

## **Microplastics as an emerging source of particulate air pollution: A critical review**

**Srinidhi Sridharan<sup>1,2</sup>, Manish Kumar<sup>2</sup>, Lal Singh<sup>1,2</sup>, Nanthi S. Bolan<sup>3,4</sup>, Mahua Saha<sup>\*1,5</sup>**

<sup>1</sup> Academy of Scientific and Innovative Research (AcSIR), Ghaziabad - 201002, Uttar Pradesh, India.

<sup>2</sup> CSIR-National Environmental Engineering Research Institute, Nagpur - 440020, Maharashtra, India.

<sup>3</sup>Global Centre for Environmental Remediation, University of Newcastle, Callaghan, NSW, 2308, Australia

<sup>4</sup>Cooperative Research Centre for High-Performance Soils, Callaghan, NSW 2308, Australia.

<sup>5</sup>CSIR-National Institute of Oceanography, Dona Paula - 403004, Goa, India.

\*Corresponding author: Mahua Saha, Senior Scientist, Chemical Oceanography Division, CSIR - National Institute of Oceanography, Dona Paula - 403004, Goa, India.

Email ID:mahuas@nio.org

### **Abbreviations**

AQI	Air Quality Index
MFs	Microfibers
MPs	Microplastics
MR	Micro rubber
NPs	Nanoplastics
PM	Particulate matter
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PE	Polyethylene
PA	Polyamide
PP	Polypropylene
PS	Polystyrene
PET	Polyethylene terephthalate
PC	Polycarbonate
PTT	Polytrimethylene terephthalate
PUR	Polyurethane
PVC	Polyvinyl chloride
PAN	Polyacrylonitrile
WHO	World Health Organization

## **Abstract**

Accumulation of plastic litter exerts pressure on the environment. Microplastics (MPs) pollution has become a universal challenge due to the overexploitation of plastic products and unsystematic dumping of plastic waste. Initial studies on MPs and their implications had been confined to aquatic and terrestrial ecosystems, but recent research has also focused on MPs in the air. Their impacts on urban air quality and atmospheric transport to pristine habitats have emerged to be a serious concern. However, the extent and the significance of impacts of airborne particulate matter (PM) MPs on human health are not clearly understood. Further, the influence of airborne MPs on indoor and outdoor air quality remains unknown. We highlight the human health impacts of airborne PM-MPs with a special focus on the occupational safety of the industry workers, their possible influence on Air Quality Index (AQI), their potential exposure, and accumulation in the canopy/arboreal, above-canopy and atmospheric (aerial) habitats. The present review emphasizes the data limitations and knowledge gaps on the atmospheric transport and contribution of particulate plastics to the worsening of overall urban air quality and throws critical perspectives on whether atmospheric MPs pollution is trivial or an actual matter of concern.

**Keywords:** Microplastic, Atmospheric fallout, Air Quality Index, Particulate matter, Human health

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## 1. Introduction

Plastic litter, which has been identified as a planetary crisis of this generation, has already become widespread in all the marine ecosystems via river transport ([Lebreton et al., 2019](#); [Routti et al., 2019](#); [PlasticsEurope, 2018](#)). Plastic waste accounts for around 80-85% of the ocean litter ([Barnes, 2019](#); [Ostle et al., 2019](#)). With a global plastic production of 400 million tons per year ([Henry et al., 2019](#)) by 2025, 11 billion metric tons of plastics are likely to pool up in the environment ([Brahney et al., 2020](#)). Within five decades, plastic production has progressed into a global industry of 600 billion USD ([Uheida et al., 2021](#)). Around 60% of the globally manufactured plastics are likely to have already accumulated in the environment ([UNEP beat plastic pollution](#)). Only 9% of plastic waste is being recycled (only in developed countries), and the remaining 91% stays in the environment for centuries ([Brooks et al., 2018](#)) and generates MPs (1  $\mu\text{m}$  – 5 mm). Primary (designed  $\leq 5$  mm) and secondary (abraded from larger plastic particles; varied size range) MPs have been detected in most biomes, which has emerged to be a critical global challenge ([Barnes, 2019](#); [Iñiguez et al., 2018](#); [Zettler et al., 2013](#)).

MPs have been widely acknowledged as a universal emerging contaminant in the terrestrial and aquatic environment. [Goeppert and Goldscheider \(2021\)](#) observed long-range transport of 1 - 5  $\mu\text{m}$  MP tracer particles in alluvial aquifers through advection and dispersion, highlighting their pervasion into groundwater. Contaminated rivers accumulate and transport MPs to the ocean. Synthetic textile fibers significantly contribute to the MPs pollution in the marine environment ([Routti et al., 2019](#)) mainly from wastewater treatment plants ([Revel et al., 2018](#)) and sewage sludge used for land applications ([Xu et al., 2020a](#); [2020b](#)). Processed biosolids and sewage sludge applications deposit MPs in the terrestrial environment and further spread them to the aquatic environment ([Xu et al., 2020a](#)). Compost spreading is recognized to be an important source of airborne MPs. For example, the New South Wales Environmental Protection Agency (2016) specified that composts supplied for land application should not contain  $>0.5\%$  (dry weight) of glass, metal, and rigid plastics ( $> 2$  mm), or  $0.05\%$  (dry weight) for flexible plastics ( $> 5$  mm). Moreover, wastewater treatment plants (e.g., textile and fiber industries), which usually do not retain primary MPs, are also recognized as a potential source of secondary MPs (disintegration of large particles to MPs during treatment processes) ([Kay et al., 2018](#)). Nearly 35% of primary MPs in the oceans are textile microfibers (MFs), with polyester being the predominantly produced synthetic fiber ([Henry et al., 2019](#)). The major synthetic fibers documented in shorelines include polyester (56%), acrylic (23%), polypropylene (PP)(7%), polyethylene (PE)(6%), and polyamide (PA)(3%) ([Henry et al., 2019](#)). However, a few recent studies document the predominance of natural fibers (like wool, cotton) in the

environment over the synthetic ones, highlighting the possible misidentification of natural fibers as synthetic MPs in the previous studies due to the limited characterization methods. For instance, Stanton et al. (2019) demonstrated the abundance of natural textile fibers (93.8%) among the total fiber amount estimated from the River Trent (United Kingdom). Nevertheless, fibrous MPs (both biodegradable and synthetic polymers) pose greater implications for the environment and health (Henry et al., 2019), but the relationship between MFs dispersion in air and the MFs abundance in the oceans and rivers remains largely unexplored. These light fibers readily get dispersed to air due to smaller sizes/lengths as opposed to comparatively heavier particulates of larger sizes (Enyoh et al., 2019). As of 2016, the global production of synthetic fibers has surpassed 60 million metric tons (Gasperi et al., 2018). Fragments and fibers are the predominant forms of atmospheric MPs (Zhang et al., 2020c). Every wash of a 5 kg load of polyester-fiber textile fabric can release more than 6 million MFs (Falco et al., 2018). However, quantitatively not much is known about the contribution of laundry in the atmospheric MPs. Although natural and biodegradable (processed) MFs such as cotton, wool, hemp, cellulose, etc. have received very little attention in comparison with synthetic MFs, the implications of natural fibers on the environment and human health are also important, which remain largely unknown.

MPs have been identified not only in water and the soil, but also in the air: an underrated, but a potential source of respiratory and oral exposure (Amato-Lourenço et al., 2020; Prata, 2018). For instance, Shruthi et al. (2020) identified MPs (epoxy, polytrimethylene terephthalate (PTT)) from public potable water fountains in 42 different metro stations in Mexico City. These contaminated decorative/potable public fountains can spray MPs along with the mist/water aerosols into the air, which may also be a potential source, but its contributions are underestimated for air MPs. However, unfortunately, the study did not explore if such contaminated public fountains could be a possible source for airborne MPs. Airborne MPs (fibers, fragments, filaments) identified so far across the world range from 2  $\mu\text{m}$  to 1 mm, with rayon, PA, PE, PP, polystyrene (PS), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polyurethane (PUR), polyacrylonitrile (PAN) being the predominant polymers (Enyoh et al., 2019). Moreover, studies confirm that plastics involved in packaging applications like PS, PE, PET, biothene (a commercial biodegradable brand) deteriorate and generate MPs much faster in the air than in water (Biber et al., 2019). Therefore, the risk of exposure to air-borne MPs is very high for industrial workers (mainly polymer, packaging, flock, textile industries) (Chen et al., 2020a), but the effectiveness of personal protection available for them is uncertain.

The risk factors associated with MPs increase with weathering of plastic waste when exposed to environmental conditions (Mao et al., 2020). Weathering mechanisms and behavior of the airborne MPs are different from terrestrial or aquatic plastics (Ding et al., 2020). The MPs that get exposed to the environment (ultraviolet rays, hydrological conditions such as turbulence) become ‘aged’ due to weathering and aged MPs pose a greater threat to the environment and health than the virgin (fresh/unaged) MPs (Mao et al., 2020; Song et al., 2021). Ding et al. (2020) explored the long-term aging and adsorption processes of PS MPs in air, seawater, and freshwater, and at high temperatures (75°C), they observed a characteristic carbonyl bond (C=O) formation in aged airborne MPs. As C=O bonds are highly reactive, it changes the surface texture and characteristics of MPs (pits, grooves) (Mao et al., 2020), which can enhance their adsorption behavior. Therefore, environmental exposure can influence the adsorption characteristics of MPs. For instance, PE MPs exposed to air can adsorb copper and tetracycline more effectively than the fresh or virgin (unexposed) particles (Wang et al., 2021d). Therefore, aged airborne MPs may possess their own intrinsic toxicity in addition to their chemical additives or adsorbed co-existing pollutants, and hence carries higher health risks than the fresh or virgin MPs entering the atmosphere. Exposure to aerial MPs or nanoplastics (NPs) can occur through oceanic waves (sea spray), atmospheric fallout from wastewater sludge through land applications or other matrices (Revel et al., 2018), waste incineration, landfills, building materials, plastic fragments from house furniture, traffic particles (tire/brake wear), industrial emissions, mulching particles in soil (Wang et al., 2021a). MPs can adsorb/desorb co-existing pollutants like polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), antibiotics, and also leach out additives like Bisphenol A (BPA), phthalates, and other endocrine disruptors into the environment (Akhbarizadeh et al., 2021; Wang et al., 2021d). Temperature plays a key role in the adsorption and release of additives to the environment. For instance, Ranjan et al. (2021) observed the release of ~25,000 small MP particles from a PE liner of a hot paper cup, with traces of heavy metals. Several studies confirm the toxicity of MPs linked with intestinal blockage, internalization by white blood cells, cerebral oxidative stress, and metabolic disorders (Revel et al., 2018). Chen et al. (2020a) carefully reviewed the ubiquity, wind transport, human exposure, health implications of airborne MPs, and the factors favoring their deposition in the aquatic environment. However, the study did not discuss whether the scavenging effect, a potential route of transfer, could lead to wet or dry precipitation of MPs in a remote ecosystem.

Worldwide, exposure and health implications of airborne MPs are much less understood than aquatic/terrestrial MPs (**Figure 1**), because detailed documentation of the major types, sources, and concentrations of MPs in ambient air is lacking in many countries. In recent times, research is

emerging to explore more about the abundance and potential threats of MPs in the aerial environment. However, very little is known of airborne MPs and more extensive studies are needed to understand and comprise them in the mainstream air pollution research as well as in governance and policy ([Amato-Lourenço et al., 2020](#); [Gasperi et al., 2015](#)). Though research on the characterization of airborne MPs started in 2015, there are just around 40 scientific articles that document atmospheric MPs and NPs ([Can-Güven, 2020](#)). Out of nearly 180 peer-reviewed papers and reports focusing on the implications of MP pollution concerning human health, only 22 papers are dedicated to the health impacts of atmospheric MPs (**Figure 1**). All the existing reviews highlighted the following: (1) MPs are present in every biome of this planet including polar regions ([Kanhai et al., 2020](#); [Reed et al., 2018](#); [Isobe et al., 2016](#); [Lusher et al., 2015](#)) and remote locations ([Allen et al., 2019](#); [Imhof et al., 2017](#); [Bouwman et al., 2016](#); [Veerasingam et al., 2016](#)) (2) MPs can be transported to remote ecosystems via atmospheric wind circulation and sea-breeze ([Chen et al., 2020a](#); [Evangelidou et al., 2020](#); [Wang et al., 2020](#); [Zhang et al., 2019](#)); (3) MPs are detrimental to the global ecosystem ([Kumar et al., 2021](#); [Wang et al., 2021b](#); [Brahney et al., 2020](#); [Kumar et al., 2020](#); [Malizia and Monmany-Garzia, 2019](#)) (4) MPs are present at non-negligible concentrations in urban air and street dust ([Allen et al., 2020](#); [Järnskog et al., 2020](#); [Thinh et al., 2020](#); [Abbasi et al., 2019](#)) (5) MPs are found not only in the outdoor but also in the indoor environment ([O'Brien et al., 2020](#); [Wright et al., 2019](#); [Yurtsever et al., 2018](#); [Dris et al., 2017](#)); (6) Airborne MPs can absorb and carry along other toxic pollutants to isolated regions ([Akhbarizadeh et al., 2021](#); [Sun et al., 2020](#); [Xu et al., 2020a](#); [Hahladakis et al., 2018](#)).

None of the available literature reports an extensive study on the implications of airborne MPs toward occupational safety and long-term inhalation exposure in plastic industries. To the best of the authors' knowledge, 30 published reviews are focusing on airborne MPs, yet there is no policy review available to date. No study attempts to quantify the influence of airborne MPs in the overall air quality of a region. A few review articles on airborne MPs have focused on the identification and characterization (from indoor/outdoor air) ([Enyoh et al., 2019](#); [Dris et al., 2017](#); [Dris et al., 2016](#)), human exposure, pathogenesis, toxicity, and health impacts ([Chen et al., 2020a](#); [Prata et al., 2020](#); [Prata, 2018](#)), their sources and fate ([Can-Güven, 2020](#); [Chen et al., 2020a](#)), polymer types and distribution in urban/rural atmosphere ([Amato-Lourenço et al., 2020](#)). However, more information is needed to understand how much airborne MPs contribute to the overall PM pollution of a region. The available literature does not highlight the potential exposure of atmospheric MPs to the top layers of the forest (canopy and emergent) ecosystem, which are prone to direct MPs deposition (flora) and inhalation (fauna). The present review critically investigates MPs as an emerging source

of particulate air pollution by atmospheric transport to remote locations (wind transport of MPs followed by wet and dry deposition by scavenging effect from the atmospheric to the terrestrial and aquatic environment), with a special focus on the emerging and less explored problems such as the current addressal(policy and science) of the industrial/domestic human exposure, implications relating to the COVID-19 pandemic, direct exposure and the possible impacts on the remote forest ecosystems (not discussed till date) and the aerial food chain, visibility and AQI. Thus, we systematically analyze the available literature on the field and provide some novel insights into the current issues. Documentation studies on airborne MPs (indoor and outdoor) along with the applied characterization methods have also been overviewed (**Table 1**).

## **2. Methodology**

The potential papers were searched, screened, and selected as represented in **Figure 2**. For this review, peer-reviewed journal articles/books, reports, and methodically scrutinized information from commercial websites were thoroughly studied. The primary search engine used for the literature survey was Google Scholar. The existing literature was thoroughly searched through the most accessible and widely acknowledged databases like PubMed (40 references), Scopus (62 references), Web of Science (10 references), ScienceDirect (18 references), ResearchGate (4 references), and other online sources ([www.who.int](http://www.who.int), [www.semanticscholar.org](http://www.semanticscholar.org), <https://www.tandfonline.com/>, <https://www.ptonline.com/>). The initial keywords used for the literature survey included plastic litter; microplastics; nanoplastics; microfibers; microplastics human health; microplastics exposure, which were further specified to airborne microplastics; atmospheric microplastics; microplastics atmospheric transport; microplastics deposition; microplastics inhalation; microplastics in indoor air, then further screened for studies or reviews linking AQI; particulate matter; aerosol. The total number of entities collected from each database was carefully saved, scrutinized, and sorted to overcome repetitive results among the search engines. Then the collected papers were studied and screened in regard to the objectives of the present review. The available review articles in this field were carefully sorted out and analyzed. Although it is acknowledged that airborne MPs are a threat to global ecosystems and health, the degree of impact is poorly understood. To understand the magnitude of the problem, the routes for atmospheric MPs emission and transport need to be explored.

## **3. Sources of atmospheric MPs**

To understand the atmospheric fallout of MPs, it is essential to understand the deterioration and disintegration characteristics of various plastics in the air. For instance, PS generates secondary MPs



very rapidly in the air as the molecular chains of the polymers can be broken easily by irradiation of solar ultraviolet rays (Biber et al., 2019). It is also important to note that plastics that persist in the environment for a long time (long service life) disintegrate less frequently but do still generate MPs (Biber et al., 2019). Compost spreading (NSW Environmental Protection Agency, 2016), wastewater sludge (Revel et al., 2018), tire (Abbasi et al., 2019), paint (Horton and Dixon, 2018) are widely identified as potential sources for atmospheric MPs. As the aerial fallout rates of plastic particulates vary with locations (local emission) depending on the source and type of polymer, the release of MPs into the air varies with geography (distribution of land, water, climate, wind) and land use pattern (agriculture, industries) (Kawecki and Nowack, 2020). The concentration and characteristics of airborne MPs are dependent on wind and distance from source areas (Wright et al., 2020). Meteorological factors like windspeed, boundary layer mixing, temperature, etc., also influence the transport of atmospheric PM-MPs (Ojha et al., 2020). An increase in the concentration of synthetic MPs in terrestrial and aquatic ecosystems during winter suggests that precipitation and rainfall can potentially influence the atmospheric MPs (Dris et al., 2017). Precipitation (monsoon) leads to the land surface deposition of tiny atmospheric particulates, which are emitted back to air through the post-monsoon winds (flow from high pressure to low-pressure zones), and hence air pollution hotspots like Indo-Gangetic Plain regularly witness increased levels of fine PM (PM<sub>2.5</sub>) in winter (Ojha et al., 2020).

Monsoon winds also play an important role in the continental transboundary transport of airborne MPs. For instance, the East Asian summer monsoon can transport some of the atmospheric MPs from Vietnam to southeastern China via the Philippines and Malaysia (Wang et al., 2021c). Rezaei et al., (2019) observed that light-density MPs were abundant in the wind-eroded sediments of natural and agricultural soils by 2.83 to 7.63 enrichment ratio (MPs content in the eroded material to the that in the original soil), suggesting a key role in atmospheric MPs transport by wind. Brahney et al. (2020) reported the sensitivity of MPs to wind entrainment due to wet and dry deposition. They studied the deposition rates of MPs in 11 protected national parks in the United States of America (U.S.A) for 2 years, where 98% of the rainwater samples contained MPs. The study established the long-range transport and precipitation of MPs into remote protected forests. Therefore, due to the airborne migration of MPs, all the atmospheric compartments (atmospheric fallout, suspended or street/road dust, outdoor and ambient air) can become their potential sink and source for terrestrial and aquatic MPs pollution (Mbachu et al., 2020).

#### 4. Role of the atmosphere in the global transport of MPs

Airborne MPs tend to have densities lower than soil minerals, and hence MP dust particulates stay in the air for a prolonged period compared to natural dust aggregates of the same size, which facilitate their transport to distant locations ([Rochman and Hoellein, 2020](#)). Thus, the atmosphere is a potential vehicle for the transport of MPs to broader biomes: terrestrial, aquatic, and aerial. Air-sea interactions are modulated by the cloud cover and meteorological factors, which play a role in the worldwide transport of atmospheric particles ([Takahashi and Hayasaka, 2020](#)). Atmospheric currents are as important as oceanic currents (gyres) in the global transport of MPs ([Gouin et al., 2011](#)). Wind stress and sea spray form sea salt-MP aerosols (<0.2 to >2000  $\mu\text{m}$ ) and disperse the aerosolized sea-surface particles to urban areas near the coasts, which also may carry MPs, which remain largely unknown ([Wright and Kelly, 2017](#)). [Liu et al. \(2019c\)](#) provided field-based evidence of atmospheric transport of MPs from terrestrial to the marine environment. Through continuous cruise sampling of suspended atmospheric MPs in the western Pacific Ocean, the study observed airborne MPs with consistent morphology and composition, having high abundance in the atmosphere along the coasts ( $0.13 \pm 0.24$  items  $\text{m}^{-3}$ ) as opposed to the pelagic area ( $0.01 \pm 0.01$  items  $\text{m}^{-3}$ ), which proved significant atmospheric transport of MPs to the marine environment. However, another study by [Liu et al. \(2020b\)](#) found inconsistency in the sizes and composition of MPs between aerosols and atmospheric deposition, suggesting only a little atmospheric transport to the ocean as opposed to the riverine inputs.

Rain (especially freezing rain at  $0^{\circ}\text{C}$ ) and snow (in colder environment around  $-10^{\circ}\text{C}$ ) can scavenge organic vapors and particles from the atmosphere ([Lei and Wania, 2004](#)), which may transport airborne MPs and their additives ([Hahladakis et al., 2018](#)) or adsorbed co-pollutants ([Akhbarizadeh et al., 2021](#)) to remote locations. [Bergmann et al., \(2019\)](#) identified MPs from polar snow, suggesting substantial contamination in the Arctic atmosphere. The authors indicated the scavenging effect as an important pathway where MPs might get transported through the atmosphere, pass through clouds, bind with snow, and get deposited in tundra (**Figure 3**). When MPs travel with the atmospheric currents, the cloud scavenges (wet/dry deposition) them along with the atmospheric particles and gases, popularly known as “scavenging effect”, which precipitates them to the terrestrial and aquatic niches. Remote Arctic lakes become a potential sink of MPs, especially MFs deposited possibly by wind-driven long-range atmospheric transport ([González-Pleiter et al., 2020](#)). [Klein and Fischer \(2019\)](#) found that atmospheric transport was responsible for the increased accumulation of MP fragments in the rural, fir forest, and urban areas of Hamburg, Germany. [Zhou et al. \(2021\)](#) interpreted that MPs (mainly < 200  $\mu\text{m}$  PA fragments, fibers) present in riparian topsoil and sub-surface soil of

remote mountains along the Yangtze River could have been transported by atmospheric deposition along with street runoff and wastewater discharge. Many studies across the world document MPs from various environmental matrices and commercial food samples, but most of them could not estimate the input of aerial transport in MP deposition. For instance, [Selvam et al. \(2020\)](#) identified natural and synthetic MPs from the sea salt samples of the Tuticorin coast (Tamilnadu), India. Though the study focused mainly on the sedimentation and resuspension from the ocean, the authors could not disregard atmospheric transfer as a potential route of transmission.

## **5. Occurrence of MPs in air**

The key sources of airborne MPs include synthetic textile clothing, furniture, construction materials, abrasion of rubber tires, and urban dust ([Dris et al., 2016](#); [Boucher and Friot, 2017](#)). Moreover, the airborne MPs that originate from the resuspension of deposited dirt from automobiles ([Dris et al., 2017](#)), suspended in the atmosphere, get carried away, and further accumulate and contaminate aquatic or terrestrial environments ([Allen et al., 2019](#)). Still, only limited knowledge exists about the concentrations of airborne MPs and MFs globally in outdoor and indoor air.

### **5.1 MPs in street dust and outdoor air**

A study on the existence of MPs in street dust ([Abbasi et al., 2019](#)) threw light on an underestimated source of airborne MPs. Street dust samples (<5 mm) retrieved from 15 sites in Asaluyeh, southern Iran, were found to be dominated by MPs (spheres, films, and fibers) and micro rubber (MR) particles, with an average as high as 900 MPs and 250 MRs per 15 g of the sample respectively ([Abbasi et al., 2019](#)). The authors prepared 15 g aliquots with 35 mL of 30% H<sub>2</sub>O<sub>2</sub> to remove organic matter so that the identified particles were inferred to be synthetic. From the above study, it can be concluded that increased vehicular movements and urban road traffic could generate synthetic MR particles through tire abrasion and lead to suspended PM. Tire and paint aggregates are important sources of urban dust contributing to atmospheric MP input ([Horton and Dixon, 2018](#)). In recent times, latex paints that typically combine water and plastics have increased dramatically in popularity. [Järnlskog et al. \(2020\)](#) identified tire and bitumen MPs from the road surface, stormwater, and sweeper sediment samples, highlighting them as a major emission source. Several desk studies have reported that vehicular tire abrasion could be a major source for MP aggregates in urban air ([Lassen et al., 2015](#); [Sundt et al., 2015](#)). [Knight et al. \(2020\)](#) identified and quantified the synthetic tire wear aggregates from environmental samples in the roadside drains of Plymouth, U.K., where they found that tire wear aggregates from the road significantly contributed to the drainage MR pollution. The above study implies that future research should focus on the environmental estimation

of urban outdoor MP pollution from tire abrasion. Generally, MPs emitted from tire abrasion are coarse particulate pollutants (EPA AQI guidelines, 2014). Airflow and strong air currents emerging from rotating vehicular tires (wheels) can also emit and transport PM into the air (Song et al., 2020). Modeling approaches can be used to understand the abrasion and release of MPs from the tire or any other source (Unice et al., 2019).

Likewise, MPs can also be emitted from brake wear particles, which predominantly contain metals and plastics (fibers, binders, fillers, etc., from the brake lining) (Evangelidou et al., 2020). Similarly, MPs emitted from paint are underrated sources of indoor or outdoor air pollution as latex paints that typically combine water and plastics have increased dramatically in popularity. For instance, Rist et al. (2020) identified several paint fragments in the Arctic coast, suggesting that ship paint could be an underestimated source of not only marine, but also airborne MPs. Even disposable plastic bags can emit MPs into indoor or outdoor air (Sobhani et al., 2020). Plastic films used for mulching in agricultural land areas can emit high concentrations of MPs to the environment (Huang et al., 2020). Incineration is a potential, but unfortunately a less explored source for airborne MPs. For instance, Yang et al. (2021) identified around 360 - 102,000 particles per metric ton of MPs (mainly PP and PS) in the bottom ash of municipal solid waste incinerators (mass burn and fluidized bed) in the Chinese cities, which suggested incineration as a potential source of MPs discharge to the environment. However, the study did not discuss if MPs occur in the fly ash of solid waste incinerators, which in the case could be a potential source for airborne MPs. Atmospheric fallout from waste dumps and landfills is known to be a potential pathway for MPs transfer in the air (Chen et al., 2020a). For instance, Chai et al. (2020) reported that the soil near an electronic-waste dump in Guiyu, China was highly contaminated with MPs (up to 34,100 particles kg<sup>-1</sup>), highlighting a possible atmospheric transport. González-Pleiter et al. (2021) sampled airborne MPs through aircraft (air sampling within and above the planetary boundary layer) and found that the urban air was generally polluted by fragments whereas the rural/sub-rural air was predominantly polluted by fibers. Using air mass trajectory analyses, the study hypothesized the atmospheric transport of MPs for over 1000 km before deposition. Synthetic textile fibers are acknowledged as a major source of MPs in atmospheric fallout (Chen et al., 2020a; Dris et al., 2016). Atmospheric fallout analysis of Dongguan city, China, indicated that PE, PP, and PS are the predominant types of urban wind-carried MPs (Cai et al., 2017). The MP levels in London's outdoor air have been estimated to be 20 times higher than any remote rural location, which infers the influence of local sources such as people or vehicular movements (Wright et al., 2020).

Despite the limited number of studies, tracing the possible sources and types of MPs in the atmosphere is crucial to understand their mechanisms of migration; because the types, shapes, and sources of airborne MPs are unevenly distributed across the world, depending on the regional anthropogenic activities, population density, and waste disposal and management practices ([Henry et al., 2019](#)). However, many studies lack seasonal sampling, and hence the combined approach of both wet and dry deposition sampling is required to understand the abundance of atmospheric MP pollution and its deposition to terrestrial and aquatic ecosystems ([Chen et al., 2020b](#)) (**Table 1**). Though recognized to be an ever-increasing global issue, there is a lack of data on atmospheric deposition and transport of MPs, with exception of a few megacities (London, Paris, Asaluyeh, Dongguan) ([Dris et al., 2017](#)) and an isolated French mountain catchment ([Allen et al., 2019](#)). To overcome this limitation, standard methods and protocols need to be improved to characterize and quantify the MPs not only in the air (ambient as well as indoor) ([Wesch et al., 2017](#)) but also in any environmental matrix ([Enyoh et al., 2019](#)). Minimization of background contamination throughout MPs analysis is quite challenging ([Miller et al., 2021](#); [Prata et al., 2021](#)). Though many research publications deal with and emphasize the atmospheric transport of MP particulates, most aspects including the mechanisms and potential pathways are unknown and need to be focused on in future research. Knowledge of the aerial deposition, transport, scavenging, and precipitation of MP particulates is crucial to map the potential sources and predict the corresponding impacts on the susceptible ecosystems (**Figure 4**). If the vulnerable regions can be identified, the extent to which MPs contribute to the particulate air pollution in these areas can be studied. The literature on the loading rates of airborne MPs from urban areas to remote or rural locations is very scarce. Therefore, future studies must explore the mechanisms and pathways of atmospheric transfer of both the primary and secondary MPs ([Brahney et al., 2020](#)).

## 5.2 MPs in indoor air

In indoor environments, airflow turbulence greatly affects the resuspension of airborne MPs and NPs ([Zhang et al., 2020b](#)). The available studies infer that synthetic fibers and MPs in indoor air usually size range from 50-250  $\mu\text{m}$  ([Catarino et al., 2018](#); [Dris et al., 2017](#)). These small MP particles can penetrate more easily in the human respiratory system ([Hwang et al., 2019](#)). A study conducted in Paris noticed the ubiquity of MPs (33% of the total fibers) in indoor and outdoor air, along with the risk of human exposure: inhalable and settled dust ingestion ([Dris et al., 2017](#)). The concentrations of fibrous MPs were higher in indoor/ambient air than in outdoor air (in France), suggesting air exchange as a transfer route from indoors to outdoors. The authors highlighted that the dynamics of fibrous MPs in an urban environment could be understood by estimating their

deposition rate and concentration. In a dry deposition fallout study that was conducted for 13 weeks in 3 indoor sites (students' dormitory, office, and corridor) of East Normal China University (Shanghai), the identified plastic particulates (rayon, acrylic, polyester, PET) were sourced mainly from clothing, beddings, and curtains. However, 60% of the collected fibrous particulates were identified to be natural fibers (cotton, wool) ([Zhang et al., 2020b](#)). [Zhang et al. \(2020a\)](#) documented MPs from air dust in the indoor environment from 12 different countries and observed a robust increase in the concentrations of terephthalic acid and BPA in PET and polycarbonate (PC) MPs, respectively.

Laundry is a widely established source for the indoor emission of fibrous MPs ([Song et al., 2021](#); [Falco et al., 2020](#); [O'Brien et al., 2020](#)). Drying of synthetic clothes under direct sunlight is a potential source for suspended atmospheric MPs ([Liu et al., 2019b](#)). [Belzagui et al. \(2019\)](#) estimated the rate of the detachment of MPs from textiles and suggested that the levels of synthetic MFs getting emitted to the ocean might be much higher than reported earlier. However, the emission levels of fibers to air from apparel wear are as important as laundry discharge (lint from washing machines) to water ([Falco et al., 2020](#)). E-waste dust may also emit MPs or additives to the air. Electrical and electronic products can release plasticizers (phthalate alternatives, monoesters) and other synthetic organic compounds into the indoor dust ([Deng et al. 2021](#)). As it is inferred that winds in urban areas may carry a non-negligible concentration of MPs, future research should throw light on the exposure and the associated health impacts of MPs/MRs from ambient air. Moreover, the extent to which the fallout of MPs from indoor environments can disperse and contribute to outdoor particulate pollution needs to be quantified. One of the ultimate aims of exploring indoor and outdoor air pollution is to understand the exposure and human health risks of airborne MPs.

### **5.3 Atmospheric MPs in the vulnerable ecosystems**

Scavenging effect (**Figure 3**) can precipitate MPs to pristine and fragile ecosystems. When atmospheric MPs deposit to the lithosphere and hydrosphere, ecosystems at high altitudes are particularly vulnerable to airborne exposure. For instance, [Napper et al. \(2019\)](#) identified MPs from remote areas of Mt. Everest, and interpreted the likely sources as the clothing and gears of trekkers. However, the authors also hypothesized wind-driven atmospheric transport as another potential source. There are several notable studies on the polar ecosystems ([Peeken et al., 2018](#); [Routti et al., 2019](#)). However, the exposure of Antarctic fauna to MPs is very limited in comparison to the Arctic. Several studies document MPs from pristine freshwater ([Napper et al., 2019](#); [2021](#)) and marine ([Peeken et al., 2018](#)) ecosystems. However, airborne MPs that get deposited to the water surface may pose the same modes of exposure to the aquatic flora and fauna. Therefore, the major emphasize of

the faunal/floral exposure to airborne MPs needs to be given to the terrestrial ecosystems. Terrestrial forests (along with the ocean) play a key role in the planetary rainfall and climate regulation. Forest ecosystems deliver a number of key ecosystem services. Canopy ecosystems are one of the most biodiverse and productive terrestrial ecosystems. As tall tree canopies can reach a height up to 30 m ([Potapov et al., 2021](#)), forest ecosystems (notably mountain and temperate forests, tropical rainforests) are susceptible to airborne MPs exposure. Unfortunately, the canopy niches and their interactions are quite complex ([Bortolazzi et al., 2021](#)), and research needs to start exploring the impacts from species level.

A typical forest (temperate deciduous or rainforest) ecosystem comprises several layers: forest floor (soil), understory (shrub layer), canopy (tree cover, mostly arboreal ecosystem), and emergent (top-most layer, tallest trees). Almost all the studies on airborne MPs highlight their health implications ([Revel et al., 2018](#)), but studies on their ecological impacts are comparably less. Particularly, their implications in the remote canopy, above-tree canopy, and aerial habitats (exposure through wet/dry precipitation) have not been discussed to date. Though knowledge on the canopy, emergent layer, and airborne ecosystems and their community interactions is very limited, aerial (avian) and emergent layer ecosystems are known to play very important roles in atmospheric biogeochemical cycles ([Gusareva et al., 2019](#)), mainly the atmospheric carbon cycle. For instance, tree canopies of the tropical rainforests play an important role in the carbon fluxes and forest dynamics, and gaps created in these canopies (due to tree mortality) can disturb the community structure of the deadwood decomposers and hence the natural carbon cycle ([Griffiths et al., 2021](#)). The canopy ecosystems are mostly arboreal, which play a crucial role in the carbon and nitrogen biogeochemical cycles ([Bortolazzi et al., 2021](#)).

Emergent and canopy layers of the forest ecosystems are directly exposed to the atmospheric MPs deposition by precipitation (wet/dry) or wind circulation. Suspended atmospheric MPs that deposit in the terrestrial environment can adhere to the plant surfaces ([Liu et al., 2020a](#)). Most of the studies on the transport and deposition of airborne MPs indicate the predominance of low-density polymers. Low-density PE MPs can alter the soil characteristics and natural microbiome (community composition) of forest soil, and enhance the anaerobic communities resulting in increased soil respiration (by carbon dioxide fluxes and methane emission), leaving direct consequences on climate change ([Ng et al., 2020](#)). Therefore, atmospheric deposition of MPs may have serious implications in not only the canopy and understory layers but also the forest floor ecosystem. The emergent and atmospheric ecosystems mostly comprise birds, bats, and insects. Migratory seabirds are known to consume MPs ([Masiá et al., 2019](#); [Zhao et al., 2016](#)), which are preyed on by many avian predators

such as hawks ([Pokharel, 2020](#)), thus transporting MPs in the aerial food chain (**Figure 5**). Even mosquitoes can consume and transport MPs through various ontogenic levels of their life cycle: from larva to adulthood, which is in turn preyed on by adult flies (in larval stage), spiders (while resting), birds, and bats (on flight) ([Al-Jaibachi et al., 2018](#)), thus contaminating the aerial food chain. As MPs can significantly accumulate in the canopy and emergent layers, there is a clear need to explore the impacts caused by MPs on the atmospheric microbial communities and arboreal biodiversity (**Figure 5**).

Moreover, carbon emissions from atmospheric and ocean plastic particulates can directly influence natural carbon sequestration and climate change ([Fadare and Okoffo, 2020](#); [Shen et al., 2020](#)). In order to understand the global plastic cycle, it is preferable to develop a methodology with very high spatial resolution, along with reliable modeling approaches based on air-mass trajectories, dust, wet/dry deposition rates, and population statistics ([Brahney et al., 2020](#)). To map the possible sources and residential/forest areas that are susceptible to airborne fallout of MPs, it is necessary to document and explore the prevalence, distribution, and of MPs in outdoor and ambient air. Reports on the estimation of MPs in indoor and outdoor air have been summarized in **Table 1**. All these studies successfully documented MPs in the air (outdoor/indoor), but unfortunately, many of them could not effectively trace the possible sources of fallout.

## **6. Exposure routes and health risk of aerial MPs**

Airborne MPs can have direct exposure and impacts on human health (**Table 2**), but unfortunately, the data available on environmentally relevant and realistic exposure is limited.

### **6.1 Routes of domestic and industrial exposure**

Airborne MPs spread in terrestrial environments by wind erosion, creating a potential risk of exposure through direct inhalation of MPs suspended in the dust ([Rezaei et al., 2019](#)). Inhalation is a major route of aerial MP exposure and dust is a significant medium for human inhalation ([Liu et al., 2019a](#); [Revel et al., 2018](#)). Aerial MPs, when inhaled, may potentially induce a wide range of diseases in the respiratory and cardiovascular systems, or even cancer ([Barboza et al., 2018](#); [Prata, 2018](#)). Inhalable fibers (small micro and nanofibers) dispersed in air, could even release absorbed chemicals into the lungs. [Catarino et al. \(2018\)](#) observed a greater exposure to MP through household fallout than that through consumption of contaminated mussel, *Mytilus edulis*. In urban China, the geometric mean daily exposure of PET for children through indoor dust is estimated to be 17,300 ng/kg body weight ([Liu et al., 2019a](#)), which is non-negligible. But [Vianello et al. \(2019\)](#) demonstrated through an indoor breathing thermal manikin experiment in 3 residential



apartments (Denmark) that the human inhalation exposure to natural MFs (91%) is greater than that to synthetic (plastic) fibers (4%). However, the study interestingly found that fibrous MPs are usually smaller than the natural fibers, making them more readily inhalable. The available studies suggest that MPs in particular MF concentrations in the indoor are higher than in the outdoor environments. However, due to the insufficiency and uncertainty in the available data, disparity arises in the pulmonary exposure and parameters (like vital capacity, expiration rate, maximal inspiratory pressure, etc.). Therefore, ingestion exposure is generally deemed to be higher than inhalation ([Senathirajah et al., 2021](#)). However, airborne MPs may also be ingested via oral exposure in a contaminated environment (ambient or outdoor) during everyday activities like talking, eating, etc. Moreover, human exposure to airborne plastic additives including phthalates and other co-pollutants remains unknown. For instance, humans can be exposed to airborne BPA through inhalation, air/dust ingestion, both from MP or non-MP sources ([Smith et al., 2018](#)). But unfortunately, inhalation, skin contact, and ingestion are not the only sources of exposure to airborne MPs. Airborne MPs may adhere to hair, and hence the dermal contact through the scalp is underestimated but a potential source of exposure ([Abbasi and Turner, 2021](#)).

In a study conducted in Iran on saliva, hair, and skin of the residents (local), PE, PET, and PP fibers (sourced from both indoor and outdoor settings) were consistently present, especially in all the hair samples, highlighting a major source of exposure ([Abbasi and Turner, 2021](#)). The study interpreted that the human head hair has a high surface area, and tortuosity, which make them acquire electrostatic charge to attract, trap and harbor airborne MPs, particularly fibers emitted from garment wear, soft furniture, etc. These harbored MPs may enter the human system through dermal contact and absorption (scalp) though it remains unproven. MF composition in air changes with different clothing demands according to seasons ([Kaya et al., 2018](#)). Therefore, to enunciate the impacts of MPs on human health with respect to exposure, one needs to understand the airborne pathways and the environmentally realistic exposure levels ([Kelly and Fussel, 2020](#); [Kelly et al., 2020](#)). Regional, inter-regional, and local sources play a major role in human exposure to outdoor airborne MPs ([Abbasi and Turner, 2021](#)). Therefore, the spatial distribution and origin of tropospheric MPs need to be tracked to estimate the inhalation exposure ([Kelly et al., 2020](#)). As humans living near the source areas (urban) are being more susceptible to aerial MP exposure, it is necessary to explore if aerial MPs do considerably contribute to PM level in urban air.

Workers of synthetic textile industries are being exposed to airborne MPs like nylon, PE, PP, PS, PET, etc. ([Kelly and Fussel, 2020](#)). A study demonstrates that inhalable MFs (polyester and nylon textile fibers) retarded the development and inhibited the cell repair of pulmonary airway organoids

(in vitro) in both human and murine cells ([Dijk et al., 2021](#)). Workers in industries dealing with electronics, packaging, automobile, chemical additives, pigment, toys, etc., are exposed to PS. A recent study on PS MPs observed significant toxicological effects including morphological change and retarded human alveolar cell proliferation within 24 hours of exposure ([Goodman et al., 2021](#)). However, another in vivo study showed no significant inhalation (intra-tracheal exposure) impact of PE MPs on pregnant mice (gestational and neonatal study) ([Han et al., 2021](#)). Almost all the available toxicity studies show inconsistent impacts, majorly due to limited knowledge on the realistic industrial exposure to airborne MPs. The Occupational Safety and Health Administration (OSHA) (United States of America) does not include long-term exposure to plastics in its 2016 guidelines ([OSHA, 2016](#)). Unfortunately, none of the countries in the world has framed active legislation or occupational exposure limit for airborne MPs. There are 2 major reasons for the lack of a legal framework: 1) MPs are still considered as contaminants of emerging concern and there is limited documentation of airborne MPs across the world; 2) The first measurements of airborne MPs were performed only 5 years ago and hence standard characterization methods are not yet available. For instance, the government of India has issued guidelines for occupational hazards like Beedi and Cigars Act (amended in 1993), The Building and Other Construction Workers Act (1996), etc., but those do not include plastic exposure ([India OSH guidelines, 2018](#)). But still, Indian workers of plastics and rubber industries have been observed to consistently develop health conditions like carcinomas, cytogenetic damage, high levels of oxidative stress, and liver enzymes, low levels of glutathione, hemoglobin, etc. ([India OSH guidelines, 2018](#)). Many countries around the world (United States of America, England, China, etc.) have updated their guidelines/regulations on outdoor and ambient PM ([EPA AQI guidelines, 2014](#)), and MPs can be considered as a part of the PM (**Table 3**). However, more studies are needed to develop an updated regulatory policy on the occupational hazards and long-term exposure and toxicity of PM. There is no recent study available on the occupational hazards of inhalable/non-inhalable PM-MPs. Also, the available PM guidelines focus mainly on the inhalable particles, while MPs can also adhere to the hair (which could be a major exposure route) and skin ([Abbasi and Turner, 2021](#)), and only a little or no information is available on the long-term dermal (scalp, face, hand) exposure of airborne MPs concerning the industrial workers. Workers in the flock (decorative fibers), synthetic textile, plastic, and packaging industries are prone to the high exposure of airborne MPs, which may lead to occupational diseases ([Prata, 2018](#)), while the general public may not. Therefore, health impacts associated with airborne MPs need to be understood in relevance to the exposure.

## 6.2 Health implications

Once inhaled, MPs or NPs can enter the central airway and distal lung ([Levermore et al., 2020](#)), and cause DNA damage, cellular damage, oxidative stress, inflammation, secretion of cytokines, etc. ([Vethaak and Legler, 2021](#)). A few in vivo and in vitro studies have provided evidence for pulmonary toxicity, cellular permeability, and teratogenicity of airborne MPs ([Lim et al., 2021](#); [Isinibilir et al., 2020](#); [Hwang et al., 2019](#)). Exposure to high concentrations of atmospheric MPs may lead to immune disorders, inflammation, and neurodegeneration ([Prata et al., 2020](#)). Airborne MPs can harbor microbes and some of the deposited invasive communities can adhere firmly to the surface ([Pickett et al., 2019](#)). Several bacterial communities isolated from environmental MP surfaces (soil, water, air) have been identified as invasive, virulent, and antibiotic-resistant strains ([Liu et al., 2021](#); [Bank et al., 2020](#)). Both synthetic and biodegradable MPs can harbor multi-drug resistant and antibiotic-resistant biofilms ([Sun et al., 2021](#)). A recent preclinical study has identified PP MPs in the amniochorial, maternal and fetal membranes of human placenta collected during vaginal birth of healthy women volunteers ([Ragusa et al., 2021](#)), highlighting the possible teratogenicity of MPs and their associated endocrine disrupting agents such as BPA, phthalates, monomers, etc. ([Rai et al., 2021](#)). In marine animals, inhaled MPs can interact with epithelial tissues, and carry pathogens, leading to toxicological, nutritional, developmental, or immunological implications, which seem very similar to ingestion, leading to tissue inflammation, cell proliferation/necrosis, and immune suppression ([Wright and Kelly, 2017](#)). Nano-sized particulates can readily interact with proteins, enzymes, or biochemical components of cells, causing injury, inflammation, etc. ([Nho et al., 2020](#)). Some notable studies on the health implications associated with exposure to airborne MPs have been summarized in (**Table 2**).

## 7. Airborne MPs and the new normal

There is a worldwide increase in domestic and medical waste throughout the COVID-19 pandemic due to the dearth of manpower to handle the accumulating litter ([You et al., 2020](#)). Disposed personal protective equipment (PPE) kits and single-use face masks used by medical personnel have led to the massive accumulation of plastics in the environment ([Adyel, 2020](#)). Moreover, the synthetic head covers, shoe covers and gowns of PPE are also expected to be a source of airborne MPs. But the rate of atmospheric fallout of MPs from this emerging waste is unclear. Fabric face masks used by people across the world have become a latent source for atmospheric MPs (natural/synthetic) ([Fadare and Okoffo, 2020](#)). Wearing and reusing synthetic face masks increase the inhalation (nasal/oral) exposure of MPs, while other commonly used masks (cotton, fashion fabric, surgical, activated carbon) other than N95, which could filter 95% of the tiny airborne particulates

(effectively reduced MPs inhalation) pose a higher risk of atmospheric MPs inhalation ([Li et al., 2021](#)). However, the study interestingly found that wearing masks, even for the long-term (720h), lowered the risk of airborne particulate (granules, fragments) MPs inhalation, while increased the risk of fibrous (synthetic fibers) MPs inhalation. Nevertheless, regardless of wearing masks, the inhalation risk of airborne (outdoor/indoor) MPs and NPs was high.

Air pollution not only transmits airborne pathogens but also suppresses innate immunity and antimicrobial peptides ([Crane-Godreau et al., 2020](#)). [Gupta et al. \(2020\)](#) estimated that the rate of COVID-19 fatality in nine Asian cities increased with increasing particulate (PM<sub>10</sub> and PM<sub>2.5</sub>) air pollution. It is already known that SARS-CoV-2 remains stable in aerosol and on solid surfaces ([Arslan et al., 2020](#)). [Enyoh et al. \(2020\)](#) suggested that contaminated MP surfaces in the air could be a potential transmission route for COVID-19 without having to travel or contact an infected person. While it has been well demonstrated that MP in aquatic system serves as a vector for the transport of microorganisms including bacteria and virus, there has not been any study so far demonstrating whether airborne MPs could be a vector for the virus. Due to the wide improper disposal of PPEs and masks, airborne MPs emitted from the contaminated waste sites can become a potential vector of transmission ([Liu and Shauer, 2021](#)). Moreover, MPs can also carry animal pathogens to various ecosystems. For instance, [Radisic et al. \(2020\)](#) identified virulent strains of fish pathogens, opportunistic human pathogens, and antibiotic-resistant microbial communities in marine plastics from the Norwegian West Coast. As atmospheric MPs can harbor resistant and virulent strains ([Liu et al., 2021](#); [Radisic et al. 2020](#)), their possible role in the transmission of variant or mutant strains must be explored. As airborne MPs are acknowledged as harmful to the environment and health, it is important to understand and quantify their influence on AQI.

## **8. Implications of MPs in the AQI**

AQI refers to the measure of the pollution in the air, which can cause health impacts upon exposure (within hours or days) ([EPA AQI guidelines, 2014](#)). It is a normalized scale to measure the overall air pollution of a region. It includes various parameters like PM, tropospheric ozone (O<sub>3</sub>), oxides of sulphur (SO<sub>x</sub>) and nitrogen (NO<sub>x</sub>), carbon monoxide (CO), ammonia (NH<sub>3</sub>), lead (Pb) ([WHO air quality guidelines, 2005](#)). The numerical scale (usually 0-500) and index vary for different countries, and hence there are various AQIs followed across the world. PM refers to fine particles (a mixture of liquid droplets or solid) suspended in the air. The minimum breathing height for an average adult human is 0 - 1.2 m above ground level, where airborne MPs (inhalable/ingestible) have been generally documented ([Mbachu et al., 2020](#)). Air pollution guidelines do not include MPs as a specified separate entity, but they come under the PM (generalized) as airborne aggregates. PM in the

air can decrease the air visibility, which is measured using nephelometer as difference in light scattering (scattering potential) (Hu et al., 2021). Particulate plastics like vehicular MR, MF, sea-spray MP aerosols, etc., can scatter light, thus changing the scattering potential. As synthetic fibers (particularly PA) absorb moisture due to their hygroscopic surface (Kreider et al., 2021), and occur in windblown street dust (Abbasi et al., 2019), MPs can form aerosols, which may restrict the visibility to a non-negligible extent. However, the possible influence of MPs on the air visibility remains unexplored to date. Even though airborne MPs potentially contaminate the urban and the industrial air, little attention has been paid to their role in policy frameworks and assessment guidelines (Abbasi et al., 2019). As discussed earlier, research needs to overcome the limitations in characterization, health impact assessment, and understand the realistic exposure levels before advancing to the policy framework. World Health Organization released a detailed report on the documentation, exposure, and possible sanitary impacts of MPs in potable water (WHO Report, 2019). But extensive exposure studies and policy standards are unavailable for inhalable MPs/NPs in ambient air.

According to AQI, plastic particulates, especially come under PM, as either PM<sub>10</sub> (<10µm) (MPs) or PM<sub>2.5</sub> (<2.5µm) (NPs). But unfortunately, universal ambient air quality standards are not available exclusively for MPs/NPs which is becoming an emerging source of PM<sub>10</sub> and PM<sub>2.5</sub>. Most of the countries of the world have not set national standards either, because many developing and industrialized nations have not yet attempted to document and monitor MPs in ambient air. For instance, in India, there are so far only 2 studies that documented airborne particulate plastics in metropolitan cities (Chennai and Nagpur) (Patchaiyappan et al., 2021; Narmada et al., 2020). Even while PM significantly increases in Delhi during winter, leading to a sudden surge in the city's AQI, there is no documentation available for atmospheric MPs. The global studies on airborne MPs are fragmented, and none of them has correlated the MP levels with an effect on AQI. No extensive research has been carried out yet to understand the extent of the contribution of MPs/NPs to PM<sub>10</sub> or PM<sub>2.5</sub> emissions. Moreover, standard methods for the measurement of airborne MPs need to be developed before the definition of air quality standards.

High PM (<10 µm) levels in the air are responsible for the increased number of deaths due to air pollution (EPA AQI guidelines, 2014; WHO air quality guidelines, 2005). Biomass burning (including bushfire) is regarded as an important source of PM pollution in the air. Airborne PM from smoke haze caused by uncontrolled biomass burning together with forest/peat fires impairs the air quality, atmospheric visibility, hydrologic cycle, ecosystems, climate, and human health (Adam et al., 2020). Plastics used for mulching and land applications may release MPs and chemical vapors when burned.

Bushfire can release these MPs into the air. However, it is still unclear if the abundance of MP/NP particulates in the air can increase the risk of fatality. [Dong et al. \(2020\)](#) has recently reported that PS MPs not only promote inflammation and cytotoxicity in BEAS-2B (human pulmonary epithelium) cells but also diminish certain proteins called zonula occludens, which can lead to chronic obstructive pulmonary disease (COPD). They concluded that PS particulates entering the lungs, even at low concentration ( $1 \mu\text{g cm}^{-2}$ ) could disrupt the pulmonary barrier, and hence could cause serious lung disorders. The toxicity of airborne MPs is influenced by weathering or aging ([Zhu et al., 2020](#)).

The available global guidelines have set the annual mean exposure for  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  as  $10 \mu\text{g m}^{-3}$  and  $20 \mu\text{g m}^{-3}$  respectively ([WHO air quality guidelines, 2005](#)) (**Table 3**). Considering MPs as atmospheric particulates, more research studies need to be undertaken to understand the impacts and exposure of airborne MPs. The global framework for air quality assessment has identified and set exposure limits for various chemical contaminants including mercury (Hg), lead (Pb), phenols, other organic compounds, etc. ([EPA AQI guidelines, 2014](#)), but not for plastic particulates, which can facilitate the transport of all the above-mentioned pollutants in the air. Atmospheric aerosol PM can also contain MPs/NPs ([Brahney et al., 2020](#)). Moreover, the rates at which atmospheric MPs adsorb and desorb the other airborne pollutants including volatile organic compounds and modes of transmission of toxic air pollutants need to be investigated and conceptualized. Air quality assessment studies should quantify the proportion of MPs in the overall PM to derive a clear insight into the sources and implications of air pollution.

### **Concluding remarks, challenges and prospects for future research**

The present article briefly summarizes the current status, recent advances, and research gaps in the field of airborne MPs, and attempts to recommend major imminent implications to the environmentalists, researchers, and policymakers. We systematically discuss the available literature on the atmospheric transport, global documentation, and health implications of airborne MPs, and provide critical and novel insights on their implications in the canopy and emergent ecosystems, overall PM pollution, AQI of a region, and airborne transmission of an epidemic or a pandemic disease. The present review highlights the crucial knowledge gaps in the field, on which future research needs to focus.

Standard characterization methods for MPs need to be established not only for aquatic and terrestrial systems but also for the MPs in the air. With the accumulating shreds of evidence, one can hypothesize that the airborne MPs are likely to have significant consequences on the environment and human/animal health. Significant MP deposition has been measured in the atmosphere (for instance,

175 - 313 particles $\text{m}^{-2}\text{day}^{-1}$  in the fallout from Dongguan (Cai et al., 2017)). Nevertheless, the extent to which they account for the increase in PM levels in the air remains unquantified. The global distribution of aerial MPs needs to be mapped to mitigate the levels and to understand the extent of pollution especially in remote ecosystems resulting from the transboundary transport of airborne MPs. Thus, irrespective of the environmental and human health impacts, aerial/terrestrial plastic waste generation needs to be curtailed and research on sustainable plastic waste management needs to be undertaken. Here are a few critical recommendations for environmentalists, researchers, and policymakers in the field:

- Future research should throw more light on the pathways of atmospheric transport of airborne MPs so that susceptible hotspots concerning potential sources can be identified.
- The contribution of airborne MPs and NPs to PM including atmospheric aerosols needs to be investigated and quantified.
- There is a need to focus on understanding the atmospheric transport of MPs and the mapping of the majorly vulnerable ecosystems. For example, as MPs can spread and accumulate in polar snow, the associated impacts on the polar ecosystem and trophic levels need to be analyzed.
- Recent research has been focusing on the development of standard characterization and quantification techniques for aquatic and terrestrial MPs and NPs, whereas sampling of MPs from air requires different tools and approaches. Future research should attempt to establish standardized techniques and methods that are specific for airborne MPs/NPs.
- There is a lack of data on the concentrations at which aerial MPs are being inhaled or ingested. Also, ecotoxicological studies on airborne MPs should be established to understand their environmental and biological impacts.
- Methods like in vivo and in vitro cell assays should be optimized to explore cellular interaction, toxicity or genetic disruptions by inhaled MPs, and other possible respiratory ailments.
- Data on MP respiratory exposure of workers in any industrial sector dealing with all forms of plastics including airborne MPs needs to be collected. Issuing policy guidelines for aerial exposure of MPs is much needed and the corresponding health effects due to long-term exposure need to be studied.
- AQI and other assessment guidelines should recognize MPs as an emerging air pollutant and suggest relevant standards and exposure limits so that the air quality of the vulnerable (near-source) areas can be monitored.

- Further intensive inter-disciplinary research should gather evidence of human health effects of air-borne MPs including the associated pollutants and additives.
- As the dust fallout precipitation in remote environments can be polluted with MPs/NPs, sensitive habitats like above tree canopies or aerial microbiota are vulnerable to atmospheric MPs. Therefore, their corresponding impacts on air and arboreal ecosystems need to be evaluated.
- Extensive studies are required to clearly understand the possible links between atmospheric MPs/NPs and the atmospheric transport of virulent/antibiotic-resistant microbial strains, particularly concerning the transmission of the ongoing SARS-CoV-2 (COVID-19) pandemic.

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The authors declare that they have no competing interests or personal relationships that could have appeared to influence the work reported in this paper.



## References

- Abbasi, S., Keshavarzi, B., Moore, F., Turner, A., Kelly, F.J., Dominguez, A.O., Jaafarzadeh, N., 2019. Distribution and potential health impacts of microplastics and microrubbers in air and street dusts from Asaluyeh County, Iran. *Environmental Pollution*. 244, 153-164. <https://doi.org/10.1016/j.envpol.2018.10.039>
- Abbasi, S., Turner, A., 2021. Human exposure to microplastics: A study in Iran. *Journal of Hazardous Materials* 403, 123799. <https://doi.org/10.1016/j.jhazmat.2020.123799>
- Adam, M.G., Tran, P.T.M., Bolan, N., Balasubramanian, R., 2020. Biomass burning-derived airborne particulate matter in Southeast Asia: A critical review. *Journal of Hazardous Materials*. 407, 124760. <https://doi.org/10.1016/j.jhazmat.2020.124760>
- Adyel, T.M., 2020. Accumulation of plastic waste during COVID-19. *Science*. 369(6509), 1314-1315. [10.1126/science.abd9925](https://doi.org/10.1126/science.abd9925)
- Akhbarizadeh, R., Dobaradaran, S., Torkmahalleh, M.A., Saeedi, R., Aibaghi, R., Ghasemi, F.F., 2021. Suspended fine particulate matter (PM<sub>2.5</sub>), microplastics (MPs), and polycyclic aromatic hydrocarbons (PAHs) in air: Their possible relationships and health implications. *Environmental Research*. 192, 110339. <https://doi.org/10.1016/j.envres.2020.110339>
- Al-Jaibachi, R., Cuthbert, R.N., Callaghan, A., 2018. Up and away: ontogenic transference as a pathway for aerial dispersal of microplastics. *Biology Letters*. 14(9), 20180479. <https://dx.doi.org/10.1098/rsbl.2018.0479>
- Allen, S., Allen, D., Phoenix, V.R., Roux, G.L., Jiménez, P.D., Simonneau, A., Binet, S., Galop, D., 2019. Atmospheric transport and deposition of microplastics in a remote mountain catchment. *Nature Geoscience*. 12, 339-344. <https://doi.org/10.1038/s41561-019-0335-5>
- Allen, S., Allen, D., Moss, K., Roux, G.L., Phoenix, V.R., Sonke, J.E., 2020. Examination of the ocean as a source for atmospheric microplastics. *PLoS ONE*. 15(5), e0232746. <https://doi.org/10.1371/journal.pone.0232746>
- Amato-Lourenço, L.F., Galvão, L.d.S., de Weger, L.A., Hiemstra, P.S., Vijver, M.G., Mauad, T., 2020. An emerging class of air pollutants: Potential effects of microplastics to respiratory human health?. *Science of the Total Environment*. 749, 141676. <https://doi.org/10.1016/j.scitotenv.2020.141676>
- Arslan, M., Xu, B., El-Din, M.G., 2020. Transmission of SARS-CoV-2 via fecal-oral and aerosol-borne routes: Environmental dynamics and implications for wastewater management in underprivileged societies. *Science of the Total Environment*. 743, 140709. <https://doi.org/10.1016/j.scitotenv.2020.140709>
- Bank, M.S., Ok, Y.S., Swarzenski, P.W., 2020. Microplastic's role in antibiotic resistance. *Science*. 369(6509), 1315. [10.1126/science.abd9937](https://doi.org/10.1126/science.abd9937)
- Barboza, L.G.A., Vethaak, A.D., Lavorante, B.R., Lundebye, A.K., Guilhermino, L., 2018. Marine microplastic debris: An emerging issue for food security, food safety and human health. *Marine Pollution Bulletin*. 133, 336-348. <https://doi.org/10.1016/j.marpolbul.2018.05.047>

- Barnes, S.J., 2019. Understanding plastics pollution: The role of economic development and technological research. *Environmental Pollution*. 249, 812-821. <https://doi.org/10.1016/j.envpol.2019.03.108>
- Belzagui, F., Crespi, M., Álvarez, A., Gutiérrez-Bouzán, C., Vilaseca, M., 2019. Microplastics' emissions: Microfibers' detachment from textile garments. *Environmental Pollution*. 248, 1028-1035. <https://doi.org/10.1016/j.envpol.2019.02.059>
- Bergmann, M., Mützel, S., Primpke, S., Tekman, M.B., Trachsel, J., Gerdt, G., 2019. White and wonderful? Microplastics prevail in snow from the Alps to the Arctic. *Science Advances*. 5(8), eaax1157. DOI: 10.1126/sciadv.aax1157
- Biber, N.F.A., Foggo, A., Thompson, R.C., 2019. Characterising the deterioration of different plastics in air and seawater. *Marine Pollution Bulletin*. 141, 595-602. <https://doi.org/10.1016/j.marpolbul.2019.02.068>
- Bortolazzi, A., Da Ros, L., Rodeghiero, M., Tognetti, R., Tonon, G., Ventura, M., 2021. The canopy layer, a biogeochemical actor in the forest N-cycle. *Science of The Total Environment* 776, 146024. <https://doi.org/10.1016/j.scitotenv.2021.146024>
- Boucher, J., Friot, D., 2017. Primary microplastics in the oceans: A global evaluation of sources. IUCN International Union for Conservation of Nature. <https://doi.org/10.2305/IUCN.CH.2017.01.en>
- Bouwman, H., Evans, E.W., Cole, N., Yive, N.S.C.K., Kylin, H., 2016. The flip-or-flop boutique: Marine debris on the shores of St Brandon's rock, an isolated tropical atoll in the Indian Ocean. *Mar. Environmental Research*. 114, 58-64. <https://doi.org/10.1016/j.marenvres.2015.12.013>
- Brahney, J., Hallerud, M., Heim, E., Hahnenberger, M., Sukumaran, S., 2020. Plastic rain in protected areas of the United States. *Science*. 368(6496), 1257-1260. 10.1126/science.aaz5819
- Brooks, A.L., Wang, S., Jambeck, J.R., 2018. The Chinese import ban and its impact on global plastic waste trade. *Science Advances*. 4(6), eaat0131. DOI: 10.1126/sciadv.aat0131
- Cai, L., Wang, J., Peng, J., Tan, Z., Zhan, Z., Tan, X., Chen, Q., 2017. Characteristic of microplastics in the atmospheric fallout from Dongguan city, China: preliminary research and first evidence. *Environmental Science and Pollution Research*. 24, 24928-24935. <https://doi.org/10.1007/s11356-019-06979-x>
- Can-Güven, E., 2020. Microplastics as emerging atmospheric pollutants: a review and bibliometric analysis. *Air Quality Atmosphere and Health*. 14, 203-215. <https://doi.org/10.1007/s11869-020-00926-3>
- Catarino, A.I., Macchia, V., Sanderson, W.G., Thompson, R.C., Henry, T.B., 2018. Low levels of microplastics (MP) in wild mussels indicate that MP ingestion by humans is minimal compared to exposure via household fibres fallout during a meal. *Environmental Pollution*. 237, 675-684. <https://doi.org/10.1016/j.envpol.2018.02.069>
- Chai, B., Wei, Q., She, Y., Lu, G., Dang, Z., Yin, H., 2020. Soil microplastic pollution in an e-waste dismantling zone of China. *Waste Management*. 118, 291-301. <https://doi.org/10.1016/j.wasman.2020.08.048>

Chen, G., Feng, Q., Wang, J., 2020a. Mini-review of microplastics in the atmosphere and their risks to humans. *Science of the Total Environment*. 703, 135504. <https://doi.org/10.1016/j.scitotenv.2019.135504>

Chen, G., Fu, Z., Yang, H., Wang, J., 2020b. An overview of analytical methods for detecting microplastics in the atmosphere. *TrAC Trends in Analytical Chemistry*. 130, 115981. <https://doi.org/10.1016/j.trac.2020.115981>

Crane-Godreau, M.A., Clem, K.J., Payne, P., Fiering, S., 2020. Vitamin D Deficiency and Air Pollution Exacerbate COVID-19 Through Suppression of Antiviral Peptide LL37. *Frontiers in Public Health*. 8, 232. <https://doi.org/10.3389/fpubh.2020.00232>

Ding, L., Mao, R., Ma, R., Guo, X., Zhu, L., 2020. High temperature depended on the ageing mechanism of microplastics under different environmental conditions and its effect on the distribution of organic pollutants. *WaterResearch*. 174, 115634. <https://doi.org/10.1016/j.watres.2020.115634>

Dehghani, S., Moore, F., Akhbarizadeh, R., 2017. Microplastic pollution in deposited urban dust, Tehran metropolis, Iran. *Environmental Science and Pollution Research*. 24, 20360–20371. <https://doi.org/10.1007/s11356-017-9674-1>

Deng, M., Han, X., Ge, J., Liang, X., Du, B., Li, J., Zeng, L., 2021. Prevalence of phthalate alternatives and monoesters alongside traditional phthalates in indoor dust from a typical e-waste recycling area: Source elucidation and co-exposure risk. *Journal of Hazardous Materials*. 413, 125322. <https://doi.org/10.1016/j.jhazmat.2021.125322>

Dijk, F. van, Song, S., Eck, G.W.A. van, Wu, X., Bos, I.S.T., Boom, D.H.A., Kooter, I.M., Spierings, D.C.J., Wardenaar, R., Cole, M., Salvati, A., Gosens, R., Melgert, B.N., 2021. Inhalable textile microplastic fibers impair lung repair. *bioRxiv*, in press. <https://doi.org/10.1101/2021.01.25.428144>

Dong, C., Chen, C., Chen, Y., Chen, H., Lee, J., Lin, C., 2020. Polystyrene microplastic particles: In vitro pulmonary toxicity assessment. *Journal of Hazardous Materials*. <https://doi.org/10.1016/j.jhazmat.2019.121575>

Dris, R., Gasperi, J., Saad, M., Mirande, C., Tassin, B., 2016. Synthetic fibers in atmospheric fallout: A source of microplastics in the environment? *Marine Pollution Bulletin*. 104(1-2), 290-293. <https://doi.org/10.1016/j.marpolbul.2016.01.006>

Dris, R., Gasperi, J., Mirande, C., Mandin, C., Guerrouache, M., Langlois, V., Tassin, B., 2017. A first overview of textile fibers, including microplastics, in indoor and outdoor environments. *Environmental Pollution*. 221, 453-458. <https://doi.org/10.1016/j.envpol.2016.12.013>

Enyoh, C.E., Verla, A.W., Verla, E.N., Ibe, F.C., Amaobi, C.E., 2019. Airborne microplastics: a review study on method for analysis, occurrence, movement and risks. *Environmental Monitoring and Assessment*. 191, 668. <https://doi.org/10.1007/s10661-019-7842-0>

Enyoh, C.E., Verla, A.W., Verla, E.N., 2020. Novel Coronavirus (SARS-CoV-2) and Airborne Microplastics. *Journal of Materials and Environmental Science*. 11(9), 1454-1461.

EPA AQI Guidelines. (2014). Retrieved from: <https://www.epa.gov/>

Evangelidou, N., Grythe, H., Klimont, Z., Heyes, C., Eckhardt, S., Lopez-Aparicio, S., Stohl, A., 2020. Atmospheric transport is a major pathway of microplastics to remote regions. *Nature Communications*. 11, 3381. <https://doi.org/10.1038/s41467-020-17201-9>

Fournier, S.B., D'Errico, J.N., Adler, D.S., Kollontzi, S., Goedken, M.J., Fabris, L., Yurkow, E.J., Stapleton, P.A., 2020. Nanopolystyrene translocation and fetal deposition after acute lung exposure during late-stage pregnancy. *Particle and Fibre Toxicology*. 17, 55. <https://doi.org/10.1186/s12989-020-00385-9>

Fadare, O.O., F, Okoffo, E.D., 2020. Covid-19 face masks: A potential source of microplastic fibers in the environment. *Science of the Total Environment*. 737, 140279. <https://doi.org/10.1016/j.scitotenv.2020.140279>

Falco, F.D., Cocca, M., Avella, M., Thompson, R.C., 2020. Microfiber Release to Water, Via Laundering, and to Air, via Everyday Use: A Comparison between Polyester Clothing with Differing Textile Parameters. *Environmental Science and Technology*. 54, 6, 3288–3296. <https://doi.org/10.1021/acs.est.9b06892>

Falco, F.D., Gullo, M.P., Gentile, G., Pace, E.D., Cocca, M., Gelabert, L., Bouta-Angnésa, M., Rovira, A., Escudero, R., Villalba, R., Mossotti, R., Montarsolo, A., Gavignano, S., Tonin, C., Aella, M., 2018. Evaluation of microplastic release caused by textile washing processes of synthetic fabrics. *Environmental Pollution*. 236, 916-925. <https://doi.org/10.1016/j.envpol.2017.10.057>

Gasperi, J., Wright, S.L., Dris, R., Collard, F., Mandin, C., Guerrouache, M., Langlois, V., Kelly, F.J., Tassin, B., 2018. Microplastics in air: Are we breathing it in? *Current Opinion in Environmental Science and Health*. 1, 1-5. <https://doi.org/10.1016/j.coesh.2017.10.002>

Gasperi, J., Dris, R., Mirande-Bret, C., Mandin, C., Langlois, V., Tassin, B., 2015. First overview of microplastics in indoor and outdoor air. 15<sup>th</sup> EuCheMS International Conference on Chemistry and the Environment, Sep 2015, Leipzig, Germany.

Gaston, E., Woo, M., Steele, C., Sukumaran, S., Anderson, S., 2020. Microplastics differ between indoor and outdoor air masses: insights from multiple microscopy methodologies. *Applied Spectroscopy*. 74 (9), 1079-1098. <https://doi.org/10.1177%2F0003702820920652>

Goeppert, N., Goldscheider, N., 2021. Experimental field evidence for transport of microplastic tracers over large distances in an alluvial aquifer. *Journal of Hazardous Materials* 408, 124844. <https://doi.org/10.1016/j.jhazmat.2020.124844>

González-Pleiter, M., Edo, C., Aguilera, Á., Viúdez-Moreiras, D., Pulido-Reyes, G., González-Toril, E., Osuna, S., de Diego-Castilla, G., Leganés, F., Fernández-Piñas, F., Rosal, R., 2021. Occurrence and transport of microplastics sampled within and above the planetary boundary layer. *Science of the Total Environment*. 761, 143213. <https://doi.org/10.1016/j.scitotenv.2020.143213>

González-Pleiter, M., Velázquez, D., Carretero, O., Gago, J., Barón-Sola, Á., Hernández, L.E., Yousef, I., Quesada, A., Leganés, F., Rosal, R., Fernández-Piñas, F., 2020. Fibers spreading worldwide: Microplastics and other anthropogenic litter in an Arctic freshwater lake. *Science of the Total Environment*. 722, 137904. <https://doi.org/10.1016/j.scitotenv.2020.137904>

Goodman, K.E., Hare, J.T., Khamis, Z.I., Hua, T., Sang, Q.-X.A., 2021. Exposure of Human Lung Cells to Polystyrene Microplastics Significantly Retards Cell Proliferation and Triggers

Morphological Changes. *Chemical Research in Toxicology*. 34, 1069–1081. <https://doi.org/10.1021/acs.chemrestox.0c00486>

Gouin, T., Roche, N., Lohmann, R., Hodges, G., 2011. A thermodynamic approach for assessing the environmental exposure of chemicals absorbed to microplastic. *Environmental Science and Technology*. 45(4), 1466-1472. <https://doi.org/10.1021/es1032025>

Griffiths, H.M., Eggleton, P., Hemming-Schroeder, N., Swinfield, T., Woon, J.S., Allison, S.D., Coomes, D.A., Ashton, L.A., Parr, C.L., n.d. Carbon flux and forest dynamics: Increased deadwood decomposition in tropical rainforest tree-fall canopy gaps. *Global Change Biology*. <https://doi.org/10.1111/gcb.15488>

Gupta, A., Bherwani, H., Gautam, S., Anjum, S., Musugu, K., Kumar, N., Anshul, A., Kumar, R., 2020. Air pollution aggravating COVID-19 lethality? Exploration in Asian cities using statistical models. *Environmental Development and Sustainability*. <https://doi.org/10.1007/s10668-020-00878-9>

Gusareva, E.S., Acerbi, E., Lau, K.J.X., Luhung, I., Premkrishnan, B.N.V., Kolundžija, S., Purbojati, R.W., Wong, A., Houghton, J.N.I., Miller, D., Gaultier, N.E., Heinle, C.E., Clare, M.E., Vettath, V.K., Kee, C., Lim, S.B.Y., Chénard, C., Phung, W.J., Kushwaha, K.K., Nee, A.P., Putra, A., Panicker, D., Yangking, K., Hwee, Y.Z., Lohar, S.R., Kuwata, M., Kim, H.L., Yang, L., Uchida, A., Drautz-Moses, D.I., Junqueira, A.C.M., Schuster, S.C., 2019. Microbial communities in the tropical air ecosystem follow a precise diel cycle. *Proceedings of National Academy ScienceUSA*. 116 (46), 23299-23308. <https://doi.org/10.1073/pnas.1908493116>

Hahladakis, J.N., Velis, C.A., Weber, R., Lacovidou, E., Purnell, P., 2018. An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. *Journal of Hazardous Materials*. 344, 179-199. <https://doi.org/10.1016/j.jhazmat.2017.10.014>

Han, Y., Song, Y., Kim, G.W., Ha, C., Lee, J., Kim, M., Son, H., Lee, G., Gautam, R., Heo, Y., 2021. No prominent toxicity of polyethylene microplastics observed in neonatal mice following intratracheal instillation to dams during gestational and neonatal period. *Toxicological Research*, in press. <https://doi.org/10.1007/s43188-020-00086-7>

Henry, B., Laitala, K., Klepp, I.G., 2019. Microfibres from apparel and home textiles: Prospects for including microplastics in environmental sustainability assessment. *Science of the Total Environment*. 652, 483-494. <https://doi.org/10.1016/j.scitotenv.2018.10.166>

Horton, A.A., Dixon, S.J., 2018. Microplastics: An introduction to environmental transport processes. *WIREs Water*. 5(2), e1268. <https://doi.org/10.1002/wat2.1268>

Hu, Q., Qiu, Z., Hong, J., Chen, D., 2021. A polarized scanning nephelometer for measurement of light scattering of an ensemble-averaged matrix of aerosol particles. *Journal of Quantitative Spectroscopy and Radiative Transfer*. 261, 107497. <https://doi.org/10.1016/j.jqsrt.2020.107497>

Huang, Y., Liu, Q., Jia, W., Yan, C., Wang, J., 2020. Agricultural plastic mulching as a source of microplastics in the terrestrial environment. *Environmental Pollution*. 260, 114096. <https://doi.org/10.1016/j.envpol.2020.114096>

Hwang, J., Choi, D., Han, S., Choi, J., Hong, J., 2019. An assessment of the toxicity of polypropylene microplastics in human derived cells. *Science of The Total Environment*. 684, 657–669. <https://doi.org/10.1016/j.scitotenv.2019.05.071>

Imhof, H.K., Sigl, R., Brauer, E., Feyl, S., Giesemann, P., Klink, S., Leupolz, K., Löder, M.G.J., Löschel, L.A., Missun, J., Muszynski, S., Ramsperger, A.F.R.M., Schrank, I., Speck, S., Steibl, S., Trotter, B., Winter, I., Laforsch, C., 2017. Spatial and temporal variation of macro-, meso- and microplastic abundance on a remote coral island of the Maldives, Indian Ocean. *Marine Pollution Bulletin*. 116, 340-347. <https://doi.org/10.1016/j.marpolbul.2017.01.010>

India OSH guidelines, 2018. Retrieved from: [https://dgfasli.gov.in/sites/default/files/service\\_file/Nat-OSH-India-Draft%281%29.pdf](https://dgfasli.gov.in/sites/default/files/service_file/Nat-OSH-India-Draft%281%29.pdf)

Iñiguez, M.E., Cones, J.A., Fullana A., 2018. Recyclability of four types of plastics exposed to UV irradiation in a marine environment. *Waste Management*. 79, 339-345. <https://doi.org/10.1016/j.wasman.2018.08.006>

Isobe, A., Matsumoto, K.U., Uchida, K., Tokai, T., 2016. Microplastics in the Southern Ocean. *Marine Pollution Bulletin*. 114, 623-626. <https://doi.org/10.1016/j.marpolbul.2016.09.037>

Isinibilir, M., Svetlichny, L., Mykitchak, T., Türkeri, E.E., Eryalçın, K.M., Doğan, O., Can, G., Yüksel, E., Kideys, A.E., 2020. Microplastic Consumption and Its Effect on Respiration Rate and Motility of *Calanus helgolandicus* From the Marmara Sea. *Front. Mar. Sci.* 7. <https://doi.org/10.3389/fmars.2020.603321>

Järllskog, I., Strömvall, A., Magnusson, K., Gustafsson, M., Polukarova, M., Galfi, H., Aronsson, M., Andersson-Sköld, Y., 2020. Occurrence of tire and bitumen wear microplastics on urban streets and in sweepsand and washwater. *Science of the Total Environment*. 729, 138950. <https://doi.org/10.1016/j.scitotenv.2020.138950>

Kanhai, L.D.K., Gardfeldt, K., Krumpen, T., Thompson, R.C., O'Connor, I., 2020. Microplastics in sea ice and seawater beneath ice floes from the Arctic Ocean. *Scientific Reports*. 10, 5004. <https://doi.org/10.1038/s41598-020-61948-6>

Kawecki, D., Nowack, B., 2020. A proxy-based approach to predict spatially resolved emissions of macro- and microplastic to the environment. *Science of the Total Environment*. 748, 141137. <https://doi.org/10.1016/j.scitotenv.2020.141137>

Kay, P., Hiscoe, R., Moberley, I., Bajic, L., McKenna, N., 2018. Wastewater treatment plants as a source of microplastics in river catchments. *Environmental Science and Pollution Research*. 25, 20264–20267. <https://doi.org/10.1007/s11356-018-2070-7>

Kaya, A. T., Yurtsever, M., Bayraktar, S.C., 2018. Ubiquitous exposure to microfiber pollution in the air. *The European Physical Journal Plus*. 133(488), 1–10. <https://doi.org/10.1140/epjp/i2018-12372-7>

Kelly, K.J., Fussell, J.C., 2020. Toxicity of airborne particles - established evidence, knowledge gaps and emerging areas of importance. *Philosophical Transactions of the Royal Society A*. 378, 20190322. <https://doi.org/10.1098/rsta.2019.0322>

Kelly, K.J., Levermore, J., Wright, S., 2020. Inhalable Microplastics: A New Cause for Concern? In: Cocca M. et al. (eds) *Proceedings of the 2nd International Conference on Microplastic Pollution in*

the Mediterranean Sea. *ICMPMS* 2019. Springer Water. Springer, Cham. [https://doi.org/10.1007/978-3-030-45909-3\\_17](https://doi.org/10.1007/978-3-030-45909-3_17)

Klein, M., Fischer, E.K., 2019. Microplastic abundance in atmospheric deposition within the Metropolitan area of Hamburg, Germany. *Science of the Total Environment*. 685, 96-103. <https://doi.org/10.1016/j.scitotenv.2019.05.405>

Knight, L.J., Parker-Jurd, F.N.F., Al-Sid-Cheikh, M., Thompson, R.C., 2020. Tyre wear particles: an abundant yet widely unreported microplastic? *Environmental Science and Pollution Research*. 27, 18345–18354. <https://doi.org/10.1007/s11356-020-08187-4>

Kreider, P.B., Cardew-Hall, A., Sommacal, S., Chadwick, A., Hümbert, S., Nowotny, S., Nisbet, D., Tricoli, A., Compston, P., 2021. The effect of a superhydrophobic coating on moisture absorption and tensile strength of 3D-printed carbon-fibre/polyamide. *Composites Part A: Applied Science and Manufacturing*. 145, 106380. <https://doi.org/10.1016/j.compositesa.2021.106380>

Kumar, M., Chen, H., Sarsaiya, S., Qin, S., Liu, H., Awasthi, M.K., Kumar, S., Singh, L., Zhang, Z., Bolan, N.S., Pandey, A., Varjani, S., Taherzadeh, M.J., 2021. Current research trends on micro- and nano-plastics as an emerging threat to global environment: A review. *Journal of Hazardous Materials*. 409, 124967. <https://doi.org/10.1016/j.jhazmat.2020.124967>

Kumar, M., Xiong, X., He, M., Tsang, D.C.W., Gupta, J., Khan, E., Harrad, S., Hou, D., Ok, Y.S., Bolan, N.S., 2020. Microplastics as pollutants in agricultural soils. *Environmental Pollution*. 265 (part A), 114980. <https://doi.org/10.1016/j.envpol.2020.114980>

Lassen, C., Hansen, S.F., Magnusson, K., Hartmann, N.B., Jensen, R., Nielson, T., Brinch, A., 2015. Microplastics: occurrence, effects and sources of releases to the environment in Denmark. Danish Environmental Protection Agency. 1793, 1–205.

Lebreton, L., Egger, M., Slat, B., 2019. A global mass budget for positively buoyant macroplastic debris in the ocean. *Scientific Reports*. 9, 12922. <https://doi.org/10.1038/s41598-019-49413-5>

Lei, Y.D., Wania, F., 2004. Is rain or snow a more efficient scavenger of organic chemicals? *Atmospheric Environment*. 38, 3557–3571. <https://doi.org/10.1016/j.atmosenv.2004.03.039>

Levermore, J.M., Smith, T.E.L., Kelly, F.J., Wright, S.L., 2020. Detection of Microplastics in Ambient Particulate Matter Using Raman Spectral Imaging and Chemometric Analysis. *Analytical Chemistry*. 92, 8732–8740. <https://doi.org/10.1021/acs.analchem.9b05445>

Li, Y., Shao, L., Wang, W., Zhang, M., Feng, X., Li, W., Zhang, D., 2020. Airborne fiber particles: Types, size and concentration observed in Beijing. *Science of the Total Environment*. 705, 135967. <https://doi.org/10.1016/j.scitotenv.2019.135967>

Li, L., Zhao, X., Li, Z., Song, K., 2021. COVID-19: Performance study of microplastic inhalation risk posed by wearing masks. *Journal of Hazardous Materials*. 411, 124955. <https://doi.org/10.1016/j.jhazmat.2020.124955>

Lim, D., Jeong, J., Song, K.S., Sung, J.H., Oh, S.M., Choi, J., 2021. Inhalation toxicity of polystyrene micro(nano)plastics using modified OECD TG 412. *Chemosphere* 262, 128330. <https://doi.org/10.1016/j.chemosphere.2020.128330>

- Liu, Y., Liu, W., Yang, X., Wang, J., Lin, H., Yang, Y., 2021. Microplastics are a hotspot for antibiotic resistance genes: Progress and perspective. *Science of the Total Environment*. 773, 145643. <https://doi.org/10.1016/j.scitotenv.2021.145643>
- Liu, Q., Schauer, J., 2021. Airborne Microplastics from Waste as a Transmission Vector for COVID-19. *Aerosol and Air Quality Research*. 21, 200439. <https://doi.org/10.4209/aaqr.2020.07.0439>
- Liu, C., Li, J., Zhang, Y., Wang, L., Deng, J., Gao, Y., Yu, L., Zhang, J., 2019a. Widespread distribution of PET and PC microplastics in dust in urban China and their estimated human exposure. *Environment International*. 128, 116-124. <https://doi.org/10.1016/j.envint.2019.04.024>
- Liu, K., Wang, X., Fang, T., Xu, P., Zhu, L., Li, D., 2019b. Source and potential risk assessment of suspended atmospheric microplastics in Shanghai. *Science of the Total Environment*. 675, 462-471. <https://doi.org/10.1016/j.scitotenv.2019.04.110>
- Liu, K., Wu, T., Wang, X., Song, Z., Zong, C., Wei, N., Li, D., 2019c. Consistent Transport of Terrestrial Microplastics to the Ocean through Atmosphere. *Environmental Science and Technology*. 53(18), 10612-10619. <https://doi.org/10.1021/acs.est.9b03427>
- Liu, K., Wang, X., Song, Z., Wei, N., Li, D., 2020a. Terrestrial plants as a potential temporary sink of atmospheric microplastics during transport. *Science of the Total Environment*. 742, 140523. <https://doi.org/10.1016/j.scitotenv.2020.140523>
- Liu, K., Wang, X., Song, Z., Wei, N., Ye, H., Cong, X., Zhao, L., Li, Y., Qu, L., Zhu, L., Zhang, F., Zong, C., Jiang, C., Li, D., 2020b. Global inventory of atmospheric fibrous microplastics input into the ocean: An implication from the indoor origin. *Journal of Hazardous Materials*. 400, 123223. <https://doi.org/10.1016/j.jhazmat.2020.123223>
- Lusher, A.L., Tirelli, V., O'Connor, I., Officer, R., 2015. Microplastics in Arctic polar waters: the first reported values of particles in surface and sub-surface samples. *Scientific Reports*. 5, 14947. <https://doi.org/10.1038/srep14947>
- Malizia, A., Monmany-Garzia, A.C., 2019. Terrestrial ecologists should stop ignoring plastic pollution in the anthropocene time. *Science of the Total Environment*. 668, 1025-1029. <https://doi.org/10.1016/j.scitotenv.2019.03.044>
- Mao, Y., Li, H., Gu, W., Yang, G., Liu, Y., He, Q., 2020. Distribution and characteristics of microplastics in the Yulin River, China: Role of environmental and spatial factors. *Environmental Pollution*. 265(part A), 115033. <https://doi.org/10.1016/j.envpol.2020.115033>
- Masiá, P., Ardura, A., Garcia-Vazquez, E., 2019. Microplastics in special protected areas for migratory birds in the Bay of Biscay. *Marine Pollution Bulletin*. 146, 993-1001. <https://doi.org/10.1016/j.marpolbul.2019.07.065>
- Mbachu, O., Jenkins, G., Pratt, C., Kaparaju, P., 2020. A new contaminant superhighway? A Review of Sources, measurement techniques and fate of atmospheric microplastics. *Water Air and Soil Pollution*. 231, 85. <https://doi.org/10.1007/s11270-020-4459-4>
- Miller, E., Sedlak, M., Lin, D., Box, C., Holleman, C., Rochman, C.M., Sutton, R., 2021. Recommended best practices for collecting, analyzing, and reporting microplastics in environmental media: Lessons learned from comprehensive monitoring of San Francisco Bay. *Journal of Hazardous Materials*. 409, 124770. <https://doi.org/10.1016/j.jhazmat.2020.124770>



- Napper, I.E., Davies, B.F.R., Clifford, H., Elvin, S., Koldewey, H.J., Mayewski, P.A., Miner, K.R., Potocki, M., Elmore, A.C., Gajurel, A.P., Thompson, R.C., 2020. Reaching New Heights in Plastic Pollution—Preliminary Findings of Microplastics on Mount Everest. *One Earth*. 3, 621–630. <https://doi.org/10.1016/j.oneear.2020.10.020>
- Napper, I.E., Baroth, A., Barrett, A.C., Bhola, S., Chowdhury, G.W., Davies, B.F.R., Duncan, E.M., Kumar, S., Nelms, S.E., Hasan Niloy, M.N., Nishat, B., Maddalene, T., Thompson, R.C., Koldewey, H., 2021. The abundance and characteristics of microplastics in surface water in the transboundary Ganges River. *Environmental Pollution*. 274, 116348. <https://doi.org/10.1016/j.envpol.2020.116348>
- Narmada, V.V., Jose, J., Patil, S., Farooqui, M.O., Srimuruganandam, B., Sivanesan, S., Krishnamurthy, K., 2020. Assessment of Microplastics in Roadside Suspended Dust from Urban and Rural Environment of Nagpur, India. *International Journal of Environmental Research*. 14, 629–640. <https://doi.org/10.1007/s41742-020-00283-0>
- Ng, E.L., Lin, S.Y., Dungan, A.M., Colwell, J.M., Ede, S., Huerta Lwanga, E., Meng, K., Geissen, V., Blackall, L.L., Chen, D., 2020. Microplastic pollution alters forest soil microbiome. *Journal of Hazardous Materials*. 124606. <https://doi.org/10.1016/j.jhazmat.2020.124606>
- Nho, R., 2020. Pathological effects of nano-sized particles on the respiratory system. *Nanomedicine: Nanotechnology, Biology and Medicine*. 29, 102242. <https://doi.org/10.1016/j.nano.2020.102242>
- NSW Environmental Protection Agency, 2016. The compost order 2016. Retrieved from: <https://www.epa.nsw.gov.au/~media/EPA/Corporate%20Site/resources/wasteregulation/RRO16-compost.ashx> (Accessed: 07.03.2021)
- O'Brien, S., Okoffo, E.D., O'Brien, J.W., Ribeiro, F., Wang, X., Wright, S.L., Samanipour, S., Rauert, C., Toapanta, T.Y.A., Albarracin, R., Thomas, K.V., 2020. Airborne emissions of microplastic fibres from domestic laundry dryers. *Science of the Total Environment*. 747, 141175. <https://doi.org/10.1016/j.scitotenv.2020.141175>
- Ojha, N., Sharma, A., Kumar, M., Girach, I., Ansari, T.U., Sharma, S.K., Singh, N., Pozzer, A., Gunthe, S.S., 2020. On the widespread enhancement in fine particulate matter across the Indo-Gangetic Plain towards winter. *Scientific Reports*. 10, 5862. <https://doi.org/10.1038/s41598-020-62710-8>
- OSHA, Personal Protective Equipment, 2016. Retrieved from: <https://www.osha.gov/personal-protective-equipment>
- Ostle, C., Thompson, R.C., Broughton, D., Gregory, L., Wootton, M., Johns, D.G., 2019. The rise in ocean plastics evidenced from a 60-year time series. *Nature Communications*. 10, 1622. <https://doi.org/10.1038/s41467-019-09506-1>
- Patchaiyappan, A., Dowarah, K., Zaki Ahmed, S., Prabakaran, M., Jayakumar, S., Thirunavukkarasu, C., Devipriya, S.P., 2021. Prevalence and characteristics of microplastics present in the street dust collected from Chennai metropolitan city, India. *Chemosphere*. 269, 128757. <https://doi.org/10.1016/j.chemosphere.2020.128757>
- Peeken, I., Primpke, S., Beyer, B., Gütermann, J., Katlein, C., Krumpfen, T., Bergmann, M., Hehemann, L., Gerds, G., 2018. Arctic sea ice is an important temporal sink and means of transport for microplastic. *Nature Communications*. 9, 1505. <https://doi.org/10.1038/s41467-018-03825-5>

Pickett, J.E., Hall, M.L., Heer, J.d., Kuvshinnikova, O., Boven, G., 2019. Microbial growth on outdoor-weathered plastics. *Polymer Degradation and Stability*. 163, 206-213. <https://doi.org/10.1016/j.polymdegradstab.2019.03.013>

PlasticsEurope., 2018. *Plastics-the Facts 2018, an analysis of European plastics production, demand and waste data*. <https://www.plasticseurope.org/en/resources/market-data>

Pokharel, A., 2020. *Prey Selection by Birds of Prey*. Dissertations and Theses in Biological Sciences. Retrieved from: <https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1116&context=bioscidiss>

Potapov, P., Li, X., Hernandez-Serna, A., Tyukavina, A., Hansen, M.C., Kommareddy, A., Pickens, A., Turubanova, S., Tang, H., Silva, C.E., Armston, J., Dubayah, R., Blair, J.B., Hofton, M., 2021. Mapping global forest canopy height through integration of GEDI and Landsat data. *Remote Sensing of Environment*. 253, 112165. <https://doi.org/10.1016/j.rse.2020.112165>

Prata, J.C., 2018. Airborne microplastics: Consequences to human health? *Environmental Pollution*. 234, 115-126. <https://doi.org/10.1016/j.envpol.2017.11.043>

Prata, J.C., Costa, J.P.d., Lopes, I., Duarte, A.C., Rocha-Santos, T., 2020. Environmental exposure to microplastics: An overview on possible human health effects. *Science of the Total Environment*. 702, 134455. <https://doi.org/10.1016/j.scitotenv.2019.134455>

Prata, J.C., Reis, V., da Costa, J.P.D., Mouneyrac, C., Duarte, A.C., Rocha-Santos, T., 2021. Contamination issues as a challenge in quality control and quality assurance in microplastics analytics. *Journal of Hazardous Materials*. 403, 123660. <https://doi.org/10.1016/j.jhazmat.2020.123660>

Radisic, V., Nimje, P.S., Bienfait, A.M., Marathe, N.P., 2020. Marine Plastics from Norwegian West Coast Carry Potentially Virulent Fish Pathogens and Opportunistic Human Pathogens Harboring New Variants of Antibiotic Resistance Genes. *Microorganisms*. 8, 1200. <https://doi.org/10.3390/microorganisms8081200>

Ragusa, A., Svelato, A., Santacroce, C., Catalano, P., Notarstefano, V., Carnevali, O., Papa, F., Rongioletti, M.C.A., Baiocco, F., Draghi, S., D'Amore, E., Rinaldo, D., Matta, M., Giorgini, E., 2021. Plasticenta: First evidence of microplastics in human placenta. *Environment International*. 146, 106274. <https://doi.org/10.1016/j.envint.2020.106274>

Rai, P.K., Lee, J., Brown, R.J.C., Kim, K.-H., 2021. Environmental fate, ecotoxicity biomarkers, and potential health effects of micro- and nano-scale plastic contamination. *Journal of Hazardous Materials*. 403, 123910. <https://doi.org/10.1016/j.jhazmat.2020.123910>

Ranjan, V.P., Joseph, A., Goel, S., 2021. Microplastics and other harmful substances released from disposable paper cups into hot water. *Journal of Hazardous Materials*. 404, 124118. <https://doi.org/10.1016/j.jhazmat.2020.124118>

Reed, S., Clark, M., Thompson, R., Hughes, K.A., 2018. Microplastics in marine sediments near Rothera Research Station, Antarctica. *Marine Pollution Bulletin*. 133, 460-463. <https://doi.org/10.1016/j.marpolbul.2018.05.068>

Revel, M., Châtel, A., Mouneyrac, C., 2018. Micro(nano)plastics: A threat to human health? *Current Opinion in Environmental Science and Health*. 1, 17-23. <https://doi.org/10.1016/j.coesh.2017.10.003>

- Rezaei, M., Ricksen, M.J.P.M., Sirjani, E., Sameni, A., Geissen, V., 2019. Wind erosion as a driver for transport of light density microplastics. *Science of the Total Environment*. 669, 273-281. <https://doi.org/10.1016/j.scitotenv.2019.02.382>
- Rist, S., Vianello, A., Winding, M.H.S., Nielson, T.G., Almeda, R., Torres, R.R., Vollertsen, J., 2020. Quantification of plankton-sized microplastics in a productive coastal Arctic marine ecosystem. *Environmental Pollution*. 266 (Part 1), 115248. <https://doi.org/10.1016/j.envpol.2020.115248>
- Rochman, C., Hoellein, T., 2020. The global odyssey of plastic pollution. *Science*. 368(6496), 1184-1185. [10.1126/science.abc4428](https://doi.org/10.1126/science.abc4428)
- Routti, H., Atwood, T.C., Bechshoft, T., Boltunov, A., Ciesielski, T.M., Desforges, J.P., Dietz, R., Gabrielsen, G.W., Jenssen, B.M., Letcher, R.J., McKinney, M.A., Morris, A.D., Rigét, F.F., Sonne, C., Styriehave, B., Tartu, S., 2019. State of knowledge on current exposure, fate and potential health effects of contaminants in polar bears from the circumpolar Arctic. *Science of the Total Environment*. 664, 1063-1083. <https://doi.org/10.1016/j.scitotenv.2019.02.030>
- Selvam, S., Manisha, A., Venkatramanan, S., Chung, S.Y., Paramasivam, C.R., Singaraja, C., 2020. Microplastic presence in commercial marine sea salts: A baseline study along Tuticorin Coastal salt pan stations, Gulf of Mannar, South India. *Marine Pollution Bulletin*. 150, 110675. <https://doi.org/10.1016/j.marpolbul.2019.110675>
- Senathirajah, K., Attwood, S., Bhagwat, G., Carbery, M., Wilson, S., Palanisami, T., 2021. Estimation of the mass of microplastics ingested – A pivotal first step towards human health risk assessment. *Journal of Hazardous Materials*. 404, 124004. <https://doi.org/10.1016/j.jhazmat.2020.124004>
- Shen, M., Ye, S., Zeng, G., Zhang, Y., Xing, L., Tang, W., Wen, X., Liu, S., 2020. Can microplastics pose a threat to ocean carbon sequestration? *Marine Pollution Bulletin*. 150, 110712. <https://doi.org/10.1016/j.marpolbul.2019.110712>
- Shruthi, V.C., Pérez-Guevara, F., Kutralam-Muniasamy, G., 2020. Metro station free drinking water fountain- A potential “microplastics hotspot” for human consumption. *Environmental Pollution*. 261, 114227. <https://doi.org/10.1016/j.envpol.2020.114227>
- Smith, M., Love, D.C., Rochman, C.M., Neff, R.A., 2018. Microplastics in Seafood and the Implications for Human Health. *Current Environmental Health Reports*. 5, 375–386. <https://doi.org/10.1007/s40572-018-0206-z>
- Sobhani, Z., Lei, Y., Tang, Y. Wu, L., Zhang, X., Naidu, R., Megharaj, M., Fang, C., 2020. Microplastics generated when opening plastic packaging. *Scientific Reports*. 10, 4841. <https://doi.org/10.1038/s41598-020-61146-4>
- Song, J., Qian, H., Zhao, D., Jiang, W., Zheng, X., 2020. Particulate matter emission by an isolated rotating wheel. *Building Simulation*. <https://doi.org/10.1007/s12273-020-0724-0>
- Song, Z., Liu, K., Wang, X., Wei, N., Zong, Z., Li, C., Jiang, C., He, Y., Li, D., 2021. To what extent are we really free from airborne microplastics? *Science of the Total Environment*. 754, 142118. <https://doi.org/10.1016/j.scitotenv.2020.142118>

- Stanton, T., Johnson, M., Nathanail, P., MacNaughtan, W., Gomes, R.L., 2019. Freshwater and airborne textile fibre populations are dominated by ‘natural’, not microplastic, fibres. *Science of the Total Environment*. 666, 377-389. <https://doi.org/10.1016/j.scitotenv.2019.02.278>
- Su, L., Nan, B., Craig, N.J., Pettigrove, V., 2020. Temporal and spatial variations of microplastics in roadside dust from rural and urban Victoria, Australia: Implications for diffuse pollution. *Chemosphere* 252, 126567. <https://doi.org/10.1016/j.chemosphere.2020.126567>
- Sun, Y., Cao, N., Duan, C., Wang, Q., Ding, C., Wang, J., 2021. Selection of antibiotic resistance genes on biodegradable and non-biodegradable microplastics. *Journal of Hazardous Materials*. 409, 124979. <https://doi.org/10.1016/j.jhazmat.2020.124979>
- Sun, Y., Yuan, J., Zhou, T., Zhao, Y., Yu, F., Ma, J., 2020. Laboratory simulation of microplastics weathering and its adsorption behaviors in an aqueous environment: A systematic review. *Environmental Pollution*. 265 (Part B), 114846. <https://doi.org/10.1016/j.envpol.2020.114864>
- Sundt, P., Schulze, P., Syversen, F., 2015. Sources of microplastic-pollution to the marine environment. Project report. Norwegian Environmental Agency. M-321.
- Takahashi, N., Hayasaka, T., 2020. Air–Sea Interactions among Oceanic Low-Level Cloud, Sea Surface Temperature, and Atmospheric Circulation on an Intraseasonal Time Scale in the Summertime North Pacific Based on Satellite Data Analysis. *Journal of Climate*. 33(21), 9195-9212. <https://doi.org/10.1175/JCLI-D-19-0670.1>
- Thinh, T.Q., Sang, T.T.N., Viet, T.Q., Tam, L.T.M., Dan, N.P., Strady, E., Chung, K.L.T., 2020. Preliminary assessment on the microplastic contamination in the atmospheric fallout in the Phuoc Hiep landfill, Cu Chi, Ho Chi Minh city. *Vietnam Journal of Science Technology and Engineering*. 62(3), 83-89. [https://doi.org/10.31276/VJSTE.62\(3\).83-89](https://doi.org/10.31276/VJSTE.62(3).83-89)
- Uheida, A., Mejía, H.G., Abdel-Rehim, M., Hamd, W., Dutta, J., 2021. Visible light photocatalytic degradation of polypropylene microplastics in a continuous water flow system. *Journal of Hazardous Materials*. 406, 124299. <https://doi.org/10.1016/j.jhazmat.2020.124299>
- UNEP beat plastic pollution: <https://www.unep.org/interactive/beat-plastic-pollution/>
- Unice, K., Weeber, M., Abramson, M., Reid, R., van Gils, J., Markus, A., Vethaak, A., Panko, J., 2019. Characterizing export of land-based microplastics to the estuary - Part I: Application of integrated geospatial microplastic transport models to assess tire and road wear particles in the Seine watershed. *Science of the Total Environment*. 646, 1639–1649. <https://doi.org/10.1016/j.scitotenv.2018.07.368>
- Veerasingam, S., Saha, M., Suneel, V., Vethamony, P., Rodrigues, A.C., Bhattacharyya, S., Naik, B.G., 2016. Characteristics, seasonal distribution and surface degradation features of microplastic pellets along the Goa coast, India. *Chemosphere*. 159, 496-505. <https://doi.org/10.1016/j.chemosphere.2016.06.056>
- Vethaak, A.D., Legler, J., 2021. Microplastics and human health. *Science*. 371, 672–674. <https://doi.org/10.1126/science.abe5041>
- Vianello, A., Jensen, R.L., Liu, L., Vollertsen, J., 2019. Simulating human exposure to indoor airborne microplastics using a Breathing Thermal Manikin. *Scientific Reports*. 9, 8670. <https://doi.org/10.1038/s41598-019-45054-w>

Wang, X., Li, C., Liu, K., Zhu, L., Song, Z., Li, D., 2020. Atmospheric microplastic over the South China Sea and East Indian Ocean: abundance, distribution and source. *Journal of Hazardous Materials*. 389, 121846. <https://doi.org/10.1016/j.jhazmat.2019.121846>

Wang, C., Zhao, J., Xing, B., 2021a. Environmental source, fate, and toxicity of microplastics. *Journal of Hazardous Materials*. 407, 124357. <https://doi.org/10.1016/j.jhazmat.2020.124357>

Wang, L., Wu, W.-M., Bolan, N.S., Tsang, D.C.W., Li, Y., Qin, M., Hou, D., 2021b. Environmental fate, toxicity and risk management strategies of nanoplastics in the environment: Current status and future perspectives. *Journal of Hazardous Materials*. 401, 123415. <https://doi.org/10.1016/j.jhazmat.2020.123415>

Wang, X., Liu, K., Zhu, L., Li, C., Song, Z., Li, D., 2021c. Efficient transport of atmospheric microplastics onto the continent via the East Asian summer monsoon. *Journal of Hazardous Materials*. 125477. <https://doi.org/10.1016/j.jhazmat.2021.125477>

Wang, Y., Wang, X., Li, Y., Liu, Y., Xia, S., Zhao, J., 2021d. Effects of exposure of polyethylene microplastics to air, water and soil on their adsorption behaviors for copper and tetracycline. *Chemical Engineering Journal*. 404, 126412. <https://doi.org/10.1016/j.cej.2020.126412>

Watts, A.J.R., Urbina, M.A., Goodhead, R., Moger, J., Lewis, C., Galloway, T.S., 2016. Effect of Microplastic on the Gills of the Shore Crab *Carcinus maenas*. *Environmental Science and Technology*. 50, 5364-5369. <https://doi.org/10.1021/acs.est.6b01187>

Wesch, C., Elert, A.M., Wörner, M., Braun, U., Klein, R., Paulus, M., 2017. Assuring quality in microplastic monitoring: About the value of clean-air devices as essentials for verified data. *Scientific Reports*. 7, 5424. <https://doi.org/10.1038/s41598-017-05838-4>

WHO air quality guidelines, 2005. Retrieved from: [https://apps.who.int/iris/bitstream/handle/10665/69477/WHO\\_SDE\\_PHE\\_OEH\\_06.02\\_eng.pdf;jsessionid=EF63FECC85490E621BB9EECB7AAD2000?sequence=1](https://apps.who.int/iris/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06.02_eng.pdf;jsessionid=EF63FECC85490E621BB9EECB7AAD2000?sequence=1)

WHO report: Microplastics in drinking water. Geneva: World Health Organization; 2019. Retrieved from [https://www.who.int/water\\_sanitation\\_health/publications/microplastics-in-drinking-water/en/](https://www.who.int/water_sanitation_health/publications/microplastics-in-drinking-water/en/)

Wright, S.L., Kelly, F.J., 2017. Plastic and human health: a micro issue? *Environmental Science and Technology*. 51(12), 6634-6647. <https://doi.org/10.1021/acs.est.7b00423>

Wright, S.L., Levermore, J.M., Kelly, F.J., 2019. Raman spectral imaging for the detection of inhalable microplastics in ambient particulate matter samples. *Environmental Science and Technology*. 53(15), 8947-8956. <https://doi.org/10.1021/acs.est.8b06663>

Wright, S.L., Ulke, J., Font, A., Chan, K.L.A., Kelly, F.J., 2020. Atmospheric microplastic deposition in an urban environment and an evaluation of transport. *Environment International*. 136, 105411. <https://doi.org/10.1016/j.envint.2019.105411>

Xu, C., Zhang, B., Gu, C., Shen, C., Yin, S., Aamir, M., Li, F., 2020a. Are we underestimating the sources of microplastic pollution in terrestrial environment? *Journal of Hazardous Materials*. 400, 123228. <https://doi.org/10.1016/j.jhazmat.2020.123228>

Xu, Q., Gao, Y., Xu, L., Shi, W., Wang, F., LeBlanc, G.A., Cui, S., An, L., Lei, K., 2020b. Investigation of the microplastics profile in sludge from China's largest Water reclamation plant

using a feasible isolation device. *Journal of Hazardous Materials*. 388, 122067. <https://doi.org/10.1016/j.jhazmat.2020.122067>

Yacobi, N.R., DeMaio, L., Xie, J., Hamm-Alvarez, S.F., Borok, Z., Kim, K.-J., Crandall, E.D., 2008. Polystyrene nanoparticle trafficking across alveolar epithelium. *Nanomedicine: Nanotechnology, Biology and Medicine*. 4, 139–145. <https://doi.org/10.1016/j.nano.2008.02.002>

Yang, Z., Lü, F., Zhang, H., Wang, W., Shao, L., Ye, J., He, P., 2021. Is incineration the terminator of plastics and microplastics? *Journal of Hazardous Materials*. 401, 123429. <https://doi.org/10.1016/j.jhazmat.2020.123429>

You, S., Sonne, C., Ok, Y.S., 2020. COVID-19's unsustainable waste management. *Science*. 368 (6498), 1438. <http://dx.doi.org/10.1126/science.abc7778>

Yurtsever, M., Kaya, A.T., Bayraktar, S.Ç., 2018. A research on microplastic presence in outdoor air. In: Cocca M., Di Pace E., Errico M., Gentile G., Montarsolo A., Mossotti R. (eds) *Proceedings of the International Conference on Microplastic Pollution in the Mediterranean Sea*. Springer Water. Springer, Cham. [https://doi.org/10.1007/978-3-319-71279-6\\_13](https://doi.org/10.1007/978-3-319-71279-6_13)

Zagorski, J., Debelak, J., Gellar, M., Watts, J.A., Kline, J.A., 2003. Chemokines Accumulate in the Lungs of Rats with Severe Pulmonary Embolism Induced by Polystyrene Microspheres. *The Journal of Immunology*. 171, 5529–5536. <https://doi.org/10.4049/jimmunol.171.10.5529>

Zettler, E.R., Mincer, T.J., Zettler, L.A.A., 2013. Life in the “Plastisphere”: Microbial Communities on Plastic Marine Debris. *Environmental Science and Technology*. 47, 7137–7146. <https://doi.org/10.1021/es401288x>

Zhang, C., Zhou, H., Cui, Y., Wang, C., Li, Y., Zhang, D., 2019. Microplastics in offshore sediment in the Yellow Sea and East China Sea, China. *Environmental Pollution*. 244, 827-833. <https://doi.org/10.1016/j.envpol.2018.10.102>

Zhang, J., Wang, L., Kannan, K., 2020a. Microplastics in house dust from 12 countries and associated human exposure. *Environment International*. 134, 105314. <https://doi.org/10.1016/j.envint.2019.105314>

Zhang, Q., Zhao, Y., Du, F., Cai, H., Wang, G., Shi, H., 2020b. Microplastic Fallout in Different Indoor Environments. *Environmental Science and Technology*. 54(11), 6530–6539. <https://doi.org/10.1021/acs.est.0c00087>

Zhang, Y., Kang, S., Allen, S., Allen, D., Gao, T., Sillanpää, M., 2020c. Atmospheric microplastics: A review on current status and perspectives. *Earth-Science Reviews*. 203, 13118. <https://doi.org/10.1016/j.earscirev.2020.103118>

Zhao, S., Zhu, L., Li, D., 2016. Microscopic anthropogenic litter in terrestrial birds from Shanghai, China: not only plastics but also natural fibers. *Science of the Total Environment*. 550, 1110-1115. <https://doi.org/10.1016/j.scitotenv.2016.01.112>

Zhou, Y., He, G., Jiang, X., Yao, L., Ouyang, L., Liu, X., Liu, W., Liu, Y., 2021. Microplastic contamination is ubiquitous in riparian soils and strongly related to elevation, precipitation and population density. *Journal of Hazardous Materials*. 411, 125178. <https://doi.org/10.1016/j.jhazmat.2021.125178>

Zhou, Q., Tian, C., Luo, Y., 2017. Various forms and deposition fluxes of microplastics identified in the coastal urban atmosphere. *Chinese Science Bulletin*. 62 (33), 3902-3909. <https://doi.org/10.1360/N972017-00956>

Zhu, K., Jia, H., Sun, Y., Dai, Y., Zhang, C., Guo, X., Wang, T., Zhu, L., 2020. Enhanced cytotoxicity of photoaged phenol-formaldehyde resins microplastics: Combined effects of environmentally persistent free radicals, reactive oxygen species, and conjugated carbonyls. *Environment International*. 145, 106137. <https://doi.org/10.1016/j.envint.2020.106137>

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**Figure 3.** A simplified representation of atmospheric resuspension, transport, scavenge, and deposition of MPs

**Figure 4.** Overview of aerial transport of MPs through wet and dry deposition

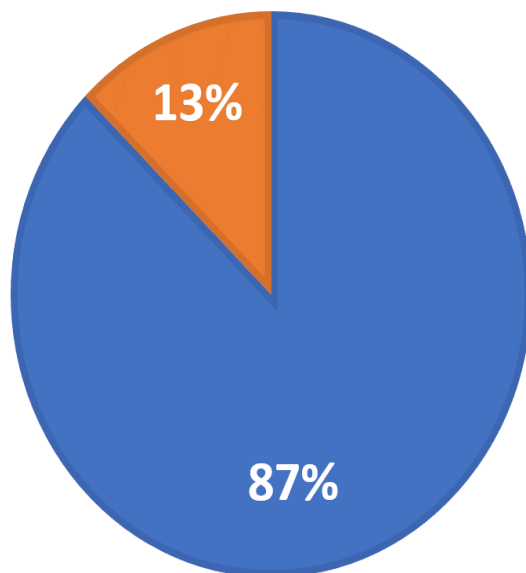
**Figure 5.** Abundance and trophic transfer of atmospheric MPs in canopy and aerial ecosystems



Figure 1.

## Available literature on the human health implications of microplastics

■ Literature: Soil/aquatic MPs on human health   ■ Literature: Airborne MPs on human health



**Figure 2.**

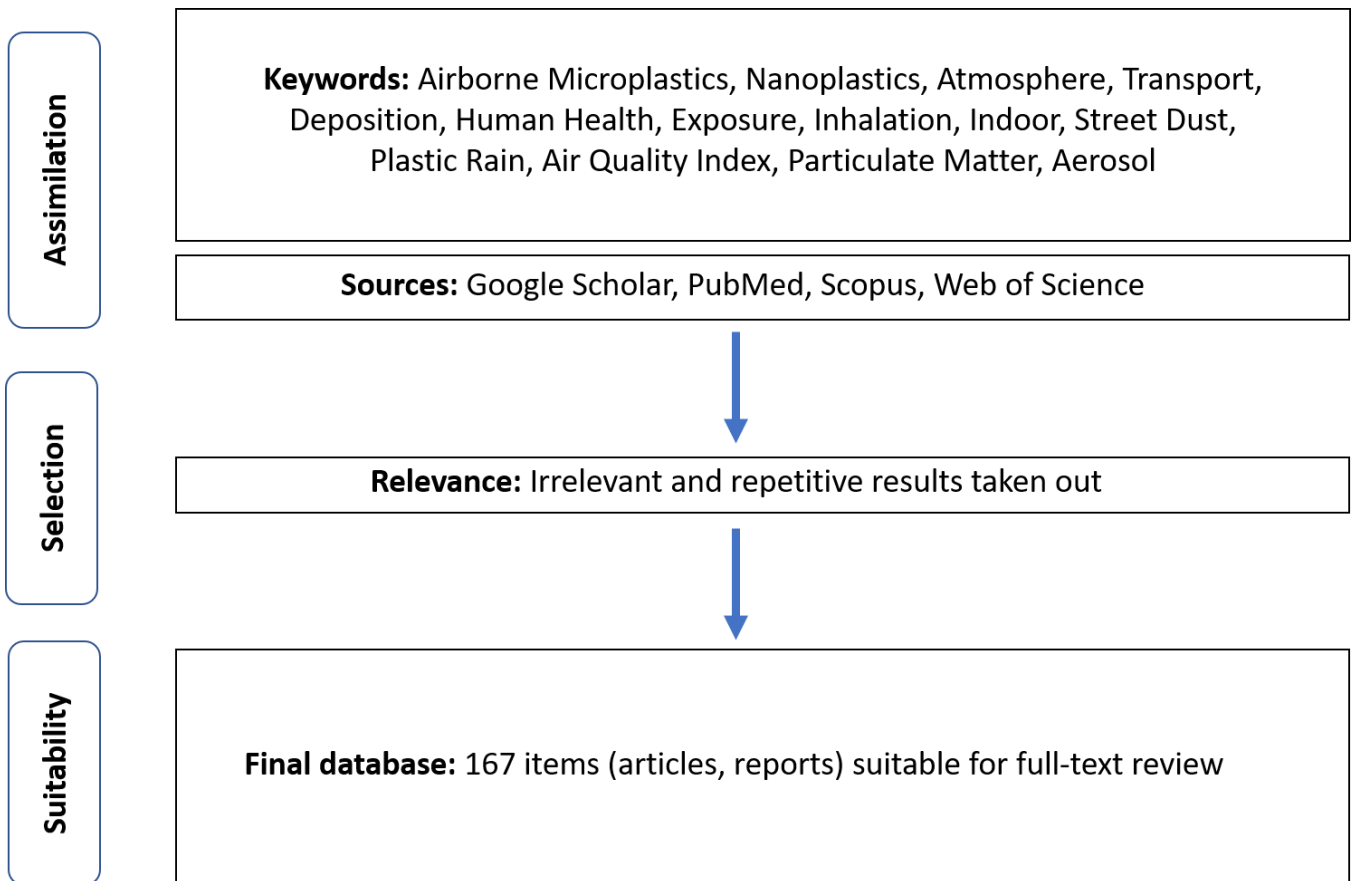


Figure 3.

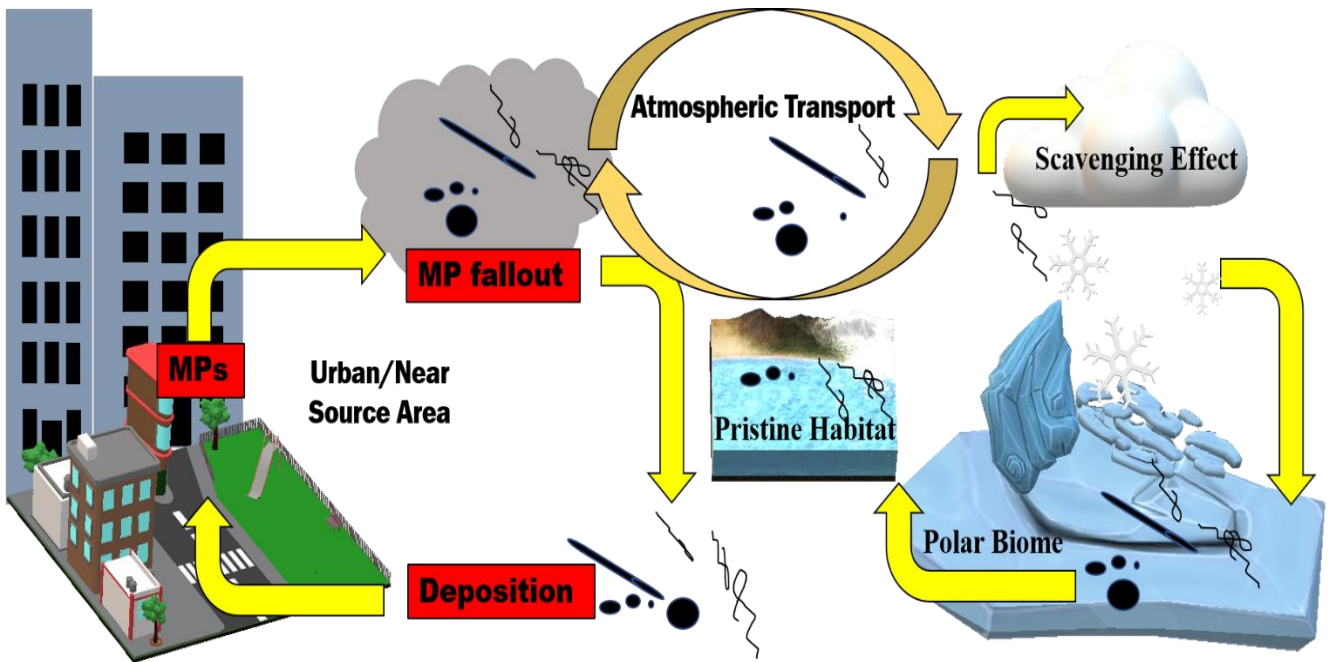


Figure 4.

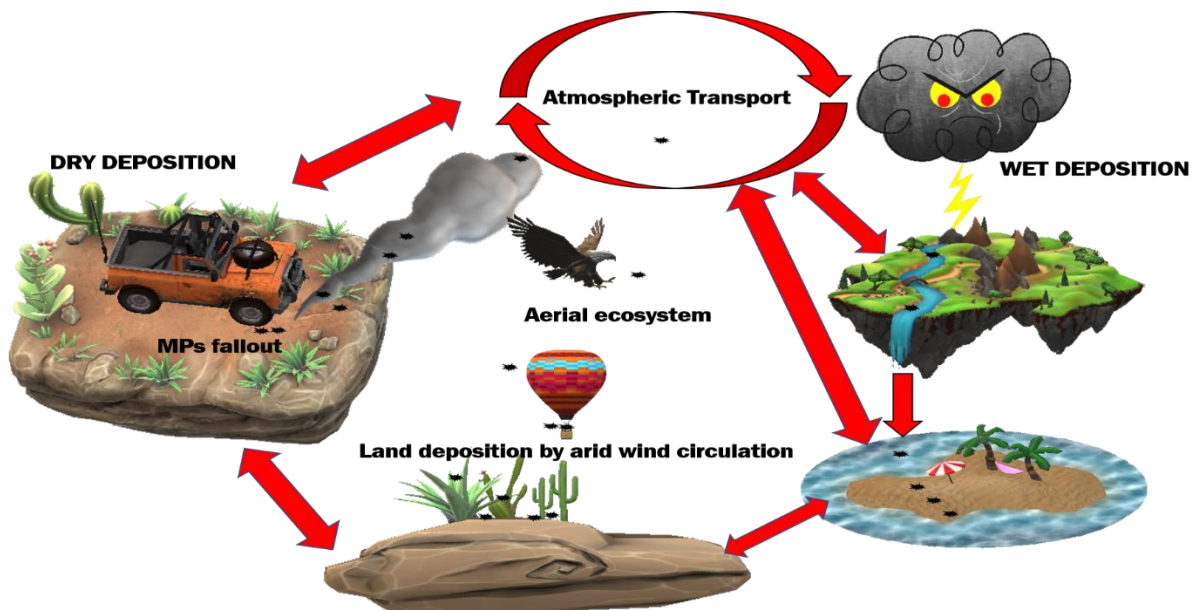
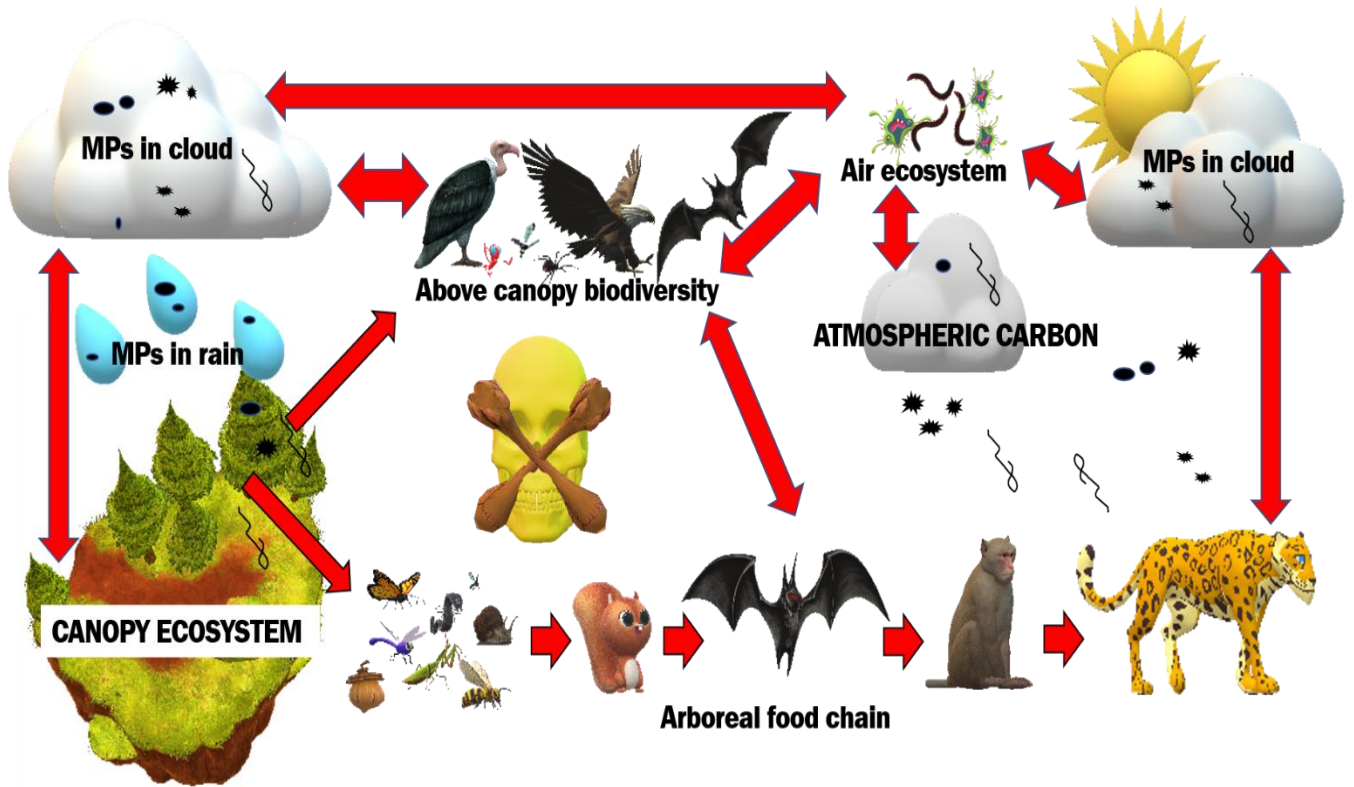


Figure 5.



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**Table 1.** Overview of the worldwide documentation studies on MPs in air

**Table 2.** Available studies on the health impacts of airborne MPs on the possible health implications in humans.

**Table 3.** Comparison of the parameters for PM and aerosol with MPs based on WHO air quality guidelines (2005).

**Table 1.**

Country	Sampling site	Forms of MPs	Assessment	Sampling method	References
India (Chennai, Tamilnadu)	Street dust (urban)	Predominantly fragments	Abundance: 227.94 ± 91.37/100g	Passive sampling (street dust collectors)	<a href="#">Patchaiyappan et al. (2021)</a>
Australia (Victoria)	Roadside dust (urban and rural)	Predominantly fibers	Abundance: 20.6 - 529.3 itemskg <sup>-1</sup>	Street dust sampling	<a href="#">Su et al. (2020)</a>
India (Nagpur, Maharashtra)	4 outdoor sites in and around Nagpur city	Predominantly fragments, filaments, fibers	Abundance: 50-120 particles d <sup>-1</sup>	Particulate samplers	<a href="#">Narmada et al. (2020)</a>
United States of America (West U.S.A)	11 protected national parks across western America	Predominantly microfibers	Mean annual deposition rate: 132 ± 6 particles m <sup>-2</sup> d <sup>-1</sup>	Passive sampling (dry deposition and precipitation)	<a href="#">Brahney et al. (2020)</a>
United States of America (California)	Indoor and outdoor air in coastal southern California (5 locations across 100km)	Microfibers and fragments	-	Active sampling (vacuum glass microfiber filter)	<a href="#">Gaston et al. (2020)</a>
Vietnam (Ho Chi Minh)	Atmospheric fallout (Phuoc Hiep landfill, Cu Chi)	Predominantly microfibers	Deposition rates: 1,801.2 particles m <sup>-2</sup> d <sup>-1</sup> (dry season) and 913 particles m <sup>-2</sup> d <sup>-1</sup> (rainy season)	A simplified sampling device to collect rainfall and dust	<a href="#">Thinhet al. (2020)</a>
United Kingdom (London)	Atmospheric deposition (a tall building in Central London)	Predominantly microfibers	Deposition rate: 712 ± 162 m <sup>-2</sup> d <sup>-1</sup> (January-February: Cool and dry season)	Passive sampling (outdoor deposition)	<a href="#">Wright et al. (2020)</a>
China (Beijing)	Urban area in northwest Beijing (at 1.5m and 18m above ground)	Predominantly microfibers	At 1.5m: 16.7 × 10 <sup>-3</sup> fibers ml <sup>-1</sup> ; At 18m: 14.1 × 10 <sup>-3</sup> fibers ml <sup>-1</sup>	Passive sampling (atmospheric deposition)	<a href="#">Li et al. (2020)</a>
United Kingdom (Nottingham)	Surface water samples (urban Trent catchments) and atmospheric fallout (Roofs of University of	Predominantly natural fibers	720 fibers (freshwater); 1100 fibers (fallout)	Passive sampling (atmospheric deposition)	<a href="#">Stanton et al. (2019)</a>

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Nottingham)

China (Shanghai)	6 sampling stations across the district (atmospheric particulate sampling)	Predominantly fibers, fragments, granules	Mean concentration: $1.42 \pm 1.42 \text{ n m}^{-3}$	Total suspended particulate sampling device (active sampling)	<a href="#">Liu et al. (2019b)</a>
Iran (Asaluyeh city)	Street dust from 2 sampling stations (an industrial zone and an urban zone)	Predominantly microfibers and filaments	Total concentration: 13,132 MPs and 3691 MRs from 15 samples	Particulate dust sampling (active sampling: ambient filter)	<a href="#">Abbasi et al. (2019)</a>
Germany (Hamburg)	6 sampling sites in Hamburg city (selected based on population density)	Predominantly fragments and fibers	Deposition rate: 275 particles $\text{m}^{-2}\text{day}^{-1}$	Passive sampling (atmospheric deposition)	<a href="#">Klein and Fischer (2019)</a>
France (Vicdessos catchment)	A meteorological station in mid-Pyrenees	Predominantly microfibers and films	Deposition rate: 365 particles $\text{m}^{-2}\text{day}^{-1}$	Atmospheric fallout	<a href="#">Allen et al. (2019)</a>
United Kingdom (Edinburg)	Mussels tissue and indoor air (dust fallout during a meal)	Microfibers	MP ingestion by consumption: 4620 particles/y/capita; MP exposure upon indoor fallout: 13,731–68,415 particles/Y/capita	Soft tissue extraction (for mussels) and passive sampling (stationary sampler for indoor airborne fibers)	<a href="#">Catarino et al. (2018)</a>
China (Dongguan)	3 air monitoring sampling sites (atmospheric fallout)	Predominantly microfibers	Concentration: $36 \pm 7$ particles $\text{m}^{-2}\text{day}^{-1}$	Passive sampling (atmospheric fallout)	<a href="#">Cai et al. (2017)</a>
Iran (Tehran)	Roadside dust from 10 sites in the central district	Microfibers and fragments (2649 particles)	Highest concentration: $605 \pm 10$ particles/30 g dry dust	Street dust collection by gentle sweeping	<a href="#">Dehghani et al. (2017)</a>
France (Paris)	Indoor (2 apartments and an office room), outdoor (building roof) air	Predominantly microfibers	Concentrations: 0.9 fibers $\text{m}^{-3}$ (outdoor), 5.4 fibers $\text{m}^{-3}$ (indoor)	Passive sampling (dust fall and deposition for 4 seasons)	<a href="#">Dris et al. (2017)</a>

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China (Shandong province)	Precipitation samples from Yantai city's coastal air	Microfibers, foam, fragments, films	Highest deposition flux: $1.46 \times 10^5 \text{ n m}^{-2} \text{ a}^{-1}$ ( $2.33 \times 10^{13}$ MP particles)	Passive sampling (precipitation deposition in the coastal atmosphere)	<u>Zhou et al. (2017)</u>
France (Paris)	2 sites (urban and semi-urban) in Paris city	Predominantly microfibers	Highest fallout: $355 \text{ particles m}^{-2} \text{ d}^{-1}$	Passive sampling (atmospheric deposition)	<u>Dris et al. (2016)</u>



**Table 2.**

Type of study	Polymers studied	Size range	Mode of exposure	Exposure dosage and time	Observation	References
Quantitative exposure study of MPs to adult humans	PE, PET, and PP fibers	<100 µm	Skin (face, hand), saliva, hair (head)	>3.5 MPs per individual per day (hair), 7 days	MPs sourced from both indoor and outdoor settings, highly heterogeneous exposure. Adherence to hair was a major source of exposure. Males had twice the MP levels of females	<a href="#">Abbasi and Turner (2021)</a>
Toxicology study of NPs translocation from the lung to the placenta	PS	20 nm (NPs)	Inhalation (intratracheal instillation during gestation)	$2.64 \times 10^{14}$ NP particles, 1 day	Upon pulmonary exposure, NPs cross maternal pulmonary barriers to reach the placenta within 24 hours during late-stage pregnancy	<a href="#">Fournier et al. (2020)</a>
In vitro study (rat epithelial cell monolayers)	PS	20-100 nm (NPs)	Transfer to alveolar epithelial cells by crossing pulmonary cell barriers	706 µg mL <sup>-1</sup> , 0-24 hours	NPs could translocate and localize the cytoplasm of the alveolar cells, with trafficking rates being dependent on particle size, temperature, charge density, and cellular energy. However, no NPs were identified in nuclei and cell junctions	<a href="#">Yacobi et al. (2008)</a>
In vivo study of chemokine-mediated inflammatory response in rat lungs	PS spherical MPs	24 ± 1 µm	Venous infusion	1.3 - 1.95 million beads per 100 g body weight, 18 hours	Tests showed accumulation of cytokine in lungs, vascular occlusion, and other changes similar to those of pulmonary thromboembolism in humans	<a href="#">Zagorski et al. (2003)</a>
An assay based invitro toxicity study in human-derived cells	PP	25-200 µm	Addition to cultures (media) of somatic cells, blood cells, and murine immune cells	0.1 - 4.5 mg per well, 24 hours	MPs triggered pro-inflammatory cytokines causing a local immune response	<a href="#">Hwang et al. (2019)</a>
Lab aquarium study on the shore crab <i>Carcinusmaenas</i>	PS spherical MPs	8 µm	Ingestion and inhalation, 1 hour	10 <sup>6</sup> and 10 <sup>7</sup> particles L <sup>-1</sup> , 24 hours	The crabs inhaled MPs into gills, but no significant impact was observed	<a href="#">Watts et al. (2016)</a>

In vivo inhalation toxicity study on rats	PS	0.10 $\mu\text{m}$	Inhalation (whole-body inhalation system), 14 days	$(0.75 \times 10^5 \text{ to } 3.00 \times 10^5) \text{ particle/cm}^3 \pm 20\%$ , 14 days (6 hours/day for 5 days/week)	Impacts were sex-dependent: male rats showed increased heart weight, decreased AST levels, and decreased inspiratory time, while female rats showed decreased immune cell counts, increased respiration frequency, and decreased inspiratory and expiratory time	<u>Lim et al. 2021</u>
Ingestion study on the copepod <i>Calanus helgolandicus</i> cultures with algae ( <i>Rhodomonas salina</i> )	Mixed (microbeads)	6 $\mu\text{m}$	Consumption	5000 MPs ml <sup>-1</sup> , 3-8 days	Impacted respiration rate, deteriorated the energy metabolism, accelerated starvation, damage to intestinal tissues (parenchyma)	<u>Isinibilir et al. 2020</u>

**Table 3.**

Parameters	PM <sub>10</sub>	PM <sub>2.5</sub>	Aerosol	MPs/NPs	Plastic particulates as airborne PM and aerosol
Aerodynamic diameter	10µm	2.5µm	0.01µm - 1mm	0.001µm - 5mm (aerodynamic equivalent diameter varies)	Apply
Particle form	Solid	Solid	Solid/liquid	Solid	Apply
Standards	Available	Available	Available	-	General PM guidelines apply, but the exposure limit of inhalable MPs is missing
Inhalability	Yes	Yes	Yes	Yes	Apply