% hydrogen peroxide to digest organic material. The samples were kept in the dark for 24 hours, filtered using 0.45 μm microporous membranes to capture potential microplastic (MP) particles, taking care to prevent plastic contamination. A control test with ultra-pure water revealed minimal MP contamination at 0.8 ± 0.4 items per filter membrane. For sediment analysis, 1 kg of sediment from each station was dried at 60°C for 48-72 hours. Three 30g replicates from each site were then treated with an 80 mL $ZnCl_2$ solution (1.58 g/cm^3), stirred, and left to settle for 24 hours. The supernatant was carefully decanted and treated with 30% hydrogen peroxide, kept in the dark for another 24 hours, and finally filtered through a 0.45 μm membrane to isolate microplastic particles.

Microplastics Extraction from Water and Sediment Samples

Water samples were filtered with glass fiber filter paper (Whatman™ Grade GF/D, 4.7 cm diameter, 2.7 μm pore size). Sediment samples were oven-dried, and their wet and dry weights were recorded. Particles on the filters were collected by rinsing with distilled water. Depending on the level of organic matter, samples were digested with hydrogen peroxide for 5–6 days, as per the method by Idris *et al.* [8]. To separate microplastic particles from inorganic materials, a saturated potassium formate solution was used in a separating funnel for 3–4 days. The denser inorganic materials settled, while the lighter supernatant, containing microplastics, was filtered using nanopore inorganic membrane filters (47 mm diameter, 0.2 μm pore size). These filters were dried at 50°C and stored in aluminum bowls to avoid contamination, preserving the microplastics for further analysis.

Flourier Transform Infrared Spectroscopy Analysis

In the quest of complete microplastic (MP) investigation, all potential particles with a size of 2mm received rigorous measurements utilizing a Vertex 70 FTIR analyzer. Furthermore, subsamples of these 2mm putative microplastics from both water and sediment samples received a more comprehensive investigation. This involves isolation and subsequent examination by FTIR analysis, done utilizing a Hyperion 2000 equipment [8].

Microplastics Risk Assessment Analysis

Microplastics risk analysis was done according to Idris *et al.* [8].

The following formula is used:

1. $Fi = Ci/Coi$;……………………………………………………….1
2. $PLI = \sqrt{Fi}$;……………………………………………………….2
3. PLI zone = $n \sqrt{F1F2 \ldots Fn}$……………………………………….3

The Pollution Load Index (PLI) acts as a tool to show how much microplastic (MP) pollution exists, especially in estuarine areas. In this study, we used PLI to figure out how much microplastic pollution is in the area we're investigating. We assess the pollution level at each sampling point using a value called Fi, where Ci is the concentration of microplastics. The background value, Coi, tells us the concentration of microplastics when there's no pollution. This helps us understand the degree of microplastic pollution in different areas.

Environmental Risk Analysis

According to Idris *et al.* [8],to assess how much risk microplastics (MPs) pose to the environment, Risk Quotient (RQ) was used. This is a common measure for understanding environmental risk. The RQ is calculated by dividing the measured concentration of the microplastics (MEC) by the predicted concentration where no harmful effects are expected (PNEC). This helps us gauge the potential environmental impact of microplastics:

$$RQ = MEC/PNEC \quad \ldots 4$$

Risk level was judged as follows: $RQ < 0.01$, very low risk; $0.01 < RQ < 0.1$, low risk; $0.1 < RQ < 1$, intermediate risk; $RQ > 1$, high risk.

Due to the absence of toxicological data for microplastics (MPs) in sediment, the Predicted No-Effect Concentration (PNEC) for sediment was computed using the equilibrium distribution method. This approach aligns with the technical guidance document of the European Union for the risk assessment of chemical substances (TGD)[8].

Statistical Analysis

The results were analyzed using statistical methods, specifically a single-factor ANOVA. Afterward, we used the Least Significant Difference (LSD) test to pinpoint the exact locations where significant differences were observed [9].

RESULTS AND DISCUSSION

FTIR Spectroscopy for Microplastics in River Benue

In this research work, FTIR spectroscopy was used to monitor various functional groups in order to explore the identification of Three distinct water and sediment samples. The images displayed the spectra, while the tables provided the explanations.

FTIR spectrum of water sample from Benue (B1):

The FTIR spectrum of B1 has bands and wave numbers of 3320 cm^{-1} as the prominent peaks. The peaks at the frequencies of 3320 cm^{-1} to 1640cm^{-1} were strong, broad and medium. The present FTIR results confirmed the presence of alkenes, and alcohols in the sample of water from Benue in Table 1.

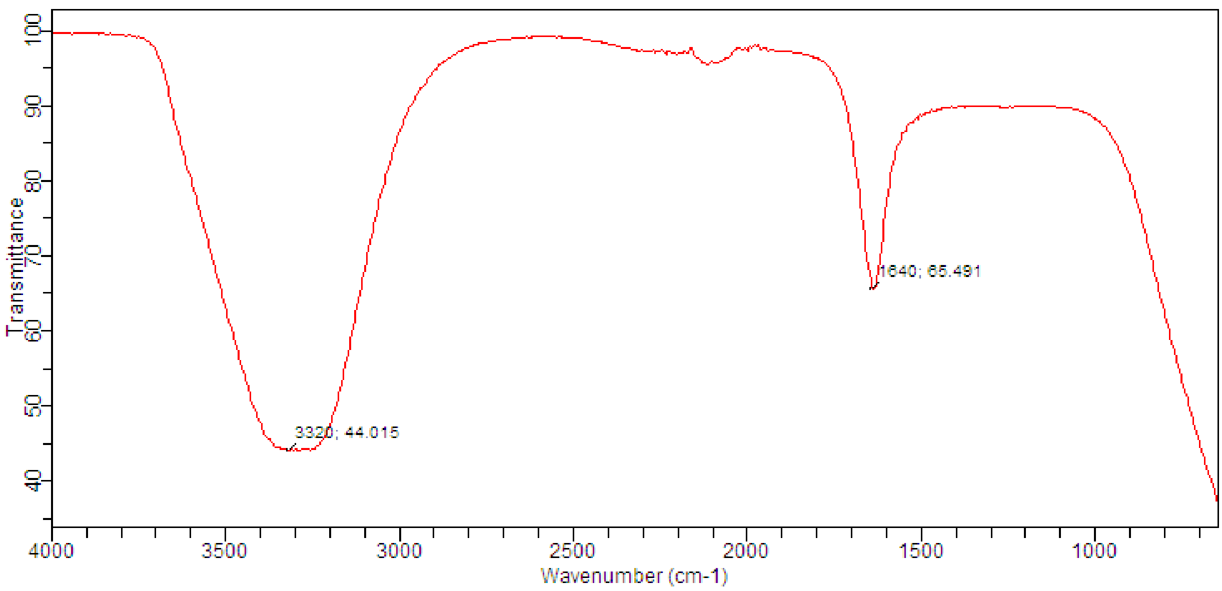

Figure 2: FTIR Spectrum ofWater Samples from River Benue (B1)

Table 1: FTIR Spectroscopy ofWater Samples from River Benue (B1)

Wavelength number ($_{cm}{}^{-1}$)	Functional group	Inference
3320	O-H stretch	Alcohol
1640	C=C stretch	Alkenes

FTIR spectrum of water sample from Benue (B2):

In the FTIR spectrum showed in the samples obtain from Benue has bands and wave numbers of 3264 cm^{-1} as the prominent peaks. The peaks at the frequencies of 3264 cm^{-1} to 1640 cm^{-1} were strong, broad and medium. The results confirmed the presence of alkenes, amines, and alcohols in the water sample from Benue as shown in Table 2.

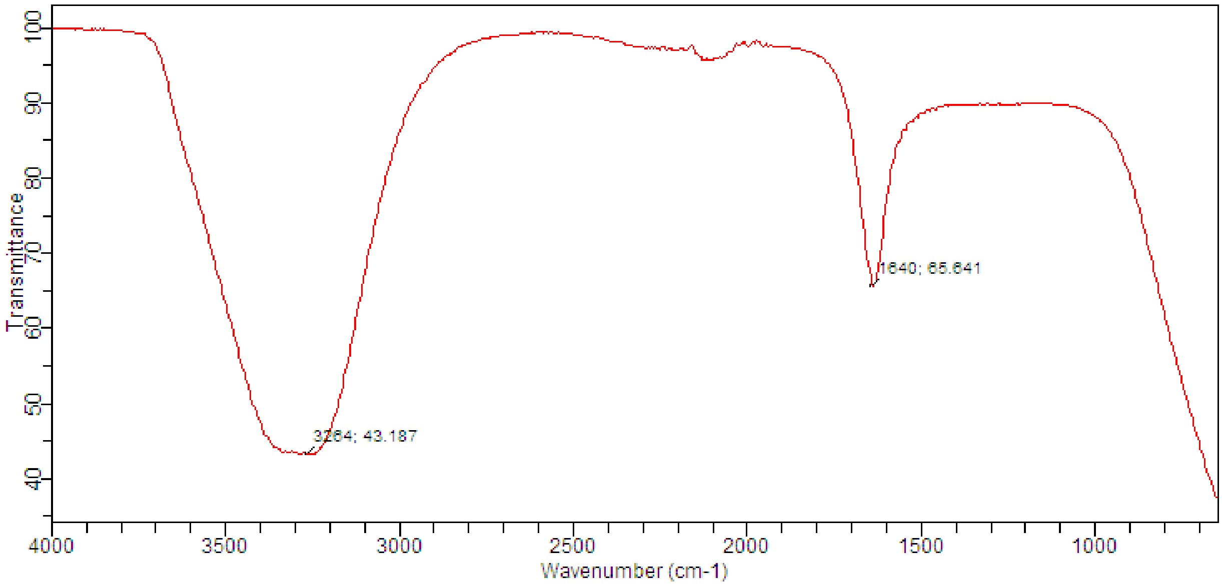

Figure 3: FTIR Spectrum of Water Samples from River Benue (B2)

Table 2: FTIR Spectroscopy ofWater Samples from River Benue (B2)

Wavelength number (cm^{-1})	Functional group	Inference
3264	N-H stretch	1°, 2° amines, amides
1640	C=C stretch	Alkenes

FTIR spectrum of sediment sample from Benue (I 1):

Sediment sample from Benue has bands and wave numbers of 3622 cm^{-1} to 2326 cm^{-1} as the prominent peaks. The peaks between the frequencies of 3622 cm^{-1} to 1041cm^{-1} were strong, broad and medium. The FTIR result confirmed presence of alkenes, alkynes carbonyls, Nitriles, alkyl halide, aliphatic and alcohols in the soil sample as shown in Table 3.

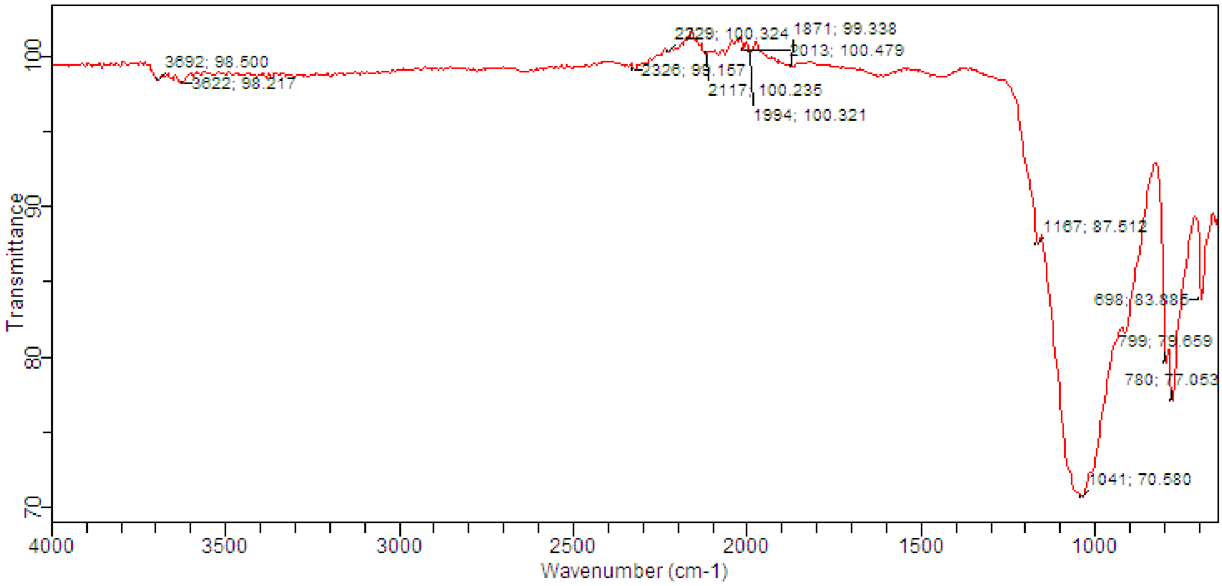

Figure 4: FTIR Spectrum of Sediment Samples from River Benue (I 1)

Table 3: FTIR Spectroscopy ofSediment from River Benue (1 1)

Wavelength number (cm^{-1})	Functional group	Inference
3622	O-H stretch, free hydroxyl	Alcohols, Phenols
2326	C=N stretch	Nitrite
1994	C=O stretch	Carbonyls (generals
1041	C-O stretch	Alcohols
780	C-Cl stretch	Alkyl halides

Microplastics (MPs) not only serve as contaminants themselves but also carry various chemical additives introduced during their manufacturing to enhance physical properties. These additives, once in the environment, can leach into biological tissues, posing health risks to organisms and potentially bioaccumulating within the food chain [8]. As a result, MPs can act as carriers for hydrophobic organic pollutants [10].

To identify the molecular and functional groups in plastic polymers, the FTIR (Fourier Transform Infrared) spectrum was utilized, focusing on the peak values in the infrared (IR) radiation range [8,11]. FTIR spectroscopy measures the IR radiation absorbed by the MP sample, revealing its molecular composition. The resulting IR spectrum serves as a unique fingerprint for each sample, with absorption peaks corresponding to the vibrational frequencies of atomic bonds within the material. Since every polymer is made up of a distinct combination of atoms, no two compounds share the exact same IR spectrum. Additionally, the FTIR technique is employed to analyze changes in chemical bond structures, such as hydroxyl, carbonyl, and carbon-oxygen groups[8].

CONCLUSION

The application of FTIR spectroscopy in this study provided a detailed analysis of the molecular and functional groups present in water and sediment samples from River Benue, revealing the presence of various chemical compounds. The findings confirmed the existence of alkenes, alcohols, amines, and other functional groups in the samples, indicating the presence of microplastics and associated chemical additives. These microplastics, along with their embedded chemicals, pose significant environmental and health risks, as they have the potential to leach into biological tissues and accumulate in the food chain. The study underscores the importance of monitoring and managing microplastic contamination in aquatic environments, particularly in vital water bodies like River Benue, to safeguard both ecological and human health.

Recommendation

1. Regular and systematic monitoring of microplastics and their associated chemical additives in River Benue should be implemented. This will help track contamination levels over time and assess the effectiveness of mitigation efforts.
2. Strengthen pollution control measures by enforcing stricter regulations on waste disposal, particularly for industries and urban areas near the river. Reducing the input of plastic waste into the river is essential to minimize microplastic contamination.
3. Conduct public awareness campaigns to educate communities about the dangers of microplastics and the importance of proper waste disposal. Involving local populations in cleanup activities can also help reduce plastic pollution.
4. Encourage further research into biodegradable alternatives to conventional plastics, as well as innovative methods for removing microplastics from water bodies. This could involve exploring new materials or technologies that can break down plastics more efficiently.

5. Develop comprehensive risk assessment frameworks to evaluate the long-term impacts of microplastics on both aquatic ecosystems and human health. This should inform the creation of targeted management strategies to mitigate these risks.

6. Foster collaboration between government agencies, research institutions, and international organizations to develop policies aimed at reducing microplastic pollution. This includes integrating microplastic management into broader environmental protection policies.

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