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Examining the Ecological Footprint of Microplastics: A Holistic Exploration from Genesis to Demise

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ABSTRACT

Microplastics are described as plastic particles smaller than 5 mm in size. Nowadays they are making an increasingly prevalent environmental issue as generated by a variety of products. Microplastics are diagnosed in various environmental compartments like soil, water, and air and affect the quality of them. Manta nets, dust samplers, shawls, trawl etc. the sampling equipment are used. They are identified and characterised by Visual identification, FTIR, SEM, RAMAN etc. This review paper addresses the origins, sources, distribution, adverse impacts and potential hazards of microplastics on the environment and living beings andidentification and quantification methods in environmental samples. Also, emphasis on Nanoparticle-mediated degradation of microplasticswith titanium dioxide, iron oxide, and zinc oxide via surface adsorption and ROS generation. Integrating nanoparticles into bioplastic degradation enhances efficiency, offering multifaceted solutions for a cleaner, sustainable future.

Keywords: Microplastic, Environmental impacts, Analytical procedures, Bioplastic.

INTRODUCTION

Plastic pollution has increased due to high consumption and production ratewhich has a severe effect on the ecosystem[1]. Largeplastic objects break down into small pieces with time and convert into small particles which are known as microplastic (>5mm in size)[2]. Primary and secondary are two types of microplastics which have been identified[3]. Primary, such as microbeads are directly discharged into the environment while secondary microplastics are produced when major plastic products break down into smaller particles[4]. They are also classified as fibre, line, foam, fragments, nurdles, microbeads, films, and sheets according to their shape[5]. Due to their small size and shapes, microplastics are difficult to manage and they may persist in the environment for several decades or centuries and transfer from one place to another. Plastic pellets6, fragmentation of large plastic debris[7], microbeads in personal care products[8], fibres from synthetic clothes and textiles[9], tire wear in road dust[10], paints and coatings[11], wastewater treatment plants[12], sludge as a fertilizer in soil[13] and agricultural practices[14] are the main sources (Fig. 1.) of microplastics. Their ubiquitous contamination has been identified from oceans to biodiversity in the Himalayan region[15]. including atmosphere[16], water[17], soil[18], plants[19], terrestrial ecosystem[20], aquatic life such as mussels[21], fish[22], planktons[23] and even in the human body[24]. Several negative impacts have identified on aquatic and terrestrial ecosystem including living beings which are described in Fig. 2. Drifting of these particles causes the invasion of alien species into a particular ecosystem[25]. Microplastic now has been declared as a 'plastisphere' in marine life by UNEP. and called a new marine microbial home[26]. However, it is becoming a serious threat to the environment day by day as it cannot be recycled and reused normally[27].

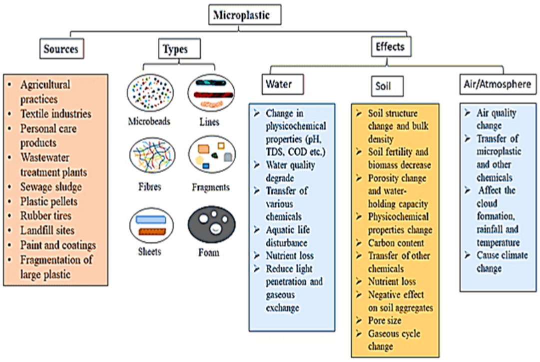

Fig. 1. Sources, types, and effects of microplastics on different compartments of the environment (Source of figures are references[28–30])

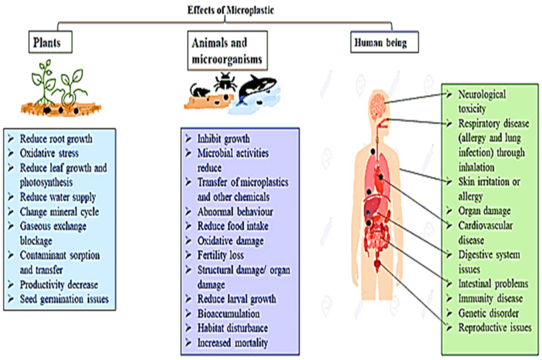

Fig. 2. Negative impacts of microplastics on plants and living beings (Source of figure-The above data for plants is taken from references[31–33] and forliving things is from[34–36])

Interaction of microplastics with organic and inorganic matter

Microplastics react with organic matter by hydrophobic interaction, electrostatic interactions, Van Der Wall force, H-bonding, and halogen bonding[37]. As they have a hydrophobic surface, this large specific surface area makes it simple to interact with organic pollutants. They also interfere with the behaviour of these pollutants through the adsorption and desorption process[38].

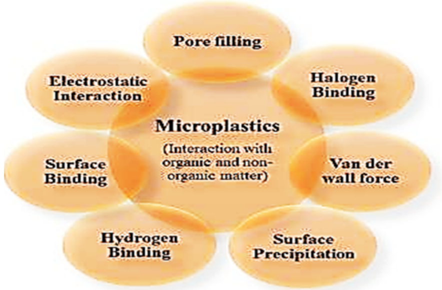

Fig. 3. Different ways of microplastic interaction with organic and inorganic matter Source of figure is reference[59] (Chemosphere., 2023, 138495)

Microplastic makes a complex with the inorganic matter such as heavy metals, chloride, phosphate, nitrate etc. by surface binding, sorption and electrostatic interactions[39]. They also interact with toxic heavy metals like cadmium and significantly increase their toxicity and accumulation properties. Microplastics act as a pathway for the movement of harmful heavy metals in different ecosystems like aquatic bodies mangroves wetlands and sediments.[40]

Analytical methods

Analytical methods include sampling, extraction, and characterisation procedures of microplastic which take a lot of time and patience. Although figure4shows all the steps very clearly.

Sampling and extraction in different compartments of the environment

Aquatic Environment: Water samples are collected with bottles (glass), manta nets, neuston nets, AVANI (All Purpose Velocity Accelerated Net Instrument) and trawl nets[41,42]. The collected samples are sieved or filtered with the help of different sizes of stainless-steel sieves[43]. Acidic or alkaline digestion with H_2O_2 (30%, 15%) or HCl or KOH[44] is done at 60°C to 75°C for 12-72 h followed by density separation by using NaCl and NaI or another salt solution[45]. The samples are filtered using filter paper or vacuum filters with aluminium oxide filters and characterised by different techniques[46].

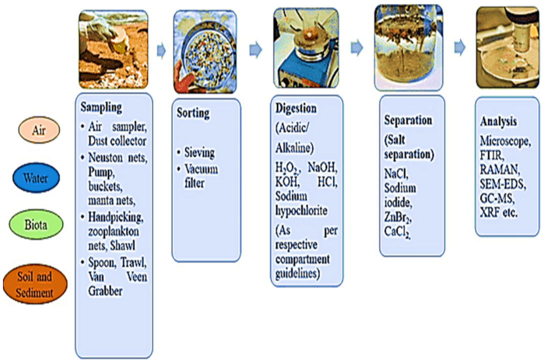

Fig. 4. Procedure for analysis of microplastic in various sectors of theenvironment. (Source of figure are reference no.[40], Trends in analytical chemistry 2020, 133, 116071, and 59Chemosphere2023, 138495)

Soil and Sediments: Soil samples can be collected with the help of wooden, metal frame[47] spoon or shovel[48]. Sediment samples are collected by using Peterson grab sampler or Van Veen sampler[45]. The collected samples are dried and sieved from different sizes of sieves (5mm, 3mm, 1mm, 300μm and 63μm)[49]. Density separation is performed with the help of NaCl, NaI, $ZnBr_2$, $CaCl_2$[50].H_2O_2 (30%), HCl, NaOH, KOH[51] and sodium hypochlorite (>40%) are used to perform acid and alkaline digestion to remove organic matter for 5 to 6 hours[52]. After that chlorination of polymers is done byNaOClto reduce the hydrophobicity of plastics[53]. The supernatant must be filtered after digestion with different pore-size filter papers and nylon filters[43]. The vacuum filtration technique can also be helpful[52].

Biota: Biological samples are mainly collected with the help of trawl nets, manta nets, fishing nets, cages, and handpicking methods[54]. For a more effective investigation, freezing is an essential step right after collection and washing. After that, soft tissues of the biological sample are separated at room temperature[55]. Digested by H_2O_2 (15%, 30%), and KOH (15%, 30%)[56] at temperatures of 50°C to 75°C for 4 to 5 hoursand stored in a petri-dish after filtration for another analysis.

Dust and Air Sample: Dust and air samples are collected with the help of a total atmospheric particulate sampler, and dust sampler. Household and indoor samples are simply collected with the help of nylon brushes by sweeping the floor. The samples are stored at low temperatures (3-4°C)[16] anddensity separation isperformedusing $ZnCl_2$ and NaCl. The samples are digested by H_2O_2, KOH and 1-pentanol.[57,49]

Quantification and Identification

In the investigation of microplastics, characterization has an essential role. Various instruments are used nowadays like Visual Sorting, Fourier Transform Infrared Spectroscopy (FTIR), SEM (Scanning Electron Microscope), Raman Spectroscopy, Gas chromatography and mass spectrometry (GC-MS) etc. These are used to identify and characterise the type of plastic polymers in various samples (solid, liquid, air). Every technique has its advantages and disadvantages which are described in Table 1.

Table 1: Instruments and their significance

No	Instrument	Application	Advantages	Disadvantages	References
1	Visual method		Large microplastics can be detected	Small size, type and composition of microplastic cannot be detected	49
2	Raman spectroscopy	Chemical and spectral composition of microplastic	Small microplastics can be detected.	A small sample is required.Detection limit 1 to 10μmExpensive instrument	58
3	SEM	Elemental interference by reflected electrons	Clear and high-resolution image of the sample	Time-consumingExpensive method	46
4	XRF	Analyse the microplastic's fluorescence by using X-ray	A little sample is required Non-destructive method	Expensive methodExposure to X-ray radiationLarge Sample required	59
5	FTIR	Polymeric functional group of microplastics by using IR	Determine the morphology Less sample required	Limit from 10 to 50μm A specific methodology is required	60
6	Chromatography	Analyse the type of plastic polymer	High sensitivity and specificity	Not suitable for very small particles	61

Degradation of microplastic as a future perspective

The phenomenon of nanoparticle-mediated degradation held a transformative era in the domain of microplastic remediation, presenting a nuanced and eco-conscious strategy to mitigate the ubiquitous ramifications of plastic contamination on environmental ecosystems[62]. TiO_2 nanoparticles gain attention to degrade polyethylene microplastics under simulated solar irradiation, effectuated through surface adsorption and the generation of reactive oxygen species (ROS)[63]. Fe_3O_4 nanoparticles catalyse the degradation of polystyrene microplastics via Fenton-like reactions, instigating oxidative cleavage of polystyrene chains through the generation of hydroxyl radicals (•OH) in the presence of hydrogen peroxide (H_2O_2)[64]. Similarly, ZnO nanoparticles were enlisted in the degradation of polyethene terephthalate (PET) microplastics under UV irradiation, facilitating oxidative PET degradation via surface adsorption and ROS generation[65]. Notably, the amalgamation of nanoparticles into bioplastic degradation paradigms represents a paradigmatic shift toward sustainable materials management. Through symbiotic engagements with microbial collectives and precise catalytic mechanisms, nanoparticles synergistically enhance the efficiency and specificity of bioplastic decomposition processes. From TiO_2 photocatalysis to AgNP-facilitated microbial consortia, nanotechnology offers a multifaceted arsenal against the intricate challenges posed by bioplastic waste. By embracing interdisciplinary cooperation and harnessing state-of-the-art nanotechnological innovations, society can aspire towards a cleaner and more sustainable future, emancipated from the perils of microplastic pollution.

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Conflict of Interest

The authors declare no conflict of interest.

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