Dhaka Univ. J. Sci. 74(1): 36-45, 2026 (January)
Prof. M. Muhibur Rahman Memorial Issue
ISSN 1022 - 2502, E-ISSN 2408- 8528
DOI: https://doi.org/10.3329/dujs.v74i1.86860

Microplastic Pollution in the Surface Water of Karnaphuli Estuary: Understanding Spatial Variation and Ecological Impacts

Adiba Mosharraf[1], Ferdousi Begum[2*], Modhuparna Dey[3], Mohammad Mahbubur Rahman[4] Md. Abu Bin Hasan Susan[5], Farhana Akter[2], Imtiaz Ahmed Sakib[6], and Md. Arman Hossain[6]

[1]Climate Change and Environment Unit, Institute of Water Modelling, Dhaka, Bangladesh
[2]Department of Chemistry, Bangladesh Maritime University, Dhaka, Bangladesh
[3]Department of Marine Fisheries and Aquaculture, Bangladesh Maritime University, Dhaka, Bangladesh
[4]Fiber and Polymer Research Division, Bangladesh Council of Scientific and Industrial Research, Dhaka, Bangladesh
[5]Department of Chemistry, University of Dhaka, Dhaka, Bangladesh
[6]Department of Oceanography, Bangladesh Maritime University, Pallabi, Dhaka, Bangladesh

(Received : 25 September 2025; Accepted : 1 January 2026)

Abstract

Microplastics (MPs) emerged as global contaminants of concern for their widespread occurrence in aquatic systems, which are mainly produced from the degradation of larger plastics and various industrial activities, posing notable threats to marine ecosystems. Since research on pollution for the abundance of MPs in coastal and estuarine areas of Bangladesh remains limited, this study examined MP contamination in surface water collected from ten stations of the Karnaphuli estuary (KE) during February 2023. The presence of MPs was assessed in terms of distributions, abundances, and potential risks through National Oceanic and Atmospheric Administration procedures. Results showed a considerable presence of MPs, dominated by *fibers* (86 %), followed by *fragments* (8 %) and *foam* (6 %). In terms of color, *black* and *transparent* MPs were most common, while *green* MPs were least observed, as well as particle size of MPs with a size smaller than 1 mm was more frequent. Attenuated Total Reflectance Fourier Transform Infrared spectroscopy characterization confirmed the presence of polymers, including ethylene vinyl acetate, nylon, polystyrene, acrylonitrile butadiene styrene, acrylic, and polyethylene as MPs. Risk evaluation through Contamination Factor (CF), Pollution Load Index (PLI), Polymer Hazard Index (PHI), and Potential Risk Index (PRI) revealed *moderate* to *very high* risks across the stations. All PLI values exceeded 1.0, confirming significant pollution; however, PHI values indicated a *moderate hazard* but were skewed by *high-risk* stations. Additionally, PRI values also varied widely, with most stations showing *considerable risk,* which corresponds to the sources including industrial effluents, agricultural runoff, and urban wastes, confirmed by Land Use and Land Cover analysis. Thus, the results of this study highlight the urgent need for effective pollution control based on long-term monitoring of MPs in the KE.

Keywords: Microplastics, Attenuated Total Reflectance Fourier Transform Infrared spectroscopy, Pollution Load Index, Polymeric Hazard Index, Potential Risk Index, Contamination Factor

I. Introduction

A significant worldwide environmental concern that is endangering aquatic ecosystems, biodiversity, and human health is microplastic (MP) pollution. Fragmentation of bigger plastics, synthetic textiles, and household care items is considered to be the source of these tiny plastic particles, which are usually less than 5 mm in size[1,2]. A number of reports[3,4,5,6] indicate that MPs can be found from the arctic to the deep oceans, demonstrating their worrying durability and abundance in freshwater as well as marine systems. Their ecological and toxicological significances are highlighted by their capacity to adsorb and transport dangerous contaminants, as well as when aquatic organisms consume them[7]. Human health and marine biodiversity are at risk due to MP contamination, which is acknowledged as a complicated and transboundary environmental problem of the 21st century[8]. Early in the 1970s, reports of these tiny plastic particles with < 5 mm in the ocean were made[9]; almost 13.2 % of the mass and 92.4 % of the total number of plastic particles worldwide were MPs, making them a major contributor to marine plastic debris[10]. Due to improper disposal of trash, 70-90 % of operations on land and 10-25 % of activities at sea are responsible for marine and coastal plastic contamination[10]. MPs originate from land-based sources: personal care goods, textiles, agriculture, packaging, building, tourism, and ship dismantling, along with sea-based sources; fisheries, aquaculture, offshore industries, and marine tourism[8,11,12], posing threats to marine life through ingestion, reproductive harm, and mortality, while also affecting industries: fishing and tourism. Human exposure has been linked to respiratory, digestive, and metabolic disorders[13]. Seasonal variation in MP abundance has been documented, with higher concentrations often observed during the wet season[14]. Furthermore, a positive correlation between the Basin Development Index and MP levels indicates that land use, especially construction activities, plays a key role in driving contamination[13]. Thus, research on the scope, sources, and impacts of MP contamination in aquatic ecosystems is urgently needed worldwide.

Bangladesh is particularly vulnerable to plastic and MP pollution due to its extensive river networks and proximity

*Author for correspondence. e-mail: ferdousi.chem@bmu.edu.bd

to the Bay of Bengal (BoB). Rapid population growth, urbanization, and inadequate waste management infrastructure further exacerbate the problem[8,11,14,20]. MPs have already been detected in major rivers such as the Buriganga and Padma, raising serious environmental and health concerns[15]. However, estuarine systems remain under studied, despite their critical role as transitional zones between freshwater and marine habitats. As a key ecological and economic hub, the Karnaphuli estuary (KE) supports diverse aquatic species, sustains fisheries-based livelihoods, and receives substantial inputs of industrial, agricultural, and urban wastes. Thus, assessment of MP contamination in the surface water of the KE is essential to understand risks and inform management strategies.

While preliminary studies indicate a notable abundance of MP pollution, detailed insights into their types, sources, and ecological impacts remain constrained[15]. This study addresses that gap by providing a comprehensive evaluation of MP contamination in the surface water of the KE. Through the quantification and characterization of MPs in surface water, the research uncovers the extent and diversity of this pollution. It further examines the potential sources of MPs, highlighting the role of human activities and environmental processes in driving contamination within the estuary. Ultimately, this study assesses the ecological and toxicological risks of MPs by analyzing spatial distribution and several indices, including Contamination Factor (CF), Pollution Load Index (PLI), Polymer Hazard Index (PHI), and Potential Risk Index (PRI). The findings are expected to offer critical insights into their impacts on aquatic ecosystems and establish a foundation for targeted mitigation measures. By focusing on this estuarine hotspot, an area heavily influenced by human activities and applying advanced analytical techniques, the research provides evidence to guide policymakers and support the development of effective strategies for addressing plastic pollution across South Asia.

II. Materials and Methods

Sampling of Surface Water

The Karnaphuli River (KR), the principal body of water in the Chattogram vicinity, originates in the Northeastern Mizo Hills of India and flows approximately 270 km south and Southeast until flowing into the Bay of Bengal (BoB), 19 km below the city of Chattogram. The investigation was conducted in surface water of the KE, collected from 10 stations during February 2023, located between latitude 22°18'60" N and 22°12'32" N, and longitude 91°48'51" E and 91°48'11" E (Fig. 1) at ~1.5 km intervals, using a water sampler, and determined using a Global Positioning System (GPS).

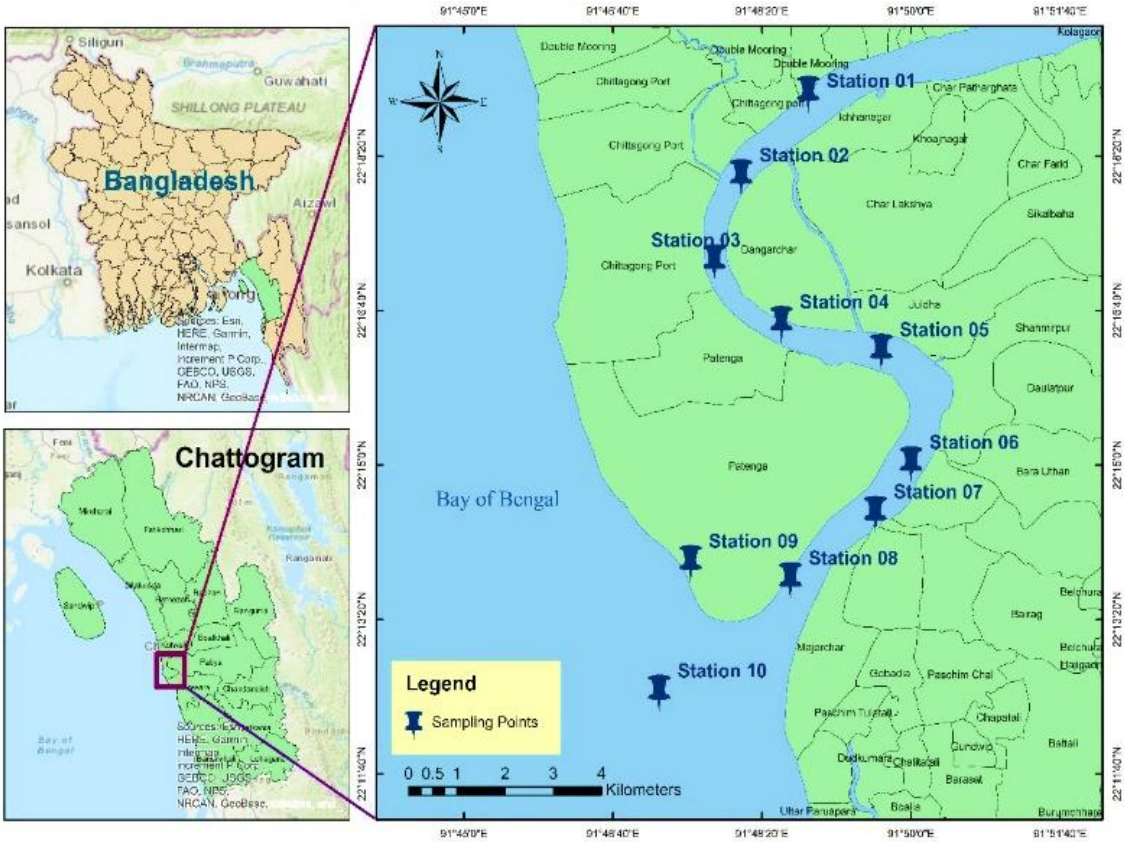


Fig. 1. Geographical coordinates of all the stations of surface water in the KE. Satellite view of Bangladesh and the KE with its adjacent neighbours (left) and stations of collected surface water around the KE (right). Stations are marked numerically, maintaining their sampling time, and stations are colored in blue.

Separation of Microplastics from Surface Water

MPs were extracted from 20 sieved surface water (0.3 mm mesh) following National Oceanic and Atmospheric Administration (NOAA) protocols[16]. Each surface water sample was transferred to a 100 mL glass beaker, treated with 20 mL of 0.05 M Fe (II) solution and 20 mL of 30 % H_2O_2, and allowed to react for 5 min. at room temperature. The mixture was then heated to 75 °C until bubbling occurred, after which it was cooled in a fume hood. For density separation, a 5.0 M NaCl solution was prepared by heating to dissolve the salts and subsequently added to the surface water in a separatory funnel. After 24 hrs of settling, the supernatant was filtered using a vacuum pump with 0.45 µm Whatman filters. Retained particles on filters were examined under a microscope for visual identification of MP.

Identification, Estimation, and Characterization of Microplastics

With magnifications ranging from 10x to 100x a dissecting light stereomicroscope (Optika Digital Microscope with Camera & Tablet, Model: B-290TB microscope) was used to identify, count, and take pictures of every MP extracted from the collected surface water of the KE. Based on shape, MPs were classified as *fiber*, *fragments*, and *foams* after being examined for color and size. With variation in lengths, they were further divided into five classes: < 1 mm, 1.0-2.0 mm, 2.1-3.0 mm, 3.1-4.0 mm, and 4.1-5.0 mm. A µ-Fourier Transform Infrared Spectrometer (µ-FTIR) (Perkin-Elmer instruments, STA) with Attenuated Total Refletance (ATR) was used to identify various polymers as MPs with a wavenumber range of 500-4000 cm^{-1} at room temperature (300 K).

Quality Control

All sampling instruments and filter meshes were thoroughly rinsed with deionized water (DI) before use to minimize contamination. During collection, surface water was immediately covered and placed in sealed airtight bottles for safe transport. In the laboratory, non-plastic attire, including lab coats, gloves, and head covers, was worn at all times. Workspace was carefully cleaned prior to analyses, and all analytical instruments were cleaned and covered before and after use. To assess potential air contamination, a laboratory blank test was conducted using 500 mL of DI water treated in the same manner as field samples. No plastic particles were detected on the blank filters, indicating that contamination from laboratory air, containers, or sample processing was negligible[17,18].

Risk Assessment

PLI is an integrated approach to determine the overall level of contamination in an environment, typically for heavy metals, but also applied to MPs in recent studies. It is calculated using CF for individual pollutants to provide a single value representing the cumulative impact of pollution[19]. Risk category for CF is classified as: < 1 (*low*), 1-3 (*moderate*), 3-6 (*considerable*), ≥ 6 (*very high*), or contamination. However, PLI is categorized into two classes, PLI < 1 and PLI > 1, indicating no contamination and contamination, respectively[19,20,21]. PHI is a metric used to evaluate the potential ecological harm caused by a specific type of MP based on its intrinsic chemical toxicity[22], classified as risk category: I (< 10), II (10-100), III (101-1000), IV (1001-10,000), and V (> 10,000). However, hazard score for HD/LD-polyethylene (PE) = 11, polystyrene (PS) = 30, nylon = 47, acrylonitrile butadiene styrene (ABS) = 6552, ethylene vinyl acetate (EVA) = 22, and acrylic (PMMA) = 1021[21], while other polymers were not available during the study period. Additionally, PRI is a more comprehensive assessment tool that incorporates the PHI to provide an overall risk score for an entire site or ecosystem[20]. This is classified as: < 150 (*low*), 150-300 (*medium*), 300-600 (*considerable*), 600-1200 (*high*), and > 1200 (*very high*)[20].

Land Use and Land Cover Pattern

By integrating the ESA World Cover 10 m product[30] with monthly VIIRS Day/Night Band (DNB) radiance composites, a high-resolution, functionally detailed Land Use and Land Cover (LULC) map can be generated. While traditional land cover models frequently struggle to distinguish between different types of urban density, night time data can be used to divide the landscape into eight categories: vegetation, water body, bare soil, suburban, mixed built-up, commercial built-up, high commercial built-up, and residential area. A more advanced feature of this approach includes exploiting high-radiance light signatures as a main signal for logistics hubs, allowing to properly separation and detection of extensive port operations and airport activities that are often concealed in standard optical images. The resulting categorization is a steady, accurate depiction of functional urban pattern of the region by carefully monitoring cloud-free coverage.

III. Results and Discussion

Visual Identification of Microplastics

Presence of MPs in the collected surface water was identified through length, color, and shape using the above-mentioned microscope (Fig. 2). Average lengths of MPs were recorded as 0.78, 0.88, 1.23, 0.93, 0.97, 0.92, 1.39, 0.86, and 0.94 mm in stations 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10, respectively, with 65 % of the MPs measuring < 1 mm[23].

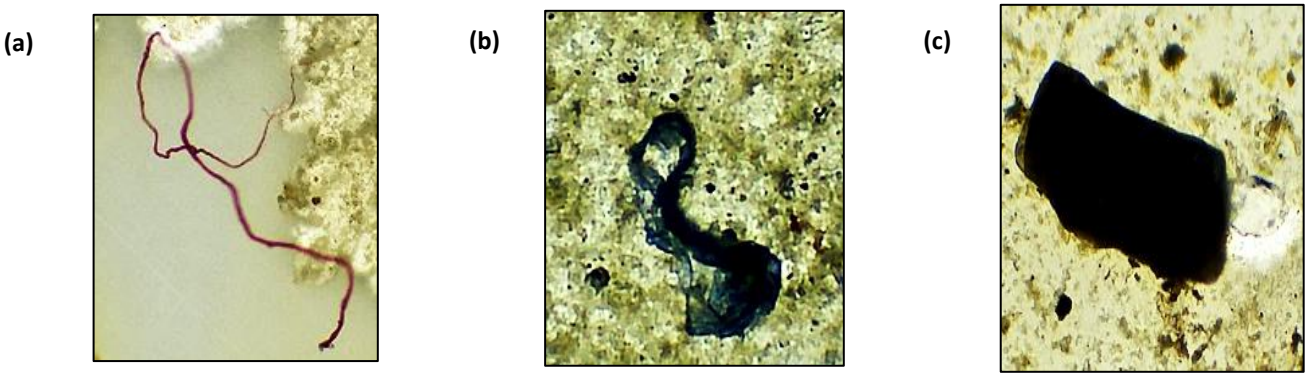


Fig. 2. Microscopic images of obtained MPs with different shapes and colors in surface water of the KE: (a) *fiber* in *red* color; (b) *fragment* in *blue* color; and (c) *foam* in *black* color.

Five colors of MPs were observed under microscopic examination: *black* (39 %), *green* (3 %), *red* (18 %), *blue* (18 %), and *transparent* (22 %). Among the three shapes of MPs observed, *fibers* were dominant, accounting for 86 % of the total MPs (Fig.3).

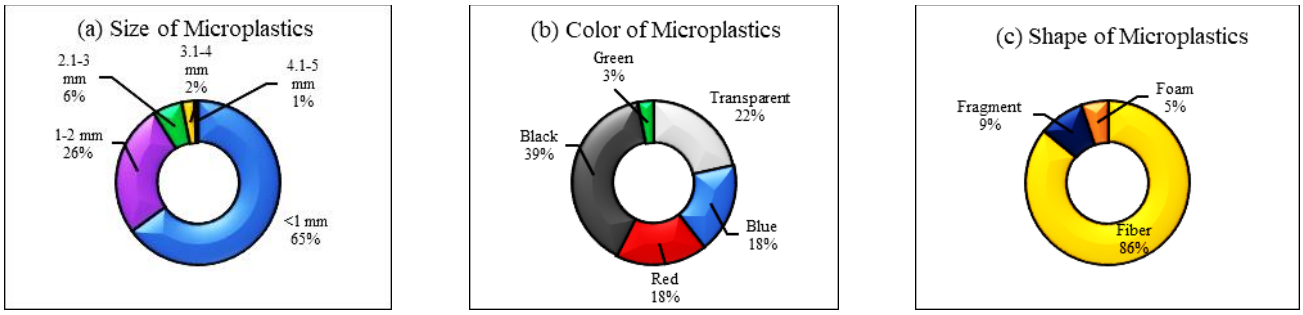


Fig. 3. Total percentage of observed MPs with (a) size, (b) color, and (c) shapes in the collected surface water of the KE.

Confirmation of Polymers as Microplastics

Different types of polymers were observed as MPs using ATR-FTIR analyses, including EVA, nylon, PS, ABS, PMMA, and PE[21,22], with specific bands in different wavenumbers for each type of polymer (Fig. 4), and the characteristic spectroscopic bands are listed in Table 1 to determine the polymer types in the collected surface water from the KE.

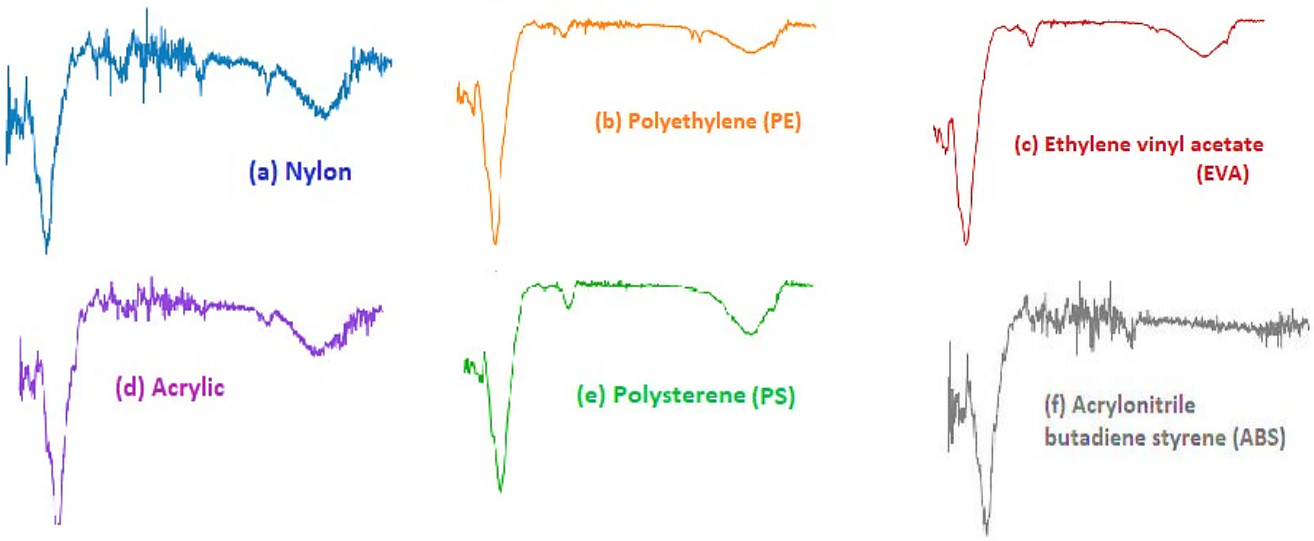
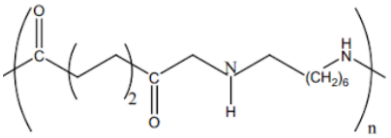
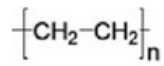
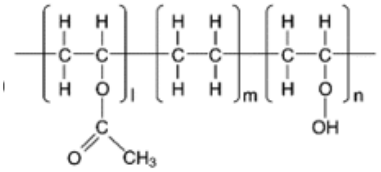
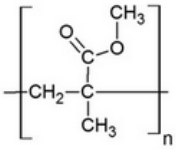
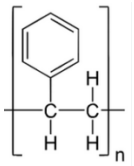
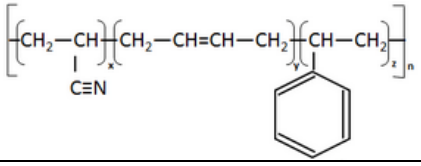


Fig. 4. ATR-FTIR spectrum of extracted MPs in surface water of the KE, characterized as (a) Nylon, (b) PE (c) EVA (d) Acrylic (e) PS and (f) ABS

Table 1. Characterized polymers as MPs in the collected surface water through reference spectroscopic bands of FTIR analysis

Name of Polymer	Respective Band (cm^{-1})	Respective Chemical Composition[26, 27, 28, 29]	Structure
Nylon	771; 1248; 1626; 2922; 3534	-NH bending, C=O bending; CH_2 bending; C=O stretching; CH stretching; N-H stretching	
PE	695; 909; 1463; 2848; 2916	CH_2 rocking; CH_2 rocking; CH_2 bending; C-H stretching; C-H stretching	
EVA	779; 997; 2848; 2924	CH_2 rocking; C-O stretching; C-H stretching; C-H stretching	
Acrylic	795; 910; 1245; 1332; 1435; 1631; 2957; 3459	CH_2 rocking, C=O bending; C-H bending; C-O stretching; CH_2 bending; CH_2 bending; C=O stretching; C-H stretching; C-H stretching	
PS	691; 1166; 1419; 1639	Aromatic CH out-of-plane bending; Aromatic CH bending; CH_2 bending; Aromatic ring stretch	
ABS	695; 1166; 1419; 1639	=CH bending; =C-H bending; Aromatic CH bending; CH_2 bending; Aromatic ring stretching	

Percent Distribution of Length, Color, and Shape of Microplastics

Across all stations, MPs (< 1 mm) were the most dominant size fraction, contributing between 42 % (St.7) and over 83 % (St.1) of total MPs. 1-2 mm category was the 2nd most common, with notable shares at St.3 (41 %), St.6 (43 %), and St.7 (42 %). Larger particles (> 2 mm) were comparatively rare, generally accounting for < 10 % at most stations, with occasional peaks such as 10 % at St.10. Overall, results indicate a strong dominance of small-sized MPs (< 1 mm), suggesting extensive fragmentation and higher potential bioavailability in the KE (Fig.5 (a)). In addition, *black*-colored MPs were the most dominant across most stations, ranging from about 23 % (St. 1) to over 55 % (St.4 and St.5). *Transparent* color was also abundant, particularly at St.3 (37 %), St.9 (36 %), and St.10 (38 %). *Blue* MPs showed notable contributions at St.1 (35 %), St.7 (30 %), and St.9 (27 %), while *red* MPs were highly concentrated at St.2 (22 %), St.3 (37 %), and St.8 (28 %), since they were absent in several stations. *Green* MPs were consistently the least common, rarely exceeding 5 %, except for St.6 (29 %). Overall, the results indicate a strong prevalence of *black* MPs across stations, with *transparent* and *blue* also widespread, while *green* remains negligible (Fig.5 (b)).

Spatial Distribution of Microplastics in the Karnaphuli Estuary

Concentration of Microplastics

Spatial distribution of MPs in surface water of the KE showed clear variations in concentration and shape across the sampling stations (Fig. 6). Elevated abundances were observed downstream[20], likely due to industrial and urban wastewater, agricultural runoff, and untreated sewage, amplified by higher population density and larger catchment areas. The highest abundance of MP was recorded at St.8 (102 items/L), St.2 (80 items/L), and St.4 (71 items/L), marking these as major hotspots influenced by dense human and industrial activity. Moderate concentrations appeared at St. 10 (59 items/L), St.7 (43 items/L), and St.3 (32 items/L), while lower levels were found at St.5 (25 items/L) and St.1 (18 items/L). The least contaminated stations were St.9 (11 items/L) and St.6 (7

items/L), highlighting the uneven distribution of MPs across the KE[23]. Overall, the abundance of obtained MPs followed a descending order of St.8 > St.2 > St.4 > St.10 > St.7 > St.3 > St.5 > St.1 > St.9 > St.6 in the surface water of the KE (Fig.6 (a)).

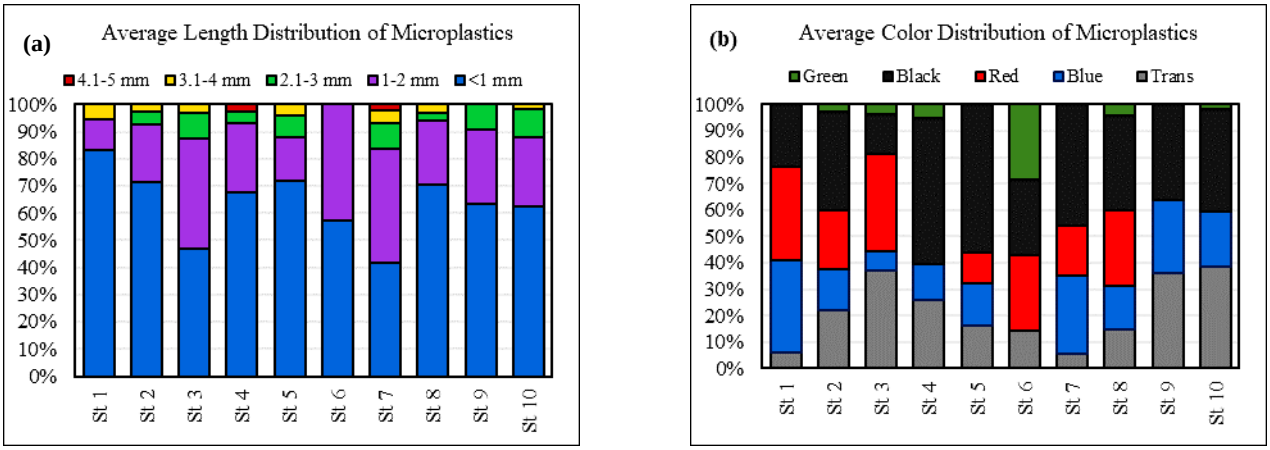


Fig. 5. Average (a) length and (b) color distribution of MPs in the collected surface water of the KE.

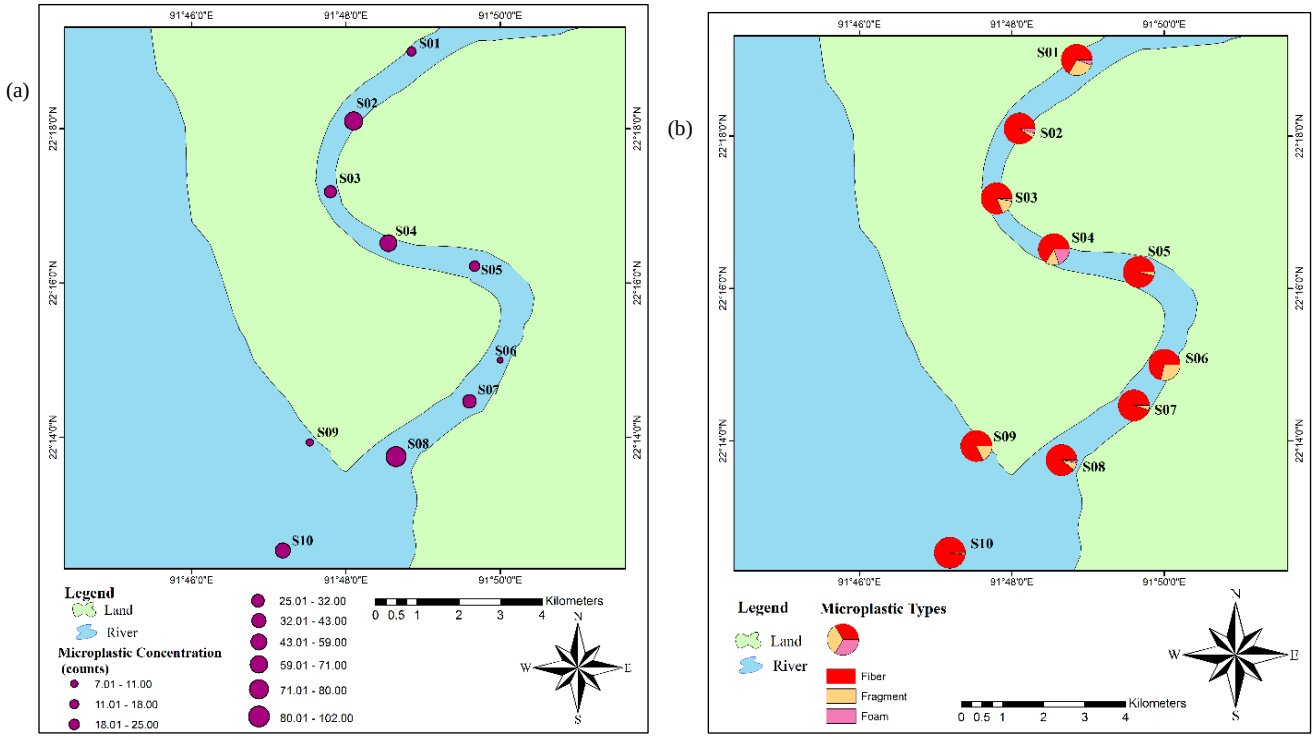


Fig. 6. Spatial distribution of (a) concentration and (b) shapes of MPs in surface water of the KE.

Shapes of Microplastics

In terms of shapes, samples collected from all stations were dominated with *fibers*, comprising the majority of MPs (Fig.6 (b)), where the highest abundance of *fiber* were observed at St.8 (91 items/L), St.2 (72 items/L), and St.10 (58 items/L), as well as St.6 (5 items/L) and St.9 (9 items/L) had the lowest quantity. *Fragments* were present in smaller quantities, peaking at St.4 (10 items/L) and St.3 (5 items/L), while *foam* was the least common, appearing mainly at St.4 (14 items/L), St.2 (4 items/L), and St.8 (3 items/L), and was absent at several stations. These patterns indicate that *fibers* were the primary type of MP throughout the KE, while *foam* was highly localized, suggesting different sources and transport pathways. Results emphasize that MP pollution was concentrated near densely populated and industrially active areas, highlighting the influence of anthropogenic activities on estuarine contamination[20, 25].

Evaluation of Microplastics Contamination

Contamination Factor and Pollution Load Index

Calculated CF of MP indicated that all sampling locations in the KE had "*moderate*" to "*very high*" contamination. Overall, the pollution status of the KE was considerably polluted with MPs ($3 \leq CF < 6$) (Fig.7). However, CF followed the decreasing sequence of contamination: St.8 > St.2 > St.4 > St.10 > St.7 > St.3 > St.5 > St.1 > St.9. MP contamination in surface water is undesirable because it can accumulate in fish and other species, having negative impacts[20]. However, the overall PLI was 4.74 (> 1), indicating MPs pollution for all surface water in the KE.

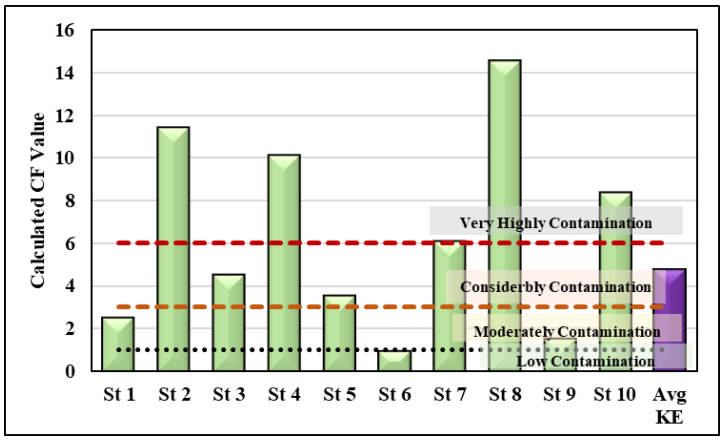


Fig. 7. Level of contamination based on the abundance of MP in the surface water of the KE.

Polymer Hazard Index

PHI values for the ten stations and their average reveal significant variations in potential hazard levels were shown in Fig.8. A few stations (St.1, St.6, and St.9) showed *category III* hazard levels, most notably St.6. However, St.1 and St.9 also had HI values that place them in the *high* hazard *category II*. In contrast, St.8 recorded the lowest HI value, falling below the *category I* threshold, suggesting a very low hazard. Remaining stations (St.2, St.3, St.4, St.5, St.7, and St.10) had HI values that place them in a *moderate* hazard range (*category II*)[20]. Average HI value was 41.84 (*moderate* range), heavily skewed by the exceptionally high values from a few stations, particularly St.6. Possible reasons for this variation could include proximity to pollution sources like industrial sites or heavy traffic, local environmental factors that trap pollutants, or even differing meteorological conditions that influence pollutant dispersion[14].

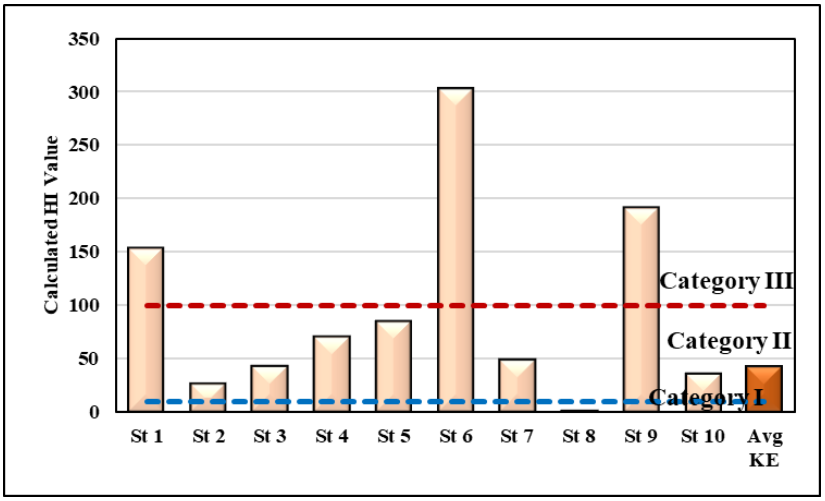


Fig. 8. Polymer hazard scenario of estimated MPs found in the surface water of the KE.

Potential Risk Index

Fig.9 indicates a wide range of contamination across the 10 stations for PRI, and the majority of stations (St.1, St.2, St.5, St.6, St.7, St.9, and St.10) were in the *marginal* to *considerable* risk category, while St.3 was at a "*medium risk*" level. St.4 was a significant outlier, suggesting a major

localized pollution source[14]. In contrast, St.8 showed a near-zero value of PRI, indicating minimal contamination. Average PRI of the KE, at ~180, falls into the "*medium risk*" category, may be of industrial discharge, as suggested by the extreme value at St.4; agricultural runoff from fertilizers and pesticides; and untreated urban wastewater. The difference between St.4 and St.8 may also be attributed to their proximity to pollution sources, with St.8 likely being located far from any such activities, while the other stations were likely subject to a mix of these contamination factors[20].

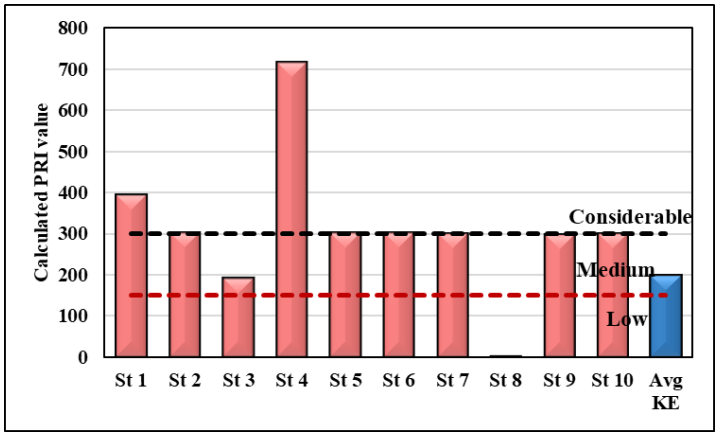


Fig. 9. Ecological risk due to the presence of MPs in the surface water of the KE.

Analysis of Land Use and Land Cover

By correlating the 10-meter physical land cover derived from Sentinel-1 and Sentinel-2 with monthly average radiance values, classified the region was classified into eight distinct categories: vegetation (38.28 %), water body (37.22 %), residential area (14.23 %), mixed built-up (6.17 %), bare soil (3.21 %), commercial built-up (0.64 %), high commercial built-up (0.06 %), and sub urban (0.20%). The spatial distribution of these land covers directly informs the significant variations in pollution due to abundance of MPs observed across the ten sampling stations. For instance, the presence of high commercial built-up and residential areas near St.2 and St.4 likely contributes to their "*very high*" CF and significant PRI, with St. 4 appearing as a major outlier due to localized industrial or port-related discharge. Conversely, the high percentage of vegetation and water bodies surrounding St.8 correlates with it's *near-zero* PRI and *very low* hazard levels, as it is situated furthest from dense urban activities. Overall, the dominance of human-influenced categories like mixed built-up and commercial zones supports the *average* PLI of 4.74 (> 1) and a "*medium risk*" PRI of ~180, suggesting that MP contamination in the KE is driven by a complex mix of untreated urban wastewater and industrial runoff.

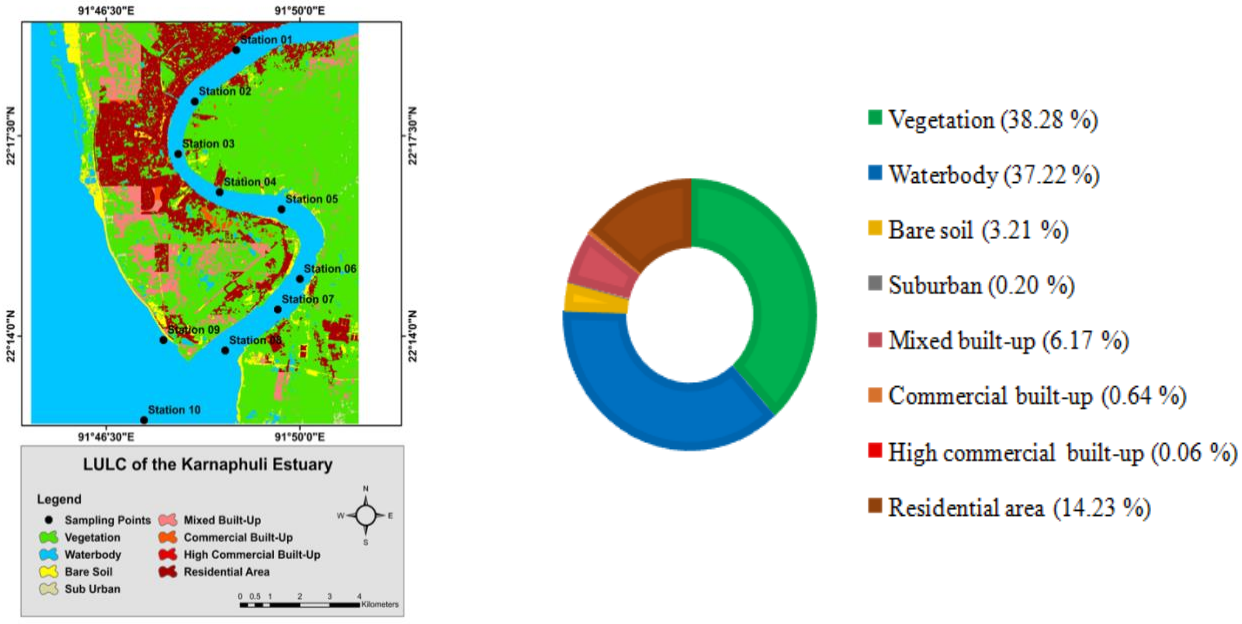


Fig. 10. LULC pattern in the KE (left) and the percentage of area (right) of LULC in the KE.

IV. Limitations of the Study

This study has various limitations that should be acknowledged in order to contextualize the findings and lead future research. Sampling is limited to the dry season; it does not account for seasonal fluctuations such as greater MP levels during monsoon runoff and flooding, which could increase pollution input. Additionally, the lack of advanced techniques like Scanning Electron Microscopy with Energy Dispersive X-ray (SEM/EDX) analysis reduced insights into MP surface morphology, weathering signs, and elemental composition, which could have better shown degradation and contamination paths.

V. Conclusions

Estuaries are essential environments for understanding how MPs are transported from land-based sources to the ocean. Since very few studies have been carried out on MP contamination, this study, in the surface water of the KE, had an abundance of MPs, and the levels of MPs increased progressively as the estuary approached its mouth. In the KE, MPs were found in larger numbers of < 1 mm, fiber-shaped, which is attributed to inputs from industrial effluents, domestic wastewater, and fishing activities. *Black* and *transparent* MPs were the most prevalent colors, while spatial variations in MP concentration and shape were observed, with the highest abundance recorded at St.8, located downstream. EVA, nylon, PS, ABS, acrylic, and PE were the identified polymers as MPs throughout the estuary. All stations along riverbanks were contaminated with MPs and constituted serious ecological hazards, according to the contaminated indices, including CF, PLI, PHI, and PRI. Overall contamination status of the KE is "*considerable*" to "*moderate*", where all station poses PLI > 1. Thus, it can be concluded from this study that untreated industrial discharges, wastewaters from densely populated areas, and the hydrodynamics of the river play critical roles in the transport and deposition of MPs which is confirmed by LULC analysis around KE. Addressing this pollution requires improved wastewater treatment systems, stricter regulation of industrial discharges, and enhanced public awareness about the environmental impacts of MPs.

Acknowledgement

This research was performed under the thesis of M.Sc. in Oceanography. Additionally, the authors appreciate the University Grant Commission (UGC), Post Graduate Research Management and Technology Transfer Centre (PRMTTC), Chemical Oceanography Lab of Bangladesh Maritime University for arranging this type of research opportunity. Special thanks to Dr. Ferdousi Begum and Farhana Akter for supervising this work. The author extends her gratitude to Mohammad Mahabubur Rahman from the Fiber and Polymer Research Division, Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka, for the identification of polymers.

References

1. Thompson, R. C., C. J., Moore, F. S., vom Saal, and S. H. Swan, 2009. Plastics, the environment and human health: Current consensus and future trends. Philos Trans R Soc Lond B Biol Sci. 364 (1526), 2153–2166. https://doi.org/10.1098/rstb.2009.0053.
2. Andrady, A. L. 2011. Microplastics in the marine environment. Marine Pollution Bulletin 62(8), 1596-1605. https://doi.org/10.1016/j.marpolbul.2011.05.030
3. Barrows, A. P. W., S. E., Cathey, and C. W. Petersen, 2018. Marine environment microfiber contamination: Global patterns and the diversity of microparticle origins. Environmental Pollution, 237, 275-284.https://doi.org/10.1016/j.envpol.2018.02.062.
4. Huang, L., Z., Shoufeng L., Lingyun Z., Siyu, W., Juying, L, Xiaoxing, and Z. Weiwei, 2023. Research progress on microplastics pollution in polar oceans. Polar Science, 36, 100946. https://doi.org/10.1016/j.polar.2023.100946.
5. Bergmann, M., W., Vanessa, K., Thomas, L., Claudia, P., Sebastian, B. T., Mine, and G. Gunnar, 2017. High quantities of microplastic in Arctic deep-sea sediments from the HAUSGARTEN observatory. Environmental Science and Technology, 51(19), 11000-11010. https://doi.org/10.1021/acs.est.7b03331.
6. Pakhomova, S. V., B., Anfisa, Z., Igor, and Y.Evgeniy, 2024. Microplastic fate in Arctic coastal waters: accumulation hotspots and role of rivers in Svalbard. Frontiers in Marine Science, 11, 1-13. https://doi.org/10.3389/fmars.2024.1392680.
7. Rochman, C. M., E., Hoh, T., Kurobe, and S. J. Teh, 2013. Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. Scientific Reports, 3, 1-7. https://doi.org/10.1038/srep03263.
8. Tasnim, J., M. K., Ahmed, K. B., Hossain, and M. S. Islam, 2023. Spatiotemporal distribution of microplastic debris in the surface beach sediment of the southeastern coast of Bangladesh. Heliyon, 9, e21864. https://doi.org/10.1016/j.heliyon.2023.e21864.
9. Chelsea, M. R. L. A., Anthony, D., Sarah, F., Joan, 2016 Sources, fate and effects of microplastics in the marine environment: part 2 of a global assessment. (IMO, FAO/UNESCOIOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP), In Rep. Stud. GESAMP No. 90, Reports and Studies GESAMP, 93, 93-96.
10. Bhuyan, M. S., A. H., Nayan, S., Chowdhury, S. Chowdhry, U. M. B., Mondal, M. A. I., Islam, M. T., Karim, S. M. R, G., Meraj, and M.Y. Abouleish, 2025. Microplastics contamination in freshwater and marine ecosystems, its impacts, and sustainable mitigation pathways in Bangladesh: a systematic review. Discover Toxicology, 2(14), 1-16. https://doi.org/10.1007/s44339-025-00034-w.
11. Carpenter, E. J., S. J., Anderson, H. P, Harvey, B. B., Miklas, and Peck. 1972. Polystyrene spherules in coastal waters, Science, 178, 4062, 749-750. https://doi.org/10.1126/science.178.4062.749.
12. Eriksen, M., L. C. M., Lebreton, H. S., Carson, M., Thiel, C. J., Moore, J. C., Borerro, F., Galgani, P. G., Ryan, and J.

Reisser, 2014. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea, PLoS One, 9, 1–15, https://doi.org/10.1371/journal.pone.0111913.

13. Ghosh, S., J.K., Sinha, S., Ghosh, K., Vashisth, S., Han, and R. Bhaskar, 2023. Microplastics as an emerging threat to the global environment and human health. Sustainability, 15, 10821. https://doi.org/10.3390/su151410821.

14. Cao, L., W., Chen, Y., Li, S., Wang, Z., Jin, J., Li, Q., Bian, and M. Li, 2023. Temporal and spatial distribution characteristics of microplastics and their influencing factors Processes, 11, 1136. https://doi.org/10.3390/pr11041136.

15. Hossain, M. S., A. S. M., Saifullah, M. J. Uddin, and M. H., Rahaman, 2024. Assessment of microplastics in coastal ecosystem of Bangladesh. Ecotoxicology and Environmental Safety, 281,116622.https://doi.org/10.1016/j.ecoenv.2024.116622.

16. Masura, J., J. E., Baker, Foster, D., Gregory Arthur, et al. 2015. Laboratory methods for the analysis of microplastics in the marine environment: recommendations for quantifying synthetic particles in waters and sediments.NOAA technical memorandum NOS-OR&R48, https://repository.library.noaa.gov/view/noaa/10296.

17. Peng, B., K. B. Y. Hossain, M. Lin, H. Zhang, J. Zheng, X. Yu, J. Meng, Y. Wang, B. Cui, L. Wu, Lou, and M. Cai. 2022. Assessment and sources identification of microplastics, PAHs and OCPs in the Luoyuan Bay, China: based on multi-statistical analysis. Marine Pollution Bulletin, 175, 113351. https://doi.org/10.1016/j.marpolbul.2022.113351

18. Cai, M., He, H., M. Liu, S. Li, G. W. Tang, P. Wang, Huang, G. Wei, Y. Lin, B. Chen, J. Hu, and Z. Cen. 2018. Lost but can't be neglected: huge quantities of small microplastics hide in the South China Sea. Science of the Total Environment, 633, 1206-1216, https://doi.org/10.1016/j.scitotenv.2018.03.197

19. Tomlinson, D. L., J. G., Wilson, C. R. Harris, et al. 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. Environmental Evaluation, 33, 566-575. https://doi.org/10.1007/BF02414780.

20. Rakib, M. R. J., M. B., Hossain, R. Kumar, et al. 2022. Spatial distribution and risk assessments due to the microplastics pollution in sediments of Karnaphuli River Estuary, Bangladesh. Science Report, 12, 8581. https://doi.org/10.1038/s41598-022-12296-0.

21. Lithner, D., A., Larsson, and G. Dave 2011. Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. Science of the Total Environment, 409(18), 3309-24. https://doi.org/10.1016/j.scitotenv.2011.04.038.

22. Xu, Pei, Guyu Peng, Lei Su, Yongqiang Gao, Lei Gao, and Daoji Li. 2018. Microplastic risk assessment in surface aaters: a case study in the Changjiang Estuary, China. Marine Pollution Bulletin, 133, 647–654. https://doi.org.10.1016/j.marpolbul.2018.06.020.

23. Lorenz, C., R., Lisa, S. M., Melanie, H., Lars, P., Julia, G. J. L., Martin, P., Sebastian, and G., Gunnar 2019. Spatial distribution of microplastics in sediments and surface waters of the southern North Sea. Environmental Pollution, 252, 1719-1729.https://doi.org/10.1016/j.envpol.2019.06.093.

24. Melissa, R. J., F. H., David, V. O., Sara, R. C., Viviana, et al. 2018. Validation of ATR FT-IR to identify polymers of plastic marine debris, including those ingested by marine organisms, Marine Pollution Bulletin, 127 704-716. https://doi.org/10.1016/j.marpolbul.2017.12.061.

25. Kelly, N. E. 2024. Spatial distribution and risk assessment of microplastics in surface waters of the St. Lawrence Estuary. Science of the Total Environment, 946, 174324.https://doi.org/10.1016/j.scitotenv.2024.174324.

26. Noda, I, A. E., Dowrey, C., Marcott, J. L. Haynes, and C., Marcott, 2007. Group Frequency Assignments for Major Infrared Bands Observed in Common Synthetic Polymers BT -Physical Properties of Polymers Handbook. New York, 395–406.

27. Beltrán, M., and A. Marcilla. 1997. Fourier Transform Infrared Spectroscopy applied to the study of PVC decomposition. European Polymer Journal, 33 (7): 1135–42. https://doi.org/10.1016/S0014-3057(97)00001-3

28. Jung, Melissa R., F. David Horgen, V. Sara Orski, Viviana C., Rodriguez Kathryn L. Beers, H. George T. Balazs, Todd Jones, et al. 2018. Validation of ATR FT-IR to identify polymers of plastic marine debris, including those ingested by marine organisms. Marine Pollution Bulletin, 127 (November 2017): 704–16. https://doi.org/10.1016/j.marpolbul.2017.12.061.

29. Veerasingam, S., M., Ranjani, R. Venkatachalapathy, et al. 2020. Contributions of Fourier Transform Infrared spectroscopy in microplastic pollution research: A review. Critical review in Environmental Science and Technology, 51(1), 1-63. https://doi.org/10.1080/10643389.2020.1807450

30. Zanaga, D., De Van R., Kerchove, D., Daems, De W., Keersmaecker, C., Brockmann, G., Kirches, J., Wevers, O., Cartus, M., Santoro, S., Fritz, M., Lesiv, M., Herold, N.E., Tsendbazar, P., Xu, F., Ramoino, O., Arino, 2022. ESA World Cover 10 m 2021 v200. https://doi.org/10.5281/zenodo.7254221.