INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 25, No. 2, p. 85-97, 2024
http://www.innspub.net

RESEARCH PAPER

OPEN ACCESS

Abundance, seasonal variations and polymer analysis of microplastics in Mahim Bay waters, Mumbai, India

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Article published on August 06, 2024

Key words: Microplastics, Mahim Bay, Seasonal dynamics, Abundance, Polymer types, Pollution, Marine ecosystems

Abstract

Microplastic pollution is a growing environmental concern globally, with potential implications for marine ecosystems and human health. This study investigates the seasonal dynamics, abundance, polymer types, and potential sources of microplastics in Mahim Bay, Mumbai, India. Water samples were collected from six locations across Mahim Bay during the pre-monsoon, monsoon, and post-monsoon seasons. Analysis revealed significant microplastic contamination in Mahim Bay, with the highest abundance observed during the monsoon season. Blue, black, and green were the dominant colors of microplastics, with fibers being the most prevalent shape. Polyethylene (PE), polypropylene (PP), and polystyrene (PS) were the predominant polymer types identified. The study highlights spatial and temporal variations in microplastic contamination, emphasizing the need for comprehensive monitoring and management strategies to address plastic pollution in coastal environments.

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Introduction

Plastic pollution has emerged as a major environmental concern globally, with microplastics-plastic particles smaller than 5 mm in size garnering significant attention due to their ubiquitous presence and potential adverse effects on ecosystems and human health (Andrady, 2011; Kye *et al.,* 2023; Pothiraj *et al.,* 2023). Microplastics can originate from the breakdown of larger plastic debris or be manufactured for specific applications, such as in personal care products and industrial abrasives (da Costa *et al.,* 2017; Hale *et al.,* 2020). These tiny particles have been found in various environmental matrices, including marine and freshwater bodies, soils, and even the atmosphere (Wang *et al.,* 2021; Xiang *et al.,* 2022; Kurniawan *et al.,* 2023; Eze *et al.,* 2024). Their small size and persistence in the environment make them bioavailable to a wide range of organisms, raising concerns about their potential to accumulate and transfer through food webs (Saikumar *et al.,* 2024; Saeedi, 2024). Coastal and marine environments are particularly vulnerable to microplastic pollution due to their proximity to urban centers and the influx of plastic waste from land-based sources (Alimba and Faggio, 2019; Horton and Barnes, 2020). Microplastics can have detrimental effects on marine life, such as physical ingestion, entanglement, and the potential for chemical transfer of additives or adsorbed pollutants (Fred-Ahmadu *et al.,* 2020; Menéndez-Pedriza and Jaumot, 2020; Arienzo *et al.,* 2021).

In India, the coastal regions face significant challenges related to plastic pollution, with a lack of comprehensive waste management strategies and inadequate infrastructure contributing to the problem (Vanapalli *et al.,* 2021; Sunitha *et al.,* 2021; Hossain *et al.,* 2022). Mahim Bay, located in Mumbai, Maharashtra, India, stands as a significant coastal region along the Arabian Sea coast, marking a notable feature in the city's landscape (Noble and Keesari, 2021). Extending from Bandra to Worli, it encompasses Mahim Creek, where the Mithi River converges with the sea (Varshney *et al.,* 1995). Surrounded by densely populated urban zones, the bay exhibits a blend of natural and human-made elements. Renowned for its rich marine biodiversity, including mangroves, tidal areas, and sandy shores, Mahim Bay holds cultural and historical importance with landmarks like Mahim Fort and the Bandra-Worli Sea Link nearby (Singare and Ferns, 2014). Serving as a pivotal economic hub for fishing, maritime trade, and tourism, it faces environmental threats such as pollution, habitat loss, and shoreline erosion (Singare *et al.,* 2014; Sapkale *et al.,* 2018).

This study aims to fill this knowledge gap by investigating the seasonal dynamics of microplastic abundance, characterizing the polymer types, and evaluating the potential sources and pathways of microplastics in Mahim Bay waters. The findings of this research will contribute to the development of effective monitoring and mitigation strategies for microplastic pollution in coastal regions of India.

Materials and methods

Study area

The study area, Mahim Bay, constitutes a significant semi-enclosed segment of the Arabian Sea located in Mumbai, Maharashtra (Varshney *et al.,* 1995). It stretches from Bandra reclamation in the north to Worli in the south, with Mahim Creek serving as its narrow opening, where the Mithi River converges. Positioned within a semi-circle in the central region are Mahim Beach, Dadar Beach, and Prabhadevi Beach (Singare and Ferns, 2014). Six sampling locations were chosen within Mahim Bay for the evaluation of microplastic types and quantities within the water samples. Spot A- Opening of Mithi (19.048466° N, 72.835726° E), Spot B- Mahim Beach (19.043469° N, 72.838022° E), Spot C- Dadar Beach (19.0208° N, 72.8293° E), Spot D- Prabhadevi Beach(19.0181° N, 72.8249° E), Spot E- Worli Jetty(19.0261° N, 72.8155° E) and Spot F- Bandra Reclamation (19.042689° N, 72.821024° E) as shown in (Fig. 1).

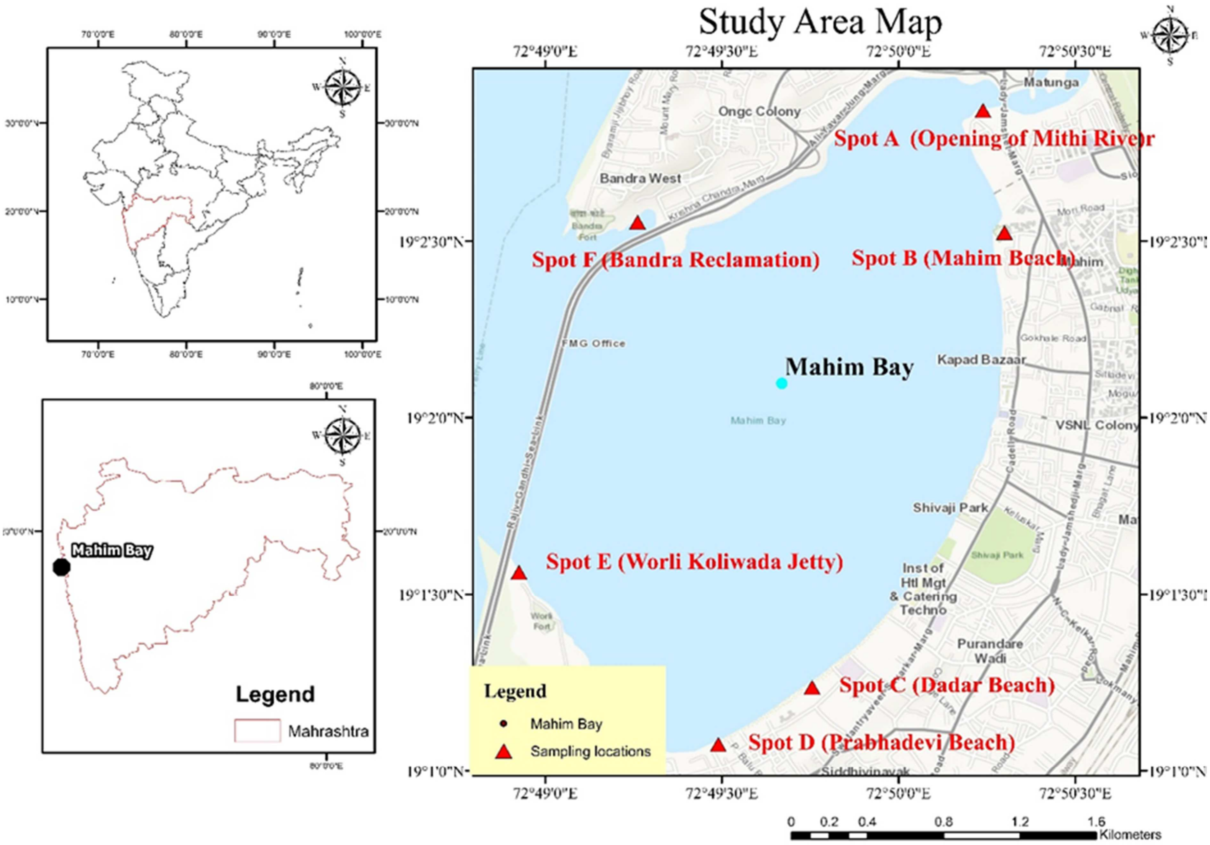


Fig. 1. Map of study area showing sampling spots along Mahim Bay

Sample collection and processing

Before collecting samples, all sampling tools and containers underwent a thorough cleaning process using ultrapure water and were securely sealed. Throughout the sampling procedure, we adhered to strict safety protocols, donning nitrile gloves and cotton clothing. Water samples were manually collected from six specified stations, covering the pre-monsoon, monsoon, and post-monsoon periods, preferably during low tide. These samples were gathered in sterile containers and subsequently filtered. Microplastics (MPs) were then isolated using a density separation method, as described by Goswami *et al.* (2020). To remove organic matter from the MPs, a solution containing 30% hydrogen peroxide (H_2O_2) was used and was filtered using Whatman filter paper (47mm) through vacuum filtration. The filtrate was then dried and stored in petri plates for further analysis to identify various types of microplastics. Furthermore, to prevent airborne or artificial plastic pollution in the laboratory, all containers and instruments were thoroughly rinsed with ultrapure water (Mao *et al.*, 2021), and tinfoil paper was utilized during the experiment to minimize external contamination.

Microscopic and polymer analysis using (FTIR)

Microscopic analysis and polymer identification using Fourier Transform Infrared (FTIR) spectroscopy were meticulously conducted following a rigorous protocol (Renner *et al.*, 2019). Microplastics were observed and classified using a NIKON SMZ25 stereomicroscope, with particular attention paid to morphological structures, colors, and sizes, in accordance with established methodologies (Yu *et al.*, 2019; Chen *et al.*, 2020). The categorization of microplastic particles on basis of morphological structure included fragments, fibers, films, pellets, and foam, while colors such as black, blue, transparent, white, red, and silver were noted during classification. The FTIR analysis protocol utilized a Spectrum instrument equipped with a model Spectrum 2 (serial number-87109), featuring a Mid-Infrared (MIR) TGS detector and MIR source incorporating an OptKBr beamsplitter. Operational parameters were meticulously set with a resolution of 8 and a strong apodization function applied. The spectrum employed a ratio beam type with phase correction implemented in magnitude. A scan speed of 0.2 was established, utilizing a double IGram type with scanning direction denoted as combined, and zero crossings maintained at 0. An IR-Laser wavenumber of 11750.00 was applied with a JStop value of 8.94.

The sample base plate employed was a diamond Universal Attenuated Total Reflectance (UATR) accessory, exerting a force of 98 N and operating within a default scan range of 4000 to 450 cm-1. The ATR crystal combination specified was diamond with a single bounce configuration, although the specific UATR option remained unspecified. This methodological framework ensured a comprehensive and systematic approach for polymer identification through FTIR spectroscopic analysis, guaranteeing robust and scientifically sound outcomes (Veerasingam *et al.,* 2021; Rathore *et al.,* 2023).

Results

Pre-monsoon

Abundance

In the present study, the analysis of water samples collected from Mahim Bay has yielded distinct concentrations of microplastics (MPs) across varying seasonal periods. During the pre-monsoon season, the analysis revealed an average concentration of 861.33 ± 273.12 (Mean ± SD, n=6) per litre. During the pre-monsoon period, the investigation of microplastic abundance along the Mumbai coastline unveiled distinct patterns across the sampled locations. At the opening of the Mithi River (SPOT A), the mean microplastic concentration was determined to be 235.6 microplastic items per litre exhibiting variations from 230 to 242 MPs/litre. Mahim Beach (SPOT B) showcased an average concentration of 205.2 MPs/litre, with a range spanning from 192 to 220 MPs/litre. Dadar Beach (SPOT C) demonstrated a mean concentration of 198 mps/litre, fluctuating between 192 and 206 MPs/litre. Prabhadevi Beach (SPOT D) exhibited an average of 171.6 MPs/litre, with values oscillating between 166 and 178 MPs/litre. Worli Koliwada Jetty (SPOT E) displayed an average concentration of 141.6 mps/litre, varying from 138 to 146 mps/litre. Bandra Reclamation (SPOT F) registered the lowest mean concentration at 81.6 mps/litre, with levels spanning between 72 and 88 mps/litre (Fig. 2). These observations underscore the spatial heterogeneity in microplastic abundance during the pre-monsoon period, indicative of diverse environmental influences and anthropogenic activities along the Mumbai coastline.

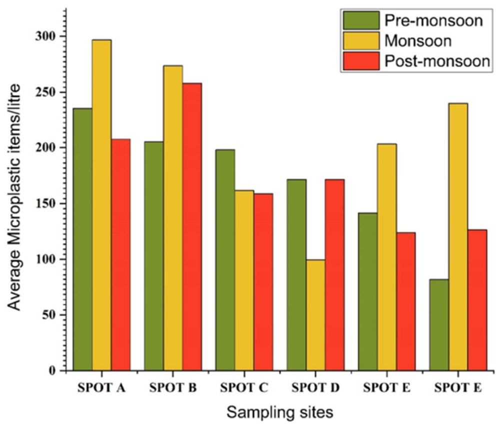


Fig. 2. Average microplastics items per litre across three seasons

Color and shape distribution

During the pre-monsoon period, our investigation into the color and shape distribution of microplastics at various locations along the Mumbai coastline unveiled intriguing patterns. At the opening of the Mithi River (SPOT A), black microplastics accounted for approximately 58.8% of the total, followed by blue microplastics at 28.2%. The predominant shapes were fragments (48.8%) and fibers (36.8%). Mahim Beach (SPOT B) exhibited a similar trend, with black microplastics comprising around 52.5% and blue microplastics around 34.1% of the total., Fragments (37.3%) and fibers (41.3%) were the predominant shapes. Dadar Beach (SPOT C) showcased a diverse mix of microplastic colors, with black (36.1%) and blue (29.9%) being prominent. Fragment shapes (50.5%) were most prevalent. Prabhadevi Beach (SPOT D) displayed a similar trend with black (41.1%)

and blue (21.3%) microplastics dominating. Worli Koliwada Jetty (SPOT E) demonstrated prevalent black (51.3%) and blue (27.5%) microplastics, primarily in fragment (47.8%) and fiber (34.5%) shapes. Bandra Reclamation (SPOT F) exhibited significant occurrences of black (69.1%) and blue (17.6%) microplastics, predominantly in fragment (47.1%) and fiber (39.2%) forms (Fig. 3).

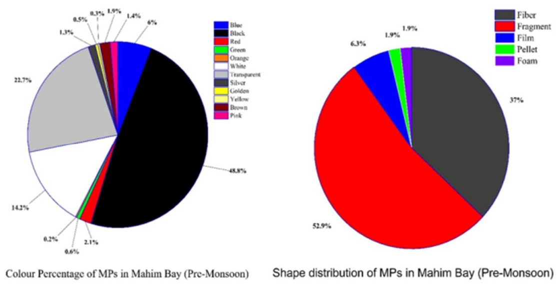


Fig. 3 Color and shape distribution within microplastic pollution across the sampled locations during pre-monsoon season

Polymer distribution

The pre-monsoon season exhibited varying distributions of polymer types in water samples collected from different locations along the Mumbai coastline. SPOT A - Opening of Mithi River: Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), Nylon, Cellulose Acetate, and Ethylene-vinyl acetate (EVA) were identified as the primary polymer types at the Opening of Mithi River during the pre-monsoon period. PE and PP dominated the polymer composition, constituting approximately 60% of the total polymer content. PS, Nylon, Cellulose Acetate, and EVA were also present but in smaller proportions compared to PE and PP. Similar to SPOT A-Opening of Mithi, Mahim Beach exhibited a predominance of PE and PP during the pre-monsoon season, constituting around 60% of the total polymer composition. PS, Nylon, Cellulose Acetate, and EVA were also detected but in lesser quantities compared to PE and PP.SPOT C - Dadar Beach:At Dadar Beach, PE and PP were again the dominant polymer types observed during the pre-monsoon period, representing approximately 60% of the total polymer composition. PS, Nylon, Cellulose Acetate, and EVA were present but in smaller proportions compared to PE and PP. SPOT D - Prabhadevi Beach: During the pre-monsoon season, PE and PP remained the predominant polymer types at Prabhadevi Beach, comprising approximately 60% of the total polymer composition. PS, Nylon, Cellulose Acetate, and EVA were also detected but in minor quantities compared to PE and PP. SPOT E-Worli Koliwada Jetty exhibited a polymer distribution pattern consistent with the other locations, with PE and PP being the dominant polymer types during the pre-monsoon period. These polymers collectively represented around 60% of the total polymer composition. PS, Nylon, Cellulose Acetate, and EVA were also detected but in smaller proportions compared to PE and PP.SPOT F - Bandra Reclamation:At Bandra Reclamation, PE and PP were the primary polymer types observed during the pre-monsoon season, constituting approximately 60% of the total polymer composition. PS, Nylon, Cellulose Acetate, and EVA were also present but in smaller quantities compared to PE and PP (Fig. 6).

Monsoon

Abundance

In monsoon season, the investigation unveiled a slightly high mean concentration of MPs, registering at 1062.33 ± 367.55 (Mean ± SD, n=6) items per litre.Throughout the monsoon season, microplastic abundance continued to exhibit dynamic fluctuations across the sampled locations. At the opening of the Mithi River (SPOT A), the mean microplastic concentration escalated to 296.8 MPs/litre, ranging from 282 to 320 MPs/litre. Mahim Beach (SPOT B) demonstrated an average concentration of 273.6 MPs/litre, with levels varying between 252 and 290 MPs/litre. Dadar Beach (SPOT C) exhibited a mean concentration of 161.6 MPs/litre, fluctuating from 140 to 172 MPs/litre. Prabhadevi Beach (SPOT D) displayed an average of 99.6 mps/litre, with values oscillating between 92 and 106 MPs/litre. Worli Koliwada Jetty (SPOT E) revealed an average concentration of 203.2 MPs/litre, ranging from 196 to 212 MPs/litre. Bandra Reclamation (SPOT F) recorded an average concentration of 240 MPs/litre, with levels spanning between 232 and 248 MPs/litre (Fig. 2). These findings underscore the temporal variability of microplastic abundance during the monsoon season, influenced by intensified hydrological dynamics and anthropogenic inputs.

Color and shape distribution

As the monsoon season set in, we noticed dynamic shifts in the color and shape distribution of microplastics across the sampled locations. At the opening of the Mithi River (SPOT A), black microplastics remained predominant, accounting for approximately 54.6%, followed by blue microplastics at 33.9%. Mahim Beach (SPOT B) displayed a similar pattern, with black microplastics comprising around 51.1% and blue microplastics around 37.8% of the total., Dadar Beach (SPOT C) exhibited significant occurrences of black (57.5%) and blue (23.2%) microplastics, predominantly in fragment shapes (56.8%). Prabhadevi Beach (SPOT D) showcased notable presence of black (58.5%) and blue (21.3%) microplastics, primarily in fragment shapes (57.1%). Worli Koliwada Jetty (SPOT E) demonstrated prevalent black (55.1%) and blue (24.6%) microplastics, mainly in fragment (52.6%) and fiber (27.8%) shapes. Bandra Reclamation (SPOT F) also exhibited significant occurrences of black (65.7%) and blue (Fig. 4).

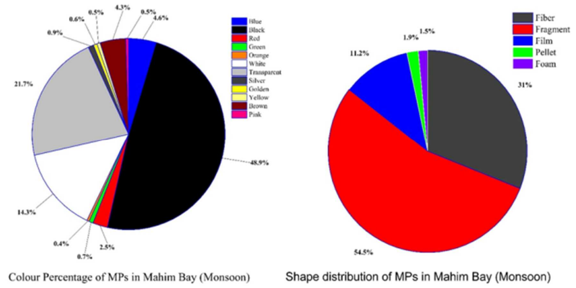


Fig. 4. Color and shape distribution within microplastic pollution across the sampled locations during Monsoon season

Polymer distribution

The monsoon season brought about changes in the distribution of polymer types in water samples collected from various locations along the Mumbai coastline. At the Opening of Mithi River (Spot A), PE and PP remained dominant, comprising about 60% of the total polymer content, similar to the pre-monsoon season, with PS, Nylon, Cellulose Acetate, and EVA present in smaller proportions. Likewise, at Mahim Beach (Spot B), Dadar Beach (Spot C), Prabhadevi Beach (Spot D), Worli Koliwada Jetty (Spot E), and Bandra Reclamation (Spot F), PE and PP continued to be the primary polymer types during the monsoon period, constituting approximately 60% of the total polymer composition. PS, Nylon, Cellulose Acetate, and EVA were also detected, albeit in lesser quantities compared to PE and PP, maintaining consistency with the pre-monsoon season (Fig. 6).

Post-monsoon

Abundance

In the post-monsoon phase, a notable elevation in MP concentration was discerned, with an average value of 872 ± 256.77 (Mean ± SD, n=6) items per litre. Following the monsoon period, the assessment of microplastic abundance revealed notable shifts in contamination levels across the sampled locations. At the opening of the Mithi River (SPOT A), the mean microplastic concentration decreased to 207.6 mps/litre, ranging from 200 to 214 mps/litre. Mahim Beach (SPOT B) exhibited an average concentration of 258 mps/litre, with levels fluctuating between 248 and 280 mps/litre. Dadar Beach (SPOT C) demonstrated a mean concentration of 158.8 mps/litre, varying from 150 to 166 mps/litre. Prabhadevi Beach (SPOT D) displayed an average of 171.6 mps/litre, with values oscillating between 166 and 178 mps/litre. Worli Koliwada Jetty (SPOT E) revealed an average concentration of 124 mps/litre, ranging from 120 to 130 mps/litre. Bandra Reclamation (SPOT F) recorded an average concentration of 126.4 mps/litre, with levels spanning between 122 and 132 mps/litre (Fig. 2). These observations underscore the complex interplay of seasonal dynamics and anthropogenic influences on microplastic contamination along the Mumbai coastline.

Color and shape distribution

Following the monsoon period, our investigation into the color and shape distribution of microplastics revealed consistent trends across the sampled locations. At the opening of the Mithi River (SPOT A), black microplastics remained prevalent, accounting for approximately 59.7%, followed by blue microplastics at 25.1%. Mahim Beach (SPOT B) continued to exhibit a significant presence of black microplastics at 57.9% and blue microplastics at 25.6% of the total., Dadar Beach (SPOT C) showcased sustained occurrences of black (61.9%) and blue (19.7%) microplastics, predominantly in fragment shapes (55.2%). Prabhadevi Beach (SPOT D) displayed consistent presence of black (58.8%) and blue (20.9%) microplastics, primarily in fragment shapes (57.3%). Worli Koliwada Jetty (SPOT E) demonstrated persistent prevalence of black (61.6%) and blue (22.6%) microplastics, mainly in fragment (47.2%) and fiber (28.4%) shapes. Bandra Reclamation (SPOT F) also exhibited ongoing presence of black (61.7%) and blue (19.7%) microplastics, predominantly in fragment (45.6%) and fiber (41.9%) forms (Fig. 5). These findings suggest that during the post-monsoon period, microplastic distribution in terms of color and shape remains stable, indicating persistent environmental influences and anthropogenic contributions along the Mumbai coastline.

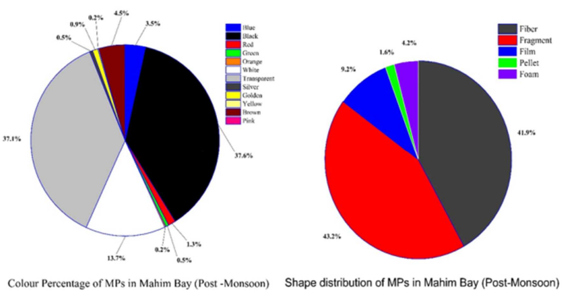
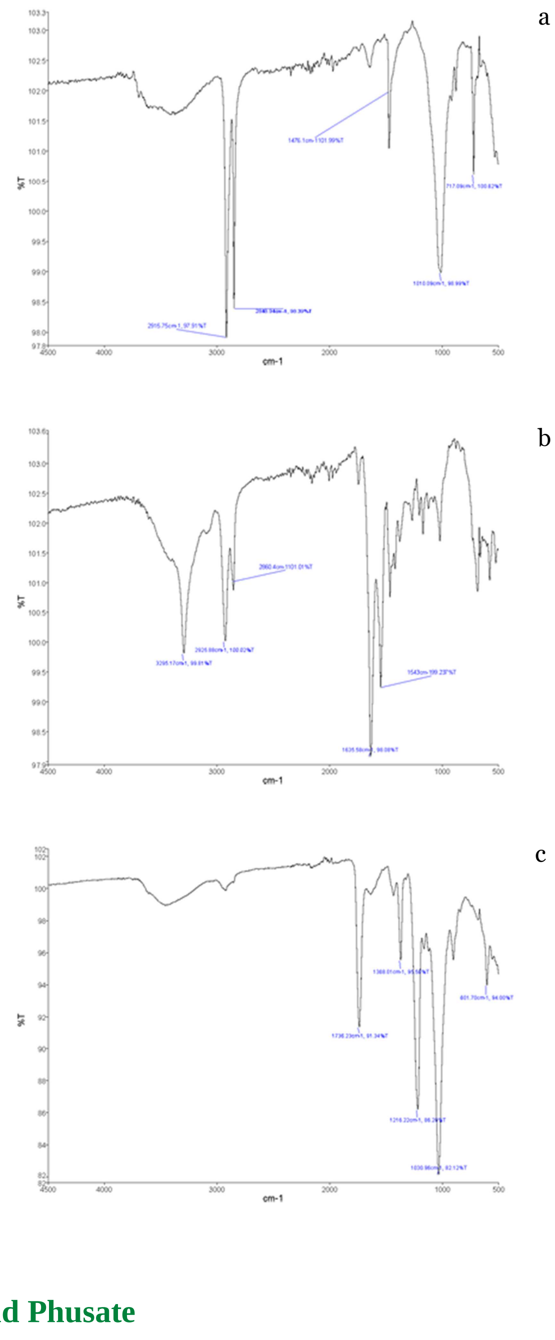


Fig. 5. Color and shape distribution within microplastic pollution across the sampled locations during Post-monsoon season

Polymer distribution

During the post-monsoon season, variations in the distribution of polymer types were observed in water samples collected from different locations along the Mumbai coastline. At the Opening of Mithi River (Spot A), PE and PP continued to dominate the polymer composition, comprising approximately 60% of the total content, with PS, Nylon, Cellulose Acetate, and EVA present in smaller proportions, similar to the pre-monsoon and monsoon seasons. Likewise, at Mahim Beach (Spot B), Dadar Beach (Spot C), Prabhadevi Beach (Spot D), Worli Koliwada Jetty (Spot E), and Bandra Reclamation (Spot F), PE and PP remained the predominant polymer types, constituting around 60% of the total composition during the post-monsoon period. PS, Nylon, Cellulose Acetate, and EVA were also detected at these spots, albeit in lesser quantities compared to PE and PP, maintaining consistency with the pre-monsoon and monsoon seasons (Fig. 6).



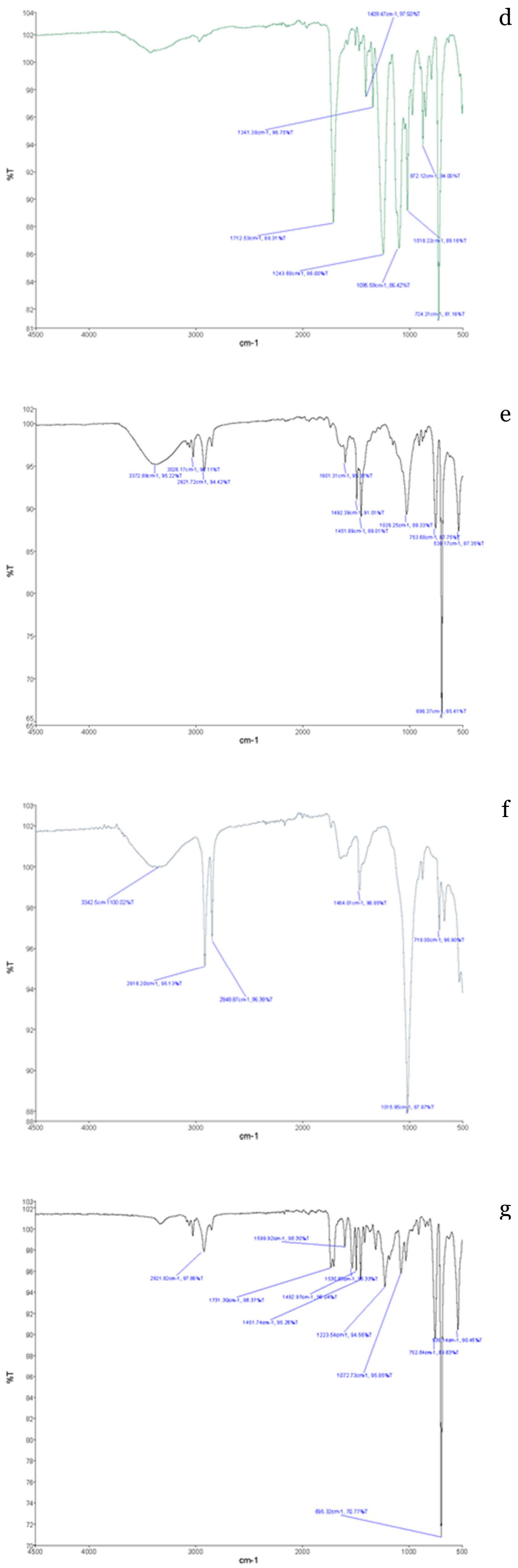


Fig. 6. FTIR spectra of microplastic samples: a. PE (Polyethylene), b. Nylon, c. CA (Cellulose Acetate), d. PET (Polyethylene Terephthalate), e. Pellet, f. EVA (Ethylene Vinyl Acetate), g. ABS (Acrylonitrile Butadiene Styrene)

Discussion

Microplastic pollution has emerged as a significant environmental concern globally, posing potential threats to marine ecosystems and human health (Laskar and Kumar, 2019; De-la-Torre, 2020). Our study investigated the abundance, seasonal dynamics, polymer types, and potential sources of microplastics in Mahim Bay, Mumbai, India, contributing to the understanding of microplastic pollution in similar environments worldwide. We observed significant microplastic contamination in Mahim Bay, particularly during the pre-monsoon season, with an average abundance of 205.2 microplastic items per litre. This abundance increased during the monsoon season to 273.6 items per litre before slightly decreasing to 258 items per litre in the post-monsoon period. The observed seasonal variation suggests fluctuations in pollution levels influenced by hydrological factors and human activities (de Carvalho *et al.,* 2021; Talbot and Chang, 2022).

Across all seasons, the dominant colors of microplastics in Mahim Bay were blue, black, and green, indicating a diverse range of polymer sources. During the pre-monsoon season, blue-colored microplastics were most abundant, followed by black and green. In the monsoon season, black-colored microplastics became more prevalent, while green-colored microplastics decreased. Post-monsoon, blue-colored microplastics remained prominent, with a slight increase in black-colored microplastics compared to the monsoon season. This shift in color distribution could be attributed to changes in waste disposal patterns and transport pathways during different seasons (Veerasingam *et al.,* 2016; Garcés-Ordóñez *et al.,* 2021; Li *et al.,* 2022).

Microplastics in Mahim Bay exhibited various shapes, including fibers, fragments, films, pellets, and foams. Fibers were consistently the most abundant shape throughout all seasons, highlighting the prevalence of textile-related microplastics in the marine environment (Henry *et al.,* 2019; Yadav *et al.,* 2022). Fragments and films were also common, indicating the degradation of larger plastic items (Kalogerakis *et* *al.,* 2017). Pellets and foams were less prevalent but still contributed to the overall microplastic abundance. The seasonal variation in shape distribution suggests changes in the breakdown and weathering of plastic debris influenced by environmental conditions (Vibhatabandhu and Srithongouthai, 2022). Polyethylene (PE), polypropylene (PP), and polystyrene (PS) were the predominant polymer types identified in Mahim Bay microplastics across all seasons. During the pre-monsoon season, PE was the most abundant polymer, followed by PP and PS. In the monsoon season, PP became the most prevalent polymer, surpassing PE, while PS remained relatively stable. Post-monsoon, PE again became the dominant polymer, with PP and PS showing similar abundances to the pre-monsoon season. This variation in polymer composition reflects the complex interplay between plastic production, usage, and disposal practices, as well as degradation processes influenced by seasonal environmental conditions (Galloway *et al.,* 2017; Zhang *et al.,* 2021).

The observed seasonal variation in microplastic characteristics in Mahim Bay underscores the dynamic nature of plastic pollution in coastal environments. The pre-monsoon season exhibited relatively high abundance and diverse color and shape distributions, indicative of continuous input from land-based sources and weathering processes. The monsoon season brought about changes in color distribution, shape composition, and polymer types, influenced by increased rainfall and runoff. Post-monsoon, while microplastic abundance decreased, the composition of colors, shapes, and polymers remained comparable to the pre-monsoon period, suggesting persistent contamination despite reduced hydrological activity. Comparisons with similar studies conducted worldwide reveal common trends in the distribution and characteristics of microplastics in coastal environments (Gupta *et al.,* 2021; Zhang *et al.,* 2121b; Setiti *et al.,* 2021; Daniel *et al.,* 2020). The dominance of PE and PP, along with the diverse shapes and colors of microplastics, underscores the global nature of plastic pollution and the need for coordinated efforts to address this issue (Nguyen *et al.,* 2023; Vuong, 2023; Ghani, 2024). Our findings contribute to the growing body of literature on microplastic pollution and provide valuable data for policymakers and environmental agencies to develop effective management strategies.

The analysis of microplastic characteristics and seasonal variations in Mahim Bay provides valuable insights into the sources, transport mechanisms, and fate of microplastics in coastal ecosystems. Understanding these dynamics is essential for developing targeted mitigation strategies and policies to address plastic pollution and safeguard marine biodiversity and ecosystem health in Mahim Bay and similar coastal regions. Furthermore, the seasonal variation observed in Mahim Bay underscores the need for comprehensive monitoring programs that capture temporal changes in microplastic pollution. These programs should consider not only abundance but also the distribution of colors, shapes, and polymer types to gain a more holistic understanding of microplastic dynamics. Additionally, identifying hotspots of microplastic accumulation and understanding the underlying drivers of seasonal variability can inform management efforts aimed at reducing plastic inputs into the marine environment. The dominance of fibers, fragments, and films highlights the importance of addressing sources such as textile manufacturing, plastic packaging, and improper waste management practices. Implementing measures to minimize plastic usage, improve waste collection and recycling infrastructure, and promote sustainable alternatives can help mitigate the influx of microplastics into Mahim Bay and protect marine ecosystems. Moreover, the shift in polymer composition between seasons suggests the need for targeted interventions tailored to specific types of plastics. For instance, initiatives focusing on reducing single-use plastics or promoting the use of biodegradable alternatives may be particularly effective in reducing the abundance of certain polymer types. By addressing the underlying drivers of microplastic contamination and implementing effective interventions, stakeholders can work towards preserving marine biodiversity, protecting human health, and promoting sustainable development in coastal regions.

Acknowledgements

I would like to express my sincere gratitude to the Principal, KJ Somaiya College of Science and Commerce, for their guidance and encouragement throughout my academic journey. I extend my heartfelt appreciation to SIES Activity and Research Center, located at D388, MIDC TTC, Navi Mumbai, for their generous provision of the Fourier Transform Infrared (FTIR) equipment. Their support and assistance were instrumental in facilitating the analysis and interpretation crucial for the success of my project.

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