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Do atmospheric plastics act as fomites for novel viruses?

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Abstract

Plastic particles are ubiquitous in various environmental compartments, the atmosphere being the least explored compartment in terms of plastic pollution. The way that atmospheric plastics affect the biological systems has not yet been explored when compared to aquatic ecosystems. There are many speculated human health impacts, one definite and direct impact of atmospheric plastics would be towards the respiratory system as these are previously found extensively in human lungs. We identify the ability of suspended atmospheric plastics to act as a potential fomite for microbes, both pathogenic and non-pathogenic. We discuss the relevance of such fomites in the wake of the current global pandemic involving a novel respiratory virus, the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2). Virus laden bioaerosols can adhere to the plastic particles and can be directly transported to the airway and lungs, besides enabling its long-distance travel. Currently, it is not known whether these pathways are more efficient than the bioaerosols itself in driving the spread of viral infections. Once sufficient data regarding the global spatial dynamics of the current virus transmission is available, it will be interesting to examine the dynamics of the disease in heavily urbanized regions where there is a substantial amount of prevailing atmospheric plastic particles. Thus, we hope that this communication will serve as a call for astute investigations in this less explored realm concerning human health impacts of suspended atmospherics plastics, and its role in the transmission and transport of novel respiratory viruses.

Keywords: microplastics; atmosphere; bioaerosols; SARS-CoV-2

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1. Introduction

The presence of plastic particles in the environment is receiving garnished attention worldwide from the scientific community, media, and the general public in recent years. This is primarily due to the multi-facet problems (Galloway and Lewis, 2016) associated with their prevalence across a wide range of biological systems (Ribeiro et al., 2019) and geographical locations from the Arctic to the Antarctic (Shahul Hamid et al., 2018). The scale of microplastic abundance in environmental matrices are currently posing various emerging long-standing scientific questions of great societal significance, and have all the makings of placing the earth system in dire straits. Despite its widespread distribution, microplastics and its smaller variants (nanoplastics) are not so conspicuous (in the environmental matrices) compared to its macro-sized contemporaries. Various techniques (for example, raman spectroscopy, fourier-transform infrared spectroscopy, scanning electron microscopy, atomic force microscopy, stimulated Raman scattering microscopy, transmission electron microscopy, and coherent anti-Stokes Raman scattering microscopy) have been developed recently to detect and identify microplastics and its smaller variants in environmental matrices. There is wide speculation that the entire planet may be under pressure due to the plastic problem, but a whole picture regarding the level of environmental contamination remains mostly unknown (Oliveira and Almeida, 2019). Most of the available research regarding microplastics deals with the aquatic environment that too in the marine waters (Li et al., 2018, Blettler et al., 2018, Weis, 2019), probably because plastic pollution was first detected (Carpenter and Smith 1972) in the marine realm.

Recent studies show that there is a substantial amount of microplastic particles in the atmosphere as well (Allen et al., 2019, Wright et al., 2020), but the atmosphere hardly gets the required priority in the rapidly growing research activity and discussion on the microplastic related topic and (Liss et al., 2020). Atmospheric Plastics (APs) were identified as a significant contributor of microplastic input into aquatic and soil compartments through wet and dry deposition (Dris et al., 2015, Zhou et al., 2017). APs have been found in remote as well as urban or industrial locations, having diversity in shapes (spheres, beads, pellets, foam, fibers, fragments, films, and flake); fibers, and fragments being the dominant ones (Zhang et al., 2020). Synthetic textile is a vital source for airborne microplastics (Huang et al., 2020), which are mostly fibers and is found higher at more urbanized sites (Dris et al., 2015). Substantial advances have been made lately in understanding the impacts of microplastic on the health of aquatic fauna (Wang et al., 2019). Microbial association within the plastisphere community have been well established in aquatic system (Jiang et al., 2018). But, there is a considerable research gap regarding the effects of microplastics on terrestrial fauna, let alone the impacts of APs on them. Recent review works (Chen et al., 2019, Huang et al., 2020, Prata et al., 2020, Zhang et al., 2020) have widely speculated various human health effects of APs. Though most of these ideas remain untested as of now, it provides valuable research directions regarding this less explored realm of planetary plastic pollution. In this communication, we propose a yet another potential human health impact of APs in the wake of the ongoing global pandemic (WHO, 2020) imposed by a new respiratory virus designated as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (Gorbalenya et al., 2020).

2. APs and pulmonary health: status quo

Air pollution is long known to cause serious pulmonary health problems (Carnow and Meier, 1973). It is currently one of the major environmental risk factors for the global burden of diseases (Babatola, 2019). There are compelling pieces of evidence showing that air pollutants are positively associated with mortality (respiratory mortality and coronary heart disease mortality) and morbidity rates of other diseases such as cancer, ischemic heart diseases, cerebrovascular diseases, kidney diseases, and diabetes (Chen and Bloom, 2019). Air pollution is found to be a fifth-ranking mortality risk factor and caused 4.2 million deaths in 2015 (Cohen et al., 2017). APs is a new addendum to the known suite of air pollutants and is evolving as a rival, due to its current glocalization in spatial distribution, to the criteria air pollutants {particulate matter, nitrogen oxides, carbon monoxide, photochemical oxidants, lead, and sulfur oxide}. The primary route of air pollutants including microplastics, into the human system, is through the bronchopulmonary tract. But the pulmonary system is endowed with natural mechanisms to fight against intrusive agents, biotic as well as abiotic. The major constituents of lung defenses are the airways and their mucosa, the epithelial cells lining the luminal surface of the airways, the blood-derived cells of the mucosa, and the immune response in the alveolar space (Nicod, 2005). Particle size plays an essential role in the evasion of defense mechanisms intended for the clearance of foreign particles from the airway. Foreign particles entering the respiratory system can generally be classified as inspirable (entering the respiratory system during breathing, <100 µm), thoracic (entering the lower respiratory tract including the trachea, bronchi, and the gas exchange regions of the lungs < 25 µm), tracheobronchial (5 – 25 µm) and respirable (capable of reaching the alveolar regions of lungs < 5 µm). Particles <10 µm have the potential of being biologically active (Heyder, 2004), and particles <3 µm have a higher chance of reaching the lower airways with 50–60% being deposited in the alveoli. Figure 1 represents the deposition fractions of inhaled particles in the respiratory system of a healthy adult generated Multiple-Path Particle Dosimetry Model (MPPD, version 2.11, Chemical Industry Institute of Toxicology, Research Triangle Park, NC) (ARA, 2014).

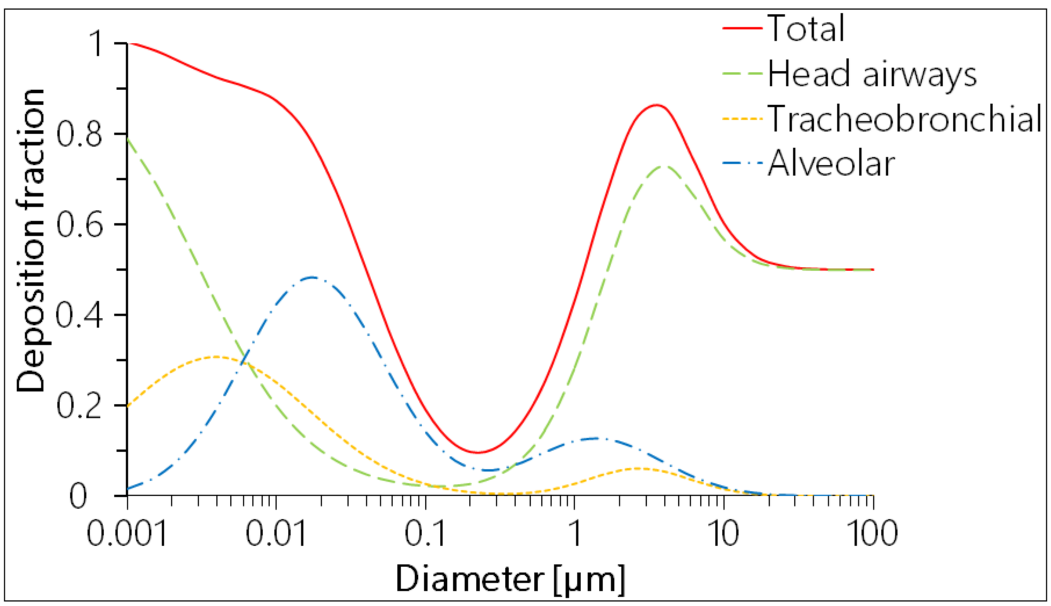

Figure 1: Respiratory tract deposition fractions of inhaled particles in a healthy adult depending on the particle size (personal communication: Jakob Löndahl, Lund University, Sweden).

All the known health impacts rendered by atmospheric particles can be attributed to APs also. Considering the significant sources of microplastics in the atmosphere, two factors can be a reliable proxy for the amount of suspended plastic particles: the global population and global plastic production. The global population has increased from 5.9 billion in 1998 to 7.7 billion in 2019 (UNDESA, 2001, UNDESA, 2019), while worldwide plastic production has increased from 188 million tonnes in 1998 to 359 million tonnes in 2018 (Geyer et al., 2017, PlasticsEurope, 2019). The quantum leap in these two factors over the years must have subjected respiratory health towards irrefutable damages. Still, this fact is currently devoid of observational evidence due to the research gap in these directions. Microplastics are present in a spectrum of inhalable particle sizes, and the aerodynamic characteristics aid it to successfully fathom the respiratory tract, including lower bronchial and alveolar regions. Once inside the body, the plastic particles avoid clearance and persist in the lungs for a longer duration due to its high durability. There is officially no lower limit to the size of microplastic, and particles smaller than a few micrometers are called as nanoplastics (Mitrano, 2019). Nanoplastics (< 100 nm) have been observed in the indoor and outdoor air as atmospheric particulate matter (PM) and can induce toxicological effects on alveolar epithelial cells (Xu et al., 2019). Human exposure occurs mainly in the indoors than outdoors due to substantial indoor sources (upholstery fibers and synthetic clothes), and exposure to these could cause a range of health issues, including autoimmunity diseases and upper respiratory illnesses (Bradney et al., 2019). Fibers and fragments are the most abundant components of APs, and these are quite hazardous to the respiratory system (Chen et al., 2019, Zhang et al., 2020, Enyoh et al., 2019, Vianello et al., 2019). Even though nasal mucus and small hairs act like filters to remove dust and particles > 5 μm (Kaya et al., 2018), fibers tend to align with the airflow and penetrate deeper into the lungs where they are deposited (Bezemer, 2009). A 1998 study found biopersistant fibers > 250 µm in length and some of which were very wide (~ 50 µm), in human lungs (Pauly et al., 1998). The aerodynamic properties of fibers can be the reason for their presence in deep lung regions.

Fibers can be transformed further into fine suspended particles by photo-oxidative degradation, abrasion, or wind shear (Gasperi et al., 2018), which are more hazardous to the respiratory system than the fibers themselves. When macroplastic particles fragment into finer ones, there is a substantial augmentation in the surface/volume ratio (de Souza Machado, et al., 2018). A recent study regarding the city of London has found the presence of smaller microplastics in the thoracic as well as potentially respirable size ranges (fluorescent non-fibrous particles < 20 µm) in the air (Wright et al., 2020). Currently, the abundance of smaller microplastics and nanoplastics (in APs) has not been documented well due to the limitations of analytical methods (Zhang et al., 2020). The inhalation of plastic particles can invoke the release of messengers and cytotoxic factors, which leads to lung inflammation, potentially leading to secondary genotoxicity following the excessive and continuous formation of reactive oxygen species (Gasperi et al., 2018). This prolonged inflammation can cause fibrosis and in certain circumstances, it also causes lung cancer. Fibers of longer sizes are not easily phagocytosed and lead to higher inflammation and as a result are more toxic than their smaller counterparts (Greim et al., 2001). Airway and interstitial lung diseases such as spontaneous pneumothorax, asthma, chronic bronchitis with bronchiectasis, chronic pneumonia, and extrinsic allergic alveolitis were observed due to occupational exposure of airborne microplastics (Pimentel et al., 1975, Eschenbacher et al., 1999, Atis et al. 2005). The prevalence of APs is dependent on factors such as consumption habits, socioeconomic status, traffic, and urbanization (Kaya et al., 2018), and these factors are on the higher side in urban areas, which render urban population much prone to ill effects of APs. For example, higher abundance was observed in Shanghai compared to Paris, possibly due to more anthropogenic activities, population density, and industrialization levels (Zhang et al., 2020). Having said that, rural areas or less urbanized regions are no exception as APs can traverse long distances depending on the prevailing air circulation and transport dynamics, implying that the respiratory health of humans anywhere in the globe (even in pristine environments) are equally susceptible to this emerging menace.

3. APs as fomites and its synergy with bioaerosols

Fomites are any inanimate object, which can become contaminated with pathogenic microorganisms that can serve as a means of transferring disease-causing agents to a new host (Stephens et al., 2019). APs are a plausible candidate due to its ability to traverse distance and stay suspended for a longer time in the air in addition to its ability to act as adhesives for surrounding particles for example, bioaerosols. Bioaerosols consist of a diverse group of airborne particles with biological origins which include bacterial cells and spores, viruses, pollen, fungi, algae, detritus, allergens, cell fragments and secondary particles in the atmosphere. The airborne particles that are formed from the condensation of gaseous molecules released by biological organisms (Löndahl et al., 2014), display a wide range of sizes, from ~ 10 nm for some viruses to > 100 μm for some pollen grains (Delort et al., 2017). In an approximate term, bioaerosols can be viewed as thermodynamically unstable suspensions of complex colloidal particles entrained in a gas (Lighthart and Mohr, 2012). They are known for transmission of infections especially respiratory and enteric infections (Yuan et al., 2018, Tellier et al., 2019), other health impacts being acute toxic effects, allergies, and cancer (Srikanth et al., 2008). The interaction of infectious bioaerosols and large fomites (objects in hospital settings, faucet handles, doorknobs, switches, elevator buttons, handles, countertops, and any objects which are frequently touched) is well documented (e.g., Boone and Gerba, 2007, Kanamori et al., 2017). In the triad of infectious disease transmission (aetiological agents, susceptible hosts, and the environment), role of the environment is the most ambiguous (Pirtle and Beran, 1991). The interaction between fomites and bioaerosols and their associated dynamics are an integral component of the environmental factor. The transfer of infectious virus can occur between two separate fomites, or fomite to animate objects, or vice versa (Goldmann, 2000). The relevance of this component in infectious disease transmission will be exacerbated when a long-range transport of the fomite-bioaerosol aggregate is involved.

Recent studies (Malcolm et al., 2017, Stephens et al., 2019) have qualified smaller particles such as dust as fomites, but APs are not considered as any class of fomite till now. We propose that APs can be included in the fomite class of objects due to its supportive characteristics in disease transmission. Microplastic particles have a large surface/volume ratio, which facilitates more room for bioaerosol adhesion on the plastic surface. Adhesion of APs and bioaerosols can be mediated by interplay of forces and various intrinsic APs-bioaerosol characteristics. This includes forces involved in the adhesion of small particles (for example APs and bioaerosols) such as London-van der Waals and electrostatic forces, and factors such as relative humidity, the contact area between the particles, shape, size, and nature of the particle, and surface material and surface roughness (Corn, 1961). In addition to the physical size, other characteristics that are significant for bioaerosol movement include density ($\sim 1.0 – 1.5$ g cm^{-3}), shape (spherical to elongated), and electrical charge (close to the “neutral” Boltzmann charge distribution) (Löndahl et al., 2014). Many bioaerosols (as airborne microorganisms) naturally carry electrical charges in their outer shell (Lee et al., 2004), which can play an essential role in its adhesion to the APs as APs can accumulate charges due to frictional effects in the air, for example, triboelectric effect. Polymers (plastic) are inherently insulative, and plastic components can quickly accumulate charge on their surfaces *(*Bell and Blackmore 2014). The most abundant APs (for example, polystyrene, polyester particles, and fibers) (Cai et al., 2017, Steve Allen et al., 2019, Vianello et al., 2019) can quickly accumulate static charges due to inter-particle as well as frictional air effects. A recent study (Toth III et al., 2020) indicated that electric fields keep dust particles suspended and also enrich the concentration of larger particles at higher elevations. The resulting electrostatic forces on charged particles help in the transport of large particles which implies that large APs can also be suspended and transported for a longer time period in the atmosphere. It is important to know about the charge on a particle as the electric forces between particles affect their dynamics and interaction, and in many instances, there is no understanding of the prevailing charge distribution (Hammond et al., 2019). There is a substantial research gap in these directions regarding the charge distribution of suspended biotic and abiotic particles in the atmosphere.

APs from various sources (such as synthetic textiles, household furniture and upholstery, rubber tire erosion, road dust, building and construction materials, landfills, vehicular emissions, waste incineration, industrial discharge, and horticulture fields) can be transferred to other environmental compartments by winds (Zhang et al., 2020). A recent air mass trajectory analysis (Allen et al., 2019) shows microplastic transport through the atmosphere over a distance of up to 95 km and its deposition in a remote, pristine mountain catchment (French Pyrenees). Sahara dust (≤ 450 µm) can be transported from the Sahara to the north Atlantic over distances of 3500 km by mechanisms such as rapid horizontal transport, turbulence, uplift in convective systems, and electrical levitation of particles (Bergmann et al., 2019), this applies to airborne plastic particles too. Once airborne, APs could remain suspended for days or weeks before being d (Wright et al., 2020) from the air by various physical or chemical mechanisms. The light-weight, durability, and other intrinsic features also contribute to the transportation of APs to remote areas and deposited through dry or wet deposition (Zhang et al., 2020). The wind is responsible for lofting of most atmospheric microbes (bioaerosols in our case), and those particles reaching the upper troposphere or the stratosphere (12 - 45 kilometers above MSL) can stay suspended for a longer time and travel significantly greater distances around the globe (Smith et al., 2011). The same mechanism is applicable for APs lazed with bioaerosols too. If suspended APs with bioaerosols adhered to it can traverse vast distances, it can bring unforeseen challenges to the prevailing global health care systems.

4. Emerging respiratory viruses and APs: de novo

According to the current knowledge, viruses are the dominant biological entities on our planet. They encompass a large pool of rapidly evolving genes that appears to continuously contribute to the emergence of new genes in cellular life-forms (Koonin et al., 2020). Viruses are also causative agents of major human infections worldwide, and the most common infective agents are enteric and respiratory viruses (Vasickova et al., 2010). Respiratory viral infections need special mention as these infections have the potential to hoist major public health problems around the world with its ease of spread in the community inducing considerable morbidity and mortality. The new millennium witnessed the emergence of three novel, highly virulent human respiratory infections: Severe Acute Respiratory Syndrome (SARS) in 2003 caused by SARS-coronavirus (SARS-CoV) (Ksiazek et al., 2003), Middle East Respiratory Syndrome (MERS) in 2012 caused by MERS-coronavirus (MERS-CoV) (Zumla et al., 2015) and the ongoing (2019-20) coronavirus disease 2019 (COVID-19) caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) (WHO, 2020). Coronaviruses are lipid-enveloped, single-stranded positive-sense RNA viruses, belong to the genus Coronavirus and include relatively benign, seasonal viruses (Tellier et al., 2019), such as HCov-229E, HCov-OC43, HCov-NL63 and HCov-HKU1 (Li et al., 2020) which causes mild symptoms of the common cold in humans. Coronaviruses are known to affect a wide range of birds and mammals, including household animals such as the cat and dog to large animals such as beluga whales. These viruses undergo mutations that enable the transmission of infections between animals to humans rendering it a zoonotic pathogen of concern. Altogether, six species of human coronaviruses are known to date, SARS-CoV and SARS-CoV-2 are two strains of the same species. The current outbreak of the highly contagious SARS-CoV-2, which was first detected in the city of Wuhan has infected more than 1.53 million people worldwide as of April 10, 2020 (Dong et al., 2020) and the governments across the globe are struggling to contain the spread of the virus.

A general consensus is that respiratory viruses are transmitted by aerosol transmission due to sneezing or coughing (Goldmann, 2000). This results in the generation of virus-containing particles in a size continuum from 1 to 500 µm. Viruses such as coronaviruses can survive for long periods in aerosols (Otter et al., 2016). Some studies showed that coughing produces droplets having sizes between 8 and 32 µm, and sneezing generates relatively smaller droplets

(Duguid, 1946). The viral transmission occurs through respiratory droplets which include larger droplets that fall rapidly near the source as well as coarse aerosols with aerodynamic diameter > 5 μm and fine-particle aerosols having droplets and droplet nuclei with aerodynamic diameter ≤ 5 μm. There is conclusive evidence for aerosol transmission as a potential mode of transmission for respiratory viruses such as coronaviruses, influenza viruses and rhinoviruses (Leung et al., 2020). In addition to this, Aerosol-generating medical procedures (AGMPs) such as dentistry, bronchoscopy, cardiopulmonary resuscitation, noninvasive ventilation, tracheal intubation, manual ventilation, sputum induction, nebulizer treatment and suctioning can potentially create aerosols of various sizes, many of these procedures are known for possible association with aerosol transmission of viruses such as SARS-CoV (Judson and Munster, 2019). The dimensions of aerosolized virus particles vary widely (ranging from nanometer to micrometer and once airborne, small particles containing viruses can remain airborne for long periods, efficiently transporting it to other locations while remaining adrift in the air for longer periods primarily due to their low settling velocity (Pan et al., 2019). Once produced (either naturally or through medical procedures), these bioaerosols are virulent, and it aids the transmission of infection directly through respiration or by a fomite to a human host. Contaminated fomites play an essential role in the transmission of viral infections, and flu viruses and other respiratory viruses are mainly spread through fomites (Vasickova et al., 2010).

Further narrowing down to the recent outbreak of novel SARS-CoV-2 (diameter ~ 100 nm), the peak concentration of SARS-CoV-2 aerosols appears in two distinct size ranges, one in the submicron region (aerodynamic diameter 0.25 - 1.0 μm) and the other in the supermicron region (diameter > 2.5 μm, the aerosol generation mechanisms are hypothesized as due to the resuspension of virus-laden aerosol from staff apparel (for submicron aerosol) and the resuspension of dust particles (for super-micron aerosols) from the floors or other hard surfaces (Liu et al., 2020). It is controversial whether SARS-CoV-2 is transmitted via aerosols (Elias and Bar-Yam, 2020). Recent pieces of evidence show that viable virus particles can travel long distances from patients (Bourouiba, 2020). However, a recent study examining the effect of simulated sunlight on the transmission of SARS-CoV-2 found out that survival of viruses over long distances would be dubious whereas short-range aerosol transmission may be possible (Schuit et al., 2020). Significant environmental contamination by patients with SARS-CoV-2 through respiratory droplets and fecal shedding indicates the environment as a potential medium of transmission (Ong et al., 2020). Several studies have highlighted the potential for aerosol transmission for other related coronaviruses, SARS-CoV, and MERS-CoV (for example, Li et al., 2005, Tellier et al., 2019). The bioaerosols having viable viral particles produced by these mechanisms can transmit the infection as respiratory viruses are known to be spread by the airborne route, and contaminated surfaces or fomites addition to person-to-person contact. Suspended plastic particles are found to be abundant in indoor environments compared to outdoor settings (Prata, 2018, Zhang et al., 2020), and hospital settings and care centers for COVID-19 patients can be hotspots of these particles emanating from sources such as clothes, upholsteries, and medical devices. The bioaerosols can contaminate these plastic particles by adhering to it by electrostatic force as one possible mechanism. Electrostatic interactions between viruses and charged surfaces are believed to govern adsorption characteristics resulting in fast and extensive adsorption. Currently, it is controversial whether virus surface charges are determined by the ionizable amino-acids in the virus capsids or by the negatively charged nucleic acid core inside the capsid (Armanious et al., 2016). Other virus properties such as hydrophobicity, size, and shape were also known to affect virus adsorption (Dang and Tarabara, 2019), besides the roughness, the charge and electrostatic properties of the target surface and the magnitude of the electrostatic interactions between virus and surface (Dika et al., 2013). It is known that hydrophobic particles are attracted to the neutral areas on a microplastic surface, and hydrophilic or charged substances are attracted to the negative areas on the microplastic surface with electrostatic interactions, the media characteristics being most important (Tourinho et al., 2019). These mechanisms are more than enough to facilitate the bioaerosol adhesion to suspended plastic particles in the air. Figure 2 shows a schematic diagram depicting the mechanism of viral transmission involving suspended plastic particles in the air.

The persistence of viruses on inanimate surfaces, APs in our case, for long periods is an important epidemiologic factor determining the spread of viral infections and avian respiratory viruses are known to persist longer on nonporous surfaces than on porous ones (Tiwari et al., 2005), plastic being a non-porous one. Most viruses from the respiratory tract such as corona-, coxsackie-, influenza virus, SARS, or rhinovirus can persist on inanimate surfaces for a few days (Kramer et al., 2006, Boone and Gerba, 2007). Respiratory viruses such as influenza A and B viruses survived for 24-48 hr on plastic but persisted for < 8-12 hr on cloth, paper, and tissues (Bean et al., 1982). A subtype of influenza virus (pH1N1) has also been detected in aerosol samples which increases the risk of its transmission through the release of airborne particles containing the virus (Zhao et al., 2019). Human coronaviruses such as SARS-CoV, MERS-CoV, or endemic human coronaviruses (HCoV) can persist on plastic for up to 9 days (Kampf, 2020). A recent study found that SARS-CoV-2 was more stable on plastic than on copper and cardboard with the viable virusus detected up to 72 hr after application to these surfaces. The results

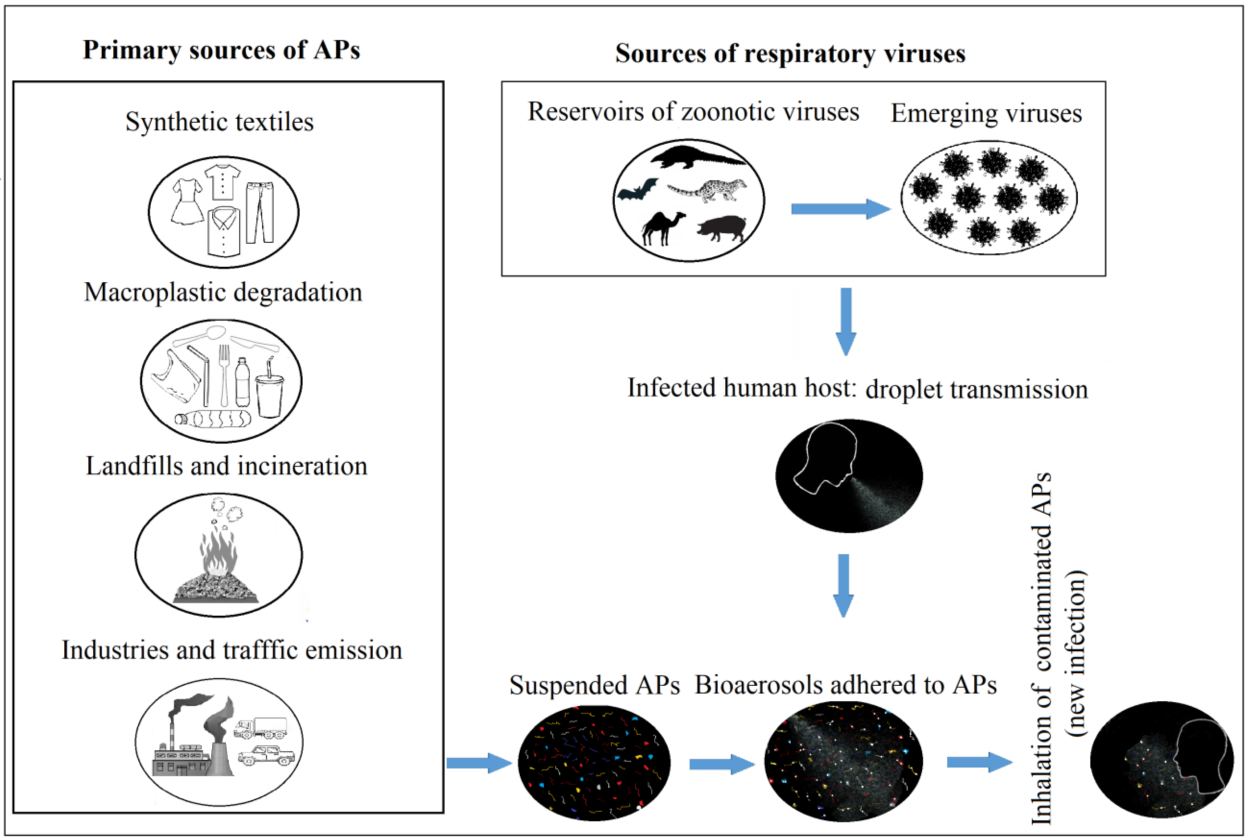

Figure 2: Schematic diagram showing the mechanism of virus transmission by suspended microplastics in the air.

indicate that aerosol and fomite transmission of SARS-CoV-2 is plausible as the virus can remain viable and infectious in aerosols for hours and on surfaces up to days (van Doremalen et al., 2020). Though it is currently believed that the primary transmission mode of COVID-19 is through large respiratory droplets and close contact, there is limited data that indicates that it may also spread through indirect contact with contaminated environments and aerosols which is evident from SARS-CoV-2 RNA contaminated environmental surfaces across the hospital (Ye et al., 2020). Besides this, swabs taken from the air exhaust outlets during the current SARS-CoV-

2 outbreak, tested positive for viable particles, suggesting that small virus-laden droplets can be transported in the airflows and deposited on equipment such as vents (Ong et al., 2020), which is an indication of airborne nature of SARS-CoV-2. Once the aerosolized viral particles adhere to suspended plastic materials, plastics' aerodynamic properties and its ability to be buoyant in the air can facilitate the suspension of bioaerosols for a long time in the air and transport to farther areas, which may not be possible with deposition of the aerosols as in normal cases of respiratory viral particles. Also, respirable APs laden with bioaerosols can make it easy for the virus to attack the host as the respirable particles itself creates inflammation in the respiratory system. This emerging pathway in which APs acting as biological rafts (Brooks et al., 2004) can bring forth myriad of challenges to humanity in the era of emerging novel viruses, as new viruses continue to emerge and existing ones continuously mutate.

4. Conclusions and way forward

A general hallmark of emerging viruses is their exhibition of heretofore unobserved behavior and chaotic transmission dynamics. Air pollution is known to exacerbate the ill effects of respiratory viral infections, and it is speculated that outdoor air pollution concentrations will have a negative impact on COVID-19 infections (Han et al., 2020). APs are a class of emerging air pollutants with a good deal of speculated detrimental effects on human health, particularly to the respiratory system. The ability of APs to act as a potential adherent for bioaerosols qualifies it as a fomite, and the flitting APs loaded with virus-laden aerosols are capable of traveling long distances through the atmosphere. The plastic particles can also act as shields for viruses in hostile environmental conditions. It is currently not clear whether viral aggregates produce biofilms as an adhesion mechanism while airborne, understanding of which can be very relevant in elucidating the less known airborne viral dynamics and biological rafts. Also, the mechanisms of viral particles regaining their composure from the attached suspended inanimate objects after it enters into a host system (as inhalable respiratory particles) are currently unknown. Research towards these directions can be beneficial for the prevailing health care systems. It should also be noted that the airborne route for a particular viral pathogen is more of an opportunistic pathway, rather than the norm (Tellier et al., 2019). Every past viral epidemic is an arcing narrative of struggle and survival of humanity against all the odds created by viruses. Recent investigations are providing previously unappreciated insights regarding the relevance of environmental factors in terms of airborne transmission of viral pandemics. Still, significant knowledge gaps remain about the airborne transmission and the role of ecological factors in sustaining the viability of bioaerosols.

The failure to protect the environment or to modify it beneficially can induce the failure to break the chains of virus transmission (Pirtle and Beran, 1991). The global influx of a vast amount of micro and nano-sized plastic pollutants in various environmental compartments can be a potential emerging medium for transmission of viral infections. After all, the earth is a cosmos of viruses for billions of years (Diehl et al., 2016) whose count outnumber (by 5-10 million times) the estimated number of stars thought to exist in the observable universe (Breedlove, 2020) and our planet can be rightly called as a planet of viruses (Zimmer, 2015). The vigorous anthropogenic activities in the past 50 years synonymous with the surging global population have initiated the dawn of a plastic era on the planet. Currently, plastic pollutants have encroached into the entire environmental compartments, making it surplus on Earth, qualifying it as a plastic planet (Hamilton et al., 2019).

We have depicted the plausibility of interaction between these two currently excess environmental entities on the Earth, which may break the conventions of the current understanding of the transmission of viral respiratory infections. Presently, there is limited data regarding the transmission dynamics of COVID-19 in urban agglomerations wherever it is reported. Also, the mounting pieces of evidence point towards the presence of a substantial amount of the suspended APs in heavily urbanized regions. Once sufficient data regarding the global spatial dynamics of the current virus transmission is available to the scientific community, it may be possible to look into the infection trends in urban areas where the air is heavily polluted, considering air pollution as a proxy for suspended APs in general terms. This can potentially reveal the prevailing dynamics and relationships between bioaerosols and APs. It is also not known whether the APs pathway is more efficient than the bioaerosols itself in driving the spread of novel viral infections. Once the global spatial trend of the virus is clear, it will also be interesting to examine the atmospheric dynamics and air circulation of regions with dense infection clusters. However, most tantalizing questions remain to be investigated concerning the mechanisms involved in the interactions between APs and viral particles, and their contribution to escalating the health problems caused by the viruses and other existing respiratory diseases.

We hope that this communication shall trigger detailed multi-disciplinary research works investigating the potential of APs in biological rafting and viral disease transmission, and can pave ways for a comprehensive, fundamental understanding of disease transmission pathways of emerging respiratory viruses such as SARS-CoV-2.

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