

Atmospheric Microplastics in Indoor and Outdoor Air: Abundance and their Potential as Vectors for Heavy Metals

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ABSTRACT

Microplastics (MPs) have emerged as pervasive atmospheric pollutants, yet their occurrence and characteristics in urban air environments remain poorly characterized. This study quantified the abundance, morphological features, polymer composition, and elemental associations of airborne MPs in indoor and outdoor environments in Marikina, Philippines. Airborne particles were collected using a respirable dust sampler and analyzed through microscopic observation, attenuated total reflectance Fourier-transform infrared spectroscopy (ATR-FTIR), and scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDX). Results revealed significantly higher MP concentrations in outdoor air (0.341 ± 0.038 MP/m³) than indoors (0.155 ± 0.106 MP/m³) ($p=0.0454$), with estimated daily intakes ranging from 0.5-3.2 MP/day indoors and 2.1-4.3 MP/day outdoors. Fibers were the predominant morphology in both environments, accounting for 80.0-95.7% indoors and 61.3-84.0% outdoors. Polymer analysis identified indoor MPs mainly as polyvinyl chloride (PVC, 50.0%), polyethylene (PE), and polyurethane (PU), whereas outdoor samples showed a broader diversity, including polyamide (PA), polyethylene terephthalate (PET), polymethyl methacrylate (PMMA), and high-density polyethylene (HDPE). Elemental analysis revealed the adsorption of toxic metals such as titanium (Ti), chromium (Cr), lead (Pb), mercury (Hg), and cadmium (Cd), with Pb concentrations reaching up to 18.13% in indoor PE fibers and Cr up to 18.29% in outdoor HDPE. These findings demonstrate that outdoor environments harbor higher concentrations and more chemically complex MPs, emphasizing the potential risk of human inhalation exposure. The study underscores the urgent need for monitoring airborne MPs and developing mitigation measures to reduce human and environmental health in urban areas.

HIGHLIGHTS

- Airborne microplastics were detected in indoor and outdoor urban sites.
- Outdoor sites showed higher microplastic levels than indoor areas.
- Black and red synthetic fibers were the dominant microplastic types.
- FTIR identified PU, PE, and PVC in indoor microplastic samples.
- PA, PET, PMMA, and HDPE were present in outdoor microplastics.

1. INTRODUCTION

Plastics have largely replaced traditional materials such as metal, glass, and wood due to their cost-effectiveness, durability, and versatility (Ng et al., 2018; Rehm et al., 2021). Their affordability and widespread applications have made them indispensable across various industries, significantly shaping the global economy (Peña et al., 2023; Ritter,

2022). Much of the research on microplastic (MPs) has focused on marine ecosystems (Bhuyan 2022; Pothiraj et al., 2023; Marcharla et al., 2024; Ellos et al., 2025) while the scale and extent of contamination in other environmental compartments, including the atmosphere, remain poorly understood. Multiple studies have confirmed the presence of MPs across various ecosystems, including river sediments

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(Gabriel and Bacosa, 2024), lakes (Arcadio et al., 2022), beaches (Sajorne et al., 2022) and agricultural soil (Gonzales et al., 2024).

However, research on airborne MPs remains limited despite their potential to pose serious risks to both human health and environmental integrity. Outdoor airborne sources include vehicle tire wear (Brahney et al., 2021; Boakes et al., 2023a), waste disposal, macro-plastic debris and construction works (Salthammer, 2022). Beyond outdoor sources, indoor environments also contribute significantly to MP contamination, as enclosed spaces can facilitate prolonged exposure. Studies have identified textiles as a dominant source, with MPs being released from vented tumbled dryer (Tao et al., 2022), degraded floor finishing materials (Suh et al., 2025), carpets (Yasin et al., 2024), and household fabrics during routine activities such as laundry and mechanized clothes drying (Kapp and Miller, 2020). The distribution of airborne MPs varies depending on location and environmental factors (Perera et al., 2022).

MPs are now ubiquitous, contaminating the human diet (Dimaongon et al., 2024), raising urgent concerns about their potential risks to environmental sustainability and public health (Koelmans et al., 2022). They have been widely reported in various environmental matrices, including atmospheric dust (Xu et al., 2024), personal care products and cosmetics (Gamage and Mahagamage, 2024), food items (Mamun et al., 2023) and water systems (Kye et al., 2023).

In the Philippines, a recent study by Romarate et al. (2023), examined MPs suspended in the atmosphere, estimated that an adult could inhale at least one suspended atmospheric MP (SAMP) after approximately 99 to 132 hours of exposure. This highlights the potential for chronic exposure, particularly in urbanized and industrialized settings. Additionally, Patilan et al. (2024) conducted a preliminary study on mercury (Hg) and lead (Pb) in the ambient air of Metro Manila. Their findings support the reported presence of MPs in the area, providing documented evidence of these toxic metals in the atmosphere of the biggest urban area in the Philippines.

Another study concerning airborne MPs focuses on road dust, which plays a significant role in atmospheric MP pollution. Tejano et al. (2024), confirmed the presence of MPs in road dust samples collected from Iligan City, a rapidly urbanizing area in Mindanao, reinforcing concerns about MP dispersion

in high-traffic environments. Given their widespread presence, human exposure to MPs is inevitable, occurring through ingestion, inhalation, and dermal contact. Studies have suggested that MP exposure may lead to oxidative stress, cytotoxicity, neurotoxicity, immune system disruption, and translocation to other tissues (Bhuyan, 2022).

Despite the increasing evidence of airborne MP contamination, the Philippines still faces a significant research gap in both indoor and outdoor environments. The lack of comprehensive studies limits the ability of policymakers' and public health officials' to assess exposure risks and formulate science-based mitigation strategies. While existing research has identified potential sources of MPs, a critical need remains to establish baseline data on MP levels, sources, and health implications across different settings. Understanding the extent of MP pollution in enclosed indoor spaces, where prolonged exposure may occur, and outdoor environments, where industrial activity, vehicular emissions, and urbanization contribute to dispersion, is essential for developing effective regulatory frameworks. Without such evidence, efforts to curb MP emissions and minimize human exposure remain insufficient.

While studies have been published on airborne MPs in outdoors environments (Discutido et al., 2024), there is a lack of research examining both indoor and outdoor airborne MPs in the Philippines. This study aims to address the knowledge gap regarding airborne suspended MPs in the Philippines by investigating their presence in both indoor and outdoor settings. The specific objectives of the study were as follows: (1) to determine the abundance of MPs in indoor and outdoor environments; (2) to characterize MPs based on shape, color, and polymer composition; and (3) to identify the adsorbed metals associated with MPs. This study provides insights into the current understanding of inhalable MP exposure in indoor and outdoor settings, highlighting the need for further research on the role of MPs as vectors for heavy metals and other pollutants and their potential risks to human health and the environment.

2. METHODOLOGY

2.1 Background of the sampling area

Marikina, is a highly urbanized city located in the eastern part of National Capital Region (NCR) of the Philippines. It serves as the main gateway between Metro Manila and the provinces of Rizal and Quezon. This study was conducted within a two-storey

residential apartment, with indoor sampling taking place on the ground floor (living room). The room had approximate dimensions of 3 m × 5.5 m × 4 m (LWH) (Figure 1). For outdoor sampling, the measurements were taken 5.6 meters from the apartment at ground level (geolocation: 14°39'6.12"N, 121°6'40.68"E. The apartment housed five adult occupants.

2.2 Air sampling and sample preparation

Airborne MP sampling was conducted from July 16 to 18, 2025. In each sampling environment, one-hour sampling sessions were carried out in both the morning and evening using a continuous sampling approach. The morning period, which included both the setup and the sampling process, was conducted between 6:00 am and 8:00 am. Similarly, the evening setup and sampling were performed between 6:00 pm and 8:00 pm.

A respirable dust sampler with an intake flow rate of 1.4 m³/min was used to collect airborne MP

particles. The sampled air volume per session was approximately 84 m³, and the intake rate was monitored every 30 min to ensure a uniform flow rate (Romarate et al., 2023). The sampler's intake was positioned 1.5 meters above the ground to simulate the average height of human breathing. GF/C Whatman filter paper (8.3×11.7 inches) was used to capture suspended atmospheric MPs during each sampling period across different sampling environments. Before sampling, filters were microscopically examined to confirm the absence of MP contaminants. After collection, the filters were transported to a controlled laboratory environment to prevent external contamination and for analysis. Each filter was subjected to microscopy with a magnification power of WF10X/22 (YANA Chemodities Inc.), where potential MP particles were handpicked and embedded in glass slides for further examination.

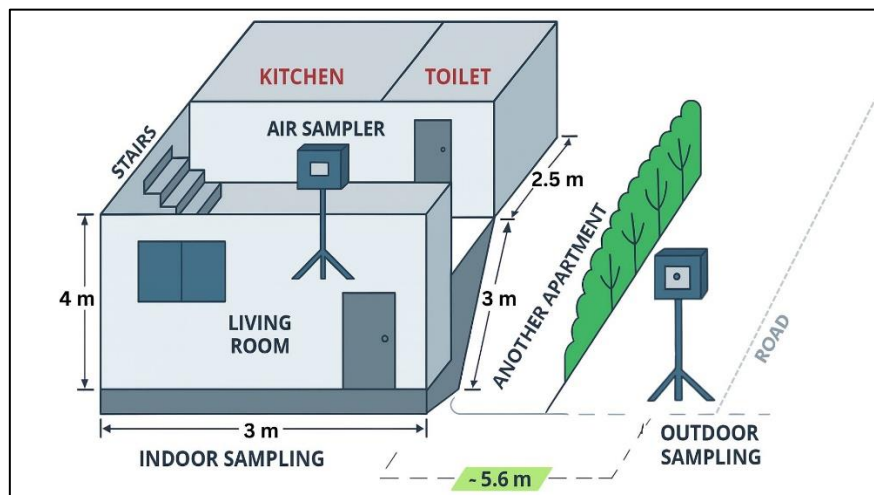


Figure 1. Schematic representation of the sampled area, showing the location of the respirable dust sampler in the indoor and outdoor settings.

2.3 Daily intake of MPs

To estimate the potential daily inhalation of MPs by an individual, a modified version of the equation proposed by Akhbarizadeh et al. (2021), was utilized as shown below:

$$\text{Daily intake } \left(\frac{\text{MP}}{\text{day}} \right) = \text{density} \left(\frac{\text{MP}}{\text{m}^3} \right) \times \text{ventilation rate} \left(\frac{\text{m}^3}{\text{min}} \right) \times \text{exposure time} \left(\frac{\text{min}}{\text{day}} \right) \quad (1)$$

Where; Density is, expressed in MP/m³, refers to the number of airborne MPs per cubic meter of air. Ventilation rate, expressed in m³/min, represents the

average volume of air inhaled per minute, with 5 L/min and 8 L/min used in this study to represent different activity levels. Exposure time was set at 24 hours, assuming continuous daily exposure.

2.4 Morphological characterization and plastic confirmation

Samples mounted on glass slides were examined under a microscope to determine their physical characteristics, such as color and shape. To confirm whether the collected particle was plastic, the “Hot Needle Test” was performed following the study of Beckham et al. (2023). Plastic particles were

confirmed if they exhibited melting or deformation under the microscope.

2.5 ATR-FTIR analysis

Some MPs confirmed using the “Hot Needle Test” were randomly analyzed using Attenuated Total Reflectance Fourier-Transform Infrared (ATR-FTIR) - Shimadzu (IRTracer 100) to confirm their polymer type. Spectra graphs generated for each MP were automatically matched against a pre-existing standard spectral library. Before each analysis, the ATR crystal was thoroughly cleaned with 70% ethanol, followed by a background scan to ensure accuracy. Additionally, the obtained spectra were cross-referenced with literature-based reference spectra, with a similarity threshold of >70% considered a positive match (Sharaf Din et al., 2024).

2.6 SEM-EDX analysis

Randomly selected MPs from each sample were analyzed using a scanning electron microscope (SEM), JEOL (JSM-IT200) coupled with energy-dispersive X-ray spectroscopy (EDX) for surface elemental composition analysis. SEM utilizes a focused electron beam to scan the sample surface, producing high-resolution images that reveal the fine surface details of the MPs. MPs were carefully picked using metal needles and placed onto stubs. These stubs were then gold-coated before SEM-EDX analysis. Images were captured at various magnifications to examine surface morphology in detail. Surface elemental composition was determined using EDX, with characteristic peaks indicating the presence of specific elements on MP surfaces.

2.7 Quality control

All filter papers were stored in labeled envelopes both before and after exposure. Before use, glass slides were thoroughly cleaned with distilled water and dried. Metal tweezers were used to handle the filter papers to minimize contamination. Exposed

filters were carefully folded and stored in labeled envelopes to prevent contamination. Samples were only opened when required for analysis, ensuring they remained free from the contamination throughout the process.

2.8 Statistical analysis

Microsoft Excel and OriginLab (2025) were used. A paired t-test was conducted to compare the means of the two sampling environments (indoor and outdoor), with statistical significance set at $p < 0.05$. The Shapiro-Wilk test was used to assess the normality of the data. Unless otherwise stated, all statistical results are presented as mean $\pm$ SD.

3. RESULTS

3.1 Microplastic abundance in air samples

Variations in MPs' abundance revealed a distinct contrast between indoor and outdoor environments. Indoor MP concentrations range from 0.071 to 0.274 MP/m³, with the highest recorded on the first day (Table 1). In contrast, outdoor concentrations remained consistently higher, ranging from 0.298 to 0.369 MP/m³. This disparity highlights the significant difference ($p = 0.0454$) in MP presence, with outdoor air containing significantly higher concentrations than indoor spaces. On average, indoor MP levels measured 0.155 ± 0.106 MP/m³, whereas outdoor concentrations were nearly double at 0.341 ± 0.038 MP/m³ (Figure 2).

Assuming that an average person spends a significant portion of their time indoors, indoor MP daily intake ranged from 0.5 to 3.2 MP/day, with the highest intake observed at Indoor 1 (2.0-3.2 MP/day) and the lowest at Indoor 3 (0.5-0.8 MP/day). Outdoor MP daily intake ranges from 2.1 to 4.3 MP/day, with Outdoor 2 recording the highest values (2.7-4.3 MP/day) and Outdoor 1 the lowest (2.1-3.4 MP/day). Outdoor intake values were consistently higher than indoor values, except for Indoor 1, which showed a broader range of intake estimates.

Table 1. MPs concentration and estimated daily intake in indoor and outdoor air samples

Sampling station	No. of MPs observed	MPs concentration (MP/m ³)	MPs daily intake (MP/day)
Indoor 1	23	0.274	2.0-3.2
Indoor 2	10	0.119	0.9-1.4
Indoor 3	6	0.071	0.5-0.8
Outdoor 1	25	0.298	2.1-3.4
Outdoor 2	31	0.369	2.7-4.3
Outdoor 3	30	0.357	2.6-4.1

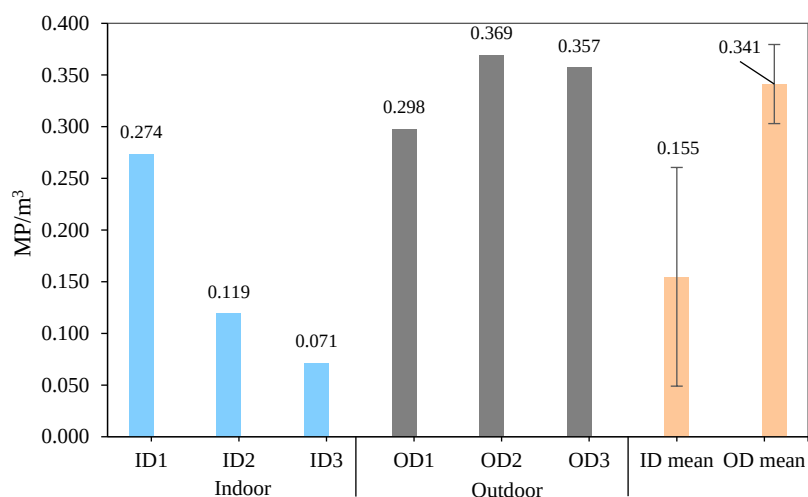


Figure 2. MPs concentration in indoor and outdoor environments

3.2 Shape, color and polymer type of microplastics

MPs in indoor and outdoor environments showed differences in color, polymer type, and shape. Color distribution varied, with indoor samples dominated by blue, transparent, and red MPs. In contrast, outdoor samples have a mix of black, blue, red, and yellow (Figure 3(a)). Shape composition is fiber-dominant indoors (80.0-95.7%) and outdoors (61.3-84.0%), though outdoor samples (Figure 3(b)) showed more fragments. The polymer composition of indoor samples was mainly polyvinyl chloride (PVC) (50.0%), with polyethylene (PE) and polyurethane (PU) at 25.0% each (Figure 3(c)). Outdoor samples have a more diverse composition, including polyamide (PA), polyethylene terephthalate (PET), polymethyl methacrylate (PMMA), and high-density polyethylene (HDPE), each at 25.0%.

3.3 Elemental mapping associated with microplastics

SEM images (Figure 4) illustrate the surface texture of various atmospheric MPs with different shapes. When analyzing with EDX, different areas of a particle's surface were considered, including the area with potentially adhered foreign material. The results of the SEM-EDX analysis are presented in Table 2. Carbon (C) and oxygen (O) are fundamental elements in all plastic materials, as they are the derivative from the petroleum products. Other metal elements such as titanium (Ti), chromium (Cr), lead (Pb), cadmium (Cd), nickel (Ni), copper (Cu), and zinc (Zn) were present in spots containing foreign materials. Ti concentrations are notably higher in outdoor PET (6.57%) compared to indoor PE (3.05%) and outdoor HDPE (0.14%).

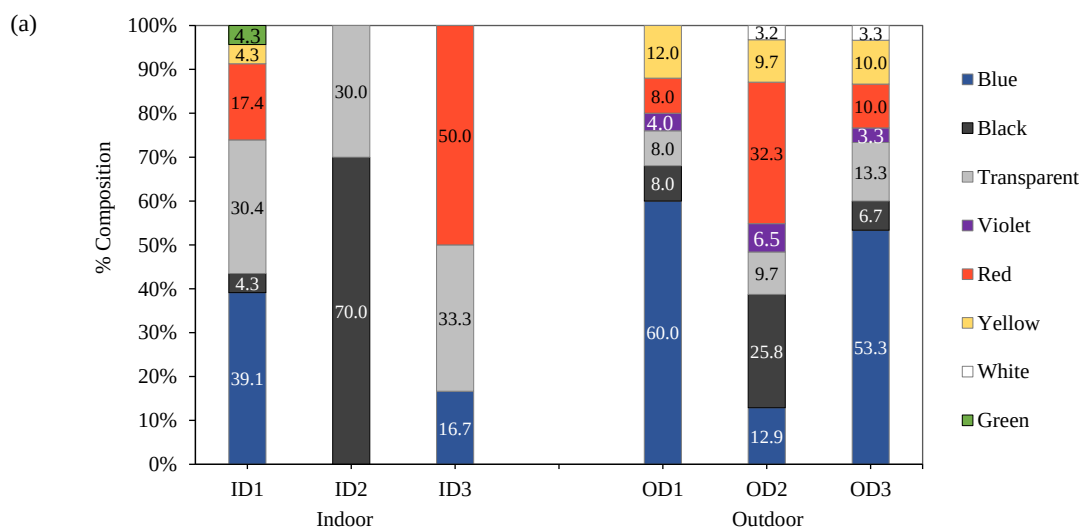


Figure 3. Relative abundance of MPs in indoor (ID) and outdoor (OD) environments (a) color, (b) shape, and (c) polymer type

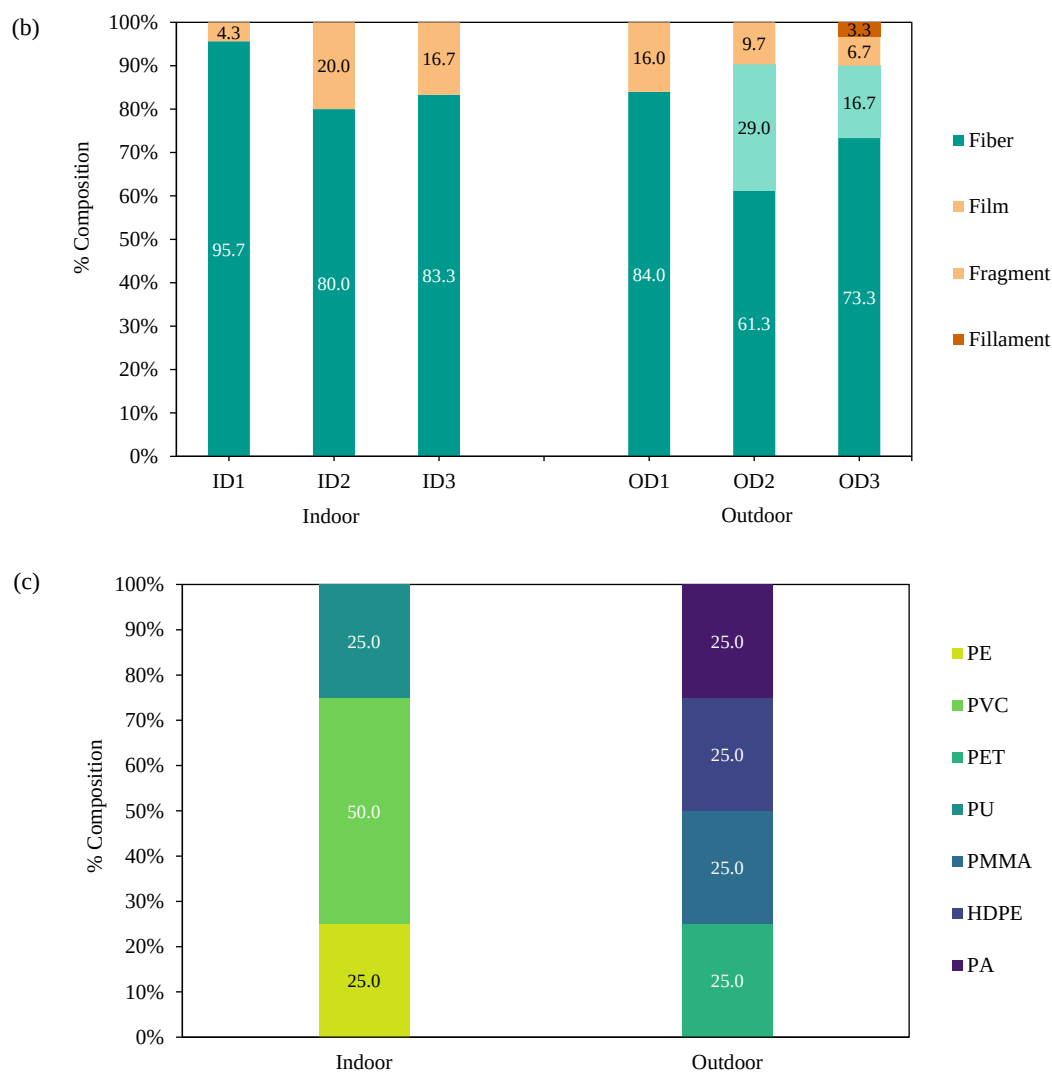


Figure 3. Relative abundance of MPs in indoor (ID) and outdoor (OD) environments (a) color, (b) shape, and (c) polymer type (cont.)

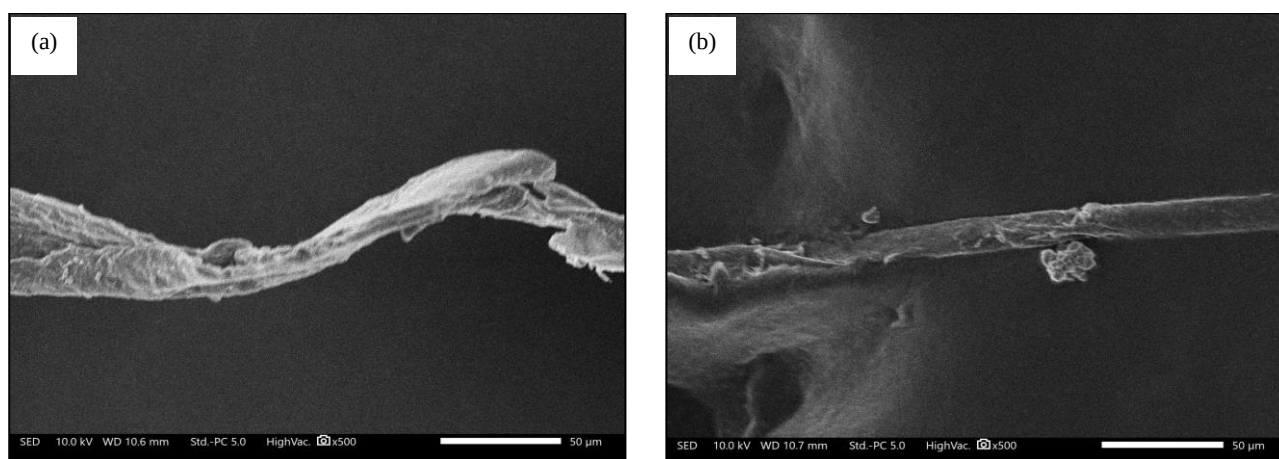


Figure 4. SEM images of MPs (a) frayed indoor PE fiber, (b-c) outdoor MPs with (b) PET fiber and (c) a fragmented HDPE particle

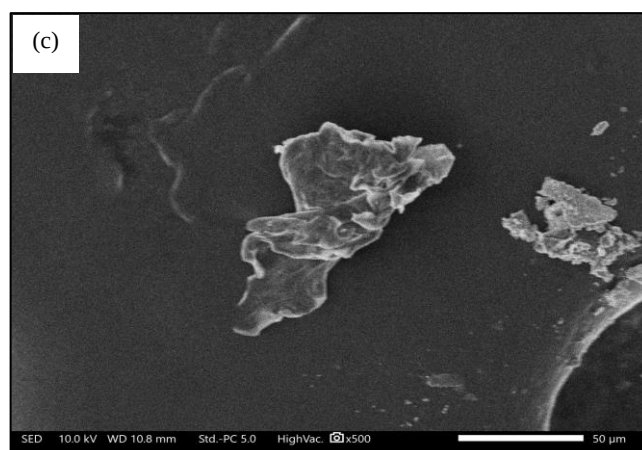


Figure 4. SEM images of MPs (a) frayed indoor PE fiber, (b-c) outdoor MPs with (b) PET fiber and (c) a fragmented HDPE particle (cont.)

Table 2. Summary of adsorbed metals associated with MPs, (a) indoor PE fiber, (b) outdoor PET fiber and (c) fragmented HDPE outdoor.

Element	a. Indoor (Polyethylene)	b. Outdoor (Polyethylene terephthalate)	c. Outdoor (High density polyethylene)
O	51.98 ± 5.24	51.35±6.45	77.42±11.95
Mg	nd	0.96±1.58	0.17±2.59
Al	nd	2.44±2.13	0.14±2.67
Ti	3.05±4.36	6.57±7.34	18.29±17.64
Cr	nd	nd	nd
Ni	0.14±30.62	nd	3.71±113.30
Cu	nd	nd	nd
Zn	16.90±5.29	16.82±5.97	nd
Cd	0.21±3.23	nd	nd
Hg	9.58±7.14	9.35±8.51	nd
Pb	18.13±8.32	12.50±10.50	nd
Total	100.00	100.00	100.00

Cr is only detected only in the outdoor HDPE sample (18.29%), while lead (Pb) and mercury (Hg) are present in both indoor and outdoor fibers, with Pb levels reaching 18.13% in indoor PE and 12.50% in outdoor PET. Cd was recorded in indoor PE (0.21%), while Ni was detected only in indoor PE, with highly variable concentrations. Cu was not found in any of the samples.

4. DISCUSSION

MPs were detected in both indoor and outdoor environments in this study. Outdoor environments may contain higher MPs concentration due to greater exposure to harsh conditions such as heat and mechanical wear. These factors accelerate the breakdown of macroplastics, increasing the likelihood of MP generation compared to the more sheltered indoor setting. Variations in indoor MP abundance may be influenced by differences in human activity

and ventilation efficiency (Sharaf Din et al., 2024), with fibers being the predominant form in both environments.

Contamination in both indoor and outdoor environments arises from multiple sources and is largely driven by poor solid waste management practices (Paler et al., 2022) and varying environmental conditions. While existing studies often focus on quantifying plastic pollution, they fall short in addressing the more pressing concern how rapidly plastics are being released into the environment (Tabañag et al., 2022). Indoor MPs are primarily linked to textiles, household items, and synthetic furnishings, which continuously shed PET and PE fibers into the air. This study found that black (70.0%) and red (50.0%) MPs were predominant indoors, consistent with prior research identifying indoor MP contamination from fabrics and furnishings (Sharaf Din et al., 2024). Similarly, Liao et al. (2021) and

Perera et al. (2022) reported significant indoor PET presence, with PET accounting for 28.4% and 60% of MPs, respectively. This suggests that synthetic textiles, carpets, and household plastics contribute to indoor MP accumulation. The presence of PVC is likely attributed to human activities, while the turbulence created by airflow, aids in the dispersion of MPs. In contrast, outdoor MP composition is more diverse, influenced by environmental exposure, weathering, and industrial or urban waste sources. This study identified blue MPs as the most prevalent outdoors (53.3-60.0%), likely due to the degradation of plastic materials such as tarpaulins and packaging. A similar trend was observed in London, where blue and transparent fibers dominated outdoor samples (Boakes et al., 2023b). The polymeric composition further supports these findings, with indoor MPs being predominantly polyvinyl chloride (PVC) (50.0%), while outdoor MPs exhibited a broader range of polymers, including polyethylene terephthalate (PET), polyamide (PA), high-density polyethylene (HDPE), and polymethyl methacrylate (PMMA). Such variations highlight the influence of regional industrial activities, waste management practices, and atmospheric transport on MP distribution.

Identifying MP sources remains challenging due to the complexity of environmental interactions. However, morphological characteristics, together with polymer composition, provide valuable insights into potential origins. This study found fibrous MPs to be the dominant morphology, comprising 80.0-95.7% of indoor MPs and 61.3-84.0% of outdoor MPs, followed by fragments. These findings align with previous studies, which consistently report fibers and fragments as the most abundant MP types in both indoor and outdoor environments (Liao et al., 2021; Cui et al., 2022; Perera et al., 2022; Romarate et al., 2023; Sharaf Din et al., 2024; Jahanzaib et al., 2025). The predominance of indoor fibers supports the link to the textile shedding, while the presence of diverse polymer types outdoors suggests multiple sources, including urban runoff, industrial emissions, and atmospheric transport. Understanding these patterns is crucial for assessing MP exposure risks and informing mitigation strategies. Given these findings, with MPs densities in this study 0.155 ± 0.106 MP/m³ indoors; 0.341 ± 0.038 MP/m³ outdoors, the implications for an adult person's exposure to MPs are concerning. On average, a person may inhale approximately 1.1 to 1.8 MPs/day indoors and 2.5 to 3.9 MPs/day outdoors, based on normal minute ventilation rates of 5 to 8 liters

of air per minute and an estimated exposure time of 1 hour (Romarate et al., 2023; Levitan, 2015). This study's estimated daily MP inhalation followed a similar trend, with indoor intake ranging from 0.5 to 3.2 MPs per day. The highest recorded indoor intake was observed at Indoor 1, ranging from 2 to 3.2 MPs per day. Outdoor MP inhalation was consistently higher, ranging from 2.1 to 4.3 MPs/day, with the peak intake recorded at outdoor 2 (2.7-4.3 MPs/day).

Research on airborne MP exposure remains limited these results highlight potential health risks, particularly concerns about MP inhalation and its possible effects on the respiratory system. Table 3 presents a comparative analysis of recent studies on MP contamination. However, direct comparisons are challenging due to variations in sampling methodologies, analytical techniques, environmental conditions, and study parameters. Understanding the sources, behavior, and potential health risks of airborne MPs is essential for informing air quality management policies and reducing plastic pollution. Future studies should explore long-term exposure risks, polymer degradation pathways, and mitigation strategies to address this growing environmental and public health issue. This study presented relatively low airborne MP concentrations (1.65 ± 0.43 MP/m³ indoors; 0.72 ± 0.37 MP/m³ outdoors), comparable to Sri Lanka (Perera et al., 2022) and India (Nandi et al., 2024), but significantly lower than those in highly urbanized areas like China (Liao et al., 2021) and Brazil (Amato-Lourenço et al., 2022). In terms of morphology, both fibers and fragments were observed, consistent with studies from Sri Lanka, India, and New Jersey (Yao et al., 2022), while fragment dominance aligns with studies in China and Brazil. The detected colors - mainly white and transparent - are similar to those reported in India, Sri Lanka, and London (Boakes et al., 2023b), suggesting common sources such as packaging or domestic items.

Polymer analysis revealed PE, PP, PS, and PVC, with PE and PP also reported in China, Sri Lanka, Pakistan (Sharaf Din et al., 2024), and India. The presence of PS and PVC reflects overlap with India, hinting at shared sources such as insulation or consumer goods. Overall, the findings mirror trends observed in developing regions and highlight the influence of local environmental and human factors on airborne MP profiles.

Environmental factors like wind, waves, and sunlight accelerate MP degradation by fragmenting polymers (Lin et al., 2022), increasing their surface

Table 3. Summary of atmospheric MPs

Sampling location	Sampling environment	Average density MP/m ³ ±SD	Dominant MPs characteristics			References	
			Shape	Color	Polymer type		
Wenzhou City, China	Indoor	1.583±1.181	Fragment	84-94%	PET	28%	Liao et al. (2021)
	Outdoor	189±85		90-96%	PE	27%	
Yangzhou, Jiangsu, China	Indoor	34-69%	Fragment	85-89%	PA	31-57%	Cui et al. (2022)
São Paulo, Brazil	Indoor	73±50.52	Fragment	64%	PE	59%	Amato-Lourenço et al. (2022)
	Outdoor	123.20±47.09		74%		67%	
Sri Lanka	Indoor	0.13-0.93	Fiber	-	PET	60%	Perera et al. (2022)
	Outdoor	0.01-0.23	Fragment	Transparent	PET	48%	
Newark, New Jersey	Indoor	(3.57±1.41) ×10 ³	Fiber	(1.09±0.61) ×10 ⁴	PE	-	Yao et al. (2022)
London, England	Indoor	106 - 344	Fiber	Blue/Transparent	-	-	Boakes et al. (2023)
	Outdoor	23		Blue/Transparent			
NUST, Islamabad, Pakistan	Indoor	4.34±1.93	Fiber	66%	PET	52%	Sharaf Din et al. (2024)
	Outdoor	0.93±0.32		58%		42%	
Ranchi, Jharkhand, India	Indoor	0.0166±0.00097	Fiber	-	PE, PP, PS	-	Nandi et al. (2024)
	Outdoor	2.92±0.0688	Fragment	White/Transparent	PVC		
Marikina, Metro Manila, Philippines	Indoor	0.155±0.09	Fiber	90%	PVC	50%	This study
Philippines	Outdoor	0.341±0.03	Fiber	72%	PET, PA, HDPE, PMMA	25%	
				41%			

area and enhancing their sorption capacity (Wang et al., 2019). SEM-EDX analysis in this study identified additional elements originating from either the natural or virgin plastic composition, suggesting either environmental adsorption. Metals such as Cu, Al, and Ti were detected, consistent with findings from indoor and outdoor air samples in Pakistan (Sharaf Din et al., 2024).

Additionally, Hg, Pb, and Cd are toxic heavy metals that pose serious health risks due to their persistence and bioaccumulation. Mercury, especially as methylmercury, is a potent neurotoxin capable of impairing cognitive function and damaging the kidneys and liver. Lead exposure, particularly in children, causes neurodevelopmental delays, anemia, and cardiovascular issues. Cadmium primarily targets the kidneys, weakens bones, and has carcinogenic potential (Balali-Mood et al., 2021). Although direct causal links between metals adsorbed on MPs and specific health outcomes remains to be established, this study highlights that airborne MPs can act as carriers of hazardous trace elements. Their potential to transport these toxic substances through inhalation pathways emphasizes the possible risks to human health and the environment.

5. CONCLUSION AND RECOMMENDATIONS

This study presents the first characterization of airborne MPs in both indoor and outdoor environments in the Philippines, revealing significant variations in abundance, morphology, and chemical composition. The findings demonstrate that outdoor air harbors nearly double the concentration of MPs compared to indoor environments, emphasizing the influence of traffic emissions, resuspension from road dust, and atmospheric turbulence in enhancing MP dispersion. The dominance of fibrous particles across both environments reflects the extensive shedding of synthetic textiles. The presence of diverse polymer types - PVC indoors and PET, PA, PMMA, and HDPE outdoors - indicates multiple anthropogenic sources, including clothing, packaging materials, and building products.

Beyond physical characterization, elemental analysis through SEM-EDX revealed that MPs serve as potential carriers of toxic metals such as Ti, Cr, Pb, Hg, and Cd, which may originate from industrial emissions, pigments, and fuel combustion. The elevated presence of Pb in indoor PE fibers (18.13%) and Cr in outdoor HDPE fragments (18.29%) highlights potential indoor-outdoor pollution linkages

and the complexity of atmospheric contamination. These findings suggest that MPs not only represent inhalable particulates but also act as vectors of hazardous substances potentially exacerbating human health risks through respiratory exposure.

While the study is limited by its sampling duration and localized scope, it establishes a foundation for understanding atmospheric MP pollution in urban tropical environments. Additionally, the use of GF/C Whatman filters, while effective for general particulate matter, has a nominal pore size and may not efficiently retain smaller MPs or nanoplastics, potentially leading to underestimation of total airborne MP concentrations. Future research should explore seasonal and spatial variability, resuspension dynamics, and human exposure pathways. Integrating toxicological assessments and long-term monitoring will be critical for evaluating the cumulative effects of MPs and their associated contaminants. Ultimately, the study underscores the need for targeted environmental policies, improved waste management, and public awareness campaigns to mitigate airborne MP pollution and safeguard public health.

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AUTHOR CONTRIBUTIONS

Jade Rae Ministerio conceptualized the study, conducted data analysis, and wrote the manuscript. Najiha Amer assisted with sampling and laboratory analysis. Rodolfo Romarate II contributed to manuscript writing and developed the sampling methodology. Hernando Bacosa conceptualized and supervised the research and provided editorial support.

DECLARATION OF CONFLICT OF INTEREST

The authors declare that they have no competing interests relevant to the content of this article.

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