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# Characteristics, Contamination Levels, and Ecosystem Risk Assessment of Microplastics in Surface Water of a Highly Urbanized River from a Developing Country

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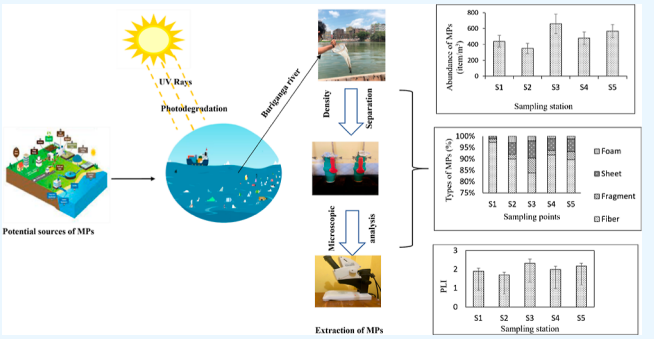
**ABSTRACT:** Microplastic (MP) contamination poses significant risks to ecosystems and human health. However, the absence of standardized protocols, detailed polymer identification, and sources identification hinders the development of targeted mitigation strategies, particularly in developing nations. There is a scarcity of comprehensive data on MP distribution, sources, and transport mechanisms in freshwater environments. This study aimed to fill these gaps by comprehensively characterizing MP contamination, elucidating distribution patterns, identifying sources, and assessing ecological risks in an urban river adjacent to a megacity. This was accomplished using stereomicroscopy, Fourier-transform infrared(FTIR) spectroscopy, and a range of risk assessment indices. The analyses revealed spatial variations in MP levels, ranging from 350 to 660 items/m$^3$ across different sampling stations along the river. Analysis of variance(ANOVA) highlighted significant differences in the average number of MPs among the stations ($F$ = 16.93, $p \ll 0.01$), with station S3 exhibiting the highest count and station S4 the lowest. Factors such as point sources of domestic and municipal waste, as well as river navigation, likely contribute to these variations. The predominant types, colors, and sizes of MPs observed were fiber, transparent, and <0.5 mm, respectively. Notably, 80% of the MPs consisted of polyethylene (PE) and polypropylene (PP), commonly associated with land-based sources like packaging materials. Despite minor ecological risks indicated by ecosystem risk assessment indices such as the risk index(RI) and pollution load index (PLI), which recorded values of 9.04 and 1.87, respectively, the potential hazard index(PHI) rose to hazard category V, posing a substantial threat to the river ecosystem. PCA facilitated the identification of trends linked to specific pollution sources, while cluster analysis categorized MPs with similar characteristics, thereby enhancing the understanding of their distribution patterns. These findings provided novel insights into the pervasive presence and pathways of plastic pollution in developing nations, offering important considerations for international efforts to address public health and environmental challenges associated with MPs.




## 1. INTRODUCTION

Plastics have become integral to modern life due to their versatility and convenience, yet their persistence in the environment has led to significant pollution challenges.[1,2] The issue of plastic pollution intensified during the COVID-19 pandemic, with global production soaring to 390.7 million tons in 2021, driven largely by single-use items like masks and personal protective equipment predominantly made of polyethylene (PE) and polystyrene (PS).[3] Alarmingly, approximately 50% of these plastics are disposed of after a single use.[3] Additionally, durable consumer products contribute to an estimated 20−25% of plastic waste entering the environment.[3] Recently, microplastics (MPs), defined as plastic particles less than 5 mm in size, have emerged as a significant environmental contaminant, recognized for their widespread distribution across various ecosystems—including water, sediment, and air—and their diverse sources and ecological risks.[2,3]

Unlike larger plastic debris, which tends to accumulate in visible clusters, MPs are dispersed throughout both aquatic and terrestrial ecosystems. Their small size enables easy transport by wind and water currents, resulting in their presence in remote habitats.[2] MPs can originate from larger plastics

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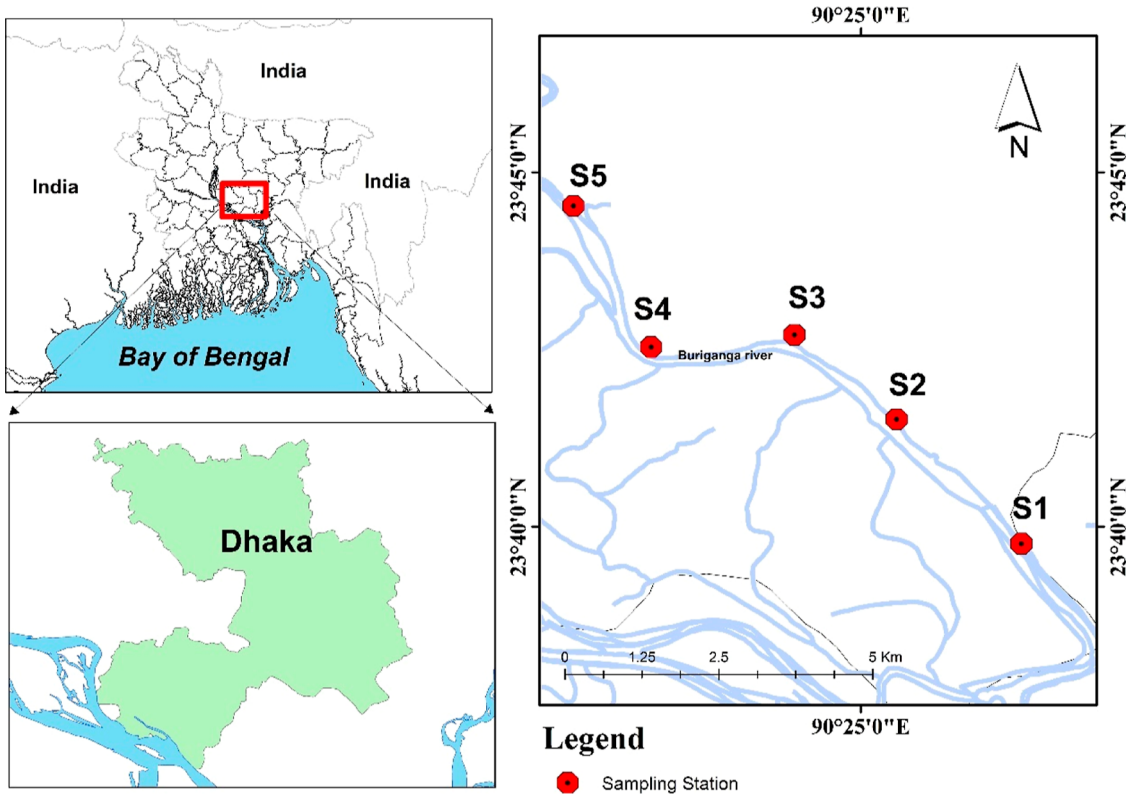


**Figure 1.** (a) Map of Bangladesh highlighting the study region, (b) Dhaka district, and (c) sampling stations (S1−S5) along the Buriganga River with different pollution sources of MPs.

through processes like weathering and fragmentation or from primary sources such as microbeads in personal care products and microfibers from clothing.[2] These pollutants pose considerable threats to aquatic environments and organisms, with their persistence in the environment leading to bioaccumulation and potential harm to human health.[1,4] Studies have documented the presence of MPs in various aquatic organisms, including zooplankton, fish, and shellfish, highlighting their infiltration into food chains.[4−7] As a result, the pervasive presence of MPs in the food web raises significant health concerns as they can act as carriers for toxic substances such as PCBs and PAHs, potentially contributing to hormonal disruptions and various diseases.[1,8−12] MPs also release hazardous contaminants like phthalates and bisphenol A, which can lead to carcinogenic diseases and reproductive issues.[12] Given these alarming circumstances, it is crucial to assess MP contamination levels across different ecosystems to understand their risks to human health and the environment.

Current methodologies for MP extraction and identification include manual sorting, chemical digestion, and advanced spectroscopic techniques such as Fourier-transform infrared (FTIR) and Raman spectroscopy.[13] While these methods are widely employed, achieving accurate separation and identification remains a challenge due to the lack of standardized protocols.[14] Manual sorting allows direct observation but is labor-intensive and prone to human error. Density separation methods may underrepresent smaller MPs, while chemical digestion can alter MP properties.[2] FTIR and Raman spectroscopy are effective for identifying MPs but may miss certain polymers.[15,16] Additionally, quantifying MPs is complicated by their size overlap with natural sediments, making differentiation difficult. Establishing standardized protocols is essential to minimize variability in research outcomes.

The contamination factor (CF), pollution load index (PLI), risk quotient (RQ), and potential hazard index (PHI) are critical metrics for assessing MP contamination and ecological risk.[1,2,7,16] Each index has its strengths and weaknesses: CF offers a straightforward baseline comparison but may overlook ecological effects, while PLI provides a broader pollution overview but can obscure specific contributions. RQ evaluates ecological risks based on harmful thresholds but relies on the accuracy of these thresholds. The PHI integrates MP abundance and composition but is constrained by data availability on ecological harm.[2] Together, these indices reveal the complexities of MP risk assessment and emphasize the need for standardized methodologies tailored to specific geographic contexts, particularly in developing regions like Bangladesh, where no standard threshold values currently exist for MP concentrations. Existing frameworks stress the importance of localized assessments to accurately evaluate the risks associated with MP contamination as generalized standards may inadequately address the unique environmental and socio-economic factors in these areas.[17]

The Buriganga River, heavily urbanized and winding through Dhaka, is a critical water resource, crucial not only ecologically but also for drinking water supply, transportation, and recreational activities.[18] Despite its significance, the river suffers from severe pollution due to mismanaged waste, with an estimated 2 million cubic meters of domestic effluents generated daily, compounded by discharges from over 7000 industries.[19,20] Toxic waste, particularly from dyeing, washing, and pharmaceuticals, contributes to the river's contamina-


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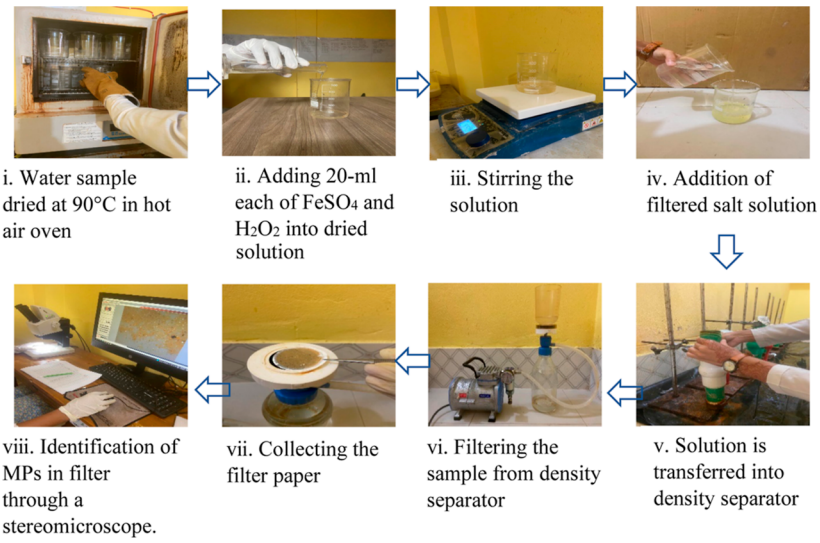


**Figure 2.** Sample preparation, digestion, and analytical process to extract MPs from water samples of Buriganga River (photo courtesy: Khadija).

tion.[20] With a per capita plastic use in Dhaka at 22.25 kg, three times the national urban average, understanding MP prevalence and impact in this urban waterway is essential for effective waste management strategies.[18,21,22]

Bangladesh is a major contributor to global plastic waste mismanagement,[2,18] and MPs have been identified across various environmental sectors, including coastal and estuarine water,[23] sediment,[19] fish,[18] shellfish,[25] and sea salts.[24] However, freshwater ecosystems have largely been overlooked in prior studies. Preliminary assessments[18,19] in the Buriganga River have provided initial data but suffer from several limitations. These studies are constrained by limited sample sizes and species diversity, reducing the ability to generalize MP bioaccumulation across the broader aquatic food web. Additionally, the absence of detailed polymer identification restricts the development of targeted pollution mitigation strategies. Furthermore, there has been no effort to trace the sources of MPs, limiting actionable insights for addressing pollution at its root. Comprehensive data on MP distribution, origins, and the specific mechanisms of transport and accumulation in freshwater environments are scarce. Therefore, this novel study aimed to address these gaps by characterizing, describing the distribution patterns, identifying sources, and assessing the ecological risks of MP contamination in the Buriganga River, a critical water resource for Dhaka Megacity, to enhance public health and environmental sustainability efforts in Bangladesh.

## 2. MATERIALS AND METHODS

**2.1. Study Site.** The city of Dhaka is bounded by the Buriganga River (23° 37′ 42″ N, 90° 26′ 30″ E), which is located close to the confluence of the Padma and Upper Meghna rivers (Figure 1). The Turag, Jamuna, Karnatali, Dhaleswari, and Tongi Khal rivers and canals, among others, flow into and out of the river. Its maximum depth is 18 m, while its average depth is 7.5 m. The water discharge fluctuates annually, from 700 $m^3$ per second in the rainy season (June to October) to 140 $m^3$ per second in the dry season (November to May).[26] There are nine industrial sites in and around the capital that contribute to river pollution, e.g., Tejgaon, Tongi, Tarabo, Hazaribagh, Savar, Narayanganj, Gazipur, EPZ, and Ghorashal.[19] An incredible 56 million tons of garbage and 0.5 million tons of sludge from the textile industry are dumped into the Buriganga River each year.

**2.2. Water Sample Collection from the River.** A total of 50 water samples were gathered from five stations (S1−S5) of the Buriganga River in Bangladesh during the wet season in July 2022 (Figure 1). Each station had ten replicates for accuracy and consistency in this study. The selection of sampling stations along the river was carefully conducted, taking into consideration various factors including land use patterns, catchment utilization, potential pollution sources, and ecological significance. This deliberate selection process aimed to capture the diverse levels of pollutants, pathways, and ecological conditions throughout the river. First, stations were strategically positioned (using GPS) in close proximity to identified sources of pollution, such as industrial zones, urban settlements, and points of wastewater discharge. These locations were anticipated to exhibit higher concentrations of MPs due to direct inputs of plastic waste into the river. Additionally, sampling stations were designated at sites of ecological importance, such as areas with rich biodiversity, fragile ecosystems, and zones allocated for recreational activities. This comprehensive approach ensures a thorough assessment of MP pollution levels and ecological impacts along the Buriganga River.

The collection process involved filtering approximately 60 L of river top layer water using a manta net (mesh size:0.3 mm) and cod-ends. The manta net was used as the predominant technique for collecting MPs from the marine and freshwater systems. In this method, a flow meter was employed to measure the volume of water coursing through the net during a specific time frame. In this approach, the volume was standardized based on factors like towing speed and duration, thereby normalizing the findings per unit volume of sampled water. The net was washed with distilled water prior to sampling to avoid contamination and flushed from the outward direction using river water, ensuring the transfer of all samples into the cod-end. The net was lowered to a minimum depth of 0.5 m during the sampling process.[23,27] Subsequently, all the samples were carefully transferred into glass storage containers equipped with PTFE-coated screw covers to ensure proper containment[28,29] and avoid cross-contamination. The collected samples were then transported to the LEEB (Laboratory for


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Ecology, Environment, and Biodiversity) for further examination and analysis.

**2.3. Processing and Separation Process of MPs from a Collected Water Sample.** To enumerate and characterize MPs in water, a step-by-step process was followed, consisting of two major stages: reducing the water volume and filtering the sample through the medium of density separation (Figure 2). There is no established standard method for these steps, so the present study adopted the methodologies of other published papers[23,27] for MP extraction. The extraction process began by transferring the collected water samples into 500 mL beakers. Subsequently, the samples were dried in a hot air oven overnight until they were dry. Afterward, wet peroxide oxidation was carried out to eliminate organic matter from the samples.[30] In this process, 20 mL of 30% hydrogen peroxide solution and 20 mL of 0.05 M ferrous sulfate solution served as catalysts.

Then, the mixture was placed in a hot plate with a stir bar and heated to 75 °C. When gas bubbles appeared at surface, the beaker was placed in the fume hood and distilled water was added to suppress the reaction. An additional 20 mL of 30% hydrogen peroxide was added to the beaker if any organic material was observed and placed in the hot plate for an additional 30 min. The digested solution underwent separation in a density separator with sodium chloride (NaCl) solution (1.19 g/mL$^{-1}$) overnight to facilitate the removal of sand and minerals. NaCl was used due to its widespread availability, cost-effectiveness, and relatively lower toxicity. After settling, the supernatant was sieved through cellulose nitrate filter paper (pore size: 5.0 $\mu$m; diameter: 47 mm). The filter paper was air-dried in a glass Petri dish, and the resulting filter paper underwent microscopic analysis for MP characterization and FTIR analysis to determine their chemical composition. This detailed procedure elucidates the steps employed in extracting MPs from water in the current study.

**2.4. Morphological Analyses of Separated MPs.** MPs from the filter paper were visually identified and quantified using an 8−35X Zoom-stereomicroscope (Model: Leica EZ4E, Germany) with a camera attached. The dimensions, shapes, and colors of the MPs were documented, and high-resolution images were taken with a camera. The sizes of the MPs were calibrated using measuring computer packages, ImageJ (v. 2).[31] To confirm the identity of ambiguous MP particles, hot needle tests were conducted.[24] This method involves placing a hot needle close to the target particle, causing plastic particles to melt or curl, distinguishing them from nonplastic or biological matter. Other characteristics of MPs, including size, color, and type/shape, were analyzed by existing literature.[2]

To identify the polymer type of MPs, collected particles from the filter paper were transferred into new Petri dishes. A representative subset by including a diverse range of MPs in terms of type, size, shape, and morpho-type were selected for FTIR analyses. Specifically, we selected 20 MPs per site (four per station), representing approximately 95% of the total isolated probable MPs. For polymer identification, we applied a 90% similarity threshold in FTIR analysis with reference spectra to ensure accuracy, which provided clear identification of all selected MPs. Polymer characterization was carried out using an FTIR 8400S spectrometer (Shimadzu Corporation, Japan), covering a wavelength range of 4000−400 cm$^{-1}$ and employing the potassium bromide pellet method. Approximately 200 mg of potassium bromide was mixed with 1−3 mg of the sample, perfectly compressed, and subsequently formed into a transparent pellet using a Shimadzu (IR Prestige-21) hydraulic press for 1 min under a continuous pressure of 10 tons, all conducted under evacuation. The resulting pellet was promptly analyzed using an FTIR spectrometer, scanning 30 times with a resolution of 2 cm-$^{1}$. To enhance identification accuracy, an automated contrast method utilizing comprehensive spectral libraries was employed to cross-reference polymer absorption bands from previous studies, minimizing the risk of misidentification.[32,33]

**2.5. Quality Assurance and Control of Contamination.** The accuracy and reliability of the data were ensured by strict attention to quality assurance and quality control (QA/QC) procedures. This encompassed careful calibration of instruments, analysis of blank or blind samples, standardization of sampling and analytical procedures, validation of results through replicate analyses during extraction, visual identification under a stereomicroscope, and FTIR analysis. Furthermore, FTIR spectral data were accurately compared with established reference data to ensure consistency and accuracy in polymer identification Throughout the experiment, numerous safety precautions were implemented to minimize the risk of contamination. All solutions, including $FeSO_4$ and NaCl, underwent filtration through a 5.0 $\mu$m filter paper to prevent cross-contamination of MPs. Specific care was taken during the wet peroxide digestion process, especially when handling hydrogen peroxide, and the entire reaction occurred within a fume hood to mitigate potential hazards. Further measures were employed to prevent cross-contamination, particularly from synthetic fibers in clothing and airborne pollutants. Thorough cleaning of laboratory equipment and surfaces was conducted using distilled water and 70% alcohol. Sieving materials through a 0.3 mm mesh yielded particles ranging from 0.3 mm to 5 mm in size. Similar procedures were applied for blank samples, where no MPs were detected. Additionally, in the case of filtering bottled water samples, the filtered water was left exposed in a beaker postfiltration.

**2.6. Ecological Risk Assessment.** As of now, there is no established model for effectively assessing the ecological risks arising from MPs pollution. However, a recently developed and reliable risk assessment model offers a promising approach for evaluating the potential ecological risks related to MP pollution. In this study, three methods were employed to assess the ecological risks of MPs.[34,35] The first strategy entails the assessment of the environmental toxicity of different kinds of MP polymers

$$\mathrm{PHI} = \sum \mathrm{Pn} \times \mathrm{Sn} \tag{1}$$

where Pn represents the % of particular polymer types obtained from each sample, and Sn corresponds to the hazard scores of the polymers.[1]

The second method created an ecological risk index (RI) with the capacity to detect the level of MP pollution in surface water:[36]

$$E_i = T_i \times \left(\frac{C_i}{C_o}\right) \tag{2}$$

$$\mathrm{RI} = \sum_{i=0}^{n} E_i \tag{3}$$

Here, $E_i$ denotes the potential ecological risk factor and $T_i$ stands for the toxicity coefficient associated with the



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constituent polymer. The toxicity coefficient is computed by combining the sample's % of each polymer type ($Pn/C_i$) with the hazard score of plastic polymers (Sn). Additionally, ($C_i/C_o$) represents the ratio of the recorded value of MP concentration to the background level. Given the absence of a background value, the lowest MP concentration found in this study (266.7 items/L) was adopted as the background value.[36]

The third approach employed to evaluate MP contamination in a surface water sample involves utilizing the PLI. The model is defined as follows:[37]

$$CF_i = \frac{C_i}{C_o} \quad (4)$$

$$PLI = \sqrt{CF_i} \quad (5)$$

**2.7. Potential Sources Identification of MPs.** To identify the sources of MPs, principal component analysis (PCA) and cluster analysis were employed based on their density and physical and chemical characteristics. PCA was utilized to reduce the complexity of the data set, transforming multiple variables into principal components (PCs) that highlighted variations among MP samples based on attributes such as size, shape, and polymer composition. This approach facilitated the visualization of relationships between different MP types, enabling the identification of trends linked to specific pollution sources.

Following the PCA, cluster analysis was applied to categorize MPs with similar characteristics into distinct groups, which indicated specific origins. Particles forming cohesive clusters often share morphological traits or chemical signatures, suggesting a common source, such as industrial discharge, urban runoff, or agricultural activities.

**2.8. Statistical Analyses.** The abundance of MPs in collected water samples was quantified as items/$m^3$ at each sampling site. The statistical techniques employed for analyzing abundance data involved descriptive statistics, such as mean, and standard deviation, to provide a concise summary of the central tendency and variability of data. Moreover, analysis of variance (ANOVA) with a significance level of 5% was conducted to test significant variation among the sampling stations. Data normality statistical was checked by the Shapiro–Wilk test. The homogeneity of variances was assessed by utilizing Levene's test. Statistical analysis was conducted using two software packages: PAST software (Paleontological Statistics; Version 4.03) and SPSS software (Statistical Package for the Social Sciences). Additionally, the sampling points were visualized on a map using mapping software (ArcGIS 10.3).

## 3. RESULTS AND DISCUSSION

**3.1. Prevalence and Abundance of MPs in the Water of Buriganga River.** Figure 3a illustrates the abundance of MPs in the surface water of the Buriganga River. The quantity of MPs varied across sampling locations, ranging from 350.00 ± 64.79 to 660 ± 122.52 items/$m^3$ of water, with an average of 499 ± 84.40 items/$m^3$. The highest and lowest abundance of MPs were noticed in S3 and S4 stations, respectively. One-way ANOVA revealed highly significant differences in mean MP concentrations across the sampling sites ($F = 16.93$, $p \ll 0.01$). Tukey's posthoc tests further confirmed distinct variations in MP abundance between locations. Generally, these differences in MP distribution can be attributed to multiple factors, including the physical properties of the plastics, local

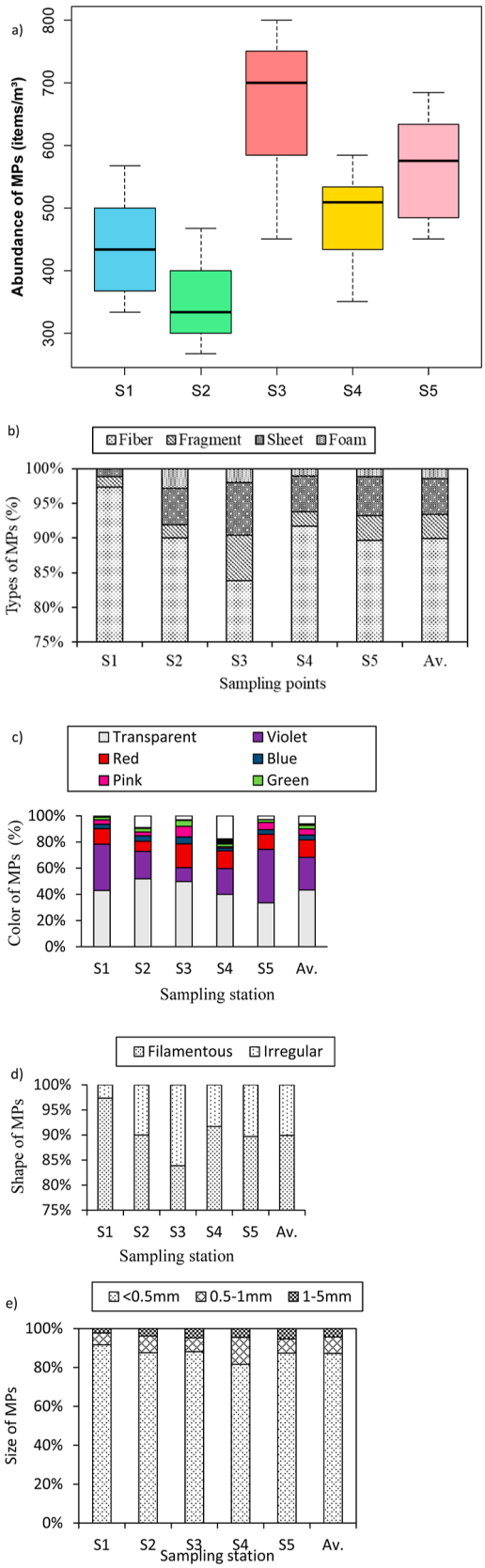


**Figure 3.** Abundance and morpho-chemical characteristics of MPs in the surface water sample of the Buriganga River: (a) abundance of MPs, with S1 representing the downstream station and S5 representing the upstream station of the river and (b) types, (c) color, (d) shape, and (e) size range of MPs.



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**Table 1. Comparison of MP Levels in Surface Waters from Global Freshwater Rivers and Creeks with Geographical and Hydrological Characteristics Similar to Bangladesh, Including Climate, Land Use, Urbanization, and Comparable Sampling and Analytical Methods**

| country | location | sampling method | abundance | dominant size | polymer | ref |
|---|---|---|---|---|---|---|
| Bangladesh | Buriganga River | 0.3 mm manta net | 486.8 ± 84.44 items/$m^3$ | <0.5 | PE, PP, EVA, PS, nylon | this study |
| China | Lake Ulansuhai | 48 $\mu$m stainless steel sieve | 1760 ± 710 to 10,120 ± 4090 items/$m^3$ | <0.5 | PE | 45 |
| China | Wei River | 75 $\mu$m stainless sieve | 3670 to 10,700 items/L | <0.5 | NA | 46 |
| USA | Milwaukee River Basin to Lake Michigan | 333 $\mu$m mesh neuston net | 0.21 to 19.1 particles/$m^3$ | 3 0.36−0.99 | vary | 41 |
| Canada | Wascana creek | 80 $\mu$m mesh conical net and 75 $\mu$m mesh size | 0.9 ± 0.3 to 7.7 ± 2.0 particles/$m^3$ | NA | NA | 42 |
| USA | San Gabriel River | Water: nets less than 1 mm mesh | 150.57 particles/$m^3$ | 1−4.75 | NA | 43 |
| Portugal | Antuã River | water pump with a 0.055 mm mesh net | 58−193 items/$m^3$ | NA | PE and PP | 44 |

geographical features, hydrological dynamics, and prevailing weather conditions, all of which influence the uneven dispersal of MPs in aquatic environments.[38] In the Buriganga River, the spatial variation in MP contamination across different sampling stations was influenced by a range of environmental and human-induced factors[18] Stations located near sewage discharge points and industrial zones—particularly those associated with textile, plastic, and chemical industries—displayed significantly higher concentrations of MPs (Figure 1), primarily due to the release of untreated wastewater, a primary source of MP pollution in river. The areas with dense populations also exhibited elevated MP levels, largely stemming from mismanagement of household waste and improper disposal of plastic products.[19] In contrast, stations situated downstream, where stronger water flow prevails, revealed fluctuating MP levels, as hydrological dynamics disperse or transport these particles. For instance, at station S3, reduced water flow caused by a partially closed river mouth and structural barriers, such as bridges, led to an accumulation of MPs. In comparison, station S2, which is situated further from direct pollution sources and with better water circulation, showed lower MP contamination. These observations stressed the role of localized pollution sources, water flow variations, and physical obstructions in shaping the spatial distribution of MPs within the Buriganga River.

The catchment area of the river is highly populated and heavily industrialized. Plastics are utilized in a wide array of applications, including household goods, food packaging, apparel, and furnishings. Therefore, MPs can originate from various sources, including daily activities like bathing and oral hygiene, as well as the shedding of fibers from textiles and the presence of plastic pellets in pharmaceuticals and personal care items. These diverse sources contribute to the high presence of MPs in rivers. Moreover, the levels of MP pollution appear to be linked to anthropogenic activities, local environmental conditions, and weather patterns.[39,40] Nevertheless, upon comparing the findings of the current study with those of freshwater ecosystems worldwide (Table 1), it emerged that the Buriganga River exhibited a higher mean MP abundance than the Milwaukee River Basin to Lake Michigan,[41] Wascana Creek in the USA,[42] San Gabriel River in the USA,[43] Antuã River in Portugal,[44] and the Meghna River.[23] In contrast, the researched area was comparatively less contaminated with MPs than the water in Lake Ulansuhai in China[45] and the Wei River in China.[46] Various factors, including domestic waste, sewage, industrial inputs, touristic activities, and the types and chemical composition of MPs in river water[47−49] could lead to the diverse prevalence of MPs in rivers. Moreover, many studies have not standardized their protocols, resulting in inconsistencies in mesh sizes, sampling volumes, and processing techniques, which complicated the cross-comparison of data.

**3.2. Structural Features of MPs Collected from the Water.** The surface water contained four different forms of MPs (Figures 3 and 4). The most common MPs discovered

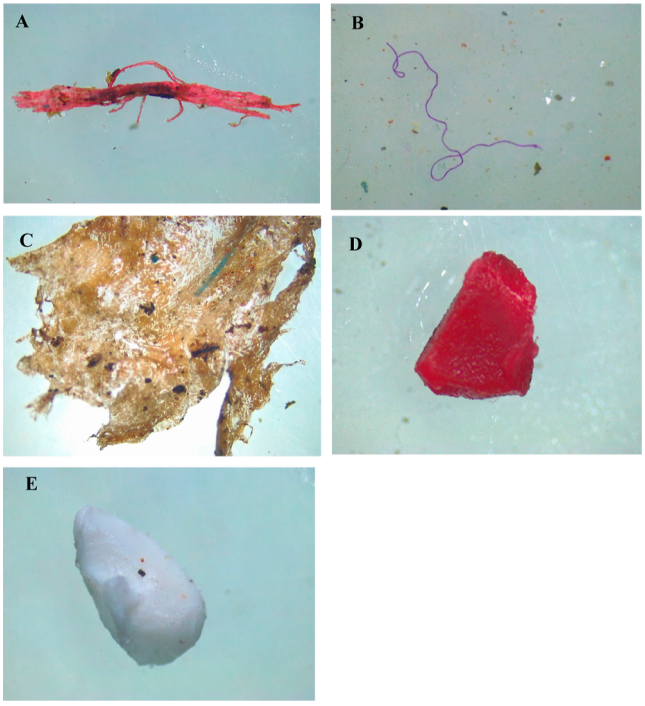


**Figure 4.** Microscopic images of MPs: (A) sheet, (B) fiber, (C) sheet, (D) fragment, and (E) foam.

(89.93%) was fiber, followed by films (5.20%), fragments (3.47%), and foams (1.40%). Furthermore, fibers predominated throughout all sampling locations (Figure 4a), with the majority of them having a filamentous morphology. While nearly all films and fragments exhibited irregular shapes, foams were predominantly spherical. The majority of fibers were detected at sampling station S1, consistent with findings from previous studies[23,46] that also noted a higher abundance of fibers in surface water. These fibers may stem from various


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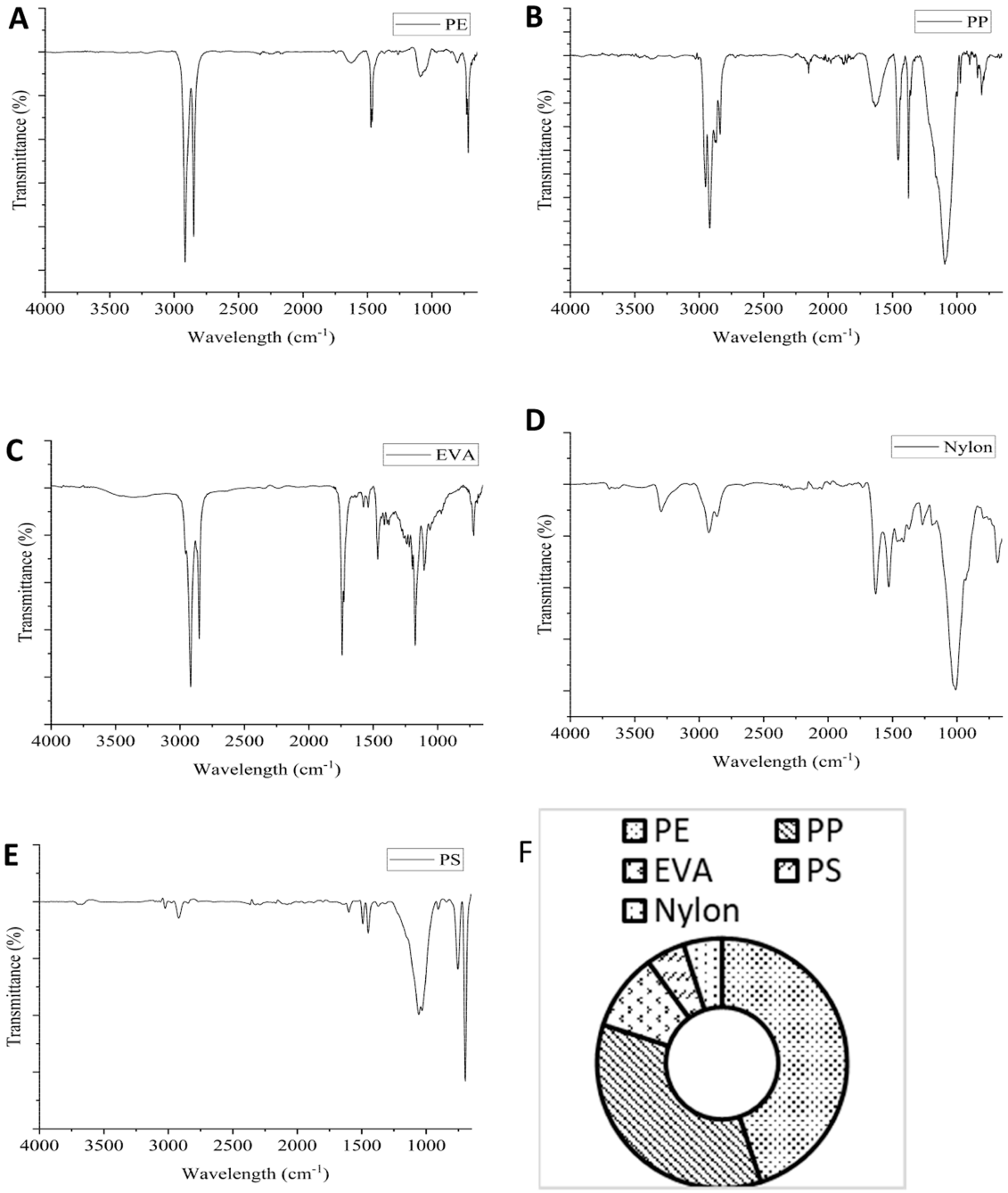


**Figure 5.** Polymer characteristics: polyethene (A), polypropylene (B), EVA (C), nylon (D), polystyrene (E), and % composition (F).

sources, including residential wastewater,[50] the degradation of fishing nets and lines,[39] or the deposition of airborne materials.[51] Films observed in the water may result from the deterioration of larger plastic bags and wrappings.[52] Additionally, the disintegration of plastic bottles or other plastic items could contribute to the formation of foam and irregularly shaped fragments.[53]

In this study, colored particles were the dominant type, accounting for 56.71% of total MPs in number. The observed colors were violet (25.05%), red (13.16%), white (6.14%), pink (4.61%), blue (3.81%), green (2.81%), and black (1.14%) (Figure 3c). Plastic plays an indispensable role in enhancing modern-day comfort, and coloration serves as a prevalent tactic to enhance the market appeal of plastic products.[54] The presence of colored items in the analyzed areas likely originates from the clothing and packaging of nearby residential areas. The prevalence of translucent plastics in fishing lines and nets may contribute to transparent particles comprising 43.29% of all MPs.[55] Plastic cups, single-use bags, and bottles, which have a short lifetime, could be the source of transparent MPs.[56]

In this study, three distinct groups of MP sizes were analyzed, with MPs smaller than 0.5 mm in size being the most common (87.24% of the total number of MPs detected). There were also a few MPs that were between 0.5 and 1 mm in size (8.48%) and 1 to 5 mm in size (4.2%) (Figure 3). The results of this investigation align with previous studies[24,50] that observed a predominance of smaller-sized MPs in surface water.[23,45] Various hydrodynamic processes, such as water current, sedimentation, wind, and wave action, along with vertical water mixing, can contribute to the breakdown of



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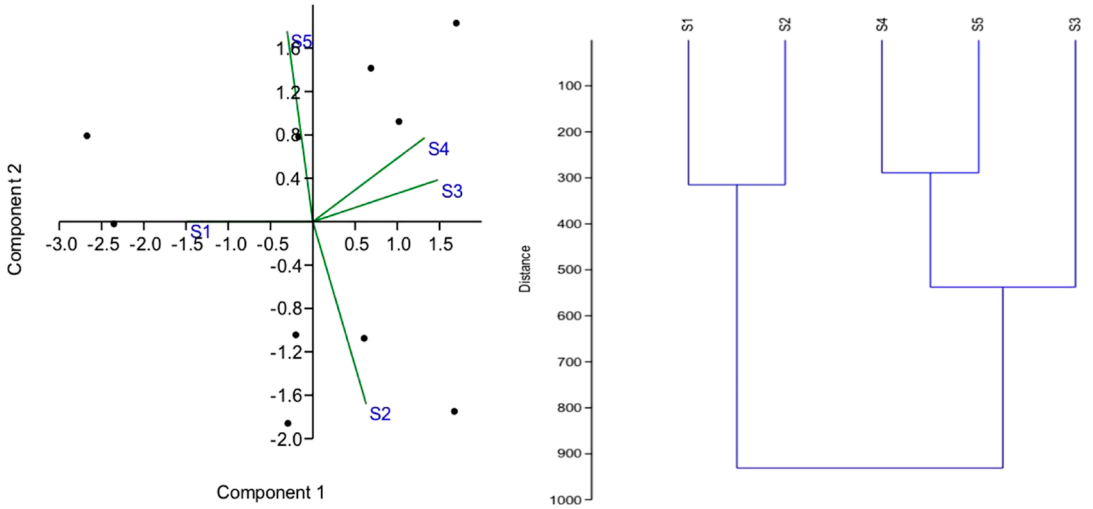


**Figure 6.** PCA (a) and cluster analyses (b) of MP types from all stations.

larger MP particles into smaller fragments, leading to the presence of minute MPs suspended in the water.[2]

**3.3. Polymer Composition of MP Particles.** A total of 20 samples were examined in FTIR spectral analysis, and all of them were verified as plastic polymers. Five different types of polymers, including PE, PS, nylon, PP (polypropylene), and ethylene vinyl acetate (EVA), were identified by FTIR spectral analysis in the water samples (Figure 5). PE emerged as the most prevalent polymer among the MPs examined, constituting 45%, followed by PP at 35%, EVA at 10%, and 5% each for PS and nylon (Figure 5). These findings align with results from other studies.[23,33,44] The prevalence of PE and PP as the most common MP polymers is in line with their extensive production and widespread use.[2] The high concentrations of PE, PP, and PS indicate the widespread use of items such as plastic cups, water bottles, toys, eyeglasses, packaging materials, and fishing nets. These items are frequently disposed of into the environment without proper recycling measures in place.[57] The widespread use of nylon in fishing nets links fishing activities to the presence of nylon in the environment.[58] EVA, a rubber employed in footwear, packaging, and fishing equipment, also featured prominently.[59]

**3.4. Pollution Source Identification.** In this study, PCA has been used to analyze the occurrence of various types of MPs in different sampling stations. The PCA output on samples from five different sites along the Buriganga River revealed significant spatial variations in the distribution of MPs. The analysis identified five PCs, with PC1 and PC2 collectively accounting for over 81% of the total variance in the data set (Figure 6a). Specifically, PC1 exhibited strong correlations with PE, PP, and EVA, indicating that these materials are the predominant types of MPs present in the river. Similarly, PC2 reinforced the prominence of PE and PP, while PCs 3, 4, and 5 highlighted the presence of other MP types, such as nylon and PS. The findings demonstrated a clear dominance of PE and PP across all sampling sites, underscoring their widespread use in consumer products and packaging, which significantly contributes to pollution in the Buriganga River. Variability in MP concentrations observed between different stations may be attributed to localized waste inputs and varying land-use practices, such as industrial activities and urbanization, which influence the quantity and type of waste entering the river. Hierarchical cluster analysis (HCA) was conducted to categorize locations exhibiting similar plastic contamination based on color, size, shape, and composition. The results of HCA unveiled three distinct clusters, as depicted in Figure 6b. Cluster 1 encompasses locations such as S1 and S2, characterized by high compositional fractions of PP. Cluster 2 includes locations like S4 and S5, exhibiting a predominant composition of PE. Meanwhile, a single sampling site, S3, forms Cluster 3, distinguished by a high composition of PE.

**3.5. Ecological Risk Assessment of Surface Water.** The evaluation of ecological risks associated with MP pollution has largely been unexplored due to the absence of systematic and standardized methods. The objective of the risk assessment in this study is to establish a preliminary approach for evaluating the ecological risks induced by MPs, aiming to comprehend potential ecological issues and provide the local government with a fundamental set of reference data for effective plastic waste management. Through the utilization of the combined polymer hazard index, PLI, and prospective ecological RI, this study enabled a preliminary quantitative assessment of the ecological risk stemming from riverine MP pollution. In this study, the ecological risk because of MPs in the surface water samples was evaluated by using PHI, $E_i$, RI, and PLI. Table 2

**Table 2. Potential Ecological Risk Assessment for MPs in Water Samples of Buriganga River**

| | $E_i$ (risk level) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | PE | PP | EVA | PS | nylon | RI[a] | PHI | PLI |
| S1 | 0.63 | 0.11 | 0.51 | 0.00 | 0.00 | 4.58 | 550 | 1.91 |
| S2 | 1.57 | 0.14 | 0.00 | 0.00 | 0.00 | 5.00 | 600 | 1.71 |
| S3 | 0.83 | 0.04 | 0.00 | 0.00 | 2.39 | 17.92 | 2150 | 2.35 |
| S4 | 1.15 | 0.05 | 0.47 | 0.00 | 0.00 | 6.67 | 800 | 2.00 |
| S5 | 0.97 | 0.04 | 0.00 | 1.32 | 0.00 | 11.04 | 1325 | 2.17 |

[a]See eq 3.

represents the PHI of MPs in the surface water of Buriganga were 550, 600, 2150, 800 and 1325 for S1, S2, S3, S4, and S5, respectively. The PHI for the entire Buriganga River was determined to be 1085 based on the average MP polymer composition from five sampling points. The overall risk of MPs pollution in the Buriganga River was assessed at Hazard Level V. Stations S3 and S4 exhibited elevated PHI values (>1000)


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owing to the presence of polymers with higher hazard scores, notably nylon and PS. Despite the comparatively lower hazard scores of PP, PE, and EVA, the chemical toxicity associated with these polymers warrants attention. Due to the higher ecological impact values ($E_i$) of PE, PS, and nylon in comparison to those of PP and EVA, these materials pose elevated risks. Notably, the risks attributed to EVA were found to be insignificant across all samples (Table 2). With the incorporation of various MPs polymers, the RI values of surface water indicated minimal ecological concern (RI 150). However, since RI is influenced by both hazard scores and the prevalence of different polymer types, higher RI values were observed in instances of heightened hazard. Therefore, further research is imperative to ascertain the potential risk MPs exposure in surface water environments.

The PLI was used to estimate the degree of riverine pollution, which was utilized as a simple and comprehensive tool for measuring the contamination in Buriganga River. The PLI values of all samples were <10, indicating "Hazard level I" (Table 2). Considering that PLI was calculated using the ratio of MP occurrence to background value, polymer kinds of MPs appear to have a negligible impact on PLI. The abundance of MPs is highly correlated with socioeconomic variables such as population density, industrialization level, way of life, level of economic development, and fisheries development. For instance, human activity in the local environment is linked to MPs availability.[60] The PLI values in the present study are relatively higher than those reported in Moheshkhali Channel, which may be because of the presence of MPs with high risk in Buriganga River.[61] The PLI values of Shiwuli River, China, in flood season and the nonflood season were 2.24 and 1.66, respectively, which indicates hazard level I, which is similar to our present study.[62]

## 4. CONCLUSIONS

This study provided a first comprehensive study on the characterization, contamination levels, potential sources identification, and risk assessment of MPs in surface water from a highly urbanized river in Bangladesh. The findings revealed the widespread presence of MPs at all stations along the river, with an average concentration of 486.8 ± 84.44 items/m$^3$. The most prevalent types of MPs were fibers, transparent particles, and those smaller than 0.5 mm. Predominantly, PE and PP polymers were identified, likely originating from plastic packaging, containers, and direct disposal of plastic waste into the river. The presence of other polymers like PS, EVA, and nylon suggested their significant use in the area. The polymer-based ecological risk assessment indicated moderate to extreme contamination levels. PCA demonstrated the relationships among MP types, aiding in the identification of trends linked to specific pollution sources. Cluster analysis then categorizes MPs with similar characteristics, enhancing the understanding of their distribution patterns and informing targeted pollution mitigation strategies by correlating clusters with known sources. Despite the ban on single-use plastic bags in Bangladesh, their substantial presence in the Buriganga River highlights widespread noncompliance with regulations and inadequate waste management practices. Future studies should prioritize the detection of smaller MP particles to increase biological relevance as these finer particles are more likely to interact with aquatic organisms and pose elevated ecological risks. Further research combining Raman spectroscopy with scanning electron microscopy holds the potential to greatly improve MP extraction and identification techniques. Moreover, incorporating automated image analysis with machine learning algorithms could increase both the accuracy and efficiency of MP detection while reducing human error. This is essential for better assessing the ecological risks posed to aquatic organisms and human health and for developing advanced removal technologies.

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### Notes

The authors declare no competing financial interest.

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## REFERENCES


(1) Lithner, D.; Larsson, Å.; Dave, G. Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. *Sci. Total Environ.* **2011**, *409* (18), 3309−3324.

(2) Banik, P.; Anisuzzaman, M.; Bhattacharjee, S.; Marshall, D. J.; Yu, J.; Nur, A. A. U.; et al. Quantification, characterization and risk assessment of microplastics from five major estuaries along the northern Bay of Bengal coast. *Environ. Pollut.* **2024**, *342*, 123036.

(3) PlasticsEurope. Plastics - the facts. 2022. https://plasticseurope.org/knowledge-hub/plastics-the-facts-2022/ (accessed 11/01/2024).

(4) Botterell, Z. L.; Bergmann, M.; Hildebrandt, N.; Krumpen, T.; Steinke, M.; Thompson, R. C.; Lindeque, P. K. Microplastic Ingestion in Zooplankton from the Fram Strait in the Arctic. *Sci. Total Environ.* **2022**, *831*, 154886.

(5) Fang, C.; Zheng, R.; Hong, F.; Jiang, Y.; Chen, J.; Lin, H.; et al. Microplastics in Three Typical Benthic Species from the Arctic: Occurrence, Characteristics, Sources, and Environmental Implications. *Environ. Res.* **2021**, *192*, 110326.

(6) Dahl, M.; Bergman, S.; Björk, M.; Diaz-Almela, E.; Granberg, M.; Gullström, M.; et al. A Temporal Record of Microplastic Pollution in Mediterranean Seagrass Soils. *Environ. Pollut.* **2021**, *273*, 116451.

(7) Hossain, M. S.; Sobhan, F.; Uddin, M. N.; Sharifuzzaman, S. M.; Chowdhury, S. R.; Sarker, S.; et al. Microplastics in Fishes from the Northern Bay of Bengal. *Sci. Total Environ.* **2019**, *690*, 821−830.

(8) O'Toole, T. E.; Conklin, D. J.; Bhatnagar, A. Environmental Risk Factors for Heart Disease. *Rev. Environ. Health* **2008**, *23* (3), 167−202.

(9) Link, M. S.; Luttmann-Gibson, H.; Schwartz, J.; Mittleman, M. A.; Wessler, B.; Gold, D. R.; Dockery, D. W.; Laden, F. Acute Exposure to Air Pollution Triggers Atrial Fibrillation. *J. Am. Coll. Cardiol.* **2013**, *62* (9), 816−825.

(10) Goncharov, A.; Rej, R.; Negoita, S.; Schymura, M.; Santiago-Rivera, A.; Morse, G.; et al. Lower Serum Testosterone Associated with Elevated Polychlorinated Biphenyl Concentrations in Native American Men. *Environ. Health Perspect.* **2009**, *117* (9), 1454−1460.

(11) Zeliger, H. I. Exposure to Lipophilic Chemicals as a Cause of Neurological Impairments, Neurodevelopmental Disorders and Neurodegenerative Diseases. *Interdiscip. Toxicol.* **2013**, *6* (3), 103−110.

(12) Vom Saal, F. S.; Hughes, C. An Extensive New Literature Concerning Low-Dose Effects of Bisphenol A Shows the Need for a New Risk Assessment. *Environ. Health Perspect.* **2005**, *113* (8), 926−933.

(13) Hanvey, J. S.; Lewis, P. J.; Lavers, J. L.; Crosbie, N. D.; Pozo, K.; Clarke, B. O. A review of analytical techniques for quantifying microplastics in sediments. *Anal. Methods* **2017**, *9* (9), 1369−1383.

(14) Wirnkor, V. A.; Ebere, E. C.; Ngozi, V. E. Microplastics, an emerging concern: a review of analytical techniques for detecting and quantifying microplastics. *Anal. Methods Environ. Chem. J.* **2019**, *2*, 13−30.

(15) Razeghi, N.; Hamidian, A. H.; Wu, C.; Zhang, Y.; Yang, M. Microplastic sampling techniques in freshwaters and sediments: a review. *Environ. Chem. Lett.* **2021**, *19* (6), 4225−4252.

(16) Zhao, B.; Richardson, R. E.; You, F. Microplastics monitoring in freshwater systems: A review of global efforts, knowledge gaps, and research priorities. *J. Hazard. Mater.* **2024**, *477*, 135329.

(17) Enyoh, C. E.; Verla, A. W.; Rakib, M. R. J. Application of index models for assessing freshwater microplastics pollution. *World News Nat. Sci.* **2021**, *38*, 37−48.

(18) Haque, M. R.; Ali, M. M.; Ahmed, W.; Siddique, M. A. B.; Akbor, M. A.; Islam, M. S.; et al. Assessment of Microplastics Pollution in Aquatic Species (Fish, Crab, and Snail), Water, and Sediment from the Buriganga River, Bangladesh: An Ecological Risk Appraisal. *Sci. Total Environ.* **2020**, *711*, 135009.

(19) Kibria, M. G.; Kadir, M. N.; Alam, S. Buriganga River Pollution: Its Causes and Impacts. In *International Conference on Recent Innovation in Civil Engineering for Sustainable Development (IICSD-2015)*, 2015; pp 323−328.

(20) Uddin, M. J.; Jeong, Y. K. Urban River Pollution in Bangladesh during Last 40 Years: Potential Public Health and Ecological Risk, Present Policy, and Future Prospects Toward Smart Water Management. *Heliyon* **2021**, *7* (2), No. e06107.

(21) Islam, M. S.; Karim, M. R.; Islam, M. T.; Oishi, H. T.; Tasnim, Z.; Das, H.; Kabir, A. H. M. E.; Sekine, M. Abundance, characteristics, and ecological risks of microplastics in the riverbed sediments around Dhaka city. *Sci. Total Environ.* **2023**, *877*, 162866.

(22) Tanim, T. T. *A Sustainable Plastic Waste Management for Dhaka City. Daily Observer*, 2023.

(23) Hossain, M. B.; Yu, J.; Nur, A. A. U.; Banik, P.; Jolly, Y. N.; Al-Mamun, M.; Albeshr, M. F. Microplastics in Surface Water from a Mighty Subtropical Estuary: First Observations on Occurrence, Characterization, and Contamination. *Environ. Res.* **2023**, *226*, 115594.

(24) Ujjaman Nur, A. A.; Hossain, M. B.; Banik, P.; Choudhury, T. R.; Liba, S. I.; Umamaheswari, S.; Albeshr, M. F.; Senapathi, V.; Arai, T.; Yu, J. Microplastic Contamination in Processed and Unprocessed Sea Salts from a Developing Country and Potential Risk Assessment. *Chemosphere* **2022**, *308*, 136395.

(25) Hossain, M. S.; Rahman, M. S.; Uddin, M. N.; Sharifuzzaman, S. M.; Chowdhury, S. R.; Sarker, S.; et al. Microplastic Contamination in Penaeid Shrimp from the Northern Bay of Bengal. *Chemosphere* **2020**, *238*, 124688.

(26) BBS *Compendium of Environment Statistics of Bangladesh*; Government of the People's Republic of Bangladesh: Dhaka, 2005.

(27) Masura, J.; Baker, J.; Foster, G.; Arthur, C. *Laboratory Methods for the Analysis of Microplastics in the Marine Environment: Recommendations for Quantifying Synthetic Particles in Waters and Sediments*; NOAA Marine Debris Division: Siver Spring, MD, 2015.

(28) Zhang, K.; Xiong, X.; Hu, H.; Wu, C.; Bi, Y.; Wu, Y.; Zhou, B.; Lam, P. K. S.; Liu, J. Occurrence and Characteristics of Microplastic Pollution in Xiangxi Bay of Three Gorges Reservoir, China. *Environ. Sci. Technol.* **2017**, *51* (7), 3794−3801.

(29) Lusher, A. L.; Hollman, P. C. H.; Mendoza-Hill, J. J. Microplastics in Fisheries and Aquaculture: Status of Knowledge on Their Occurrence and Implications for Aquatic Organisms and Food Safety. In *FAO Fisheries and Aquaculture Technical Paper No. 615*; FAO: Rome, 2017; Vol. *615*.

(30) Baldwin, A. K.; Corsi, S. R.; Mason, S. A. Plastic Debris in 29 Great Lakes Tributaries: Relations to Watershed Attributes and Hydrology. *Environ. Sci. Technol.* **2016**, *50* (19), 10377−10385.

(31) Hossain, M. B.; Banik, P.; Nur, A. A. U.; Rahman, T. Abundance and Characteristics of Microplastics in Sediments from the World's Longest Natural Beach, Cox's Bazar, Bangladesh. *Mar. Pollut. Bull.* **2021**, *163*, 111956.

(32) Noda, S.; Fujita, M.; Asano, T. Spontaneous-Emission Control by Photonic Crystals and Nanocavities. *Nat. Photonics* **2007**, *1* (8), 449−458.

(33) Jung, M. R.; Horgen, F. D.; Orski, S. V.; Rodriguez C, V.; Beers, K. L.; Balazs, G. H.; Jones, T. T.; Work, T. M.; Brignac, K. C.; Royer, S. J.; et al. Validation of ATR FT-IR to Identify Polymers of Plastic Marine Debris, Including Those Ingested by Marine Organisms. *Mar. Pollut. Bull.* **2018**, *127*, 704−716.

(34) Liu, K.; Wang, X.; Fang, T.; Xu, P.; Zhu, L.; Li, D. Source and Potential Risk Assessment of Suspended Atmospheric Microplastics in Shanghai. *Sci. Total Environ.* **2019**, *675*, 462−471.

(35) Xu, P.; Peng, G.; Su, L.; Gao, Y.; Gao, L.; Li, D. Microplastic Risk Assessment in Surface Waters: A Case Study in the Changjiang Estuary, China. *Mar. Pollut. Bull.* **2018**, *133*, 647−654.

(36) Li, R.; Yu, L.; Chai, M.; Wu, H.; Zhu, X. The Distribution, Characteristics and Ecological Risks of Microplastics in the Mangroves of Southern China. *Sci. Total Environ.* **2020**, *708*, 135025.

(37) Tomlinson, D. L.; Wilson, J. G.; Harris, C. R.; Jeffrey, D. W. Problems in the Assessment of Heavy-Metal Levels in Estuaries and the Formation of a Pollution Index. *Helgoländer Meeresunters* **1980**, *33*, 566−575.




https://doi.org/10.1021/acsomega.4c01528
*ACS Omega* 2024, 9, 50922−50932

(38) Ballent, A.; Purser, A.; de Jesus Mendes, P.; Pando, S.; Thomsen, L. Physical Transport Properties of Marine Microplastic Pollution. *Biogeosciences Discuss.* **2012**, *9* (12), 18755−18798.
(39) Cole, M.; Lindeque, P.; Halsband, C.; Galloway, T. S. Microplastics as Contaminants in the Marine Environment: A Review. *Mar. Pollut. Bull.* **2011**, *62*, 2588−2597.
(40) Kim, I. S.; Chae, D. H.; Kim, S. K.; Choi, S.; Woo, S. B. Factors Influencing the Spatial Variation of Microplastics on High-Tidal Coastal Beaches in Korea. *Arch. Environ. Contam. Toxicol.* **2015**, *69*, 299−309.
(41) Lenaker, P. L.; Baldwin, A. K.; Corsi, S. R.; Mason, S. A.; Reneau, P. C.; Scott, J. W. Vertical Distribution of Microplastics in the Water Column and Surficial Sediment from the Milwaukee River Basin to Lake Michigan. *Environ. Sci. Technol.* **2019**, *53* (21), 12227−12237.
(42) Campbell, S. H.; Williamson, P. R.; Hall, B. D. Microplastics in the Gastrointestinal Tracts of Fish and the Water from an Urban Prairie Creek. *Facets* **2017**, *2*, 395−409.
(43) Moore, C. J.; Lattin, G. L.; Zellers, A. F. Quantity and Type of Plastic Debris Flowing from Two Urban Rivers to Coastal Waters and Beaches of Southern California. *Rev. Gestão Costeira Integr.* **2011**, *11* (1), 65−73.
(44) Rodrigues, M. O.; Abrantes, N.; Gonçalves, F. J. M.; Nogueira, H.; Marques, J. C.; Gonçalves, A. M. M. Spatial and Temporal Distribution of Microplastics in Water and Sediments of a Freshwater System (Antuã River, Portugal). *Sci. Total Environ.* **2018**, *633*, 1549−1559.
(45) Wang, Z.; Qin, Y.; Li, W.; Yang, W.; Meng, Q.; Yang, J. Microplastic Contamination in Freshwater: First Observation in Lake Ulansuhai, Yellow River Basin, China. *Environ. Chem. Lett.* **2019**, *17*, 1821−1830.
(46) Ding, L.; Fan, M.; Guo, X.; Yang, X.; Zhang, Q.; Yang, C. Microplastics in Surface Waters and Sediments of the Wei River, in the Northwest of China. *Sci. Total Environ.* **2019**, *667*, 427−434.
(47) Meijer, L. J.; Van Emmerik, T.; Van Der Ent, R.; Schmidt, C.; Lebreton, L. More Than 1000 Rivers Account for 80% of Global Riverine Plastic Emissions into the Ocean. *Sci. Adv.* **2021**, *7* (18), No. eaaz5803.
(48) Yonkos, L. T.; Friedel, E. A.; Perez-Reyes, A. C.; Ghosal, S.; Arthur, C. D. Microplastics in Four Estuarine Rivers in the Chesapeake Bay, USA. *Environ. Sci. Technol.* **2014**, *48* (24), 14195−14202.
(49) Reisser, J.; Shaw, J.; Wilcox, C.; Hardesty, B. D.; Proietti, M.; Thums, M.; Pattiaratchi, C. Marine Plastic Pollution in Waters Around Australia: Characteristics, Concentrations, and Pathways. *PLoS One* **2013**, *8* (11), No. e80466.
(50) Browne, M. A.; Crump, P.; Niven, S. J.; Teuten, E.; Tonkin, A.; Galloway, T.; Thompson, R. Accumulation of Microplastic on Shorelines Worldwide: Sources and Sinks. *Environ. Sci. Technol.* **2011**, *45* (21), 9175−9179.
(51) Dris, R.; Gasperi, J.; Saad, M.; Mirande, C.; Tassin, B. Synthetic Fibers in Atmospheric Fallout: A Source of Microplastics in the Environment? *Mar. Pollut. Bull.* **2016**, *104*, 290−293.
(52) Nor, N. H. M.; Obbard, J. P. Microplastics in Singapore's Coastal Mangrove Ecosystems. *Mar. Pollut. Bull.* **2014**, *79* (1−2), 278−283.
(53) Zhang, K.; Gong, W.; Lv, J.; Xiong, X.; Wu, C. Accumulation of Floating Microplastics Behind the Three Gorges Dam. *Environ. Pollut.* **2015**, *204*, 117−123.
(54) Thetford, D.; Chorlton, A.; Hardman, J. Synthesis and Properties of Some Polycyclic Barbiturate Pigments. *Dyes Pigm.* **2003**, *59*, 185−191.
(55) Stolte, A.; Forster, S.; Gerdts, G.; Schubert, H. Microplastic Concentrations in Beach Sediments Along the German Baltic Coast. *Mar. Pollut. Bull.* **2015**, *99*, 216−229.
(56) Zhang, K.; Shi, H.; Peng, J.; Wang, Y.; Xiong, X.; Wu, C.; Lam, P. K. Microplastic Pollution in China's Inland Water Systems: A Review of Findings, Methods, Characteristics, Effects, and Management. *Sci. Total Environ.* **2018**, *630*, 1641−1653.
(57) PlasticsEurope. Plastics - the Facts. 2017. http://www.plasticseurope.org/application/files/5715/1717/4180/Plastics_the_facts_2017_FINAL_for_website_one_page.pdf (accessed 11/01/2024).
(58) Andrady, A. L. Microplastics in the Marine Environment. *Mar. Pollut. Bull.* **2011**, *62* (8), 1596−1605.
(59) Emblem, A. Plastics Properties for Packaging Materials. In *Packaging Technology*; Woodhead Publishing, 2012; pp 287−309..
(60) Lechner, A.; Keckeis, H.; Lumesberger-Loisl, F.; Zens, B.; Krusch, R.; Tritthart, M.; Glas, M.; Schludermann, E. The Danube So Colourful: A Potpourri of Plastic Litter Outnumbers Fish Larvae in Europe's Second Largest River. *Environ. Pollut.* **2014**, *188*, 177−181.
(61) Al Nahian, S.; Rakib, M. R. J.; Kumar, R.; Haider, S. M. B.; Sharma, P.; Idris, A. M. Distribution, Characteristics, and Risk Assessments Analysis of Microplastics in Shore Sediments and Surface Water of Moheshkhali Channel of Bay of Bengal, Bangladesh. *Sci. Total Environ.* **2023**, *855*, 158892.
(62) Hong, L.; Meng, X.; Bao, T.; Liu, B.; Wang, Q.; Jin, J.; Wu, K. Spatial-Temporal Distribution and Ecological Risk Assessment of Microplastics in the Shiwuli River. *Water* **2023**, *15* (13), 2330.


https://doi.org/10.1021/acsomega.4c01528
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