microplastics

MDPI

Review

Indoor Airborne Microplastics: Human Health Importance and Effects of Air Filtration and Turbulence

Christine C. Gaylarde [1], José Antonio Baptista Neto [2,*] and Estefan M. da Fonseca [2]

[1] Department of Microbiology and Plant Biology, Oklahoma University, 770 Van Vleet Oval, Norman, OK 73019, USA; cgaylarde@gmail.com

[2] Department of Geology and Geophysics/LAGEMAR—Marine Geology Laboratory, Institute of Geosciences, Universidade Federal Fluminense, Avenida Litorânea s/n, Niterói 24210-340, RJ, Brazil; estefanmonteiro@id.uff.br

* Correspondence: jabneto@id.uff.br

Abstract: Microplastics (MPs) are omnipresent particles that receive special attention because of their persistent nature and their potential impact on human disease and on the environment. Most MPs are generated by the degradation of larger plastic items such as clothing, car tires, and discarded plastic materials. In indoor environments, where human beings spend most of their time, aerial MP levels are higher, and the majority are fibers produced from textiles. Airborne MPs indoors are a greater potential danger to humans than MPs ingested in food and drink. Fragments small enough to remain substantially suspended in the air column, the small airborne microparticles that are measured as PM_{10} and $PM_{2.5}$, become available for assimilation by human beings through respiration, potentially producing various health problems. Larger MPs act by ingestion and skin contact. MPs can carry microorganisms and micropollutants adsorbed to their surfaces, facilitating their uptake and survival within the human body. Indoor airborne MPs thus represent emerging pollutants of fast-growing concern that are especially important as potential invaders of the human respiratory system, reaching the alveoli of the lungs and finally entering the circulatory system and other tissues. Since this direct human exposure to MP contamination via indoor air is so important, we discuss in this article the ways in which MP concentration and dispersal in indoor air can be affected by air turbulence that is induced by anthropogenic objects such as air conditioners, filters, and purifiers. Much evidence is equivocal and further research is necessary.

Keywords: adsorbed pollutants; air conditioners; air purification; air turbulence; dust; human respiratory system

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1. Aims and Identification of Relevant Literature

This review aims to synthesize and present information on the ubiquity and importance to humans of indoor airborne microplastics, together with the influence on these particles of anthropogenic objects that cause air disturbance. Peer-reviewed published literature and conference abstracts covering microplastics in the atmosphere and processes influencing them were identified using traditional search tools such as Scopus and Google Scholar with search terms like “indoor”, “microplastic”, “air”, “airborne”, “anthropogenic”, “atmosphere”, “agitation”, “turbulence”, “filtration”, “purifiers”, “conditioners”, “particles”, “human health”, etc. More recent articles were preferred, unless older articles contained important, and still current, information. Relevant reviews were normally included only if published within the last 10 years.

2. Introduction

Our knowledge of microplastics (MPs) in the air is considerably less than that in other milieux [1–3]. There has been much emphasis on contamination of the seas with MPs [4–6] with the concomitant pollution of marine animals [4,7–10] and the transmission of MPs to humans by animal consumption [1,11–15]. However, Catarino et al. [15] emphasized early on the importance of atmospheric MPs when they calculated that human ingestion of MPs from contaminated mussels is 123 MP particles per person per year in the UK, potentially rising to a figure of 1620 in countries with a higher consumption of shellfish, but that atmospheric exposure during meal preparation is much higher, at 13,731–68,415 particles per person per year. These particles can be inhaled by all those present in the food preparation area. Zhao and You [16] calculated much higher figures for the inhalation of MPs in the high-seafood-consuming countries of South and Southeast Asia, up to 2.8 million particles/day. Cox et al. [11] calculated that annual human MP consumption in the USA is 39,000 to 52,000 particles, rising to 74,000 to 121,000 when inhalation is included, and Zhang et al. [17] confirmed that MP intake by inhalation, especially in the more highly contaminated indoor air, is greater than that by ingestion. Not all inhaled particles reach the lungs; only those below 11 µm long have been said to have this facility, [18] with only those below 5 µm reaching the alveoli [19]. Ingestion and skin contact add to the potential effects of atmospheric MPs on humans [20].

People spend most of their time, 80% or more, indoors, [20–23] where atmospheric MP concentrations have been shown to be highest [1,24–26]. Perera et al. [27], working in SE Queensland, Australia, showed that major MP exposure sites were childcare facilities, offices, schools, and the home, with males between the ages of 18 and 64 years predicted to suffer the most respiratory exposure because of their higher activity and lung size. Yang et al. [28] showed the reduced generation of fibers from clothing worn by older people in the home, presumably because of reduced body movement. Since aging is accompanied by both reduced lung and motor function, [29] age reduces both MP generation and inhalation risk.

The majority of MPs in indoor air are present as microfibers and fragments [30], with up to 98% being fibers [31–33]; these are differentiated by their length to width ratio (fibers $>$ 3; fragments $\leq$ 3 [18]). The differences in the size and composition of fibers in indoor and outdoor air are still to be definitively determined, with different studies producing various results [30,31,34]. Indoor MPs are considered to originate mainly from fabrics used in domestic environments, clothes, and furnishings, [35–37] which contribute 59% of indoor dust, according to Peng et al. [38]. Clothes washing and drying add to this load [39–42]; these laundry activities release considerably more MPs when machines are involved [43]. Some MPs originate from wall paints and floor finishes [25], and these are more likely to occur as fragments. In a survey of indoor air in Japanese houses, [44] the lack of carpeting over wooden floors led to laser direct infrared (LDIR) identification of polyurethane (PU) as the major MP (sized at <490 µm) collected in specially cleaned vacuum cleaners. However, polyethylene (PE), often as PE terephthalate (PET), is often the major MP detected in indoor air [36,45–47]. This is the dominant fiber used in clothing and furniture [48]. In less developed tropical countries, natural materials may replace artificial ones, with wooden furniture, light cotton or semi-synthetic clothing, and clothes washing and drying in the open air being common, reducing the indoor atmospheric MP load [31]. The latter authors found, nevertheless, that indoor airborne MPs in Sri Lanka were 2–28 times greater than outdoor, depending on population density, the level of industrialization, and human activity. Indoor atmospheric MP levels have been shown to decrease from residential towns and cities with high population densities down to more remote and rural areas [49].

Indoor airborne MPs are found at particularly low concentrations in coastal areas, possibly because of the influence of outdoor air currents [50,51] or because of increased humidity, which increases particle weight, making them more liable to settle out of the air [52,53]. Nevertheless, indoor MP levels are still higher than outdoor levels. Liao et al. [24] found that air samples in the Chinese coastal city of Wenzhou demonstrated the prevalence of indoor ($1583 \pm 1181/\mathrm{m}^3$, n = 39) over outdoor ($189 \pm 85/\mathrm{m}^3$, n = 63) atmospheric MPs, around 8 times as many and statistically significantly more. This is, however, a much smaller difference than was demonstrated between the air inside an unventilated domestic dwelling in non-coastal rural SE England and that outside, where, at their peak, indoor air MP levels were more than 70 times higher than those outdoors [54]. The market town in which the house investigated is located once had a thriving iron industry but is now free from such polluting industries and may be regarded as a completely rural area. The extreme difference between indoor and outdoor MP levels reported here can be related to very low outdoor air levels with normal human furnishings and activities indoors.

Xie et al. [51], using a method that allowed the detection of MPs down to 1 µm, showed a similar prevalence of indoor over outdoor MPs in Shanghai; they also noted that indoor MPs were more colorful than outdoor, probably reflecting their origins in domestic clothes and textiles. Human activity was positively correlated with MP numbers, but these were reduced when the rooms were well ventilated, regardless of the activity within them. The authors' comparison of results with others having higher minimum MP detection sizes, although limited, indicated that size limits of 11 and 12 µm could give reasonably similar counts, but that methods with lower detection limits of 23 and 50 µm resulted in smaller determined indoor MP levels, showing the relevance of smaller MPs in indoor air.

3. Influence of Air Turbulence on Airborne Microplastic Load: Fans and Vacuum Cleaners

Although air turbulence resulting in the dilution of indoor with outdoor air reduces MP concentrations, [51] under conditions of high turbulence, such as would be expected with high-flow air conditioning, attrition from textile surfaces indoors is increased, [36] leading not only to increased MP numbers but also smaller-sized particles in indoor air [30,55]. Kim et al. [53], however, using only a variable-speed domestic fan, found that under equal conditions of humidity, high fan speeds could increase the removal of particles from the air, depositing them on surrounding surfaces. Later, this group quantified the parameters determining this deposition, [56] showing that faster fan speeds and closeness to walls/floors led to increased deposition.

It is known that air movement from air conditioners can resuspend deposited MPs back into the air, [36,57] as can human activities indoors, such as walking and vacuuming; this causes the resuspension of settled dust particles, including MPs, into a limited space, hence increasing their airborne concentration [55,58–60]. Soltani et al. [61] showed a significant correlation between the use of vacuum cleaners in Australian households and MP levels in indoor air. Airborne particle levels can, however, sometimes be reduced under conditions of high air turbulence through increased particle deposition, removing them from the air via decreased disorder [55] and deposition. The effect of air turbulence on suspended particles, including MPs, is thus a subject of ongoing investigation.

Soltani et al. [61], in an international study on indoor MPs that involved both laboratory investigations and population questionnaires in 108 homes and 29 countries of various economic levels, found that greater vacuuming frequency was associated with reduced MP concentrations in house dust. This may be explained by two facts: (a) vacuum cleaners may only increase local air turbulence in a room, and (b) it is likely that the participants in the survey would be aware of the need to clean filters and empty dust bags frequently, thus removing collected dust from potential resuspension. It has been shown that these vacuum cleaner "maintenance" activities are effective in continuing the removal of ultrafine particles (PM_{10}) from the air [62]. Vicente et al. [63] carried out a small test (four different vacuum cleaners) in one household in Spain. Many of the collected PM_{10} particles were of copper and elemental carbon, indicating their origin in the motors of the machines, and total airborne concentrations could increase by 4–61 times after vacuuming, except in the case of the cleaner equipped with a HEPA (high-efficiency particulate absorbing) filter. This distinction between MP particles and those generated by the machine motor is rarely made, since investigators do not necessarily employ suitable analytical techniques. There are no publications on airborne MP concentrations in relation to various types and times of domestic vacuuming. The available literature is insufficient to allow definitive conclusions to be drawn.

4. Domestic Air Filters

4.1. Air Conditioners (ACs)

ACs represent indispensable equipment in modern society to adjust the ambient temperature. This is especially so in the case of tropical countries, which experience high temperatures and elevated humidity levels for much of the year. During their use, the majority of ACs promote the recirculation of the air inside a room, rather than sucking in fresh air from the outside [64]. This is in order to save energy in cooling the air, but removes any possibility of reducing indoor MP levels by dilution with outside air. A comparison of residential apartments and workplaces with and without air conditioning in Colombia showed the highest concentration of airborne MPs (1.1×10^4 MP/m^2/day) in air-conditioned rooms [65]. ACs can purify the air by filtration, but the filters must be changed frequently [65].

Some researchers have used these filters as long-term suspended particulate samplers, which are capable of capturing pollutant MPs, in addition to other elements such as volatile organic compounds, polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ethers, and microbial contaminants (e.g., [64–67]). In similar cases, for example in more restricted environments such as within cars, research has shown that air quality improves significantly after simply renewing old air conditioning filters, proving the importance of maintaining and cleaning air filters [68,69]; this was also pointed out by Chen et al. [70], who found that filters in split-type air conditioners gradually became loaded with MPs and, after 35–42 days, began to act as a source of MPs in the air.

Zhai et al. [55] cite the findings of indoor atmospheric MP research carried out in Denmark in 2019. Four AC operating modes, "off", "sleep", "stroke" (increase volume), and "gale", were investigated. The number of airborne MPs was increased significantly simply by switching the mode, but in the "gale" setting, a very high reduction in MPs occurred, reaching values below non-AC air. They suggested that a substantial increase in wind speed reduced the disorder of the particles, allowing increased deposition. These deposited MPs would then become available for future resuspension, as indicated by Zhang et al. [35]. The latter authors reported that the load of airborne MPs increased in a monitored room when the AC was on and suggested that the airflow did not elevate the total number of MPs but promoted the resuspension of those already deposited back to the air column, increasing their airborne concentration and making them once again available to human respiration.

In the many commercial buildings in tropical developing countries that do not have AC cleaning practices in place, the occurrence of MPs and their ability to absorb organic pollutants and form biofilms becomes a very serious problem. ACs create a conducive environment for the growth of fungi, bacteria, and other microorganisms, which can be dispersed into the air and cause health issues [71–73]. This scenario is more worrying in view of climate change and the increase in the Earth's temperatures, which have led to heat waves in previously temperate environments, increasing the use of air conditioning in these countries. Constant exposure to poor-quality air can lead to health problems such as allergies, asthma, respiratory irritations, headaches, and fatigue and can result in increased absenteeism and decreased employee productivity [74]. Hence the influence of ACs on indoor airborne MPs is becoming even more relevant in the modern world.

4.2. Air Purifiers

Air purifiers are becoming increasingly used in developed countries to remove small polluting microparticles from domestic spaces (e.g., from school classrooms, [75]). They have also become useful machines in MP research laboratories, where they are often employed to lower the risk of aerial contamination during experiments and measurements (e.g., [76,77]). The machines consist basically of a fan and one or more filters, the best containing a HEPA filter. They are intended to remove particles down to 0.3 µm in size from the air, thus covering pollutant chemicals and many allergens. A portable air cleaner with a HEPA filter, running for 48 h in Chinese living rooms, has been shown to remove about 40% of $PM_{2.5}$ particles from the air [78], while similar instruments running in the dormitories of college students in Shanghai reduced airborne levels of these particles by 57% in 48 h [79]. MPs can fall within the target range, although there is, as yet, no stated aim of producers to cover these domestic pollutants, whose importance has only relatively recently spread throughout the general public. Lee et al. [80] evaluated the efficiency of two portable air purifiers in removing <0.10 μm and 0.10–0.53 μm MPs from the air in an apartment. They found that filtration removed the larger particles, while deposition was more important for removal of the ultrafine particles from the air. There are, however, few reports of the testing of air purifiers for their effects on airborne MP levels.

Plants as Purifiers of Polluted Air (Phytoremediation)

Following the attempts (sometimes successful) to use algae and higher plants to remove polluting particles from soil and water, [81–87] the ability of plants to remove suspended microparticles from air (both outdoors and indoors) has been investigated by several groups (e.g., [88–90]). They reported that small particles could be removed from the air by leafy plants. Ryu et al. [91] showed that the removal of microparticles sized below 2.5 μm ($PM_{2.5}$) from an enclosed airspace occurred by plant evapotranspiration, with maximum removal levels reaching 90%. They determined that the removal of the particles depended on the increase in relative humidity (RH) caused by plant transpiration and that PM_{10} particle deposition was not affected by the presence of the plants. Han et al. [92] had previously shown that the deposition velocity of 1 μm particles increases with increasing RH, and it may be that alternative methods of increasing RH may be more reliable than the use of plants.

The difficulties in developing phytoremediation technologies for emerging pollutants were discussed by Kristanti et al. [93] and the immense advantage of phytoremediation for the potential control of highway pollutants by Guo et al. [94]. The latter, however, concentrated on the removal of vehicle exhaust fumes; no attention was paid to the MPs that are produced by tire wear [95,96] and from road markings [97,98]. Gong et al. [99] discussed the possibility of using phytoremediation to remove MPs and nanoparticles from air, and Leonard et al. [100] reported that MP retention on leaves collected from the urban canopy in Los Angeles, USA, did not depend on surface hydrophilicity and was, in fact, difficult to predict from the leaf properties. However, Budaniya and Rai [101] found that removal capabilities for aerial microparticles in the indoor environment were low, and Perera et al. [102] demonstrated a low accumulation of 0.02 to 0.87 MPs/cm^2 on leaf surfaces under controlled conditions. The concentrations depended on leaf shape, with *Monstera* leaves accumulating the highest numbers. PET was the main MP identified on the surfaces, and only fibers and fragments were found. The authors pointed out that plant leaves can only be temporary MP sinks. The suggestion of green plants for the alleviation of airborne MP levels remains, for the present, contentious.

5. Airborne Microplastics as Disseminators of Microorganisms and Disease

Humans spend around 90% of their lives in indoor sites; each person breathes in about 10 m^3 of air per day [103–105]. Data obtained over the last 20 years by the US Environmental Protection Agency indicate that the air in indoor spaces can contain ∼100 times higher concentrations of contaminants than outdoor atmospheric air, with indoor air pollution being one of the top five health issues in the world [106–108].

The primary indicator of indoor air quality is currently the level of bioaerosols [109]; these are a significant airborne risk factor. Biological aerosols can include bacteria, fungal spores, viruses, and pollen always present in the air [110–112]. Other dust particles include MPs. Air samples taken near a large hospital complex, part of the University of São Paulo, Brazil, showed that the higher the air MP level, the higher the viral load [113]. These investigators suggested that SARS-CoV-2 can bind to MPs, which then act as carriers of the virus to the upper airways and lungs. Wang et al. [114] showed that MPs significantly increased the likelihood of airborne respiratory diseases. Polystyrene (PS) MPs promoted influenza A infection not only by acting as transportation vehicles into cells by endocytosis but also by reducing cellular antiviral immune reactions. More information on the effect of MPs on viruses came from experiments carried out by Lu et al. [115]. They used bacteriophage T4 as a model virus to show that over 98% of the virus particles were adsorbed by PS microparticles in water and that UV-aged MPs more effectively prolonged the infective nature of the virus, even under raised temperatures. There is considerable literature on the interaction of viruses with MPs, and this is reviewed, along with other microbial interactions, by Yang et al. [116] and Kutralam-Muniasamy et al. [117].

5.1. The Health Impacts of Microplastics in the Air

During the last few years, aerial MP particles have received more attention. Being recorded in the air, mainly in large and densely populated cities such as Shanghai, Beijing, and London, [50,118,119] their features and concentrations are mainly determined by local population lifestyles, human activities, and climatological patterns [120,121]. Atmospheric MPs can land on the ground or be carried by wind and air fluxes. Because of their small size, they can be directly assimilated into the human body via respiration [120,122,123], and, as previously stated, they present a greater negative impact on human health than polymers ingested via food and drinks [124]. The inhalation of MP fibers, especially in work environments where levels can be high, often results in respiratory discomfort, reflecting inflammatory responses in the airways and interstitium. Even at very low ambient levels, susceptible individuals are at risk of developing lesions [57,125].

A critical aspect of the incidence of atmospheric MPs is their ability to be inhaled and hence reach the lung alveoli [126]. The "breathing gateway" directly depends on particle features like size and shape. According to some references, only particles smaller than 5 μm and with a fibrous nature are able to accumulate in the deep lungs [126,127]. A greater portion of the larger inhalable particles is retained by mucociliary clearance in the upper airways; a small portion passes this filter and becomes concentrated in the lungs. Finer MP fibers especially can accumulate [128].

Many authors have investigated human health impacts resulting from MP/NP contact and its potential negative effects on health [57,67,68,129]. The greater part of this research was directed to the gastrointestinal organs as a consequence of the outdated theory that the predominant intake of MPs was the ingestion of contaminated food and water, [15,128–130] although some studies have focused on inhalation as a potential assimilation pathway [57,130–135]. However, Catarino et al. [15] suggested that the ingestion of synthetic fibers through the consumption of mussels was less significant than the inhalation of household dust during the same meal. The toxic effect of airborne particles has been confirmed in several early in vitro and in vivo studies [57,120,136]. Nanoparticles are especially harmful, having increased potential to enter the bloodstream through the pulmonary epithelial barrier (Figure 1). Recently, they have been found in carotid artery plaque [137] and in brain tissue from autopsies, [138] suggesting that their diffusion can result in damage to various parts of the body, including the heart and central nervous system, as previously suggested [139,140].

The assimilation of MPs via the human respiratory system has been demonstrated by their detection in the human lung [141,142] and in the sputum of patients with respiratory diseases [143]. However, studies on the potential negative effects of these MPs accumulated in the lung tissue, especially in patients presenting respiratory abnormalities, are still in the early stages [144], and definitive causal links have not been established [145].

While research into the transport of MPs in air streams is still new, studies into their health impacts when inhaled suggest various effects throughout the respiratory tract and beyond, ranging from irritation to the appearance of cancer in cases of chronic exposure. These adverse effects include shortness of breath, similar to that caused by asthma; respiratory inflammation such as chronic bronchitis; extrinsic allergic alveolitis and chronic pneumonia; pulmonary emphysema; [139] increased likelihood of developing interstitial lung disorders; [146] coughing, breathing difficulty, and reduced lung capacity; [126] oxidative stress and associated cytotoxic effects; [146] and autoimmune diseases [139]. In spite of the many articles on the dangers of aerial MPs to human health, a dose–response curve has never been published [61].

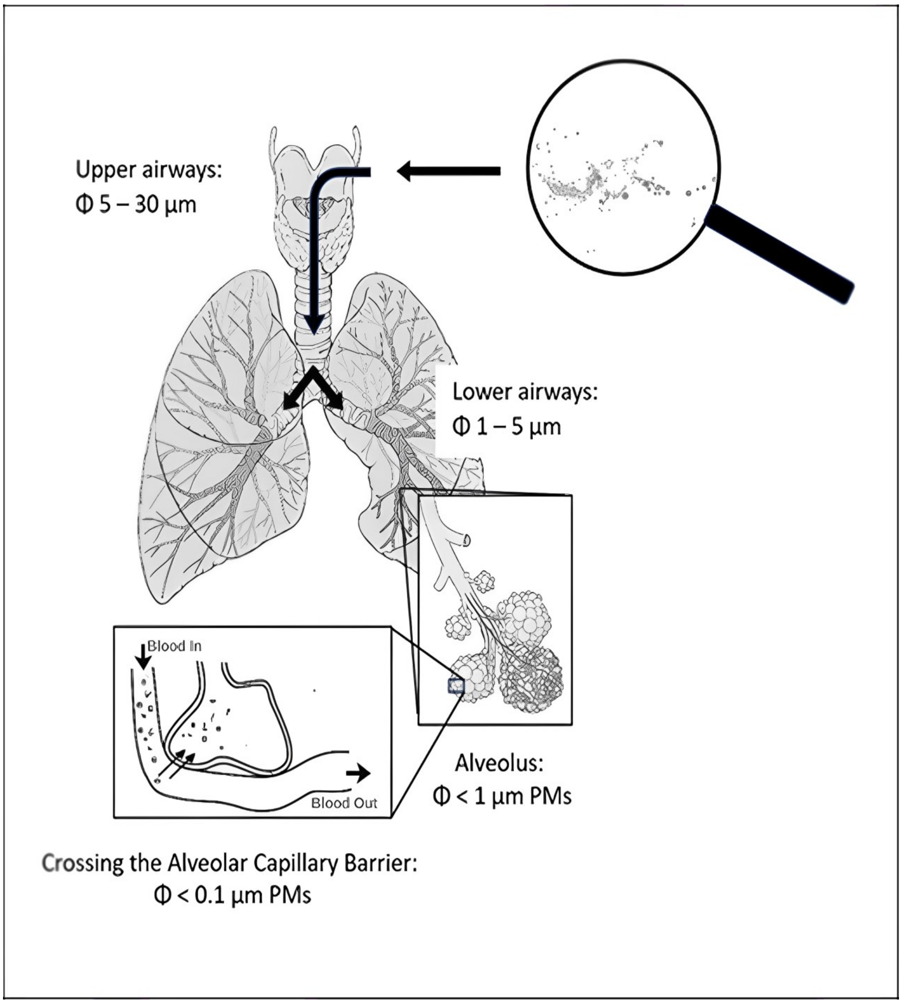

Figure 1. Trajectory of microplastics through the respiratory system (adapted from [139]).

5.2. Aerial Chemical Pollutants and Microplastics

Numerous chemical compounds, many of them toxic, are used in the production of plastics. Additives such as bisphenol A and phthalate esters, for example, are used to increase durability and malleability, while polybrominated diphenyl ethers act as flame retardants [147]. Both these classes of chemicals are endocrine disruptors [148–150]. During use and after disposal, the aging and consequent degradation of the plastic causes the release of these additives, along with degraded plastic monomers, into the environment [57,151,152], where they can be taken up by living organisms. The effects of inhaling these aerial contaminants may include reproductive (hormonal) problems, cancer, and cell mutations [57,60,68,147,153], although none of these effects have been proven to occur in humans by direct measurements [74].

Not only dangerous pollutants released from within the MPs by their degradation but also inorganic and organic pollutants adsorbed from the atmosphere can be carried by the particles, [154–157] potentiating their transport and uptake into plants and animals [158]. The high surface area–volume ratio of MPs and especially NPs means that there are ample surface sites for the adhesion of atmospheric pollutants. The type of polymer, its crystallinity, the MP size, and the degree of weathering all influence the interaction of chemical pollutants with MPs [159,160].

5.2.1. Inorganic Pollutants

Inorganic pollutants such as heavy metals can be adsorbed onto MP surfaces and transported and taken up by living beings; most of the research in this area has been carried out in relation to the aquatic systems of the world [161–163], and a variety of different adsorption mechanisms, from electrostatic to hydrophobic interactions, have been suggested [163–166]. Inorganic ions (heavy metals) have been detected on airborne MPs (e.g., [167]), and there is no doubt that this will be a common phenomenon. Tang et al. [168], working with nylon MPs, determined that their adsorption of divalent ions of Cu, Ni, and Zn was endothermic and that O-containing groups on the MP surfaces were important in the reaction. Much work remains to be conducted before we can understand the reactions between MPs and inorganic pollutants, even in aqueous environments, and further still will be required to understand MP interactions with inorganic and organic pollutants in conjunction. Fulvic acid, for example, reduces the adsorption of Pb(II) to nylon, [169] while chromium uptake by PS microparticles is higher in the presence of benzophenone filters (used as a model organic compound). This results in a higher oxidation state of the heavy metal, along with greater inhibition of algal growth [170]. There is little or no work on analyzing such trifold interactions on airborne particles.

5.2.2. Organic Pollutants

Organic pollutants, such as polychlorinated biphenyls (PCBs), PAHs, and dichlorodiphenyltrichloroethane (DDT), have been said to adsorb to MPs mainly by hydrophobic interactions [171]. However, Budhiraja et al. [155] showed that aged PE became more hydrophilic, allowing it to adsorb the pollutants triclosan and methylparaben more readily. The aging process occurs naturally in air by exposure to UV light and oxygen and results in altered surface chemistry. Ding et al. [172] showed that an important change in the MP surface was the formation of highly active carbonyl bonds, enhancing the ability to adsorb some foreign molecules, such as antibiotics, but decreasing that of others, such as PAHs. Moreover, Budhiraja et al. [155] demonstrated that the adsorption behavior of one pollutant could be altered by the presence of another, similar to the model experiments of Ho et al. [170] with organic and inorganic pollutants, cited in a previous paragraph.

Sharma et al. [173] demonstrated that the adsorption of carcinogenic PAHs on MPs varies from 46 to 236 μg/g, and it takes just 45 min for maximum binding to occur in water. PAHs also concentrate in the air or in fine particles deposited on the ground, which can be resuspended into the air. Srogi [174] suggested that, since the majority of PAHs in dry air are adsorbed onto particles like soot from road dust, [175] MPs may act in a similar way. Given the higher concentrations of PAHs [176] and MPs [52,177,178] in the air in urban centers, inhalation is likely to be one of the main routes of human PAH assimilation, both directly from the air and adsorbed on MPs in the atmosphere. Akhbarizadeh et al. [179] monitored the levels of $PM_{2.5}$ and associated concentrations of MPs and PAHs in the ambient air of Bushehr port, located in the northern region of the Persian Gulf. They evaluated temporal oscillations and potential sources and finally estimated the human health risk. Higher levels of PAHs and $PM_{2.5}$ were found in the winter season, with higher risk values.

5.2.3. Controversy

There has been much discussion on the transport of pollutants on aerial MPs [57,145,180–182]. For example, there is some controversy about whether PAHs, persistent organic pollutants (POPs), and heavy metals really do adsorb to MPs in the environment and thus facilitate their entry into the organism [132,183]. However, the capacity of MPs to adsorb PAHs has been proven [184–187]. There have been experiments in milieux other than air showing the adsorption of various pollutants on MPs and the uptake of the resultant particles by various living organisms, with several potentiating or non-potentiating effects [188]. Examples of potentiating effects are that of benzo(a)pyrene on PVC, which increased the impairment of cell functions in an annelid worm, [189] and the dose-dependent effects of Cd adsorbed on aged PE-MPs against *Moina monogolica* [190]. An apparent lack of influence of MP adsorption was shown by the similar effects of fluoranthene adsorbed or not on PE-MPs [191] and the toxic effects on zebrafish of mixed pollutants in a stream with and without added MPs [192]. Antagonistic interactions have been shown by the reduction in As toxicity in earthworms by PVC or PE [193] and of PCB toxicity to *Daphnia magna* by low PS concentrations [194].

In spite of some basic measurements, the adsorption and desorption of pollutants on airborne MPs is still incompletely understood [46,150,195], and, once again, there are no determined correlations between the levels of these pollutants in the environment and in the human body and their presumed effects. The negative impact is suggested by studies that have established a relationship between fibers accumulated in terminal bronchioles, alveolar ducts, and alveoli and chronic inflammatory reactions, granulomas, or fibrosis [46]. The increased incidence of interstitial lung disease has been associated with the inhalation of MPs [196]. On the other hand, these authors based their data on results of controlled trials, which may not represent reality in natural polluted environments.

The European Union Human Biomonitoring initiative (project HBM4EU, 2017–2021) aims to tackle this lacuna [197] through the collation of relevant data. Louro et al. [198] discussed the biomonitoring initiative and similar schemes worldwide, such as those published by the WHO and EFSA (European Food Safety Authority) and the UNAS (United National Academy of Sciences), and suggested the development of non-animal-testing research tools that incorporate in silico screening and computer modeling to integrate the acquired data. The results of this initiative are beginning to be published. Zuri et al. [199] reported the results of 91 studies on the effects of MPs in humans, indicating high levels in adult and infant feces and moderate levels in human placentas. MPs were also found in human lung tissue, the majority being microfibers. This review is recommended to those who wish to know more about the levels of MPs that have so far been detected in human tissues and the relevance of these studies to the assessment of the dangers of MPs to the human population, a discussion that is beyond the scope of this article.

6. Conclusions and Perspectives

It is now known that small airborne microplastics (MPs), 11 µm or less, can be inhaled by human beings and may penetrate into other tissues via the bloodstream. They may cause various metabolic disorders and may also carry chemical pollutants and viruses into the tissues, exacerbating the effects of viruses by interfering with the body's immune reactions. The size and concentration of airborne MPs is thus of immense importance to the wellbeing of humans. However, there is more research necessary before we can confirm and properly understand the interactions between these MPs, air pollutants, and the human organism.

The sizes and levels of MPs in interior air, where people spend 80–90% of their time, are determined to a large extent by the activities in the room. Any activity that results in the agitation of the air (e.g., human exercise and vacuum cleaning) may increase MP concentration and decrease MP size. The majority of MPs in indoor air are fibers derived from textiles, such as clothing, carpets, etc. Increased air agitation increases attrition, raising MP concentration and decreasing particle size. This can be caused by air conditioners, vacuum cleaners, air purifiers, etc., especially when filters are not regularly cleaned. Increased relative humidity increases MP deposition, potentially offsetting high air agitation. Increased fan speed alone, without changes in RH, can increase MP deposition on walls and floors, resulting in lower air concentrations, but a greater reservoir of MPs for future resuspension.

Opening windows can reduce internal MP levels by mixing with outdoor air, with its lower MP load, but there is no evidence that this is an effective control method. Certainly, however, increasing the ventilation into a room by opening windows and doors will dilute the indoor airborne MP load, although this outdoor air can also bring in other air pollutants from highways and local industries. Only clean coastal air could be considered a potential diluent of the normal heavily contaminated indoor air, with its loading of MP fibers from clothes, carpets, plastic utensils, paints, and varnishes. Coastal air can also have relatively high humidity. This increased RH can reduce airborne MP concentrations, one of the reasons why leafy plants may be considered for phytoremediation of MP-polluted airspaces. It is unlikely, however, that this could cope with the MP levels in a normal, active household.

The improvement of plastic waste treatment worldwide is the best way of reducing current MP levels in all environmental departments, including the air. Future attempts to reduce the MP content of internal air could involve changing clothing and household furnishings to replace synthetic or semi-synthetic materials with natural materials such as wood, cotton, silk, etc., and ensuring that all paints utilized indoors are water-based. Any filters used in domestic machines should be changed regularly and floors and walls cleaned to remove deposited MPs. There is no immediate and simple answer to the problem of MP contamination of indoor air.

A considerable amount of research is still necessary before we can appreciate the levels, effects, and potential control of indoor air MPs. More basic measurements, including detailed chemical analyses of the plastics, will help us to understand the origin of the particles and the ways in which they are distributed around buildings. Once the problems of the lack of standardization in the quantification and analysis of MPs are solved, modeling should enable increased understanding and the adoption of potential control methods. The effects of air agitation, produced by various machines, are not yet clear, with conflicting results probably caused by a lack of detailed measurements and, indeed, the absence of standardized methodology. The study of MPs in the atmosphere is still in its infancy; much less attention has been devoted to specific sections within the aerosphere. The influence of modern technologies aimed at increasing comfort within our homes on the turbulence of indoor air and redistribution of MPs requires much more detailed analyses. The situation is urgent in view of the increasing temperatures linked to global warming.

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