

SPATIOTEMPORAL ANALYSIS OF MICROPLASTIC POLLUTION AND POLYMER BIOACCUMULATION IN MAJOR RIVERS OF BANGLADESH

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Abstract: Microplastic pollution is a global environmental concern linked with aquatic food security and public health. This study explores the cross-compartmental (water, sediment, and *Labeo rohita*, a vital fish species common in the local diet) analysis of microplastic concentration in the three major rivers of Bangladesh, namely Buriganga, Dhaleshwari, and Meghna, over a three-month sampling period (October-December 2024) to highlight the distribution of microplastics during the post-monsoon season, as most rivers in Bangladesh are monsoon-influenced. The spatial and temporal distribution, bioaccumulation of specific polymers in *Labeo rohita* fish, and the composition of the polymers in each of the three compartments were examined using a multidisciplinary approach that included microscopic examination and Fourier Transform Infrared Spectroscopy (FTIR). Additionally, multivariate statistical analysis using K-means Clustering and Principal Component Analysis (PCA) was conducted, along with GIS spatial mapping to examine land-use trends. This study confirms the pervasive distribution of microplastics with fibres and fragments as the dominant types. The bioaccumulation and bioconcentration of polymers were confirmed by the presence of polymers such as polyethylene terephthalate (PET) and polyethylene (PE) in *Labeo rohita*, indicating direct transfer into the food chain and into humans. The sources of pollution were identified, addressing the research gaps of freshwater systems. Thus, to safeguard the aquatic ecosystem and maintain food security and nutritional health, urgent mitigation strategies are needed to keep pace with urban and industrial development in South Asia.

Keywords: microplastic pollution, bioaccumulation, *Labeo rohita*, K-means clustering, PCA, food security

1. Introduction

Plastic goods break down in the environment, releasing microplastics (particles smaller than 5 mm) into rivers, lakes, and seas. These particles are pollutants that harm aquatic life (Adam et al., 2021; Burns & Boxall, 2018). This rampant plastic pollution adversely affects ecosystems and human health, while posing challenges for waste management and environmental sustainability. (Motivarash, 2024). Recent research indicates that freshwater systems are significantly polluted and serve as critical conduits for microplastics from terrestrial sources, in contrast to earlier studies that focused on marine ecosystems (Burns & Boxall, 2018; Chen et al., 2023). Microplastics enter freshwater habitats through

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various pathways, including domestic wastewater effluent, agricultural runoff, stormwater overflow, industrial discharges, vehicular traffic, and atmospheric deposition (Malla-Pradhan et al., 2022). Microplastic contamination has quickly become a problem, and people are worried about how it may affect public health and the safety of food in the water. Microplastics have been detected in many freshwater and marine organisms, prompting concerns over bioaccumulation within food webs and potential human exposure via seafood consumption (Islam et al., 2025; Oza et al., 2024).

Bangladesh has a large population, but as cities grow rapidly and waste is poorly managed, the country is now facing an increasing problem of microplastic pollution in its inland waters (Islam et al., 2022a).

Additionally, microplastics have been found in river water and soil (Fatema et al., 2022; Jahan et al., 2024) and in fish and other aquatic species (Haque et al., 2023a; Hossain et al., 2019). Bangladesh has one of the largest water systems in the world, and many people there depend on fishing for food. There are concerns that microplastics may be entering the human food chain, as they have been found in economically important fish (Hossain et al., 2019; Nath et al., 2023.3). Most studies have examined only small parts of the ecosystem or specific locations, so it is still unclear how microplastics move between different parts of the environment. Only a few studies have investigated the problem in an integrated manner across water, sediment, and fish (Burns & Boxall, 2018; Islam et al., 2022b). In particular, very little is known about which types of plastic accumulate in freshwater fish, making it difficult to assess risks to food security and plan effective solutions.

The purpose of this research is to fill a knowledge gap by examining three major rivers in Bangladesh for evidence of microplastic contamination and its possible effects on aquatic food security. After the monsoon season, researchers analyzed water and sediment samples from rivers for microplastic levels and examined how these plastics ended up in *Labeo rohita*. To protect aquatic food security through improved local and global environmental management strategies, this study provides valuable insights into the risks posed to human health and the aquatic ecosystem by microplastic pollution.

2. Methodology

2.1 Study Area and Sample Collection

From October to December 2024, we collected Rui fish, also known as *Labeo rohita*, from the Buriganga (urban), Dhaleshwari (semi-urban), and Meghna (rural) rivers. People in the area eat these fish, and they are important to the local economy. One fish sample was collected each month from each

river to ensure the post-monsoon phase was captured over time. The fish samples were frozen and transported to the lab, where they were maintained at -20°C until further analysis.



Figure 1: Dissection of the gastrointestinal tract and digestion of organic matter with 30% hydrogen peroxide (H_2O_2)

2.2 Dissection and Microplastic Extraction

The sample fishes were rinsed, thawed, and weighed before the gastrointestinal tract (GT) was dissected and weighed as shown in Figure 1. 30% hydrogen peroxide (H_2O_2) was used for organic matter digestion. At the same time, sodium chloride (NaCl) solution (1.2 g/mL) was added for density separation. The supernatants were transferred to freshly prepared petri dishes for additional study after 14 days, and then filtered using a $45 \mu\text{m}$ sieve (Haque et al., 2023b). The next step was to sort the filter papers for microplastics (MPs) by size, colour, and shape using a stereomicroscope.

2.3 Identification and Characterization

After the stereomicroscopic analysis, the representative particles were analyzed further by Attenuated Total Reflectance Fourier Transform Infrared (ATR-FTIR) spectroscopy to confirm polymer composition, revealing six polymers: polyethylene (PE), polypropylene (PP), polyamide (PA), polyethylene terephthalate (PET), polystyrene (PS), and polyester (PES)(Alam et al., 2023a). SEM (Scanning Electron Microscopy) was used to examine the surface shapes of microplastics and their breakdown.

2.4 Statistical Analyses

ANOVA was used for quantitative data analysis, which confirmed temporal variation, while MANOVA with Hotelling's T^2 tests confirmed spatial variation. K-means clustering, Principal Component Analysis (PCA), and Linear Discriminant Analysis (LDA) confirmed the cross-compartmental differences and polymer distribution profiles.

3. Results and Discussion

3.1 Abundance of Microplastics

All the fish samples across the three rivers contained microplastics. The fish samples from Buriganga exhibited the highest microplastic concentrations, with 28, 20, and 24 MPs recorded in October, November, and December, respectively. Dhaleshwari followed this with 16, 7, and 9 MPs, and Meghna with 12, 8, and 5 MPs. These data indicate a distinct contamination gradient, aligned with the urbanization levels of the rivers.



Figure 2: Different types of microplastics observed under the Stereomicroscope

3.2 Morphotypes and Color Distribution

Across all the rivers, fibers were the dominant morphotype, accounting for 44-50% of the fibers, followed by fragments at 28%, as shown in Figures 2 and 3. Other shapes, including films, foams, and pellets, occurred sporadically, with the highest diversity recorded in December. Black was the predominant color in *Labeo rohita* throughout all rivers, succeeded by blue and red, as illustrated in Figures 2 and 4. This corresponds with previous research by Dhaleshwari and Buriganga, which indicated that black and blue MPs predominate in aquatic environments (Alam et al., 2023b; Haque et al., 2025). The predominance of dark fibers indicates textile effluents as major sources, consistent with known industrial activity along these rivers.

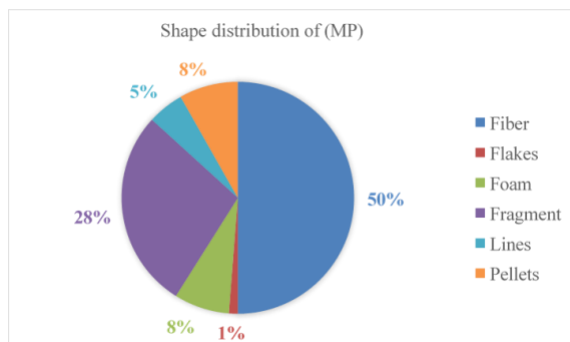


Figure 3: Shape Distribution of

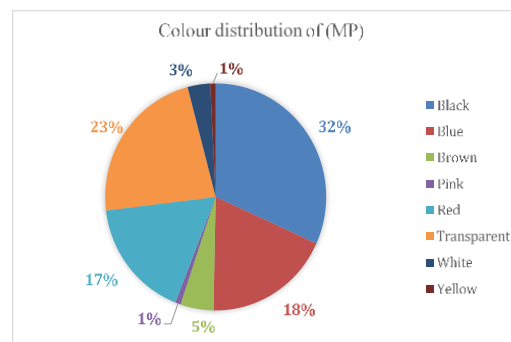


Figure 4: Colour Distribution of Microplastic

3.3 Polymer Composition

PE and PP were the most abundant polymers in all the rivers, while PA, PET, and PS were detected at lower levels by ATR-FTIR analysis. PES was detected in Buriganga and Dhaleshwari fish, but not in the associated sediment samples, indicating selective bioaccumulation. This discovery offers new evidence of industrial polymer translocation into aquatic food webs (Haque et al., 2024).

3.4 Spatial and Temporal Patterns

Substantial spatial variation ($p < 0.001$) indicated higher pollution levels in Buriganga than in Dhaleshwari and Meghna, as assessed by Hotelling's T^2 test. Nonetheless, the temporal variation, as assessed by ANOVA, was constrained, indicating substantial monthly fluctuations in the Meghna water samples ($p = 0.0155$), suggesting that hydrological dynamics influenced the movement of microplastics.

3.5 Bioaccumulation and Bioconcentration Factors (BAF and BCF)

The Bioaccumulation Factor (BAF) and Bioconcentration Factor (BCF) were determined for fish samples to investigate the correlation between environmental microplastics and biota. When water mostly helps the organism (a fish) take in contamination, BCF is the ratio of the contaminant's concentration in the organism to its concentration in the surrounding water. BAF is similar, but it looks at all the ways organisms can be exposed (water, sediment, food) and compares the concentrations in organisms to those in the environment. The low BCF and BAF levels observed in this study indicate that fish did eat and come into contact with microplastics, but they do not retain them in large amounts. This means that fish from these rivers are unlikely to accumulate much of these chemicals in their bodies. Nonetheless, even minimal concentrations of microplastics in consumable foods raise concerns about long-term ecological and health consequences (Pei et al., 2024). In this study, the BCF (0.12–0.32) surpassed the BAF (0.14–0.19), indicating that the exposure pathway through aqueous microplastics is more significant than sediment ingestion for this species. The low BAF and BCF readings indicated minimal retention and biomagnification.

3.6 Ecological and public health implications of microplastic contamination

Microplastic pollution is common in Bangladesh's major rivers, such as the Buriganga, Dhaleshwari, Meghna and other rivers. The water has a lot of it and the sediments have a lot of it which shows that the pollution is serious and long-lasting. These rivers are both places where things collect and ways to get to the Bay of Bengal.

Small microplastics (<0.5 mm) are easily eaten by aquatic organisms, which can hurt them physically, slow their growth, and make it harder for them to reproduce. They can also carry toxic pollutants like

heavy metals and POPs. High BAF and BCF values show that bioaccumulation and trophic transfer are strong, which raises the risk of biomagnification in the food chain.

Microplastics also harm habitats, disturb microbial communities, and may carry pathogens, which makes ecosystems less resilient. From a public health point of view, people can get sick from water, fish, and crops. Some of the risks include inflammation and problems with the endocrine system. Because Bangladesh relies on fish, chronic dietary exposure is a big worry, and poor plastic waste management makes it even worse.

Microplastic pollution is a serious threat to the environment and public health as a whole, and it needs to be dealt with quickly through management and policy changes.

4. Conclusion

Labeo rohita could provide a reliable bioindicator for assessing microplastic contamination in freshwater ecosystems, mirroring the pollution dynamics within the riverine food webs of Bangladesh. The substantially higher microplastic load in samples from the Buriganga River demonstrates the extent to which urbanization and industrial discharge affect the river. The lower levels found in the Meghna River, on the other hand, indicated less human activity. The existence of many polymer types, especially textile-derived fibers and industrial plastics, underscores the significant role of urban effluents in microplastic pollution.

This study also provides important insights into how microplastics move through the food chain, showing that they can accumulate in aquatic food webs. The findings, however, are confined to a single species and seasonal sampling, establishing a significant foundation for subsequent study on long-term ecological and human health effects. The data clearly show that Bangladesh and other countries like it need to take swift action on policies, such as improved waste management and tougher controls on industrial discharges, to minimize microplastic pollution and protect aquatic ecosystems and food security.

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