Review Article

A Review on Microplastic, an Environmental Pollutant

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Abstract

Microplastics (MP) have the greatest impact on human health through drinking water and food exposure. A variety of MPs are abundant in different study areas, such as urban and rural areas, both indoors and outdoors, from soils to aquatic systems, as well as the digestive tract of vertebrates and invertebrates. In this field, more than 75,000 research articles have been published but the public was less aware of the problem. Although, government introduces new policies and regulations on plastic waste disposal, implementation of such measures is still challenging. In this review article, existing scientific literature is reviewed in an attempt to understand MP pollution. The article discusses various topics such as the sources of microplastics, transport methods, their physical and chemical nature, sampling techniques, identification methods, as well as policies and mitigation strategies.

Key words: Microplastics, Environment, Pollution, Policies, Mitigation

Introduction

Over the past four decades, the worldwide production of plastic has increased from 50 to 367 million metric tons. Plastic pollution in the ocean today is the result of a $600 billion global industry whose life-cycle end contributes to approximately 8 million metric tons of plastic entering the oceans each year. Digestion of plastic waste leads to pollution of the environment. Over time non-degradable plastics on the environment erode and break down into nanoplastics and microplastics (MPs). In 2004, a marine biologist named Richard Thompson first recognized 20m microplastic particles as pollution pollutants (Thompson et al., 2004). Later in 2009, the NOAA (National Oceanic and Atmospheric Administration) defined MPs as plastic particles less than 5 mm in size (Arthur et al., 2009). Following the logical differentiation along SI units, the latest definition of MPs is ranges from 5 mm to 1 µm (Hartmann et al., 2019). A variety of MPs are abundant in different study areas, such as urban and rural areas, both indoors and outdoors, from soils to aquatic systems, as well as the digestive tract of vertebrates and invertebrates (Bank and Hansson, 2019; Zhang et al., 2020).

Recent studies suggest that microplastics are transported by atmospheric movement, which could lead to deposition on land or in water bodies. As a result of this plastic pollutants transport, source-sink dynamics are strongly affected in terrestrial and marine ecosystems (Van Colen et al., 2021).

Methodology

This study is aimed at understanding the underlying principles behind microplastic research and is divided into several sub-titles. Using international databases like Google Scholar, PubMed, and Scopus, subtitles were searched. The key words in the search bar were microplastic pollution, source of microplastic pollution, physical and chemical nature, sampling techniques, identification techniques, and Indian plastic waste management policies. Both old and new research articles were taken into consideration during the data collection process. Each topic discusses the area-specific research results and effective information.

Source of microplastics

Microfibres and microbeads are the major microplastics found in polluted environment. Plastics can enter into environment through many different routes. For example, plastics can become primary microplastics or they can break down into secondary microplastics (Cole et al., 2011; Lassen et al., 2012).

Primary microplastics are defined as being microplastics made of micron-size resins. There are four main sources of primary microplastic found in polluted environment: microbeads from (i) personal care products, such as facial scrub, body wash and toothpaste, (ii) exfoliate or cleanse used in air blasting technology, (iii) Ingestible or inhalable medicines, (iv) virgin resin pellets spillage at their sources (de Araujo et al., 2006; Fendall & Sewell, 2009; Costa et al., 2010; Browne, 2015; Conkle et al., 2018). Microplastic polyethylene is used in facial cleansers and in air blasting to remove paint from metallic surfaces and clean engine parts. Since these microplastics are not removed in wastewater treatment plants during recycling, they enter the oceans and can contain heavy metals (Gregory, 1996; Derraik, 2002). Microplastics have the capability of facilitating drug delivery from the lungs and gut into the circulatory system from ingestible or inhalable medicines. Microspheres, including polystyrene, polycarbonate, and polyester have been used as alternatives to aluminium for decades due to the potential toxicity of aluminium compounds (Thanoo et al., 1993; Dalmo et al., 1995; Curley et al., 1996; Kockisch et al., 2003). It is anticipated, however, that microplastics in pharmaceuticals may also end up in waterways through sewage, storms, or more directly by way of farm animals or aquaculture, but their volume or possible entry routes into the environment have not been extensively studied. Yet no detailed studies exist on either the quantities of microplastics used in pharmaceuticals or their possible route of entry into the environment (Lassen et al., 2012). The major types of plastics found as primary source are is polyethylene, polypropylene, polystyrene, polycarbonate and soon (Table 1).

Table 1: Source and components of primary microplastic found in polluted environment.

Primary microplastic	Products	Component	References
Personal care products	facial scrub, body wash, Soap, detergents, and toothpaste	polyethylene and polypropylene granules and polystyrene spheres	(Fendall & Sewell, 2009; Conkle et al., 2018; Piotrowska et al., 2020) Gregory, 1996
Exfoliate or cleanse	Dry Strip, JETplast	acrylic, melamine, urea resin, polyester microplastic scrubbers	(Browne et al., 2015, Derraik, 2002, Gregory, 1996, Lassen et al., 2012)
Medicine	Ingestible or Inhalable medicines	polystyrene, polycarbonate, and polyester,	(Thanoo et al.,1993; Dalmo et al.,1995; Curley et al.,1996; Kockisch et al.,2003)

Secondary microplastics are fragments of plastic that get accumulated over time. The majority of plastics found in aquatic environments originate from land-based sources (Liu et al., 2019; Zhang et al., 2020). Secondary microplastics are caused by the abrasion of synthetic textiles, tires, domestic plastics, and materials discarded from fishing boats and merchant ships (Kole et al., 2017; Wang et al., 2019). When plastic debris is exposed to the environment for an extended period of time, it may undergo various physical and chemical changes. As a result of photodegradation and photooxidation caused by sunlight and UV radiation, additives are released into the environment (Costa et al. 2010; Cole et al., 2011). Despite the fact that plastic products are inert, the additives released, called endocrine disrupting compounds, are harmful to biota (Talsness et al., 2009).

Every day, about 65 million MPs are found in sewage water. The treatment of wastewater also contributes to the release of microplastic particles; whereas large plastic particles are effectively removed, microplastics commonly escape and accumulate in the aquatic environment (Browne et al., 2011; Carr et al., 2016; Long et al., 2019). Most of these microplastics are derived from personal care products containing microbeads and fibers from washing clothes (Browne et al., 2011; Murphy et al., 2016)

Characteristics of microplastics

Physical nature

The physical characteristics and properties of microplastics vary with their occurrence in the environment. Moreover, the physical properties of microplastics such as shape, size, density, and color can be considered when analyzing isolated microplastics from different sources of pollution (Table 2). In the environment, microplastics are weathered or aged, which causes degradation and the main effects of degradation are changes in color, surface morphology, particle size, crystallinity and density (Guo and Wang, 2019). The physical properties of microplastics also affect their sinking velocity. Research has shown that biological fouling and weathering may influence the sinking behavior of microplastics (Kowalski et al., 2016). According to the researchers, surface longevity of microplastics is strongly correlated with fragment size. Thinner microplastics sink within 17 days, whereas thick macroplastics take 66 days (Fazey and Ryan, 2016).

As the plastic particle's surface erodes and breaks down, the shape will change depending on its source and residence time in the environment. Among the many descriptions of microplastics, spheres, beads, pellets, foams, fibers, fragments, films, and flake are the most common shapes, proving that fibers and fragments are the most dominant shapes (Rocha-Santos and Duarte, 2017). Microplastic particle shapes and densities will affect the way they are transported and retained in sediments. Most of the MP found in environmental samples are transparent, white, blue, purple, red, green, pink (Table 2).

Microplastic particle shapes and densities will affect the way they are transported and retained in sediments. Several studies have found that microplastics collected from different sources have a greater density than virgin plastics (Moret et al., 2010; Fazey and Ryan, 2016). This is because plastics are chemically modified and physically changed during transport (Vlietstra and Pargya, 2002; Ballent et al., 2012). However, aggregate PP displays a density of 1.19, which is much higher than virgin PP, which is 0.90 (Lagarde et al., 2016).

Table 2: Physical characters of microplastics found in different study areas

Study area		Polymer type	Shape	Color	References
Atmosphere	Urban cities	PP, PV, PS, PVC	fibers, fragments, films and foams	Transparent, white, light blue, blue, purple, red	Zhou et al., 2022
	Remote areas	PS, PE	Fragments, films, fiber		Allen et al., 2019
	Snow/Glaciers	PE, polyester, PP, polyurethane, HDPE, PET, LDPE, PA, PA, PP	Fibers, fragments, sphere		Ambrosini et al., 2019; Parolini et al., 2021
Marine	Beach sediments	PVC, PE, PS, PP, PET	Pellet, fragments	blue, green, pink and red	Sunitha et al., 2021; Hong et al. 2018
	Sea water	PE, PP, PS, PET	fragments		Iniguez et al., 2017
Lake	Fresh water	PE, PP, PS	Fibers, fragments	white, blue, green, and red	Herbort et al., 2018; Uurasjarvi et al., 2020
Sewage water treatment plant		PP, PE, PS, propylene/ethylene copolymer, PET	Fiber, fragment, sphere, pellet	white, blue	Browne et al., 2011; Carr et al., 2016; Long et al.,2019; Zhou et al. 2022

PA-polyamide, PE- polyethylene, PP-polypropylene, PS- polystyrene, PVC- polyvinylchloride, PET-polyethylene terephthalate, HDPE -high density polyethylene, LDPE -low density polyethylene.

Chemical nature

Polystyrene, polyethylene, polypropylene, polyvinyl chloride, and polyethylene terephthalate are the major microplastics found in the environment (Table 2). The use of chemical additives to improve plasticity is believed to be responsible for many of the dreadful problems associated with plastic usage. There is growing evidence that chemical additives used in raw plastic synthesis to improve plasticity, such as bisphenol A, phthalates, and polybrominated diphenyl ethers, tetrabromo bisphenol-A are cancer causing and disrupt the endocrine system (Talsness et al. 2009; Halden,2010; Hirai et al., 2011). Most microplastic polymers contain these plastic additives (Fasano et al., 2012; Jiang, 2018).

Upon contact with microplastic fragments, algal growth is directly affected, while extracellular polysaccharide release quickly enables microalgae to colonize on microplastic fragments. Studies have shown that genes involved in sugar biosynthesis pathways of microalgae are over-expressed when exposed to microplastics like HDPE and PP (Bafana, 2013; Lagarde et al., 2016). According to another study, size and charge of polymer particles have little impact on microalgal growth, which found that uncharged polystyrene particles negatively affect microalgae growth only at high concentrations (Sjollema et al., 2016).

Chemical nature of microplastics has major impact in source-sink dynamics. Microalgae colonization on microplastics varies with the chemical nature of the plastic, which results in increased aggregation of plastics on aquatic surface, which facilitates vertical transport of microplastics from surface to sediments (Lagarde et al., 2016).

Transport

In recent years, atmospheric transport of microplastics has been considered an important vector and that could lead to deposition of microplastics to land or aquatic environments (Windsor et al., 2019). Such transportation strongly impacts the source-sink dynamics of plastic pollution in different ecosystems including transfer between terrestrial and marine environment. The density and shape of microplastic particles will have important effects on their transport and retention in sediments (Bank and Hansson, 2019).

Sampling methods

Diverse types of microplastics are distributed in sediments, water column, and across various tissues of aquatic organisms and packed food. Sampling location and equipment used for sample collection can help in understanding MP quality and quantity. As a result, there are several methods used for collecting them from environmental samples. Well-studied sampling techniques are used in the water column. Besides environmental conditions such as density, wind speed, and waves, a sampling method is influenced by microplastic characteristics such as density, shape, size, adsorption of chemicals, and biofouling. Moreover, the sampling method for fresh and salt water should be standardized. However, the density of fresh water (1.00g/ cm^3) is less dense than sea water/ salt water (1.03g/ cm^3), can make major location difference. In case of fresh water, the MP is found mostly deep into the water column. Thus, depth and location may need to be adjusted depending on the sample location and salinity (Prata et al., 2019). The plastic samples should also be subjected to a pre-sampling inspection for sources of contamination during the sampling and handling process. Major contaminants found during sampling are fabrics, gear, and atmospheric fallout (Lusher et al., 2020).

Depending on the application, various types of sampling equipment are available. For example, water sampling equipment such as neuston nets, manta trawl, bongo nets, plankton nets, stacked Tyler sieves, telescopic sampling poles, sieve nets, gill nets, conventional tackles, minnow traps have been used (Sutton et al.,2016; McCormick et al., 2016; Tagg et al., 2015; Campbell et al., 2017), whereas sediment sampling equipment such as mesh, sieve, metal spoon, wood frame, sediment cores, stainless steel scoops, ekman dredge have been used (Fries et al., 2013; Wessel et al. , 2016; Käppler et al. , 2016; Imhof et al., 2016; Dümichen et al.,2017; Horton et al., 2017). For sampling biological tissue, equipment such as 90 mm GF/A 1.6 micro glass fiber fillers, tweezers, gillnets, baka, GOC 73 trawl/ gears, and gillnet demersal trawls are used (Dehaut et al., 2016; Bellas, 2016; Avio,2017; Fischer, 2017).

Sample preparation

All samples collected will be subject to further identification. The methods used to process liquid samples are filtration by size fractionation or density separation via salting (Prata et al., 2019). The method of separating plastic particles from sediment particles, however, relies on the difference in densities between plastic and sediment particles. The separation is most efficient when zinc chloride and sodium iodide are used instead of sodium chloride, due to density differences (Van Cauwenberghe, 2015; Hanvey, 2017). Additionally, the US National Oceanic and Atmospheric Administration (NOAA) released a memorandum containing a number of recommendations and procedures for analyzing microplastics in specific environments like marine and sediments (Masura, 2015).

Prior to identifying MP, it is important to remove organic matter, which may interfere with or complicate characterization. For visual inspection, it is highly recommended to use a digestion step to remove organic matter. Most of the researchers used hydrogen peroxide and Fenton regent to digest organic matter (Chen, 2020). According to NOOA recommendation, heating 30% hydrogen peroxide with 0.05 M Fe (II) sulfate solution (Fenton's Reagent) in a glass beaker containing the microplastic fraction at 75^{o} C can be followed to remove organic matter from both the water and sediment samples (Masura, 2015).

Especially biological tissue samples are subjected to acid or alkali digestion in order to remove bone and greasy matter. A researcher has studied varying concentrations of nitric acid along with varied incubation times. The use of alkali such as sodium hydroxide and potassium hydroxide to facilitate digestion results in poor removal of hard parts and fats (Dehaut et al., 2016; Silva et al., 2018). In order to avoid degradation of acid-resistant, temperature-resistant MP, leave oily deposits, bone fragments, and discoloration of plastic, caution must be taken before choosing the digestion method. Therefore, the use of acid and alkali sequentially is recommended to ensure good digestion and recovery of biological materials (Roch and Brinker, 2017; Catarino et al., 2017). When MP is acid or alkali digested, it is destroyed, degraded, melted, and yellowed, resulting in poor peak identification during spectroscopic analysis. The researchers have tried a number of methods to digest organic matter using hydrogen peroxide (Prata et al., 2019). In fact, MP treated with hydrogen peroxide has less damage than MP treated with acids or alkalis (Qiu et al., 2016). In addition, enzymes such as proteinase K, trypsin, papain, and collagenase are used in the organic digestion process. Enzymatic digestion, on the other hand, doesn't harm the MP like acid and alkali digestion process (Catarino et al., 2017). Nevertheless, enzymatic digestion is a less hazardous, more efficient, and more cost-effective method of removing organic matter from microplastics (Courtene-Jones et al., 2017).

Identification and chemical characterization

After sample preparation, multiple techniques have been used to detect and quantify MP from environmental samples. In general, identification is done visually using a stereomicroscope. The identification of MP by visual method can be based on morphological features such as shape and color, which can then be quantified (Gopinath et al., 2020). The abundance of MP contamination in environmental samples has been quantified by researchers using a variety of statistical tools, including t test, Pearson correlation analysis (Irfan et al., 2020), Kruskall Wallis H test, Dunn-Bonferroni post hoc test (Malla-Pradhan et al., 2022). By using these statistical tools, the area-wise distribution of microplastics (particles/L) has been compared and analysed effectively. The chemical characteristics of identified MP must be determined, however, in order to avoid misinterpretation with aquatic plankton. A variety of spectroscopy methods were used to identify microplastics, including Fourier-transform infrared spectroscopy (FTIR), Raman spectroscopy, and gas chromatography-mass spectroscopy ((Qiu et al., 2016; Catarino et al., 2017; Gopinath et al., 2020; Anifowoshe et al., 2022). In addition, studies showed that hot needle tests can be used to prove whether the particles are plastic or non-plastic material (De Witte et al., 2014; Gopinath et al., 2020; Malla-Pradhan et al., 2022). Further information indicates that plastic materials melt or change structure when hot needles touch them, whereas organic or cellular materials char (Lira et al., 2020). According to research, morphology and chemical composition of microplastics can be determined by using scanning electron microscopy. Furthermore, biofilm formation along with metal deposition can be identified from SEM images (Padervand et al., 2020; Gopinath et al., 2020; Anifowoshe et al., 2022).

Ill effects

Microplastics have a detrimental ecological impact on zooplankton, a key component of marine food-webs, as well as a wide range of marine biota ingesting them, including mussels, worms, fish, and sea birds (Desforges et al., 2015; Botterell et al., 2019; Wang et al., 2021). Number of studies have been undertaken to understand the MP ingestion by zooplankton, such as rotifers, copepods, bivalves, echinoderms (Beiras et al., 2018).

Interestingly, results from the study on MP's effects on predator-prey interactions indicate that tropic transfer of MP can occur from zooplankton to benthic filter feeders (Nelms et al., 2018; Botterell et al., 2019). In addition, the predation rate of contaminated prey has been significantly lower than those of prey that had no MPs ingested. This may be due to plastic-contaminated zooplankton have disruption in swimming behaviour and enter the benthic region, reducing predators' ability to feed on the surface (Van

Colen et al., 2020). However, the free-swimming crustaceans ingests beads compared with the benthic animals, which feed only on the sediment surface (Setälä et al., 2016)

Several studies have documented the toxicological and pathological effects of microplastic on fish (Enyoh et al., 2020; Yong et al., 2020). MP is frequently found in larvae and adults' guts, and sometimes in gills and livers (Lu et al., 2016). As a result of MP feeding, adults and larvae tend to behave abnormally, behaving abnormally with regard to feeding, movement, and reproduction (Mattsson et al., 2015; Chen et al.,2017; Yin et al., 2019; Pannetier et al.,2020; Yang et al.,2020).

Microplastics have the greatest impact on human health through drinking water and food exposure. Primary MP enters the food chain directly, whereas secondary MP acts as vectors for pathogens. The MP along with the metals and chemicals it absorbs get eaten by marine organisms. These contaminates can accumulate and reach humans via the food chain (Seltenrich, 2015). According to the latest research, both marine products and terrestrial food products have the greatest potential for MP contamination. According to recent information, microplastics can be found in tap water, bottled water, table salt, honey, beer and soft drinks (Seltenrich, 2015; Diaz-Basantes et al., 2020).

Human exposure:

Approximately 74,000 to 121,000 microplastic particles are consumed and inhaled by 15% of humans in the U.S. every year, depending on their age and gender. Also, it has been estimated that consumers who drink only bottled water each year may consume 90000 additional microplastics, whereas those who drink only tap water may ingest only 4000 microplastics (Cox et al., 2019).

Researchers in New York State have detected polyethylene terephthalate and polycarbonate MP in meconium, infant and adult feces (Zhang et al., 2020). According to a study report, fecal MP concentrations in inflammatory bowel disease patients are significantly higher than in healthy individuals. In addition, 15 different kinds of MP were found in feces, mostly poly (ethylene terephthalate) sheets and polyamide fibers. It is evident, however, that the major source of MP comes from plastic packaging of drinking water and foods, as well as exposure to dust (Yan et al., 2021).

The presence of MP particles in human feces indicates active interaction with the digestive system. However, the adverse effects of chemical additives and mechanisms of entry into the organs are still largely unstudied. Until recently, these issues were studied mostly in animal models, using much higher MPs levels than those found in edible foods and beverages (Lu et al.,2018; Jin et al., 2019; Li et al., 2020).

The study has been conducted to understand the mechanisms of gut interaction with MP after consumption. Researchers conducted a digestion simulation study using a standardized in vitro static model and a gut-microbial dynamic fermentation using the Simgi® model to understand how MP enters the human body at realistic exposure levels. The results of this study suggest that MP have an adverse effect on colonic microbiota, which may negatively affect human health (Tamargo et al., 2022).

Mitigation and policies

A variety of methods have been studied in the laboratory to remove microplastics, including adsorption on green microalgae, dynamic membranes, membrane bioreactors, conventional activated sludge, waste water treatment plants, classic coagulation and agglomeration methods, electrocoagulation, photocatalytic degradation, biological degradation (Padervand et al., 2020).

Scientists have investigated numerous methods to remove MP from the environment, including physical, biological, and chemical treatments. However, mitigation policies need to be strictly enforced.

In India, according to the plastic management Rule, 2022, the guidelines for Extended Producer Responsibility cover multiple aspects of plastic waste management such as reuse, recycling, use of recycled plastic content, and end-of-life disposal. A lot of different state metro cities have banned the use of thin plastic bags as the littering of the plastic waste has stimulated public outcry and shaped policy (Mutha et al., 2006). Although the Government of India has pledged to abolish all SUP from the nation by 2022, the implementation of relevant regulatory measures still faces difficulties. Despite the existence of plastic policies and regulations, they are only present in a few countries and most of the time is not fully implemented due to socioeconomic factors, therefore, they cannot address the problem across the entire life cycle of plastics, from production to disposal (Nøklebye et al., 2023).

Conclusion

Microplastic pollution is threat to life on Earth. Therefore, it is essential to educate people about proper disposal of plastic waste and create awareness about the 5R's (Refuse, Reduce, Reuse, Repurpose, Recycle). Unfortunately, many plastics are not recyclable; therefore, it is essential to know about chemical quality, which can be determined by its resin identification code (RIC). Further, only plastics with RICs "1" and "2" (polyethylene terephthalate and high-density polyethylene, respectively) were accepted to be recycled. In spite of more than 75,000 research articles being published, policies and mitigation are poorly researched. In addition, the public was less aware of the problem and a lack of action on the part of government. This review is not only briefing about MP pollution in environment also to create awareness and influence policies in waste management.

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