A systematic review of airborne microplastics emissions as emerging contaminants in outdoor and indoor air environments

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Abstract

Microplastics (MPs), the emerging contaminants of the present century, are potentially a major threat to human health and ecology. There is currently no comparison of the properties of MPs in indoor and outdoor air. Thus, there is a need a systematic review (SR). The goals of this study were to answer the following questions: (1) what are the geographical distribution, sources, abundances, and characteristics (polymer, type, shape, color, size) of MPs in outdoor and indoor air? (2) What are the limitations of the published studies and recommendations for future research? To achieve these objectives, four electronic databases were searched to find works published before December 31, 2022. In total, 37 publications were selected based on the PRISMA guidelines. The study found that polyester and polyethylene terephthalate were the most dominant polymer types in outdoor and indoor environments, respectively. The most important indoor sources for MPs included synthetic textiles, kitchen plastic utensils, synthetic fiber carpets, detergents, and furniture, while the most important sources for outdoor MPs include industrial emissions, particulate emissions from vehicles, burning of plastic waste, the expulsion of air bubbles and wave action in ocean and decomposition and destruction of plastic materials. Fibers were the dominant shape of airborne MPs in both environments. The predominant colors of the MPs in samples of the indoor air were white and transparent, whereas black was most abundant in the microplastic samples collected from the air outside the building. Finally, given the ubiquitous nature of MPs and their potential for adverse effects, governments should take effective measures to reduce the production of plastic materials and finally increase plastics reuse, and recycling rate.

Keywords: Microplastics; Systematic review; Airborne transmission; Indoor air; Outdoor air

Chapter 1

1. Introduction

From the beginning of 20th century to the present day, plastics have been recognized as important materials with multiple useful purposes. Due to their durability, cost-effectiveness, and resistance towards temperature, light, and moisture, plastics are used in multiple consumer goods and packaging. Rapid urbanization and industrialization across the globe have increased environmental challenges such as energy demand, global warming, and environmental pollution (Soltani et al., 2021; Zhu et al., 2022). The role of plastics in both creating and solving these challenges are just beginning to be fully recognized.

Plastic production with a compound global annual growth rate of 8.4 percent, increased from 2 million metric tons (Mt) to 380 Mt between 1950 and 2015. It is expected that by 2050, plastic production rate was increased to 1606 Mt. In addition, recently SARS-CoV- 2 pandemic plays a major role in the production of plastic compounds such as personal protective equipment and other types of medical and non-medical plastics. It is reported that the global generation of plastic waste is approximately 6300Mt by 2015, of which 12% were incinerated, 79% of them were landfilled and only about 9% were recycled. Unfortunately, the growth of plastics and the poor management of plastic waste (only about 5-9% are recycled) causes a significant leakage of plastics into the environment. Several publications reported that there were 60-90 Mt of mismanaged plastic wastes generated worldwide in 2015, and they expected this total to triple to 155-265Mt per year by 2060 (Akanyange et al., 2022; Lebreton and Andrady, 2019). After entering the environment, plastics may decompose due to the environmental physical and biological weathering and finally producing microplastics (MPs) (Akanyange et al., 2022; Zhu et al., 2022).

MPs are the synthetic organic polymer particles that are classified as 1 µm to 5 mm in size and are known as emerging pollutants. MPs are now widely emitted into the atmosphere, soil, and surface waters impacting freshwater, marine, and terrestrial ecosystems by affecting humans, wild animals, and plants. MPs are now particulate air pollutants and can be divided into primary and secondary groups according to the sources of the particles. The existence, abundance, characteristics (polymer, type, shape, color, size), and composition detection and visual analysis methods of airborne MPs of indoor and outdoor environments have been investigated (Liu et al., 2019a; Wright et al., 2020; Xumiao et al., 2021; Zhang et al., 2020a; Zhang et al., 2020b; Zhu et al., 2022).

Primary MPs are particles that are produced for commercial use, such as particles used in clothing, cosmetics and personal care products (creams, scrubbers, facial cleaners and toothpastes). Primary MPs are also used in dentistry products and biomedical research. While secondary MPs result from the breakdown and fragmentation of large plastic materials under the influence of different physical and chemical mechanisms such as: bio/photodegradation, microbial/mechanical degradation, water cavitation, oxidative and thermal destruction, or shock and abrasion occur (Akanyange et al., 2022; Enyoh et al., 2019; Sharma et al., 2021).

Human exposure to MPs occurs through dermal deposition, food consumption, and inhalation from outdoor and indoor air. They can cause potential adverse effects such as inflammation, lung injury and oxidative stress (Enyoh et al., 2019; Sharma et al., 2021). Since air is critical for human survival, MPs pollution in air of indoor and outdoor environments is caught the attention of non-governmental organizations, public media and researchers in this century. MPs in the air can result in exposure to the human digestive and respiratory systems. Suspended microplastics can be inhaled and deposited microplastics can be swallowed through hand-to-mouth contact (especially for children) (Enyoh et al., 2019; Sharma et al., 2021) or moved from deposition in the nasal passages to the digestive tract through mucosal movement (Hilding, 1932).

Recent research indicates factors such as relative humidity, wind velocity, rainfall, and mean air temperature in outdoor environments and factors like the number of people in the location, ventilation in indoor environments, influences the distribution and movement of airborne MPs. Several studies reported different results, which creates more debate (Amato-Lourenço et al., 2022a; Choi et al., 2022; Dehghani et al., 2017; Dris et al., 2017; Liu. et al., 2019a; Wright et al., 2020; Xumiao et al., 2021; Zhang et al., 2020a; Zhang et al., 2020b; Zhu et al., 2022). Therefore, the purpose of this present study is to collect the available information related to the characteristics of microplastics in outdoor and indoor air to identify the critical directions needed for future research.

This review compares the geographical distributions, sources, abundances, and MP characteristics (polymer, type, shape, color, size) and identifies the key factors that affect the presence/absence of MPs pollution as emerging pollutants in indoor and outdoor atmospheric environments. The existing challenges and bottlenecks are presented and discussed.

Chapter 2

2. Methodology

2.1. Literature sources and search strategy

This review was performed utilizing by an internationally accepted guideline for writing review paper i.e. PRISMA guideline (Preferred Reporting Items for Systematic Reviews (SRs) and Meta-Analyses) (Liberati et al., 2009; Maleki et al., 2023; Mirzaee et al., 2021; Moher et al., 2015). The PRISMA guidelines for SRs were applied to collect similar but relevant peer-reviewed papers, book chapters, and scientific reports on the purpose of the study. We did not find any previously published systematic reviews regarding airborne routes for MPs transmission in outdoor and indoor environments.

The eligibility criteria for included studies were considered studies with focus on the airborne MPs emissions in indoor and outdoor environments. A comprehensive screening of the journal literature for details of the global distribution, characteristics (polymer type, shape, color, size), sources and abundance of MPs in indoor and outdoor environments was performed using electronic databases including the Web of Science, Scopus, and PubMed. All related and eligible papers published before December 31, 2022, were identified based on MeSH (Medical Subject Headings) with the following keywords: (("Micro Plastic"[Mesh]) AND "Indoor Air Pollution"[Mesh]), OR ("MPs" AND "Indoor Air Pollution") OR ("Micro Plastic"[Mesh]) AND "Indoor Air"[Mesh]), OR ("MPs" AND "Indoor Air") OR ("Micro Plastic"[Mesh]) AND "Outdoor Air Pollution"[Mesh]), OR ("MPs" AND "Outdoor Air Pollution") OR ("Micro Plastic"[Mesh]) AND "Outdoor Air"[Mesh]), OR ("MPs" AND "Outdoor Air") OR ("Micro Plastic"[Mesh]) AND "Airborne"[Mesh]), OR ("MPs" AND "Airborne" [Mesh]). Further, the Open Gray online literature and the references of identified studies were investigated to select the most relevant articles. In addition, manual searches for references (forward search) and references to other studies (backward search) were conducted.

2.2. Inclusion and exclusion criteria

In the present study, Mendeley software was used to identify duplicate articles retrieved from the initial search and duplicate studies were excluded. The title and abstract of each of the remaining article from the initial search were carefully examined to remove irrelevant papers. In the next step, the full text of the relevant studies was obtained and assessed, Some articles were excluded if they were book reviews, grey literature, review articles, non-peer-reviewed articles, *meta-*

analyses, book chapters, protocols, conference abstracts, letters to editors, guidelines, media and social media published articles, written in languages other than English, white papers, unpublished thesis and dissertations, oral presentations, and articles with clearly unacceptable methodology based on predetermined criteria. Finally, according to the inclusion criteria such as availability of electronic version of articles and only the original reports, articles published in peer-reviewed journals focused on airborne MPs emissions in outdoor and indoor environments were included.

2.3. Selection of systematic reviewers and data extraction

Two reviewers independently studied the papers as to whether they should be included. If there were any disagreements on inclusion between the reviewers, they solved them via discussions. Briefly, we reviewed 188 published articles. Collected data from each included article were as follows: (a) study ID; (b) country; (c) air sampling site (indoor or outdoor); (d) sampling location; (e) number of samples; (f) polymer identification and analytical methods of MPs; (g) quality assessment/quality control (QA / QC); (h) abundance of MPs; (i) characteristics (polymer, type, shape, color, size) of MPs in indoor and outdoor environments and (j) the main key findings.

2.4. Assessment of methodological quality

Table S1 and **Fig. S1** show the methodologically assigned quality of the reviewed articles that were included in the present review.

Chapter 3

3. Results

Of the 188 articles that were initially identified during the systematically scientific database searches, they were assessed as shown in the flowchart in **Fig. 1a**. The articles were screened in four stages. First, due to the duplicate criteria, 28 duplicate studies were removed manually or automatically using Mendeley software. In assessing the titles and abstracts, 37 studies were excluded for the following reasons: non-English language articles, book chapters, letters to editor, and review papers. From the remaining 123 articles, 86 articles were excluded after reading the full-text because they were not related to measurement of MPs in indoor and/or outdoor air. Some articles had measured MPs in other environments such as marine sediments, sludge, soil, etc. that may not have been transmitted by airborne route. The purpose of this SR was to investigate only airborne transmission of the MPs in indoor and outdoor air. Thus, the remaining 37 studies were included in this systematic review and are summarized in **Table 1**.

Based on **Fig. 1b** and **1c**, most of the studies were published in 2022 and in environmental science journals. Studies were conducted on different continents in outdoor air including Asia (n = 12), Europe (n = 5), North America (n = 2), and South America (n = 2) (as illustrated in Fig. 2a).

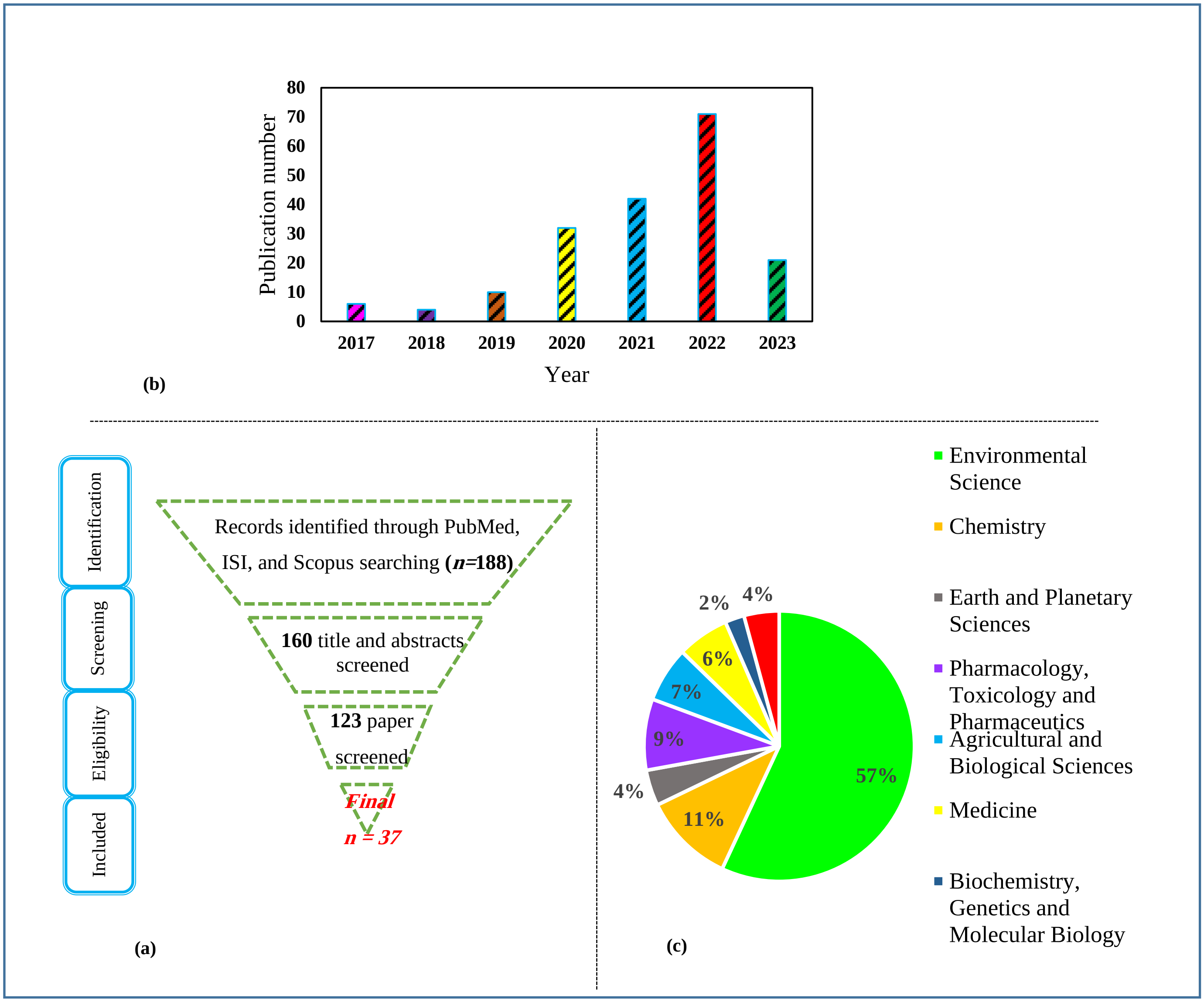

Fig. 1. PRISMA Flow diagram for selection of eligible studies

Table 1. Summary of study characteristics of identified in the original studies

Ref.	Air sampling site		Country	Sampling location	Sample number	Method	Sample digestion	QC/QA**
	Indoor	Outdoor						
(Tian et al., 2022)	✓	---	Netherlands	Households	20	LC-UV (LOD= 62 µg/L) LC-ESI-MS (LOD= 11 µg/L)	Ethylene glycol	✓
(Zhu et al., 2022)	✓	---	China	Apartment, offices, business hotels, classrooms and dormitories university	242	Stereo-microscope µ-FTIR	30% H_2O_2	✓
(Zhang. et al., 2020a)	✓	---	12 Countries*	Bedrooms or living rooms	286	LC	KOH 1-pentanol	✓
(O'Brien et al., 2020)	✓	---	Australia	Ambient air room blank, during operation of the empty dryer as a procedural blank, whilst mechanically drying a blanket	N*	Microscope FTIR Pyr-GC/MS	N	✓
(Kashfi et al., 2022)	✓	---	Iran	30 buildings in Bushehr and Shiraz (hospitals, mosques, kindergartens, universities, residential houses)	2574	Binocular-microscope µ-Raman SEM-EDS	30% H_2O_2	✓
(Cui et al., 2022)	✓	---	China	Twenty families in Yangzhou, Jiangsu (bedroom, dining room, living room, bathroom)	300	LDIR (LD=20–500 µm) FTIR	N	✕
(Chen et al., 2023)	✓	---	China	10 sites in Shanghai (dormitories, offices, family living rooms)	N	FTIR Ultra-microscopic	N	✓
(Liu et al., 2019b)	✓	✓	China	**For indoor**: 39 families in 39 major cities in southern China (n=21) and northern China (n=18) **For outdoor**: from the windowsills and open-air balconies connected to the apartments	39	µ-FTIR ESI–MS/MS	KOH 1-pentanol	✕
(Wright et al., 2020)	---	✓	London	High roof (~50 m above ground level) at a riverside urban site	N	FTIR	Methanol	✓
(Soltani et al., 2021)	✓	---	Australia	22 local government areas of metropolitan Sydney	32	Stereo-microscope FTIR	N	✓
(Chen. et al., 2022a)	✓	---	China	Living places including student dormitories (n = 8), offices (n = 4), and living rooms (n = 8) in Shanghai	20	µ-FTIR	TWEEN 20	✓
(Torres-Agullo et al., 2022)	✓	---	Spain	Houses, buses, subway, working place	15	µ-FTIR	N	✓
(Liu et al., 2020)	---	✓	China	Six coastal cities (Cangzhou, Lianyungang, Zhoushan, Xiamen, and Haikou)	521	µ-FTIR	30% H_2O_2	✓
(Abbasi et al., 2022)	✓	---	Iran	Schools in the from various elementary (6–14 years), high schools (15–18 years) city of Shiraz	50	Optical-microscope Raman SEM-EDX	30% H_2O_2	✓
(Abbasi et al., 2023)	---	✓	Iran	16 occasions free from any precipitation	32	Binocular microscopy	30% H_2O_2	✓

				S1; industrial S2; urban		Raman		
(Ding et al., 2021)	---	✓	China	South China Sea (163 for active sampling and 185 for passive sampling)	348	Stereo-microscopy FTIR	N	✓
(Bahrina et al., 2020)	✓	---	Indonesia	Offices, two schools, and two apartments in Surabaya	N	Digital-microscope	$ZnCl_2$	×
(Yao et al., 2022)	✓	✓	The United States	**For indoor**: office, hallway, classroom, single-family house **For outdoor**: on the roof of Bradley Hall	N	Raman SEM-EDS Microscope	30% H_2O_2	×
(Jiang et al., 2022)	✓	✓	China	Nasal lavage and sputum of office staff	8	Polarized light microscopy	30% H_2O_2	✓
(Chen, E.-Y. et al., 2022)	✓	✓	Taiwan	Indoor and outdoor air samples of six nail salons	6	Microscope FTIR	30% H_2O_2	×
(Amato-Lourenço et al., 2022a)	✓	✓	Brazil	Atmospheric fallout (wet and dry deposition) in São Paulo	20	Microscope FTIR-ATR	N	✓
(Xie et al., 2022)	✓	✓	China	**For indoor**: Shanghai (three living rooms, two office rooms) **For outdoor**: Eight sites in Jiangqiao, Yuqiao, Sizao in Shanghai	23	Microscope Raman	Dilute hydrochloric acid	×
(Dris et al., 2017)	✓	✓	France	**For indoor**: Two private apartments apartments A and B **For outdoor**: the roof of the office building	N	FTIR-ATR	$ZnCl_2$	×
(Amato-Lourenço et al., 2022a)	---	✓	Brazil	Three sites in the area surrounding the largest medical center in Latin America	38	Fluorescence FTIR-ATR	N	✓
(Liao et al., 2021)	✓	✓	China	15 urbans and 6 rural sites of Wenzhou City **For indoor**: 5 apartments, 2 offices, 2 classrooms, 2 hospitals (main corridor) and 2 transit station waiting halls **For outdoor**: 2 urban sites (city parks) and from 6 rural sites (2 farmland, 2 wetland and 2 mountain tops)	21	μ-FTIR Fluorescence stereo-microscope	30% H_2O_2	✓
(Fang et al., 2022)	✓	✓	China	21 indoor sites and 10 outdoor in Wenzhou City **For indoor**: apartment dining rooms, offices, classrooms, university dining halls, restaurants **For outdoor**: urban parks, wetlands, mountain top, riverside	31	μ-FTIR	30% H_2O_2	✓
(Jenner et al., 2021)	✓	✓	United Kingdom	**For indoor**: 20 houses in the city of Hull and wider East Riding of Yorkshire **For outdoor**: Five sampling locations of Kingston Upon Hull	118	μ-FTIR	30% H_2O_2	✓
(Xumiao et al., 2021)	✓	---	Portugal	Indoor air of living rooms of houses in Saveiro	5	Stereo-microscope μ-spectroscopy	30% H_2O_2	×
(Jenner et al., 2022)	---	✓	United Kingdom	Five sampling locations of Kingston Upon Hull	N	μ-FTIR	30% H_2O_2	✓
(Dehghani et al., 2017)	---	✓	Iran	Ten street dusts were collected from the central district of Tehran	2649	Binocular-microscope Fluorescence	30% H_2O_2	×

						SEM-EDX		
(Uddin et al., 2022)	✓	---	Kuwait	Public/government buildings, residential dwellings of different types spread over the city, a hospital, and a mosque	N	Stereo-microscope µ-Raman	N	✕
(Liu, K. et al., 2019)	---	✓	China	Four different municipal districts across Shanghai (three of the stations were located at different altitudes of 1.7 m, 33 m, and 80 m)	N	µ-FTIR	N	✓
(Zhang, Q. et al., 2020)	✓	---	China	Three indoor environments of the East China Normal University, Shanghai (dormitory, an office, and a corridor)	234	Stereo-microscope µ-FTIR	N	✕
(Choi et al., 2022)	✓	✓	South Korea	**For indoor**: Five sample inside of residential houses **For outdoor**: Three sample on the rooftop of a neighboring building	29	FTIR	30% H_2O_2	✕
(Gaston et al., 2020)	✓	✓	The United States	Five locations coastal southern California	21	µ-Raman (LOD=20mm) µ-FTIR	N	✓
(Levermore et al., 2020)	---	✓	The united Kingdom	Urban road side site in London	N	Raman (LOD=10µm)	N	---
(Aslam et al., 2022)	✓	---	Pakistan	Dusty samples in houses of urban (Lahore) and rural (Sahiwal)	40	Stereo microscope FTIR-ATR	30% H_2O_2	✓

*China, Colombia, Greece, India, Japan, Kuwait, Pakistan, Romania, Saudi Arabia, South Korea, USA, Vietnam
*Not reported= N
**QC/QC: Quality Control and Quality Assurance

Table 2. Key findings, abundances, and characteristics of MPs from indoor air sampling

Study ID	Abundance of MPs	MPs Characteristics				Key findings
		Polymer type	Shape	Color	Size (µm)	
(Tian et al., 2022)	1.2-305 mg/g	PET	---	---	---	MNPs were detected in indoor dust samples at levels up to about 30% of total dust mass
(Zhu et al., 2022)	---	PE, PP, PES	Fiber> Fragment > Film	Black, red, blue, yellow, green, white, transparent	200-1000	Residential apartments had the highest abundance of MPs in indoor dust samples, followed by offices, business hotels, university dormitories, and university classrooms
(Zhang, J. et al., 2020)	PET: 29-110000 µg/g TPA: 2.0-34 µg/g PC: <0.11-1700 µg/g Free BPA: *<0.05–36* µg/g	PET, TPA, PC, free BPA	---	---	<150	PET- and PC-based MPs are ubiquitous in indoor dust from different countries and are found at notable concentrations in some cases
(O'Brien et al., 2020)	Room blank: 0.17 ± 0.27 Fibers/m^3 Procedural blank: 0.5 ± 0.5 Fibers/m^3 Sample: 1.6 ± 1.8 Fibers/m^3	PET	Fiber	Blue	19-3948	Airborne emissions of 58±60 fibers per 660 g blanket sample were higher than the amount of blue fibers present in the ambient air, being 6.4 ± 9.21 fibers

(Kashfi et al., 2022)	90.8 items/mg in Shiraz 80.8 items/mg in Bushehr	PE, PC, PP, PET, nylon	Fiber (85%)> Fragment (13%)> Film (2%)	**White/transparent**, orange, red, black, green, purple	100-1000	The MPs were detected in all 30 samples of the internal dust. MPs are present in high concentrations in indoor environments and may pose a high exposure risk for different age groups
(Cui et al., 2022)	93772- 311040 Particles/m^2/ day	PA, PUR, PE, PET	Fragment (88%)> Fiber (12%)	---	---	Various rooms in the home exhibit distinct MP abundances that may be affected by age, cleanliness, and human activities
(Chen et al., 2023)	---	PET, rayon, PP, nylon, AR, cellophane,	Fiber	---	---	Dust contained MFs, especially plastic MFs
(Liu et al., 2019b)	PET: 1550- 120000 mg/kg PC: 4.6 mg/kg	PET, PC	Fiber (88.0%)	---	50μm- 2mm	Compared with PET MPs, the concentrations of PC MPs in indoor and outdoor dust were notably lower.
(Soltani et al., 2021)	22- 6169 Fibers/m^2/day	PE, PES, PA, PAC, PS	Fiber (96%)> Fragment (2%)> Film (0.6%)	Black, green, blue, red, grey, brown, transparent	200-400	PE , polyester, polyamide, polyacrylic, and polystyrene fibers were found in higher abundance in homes with carpet as the main floor covering
Chenetal., 2022	1.47-21.4 × 10^2 Items/cm^2	PET, PP, PPA, PP, PE, PS, PAN, PUR	Fiber	Transparent, **blue, black**, purple	5-5000	AC filters should be evaluated not only for their substantial impact on the distribution of indoor airborne MPFs, but also for their role in the prevalence of the related health risks
(Torres-Agullo et al., 2022)	Buses: 17.3 ± 2.4 MPs/m^3 Subways: 5.8 ± 1.9 MPs/m^3 Houses: 4.8 ± 1.6 MPs/m^3 Workplaces: 4.2 ± 1.6 MPs/m^3	PA, PES, PP	Fiber (61%) > Fragment (43%)	---	Below 100	The frequency of MP particles decreased with increasing size, which points to their potential as an inhalation hazard
(Abbasi et al., 2022)	80-56000 MP/g of dry dust	PET, PP PS, nylon	Fiber (85%)> Fragments (4%)	**White-transparent, black-grey** yellow-orange	>250	The geographical distribution is attributed to a larger population and student density, higher traffic loading and greater industrialization in the center and southeast and a prevailing wind from the northwest
(Bahrina et al., 2020)	---	---	Fiber > Fragment > films	---	3000-3500	The amount of indoor MPs is influenced by the activities and the number of occupants/people in the space
(Yao et al., 2022)	Single-family house 1.96 ± 1.09 × 10^4 Fibers/ m^2/day	PS, PE, PVC, PET	Fiber> Films> Fragment	**Blue**, red, **grey**, and brown	35-1000	The deposition rate of MPs in the ambient air acquired on a building roof was only about 2–8% of the indoor deposition rates
(Jiang et al., 2022)	---	PVC, PA	Fiber	---	---	The daily work environment for office staff is mainly indoors, with PVC widely used in building materials and furniture. They have a high daily exposure to PVC
(Chen, E.-Y. et al., 2022)	46 ± 55 MPs/m^3	AR, rubber, PUR	Fragment (99%)> Fiber	Transparent	<50-100<	Air conditioner, nail treatment, ceiling and flooring with plastic materials, and number of occupants were factors affecting indoor MP concentrations

(Amato-Lourenço et al., 2022b)	309.40±214.71 MPs/m^2/day	PES, PE, PP	Fragment (64-74%)> Foam (23%)> Film (9%)> Granule (4%)	---	100-200	Polypropylene, polyethylene, and polyester are among the mostly produced and consumed plastic because of their low price,polymers
(Xie et al., 2022)	15-94 N/m^3	PE, PES, PVC, PP, PU, rubber	Fragment (85%)> Bead> Fiber	Black, blue, green, indigo, pink, purple, red, **transparent**, white, yellow	2.40-2181.48	Ventilation played an important role in lowering indoor MPs concentrations, and MPs in better ventilated indoors displayed similar distribution patterns as outdoors
(Dris et al., 2017)	1.0-60.0 Fibers/m^3	PP, PA	Fiber	---	---	The observed fibers are supposedly too large to be inhaled but the exposure may occur through dust ingestion, particularly for young children.
(Liao et al., 2021)	1583 ± 1180 n/m^3	PES, PA, PP,	Fragment (83.5-94.2%)> Fiber	---	5-5000	Airborne MP abundance in the five indoor environments followed urban apartments > offices > transit stations ≈ classrooms > hospitals
Fang et al.,) (2022	---	PET, PE, PA	Fragment (80.8–93.5%)> Fiber	---	<30-5000	Among indoor environments, atmospheric MP deposition rates in apartment dining rooms, offices, and classrooms were significantly higher than that in university dining halls and restaurants
(Jenner et al., 2021)	0-5412 *MP* m^2/day	PET PA, PP, PE, PAN, PVC	Fiber (90%)> Fragment (10%)> Film (8%)> Sphere (1%)	---	5–250	Results indicate that humans are exposed to significantly (1–45 times) higher concentrations, and ranges, of MPs within homes compared with the outdoor environment.
(Xumiao et al., 2021)	0.5-2.6 F/m^3	---	Fragment (71.4%)>Sphere (28.6%)	**White**, brown, **yellow**, black, blue, purple	37-10822	Concentrations of MPs were higher than the concentration of synthetic fibers
(Uddin et al., 2022)	3.24-27.13 MP/m^3	PES, nylon, PA	Fiber (67-80%)> Fragment (30%)> Granule (3%)	Black, transparent, blue, red, grey	0.45-2800	For the total number of MPs and the inhalable fraction, the concentration was significantly higher for the split unit air-conditioning as compared to the central air-conditioning plants. The presence/absence of carpets had no significant effect on the MP concentrations
(Zhang, Q. et al., 2020)	Dormitory 2.1×10^3-2.9×10^4 MPs/m^2/d Office 6.0×10^2–4.5×10^3 MPs/m^2/d Corridor 5.0×10^2-6.0×10^3 MPs/m^2/d	PES, RY, AR, cellophane	Fiber> Fragment	Transparent, blue, red, black, yellow, purple, and green	50-2000	The highest average MP abundance appeared in the dormitory, followed by the office and the corridor.
(Choi et al., 2022)	0.49–6.64 Particles/m^3	PE, PP PA, PES, PS	Fiber	---	20.1–6801.2	Indoor ventilation affects MP

						abundance; in the future, adequate ventilation will be an important management method for reducing indoor MPs.
(Gaston et al., 2020)	3.3-2.9 Fiber/m^3 12.6-8.0 Fragment/m^3	PVC, PE, PT, PES	Fragment > Fiber	---	**Fiber:** 22-8961 **Fragment:** 20-850	Indoor MP fragments were half the size of outdoor fragments
(Aslam et al., 2022)	**In Lahore**: 241.45 items/m^2 **In Sahiwal**: 162.1 items/m^2	PES, PE, PP, PUR	Fiber> Film> Fragment	**White/transparent**, red/pink, blue/purple, yellow/brown, green, black/gray, orange	---	The urban region of Punjab (Lahore) exhibited 67.14% more MPs than the rural area (Sahiwal). toddlers were more vulnerable as compared to adults at both low and high exposure risk scenarios

Fifteen studies have reported sampling and analysis of MPs in indoor air, 8 studies based on sampling the outdoor air and 12 studies investigated MPs pollution in both indoor and outdoor air (as shown in **Table 1**). Of the 37 articles, 25 studies had QC/QA information (see **Table 1**). Accordingly, **Tables 2 and 3** show details of the indoor and outdoor studies, respectively.

Table 3. Key findings, abundances, and characteristics of MPs from outdoor air sampling

Study ID	Abundance of MPs	MPs Characteristics				Key findings
		Polymer type	Shape	Color	Size (µm)	
(Liu et al., 2019b)	PET: 1550-120000 mg/kg PC: 4.6 mg/kg	PET, PC	Fiber (73.7%)	---	50*µm*-2*mm*	The regional differences in economic development and population density, indicating the important influence of anthropogenic activity on the distribution of these MPs
(Wright et al., 2020)	575-1008 MPs/m^2/d	PAN, PES, PA	Fiber	---	10- 2500	Bivariate polar plots indicated dependency on wind, with different source areas for fibrous and non-fibrous airborne MPs
(Liu et al., 2020)	DAMPs: 23.04-67.54 n/m^3 SAMPs: 0-1.37 n/m^3	---	Fiber	---	---	The increasing load of ingestible plastics from sea air could have a far-reaching impact on marine ecosystem
(Abbasi et al., 2023)	0.017 N/m^3	PET, PP, nylon, PS	Fiber> Film> Fragment> Spherule	White-transparent, yellow-orange, red-pink, blue-green, **black-grey**	<100-1000<	Mean air temperature or mean wind speed for either station and no significant (linear) relationship ($p > 0.05$) between concentrations at the different sites determined on the same dates
(Ding et al., 2021)	0.013-0.063 N/m^3	PP, RY, PE, PA, PES, PS, PR	Fiber> Fragment> Foam	White, blue, red, brown, **black**, transparent	50-2210	Long-term monitoring of atmospheric MPs and the development of relevant evaluation standards are viable

						strategies for the reduction of amount of MPs entering the ocean
(Yao et al., 2022)	Fibers: 139 ± 19 m^2/day Films: 114 ± 12 m^2/day Fragments: 74 ± 12 m^2/day	PS, PE, PVC, PET	Fragment>Fiber > Film	Blue, red, grey, and brown	35-1000	Minerals or particulate matters containing Na, Al, Ca, Cl, and other elements were present on the ambient particle samples, which could accelerate the MP degradation process
(Jiang et al., 2022)	---	PE, PVC	Fiber	---	---	PE is the main component of melt-blown cloth, and is the core material used in masks. Couriers are therefore exposed to high levels of PE due to their long daily close contact with face masks.
(Chen, E.-Y. et al., 2022)	28 ± 24 MPs/m^3	AR, rubber	Fragment (99%)> Fiber	Blue, red	<50-100	Acrylic billboards are very common in the streets of Taiwan and the nail salons were in the downtown area.
(Amato-Lourenço et al., 2022b)	123.20 ± 47.09 MPs/m^2/day	PES, PE, PET	Fragment (64-74%)> Film (13%)> Granule (8%)> Foam (5%)	---	100-200	Outdoor MPs fallout correlated positively with rainfall, wind velocity, and relative humidity
(Xie et al., 2022)	15-94 N/m^3	PE, PES, PR, PVC, PP, PU, Rubber	Fragment (85%)> Bead> Fiber	Black, blue, green, indigo, pink, purple, red, **transparent**, white, yellow	2.40-2181.48	The exposure level of MPs differed among individuals, depending on where participants live and other lifestyle factors.
(Dris et al., 2017)	0.3 and 1.5 Fibers/m^3	PES, PP, PA, PE	Fiber	---	---	The observed fibers are supposedly too large to be inhaled but the exposure may occur through dust ingestion, particularly for young children
(Amato-Lourenço et al., 2022a)	13-16 n/m^3	PES, PA, PR	Fiber	---	<50	The total amount of MPs was positively associated with the quantification of SARS-CoV-2 envelope genes and negatively associated with weather variables (temperature and relative humidity)
(Liao et al., 2021)	189 ± 85 n/m^3	PE, PS, PES	Fragment (89.7-93.6%)> Fiber	---	5-5000	The abundance of outdoor airborne MPs was highest at urban transit station, hospital and apartment sites, and lowest at rural farmland, wetland and mountain sites
(Fang et al., 2022)	---	PE, PS, PP	Fragment (85–96.2%)> Fiber	---	<30-5000	The deposition rate of outdoor atmospheric MPs at urban parks was higher than for wetlands and the mountain top, while that of the riverside was also higher than for the mountain top
(Jenner et al., 2022)	3055 -5072 MP/m^2/day	PE, resins, nylon	Fragment (52%)> Film (42%)	---	5-50	No relationship between rainfall and MP fallout levels was observed.
(Dehghani et al., 2017)	88-605 MPs/g dry dust	---	Fiber (33.5%)> granule microplastics (65.9%)	**Black, yellow,** transparent, Blue, red, green, brown, pink, orange	250-500	Street dust is a potentially important source of MP contamination in the urban environment and control measures are required

(Liu. et al., 2019a)	0-4.18 n/m^3	PET, PE, PES, PAN, PAA, RY, EVA, EP, ALK	Fiber (67%)> Fragment (30%)> Granule (3%)	**Black, blue**, red, transparent, brown, green, yellow, grey	23.0-9555	Modeling estimated that approximately 21 particles of MPs are inhaled daily by people in Shanghai from outdoor environments
(Choi et al., 2022)	0.45–5.16 $Particles/m^3$	PE, PP PA, PES, AR, PS	Fiber	---	20.3–4497.4	The average number of MPs in the indoor environment was approximately 1.5 times higher than that in the outdoor environment.
(Gaston et al., 2020)	0.6-0.6 $Fiber/m^3$ 5.6-3.2 $Fragment/m^3$	PVC, PE, PT, PES	Fragment > Fiber	---	**Fiber:** 25-2061 **Fragment:** 50-481	The ubiquity of airborne MP points to significant new potential sources of plastic inputs to terrestrial and marine ecosystems and raises significant concerns about inhalation exposure to humans both indoors and outdoors.
(Levermore et al., 2020)	2502 $Particulates/m^3$	PE, PET, PP	---	---	>4.7	Using the developed Pearson's correlation and agglomerative hierarchical cluster analysis for the identification of microplastics in spectral data sets

The studies conducted in indoor and outdoor air in different countries and the number of studies are shown in **Fig.2a and 2b**.

As shown in **Fig. 3**, the different types of the devices used in the studies including composition detection and visual analysis apparatus were presented and its number is determined. Briefly, the most used device in these studies is FTIR for composition detection and Stereo-Microscope for visual analysis. Dominant shape of MPs extracted from indoor and outdoor environment has been fiber (see **Fig. 4**). It has been used to sample MPs in the atmosphere through different methods, including dry and wet sedimentation, air sampling and dust collection.

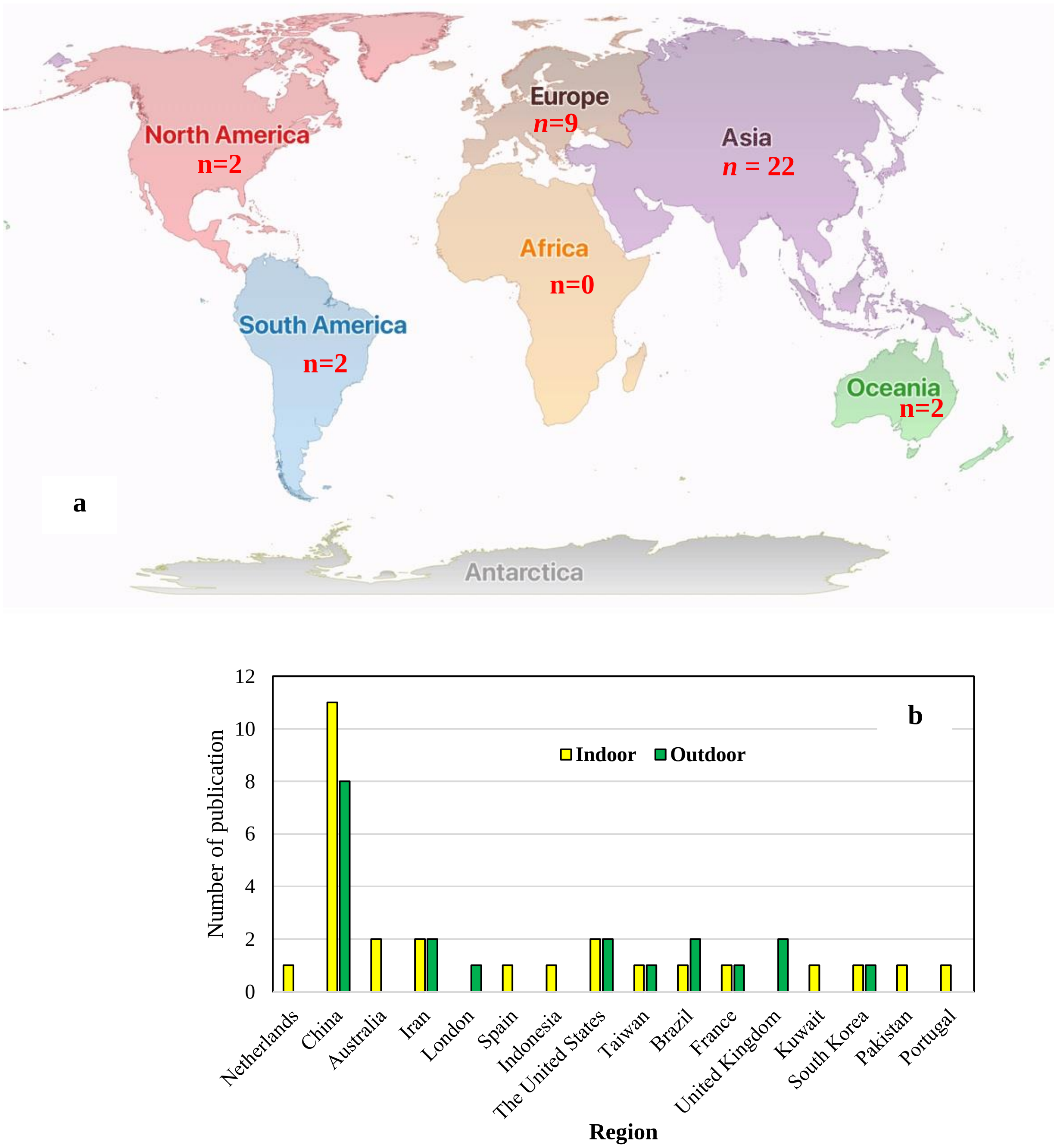

Fig. 2. World map indicating locations with included outdoor and indoor MPs studies.

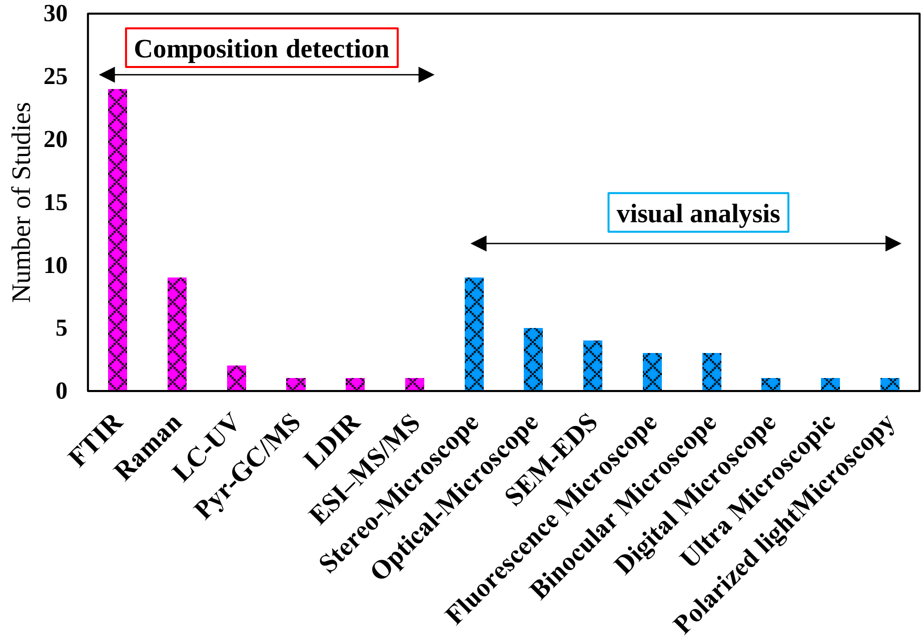

Fig. 3. The frequency of different composition detection and visual analysis methods.

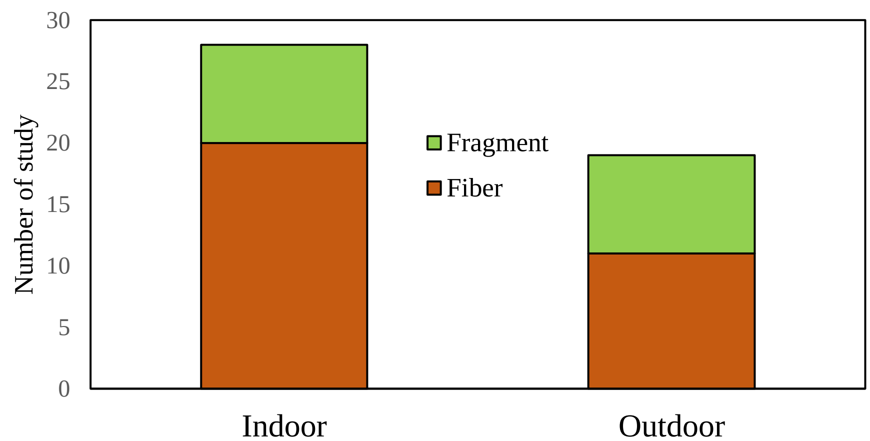

Fig. 4. Dominant shape of MPs extracted from indoor and outdoor environments.

Chapter 4

4. Discussion

The indiscriminate production and disposal of plastics seems uncontrollable and the amount of plastic waste in the environment increases every year. Recent research shows that microplastic particles as emerging pollutants have created potential new threats for humans and the environment. MPs are now in our air (Enyoh et al., 2019). Therefore, humans may be inhaling plastics since they are ubiquitous in the atmosphere (both indoor and outdoor air). These particles with high specific surface area and chemical additives can have direct and indirect and even immediate toxic effects on all kinds of living organisms (Enyoh et al., 2019). In addition, these particles as carriers, are able to introduce other pollutants into the body of living beings including humans, and the environment through multiple mechanisms. These particles can also enter the human body through air inhalation and cause serious damage to the functioning of body organs (Enyoh et al., 2019).

4.1 Global distribution of MPs in outdoor air

The presence of MPs in the air has attracted attention since 2015. Deposition, dispersion, and advection are atmospheric influencing factors that are responsible for the movement of airborne MPs. In addition to meteorology conditions (precipitation: snow or rain), the topography of the site can also affect the deposition and dispersion of MPs in the atmosphere. So, MPs concentrations in of the atmosphere depend on temperature, wind, atmospheric pressure, and precipitation (Enyoh et al., 2019; Jenner et al., 2022).

Synthetic textiles (plastic fibers or parts from clothing), destruction and fragmentation of plastic products, and road dust are thought to be the main primary sources of atmospheric MPs that can be carried by the wind to other environments. Other sources of MPs in the air may be household furniture products, building materials, incineration of waste, and industrial and traffic emissions (Dehghani et al., 2017; Enyoh et al., 2019; Jenner et al., 2022; Liao et al., 2021).

The number of studies conducted on the presence of MPs in the atmosphere and their distribution on different continents are shown in **Fig. 2a** to display the pattern of atmospheric plastics around the world. The atmospheric residence time for particles can range from hours to almost a week depending on size and shape. This period is long enough for MPs to undergo long range transport including intercontinental transport. However, to be certain about the presence of these emerging pollutants in the atmosphere across the whole earth, it is necessary to monitor the presence of MPs in Africa and Oceania where there is currently little or no data.

Because of their small size and low densities, some MPs are easily aerosolized and are inhalable. The problem of plastic pollution has intensified so much that MPs are now likely in large scale atmospheric circulation. Plastic particles that are ejected into the air from the ocean and road surfaces, cross continents, and reach the farthest corners of the planet. It seems that these plastics circulate in ecosystems for a long time (Enyoh et al., 2019; Sharma et al., 2021).

4.2. Composition detection and visual analysis methods of MPs in indoor and outdoor environments

Differences in identification methods have been reported as an important factor influencing the size range and abundance of MPs. MPs have been collected in atmospheric fallout containers in outdoor and indoor environments via dry deposition, rain samplers, and vacuum cleaner. After collecting MPs in different ways. Removing the organic and inorganic substances from samples is done using hydrogen peroxide (H_2O_2), zinc chloride ($ZnCl_2$), potassium hydroxide (KOH), hydrochloric acid (HCL), methanol and/or ethylene glycol solutions to prepare the sample for MPS identification and counting. Among these substances, H_2O_2 has been the most commonly used among all of the agents (**Table 1**). To count of MPs as well as survey the shape, color, size of MPs, visual analysis methods such as stereo microscope, optical microscope, fluorescence microscope, binocular microscope, digital microscope, ultra-microscope, polarized light microscope, and scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) are used. Raman, Fourier-transform infrared spectroscopy (FTIR), pyrolysis gas chromatography/mass spectroscopy (GC/MS), Electrospray ionization mass spectroscopy (ESI/MS), Liquid Chromatography-Ultraviolet (LC/UV) and laser direct infrared imaging (LDIR) for composition detection of MPs are used (**Tables 2 and 3**). An important difference among them is the range of particle sizes they are able to detect. FTIR and stereo microscope are most frequently used among the composition detection and visual analysis devices, respectively (**Fig. 4**).

4.3. Characteristics (polymer type, shape, color, size) of MPs in indoor and outdoor environments

Examination of the characteristics of MPs in indoor and ambient air in terms of their polymer type, shape, color, and size can be provide the information about these emerging pollutants such that control methods can be proposed based on the available information. MPs were observed a variety of polymer type, shape, color, and size.

The MP polymer types detected in the samples collected in indoor (private apartments, public buildings and office) and outdoor (outside of the buildings and the apartment) air were diverse. Based on Tables 2 and 3, nine species including polyethylene terephthalate (PET), polystyrene (PS), polypropylene (PP), polyethylene (PE), polycarbonate (PC), polyvinylchloride (PVC), polyamide (PA), phenolic resin (PR), polyurethane (PUR), polyacrylonitrile (PAN), free bisphenol A (free BPA), polyacrylic (PAC), polyester (PES), rayon (RY), polylactic acid (PLA), terephthalic acid (TPA), poly(N-methyl acrylamide) (PAA), ethylene vinyl acetate (EVA), alkyd resin (ALK), acrylic (AR), rubber, cellophane, and nylon have been identified in outdoor and indoor environments. According to **Tables 2** and **3**, PET, PP, PE, and PES had the highest rate of detection among other polymers in both indoor and outdoor air. PES and PET are the most dominant polymer types in outdoor and indoor environments, respectively. PES is used widely in carpets, furnishings, furniture, and clothing, while PET is an applied polymer in producing fabrics, synthetic fibers, textiles and packaging materials. PP is widely used in household materials including containers, furniture, and plastic bags. PE is in reusable consumer products, packaging materials, textiles, and fabrics (Jenner et al., 2022; Jenner et al., 2021; Liu et al., 2019a; Liu et al., 2019a; Prata, 2018).

Airborne MPs were detected in outdoor and indoor environmental samples having multiple morphologies including spheres, foils, fibers, fragments, films, pellets, sheets, and foams. Frequencies of specific MPs shapes detected in outdoor and indoor environmental samples were fibers> fragments> films> foams> sheets≈ pellets≈ spheres≈ foils (**Tables 2 and 3**). Comparing the number of fibers and fragments, indoor studies reported 20 cases of fibers and 8 cases of fragments, while outdoor studies found 11 cases of fibers and 8 cases of fragments (see **Fig.3**). Therefore, fibers were the dominant MP shape and fragments were the second most common MP shape. Usually, the shape of the primary MPs does not change in the environment and remains similar to its original shape.

A wide range of colors of MPs have been detected in air samples (**Tables 2 and 3**). White, transparent, black, red, pink, green, yellow, orange, blue, brown, indigo, purple and grey were identified in the samples collected in both environments. The predominant colors of the MPs in samples of the indoor air were white and transparent whereas black was most abundant in the outdoor microplastic samples. According to this review, the use of various disposable plastics such as plastic bags used in commercial and residential areas is likely the reason for the light colors of MPs in indoor samples.

MPs are mostly defined based on particle size. In general, MPs are solid polymer particles that are insoluble in water whose size is less than 5 mm, but larger than 1 µm (Gigault et al., 2018; Ter Halle and Ghiglione, 2021). There is no exact range for the smallest dimensions of MPs, but particles smaller than 1 µm are generally known as nanoplastic (Gigault et al., 2018). According to **Tables 2 and 3**, the size range of detected MPs in indoor and outdoor air were mainly in 0.4 µm to 8 mm in length and 2 µm to 10 mm in length, respectively. The MPs sizes in indoor and outdoor environments reported in the retrieved articles included in this study were < 500 µm on average and made of PES and PET. MPs with smaller sizes are more easily suspended in the atmosphere than larger sizes and are easily transported. Therefore, MPs with smaller sizes remain airborne longer. Thus, they pose greater potential threats to ecosystems and ultimately to humans. In a study conducted in 2018, (Prata, 2018) reported that fibers with sizes less than 250 micrometers were found in the terminal parts of the human lung. Therefore, MPs with sizes less than 500 micrometers can be inhaled and present a potentially dangerous result for humans (Prata, 2018).

4.4. Abundances of MPs in indoor and outdoor environments

MPs have been widely detected in the air inside various buildings, including houses and residential apartments and workplaces, as well as in the ambient atmosphere in many countries (**Table 2** (indoor air) and **Table 3** (outdoor air)). The abundance of MPs in indoor and outdoor air is widely different. The articles that have reported the presence and abundance of MPs in indoor and outdoor air used different methods and devices for collecting MPs including the particle fallout collector, rain sampler, and filters. Different measurement units have been reported. These MPs measurement units reported in the articles include a) MPs/m^3, b) MPs/m^2, c) MPs/g of particulate matter (PM) and d) µg/g PM.

In the MPs/m^3 group, the highest abundance of MPs (mean ± SD) in indoor air in China has been detected in 5 apartments, 2 offices, 2 classrooms, 2 hospitals (main corridor) and 2 transit station waiting halls (1583 ± 1180 MPs/m^3). Airborne microplastic abundances in the five indoor environments followed urban apartments > offices > transit stations ≈ classrooms > hospitals (Liao et al., 2021). The abundances of MPs in outdoor air in China were reported for 2 urban sites (city parks) and 6 rural sites (2 farms, 2 wetlands, and 2 mountain tops) (189 ± 85 MPs/m^3) (Liao et al., 2021). (Liao et al., 2021) reported that the abundance of airborne MPs in urban areas (224 ± 70 MPs/m^3) were higher than rural areas (101 ± 47 MPs/m^3).

In the MPs/m^2 group, the highest abundance of MPs in indoor air in China has been detected in twenty family homes in Yangzhou, Jiangsu (bedroom, dining room, living room, and bathroom sites) (93772 to 311040 MPs/m^2) (Cui et al., 2022). Cui et al. (2022) reported that the abundance of airborne MPs was related to the intensity of human activities, cleanliness, the duration of usage, the number of occupants (family members) in the household and etc.

In the MPs/g PM group, the highest abundance of MPs in indoor air in Iran was detected in schools from various elementary (6–14 years) and high schools (15–18 years) in city of Shiraz (80-56000 MPs/g) (Abbasi et al., 2022). The MPs abundances in outdoor air in United Kingdom were detected in five sampling locations of Kingston upon Hull (3055 to 5072 MPs/m^2) (Jenner et al., 2022). The abundance of MPs in outdoor air in Iran has been detected in ten street dusts were collected from the central district of Tehran (88 to 605 MPs/g)(Dehghani et al., 2017).

In the µg/g PM group, the highest abundances of MPs in indoor air in China were detected in the homes of 39 families in 39 major cities in southern China (n=21) and northern China (n=18) with values of 1,550 to 120,000 µg/g for PET and 4.6 µg/g for PC(Liu, C. et al., 2019). The abundances of MPs in outdoor air in China were detected on windowsills and open-air balconies associated with apartments with values ranging from 212 to 9020 µg/g for PET and 2.0 µg/g for PC (Liu, C. et al., 2019).

Overall, these studies showed that concentrations of MPs in indoor air were much higher than in the ambient air. Various factors such as wind direction, wind speed, vertical pollution concentration gradient, temperature, and precipitation can affect the transport and behavior of MPs in the ambient environment (Alzona et al., 1979; Prata, 2018). The abundance and size of MPs in indoor air depends on the location of the building, number of inhabitants, behavioral habits, heating/cooling systems, density and human activities. Also, using furniture composed of synthetic textiles, cleaning processes, toys, carpets, and clothing can release MPs into the indoor environments (Liao et al., 2021; Zhang, J. et al., 2020; Zhang, Q. et al., 2020). Due to the higher populations, the presence of industrial activities, higher traffic volumes than rural areas, and workshop units, concentrations of MPs in urban areas were greater than in rural areas (Abbasi et al., 2022; Nematollahi et al., 2022; Torres-Agullo et al., 2022).

4.5. Sources of MPs in indoor and outdoor environments

Determining the sources and mechanisms of their formation of MPs in indoor and outdoor air is necessary as air represents something that is fundamental for survival. Several studies have reported that various sources of MPs in indoor air are synthetic textiles (furniture, curtains, bedding, mattresses, clothing (pullovers, socks, etc.), kitchen plastic utensils (brushes, scouring pads, plates, cutting boards, bowls, utensils, glasses, and general multipurpose cleaning products), rubber toys, ropes, synthetic fiber carpets, foam rubber, electronic materials, electrical wiring, aging indoor walls (PVC production), and furniture paint. Residential kitchens will produce more MPs than similar office facilities. MPs from various sources can be released into the indoor air typically through daily use (Abbasi et al., 2022; Amato-Lourenço et al., 2022b; Gaylarde et al., 2021; Kashfi et al., 2022; Liao et al., 2021; Torres-Agullo et al., 2022).

Currently, the use of textile products has increased worldwide (6% increase in the production of synthetic textiles every year), and synthetic fibers are widely used in textile products. Thus, synthetic fibers are the main source of MPs in the air (Dris et al., 2017; Gasperi et al., 2018). In addition to domestic sources of MPs production, MPs produced from sources outside the building can easily penetrate internal spaces through different ways (level of outside air penetration of the indoor space) such as the windows, mechanical ventilation or infiltration. For this reason, concentrations of MPs in indoor air were much higher than outdoor air and because people spend 90% of their time indoors, this issue is considered a big threat to the current human health (Bahrina et al., 2020; Dris et al., 2017; Xumiao et al., 2021; Zhang, J. et al., 2020; Zhang, Q. et al., 2020).

The major source of MPs in the outdoor environment derives from agricultural emissions, industrial emissions, the wear and tear of tires, smoke from vehicles, burning of plastic waste, and ocean (the breaking of air bubbles and wave action, approximately 136,000 tons of MPs per year).

Another external source of MPs in outdoor air is generated by decomposition and destruction of plastic materials in nature due to sunlight, weathering, and biological activity (Jenner et al., 2022; Liu, K. et al., 2019; Nematollahi et al., 2022; Prata, 2018; Sharma et al., 2021; Ter Halle and Ghiglione, 2021; Torres-Agullo et al., 2022; Wright et al., 2020).

4.6. Quality Control and Quality Assurance (QC/QA) of measurements of MPs in indoor and outdoor environments

In the various studies included in this systematic review, traditional measures were taken to minimize cross contamination of samples to MPs during sampling, collection, extraction, analysis and storage. These precautions include cleaning work surfaces with 95% alcohol using paper towels and paper wipes, eliminating the use of plastic equipment and materials in the laboratory, using 100% cotton lab coats, washing of laboratory equipment with ultrapure water before use, covering all devices and samples with aluminum foil, considering one blank sample next to the samples to check for possible contamination of cross- MPs, using latex gloves, using glass vessels, place petri dishes in parafilm after rinsing and drying, etc. (Aslam et al., 2022; Fang et al., 2022; Jenner et al., 2022; Kashfi et al., 2022; Torres-Agullo et al., 2022).

4.7. Health consequences of MPs presence in the indoor and outdoor air

In recent years, chronic human exposure to high concentrations of MPs in the indoor and outdoor air has raised concern about their potential human health effects (Wright et al., 2020). Among these exposure pathways, inhalation is an important pathway for human exposure to MPs. Skin contact is considered to be less significant MPs as an exposure pathway, while ingestion and inhalation have been identified as the most important exposure route of MPs (Prata, 2018; Sharma et al., 2021; Zhang, J. et al., 2020; Zhang, Q. et al., 2020). By ingestion, MPs can move and accumulate in different organs and tissues. It is known that MPs enter the digestive system, and the unabsorbed part is excreted with human feces (Enyoh et al., 2019; Kashfi et al., 2022; Prata, 2018; Schwabl et al., 2019).

Exposure to MPs in the indoor air have been reported to lead to the inhalation of 26 to 272 particles per day by humans, which can be attributed to the difference in sampling methods, different environments, the presence or absence of ventilation, the location of the sampling device, the level of penetration of outside air into the indoor space, etc. Some MPs may enter the respiratory system. The settling depth of MPs depends on their aerodynamic diameter, which is used to measure the settling speed of particles with different densities and shapes.

MPs larger than 150 micrometers are not absorbed through the intestine. However, studies have shown that particles smaller than this size can enter the lymph and blood circulation through the intestine. Both length and diameter should be considered when reporting the presence of microplastics because diameter is critical for respirability, while length plays an important role in persistence and toxicity. Despite the presence of clearing systems in the body, removing MPs from the body is not an easy task due it is individual particle's properties that govern it residence time in the body. The surface area of MPs provides conditions for other pollutants in the air such as heavy metals to be absorbed on these materials and create activate oxidative stress pathway, causing cytotoxicity, disrupting metabolism, causing inflammation and eventually lead to cancer (Chen et al., 2022b; Chen et al., 2023; Gasperi et al., 2018; Prata, 2018; Wright et al., 2020).

4.8 Limitations of the study and recommendations for future research

The limitations of this SR include: 1) there are no standard methods for sampling, measuring, and evaluating MPs leading to reports of different analyses that do not have the same sensitivity or units to allow comparisons. Thus, meta-analyses were not possible, 2) In the articles included in this study, the detailed mechanisms of the transport of microplastics in the atmosphere have not been investigated, and 3) Considering that there are no air quality standards for the amounts of MPs in the indoor and outdoor air that would protect human health against adverse effects, it is not possible to categorize the hazards in different locations based on the presence of this pollutant. These limitations should be considered for future research.

Currently, because waste recycling rates are very low (less than 10%), it is recommended that future studies focus on methods of reducing consumption and increase plastics reuse and recycling rates. These aims will require governments enact strict laws to manage the production and consumption of plastic materials by industries and people and expand the collection systems to provide significant improvements and extension of the recycling industry.

Chapter 5

5. Concluding remarks

To the best of our knowledge, this study is the first review to compare the geographical distribution, sources, abundances, and characteristics (polymer, type, shape, color, size) and determine the key factors driving the presence/absence of MPs pollution as emerging pollutants in indoor and outdoor air environments. The review showed that most of the studies were conducted in Asia and Europe. Thus, monitoring for the presence of MPs on the continents of Africa and Oceania is essential to obtain a true global perspective.

The review found that the concentrations of MPs in indoor air were much higher than in outdoor air. PES and PET are the most dominant type of polymer in outdoor and indoor environments, respectively. PES is usually used in carpet, furnishing, furniture and clothing and PET are polymers used in producing fabrics, synthetic fibers, textiles, and packaging materials. Fibers and fragments have been reported to be the most common and second most dominant shapes of airborne MPs in indoor and outdoor environments. The predominant colors of the MPs in samples of the indoor air were white and transparent, whereas black color was the most abundant in the microplastic samples collected in the ambient atmosphere. MPs sizes were on average <500 μm in both environments. FTIR and stereo microscopy are the most frequently used to determine the composition detection and visual analysis devices, respectively. In addition, a wide variation in the abundances of MPs with the various units in outdoor and indoor air is reported by the 37 reviewed studies. Finally, concerns about microplastic pollution have been raised around the world and further work is needed to fully understand the scope of the potential threats that MPs pose to health and the environment.

CRediT authorship contribution statement

Zahra Noorimotlagh and Seyyed Abbas Mirzaee: Project administration, Conceptualization, Writing – original draft, Methodology, Data curation, Writing – review & editing, Validation. **Philip K. Hopke:** Writing – original draft, Writing – review & editing.

Declaration of competing interest

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

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at

References

Abbasi, S., Jaafarzadeh, N., Zahedi, A., Ravanbakhsh, M., Abbaszadeh, S., Turner, A., 2023. Microplastics in the atmosphere of Ahvaz City, Iran. Journal of Environmental Sciences 126, 95-102.

Abbasi, S., Turner, A., Sharifi, R., Nematollahi, M.J., Keshavarzifard, M., Moghtaderi, T., 2022. Microplastics in the school classrooms of Shiraz, Iran. Building and Environment 207, 108562.

Akanyange, S.N., Zhang, Y., Zhao, X., Adom-Asamoah, G., Ature, A.-R.A., Anning, C., Tianpeng, C., Zhao, H., Lyu, X., Crittenden, J.C., 2022. A holistic assessment of microplastic ubiquitousness: Pathway for source identification in the environment. Sustainable Production and Consumption 33, 113-145.

Alzona, J., Cohen, B., Rudolph, H., Jow, H., Frohliger, J., 1979. Indoor-outdoor relationships for airborne particulate matter of outdoor origin. Atmospheric Environment (1967) 13(1), 55-60.

Amato-Lourenço, L.F., Costa, N.d.S.X., Dantas, K.C., dos Santos Galvão, L., Moralles, F.N., Lombardi, S.C.F.S., Júnior, A.M., Lindoso, J.A.L., Ando, R.A., Lima, F.G., 2022a. Airborne microplastics and SARS-CoV-2 in total suspended particles in the area surrounding the largest medical centre in Latin America. Environmental Pollution 292, 118299.

Amato-Lourenço, L.F., dos Santos Galvão, L., Wiebeck, H., Carvalho-Oliveira, R., Mauad, T., 2022b. Atmospheric microplastic fallout in outdoor and indoor environments in São Paulo megacity. Science of the Total Environment 821, 153450.

Aslam, I., Qadir, A., Ahmad, S.R., 2022. A preliminary assessment of microplastics in indoor dust of a developing country in South Asia. Environmental monitoring and assessment 194(5), 340. https://doi.org/10.1007/s10661-022-09928-3.

Bahrina, I., Syafei, A.D., Satoto, R., Jiang, J.J., Nurasrin, N.R., Assomadi, A.F., Boedisantoso, R., Hermana, J., Nasir, M., 2020. An Occupant-Based Overview of Microplastics in Indoor Environments in the City of Surabaya, Indonesia. Journal of Ecological Engineering 21(8), 236-242. https://doi.org/10.12911/22998993/126876.

Chen, Y., Li, X., Zhang, X., Zhang, Y., Gao, W., Wang, R., He, D., 2022a. Air conditioner filters become sinks and sources of indoor microplastics fibers. Environmental Pollution 292, 118465. https://doi.org/https://doi.org/10.1016/j.envpol.2021.118465.

Chen, E.-Y., Lin, K.-T., Jung, C.-C., Chang, C.-L., Chen, C.-Y., 2022b. Characteristics and influencing factors of airborne microplastics in nail salons. Science of the Total Environment 806, 151472. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.151472.Chen, Y., Li, X., Gao, W., Zhang, Y., Mo, A., Jiang, J., He, D., 2023. Microfiber-loaded bacterial community in indoor fallout and air-conditioner filter dust. Science of the Total Environment 856, 159211. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.159211.

Choi, H., Lee, I., Kim, H., Park, J., Cho, S., Oh, S., Lee, M., Kim, H., 2022. Comparison of microplastic characteristics in the indoor and outdoor air of urban areas of South Korea. Water, Air, & Soil Pollution 233(5), 169.

Cui, J., Chen, C., Gan, Q., Wang, T., Li, W., Zeng, W., Xu, X., Chen, G., Wang, L., Lu, Z., 2022. Indoor microplastics and bacteria in the atmospheric fallout in urban homes. Science of the Total Environment 852, 158233.

Dehghani, S., Moore, F., Akhbarizadeh, R., 2017. Microplastic pollution in deposited urban dust, Tehran metropolis, Iran. Environmental Science and Pollution Research 24, 20360-20371.

Ding, Y., Zou, X., Wang, C., Feng, Z., Wang, Y., Fan, Q., Chen, H., 2021. The abundance and characteristics of atmospheric microplastic deposition in the northwestern South China Sea in the fall. Atmospheric Environment 253, 118389. https://doi.org/https://doi.org/10.1016/j.atmosenv.2021.118389.

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.
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, 1-17.
Fang, M., Liao, Z., Ji, X., Zhu, X., Wang, Z., Lu, C., Shi, C., Chen, Z., Ge, L., Zhang, M., 2022. Microplastic ingestion from atmospheric deposition during dining/drinking activities. Journal of hazardous materials 432, 128674.
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 & Health 1, 1-5. https://doi.org/https://doi.org/10.1016/j.coesh.2017.10.002.
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/10.1177/0003702820920652.
Gaylarde, C., Baptista-Neto, J.A., da Fonseca, E.M., 2021. Plastic microfibre pollution: how important is clothes' laundering? Heliyon 7(5), e07105. https://doi.org/https://doi.org/10.1016/j.heliyon.2021.e07105.
Gigault, J., Ter Halle, A., Baudrimont, M., Pascal, P.-Y., Gauffre, F., Phi, T.-L., El Hadri, H., Grassl, B., Reynaud, S., 2018. Current opinion: what is a nanoplastic? Environmental Pollution 235, 1030-1034.
Hilding, A., 1932. The Physiology of Drainage of Nasal Mucus: I. The Flow of the Mucus Currents Through the Drainage System of the Nasal Mucosa and Its Relation to Ciliary Activity. Archives of Otolaryngology 15(1), 92-100.
Jenner, L.C., Sadofsky, L.R., Danopoulos, E., Chapman, E., White, D., Jenkins, R.L., Rotchell, J.M., 2022. Outdoor atmospheric microplastics within the Humber Region (United Kingdom): Quantification and chemical characterisation of deposited particles present. Atmosphere 13(2), 265.
Jenner, L.C., Sadofsky, L.R., Danopoulos, E., Rotchell, J.M., 2021. Household indoor microplastics within the Humber region (United Kingdom): Quantification and chemical characterisation of particles present. Atmospheric Environment 259, 118512.
Jiang, Y., Han, J., Na, J., Fang, J., Qi, C., Lu, J., Liu, X., Zhou, C., Feng, J., Zhu, W., Liu, L., Jiang, H., Hua, Z., Pan, G., Yan, L., Sun, W., Yang, Z., 2022. Exposure to microplastics in the upper respiratory tract of indoor and outdoor workers. Chemosphere 307, 136067. https://doi.org/https://doi.org/10.1016/j.chemosphere.2022.136067.
Kashfi, F.S., Ramavandi, B., Arfaeinia, H., Mohammadi, A., Saeedi, R., De-la-Torre, G.E., Dobaradaran, S., 2022. Occurrence and exposure assessment of microplastics in indoor dusts of buildings with different applications in Bushehr and Shiraz cities, Iran. Science of the Total Environment 829, 154651. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.154651.
Lebreton, L., Andrady, A., 2019. Future scenarios of global plastic waste generation and disposal. Palgrave Communications 5(1), 6. https://doi.org/10.1057/s41599-018-0212-7.
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(13), 8732-8740. https://doi.org/10.1021/acs.analchem.9b05445.
Liao, Z., Ji, X., Ma, Y., Lv, B., Huang, W., Zhu, X., Fang, M., Wang, Q., Wang, X., Dahlgren, R., 2021. Airborne microplastics in indoor and outdoor environments of a coastal city in Eastern China. Journal of hazardous materials 417, 126007.
Liberati, A., Altman, D.G., Tetzlaff, J., Mulrow, C., Gøtzsche, P.C., Ioannidis, J.P., Clarke, M., Devereaux, P.J., Kleijnen, J., Moher, D., 2009. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. Annals of internal medicine 151(4), W-65-W-94.

Liu, C., Li, J., Zhang, Y., Wang, L., Deng, J., Gao, Y., Yu, L., Zhang, J., Sun, H., 2019. Widespread distribution of PET and PC microplastics in dust in urban China and their estimated human exposure. Environment international 128, 116-124.

Liu, K., Wang, X., Fang, T., Xu, P., Zhu, L., Li, D., 2019. Source and potential risk assessment of suspended atmospheric microplastics in Shanghai. Science of the Total Environment 675, 462-471.

Liu, K., Wang, X., Song, Z., Wei, N., Ye, H., Cong, X., Zhao, L., Li, Y., Qu, L., Zhu, L., 2020. Global inventory of atmospheric fibrous microplastics input into the ocean: an implication from the indoor origin. Journal of hazardous materials 400, 123223.

Maleki, M., Noorimotlagh, Z., Mirzaee, S.A., Jaafarzadeh, N., Martinez, S.S., Rahim, F., Kaffashian, M., 2023. An updated systematic review on the maternal exposure to environmental pesticides and involved mechanisms of autism spectrum disorder (ASD) progression risk in children. Reviews on Environmental Health 38(4), 727-740. https://doi.org/10.1515/reveh-2022-0092.

Mirzaee, S.A., Noorimotlagh, Z., Ahmadi, M., Rahim, F., Martinez, S.S., Nourmohammadi, A., Jaafarzadeh, N., 2021. The possible oxidative stress and DNA damage induced in Diclofenac-exposed Non-target organisms in the aquatic environment: A systematic review. Ecological Indicators 131, 108172.

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L.A., Group, P.-P., 2015. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Systematic reviews 4, 1-9.

Nematollahi, M.J., Keshavarzi, B., Mohit, F., Moore, F., Busquets, R., 2022. Microplastic occurrence in urban and industrial soils of Ahvaz metropolis: a city with a sustained record of air pollution. Science of the Total Environment 819, 152051.

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/https://doi.org/10.1016/j.scitotenv.2020.141175.

Prata, J.C., 2018. Airborne microplastics: consequences to human health? Environmental Pollution 234, 115-126.

Schwabl, P., Koppel, S., Konigshofer, P., Bucsics, T., Trauner, M., Reiberger, T., Liebmann, B., 2019. Detection of various microplastics in human stool: A prospective case series. Annals of internal medicine 171(7), 453-457. https://doi.org/10.7326/m19-0618.

Sharma, S., Basu, S., Shetti, N.P., Nadagouda, M.N., Aminabhavi, T.M., 2021. Microplastics in the environment: occurrence, perils, and eradication. Chemical Engineering Journal 408, 127317.

Soltani, N.S., Taylor, M.P., Wilson, S.P., 2021. Quantification and exposure assessment of microplastics in Australian indoor house dust. Environmental Pollution 283, 117064.

Ter Halle, A., Ghiglione, J.F., 2021. Nanoplastics: a complex, polluting terra incognita. Environmental science & technology 55(21), 14466-14469.

Tian, L., Skoczynska, E., Siddhanti, D., van Putten, R.-J., Leslie, H.A., Gruter, G.-J.M., 2022. Quantification of polyethylene terephthalate microplastics and nanoplastics in sands, indoor dust and sludge using a simplified in-matrix depolymerization method. Marine Pollution Bulletin 175, 113403.

Torres-Agullo, A., Karanasiou, A., Moreno, T., Lacorte, S., 2022. Airborne microplastic particle concentrations and characterization in indoor urban microenvironments. Environmental Pollution 308, 119707.

Uddin, S., Fowler, S.W., Habibi, N., Sajid, S., Dupont, S., Behbehani, M., 2022. A Preliminary Assessment of Size-Fractionated Microplastics in Indoor Aerosol—Kuwait's Baseline. Toxics 10(2), 71.

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.

Xie, Y., Li, Y., Feng, Y., Cheng, W., Wang, Y., 2022. Inhalable microplastics prevails in air: Exploring the size detection limit. Environment international 162, 107151.

Xumiao, L., Prata, J.C., Alves, J.R., Duarte, A.C., Rocha-Santos, T., Cerqueira, M., 2021. Airborne microplastics and fibers in indoor residential environments in Aveiro, Portugal. Environmental Advances 6, 100134.

Yao, Y., Glamoclija, M., Murphy, A., Gao, Y., 2022. Characterization of microplastics in indoor and ambient air in northern New Jersey. Environmental Research 207, 112142. https://doi.org/https://doi.org/10.1016/j.envres.2021.112142.

Zhang, J., Wang, L., Kannan, K., 2020a. Microplastics in house dust from 12 countries and associated human exposure. Environment international 134, 105314.

Zhang, Q., Zhao, Y., Du, F., Cai, H., Wang, G., Shi, H., 2020b. Microplastic fallout in different indoor environments. Environmental science & technology 54(11), 6530-6539.

Zhu, J., Zhang, X., Liao, K., Wu, P., Jin, H., 2022. Microplastics in dust from different indoor environments. Science of the Total Environment 833, 155256.