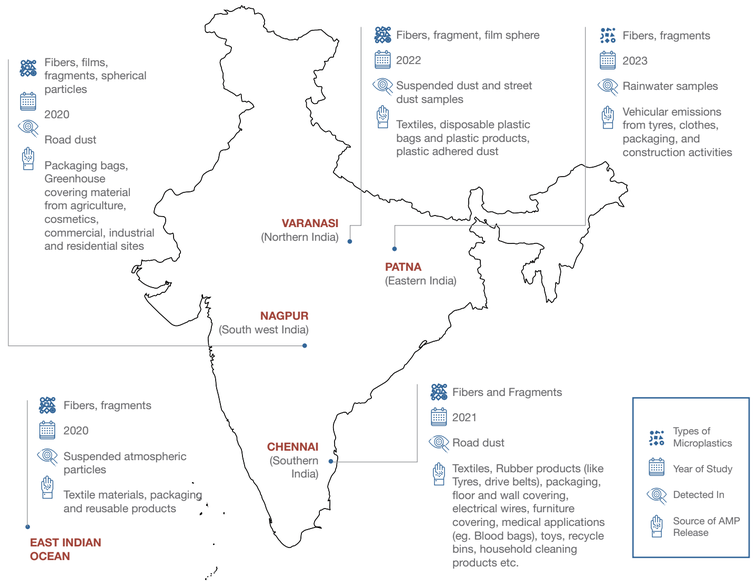
Figure 2: Studies on AMP in India



WAY FORWARD

- Despite the fact that AMPs have the potential to pollute urban, rural, and industrial air, little attention has been paid to their function in policy frameworks and assessment criteria. The World Health Organization (WHO) published a comprehensive analysis on the documentation, exposure, and potential sanitary effects of MPs in drinking water in 2019 [20]. However, extensive exposure research and policy requirements for inhalable MPs in ambient air are not available.
- Given that AMPs are a worrisome atmospheric pollutant, further research is needed to understand the consequences and exposure concerns connected with AMPs. The WHO, the United States Environmental Protection Agency, and the worldwide framework for air quality assessment have established exposure limits for numerous air pollutants and chemical contaminants, but not for AMPs, which operate as a facilitator for the movement of various contaminants into the air.
- MPs can also be found in particulate matter (PM). To gain a better understanding of the sources and consequences of air pollution, air quality assessment studies should quantify the proportion of MPs in total PM.
- AMPs are so small that much research has categorized them under PM, a critical air pollutant. As a result, they should be considered as a criteria air pollutant, and, in the future, should be used to calculate the Air Quality Index (a value to indicate the pollution level of a place) in order to comprehend the pollution rate caused by AMPs.
- The rates at which AMPs adsorb and desorb other airborne pollutants, (such as volatile organic compounds, heavy metals etc.) must be explored and conceptualized.
- It is also strongly advised that before setting air quality standards for AMPs, standard methodologies for measuring AMPs be developed in order to have a proper knowledge of their role as a key air pollutant affecting living beings.

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MICROPLASTICS MEANDERING IN AIR: ARE THEY ALARMING?

Toxics Link
for a toxics-free world

PLASTICS TO MICROPLASTICS

Human dependability on plastic and its products dates back more than 50 years [1]. Humans were drawn to it because of its low cost, excellent durability, and adaptability. As a result, it eventually became a component of every sector (household, food packaging, industry, and so on). However, as manufacturing, consumption, and overuse of plastics increased, the non-biodegradable nature of plastics made plastic waste management and plastic pollution extremely challenging. Adding to it, the improper management of plastic waste resulted in the accumulation of plastic garbage and aggravated environmental pollution.

Wherein plastic waste accumulation and its effective disposal were posing a serious issue around the globe, a study carried out by **Thompson in 2004** in marine water in Europe highlighted the presence of a new plastic associated emerging contaminant, "**The Microplastics (MPs)**" [2]. Eventually, with the discovery of MPs, reports and studies asserting MP contamination in oceans, lakes, seas, freshwater ecosystems, arctic ice, and other water bodies became a major source of concern.

MICROPLASTICS: WHAT ARE THEY?

Plastics, being non-biodegradable in nature, do not decompose, and thus, with the passage of time, begin eroding and weathering, progressively breaking down into smaller particles referred to as Microplastics (MPs).

TERMINOLOGY

The term MPs was initially used in 2004 to designate small plastic particles (millimeters to sub-millimeters in size), but it wasn't until 2008 that The National Oceanic and Atmospheric Administration (NOAA) defined them as plastic particles smaller than 5mm.

WHITE POLLUTION IN AIR: DISCOVERY OF ATMOSPHERIC MICROPLASTICS

The prevalence of MPs in both water and land ecosystems has been established in numerous studies and has been a source of worry, whereas their existence in the atmospheric compartment has been overlooked due to lack of awareness of its presence and potential health effects during exposure. The presence of man-made fibers in the atmosphere was highlighted during a study conducted by Dris in 2016 over metropolitan regions of France, which became the first ever study to highlight the presence of a new alarming pollutant in the air that could cause similar or more severe issues among living organisms as other air pollutants [3].

THE ATMOSPHERIC MICROPLASTICS (AMPs): AN EMERGING PARTICULATE POLLUTANT

- AMPs remain in the air for a longer duration until removed by atmospheric washout (includes precipitation in the form of rain or snowfall etc.) or transported to different regions via wind.
- Till date AMPs are known to exist in varied shapes/forms such as fragments, foams, granules, fibers, microbeads.
- Few listed AMPs identified in air includes: Poly vinyl acetate, Polyurethane; Polytetrafluoroethylene, Teflon, Polyethylene terephthalate; Polyethylene; Polyester; Polyacrylonitrile; Poly (N-methyl acrylamide); Rayon; Ethylene vinyl acetate; Epoxy resin; Alkyl resin) and Synthetic fibers blended with natural fibers like cotton and wool [4].

TYPES OF AMPs

Though there are no distinct classification for AMPs, they also fall into the broader classification of MPs as primary (deliberately made) or secondary (formed as a result of the breakdown of bigger plastics) [5].

DOES MPs DEGRADE FURTHER?

MPs can further degrade into nano-sized particles (Nano-plastics) due to hydrolytic (includes the action of water) or wind or thermal (heating or cooling) activity, which can be even more hazardous to all living organisms than MPs.

SOURCES OF AMPs

The major sources of AMPs are soil and water (MPs from these sources gets suspended into the air). Varied processes through which these MPs are driven into the air includes:

- **Breakdown and re-suspension of plastics**: Plastics breaks down in the atmosphere, soil, or water due to the friction, thermal (sunlight) decomposition etc. and gets re-suspended in the atmosphere.
- **Breaking of water bubble**: The breaking of water bubbles and wave motions, from contaminated sources, cause transmission of MPs into the air [6].
- **Dust as a mode of transport**: MPs can also be transferred into the atmosphere by dust. MPs stick to dust and are carried into the atmosphere by wind movement [7].
- **Recycling of plastic**: During recycling of macro plastic, the abrasion and breakdown of plastics releases MPs in air [8].
- **Suspension/re-suspension of tyre wear**: Friction between vehicle tyres and road surface results in the grating of tyres causing subsequent release of tyres fibers into the air [8].
- **Wear and tear of synthetic fibers**: During mechanical processes (such as washing clothes, human movement while wearing) the detachment and loss of fibers occurs which subsequently enter the atmosphere [8].
- **Open landfill dumping**: Complex chemical and physical processes along with the influence of climatic conditions in landfill sites results in the breakdown of plastic waste which via wind enters into the air [8].

AMPs OMNIPRESENT: ARE WE SAFE INDOORS?

MPs in atmosphere are reported outdoor and indoor and a study done by Zhao stated that the outdoor concentration of AMPs vary from 0.3 particles/L to 154,000 particles/L, including the Arctic [9]. While, indoor AMP concentrations have been found to vary from 1 piece/m^3 to 9900 pieces/m^2/day, and are frequently greater than outside MP concentrations [9].

Though AMPs are found everywhere, when compared with rural areas, the concentration of AMPs is higher in urban areas. Dense population with higher rate of development results in increased anthropogenic activities, which becomes a major source of AMPs in cities [23].

TRASNPORT AND FATE OF AMPs

Transport/distribution of AMPs

1. AMPs can get suspended and re-suspended in outdoor and indoor environments and can travel longer distances through airflow [natural or human activity-induced (fans, desert coolers, air conditioners, wind mills etc.)].
2. Climatic conditions (wind speed and temperature) have a significant impact on the distribution and deposition of AMPs.
   i. Higher rates of wind speed cause continual dispersal of AMPs to different locations.
   ii. Changes in vertical temperature from lower to higher altitudes (heights) also influence the ascending movement of wind and thereby affecting the movement of AMPs [12].

Environmental fate of AMPs

- Once the MPs enter the atmosphere, they can interact with the water vapor present in the air to form small solid or liquid particles that remains suspended in the air (also known as aerosols).
- Larger AMP sink back to the ground due to gravity, whereas smaller ones that are dispersed by air and may reach a land or water body by precipitation (also known as wet deposition).

TOXICITY ASSOCIATED WITH AMPs ON AQUATIC AND TERRESTRIAL FORMS

Impact on aquatic ecosystems:

- **On aquatic creatures**: Depending on the density of AMPs, they may float or sink in water and can also enter bodies of aquatic creatures and may accumulate in their digestive tracts, clog their stomachs, limiting their ability to consume more food. Thus, the toxicity of AMPs, either directly or due to the presence of toxins (heavy metals, organic or inorganic contaminants, etc.), can disrupt the endocrine system, affect reproductive activity, cause gastrointestinal issues, impact the nervous system, and affect the immune system, making them susceptible to infection and death of aquatic forms [6].
- **On Aquatic plants**: MPs floating in water may hinder aquatic plants from absorbing light, affecting photosynthesis and hence impacting their development [6]. MPs can also enter the plant's roots and stems through absorption [6].

Impact on the terrestrial ecosystem: The AMPs become a part of the terrestrial ecosystem as soon as they enter the soil.

- **On soil dwelling organisms**: AMPs, depending on their size, might change the characteristics of the soil. MPs smaller in size to that of soil pores, may shut these soil pores, restricting water and air circulation. This eventually disrupts the living systems that rely on soil for food and shelter [6]. AMPs may enter the bodies of soil organisms through ingestion and inhibit their growth. Chemicals found on MPs can potentially harm the growth and survival of soil-dwelling organisms [19].
- **On terrestrial plants**: AMPs can get attached to the leaf surfaces and can penetrate into the stem or root sections through minute pores present on the surface of the leaves, distorting the size and shape of leaves and roots thereby affecting growth of plant [6]. AMPs attached on leaf surfaces can also block the sunlight and reduce the content of chlorophyll a (a major photosynthetic pigment) thus reducing the rate of photosynthesis [21].

HUMAN EXPOSURE ROUTES OF AMPs

Studies by Pauly et al. 1998 and Prata et al. 2018 revealed that the AMPs can cause greater risk to public well-being than MPs found in water and soil as AMPs can get more easily into the human body via inhalation, ingestion and dermal contact.

- **Inhalation**: Because AMPs are so tiny, they are not removed by the mucus and hair in the nose, and consequently enter the lungs upon inhalation.
- **Oral ingestion**: AMPs may enter into water bodies, soil or may get deposited on plant surfaces via rain, or snowfall or through dust that acts as carriers of MPs. Thus, these particles, after passing through terrestrial (land) or aquatic systems, reach humans directly/indirectly through food or water consumption.
- **Dermal (skin) contact**: The AMPs after breaking down into nano-plastics may come in contact with the human skin. Small pores on the skin normally prevent MPs but, if these MPs are degraded to Nano plastics, then they can easily make their way into the human body via skin. [15,16,17].

AMPs AS VECTORS OF POLLUTANTS IN AIR

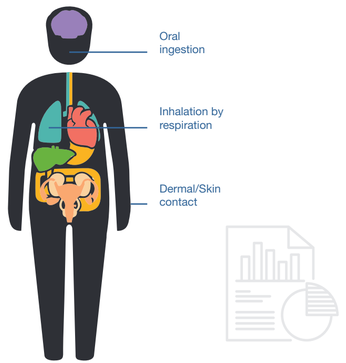
A study on atmospheric polyethylene terephthalate (APET) MP revealed that APET MPs can act as vectors for the transport of primary air pollutants (CO, CO_2, NO, N_2O, NO_2, NH_3 and SO_2), poly aromatic hydrocarbons (PAH) and transition metals [22]. Though further studies on different types of AMPs acting as vector for air pollutants can be explored in near future.

CIRCULATION OF AMPs INSIDE RESPIRATORY TRACT OF HUMAN BODY

Once AMPs enter the human body, these get circulated and trapped in various locations based on their size.

- AMPs > 5 µm can become trapped in the upper respiratory airways;
- AMPs of size ranging between 1-5 µm gets deposited deep in the lungs;
- AMPs < 1 µm can reach pulmonary alveoli through diffusion and
- AMPs less than 500 nm interfere with phagocytosis (process by which certain cells ingest other cells or particles) by alveolar macrophages (cells involved in phagocytosis) that can eventually increase the chances of respiratory infections.

Figure 1: Human exposure routes of AMPs



TOXICITY OF AMPs INSIDE HUMAN BODY

AMPs and their associated contaminants like polyaromatic hydrocarbons, organochlorine, biphenyls, Cadmium, Lead, pathogens, etc., after entering the human body, can cause:

- **Respiratory issues**: lung cancer, coughing, dyspnea, wheezing, occupational asthma, and inflammation [6,13],
- **Cardiovascular issues**: clotting of blood, heart attack, heart muscle disease,
- **Oncogenicity**: Development of cancer cells by inducing changes in the structure of DNA.
- **Reproductive health impacts** causing reduced sperm quality and endometriosis, delayed time to pregnancy
- **Neurodevelopment disorders:** AMPs can enter into the circulatory system via blood and may reach out to several internal organs like the brain and can cause nervous system damage leading to autism, decreased IQ, attention deficit hyperactivity disorder [14].

CONSTRAINTS ON THE STUDY OF AMPs

Though there are upcoming research that is emerging to understand the AMPs but lack of expertise or low-optimized sampling procedures and devices to study them are becoming a constraint on its wider range of studies particularly in India. Moreover, the current knowledge on environmental behavior and ecological impacts of AMPs is limited, which further complicates the issue of understanding the AMP contamination and also the methods for eliminating these micro sized plastics from the environment. Thus, many developing countries have yet to attempt to document and monitor MPs in air and have thereby not set any national norms for AMPs. For instance, there are only 5 studies that document the presence of AMPs in regions of India till date which are listed in Table on the next page.

A recent study (2023) clearly stated that the ingestion of microplastics by human body is mainly by inhalation followed by drinking water. It also reported the inhalation of MPs via air was nearly **(0.21-2.51)** × 10^6 considering both indoor (0.16-2.30) × 10^6 and outdoor (0.46-2.10) × 10^5 environment [18].