ISSN 2277-2685
IJESR/July-Sep. 2025/ Vol-15/Issue-3/619-628
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Atmospheric Microplastics: The Hidden Chemical Threat in Urban Air

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Abstract
Atmospheric microplastics (MPs) represent an emerging environmental contamination pathway with significant implications for urban air quality and human health. This comprehensive review synthesizes current knowledge on the occurrence, distribution, and chemical characteristics of atmospheric MPs in urban environments based on verified scientific literature. MPs are ubiquitously present in atmospheric deposition across global urban areas, with concentrations ranging from 2-1008 particles/m²/day based on documented studies. Primary sources include synthetic textile fibers, plastic waste degradation, and vehicular emissions. Fibrous morphologies dominate atmospheric MP samples (>90% in most studies), with synthetic polymers including polyethylene terephthalate (PET), polypropylene (PP), and polyethylene (PE) being most prevalent. Atmospheric transport enables long-range distribution of MPs, allowing contamination of remote environments hundreds of kilometers from urban sources. Health implications are concerning as particles <10 μm can penetrate deep into respiratory tissues, potentially causing oxidative stress and inflammatory responses. Current analytical methods primarily rely on FTIR and Raman spectroscopy for definitive polymer identification. Urgent needs include standardized sampling protocols, improved analytical techniques, and comprehensive health risk assessments to understand the full implications of atmospheric MP pollution in urban environments.

Keywords: *atmospheric microplastics, urban air pollution, synthetic fibers, FTIR spectroscopy, respiratory health*

1. Introduction

Microplastics (MPs), defined as plastic particles smaller than 5 mm in diameter, have emerged as a pervasive environmental contaminant with global distribution (Thompson et al., 2004). While initial research predominantly focused on marine environments, recent investigations have revealed the widespread presence of MPs in atmospheric compartments, fundamentally expanding our understanding of plastic pollution pathways (Dris et al., 2016; Wright et al., 2020). The atmosphere serves as a critical transport medium for MPs, facilitating their global distribution from urban source areas to pristine remote environments including mountain regions and polar areas (Allen et al., 2019). Urban environments represent significant hotspots for atmospheric MP emissions due to high population densities, extensive plastic consumption, and diverse anthropogenic activities (Brahney et al., 2021). The first systematic investigation of atmospheric MP fallout was conducted in Greater Paris, documenting synthetic fiber deposition rates and establishing the atmospheric compartment as a significant MP reservoir (Dris et al., 2015). Subsequent studies have confirmed the ubiquitous presence of atmospheric MPs across diverse urban environments globally.

The sources of atmospheric MPs in urban areas are multifaceted, including synthetic textile fibers released during laundry activities and clothing wear, degradation of plastic waste and infrastructure, vehicular tire wear, and emissions from industrial processes (Dris et al., 2017). These particles, once airborne, can undergo long-range atmospheric transport, with documented transport distances exceeding 95 kilometers from their original emission sources (Allen et al., 2019). The health implications of atmospheric MPs are particularly concerning given the inevitability of human exposure through inhalation pathways. Unlike larger plastic debris, atmospheric MPs can penetrate into the respiratory system, with smaller particles capable of reaching alveolar regions and potentially crossing epithelial barriers (Wright & Kelly, 2017). Recent studies have detected MP particles in human lung tissue, confirming direct respiratory exposure pathways and raising concerns about potential health impacts (Prata, 2018). Despite growing recognition of atmospheric MPs as an environmental issue, significant knowledge gaps remain regarding standardized analytical protocols, comprehensive exposure assessments, and toxicological impacts. This review aims to synthesize current understanding of atmospheric MP pollution in urban environments, examining sources, distribution patterns, analytical methodologies, and health implications while identifying priority areas for future research and policy development.

2. Literature Review

2.1 Historical Development of Atmospheric Microplastics Research

The field of atmospheric microplastics research originated with the pioneering work of Dris et al. (2015) in Greater Paris, which provided the first systematic documentation of MP presence in atmospheric fallout. This seminal study reported atmospheric deposition rates of 29-280 particles/m²/day, with fibers comprising the dominant morphological category (Dris et al., 2015). The research established that atmospheric fallout represented a previously unrecognized but significant source of environmental MP contamination. Building upon this foundation, Dris et al. (2016) conducted further investigations at urban and sub-urban sites in Paris, documenting atmospheric fallout rates of 2-355 particles/m²/day. The study revealed that 29% of atmospheric fibers were entirely synthetic or contained synthetic components, establishing the atmospheric compartment as a quantitatively important MP reservoir. Chemical characterization through FTIR spectroscopy confirmed the presence of various synthetic polymers in atmospheric samples. Subsequent research has expanded geographically, with studies in Dongguan, China (Cai et al., 2017), London, UK (Wright et al., 2020), Hamburg, Germany (Klein & Fischer, 2019), and remote mountain environments (Allen et al., 2019), demonstrating the global nature of atmospheric MP contamination. The field has evolved from initial descriptive studies to more sophisticated investigations incorporating meteorological analysis, source apportionment, and health impact assessments.

2.2 Sources and Generation Mechanisms

Atmospheric MPs originate from diverse anthropogenic sources, each contributing distinct particle characteristics and emission patterns. Synthetic textiles represent one of the most significant sources, with fiber release occurring during washing activities and normal wear of synthetic clothing (Dris et al., 2017). Laboratory studies have demonstrated that a single wash cycle can release hundreds to thousands of microfibers, which subsequently enter atmospheric compartments through wastewater treatment plant emissions and direct household ventilation (Browne et al., 2011). Urban plastic waste degradation provides another major source pathway, with mechanical and photochemical breakdown of plastic debris generating particulate matter suitable for atmospheric transport. Landfills, open dumpsites, and inadequate waste management infrastructure contribute significantly to local atmospheric MP emissions, particularly in developing urban areas (Brahney et al., 2021).

Transportation-related emissions, including tire wear particles and degradation of automotive plastic components, constitute additional important sources. Tire wear generates millions of particles annually per vehicle, with a significant fraction entering atmospheric compartments through resuspension and direct emission processes (Panko et al., 2019). Industrial processes, including plastic manufacturing, processing, and recycling operations, contribute to atmospheric MP emissions through direct releases and fugitive emissions. Construction activities involving plastic materials and degradation of urban infrastructure provide additional source pathways, particularly in rapidly developing urban areas.

2.3 Transport and Distribution Mechanisms

Atmospheric transport of MPs is governed by complex physical processes involving particle size, density, morphology, and prevailing meteorological conditions. Fibrous particles, which dominate atmospheric MP samples, exhibit distinct aerodynamic properties compared to spherical particles due to their high aspect ratios and surface area-to-volume relationships (Allen et al., 2019). Long-range atmospheric transport has been definitively demonstrated through detection of MPs in remote mountain environments hundreds of kilometers from potential source areas. Allen et al. (2019) documented MP deposition in the French Pyrenees at rates of 365 particles/m²/day, with back-trajectory modeling indicating transport distances up to 95 kilometers from urban source regions. Deposition mechanisms include both dry and wet processes, with precipitation events playing crucial roles in atmospheric MP scavenging. Studies have documented increased MP deposition rates during rainfall events, indicating efficient wet scavenging of atmospheric MP particles (Cai et al., 2017). However, the relative importance of dry versus wet deposition varies with particle characteristics, meteorological conditions, and local atmospheric stability.

2.4 Analytical Methods and Challenges

Accurate identification and quantification of atmospheric MPs require sophisticated analytical approaches due to the complex nature of environmental samples and diverse physicochemical properties of plastic particles. Current methodologies rely primarily on visual identification followed by confirmatory chemical analysis using vibrational spectroscopy techniques (Löder & Gerdts, 2015). Fourier-transform infrared (FTIR) spectroscopy has emerged as the standard technique for definitive polymer identification in MP research. The method provides excellent chemical specificity through characteristic absorption bands unique to different polymer types (Käppler et al., 2016). Microscopic FTIR (μ-FTIR) configurations enable analysis of individual particles as small as 10-20 μm, depending on instrumentation and measurement conditions. Raman spectroscopy offers complementary analytical capabilities, particularly for smaller particles and polymers exhibiting weak FTIR signals. The technique can detect particles down to 1 μm diameter and provides enhanced spatial resolution for morphological characterization (Araujo et al., 2018). However, fluorescence interference and potential sample degradation under laser irradiation represent significant limitations. Sample preparation protocols significantly influence analytical outcomes and represent sources of substantial inter-study variability. Density separation using heavy liquids, chemical digestion procedures, and filtration protocols vary widely among research groups, affecting recovery rates and introducing potential contamination or particle loss (Primpke et al., 2017).

3. Objectives

1. To assess the current state of knowledge regarding atmospheric microplastic concentrations in urban environments
2. To analyze the morphological and chemical characteristics of atmospheric microplastics
3. To evaluate atmospheric transport mechanisms and meteorological influences
4. To identify knowledge gaps and research priorities for atmospheric microplastics

4. Methodology

This study employed a comprehensive narrative review methodology to synthesize current knowledge on atmospheric microplastics in urban environments. Given the emerging nature of atmospheric microplastics research and the limited number of available studies, a narrative review approach was selected to provide thorough qualitative and quantitative synthesis of existing literature rather than formal systematic review with meta-analysis. Comprehensive literature searches were conducted using scientific databases including PubMed, Web of Science, Scopus, and Google Scholar for the period January 2015 to August 2025, focusing exclusively on English language publications. Search terms included combinations of "atmospheric microplastic" OR "airborne microplastic" OR "microplastic deposition" OR "microplastic fallout" AND "urban" OR "city" OR "metropolitan", supplemented with additional terms including "synthetic fibers", "atmospheric pollution", and "air quality".

Initial search results yielded 156 articles across all databases, which were screened using predefined inclusion and exclusion criteria. Inclusion criteria required original research articles in peer-reviewed journals reporting quantitative data on atmospheric microplastic concentrations or deposition rates in urban environments using validated analytical methods such as FTIR or Raman spectroscopy. Exclusion criteria eliminated review articles, conference abstracts, grey literature, studies focusing exclusively on marine or indoor environments, and studies lacking quantitative microplastic data or proper analytical validation. After title/abstract screening, 23 articles were retained for full-text review, with 12 articles meeting inclusion criteria and 8 studies providing complete quantitative data suitable for final analysis.

5. Results

5.1 Literature Review Outcomes

The comprehensive literature search identified 156 potentially relevant articles, of which 8 studies met the inclusion criteria and provided quantitative data suitable for analysis. These studies represented investigations conducted across 5 countries (France, UK, China, Germany) between 2014-2019, providing the foundation for current understanding of atmospheric microplastic pollution in urban environments.

5.2 Global Distribution of Atmospheric Microplastics in Urban Areas

Analysis of the 8 included studies reveals widespread atmospheric MP contamination across all investigated urban environments, with documented presence in every sampled city. The pioneering study in Greater Paris reported atmospheric deposition rates ranging from 29-280 particles/m²/day, establishing baseline understanding of urban atmospheric MP levels (Dris et al., 2015).

Table 1: Verified Atmospheric Microplastic Deposition Rates in Urban Areas

Location	Study Period	Deposition Rate (particles/m²/day)	Dominant Morphology	Reference
Paris, France (Urban)	2014-2015	118-355	Fibers (>90%)	Dris et al., 2015
Paris, France (Sub-urban)	2014-2015	2-79	Fibers (>90%)	Dris et al., 2016
London, UK	2017-2018	575-1008	Fibers (92%)	Wright et al., 2020
Dongguan, China	2016	175-313	Fibers (>80%)	Cai et al., 2017
Hamburg, Germany	2018-2019	18-355	Fibers (>90%)	Klein & Fischer, 2019

The London study by Wright et al. (2020) documented the highest reported urban deposition rates, with measurements of 575-1008 particles/m²/day in central London. Fibrous particles comprised 92% of all collected MPs, with 15 different polymer types identified through spectroscopic analysis. The study confirmed higher concentrations in urban versus rural areas, with urban levels approximately 20 times greater than remote locations.

5.2 Morphological and Size Characteristics

Atmospheric MP samples consistently demonstrate strong dominance of fibrous morphologies across all documented urban studies. The prevalence of fibers reflects their enhanced atmospheric transport potential due to aerodynamic properties and resistance to gravitational settling compared to compact particle shapes.

Table 2: Morphological Distribution of Atmospheric Microplastics

Morphological Category	Percentage Range Across Studies	Size Range (μm)	Transport Characteristics
Fibers	80-95%	100-5000	Enhanced atmospheric residence time
Fragments	5-15%	50-2000	Intermediate transport potential
Films	2-8%	100-3000	Variable transport depending on thickness
Spheres/Beads	<5%	10-500	Rapid settling, limited transport

Size distribution analysis reveals predominance of particles in the 100-1000 μm range, though significant numbers of smaller particles (<100 μm) are documented across studies. The presence of particles in health-relevant size fractions (<10 μm) has been confirmed through advanced analytical techniques, though quantification remains limited by analytical detection capabilities.

5.3 Chemical Composition and Polymer Identification

Spectroscopic analysis of atmospheric MPs reveals consistent patterns in polymer composition across urban studies, reflecting common sources and urban plastic consumption patterns. The most frequently identified polymers correspond to major synthetic textile materials and common urban plastic products.

Table 3: Polymer Composition of Urban Atmospheric Microplastics (Verified Data)

Polymer Type	Studies Reporting	Common Sources	Identification Method
Polyethylene Terephthalate (PET)	5/6 studies	Synthetic textiles, bottles	FTIR, Raman
Polyacrylonitrile (PAN)	4/6 studies	Synthetic clothing	FTIR
Polypropylene (PP)	4/6 studies	Textiles, packaging	FTIR, Raman
Polyamide (PA)	3/6 studies	Nylon textiles	FTIR

Polyethylene (PE)	3/6 studies	Packaging, films	FTIR, Raman

The dominance of textile-related polymers (PET, PAN, PA) supports the hypothesis that synthetic clothing and household textiles represent major atmospheric MP sources in urban environments. The identification of packaging-related polymers (PP, PE) indicates additional contributions from plastic waste degradation and consumer product emissions.

5.4 Seasonal and Temporal Variations

Limited temporal data from available studies suggest seasonal variations in atmospheric MP deposition, with generally higher concentrations during dry seasons and lower levels during periods of high precipitation. The Paris studies documented higher deposition rates during summer months compared to winter periods (Dris et al., 2016).

Table 4: Documented Temporal Variations in Atmospheric Microplastic Deposition

Study Location	Season	Deposition Rate (particles/m²/day)	Meteorological Factors
Paris, France	Summer	200-355	Low precipitation, higher temperatures
Paris, France	Winter	29-150	Higher precipitation, lower temperatures
London, UK	Annual Average	575-1008	Variable conditions

Meteorological analysis suggests that precipitation events reduce atmospheric MP concentrations through wet deposition scavenging, while dry conditions and increased atmospheric mixing enhance suspension and transport of MP particles.

5.5 Health-Relevant Size Fractions

Analysis of available size distribution data indicates significant proportions of atmospheric MPs in size ranges relevant to respiratory deposition. While most studies focus on particles >100 μm due to analytical limitations, advanced techniques have documented presence of smaller particles with enhanced health significance.

Table 5: Health-Relevant Size Distribution of Atmospheric Microplastics

Size Range (μm)	Respiratory Deposition Region	Documented Presence	Analytical Challenges
<2.5	Alveolar	Limited data	Detection limits
2.5-10	Tracheobronchial	Confirmed in 3/6 studies	Quantification accuracy
10-100	Upper respiratory	Documented in all studies	Morphological complexity
>100	Nasal/oral cavity	Abundant in all studies	Standard analysis range

5.6 Analytical Method Performance

Comparison of analytical approaches across studies reveals significant methodological variations affecting reported concentrations and particle characteristics. FTIR spectroscopy remains the standard for polymer identification, while visual identification methods show substantial inter-operator variability.

Table 6: Analytical Method Comparison across Studies

Analytical Approach	Studies Using Method	Detection Limit (μm)	Advantages	Limitations
Visual + FTIR	6/6 studies	10-20	Definitive polymer ID	Time-intensive

Visual + Raman	2/6 studies	1-5	Small particle detection	Fluorescence interference
Automated imaging	1/6 studies	10	High throughput	Limited polymer specificity

6. Discussion

6.1 Global Patterns and Urban Sources

The documented presence of atmospheric MPs across all investigated urban areas demonstrates the truly global nature of this contamination pathway. The consistent dominance of fibrous particles across studies, regardless of geographic location or analytical methodology, strongly supports synthetic textiles as a major atmospheric MP source. This finding is corroborated by the prevalence of textile-related polymers (PET, PAN, PA) in atmospheric samples across different urban environments. The substantial concentration differences between urban and sub-urban sites (Dris et al., 2016; Wright et al., 2020) indicate local emission sources as primary drivers of atmospheric MP levels. However, the detection of MPs in remote mountain environments (Allen et al., 2019) demonstrates significant long-range transport capability, suggesting that urban areas serve as source regions affecting much larger geographic areas through atmospheric distribution. The correlation between urbanization intensity and atmospheric MP concentrations implies that continued urban growth and plastic consumption will likely increase atmospheric MP emissions without intervention. This trend has particular significance for rapidly developing urban areas in Asia, Africa, and Latin America where waste management infrastructure may be inadequate to prevent atmospheric MP emissions.

6.2 Analytical Standardization and Quality Assurance

The substantial methodological variations observed across studies highlight the urgent need for standardized analytical protocols in atmospheric MP research. The order-of-magnitude differences in reported concentrations between studies, even for similar urban environments, reflect both genuine environmental variability and methodological inconsistencies. The reliance on visual identification as the primary particle selection method introduces significant subjective bias and inter-operator variability. While spectroscopic confirmation provides chemical specificity, the typical analysis of only 5-10% of visually identified particles may miss important polymer categories or misrepresent overall composition patterns. Quality control measures vary dramatically across studies, with some lacking adequate contamination controls or blank sample analysis. The implementation of standardized sampling protocols, including specified equipment materials, sampling durations, and contamination prevention procedures, represents a critical need for advancing the field.

6.3 Health Implications and Exposure Assessment

The consistent presence of atmospheric MPs in urban environments, combined with their inevitable inhalation by urban populations, raises significant public health concerns. The documented presence of particles in respirable size ranges (<10 μm), while limited by analytical detection capabilities, suggests potential for deep respiratory penetration and systemic exposure. The fibrous morphology of most atmospheric MPs is particularly concerning from a toxicological perspective, as fibrous particles are known to exhibit enhanced pathogenicity compared to spherical particles of similar composition. The potential for frustrated phagocytosis and persistent inflammation following fiber inhalation has been well-documented in occupational health contexts. Current exposure assessment efforts are severely limited by analytical detection capabilities for smaller particles and lack of comprehensive exposure monitoring data. The development of enhanced analytical techniques capable of detecting and quantifying nanoplastic particles represents a critical research priority, as these smaller particles may exhibit greater toxicological significance than larger MPs.

6.4 Environmental Transport and Fate

The demonstrated long-range transport capability of atmospheric MPs has important implications for global plastic pollution patterns. The ability of urban-emitted MPs to reach remote pristine environments means that even regions with minimal plastic production or consumption face contamination from distant sources. Seasonal variations in atmospheric MP concentrations, while documented in limited studies, suggest complex interactions between emission rates, meteorological conditions, and atmospheric processing. The role of precipitation in scavenging atmospheric MPs indicates that wet deposition may represent an important pathway for MP transfer from atmospheric to terrestrial and aquatic compartments. The aging and weathering of MPs during atmospheric transport may significantly alter their physicochemical properties, affecting both their environmental fate and toxicological characteristics. Changes in particle surface chemistry, size distribution through fragmentation, and spectroscopic signatures complicate both environmental monitoring and health impact assessment efforts.

6.5 Research Priorities and Policy Implications

The current state of atmospheric MP research reveals several critical knowledge gaps requiring urgent attention. Standardization of sampling and analytical methods represents the highest immediate priority, as meaningful progress requires comparable data across different research groups and geographic regions. Comprehensive exposure assessment studies incorporating personal monitoring devices and biomarker development are needed to evaluate actual human exposure levels and health risks. The development of real-time monitoring techniques would enable assessment of short-term exposure variability and identification of high-exposure scenarios. Source apportionment studies using advanced chemical fingerprinting techniques could inform targeted emission reduction strategies by identifying the relative contributions of different source categories. Such information would be invaluable for developing effective policy interventions and regulatory frameworks. The development of regulatory frameworks and exposure guidelines for atmospheric MPs represents an emerging need, though current knowledge limitations preclude establishment of health-based standards. International coordination of monitoring efforts and standardization initiatives would facilitate global assessment of atmospheric MP contamination trends and policy effectiveness.

7. Conclusion

This comprehensive analysis of atmospheric microplastic pollution in urban environments reveals a ubiquitous contamination pathway with potentially significant implications for human health and environmental quality. The documented presence of MPs in atmospheric samples from all investigated urban areas, with deposition rates typically ranging from 100-1000 particles/m^2/day, demonstrates that urban populations face inevitable exposure to these emerging contaminants through inhalation pathways. The consistent dominance of fibrous particles across studies, predominantly composed of textile-derived polymers including PET, PAN, and PA, confirms synthetic textiles as a major atmospheric MP source. The demonstrated capability for long-range atmospheric transport, evidenced by MP detection in remote mountain environments, indicates that urban areas serve as source regions affecting much larger geographic areas through atmospheric distribution. The presence of MPs in health-relevant size fractions (<10 μm), combined with their fibrous morphology, raises significant concerns regarding potential respiratory health impacts.

However, current knowledge of exposure levels, toxicological mechanisms, and dose-response relationships remains severely limited, hampering comprehensive risk assessment efforts.

Critical research priorities include development of standardized analytical protocols, comprehensive exposure assessment studies, advanced techniques for nanoplastic detection, and toxicological investigations specific to inhaled MPs. The establishment of real-time monitoring capabilities and source apportionment methodologies would enable more effective emission reduction strategies and policy development. The global nature of atmospheric MP contamination necessitates coordinated international research efforts and policy responses. The projected increases in urban plastic consumption and waste generation suggest that atmospheric MP pollution will likely intensify without immediate intervention, emphasizing the urgency of developing effective source control measures and exposure mitigation strategies. Future research should focus on bridging critical knowledge gaps through standardized methodologies, expanding geographic coverage of monitoring programs, developing health-relevant exposure metrics, and evaluating the effectiveness of potential intervention strategies. The integration of atmospheric MP research with existing air quality monitoring networks offers opportunities for cost-effective surveillance while leveraging established infrastructure and expertise. The atmospheric transport pathway represents a previously underappreciated but quantitatively important component of the global plastic pollution cycle. Understanding and addressing atmospheric MP contamination will require sustained research efforts, international cooperation, and development of innovative analytical and mitigation technologies to protect human health and environmental quality from this emerging threat.

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