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Review Article

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A narrative review of microplastics in the indoor and outdoor environment, human effects, and ecological risks

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ABSTRACT

Due to their widespread identification in all environmental compartments, Microplastics (MPs) are emerging pollutants that have garnered growing scientific and public attention over the last decades. Early research on MPs and their effects was limited to studies of terrestrial and aquatic ecosystems, but more recent studies have included MPs in the air. There is now considerable concern about the effects of MPs on pristine environments and urban air quality.

A literature search was conducted in Science Direct and Google Scholar using the following keywords: microplastics, indoor environment, outdoor environment, human effects, and ecological risks.

Finally, eligible studies were selected for the review. Textiles, such as clothes, carpets, and curtains, are the main indoor sources of MPs. As well as the primary sources of MPs outdoors, there are landfills, urban and home dust, and synthetic particles. According to current theories, human exposure to MPs occurs through dermal contact, ingestion, and inhalation. Recent research has demonstrated that inhalation is the principal mechanism of human exposure to MPs. Early toxicological research suggests that MPs may lead to inflammation and oxidative stress. However, there is growing concern about the possible leaching of hazardous chemicals used as plastic additives. Nevertheless, MP exposure and risk assessment in humans is still in its infancy, and more research on the presence of MPs in various indoor and outdoor environments is required to provide the knowledge base needed for regulations to protect human health and the environment from MPs.

Review

Since the first synthetic polymer was created, studies on how plastics affect the environment have been conducted, leading to innumerable advances in their usage and production. The environment now contains plastic remnants due to their prolonged and uncontrolled use. Annual growth of about 3% in global plastic manufacturing has resulted in an extraordinary surge in plastic pollution over the last three decades because of society's growing dependence

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on plastic. Worldwide, the plastic output reached 348 million tons in 2017 and was projected to increase by a factor of four from 311 million tons in 2014 to 1.2 billion tons in 2050. Attention to plastic waste byproducts, known as MPs, has grown because of problems, including the improper disposal of plastic waste and its slow decomposition in the environment, which have caused new environmental and health concerns [1-3].

MPs are defined as minuscule plastic particles smaller than 5 mm in size [4-6]. The prefix "micro" conflicts with this size cut-off; however, this phrase has gained widespread use. Nanoplastic (NPs) particles, <1 μm in size, are smaller than the minimum size of MPs. Depending on the size and structure of the plastic, MPs, and NPs have different effects. The particle-fluid interaction, which determines whether the particle continues floating or settles, is directly related to the dispersion of plastic particles in water and air.

The consumption cycle of plastic goods (production, utilization, recycling, and ultimate disposal) produces MPs between 300 μm and 5 mm, primarily due to the destruction of large plastic components by UV radiation, weathering, water erosion, biodegradation, and other processes. Because of their low density and low sedimentation rate, MPs are easily airborne and can be transported through the atmosphere [7-9]. MPs enter the environment following several activities, including rubber wear, household activities, improper plastic waste disposal, agricultural operations, and industrial emissions in densely populated regions [10, 11]. MPs can sit on the ground through dry and wet sedimentation and pollute the soil and surface waters [12].

Due to the widespread usage of plastics in indoor environments, recent studies have provided evidence of the presence of MPs in indoor air [13]. Plastics can influence human health because individuals spend 70-90% of their time inside [14]. In the house, MPs are primarily found in textiles, including clothes, carpets, and curtains [15, 16]. By being inhaled and ingested, these pollutants enter the body and accumulate there, which could have negative health impacts such as a pro-inflammatory effect that induces the release of reactive oxygen species, altered airway cell metabolism, inhibited cell proliferation, and altered cohesion between cells [17]. Many studies reported that the intake rate of MPs is higher through inhalation than ingestion [13, 18]. Due to MPs' buoyant properties and size in the air, they may be present at 1.2 m above ground level. Besides, the altitude of 1.5 m is the minimal breathing height for an adult, so they may swiftly infiltrate the human body [19]. It was estimated that the annual exposure of humans to airborne MPs may reach 1 million/year [20].

Due to their small size, inhaled MPs can lodge and aggregate in the lung alveolar area. Inhaled fibers and particles may stay in the lungs for a very long time, potentially forever. These particles often include a variety of compounds that may be hazardous to lung tissue and result in acute or chronic inflammation, nonmalignant lung disorders, or both. Sediment particles may modify the content and characteristics of the lung surfactant, "a thin layer of blue coating that covers the alveoli," thereby limiting lung function and causing respiratory disorders [21-24]. Additionally, MPs may have more severe health impacts due to their numerous additives, capacity to absorb hydrophobic organic contaminants and heavy metals from the environment, and the formation of biofilms on their surface.

The lack of sufficient knowledge about human exposure to these pollutants is a significant problem in determining the risks of MPs to human health. MPs have been extensively investigated in the aquatic environment since 2004, but research on MPs in the air has received less attention. Accordingly, the main purposes of this review were to examine the (i) occurrence of MPs in the indoor environment, (ii) occurrence of MPs in the outdoor environment, and (iii) environmental and human risks of MPs. These investigations help comprehensively and quickly grasp the environmental behavior and health risks caused

by MPs in the air.

Methods

A focused literature search for original peer-reviewed articles on MP occurrence in indoor and outdoor environments was carried out on Google Scholar and Science Direct, published between 2015 and 2023, and was identified and examined. The MeSH terms "microplastics," "outdoor environment," "indoor environment," "human effects," and "ecological risks" were used as search terms. A combination of the search terms (microplastic* OR micro-plastic OR plastic*) AND (outdoor OR indoor OR air environment) AND (human health OR human exposure OR health*) AND (ecological risk OR risk*) were used with all searches by condition. Furthermore, the reference lists of the identified papers were reviewed and manually searched for additional publications. Eligible studies were reviewed based on the objectives of this study. Experimental studies and those not published in the English language were excluded.

The occurrence of MPs in the indoor environment
Since most activities in contemporary society occur indoors, indoor air quality remarkably influences human health. Recent investigations on MPs have confirmed their prevalence in indoor environments with diverse concentrations, forms, sizes, and suspension or deposition. According to Liao, et al. [20], MP concentrations are substantially greater within buildings than outdoors and higher in urban than rural areas. Textiles, including clothing, carpets, and curtains; construction materials; packaging; and other household plastic goods are the main sources of MPs in the indoor environment [16, 25].

As shown by Kawecki, et al. [26], the main sources of MPs indoors are clothing and other textiles (75%), followed by other household plastics (16%) and building coatings (9%). In each washing of clothes, about 1,900 fibers may be released from a single piece of clothing [27]. More importantly, suction allows outdoor air to enter the buildings. However, indoor air contains more MPs than outdoor air [28-30]. Room partitions, ventilation, and airflow affect the MP behavior indoors [31].

To correctly evaluate exposure to MPs, the difference between the major MPs produced in both the indoor (primarily textiles) and outdoor environment (especially tire wear particles), as well as the air exchange between these two environments, should be considered [32-34].
The abundance and types of MPs in indoor environments

The quantity of suspended particles that people may breathe is the concentration or abundance of MPs in the air, expressed in terms of their number or mass/m^3 of air. Table 1 shows the location, number of samples, average MPs in indoor air, type of polymer, size, shape, and color of MPs in previous studies.

According to the research by Jenner, et al. [35] conducted over six months in 20 houses in the Hull and Humber area of England, the average quantity of MPs was about 1414±1022 MP/m^2.day. Small fibrous particles (5-250 µm) were found to be the most prevalent (90%). This investigation revealed that polyethylene terephthalate (PET), which constituted 62% of MPs, was found in 90% of the samples.

Soltani, et al. [36] objectively evaluated the prevalence, source, and type of MPs in Australian households to determine the potential for human health exposure. Among the 32 samples collected, the most significant incidence of accumulated MPs was found in fibers. The number of deposited MP fibers ranged from 22 to 6169 MP/m^2.day. Original floor covering is one of the main factors affecting the sedimentation rate of MPs. In houses having carpet as the primary floor covering, Polyethylene (PE), polyester, Polyamide (PA), polyacrylic, and Polystyrene (PS) fibers were widely detected in the MP composition. Furthermore, polyvinyl fibers were observed as the most prevalent form of petrochemical fiber in areas without carpet, demonstrating the importance of flooring components in MP composition.

Table 1. Characteristics of MPs and sampling locations in different studies (indoor)

Location	Sample number	MP average content	Polymer types	Size	Shape	Color	Reference
Australia	32	22 to 6169 fibers/m^2.day	Polyethylene, polyester, polyamide, polyacrylic, and polystyrene	200–400 µm	Fibers	-	[36]
Shiraz	28	195 MPs/g	Polyethylene terephthalate and polypropylene	500–1000 µm	Fibers	white	[37]
China	-	1583 ± 1180 MPs/m^3	-	smaller than 100 µm	Fragments	-	[20]
U.K.	20	1414 ± 1022 MP/m^2.day	PET, PA, PP	5–250 µm	Fibers	-	[35]
Coastal California	-	3.3 ± 2.9 and 12.6 ± 8.0 MPs/m^3	PVC, PE, PS, PET	58.6 ± 55 µm	Fibers, fragments	-	[38]
France	45	1.0 - 60.0 fibers/m^3 1586 -11130 fibers/m^2.day	PP, primarily cellulosic	-	Fibers	-	[19]
Kuwait	-	3.2 - 27.1 MPs/m^3	-	0.45 µm to 2800 µm	Fibers, fragments	-	[39]
atin America (São Paulo)	-	309.40 ± 214.71 MPs/m^2.day	Polyester, polyethylene, polypropylene,	-	Fragment	-	[40]
South Korea	-	-	-	-	-	-	[41]
Sweden		7360 fibers/m^2.L	Acrylic, nylon, polyester	-	Fibers	-	[42]
Australia	58±60	1.6 ± 1.8 fibers/m^3	Polyester	-	Fibers	Blue	[15]
China	sampling sites (dormitory and office)	dormitory (9.9 × 10^3 MPs/m^2.d), office (1.8 × 10^3 MPs/m^2.d)	Polymer compositions	-	Fibers	-	[13]
Indonesia	Two offices, two apartments	two offices (334 and 351 particles on a weekday) and (242 and 252 particles on a weekend), two apartments (133 and 108 particles on a weekday) and (127 and 95 particles on a weekend)	-	3000–3500 µm	Fibers	-	[43]
New Jersey, United States	An office, a hallway, a classroom, and a single-family house	highest single-family house (1.96±1.09) × 10^4 fibers/m^2·day and lowest in the classroom (6.20 ± 0.57) × 10^3 fibers/m^2·day	PS, PET, PE, PVC, PP	35 µm to 1000 µm	Fibers, films, fragments	-	[44]

Gaston, et al. [38] determined the number of MPs in both the indoor and outdoor air of buildings in coastal California bypassing known volumes of air through glass fiber filters. According to their findings, MPs were about twice more prevalent (3.3±2.9 fibers and 12.6±8.0 fragments/m^3) in the indoor air of buildings than outdoors (0.6±0.6 fibers and 5.6±3.2 fragments/m^3). There was no significant difference in the length of MP fibers between indoor and outdoor air, although the size of MP particles indoors was half that of the particles outdoors. Yao, et al. [44] examined the occurrence of MPs in several indoor environments, including a single-family home and a college in New Jersey. MPs in these areas comprised the shapes of fibers, films, and pieces made of PS, PE, Polyvinyl Chloride (PVC), and Polypropylene (PP). This research demonstrated that film in classrooms and fibers in residential buildings are the dominant types of MPs. Additionally, PE was the predominant MP indoors in terms of chemical composition.

According to some studies, MPs have been found in the dust on indoor floors. In 28 schools in Shiraz (Iran), Nematollahi, et al. [37] examined the characteristics and human exposure to settled MPs in indoor dust MPs. The city's south and center had the largest concentrations of MPs out of all the sampling areas, caused by population density, heavy traffic, industrial units, and workshops. Dris, et al. [19] found fiber content and deposition rate in the dust left behind in two apartments and an office. It has been shown that 1586 to 11130 fibers are deposited per m^2 per day in indoor settings and that 67% of the fibers studied there are composed of natural materials, namely cellulose. The other 33% of the fibers are formed of synthetic materials, including petroleum-based substances, with PP predominating.

Effect of textile washing and air conditioning on the number of MPs in indoor environments

Generally, the amount of MP emission from clothing contributing to indoor and outdoor air pollution depends on the spatial and temporal distribution between indoor and outdoor environments and the type and material of clothing. The mentioned factors also depend on weather and behavioral habits. [25]. For instance, the washing and drying of textiles releases MPs that pollute indoor spaces, while the cooling of indoor air causes the emission and pollution of outdoor spaces [45]. Carney Almroth, et al. [42] showed microfiber shedding rates from three synthetic textile materials: acrylic, nylon, and polyester. Although all textiles shed, polyester wool fabrics shed more than polyester ones (87 fibers/m^2.mL). De Falco, et al. [46] assessed the number of microfibers released into the air and water after washing polyester clothing with various textile properties, such as distinct material combinations, fabric structure, thread twist, fiber type, and hairiness. Compared to clothing with a looser structure (woven, short main fibers, less warp), the quantity of release in air and water was the lowest for a garment with an extremely tight texture structure and highly warped yarns from continuous strands. Moreover, the direct release of microfibers into the air due to wear was just as significant as the release into water. O'Brien, et al. [15] studied whether the mechanical drying of synthetic textiles releases MP fibers, which are absorbed by the internal filtration system, into the ambient air. A blue polyester blanket was dried in a typical home dryer between 56 and 59 °C. On average, the number of blue fibers in the empty room was 6.4±9.2 fibers (0.17±0.27 fibers/m^3), indicating that mechanical drying had released MP fibers into the atmosphere. In-house contexts (such as living rooms, dorm rooms, and workplaces) were the focus of Chen, et al. [47] investigation into the impact of air conditioning on the dispersion of indoor airborne MPFs, the bulk of which was polyester (45.3%), rayon (27.8%), and cellophane (20.1%). The findings showed that MP fibers may be produced and sucked up by AC filters. As a result, the distribution of MPFs in indoor air is greatly influenced by AC filters. Zhang et al. [49] monitored MP shedding in a dorm, an office, and a corridor for three months on weekdays and weekends. An air conditioner was also employed to comprehend how airflow affects the suspension of MPs in the hostel. The

dormitory was the area with the greatest average frequency of MPs among the three sampling sites (9.9×103 MPs/m^2.d), making the weekend's intermediate frequency of MP (1.4×10^4 MPs/m^2.d) about three times higher than that of the weekdays (5.8×10^3 MPs/m^2.d). The majority of MPs discovered were fibers and shared polymer compositions of textile goods. The resuspension of MPs is accelerated by airflow turbulence, according to airflow tests conducted using air conditioners. In a similar study, the deposition of MPs in dust in two offices, two schools, and two residences in Surabaya, Indonesia was assessed by Bahrina, et al. [43]. According to this study, more MPs were detected throughout the week on weekends in each area where samples were collected. The findings demonstrated how the activities and the number of occupants impact the number of interior MPs.

Other sources

Apart from textiles, various other products, including packaging, toys, construction products, and personal care products, can introduce MPs into indoor spaces [48]. Only a few studies have reported the indoor release of non-fibrous MPs (fragments and films). Vianello, et al. [49] reported that 87% of non-fibrous MPs were in indoor air, while Allen, et al. [50] reported that 88 to 95% were in outdoor air. Making fuse filaments from plastic in three-dimensional (3D) printers is a less frequent source of MPs. This reflects a substantially higher particle emission per use of the 3D printer than that observed for textiles, with emission rates ranging from 1010 to 1012 particles per hour. Compared to the particles generated by textiles, those released during 3D printing are far smaller. Some particles released due to 3D printing are classified as NPs [51].

The occurrence of MPs in the outdoor environment

MPs are readily suspended in the air and dispersed by the wind in the atmosphere due to their small size and low density, ultimately contaminating many environmental matrices [52]. There have been few studies on the concentration, deposition rate, and properties of MPs in the atmosphere. Dris, et al. [53] conducted the first investigation in this area in Paris in 2015. Tire erosion and wear, urban and household dust, synthetic textiles, construction materials, waste burning, landfills, industry, road particles, and synthetic particles such as PS peats in soils (applied in horticulture), and sewage sludge in agriculture (used as fertilizer and the output of dryers) are among the most significant sources of MPs in the atmosphere [9, 54]. Transport, dispersion, and deposition, which are accomplished by wind, air turbulence, and dry and wet sediment, are the driving forces behind the movement of MPs in the atmosphere [55]. Wind transport accounts for 7% of ocean pollution with airborne MPs [56].

The abundance of MPs in remote environments

Using continuous sampling on a trip in the western Pacific Ocean, Liu, et al. [57] evaluated the prevalence and distribution of suspended atmospheric MPs (SAMPs). Regarding abundance, fiber, fragment, and granule SAMPs ranged from 0 to 1.37 MPs/m^3, representing 60, 31, and 8% of the total MPs. Coastal regions had the greatest concentration of MPs suspended in the atmosphere (0.24±0.13 MPs/m^3), while the ocean atmosphere had the lowest concentration (0.01±0.01 MPs/m^3). The results of this research demonstrated that suspended air MPs, notably pollution from textile microfibers, are a significant source of MPs in the sea.

Allen, et al. [50] reported air MP deposition in wet and dry atmospheric sediment samples collected over five months in the French Pyrenees. The results showed fibers with a length of ~750 µm and pieces ≤300 µm with a daily relative number of 249 pieces, 73 films, and 44 fibers per m^2. It has been shown that MPs are transported by the atmosphere to far and sparsely inhabited locations. Analysis of the air mass pathway revealed that MPs were transmitted via the atmosphere at a distance of up to 95 km.

The abundance and types of MPs in outdoor environments

All these processes depend on MPs' size, shape, and length. For example, particles smaller than 25 μm in the highest percentage (higher than 50%) and particles larger than 300 μm in the lowest rate of distribution, as well as fibers with a length shorter than 100 μm, had a higher allocation than fibers with a length of more than 2500 μm [50, 58]. In a coastal city in eastern China, Liao, et al. [20] investigated the occurrence of MPs in outdoor settings from urban and rural regions. MP size reduction was associated with increased quantity, mainly comprising film-shaped MPs made of PE and nylon materials. The primary form of MPs was fiber, and a significant number of MPs in the dust samples were composed of polyester.

A few studies have directly assessed the type of MPs in the atmosphere. The different kinds of MPs found in the atmosphere so far are synthetic (PVA, poly (vinyl acetate); PUR, polyurethane; PTFE, Teflon; PET, polyethylene terephthalate; PE, polyethylene; PES, polyester; PAN, polyacrylonitrile; PAA, poly (N-methyl acrylamide); RY, rayon; EVA, ethylene vinyl acetate; EP, epoxy resin; ALK, alkyd resin) and natural (cotton and wool). They may also be pieces, foams, films, granules, fibers, and microbeads. (Table 2). An urban location in the Humber area of the United Kingdom was sampled over 13 months by Jenner, et al. [59], giving a profile of size, shape, and polymer types to which people are exposed. The passive infiltration method determined the mean MP levels of 3055±5072 MP/m^2.day (mean 1164). Decreases in MP size were associated with an increase in quantity, which mainly comprised film-shaped MPs (67%) made of PE (31%) and nylon (28%) materials. Over two weeks, MPs linked to human exposure were also identified in five metropolitan areas. Petroleum resin accounted for 32% of the MPs, which had a greater frequency in industrial and roadside locations, with an overall mean MP of 1500±1279 MPs/m^3 (mean 1012). These mostly included the piece form (52%) and the film form (42%). The properties of MPs in the atmospheric fallout from Dongguan City were investigated by Cai, et al. [60]. Three distinct polymers were identified, namely PE, PP, and PS. MPs were discovered in various shapes, including fiber, foam, bits, and film, with fiber predominating. There were 175 to 313 particles/m^2.day of MPs and non-fibrous fibers in atmospheric fallout.

Effect of weather conditions on airborne MPs

MP air pollution is influenced by the type and intensity of emissions and the weather (rain and snow). Topography and climate significantly affect the dispersion and deposition of MPs. MPs are distributed in an environment with low atmospheric pressure and significant air turbulence, while high pressures are linked to air stability and pollution. The vertical temperature gradient propels MPs in the atmosphere, and the lower atmosphere becomes contaminated with MPs because of temperature inversion [61]. The results of a study conducted by Allen, et al. [50] in the French Pyrenees showed that the distribution of MP types differs in various weather conditions. For example, in November and December (less rain and fewer stormy days), the amount of PS was higher, and PE had the lowest amount; however, in February and March (increasing rainfall and snowfall), the amount of PS was less, and the content of PE was higher.

In Bushehr's northern Persian Gulf city, Akhbarizadeh, et al. [62] investigated probable relationships (presence, origins, and health hazards) between PM2.5 and MPs. Further evidence of the considerable influence of atmospheric circumstances on MP transport came from the significant positive relationships between MPs, wind speed, and wind direction. Jenner, et al. [35] found no significant relationship between rainfall and MP precipitation.

Table 2 shows the location, number of samples, average MPs in outdoor air, the type of polymer, size, shape, and color based on previous studies.

Table 2. Different characteristics of MPs and sampling locations in different studies (outdoor)

Location	Sample number	MPs average content	Polymer types	Size	Shape	Color	Reference
China	-	189 ± 85 MPs/m^3	-	Smaller than 100 µm	Fragments	-	[20]
Humber region (U.K.)	-	3055 ± 5072 MPs/m^2.day overall MP mean±SD: 1500 ± 1279 MPs/m^2.day	Polyethylene, nylon, polymer	-	Fragment, film	-	[61]
Bushehr, Iran	-	5.2 items/m^3	PET	-	Fragments	-	[62]
U.K.	13	1.42 ± 1.50 MPs/g	PP, PET, resin	3 µm	-	-	[63]
United States	-	-	Polystyrene	1 and 10 µm	-	-	[17]
France	Three indoor sites: two private apartments and an office	0.3 and 1.5 fibers/m^3	PP, primarily cellulosic	-	Fibers	-	[19]
Asaluyeh, Iran	15	900 MPs and 250 MRs per 15 g of sample	-	<100 to >1000 µm	Spherical, film, fragments, fibers	-	[64]
China	Three apartments	1.7 and 16.2 MPs/m^3	Polyester, polyethylene, nylon	11µm	Fragments, fibers	-	[49]
China	39	212–9020 mg/kg	PET, PC		Fiber	-	[65]
Pyrenees, France	-	249 fragments, 73 films, and 44 fibers per square meter	-	~750 µm, fragments ≤300 µm	Fibers, fragments, films	-	[50]
China	-	175 to 313 MPs /m^2.day	PE, PP, PS	-	Fiber, foam, fragment, film	-	[60]
Tibetan Plateau	7	8 ± 14 to 563 ± 1219 items/m^2	Polyethylene, polypropylene, polystyrene, polyethylene terephthalate, polyvinyl chloride	<5 mm	-	-	[66]
China	-	0 to 1.37 MPs/m^3	-	-	Fiber, fragment, granule	-	[57]
China	-	189 ± 85 MPs/m^3	-	Smaller than 100 µm	Fragments	-	[20]
Sri Lanka	-	0.00–0.23 MPs/m^3	Polyethylene terephthalate, polyester	100–300 µm	Fibers, fragments	-	[67]

Table 2 (continued)

New Jersey, United States	Ambient air	Ambient air acquired on a building roof was only about 2–8% of the indoor deposition rates	PVC	-	Fragments	-	[44]
Latin America (São Paulo)	-	123.20 ± 47.09 MPs/m^2.day	Polyester, polyethylene, polyethylene terephthalate	-	Fragment	-	[40]
Ahvaz, Iran	322	0.017 MPs/m^3	polyethylene terephthalate, nylon, polypropylene	-	Fibers	-	[68]
European Countries	120	0.02-16 mg/m^2	-	0.5-9.5 µm	-	-	[69]
London	-	575 to 1008 MPs/m^2.d	15 petrochemical-based polymers	-	Fibers	-	[70]

Temperature, humidity, and solar radiation decompose MPs in the atmosphere into smaller particles, such as nanoplastics or femtoplastics, which pose more significant health concerns when inhaled. The human nose and mouth are entry points for MPs smaller than 25 µm; the human lung tissue has been discovered to contain MPs as small as 5 µm [71].

Environmental and human risks of MPs

Human Risks

Studies have shown that MPs exist in the atmosphere and, thus, humans are exposed to them. Humans are thought to breathe between 26 and 130 MPs of air daily [9]. Liao, et al. [20] in China suggested that one million individuals might annually be exposed to airborne MPs at the most. Adults breathed 32.5 and 161.2 instances of MP per day on normal and dusty days, respectively, according to Akhbarizadeh, et al. [62]. Liu, et al. [72] reported that residents of Shanghai inhale around 21 MPs particles daily from their surroundings. When MPs reach the human lungs, they are likely to be removed by mechanical means (sneezing), macrophage phagocytosis, and lymphatic transfer. This separation might stop many MPs from entering the body [9].

However, some MPs may evade the clearing systems, enter the lungs, and then inflame them. Huang et al.'s [73] study focused on the presence of MPs in human sputum. MPs were discovered in 21 distinct types, with polyurethane being the most prevalent. MPs were found in every sample of sputum used in this study, demonstrating that inhalation is a feasible route for plastics to reach the human body. Baeza-Martinez et al. [74] collected Broncho alveolar lavage fluid (BALF) to count the MPs in the lower parts of the lungs. The results showed that most MPs (97.06%) are microfibers (MFs) with an average concentration of 9.182.45 particles per 100 mL BALF. Jenner, et al. [63] investigated and characterized the MPs found in digested human lung tissue samples (n = 13). Eleven out of 13 lung tissue samples contained 39 MPs with an average of 1.501.42 MP/g tissue. The discovered MPs included 12 distinct types of polymers, with PP (23%), PET (18%), PET (18%), and resin (15%) being the most common Reactive oxygen species (ROS) are produced when these contaminants penetrate cells [75]. For 180 days, plastic fibers on the surface of artificial extracellular lung fluid did not change [76]. As a result, MPs might build up in human lungs over time and result in chronic ROS-induced oxidative damage. There were very few studies into the harms of MPs on the human body. Lung fibrosis and perhaps even cancer may result from ongoing inflammation and irritation. Plastics comprise monomers, additives, and dyes, most of which are toxic [9]. Hazardous compounds and unreacted monomers may have health consequences. Numerous plastics, including Polycarbonate (PC), PS, and PVC, produce hazardous monomers that may cause cancer, mutagenesis, and reproductive damage [77]. Shi, et al. [78] looked into the connection between PS and Lung Surfactant (LS) from naturally occurring lung fluid obtained from pig lungs. The results showed that PS impacted the LS phase behavior, surface tension, and membrane structure. Additionally, the absorption tests showed that PS absorbed phospholipid components far more quickly than proteins in the combined system of PS and LS (The main active components are proteins and phospholipids). Furthermore, PS can accelerate the conversion of ascorbic acid to deoxyascorbic acid, resulting in the generation of hydrogen peroxide (HOOH) and a rise in the quantity of Hydroxyl radicals (OH) in LS-containing simulated lung fluid. Many studies have demonstrated that MPs absorb and

accumulate pollutants such as heavy metals, polychlorinated biphenyls (PCBs), and PAHs, which have caused increasing concerns due to their wide distribution and ability to mutate and cause cancer. MPs may act as vectors and transport organisms over long distances in the atmosphere [79]. As a result, poisonous substances and bacteria adsorbed on MPs may induce tissue toxicity when inhaled or consumed, and microorganisms adsorbed on MPs may cause inflammation and infection [75]. Although several studies have noted the health risks associated with MPs, additional information is required to fully understand how these materials affect ecosystems and people [80].

Ecological risks

Ecological risk is predicated on the potential for the atmosphere to transport MPs to and contaminate new areas. Consequently, MPs can contaminate terrestrial and aquatic ecosystems in the air, a pollution source. In addition, there may be a dynamic interaction between MPs in different environments (e.g., soil or water become suspended in the air and pollute the air, while airborne MPs may be deposited in soil or water), and this process can include the cycle of MP pollution in the ecosystem. Common models used to study soil, sediment, and water columns may be adopted to assess the ecological risks caused by MPs in the air. One example is the potential ecological risk originally developed by Hakanson [81]. This model was used in a study conducted in China on MPs suspended in the air. It is calculated using the Eq. 1 (72):

$$RI = \sum T_r \times C_f \quad (1)$$

where RI is the potential ecological risk; T_r, which was the toxicity response of heavy metals in the original model, was replaced by the chemical toxicity coefficient for polymers; C_f is the pollution factor, calculated from the ratio of C_i (MP polymer concentration observed in the air) to C_d (polymer background values considered 0.9 in the air) [53]. The ranking for RI of MPs included minor (RI<150), medium (RI 150-300), high (RI 300-600), dangerous (RI 600-1200), and extreme risk (RI≥12000). The RI value for atmospheric MPs suspended in Shanghai was estimated by Liu, et al. [72]. The greatest value was 6.54, and the lowest was 0.23 (a location with few human activities). Additionally, the findings demonstrated that greater elevations provide less of an environmental concern than samples taken close to the surface.

Based on the description above, there are significant research gaps regarding MP toxicity, quantitative study of the various pathways by which microplastics enter the human body and the environment, and toxicity mechanisms of microplastics after inhalation by humans. Thus, more in-depth, thorough research on the toxicity of plastic to humans and ecological risks is needed.

Conclusion

Over the past decade, extensive research on the identification and characterization of MPs has established their ubiquitous distribution in all environmental matrices. While most of these studies focused on the aquatic environment, recent studies have highlighted concerns about the presence of MPs in the indoor environment in quantities relevant to human exposure. MP fibers from textiles, together with tire wear particles, are highlighted in many studies and reports as a major contribution to MPs

in indoor air and the air in general. However, recent assessments of the abundance of MPs show that fragments rather than fibers may significantly contribute (up to 90%). Although these fragments may still be related to degraded microfibres or discharged directly from textiles, looking into other sources of MPs is essential. The present literature review highlighted the dearth of information on human exposure to MPs indoors and outdoors and the risk involved. There is an immediate need for data on the human health impacts of MPs. However, it is crucial to more accurately analyze how we are exposed to MPs before this is decided. The current understanding of the origins and extent of human exposure to MPs and the relative contributions of various exposure routes to human body with MPs has significant research gaps. For establishing pertinent research programs, which include specific monitoring strategies, it is necessary to conduct more studies in a variety of indoor and outdoor environments, perform human and ecological risk assessments for various MPs, and have collaborations between environmental, epidemiological, and air quality communities. Therefore, it is recommended that the following topics be given priority in MP research:

1) Validated and standardized techniques are required for calculating MP concentrations in samples of indoor and outdoor air and dust, as well as agreement on the units for reporting these concentrations on a mass basis appropriate for exposure assessment models.

2) Extensive human exposure assessment studies are urgently needed to estimate exposure to MPs at the individual and population levels.

3) Due to various MPs in the atmosphere, more research on ecological and human risk assessment is essential. Due to the significant inter-species variance, these studies should best be conducted using human cell lines, tissues, or relevant mammalian laboratory animals.

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Competing interests

The authors declare no competing interest concerning the publication and authorship of this paper.

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Ethical considerations

The authors have completely observed ethical issues (plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.). This work has been done under the ethics code of IR.TBZMED.REC.1402.074.

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