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Airborne Microplastics: A Review Study on Method for Analysis, Occurrence, Movement and Risks

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Abstract

Microplastics (of size < 5mm) pollution in our environment is of current concern by researchers, public media and non-governmental organizations. Implications by their presence in aquatic and soil ecosystems have been well studied and documented, but less attention has been paid on airborne microplastics (MPs). Studies concerning airborne microplastics started from 2016 and only a few (n=7) have been published till date. Although, studies may increase in the following years, since air is very important for human survival. Microplastics have been observed in atmospheric fallouts in indoor and outdoor environments using a sampling or vacuum pump, rain sampler and/or particulate fallout collector. Identification and quantification have been carried out by visual, spectroscopic and spectrometric techniques. Factors such as meterological, climatic and anthropogenic influence the distribution and movement of airborne MP. Human exposure may be through inhalation or dermal route with their potential biopersistence and translocation. Ingestion may cause localized inflammation and cancer due to responses by the immune cells, especially in individuals with compromised metabolism and poor clearance mechanisms. Ecological risks involve possible contamination of the ecosystem through a dynamic relationship of MPs in soil, water and air forming a MP contamination cycle. The present review aimed at providing a comprehensive overview of current knowledge or information regarding microplastics in air, identifies gap in knowledge and give suggestions for future research.

Keywords: air pollution; dermal route; fibers; health risk; inhalation; micropollutants

Introduction

The production of plastic worldwide continues to increase annually by approximately 3%. Production reached 348 million metric tons in 2017 (Verla et. al., 2019a). Increasing production has brought with increased plastic waste generation. It was estimated that

10 % of worldwide produced plastic ended up as waste and only about 3 % was recycled in 2016 (Thompson, 2006; Verla et. al., 2019a). Following current trend of increasing production and waste generation, estimates put it that approximately 67.8 million metric tons will be in the natural environment or landfill as waste in the year 2050.

Microplastic pollution is an emerging concern worldwide, with the majority of studies focusing on their occurrence, fate and effect in marine environment (Wright et. al., 2013; Gall and Thompson, 2015; Duis and Coors, 2016; GESAMP, 2016; UNEP, 2016; Carbery et. al., 2018), and less studied, soil environments (Zhu et. al., 2019). MPs are ubiquitous in nature, of which has been demonstrated in many studies. However, the dynamics of their sources, pathways and reservoirs are not well documented, which raises more questions regarding their distribution and deposition in the environment. Focusing on MPs in atmospheric compartment, this paper addresses both issues by reviewing empirical studies on method for analysis, distribution and movement as well as potential human health and ecological risks of MPs in the atmosphere.

2. Microplastics are now in our atmosphere

Air remains the most important substance for human and animal survival, as they breathe them in. However, breathing polluted air is detrimental and can lead to human and animal death. The pollutants in the air or transported by air are considered air pollutants. The threat posed by air pollution is of growing concern globally, majorly due to the increasing global population, which plays an important role in polluting and causing severe degradation of the ecosystem (pedosphere, hydrosphere and atmosphere) (Verla et. al., 2017; Ibe et al., 2016; 2017). Among many pollutants in the atmosphere, airborne microplastics are newly indentified and are of current concern by scientists, non-governmental organizations and the public media.

To date, general studies regarding microplastics pollutant in the environment have placed emphasis on the marine environment (water and sediments) including their abundance and effects on organisms and seabird (Cole et. al., 2011; Van Cauwenberghe et. al., 2013; Van Cauwenberghe et. al., 2015). Soil environment have also started gaining attention recently with studies assessing impact on soil organisms and plants growing on them (Qi et. al., 2018; Joao et. al., 2019; Zhu et. al., 2019). Meanwhile, information about airborne microplastics is still very limited in this regard. Recent research published in Marine Pollution Bulletin (2016) and Environment Pollution (2017) by Dris and his colleagues suggested that microplastics are now present in the atmosphere (air), both in indoor and outdoor air. This was confirmed in subsequent study by researchers which reported that microplastics can be transported in air in different forms or shape (Zhou et. al., 2017; Cai et. al., 2017; Kara et. al., 2018; Allen et. al., 2019; Liu et. al., 2019).

These findings therefore confirm that microplastics are now ubiquitous in global ecosystem.

So far, microplastics types indentified in the atmosphere include synthetic; PET: polyethylene terephthalate, PE: polyethylene, PES: polyester, PAN: polyacrylonitrile, PAA: poly(N-methyl acrylamide), RY: rayon, EVA: ethylene vinyl acetate, EP: epoxy resin; ALK: alkyd resin, and natural; cotton and wool while the shape/forms in which they are present include fragments, foam, films, granules and fibres (Table 1). These forms are produced primarily through natural degradation of large plastics by ultra violet light or secondarily from clothing, personal health care products and nurdles. The degradation may occur in the atmosphere or on soil or water and may be blown by wind into the atmosphere. Other source of airborne MPs could be from emissions during recycling of macroplastics. It was demonstrated that emissions during from plastic waste recycling processes have affected the ambient environment (Huang et al. 2013; Hahladakisa et. al., 2018), a process which may also deposit MPs in air.

3. Methodology for assessing airborne microplastics

There are currently no standard operation protocols (SOP) for microplatics analysis in the environment. While possible strategies focusing on marine environment analysis have been extensively reviewed and documented (Martin and Gunnar, 2015; Wagner et. al., 2016; Besley et. al., 2016; Verla et. al., 2019), none reported on analysis of airborne microplastics. This is majorly due to the lack of studies regarding airborne MPs and only few studies have been published till date. Therefore, in this section we reviewed available methods reported in literature for assessing airborne MPs in the atmosphere. The possible procedures for assessing airborne MPs, from sampling to results are presented in Figure 1. These procedures have been reported for analysis of MPs in soil, sediment and water media, but the difference is majorly on the sampling techniques.

The sample collection materials/instruments and methods are different based on the location of studied air whether indoor or outdoor. For indoor air, a sampling pump can be used for sample collection. An example of such pump is the Stand-alone sampling pump used by Dris et. al., (2016). Meanwhile for deposited MPs in indoor dust can be sampled by a vacuum pump or vacuum cleaner normally used in homes and dust particles collected in the cleaner bags. For outdoor analysis of airborne MP, two methods of sample collection have generally been used, which include rain sampler and particulate fallout collector. These instruments are set in outdoor atmosphere at a particular height (ground, aerial or upper; ref. Liu et. al., 2019) over period of time.

The samplers for airborne MPs is presented in Figure 2a,b. The sampler basically contains a funnel (stainless steel) for channeling and sampling bottle (often glass) for

collecting the rain. After collecting samples, the funnel is often rinsed with water by reverse osmosis, which removes all particles adhering to the funnel surface. After sample collection, it is then pre-treated by reducing sample volume either by sieving through a mesh (e.g 2.5 mm), elutriation, decantation or filtration depending on the sampler used. Common filters used in MP studies include quartz fiber GF/A Whatman filters (1.6 μm) (Dris et. al., 2016) or a 0.45 μm polytetrafluoroethylene 47 mm diameter membrane (Whatman) (Allen et. al., 2019). Settled MP in indoor dust has the tendency of adhering onto dust particle, so they are separated based on their density. Density separation is achievable by the use of $ZnCl_2$ solution; this will make the microplastic particle to either float or sink in the solution depending on plastic type, thus enabling separation. Once they are separated, they are then further treated (post-treatment) for removing natural debris or unwanted material on MP surface using fairly aggressive chemical such as potassium hydroxide (KOH), hydrogen peroxide (H_2O_2), perchloric acid ($HClO_4$) and nitric acid (HNO_3) or enzymatic digestion (Wagner et. al., 2016; Erni-Cassola et. al., 2019: Verla et. al., 2019).

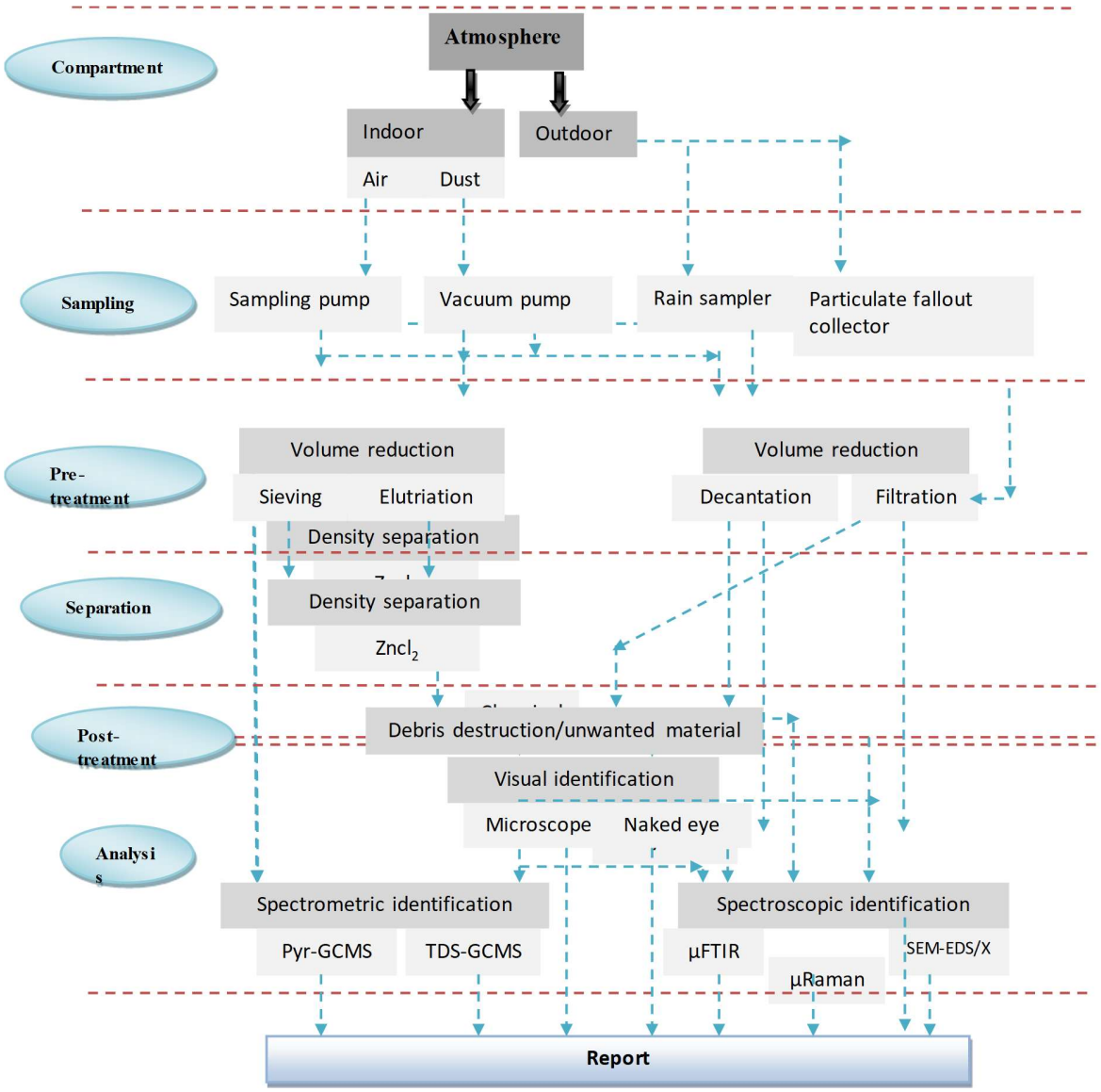
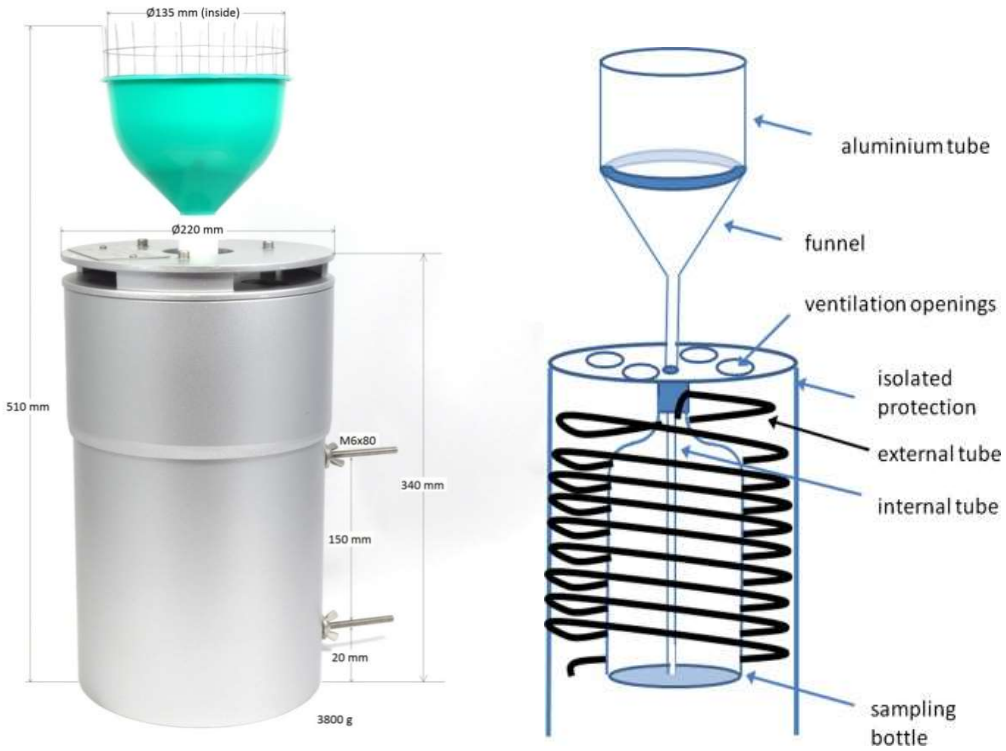


Figure 1. Possible methodology for sampling, treatment and analysis of airborne MPs. Pyr-GCMS: Pyrolysis Gas Chromatography-Mass Spectroscopy; TDS-GCMS: Thermal Desorption System Gas Chromatography-Mass Spectroscopy; µFTIR: Micro Fourier Transform Infrared Spectroscopy; µRaman: Micro Raman Spectroscopy; SEM-EDS/X: Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy.



a

b

Figure 2. Outdoor airborne microplastics sampling methods **(a)**. Simple rain sampler (Image credit: Gröninga et. al., 2012), **(b)**. Particulate fallout collector (Image credit: Innovation nilu, 2019).

The unwanted material could be organic and inorganic matter, including biofilm and dust (Allen et. al., 2019) and if not removed could interfere with the analysis and poses

a major problem when identifying microplastics as synthetic polymers (Song et. al., 2015; Verla et. al., 2019). The final analysis before reporting of results includes the use of different spectroscopic or spectrometric technique. The common techniques for identification and quantification include use of microscope or naked eye for visual identification, Pyr-GCMS, TDS-GCMS, FTIR, Raman and SEM-EDS for compositional profile. The experimental principle and their usefulness for MP analysis have been extensively reviewed (Wagner et. al., 2016; Klein et. al., 2018; Verla et. al., 2019). The analytical techniques are often used in tandem, one separating and the other quantifying or one observing and the other confirming. For example, identification of MP of size <500 μm by visual identification alone is not recommended and so a follow up technique for confirmation such as micro-FTIR and micro-Raman was recommended (Hidalgo-Ruz, et. al., 2012; Shim et. al., 2017).

4. Occurrence of airborne MPs

Microplastics are of low densities and small sizes, which make them to distribute easily by wind and commonly observed at downwind sites in great quantity (Browne et al., 2010). Few studies (n=7) reported on the occurrence of airborne MPs have been conducted only in three locations in two continents viz France (Europe), Turkey (Europe) and China (Asia). The characteristics, deposition rate and concentrations of MPs in atmospheric compartment reported in literature are presented in Table 1.

Table 1. Available data on characteristics, deposition rate and concentrations of MPs in atmospheric compartment

Study Location (continent)	Air type	Characteristics				Deposition rate (Particle/day/m²)	Concentration	Reference
		Shape /form	Size (μm)	Colour	Polymer types			
Paris, France (Europe)	Outdoor (Urban)	Fiber	50-600	N/A	RY, PET, PA	2.1-355.4	N/A	Dris et. al., 2016
Paris, France (Europe)	Indoor	Fiber	50-600	N/A	RY, PE, PA, PP	1600-11,000	1.0 - 60.0 [a]	Dris et. al., 2017
Paris, France (Europe)	Outdoor	Fiber	50-3250	N/A	RY, PE, PA, PP	1586 -11,130	0.3 - 1.5 [a]	Dris et. al., 2017
Dongguan, China (Asia)	Outdoor (Urban)	Fiber, foam, film, fragment	<200-4200	Blue, red yellow, White, Pink	RY, PE, PP, PS	175 -313	31 - 47 [b]	Cai et. al., 2017
Yantai, China (Asia)	Outdoor (Urban)	Fiber, foam, film, fragment	50-1000	Black, red, white, transparent	PET, PE, PVC, PS	0.0 – 602	2.33×10^{13} [c]	Zhou et. al., 2017
Sakarya province, Turkey (Europe)	Outdoor (Urban)	Fiber, fragment	≤500	Dark blue, white, transparent, brown	RY, PA, PE, NW, NC, AR	N/A	259-12895[d]	Kaya et. al., 2018
Pyrenees	Outdoor	Fiber,	<25-	Transparent	PS, PE,	365±69 (mean)	N/A	Allen et.

mountains, southwest of France (Europe)	(remote)	film, fragment	2600	, white, bright orange, blue, green, purple, black.	PP, PVC, PET.			al., 2019
Shanghai, China (Asia)	Outdoor (Urban)	Fiber, fragment, granule	23.07-9554.88	Black, red, transparent, yellow, grey, brown, green	PET, PES, PE, PAN, PAA, EVA, EP, ALK	N/A	0-4.18 [a]	Liu et. al., 2019

*Urban- highly populated area; remote- limited development, difficulty of human access and distance from major populations or industrial centres; [a] concentration in particle/m^3, [b] concentration in particle/m^2, [c] concentration in particle/100km, [d] concentration in particle/Litre, N/A- not available, PET: polyethylene terephthalate, PE: polyethylene, PES: polyester, PAN: polyacrylonitrile, PAA: poly(N-methyl acrylamide), RY: rayon, EVA: ethylene vinyl acetate, EP: epoxy resin; ALK: alkyd resin, AR: acrylic resin, NW: natural wool, NC: natural cotton

First study, to the best of our knowledge, published regarding occurrence of MPs in air was by Dris et al. (2016), who evaluated total atmospheric fallout (TAF) collected in dense urban and less dense sub-urban Paris, France. Using rain sampling technique, microplastics were collected, filtered and observed visually with a stereomicroscope. From counting, high abundance of fibers was found while the rate of deposition was systematically lower at the sub-urban site than at the urban than. As a follow-up study also in France, indoor and outdoor air was evaluated for airborne fibers by Dris et. al., (2017). Study sites were private apartments and office (for indoor) while outdoor air sampled just outside the apartment. Result revealed that indoor had higher deposition rate and concentrations of the fibers than outdoor, probably due to factors such as partition, ventilation and airflow of the room (Alzona et al., 1979; Prata, 2018), favouring indoor deposition rate. Cai et. al., (2017) analyzed fibrous and non-fibrous microplastics in TAF from Dongguan city, China and reported concentrations ranged of 175 to 313 particles/m^2/day in the atmospheric fallout. Fibers were the dominant shape while non-fibers (foam, fragment, and film) were less dominant. Also in China, Zhou et. al., (2017) evaluated airborne microplastics in Yantai, a coastal city in Shandong Province using FTIR. General shape identified were fibers (95 %), fragments (4 %), films (0.5 %) and foams (0.5 %) and fibers colours varied including white, black, red and transparent. In Sakarya province, Turkey, Kaya et. al., (2018) studied microfibers in air at an intercity terminal in front of a university campus using micro-FTIR. Samples were collected using vacuum suction/pump at volume of 0.3 m^3/minute for 30 minutes. The authors found MP in two forms (fibers and fragments) of varying colours and through visual sorting under a microscope counted particle in range of 259-12895 particles/L. Liu et. al., (2019) using the principal component analysis identified of airborne microplastics in Shangai city from from textile clothes. Through spatial analysis fibrous MP (67 %) was most abundant, followed by fragments (30 %) and granules (3%) respectively.

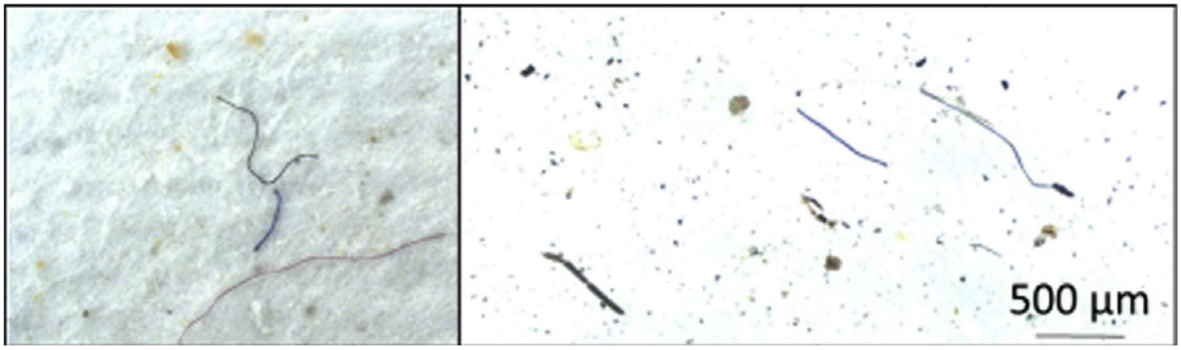


Figure 3. Fibre shape of airborne microplastics (Gasperi et. al., 2018)

The size ranged < 25 to ≥ 4200 µm have generally been studied (Table 1). Colour of plastics reveals degradation stage of plastics. Generally investigation was done by visual inspection and reported colours varied including transparent, white, bright orange, blue, green, purple, black, grey, pink, yellow and red. Furthermore, available studies have generally implicated higher percentage of fiber shape of microplastics in TAF, suggesting fibrous microplastic are more common than non-fibrous (fragment, foam, granule, and film) in atmospheric compartment (Figure 3). Analysis of the fibers revealed they are synthetic and high abundance of synthetic fibers could be due to its high production rate, thus high waste generation. The production of synthetic fibers continues to increase annually at an approximate rate of 6.6 % (Gasperi et al., 2018). In 2016, more than 90 million metric tons of textile fibers were produced (Gasperi et al., 2018), of which approximately 10 million metric tons are synthetic, plastic fibers. Natural fibres often exist in indoor as opposed to synthetic fibres in outdoor compartment. For example, 67% of fibers reported in indoor environments were made of natural material while synthetic ones were less (33 %) (Dris et. al., 2017). However, this is a single study and may not be enough to draw any conclusion. Further study is therefore required to better understand this phenomenom.

The deposition rate varied with location, which also influence concentrations probably dependent on climate conditions and seasonality, but also on sampling methodology as well as population. For example, Dris et. al., (2017) while assessing indoor airborne MP observed that the presence and number occupant influences sample volumes and rate of deposition. Highest deposition rate was observed in condensed area with minimal wind such as the indoor environment. It is difficult to compare the reported concentrations due to differences in reported units. However, comparing area with same units, Paris (France) showed lower concentration to Shanghai (China), perhaps due to population, density of buildings and anthropogenic activities. These are single studies and thus not enough to draw any meaningful conclusion. There need for more

studies assessing TAF for MPs in more areas of the world. However, in factual anthropogenic activities in a particular area, influences the amount of MPs in TAF of the area (Allen et. al., 2019).

5. Atmospheric movement of microplastics

According to Perry (1988), in the atmosphere, the driver for pollutants movement is transport, dispersion, and deposition mechanisms. These factors are also responsible for movement of airborne microplastics. Transport is movement caused by ambient wind flow and direction. Dispersion results from local turbulence/disturbance, while deposition is downward movement of airborne MPs to the ground surface, which relies on precipitation, scavenging, and sedimentation. The entire movement (transport, dispersion, and deposition) processes is assisted by size, shape and length of the MP particle. This phenomenon has been demonstrated in recent studies (Zhou et. al., 2017; Kara et. al., 2018; Allen et. al., 2019). For example, smaller fragments of size 25 μm was found in highest percentage (> 50%) while the distribution dropped with increasing size viz 25 – 50 μm > 50-75 μm > 75-100 μm …… > 300 μm. Similarly, higher distribution was reported for shorter fibre length of < 100-900 μm than longer length of 1000- > 2500 μm (< 2 %). Another example is from the study of Zhou et. al., (2017), who observed that with increasing particle size, amount of microplastics in the atmosphere of Yantai, China decreased dramatically over the year. The smaller the size of MPs coupled with its small relative density, the easiness for them to eco-persist in the atmosphere, with potential long-term threats to ecosystems (Dris et. al., 2016; Lui et. al., 2019).

Atmospheric microplastic (MP) source and transport analyses are new to MP research. Microplastic pollution in air is not only determined by the type and intensity of the emissions. Meteorology conditions (precipitation and rain or snow) and the climate, as well as the topography of the site, all have a major influence on the dispersion and deposition of MPs. Allen et. al., (2019) observed that distribution of different MP types (polyethylene (PE), polystyrene (PS), polypropylene (PP), polyvinylchloride (PVC), and polyethylene terephthalate (PET)) varies with climate. For example in November and December periods (lower relative precipitation and fewer storms viz rain or snow) higher percentage of PS was observed in the atmosphere but February and March period (increased rainfall and snowfall) distribution was low while PE was higher in March and low in November. Similarly, Zhou et. al., (2017) observed higher percentage of airborne MPs in spring, summer and winter and lowest in the autumn periods. In terms of site topography, Liu et. al., (2019) reported that spatial distribution and deposition of airborne MP was influence by the complex landscape and densities of building of the Shanghai study area. However, these observations are not enough to draw conclusion but it is factual that these conditions (climatic and topography) plays an important role on the distributions of MP in the atmosphere.

The concentration of MPs in the low layers of the atmosphere depends on the atmospheric pressure, wind, temperature, rainfall and snowfall (Allen et. al., 2019). Atmospheric depressions (low atmospheric pressures) are associated with strong turbulence of air and, thus, with good conditions for dispersion, while anticyclones (high pressures) correspond to air stability and, thus, breed episodes of pollution. The dispersion of MPs increases with the speed and turbulence of the wind, and its direction either vertically or horizontally. The vertical temperature gradient helps ascending movement of airborne microplastics. However, in case of temperature inversion, MPs may be blocked in the low layers of the atmosphere, which creates episodes of pollution. MPs maybe transformed in air to smaller particles (e.g nanoplastics or femtoplastics) pollutants by the influence of temperature, humidity and solar rays. Such situation will be dangerous for human as at that size they can easily be inhaled compared to MP sizes.

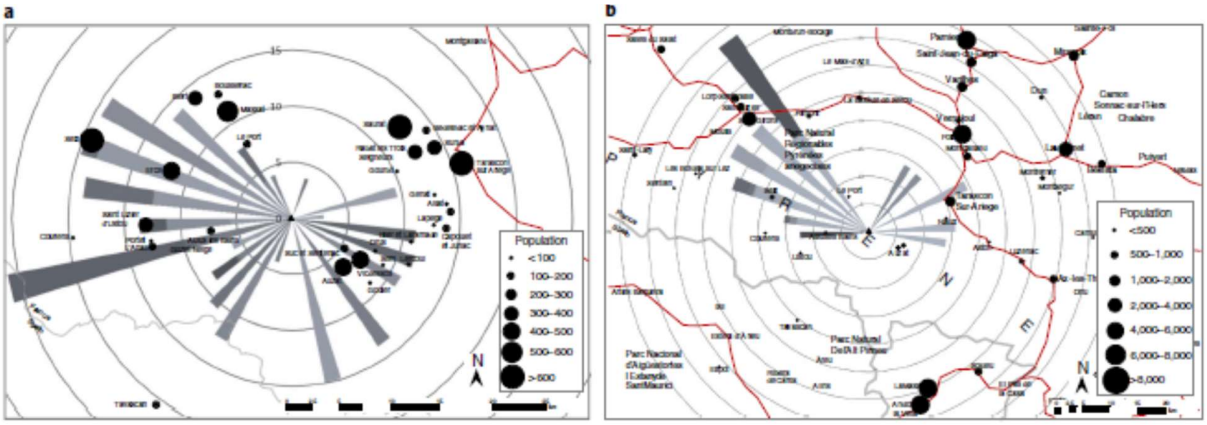


Figure 4. Transport trajectories of airborne MP. a, Rain and snow event trajectories. b, Trajectories of wind events (reprinted from Allen et. al., 2019).

While many factors control the movement of MPs in the atmosphere, models can be used to study/monitor as their dispersion and deposition. By using a simple MP settling calculation, the movement of airborne MP can be studied. Allen et. al., (2019) was able to study the local to regional transport of MPs in French Pyrenees atmosphere using the simple MP settling calculations. The simple MP settling calculations was calculated as the ratio of back−trajectory duration to the wind speed. Using MP settling velocity, event wind speed and direction and planetary boundary layer depth, provide basic, linear back-trajectories for MP deposited at the field site due to the initial entrainment or uplift and horizontal (wind) conveyance (without further mechanical or convective lift). The transport trajectories obtained in the study are presented in Figures 4a,b. The MP source area or zone of influence defined by this method extends for 28 km northwest to southwest, along the sparsely populated Aulusles- Bains, Ercé and Massat

valleys, over the Guzet-Neige ski fields and south-east along the Vicdessos valley (Fig. 1a, b). Wind events >2 m/s, as illustrated in the study, showed from a local MP source area, airborne MP travel up to 42 km to the northwest across Aulus-les-Bains and the Saint-Girons valleys, 20 km to the northeast over Tarascon-sur-Ariège (village populations <6,000) and up to 95 km north. These observations made in the study suggest that MPs are easily transported in air for a distance of less than 100 km and influenced by population, thus anthropogenic activities, which also influence their deposition rate. Although they can potentially be transported with dust particles as airborne microplastics have been reported to settle in dust particles (Dris et. al., 2016). Long-range transport of dust (ultragiant particles of <400 μm size) up to 3,500 km across oceans was reported by van der Does et al. (2018). Established evidence has revealed the possibility of short term travel of airborne MP while currently unknown is the possibility of long term travel. Therefore, studies should be conducted on long-range transport (> 100 km), to determine if air considering all factors for transport, dispersion and deposition of MPs over long distance.

6. Risks of airborne MPs

Microplastics are now in our air, human needs this air for survival and proper functioning of body organs. Therefore, humans may be breathing in plastics as they are ubiquitous in the atmosphere (both indoor and outdoor air) (Enyoh and Verla, 2019). Other route of exposure to airborne MPs could occur through the skin (dermal) from the deposition of atmospheric fallouts. However, apart from the potential risks posed to human health, potential risks are also posed to the environment.

6.1 Potential risks to human

There is no evidence regarding ingestion of airborne MPs via contact or inhalation, although studies have suggested the idea. The possibility of inhaling airborne MPs relies on size, which also determines if will reach the respiratory system. So particle may be inhalable (i.e able to be deposited in upper airways after entering from the nostrils or mouth) and respirable (able to reach and deposit in the deep lung) (Gasperi et. al., 2018). Fibrous MPs that may be inhalable are those that do not conform to the criteria of fibre provided by World Health Organisation i.e must have a length of more than 5 μm, with a diameter of less than 3 μm and a length-to-diameter ratio of more than 3:1 (WHO, 1997). Contact exposure will be through skin pores penetration. Exposure by this means is based on individual susceptibility as human skin pores vary by individual. Frederic et. al., (2015) reported varying skin pores sizes to as small as 40-80 μm, which will fit well for airborne MPs penetration (synthetic fibers as low as 25 μm in size have been reported, ref. Dris et. al., 2016 and Allen et. al., 2019).

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The deposition of inhaled MP in the upper airways (nasal cavity, pharynx, larynx) through to the respiratory zone (lower airways; trachea, primary bronchi and lungs) is a function of aerodynamic equivalent diameter (AED), dependent on the particle density (P_ρ) in g/cm^3 and its physical diameter (d_m) (calculated as $AED = d_m\sqrt{P_\rho}$) (Swift, 1980). Based on this, some polymer with lower density (e.g. low density polyethylene, LDPE) and small diameter have higher potential to be respirable, reaching lower airways (Prata et. al., 2018). Mechanism of particle deposition relies on the AED value, which may occur by impaction (AED of 5-30 μm), interception, sedimentation (1-5 μm AED), or diffusion (AED of < 1 μm) (Prata et. al., 2018). In the upper airways deposition occurs by (1) impaction, where particle's collide with the walls due to their maintained momentum (2) Interception, when particle edges touches the surface (Lippmann et al., 1980) with higher potential for penetration (Donaldson and Tran, 2002) (3) sedimentation, relies on time and gravity (Carvalho et al., 2011), where particle settles down in the lower airways and (4) diffusion relies on brownian motion and particles (Bakand et al., 2012; Carvalho et al., 2011) (see Fig. 5).

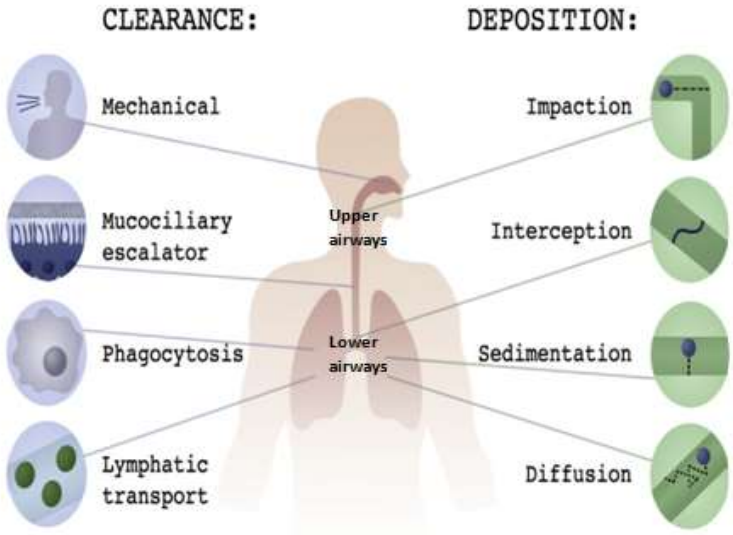

Figure 5. Particle deposition and clearance mechanism in human lung (Source: Prata (2018) with slight modification)

The potential risk of ingested airborne MPs to human organ is dependent on deposition and clearance rate. If deposition rate is higher than clearance rate, human may be at risks of particle (particle localization/accumulation) and chemical toxicity as well as microbial toxins, even when particles are in low concentration. Studies by Churg and Brauer (2000), Heyder (2004) and Morrow (1988; 1992) showed that particles low in toxicity can lead to disease in susceptible individuals. The clearance mechanism presented in Figure 5, serve as a mechanism of defense protecting the airways by

trapping foreign particles that enter them through the nose, during normal breathing (Lillehoj and Kim, 2002). Clearance depends on (1) mechanical methods (which involves sneezing) (2) the mcociliary escalator, prevents inhaled particle from descending down the lungs, by producing a sticky mucoid, which end up being excreted from the mouth (3) phagocytosis, where particle (≥ 0.5 μm) gets eaten by the cell using its plasma membrane and gets digested in the phagosome and (4) lymphatic transport, operates by collecting particles from tissues (for detailed explanation of these mechanisms see Prata 2018). However, some fibrous MP posses high surface area (Donaldson and Tran, 2002) and therefore exhibit biopersistence property and remain the lung. Pauly et. al., (1998) in their study found fibres in the deep lung in dimensions up to 250 μm. Perhaps the remaining ones may undergo translocation and induce toxicity in secondary sites or be cleared through faeces. Studies have reported that human excretes more than 90 % of ingested MP through faeces (Wright and Kelly, 2017; Smith et. al., 2018).

Potential effects of airborne MPs ingested by human rely on individual differences in metabolism and susceptibility, including clearance mechanism. Individual with compromised clearance mechanism may be at higher risk of particle toxicity compared to individual with proper clearance mechanism. When particles are inhaled, immediate bronchial (asthma-like) reactions as the first response expressed (Beckett, 2000; Pimentel et al., 1975; Prata, 2018) and adverse effects of particle toxicity are mainly attributed to inflammation, due to particle localization and of immune cells, producing cytokines, proteases and reactive oxygen species (ROS) to combat the foreign material (Schwarze et al., 2006). Furthermore, chronic inflammation may lead to cancer, as a result of DNA damage (adducts and mutations) caused by oxidative stress and particle's direct action, evasion of detection by the immune system and pro-inflammatory mediators promoting angiogenesis and mitogenesis, favoring the formation and progression of malignant cells (Chang, 2010; Churg and Brauer, 2000; Donaldson et al., 2002; Donaldson and Tran, 2002; Schwarze et al., 2006; Valavanidis et al., 2013; Prata, 2018).

Chemical toxicity of MP particles is from their ability to absorb toxic chemicals on their surface due to their large surface area and hydrophobicity (Teuten et al., 2007; 2009; Wang et al., 2016). The entire adsorption processes have not been fully understood but plausible adsorption mechanism is believed to be from electrostatic charges on their large surface, biofilm growth and additives or chemicals present in resins (Verla et. al., 2019b). In the marine environment, many studies have shown that microplastics have the tendency of absorbing heavy metals and hydrophobic organic contaminants (HOCs) such as persistent organic pollutants (POPs) (Rochman et. al., 2014; Ogata et. al., 2009). Microplastics suspended in the atmosphere also follow the same processes of attaching toxic chemicals. Inorganic pollutants such as heavy metals (Kweon and Son, 1985; Jeong et. al., 1987; Park, 2004; Chun-Huem Kim et. al., 2010) and organic pollutants such as

POPs (Van Vaeck and Van Cauwenberghe, 1978; Schnelle-Kreis et al., 2001) have been detected in atmospheric particulate matter. However, adsorption in atmosphere is controlled by time of MP suspension as revealed by Mato et. al., (2001), who exposed virgin plastic pellets in atmosphere for 6 days and reported no significant adsorption of POPs. Prolonged exposure may have given a different result, as virgin pellets may undergo further degradation by UV light and biofilm may be formed which will increase pits on the MP surface. Nonetheless, suspended MP in the atmosphere carries toxic chemicals and exposes human lungs simultaneously to both contaminants. While in the body these toxic chemicals may desorp and pose health-related problem as they have been associated with mutagenic, teratogenic and carcinogenic effects (Verla et. al., 2019c). There are no studies that have quantified toxic chemicals sorped on airborne MPs surface.

The microbial effect follows the paradigm of microbial community forming biofilm on surface of MPs. In the marine environment, there are many reports supporting these phenomena (Richard, 2016) while none regarding airborne microplastics. With the formed biofilm, harmful human pathogens such as strains of Vibrio spp may be found. Recently, Zettler et. al. (2013) and Kirstein et. al. (2016) isolated strains of Vibrio spp in formed biofilm on microplastics. In air, MPs may acquire microorganisms from aerosol as urban aerosols habor diverse and dynamic population of microorganism (Lester et. al., 1966; Brodie et. al., 2007). Harmful pathogens or microorganism may be conveyor to the human lung by airborne microplastics through the formed biofilm and possibly resulting in infection (Prata, 2018), heavy metals may also be transported with the formed biofilm as the serve as chelating agent for metals (Verla et. al., 2019c).

6.2 Ecological risks

The ecological risk is based on the ability of air to transport MPs to new areas and contaminating the area by re-concentrating. Therefore, terrestrial and aquatic ecosystem could be polluted by airborne microplastics serving as a source of contamination. Furthermore, there could be a dynamic interaction between microplastics from different media e.g soil or water becoming airborne and contaminating air while airborne MPs in the atmosphere may deposit on soil, in water, or in water through surface run-off (Figure 6). For instance, atmospheric aerosols may be transported to oceans (Paytan et al., 2009), but oceans through sea spray also generates aerosols up to a few micrometers (O'Dowd and de Leeuw, 2007). This process could involve microplastics contamination cycle in the ecosystem. Graphical illustration of microplastics contamination cycle in the environment is presented in Figure 6. Knowledge or information concerning on microplastics contamination cycle and its consequences in the ecosystem is scarce due to their complexity.

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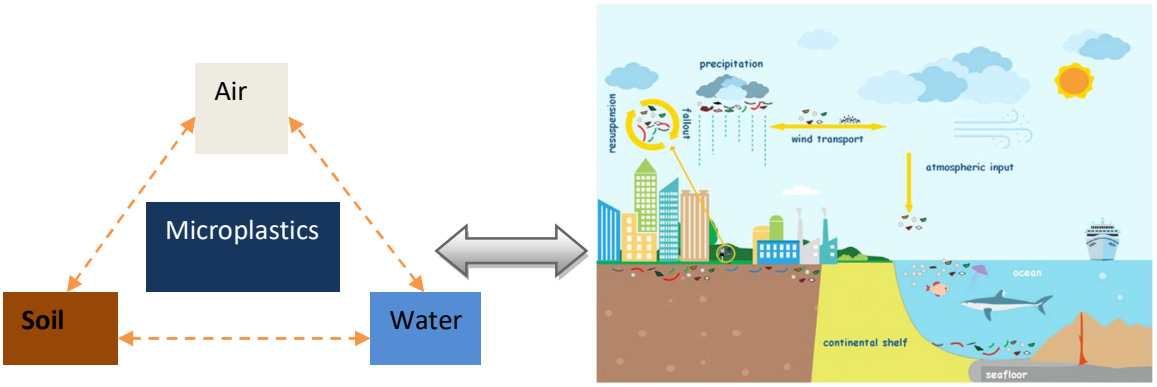

(a) Image credit: This study (b) image credit: Liu et. al., (2019)

Figure 6. Graphical illustration of possible microplastics contamination cycle in the environment

To assess ecological risks posed by the presence of airborne MPs, common models originally used for soil, sediment and water column study may be used. Model such as potential ecological risk (RI) originally developed by Hakanson et. al., (1980) was used in a recent study on suspended atmospheric microplastics in Shanghai, China (Liu et. al., 2019). The expression of the model is; $RI = \sum T_r \times C_f$, where RI correspond to the potential ecological risk. Tr, which was the heavy metal toxic response in the original model, was replaced by the chemical toxicity coefficient for polymers, as described by Lithner et al. (2011). C_f is contamination factor calculated as ratio of C_i (observed/recorded airborne MP polymer concentrations) and C_b (background values). As pointed in the study by Liu et. al., (2019), ideal C_b value would be that from an air sample for total suspended particulates prior to the rapid development of the synthetic fiber economy. Furthermore, the rating for RI of microplastics was given as minor (RI < 150), medium (RI; 150-300), high (RI; 300-600), danger (RI; 600-1200) and extreme danger (RI; ≥1200) respectively.

7. Conclusion

Studies on airborne MPs are scarce as only seven studies so far have quantified airborne MP in only three locations viz China, France and Turkey. Microplastics are present in the atmosphere and we may be breathing it and potentially contaminating the ecosystem by fallout. Since fibers of size 250 μm have been found in deep human lung (Pauly et. al., 1998; Prata, 2018), the danger of airborne microplastics cannot be overemphasized. Sampling techniques for airborne MPs include the use of sampling

pump for indoor air compartment and deposited ones in dust by vacuum pump while outdoor air compartment by a rain sampler or particulate fallout collector, of which after treatment processes can be analyzed by visual, spectroscopic or spectrometric methods. Their distributions in the atmosphere are generally controlled by factors such as local turbulence, wind flow and direction, precipitation, scavenging and sedimentation, particle size, shape and length. Fiber forms are generally more common in air. Smaller sizes and shorter lengths are transported easily as opposed larger sizes. However, concentrations are generally influenced by anthropogenic activities, population, time, space, seasonal conditions and topography of sites including building densities.

7.1 Future areas of research

On the basis of the literature discussed above, we recommend further studies that must be carried out in order to understand better the implications airborne microplastics occurrence to human health and environment:

- Identify and quantify microplastics forms in human lung biopsies.
- Due to sizes of skin pores, MPs may be able to pass through it. Therefore, studies investigating dermal exposure route of human to airborne MPs should be initiated, in order to better understand how MPs penetrates skin pores.
- Determine environmental concentrations of airborne microplastics (also interms of shape, size, length and colour) in space and in time from more study areas of the world (especially Africa with high population and poor waste management) to better understand their distribution globally.
- Identify and quantify atmospheric contaminants adsorbed to airborne microplastics.
- Event-based study should be conducted to determine long range transport of airborne MPs.
- Develop proper chemometric model for assessing and interpreting ecological risks posed by airborne MPs.
- Develop standard methods or operating protocol (SOP) the analysis of airborne MPs as well as creating a standardized reporting unit for the analysis.

Conflict of interest

The authors declare there are no conflicts of interest

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