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Microplastics: Classification, Sources, Characterisation, Fate, and Control Measures

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Systematic Review Article

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ABSTRACT

Plastic use has now permeated all aspects of life and new applications are developed every year, and the substitution of other materials with plastic is still expanding in many sectors. They are currently used in single-use packaging, consumer goods, construction materials, automotive, electrical and agriculture applications. Several decades of plastic release into the environment have brought about a wide range of associated problems. Microplastics encompass a wide range of materials composed of different substances, with different densities, chemical compositions, shapes and sizes. They are ubiquitous in the environment and have been detected in a broad range of concentrations in marine water, wastewater, fresh water, food, air and drinking water, both bottled and tap water. Key sources of microplastic pollution are terrestrial run-off and wastewater effluent. Present paper deals with recent approaches on 'microplastics' with respect to: definition, common

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examples, classification, sources by usage sectors, key sources, characterisation, methods for analysis, fate in the aquatic environment, control measures, and research gaps is critically evaluated.

Keywords: Microplastics; nanoplastics; plastics; pollution; persistent organic pollutant; fate.

1. INTRODUCTION

Plastics are the synthetic polymers produced using the chemical additives and are modified as per the need of the consumer [1]. They are synthesized by the process of polymerization and because of their properties, worldwide use of plastic has been increased tremendously [2]. Properties such as cheap, durable, lightweight and malleable, plastic has occupied every sector of human need [3,4]. Rampant use of plastic has resulted into a major environmental problem and since they are non-biodegradable, plastic waste finally ends up in the seas causing severe ocean pollution, affecting the marine biota and water quality [5]. As a result, government, scientific community and social organizations have considered it as a burning environmental issue [6].

Plastic wastes which are released or disposed in the environment, remain for hundreds of years without any decomposition. By various environmental actions, plastics are fragmented into small pieces and minute particles [7]. Since the plastics are hard and non-biodegradable, they are disposed either by burning or released into the environment, will finally end up in the ocean to form the marine waste [8].

Because of their non-degradable nature, plastic pieces or particles formed due to photodegradation, mechanical impact, ambient weathering, or microbial degradation, remain in the environment for many years and cause detrimental effect on the quality of environmental parameters and persists there [9,10]. As the plastics are cheap and durable, human being make use of plastics in every necessary field, from packaging material to the clothing. Though many earlier reports are available on the various aspects of plastics, meagre information is available on the characteristics and hazards caused by the microplastics. In recent years, large quantity of microplastics was detected in the environment, which attracts the scientific community to focus more on ecological aspects of the microplastics [11]. Plastic particles less than 5 mm were considered as ‘microplastics’ [12], and are posing a severe threat to the health of both the human and the environment [13,14].

Though plastics have benefited to the human in every sector of life, its production and disposal have become an alarming issue. Single use plastics and other post-use discarded plastic and their fragments finally forms the macroplastic, microplastic, and recently invented nanoplastics materials, which hamper the life and health of both terrestrial and aquatic life, including the human [15,16].

This review paper deals with recent approaches on definition, common examples, classification, sources by usage sectors, key sources, characterisation, methods for analysis, fate in the aquatic environment, control measures and research gaps is critically evaluated.

1.1 Structure of the Review paper

Table 1. Structure of the review paper

Section	Details
I	Introduction, Structure of the Review paper
II	Literature Search Methods
III	Definition of ‘Microplastics’ (MPs)
IV	Common examples of Microplastics
V	Classification of Microplastics: Based on Origin & Chemical composition
VI	Sources of Microplastics by Usage Sectors
VII	Key Sources of Microplastics
VIII	Characterisation of Microplastics
IX	Methods for Analysis of Microplastics
X	Fate of Microplastics in the Aquatic Environment
XI	Control Measures for Microplastics
XII	Research Gaps and Next Steps

2. LITERATURE SEARCH METHODS

The review was carried out through extensive literature search, using electronic databases, and online search tools, such as EMBASE, Google Scholar, Medline, NCBI, PubMed, Science Direct, Scopus, and Web of Science databases. Data and information was collected from the thorough study of the journal articles, research papers, reports and various literatures. This review paper analysed a total of 24 research articles published in reputed journals. The keywords used for reviewing the literature were the ones that refer to the issues concerning the 'Microplastics'. For literature search, keyword "Microplastics" is combined with: definition, classification, characterisation, sources, fate, detection methods, abundance, and control measures.

3. DEFINITION OF MICROPLASTICS (MPs)

Thompson et al. [17] while studying the oceanic plastic pollution, first described the 'microplastics". Further, Lassen et al. [7] noted that, no official definition of microplastics has been adopted (Table 2).

4. COMMON EXAMPLES OF MICROPLASTICS

Microplastics reported in the environment show all chemical categories of the plastic polymers. Some commonly available examples of MPs were presented in Fig. 1 and Table 3.

Table 2. Definition of microplastics (MPs)

Authority	Definition of Microplastics
Leslie [18]	A wide range of plastic particulates in the milli range (1-5 mm), micro range (1-999 µm) and in the nano-range (1-999 nm).
Duis and Coors [11]	Solid synthetic organic polymer particles with a size between 100 nm and 5 mm.
Boucher & Friot [3]	Small plastic particles (< 5 mm size) directly released into the environment.
Ganesan et al. [2]	Plastic particles less than 5 mm and are again divided into primary and secondary.
OECD [19]	Plastics with a size smaller than 5mm, and are found in the environment as fragments, fibres, pellets, or beads of different sizes and physico-chemical compositions.
Zhang et al [14]	Smaller plastic particles of size is < 5 mm formed due to action of physical, chemical and biological processes on plastic wastes are considered as "microplastics".
Osman et al [8]	Tiny plastic particles with <5 mm in length.

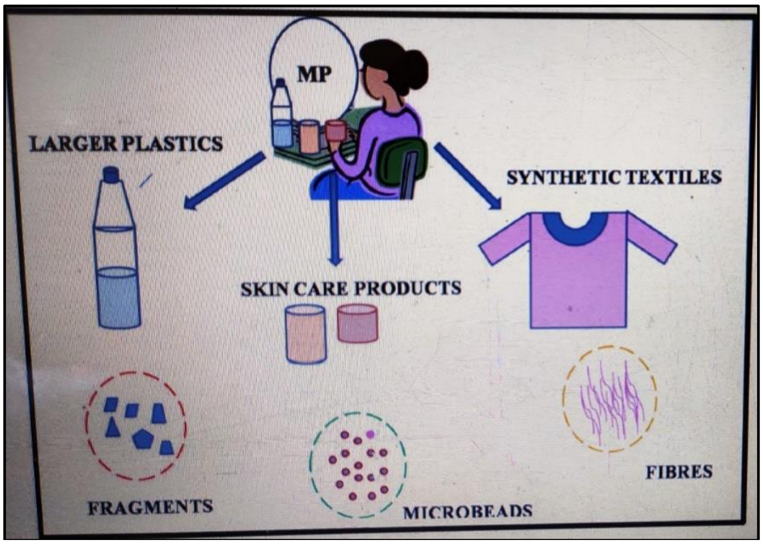

Fig. 1. Common forms of microplastics
(Source: Issac and Kandasubramanian [20])

Table 3. Common examples of microplastics

Microplastics	Details
Fibres	Fibres from clothing and other products such as cigarette filters. End up in water systems when clothes containing synthetic fibres are washed in a washing machine.
Foam	Foam particles from sources such as packaging, commercial fishing gear and styrofoam cups.
Microbeads	Small particles of plastic that are used in products such as exfoliating facial scrub or toothpaste.
Nurdles	Pellets of plastic that are used as a raw material in manufacturing. Enter in water systems due to spills such as containers lost at sea.
Plastic Powders	Powders used in industrial moulding.
Scrubbers	Particles of plastic used in industrial processes as a cleaning agent.

5. CLASSIFICATION OF MICROPLASTICS ACCORDING TO ORIGIN (LASSEN ET AL. [7])

5.1 Primary Microplastics

They have particle size less than 5 mm and are produced in most of the industries. They are produced with a specific purpose, mainly for addition in the consumer and commercial products. They are widely used in personal hygiene products cosmetics formulations, fiber and textile manufacture [21].

5.2 Secondary Microplastics

They are derived from meso (5 mm–25 mm)/macro (>25 mm) plastic waste through physical, chemical and biological processes. Secondary microplastics are formed in the environment by natural actions such as fragmentation, photodegradation or biological degradation [22] (Table 4).

6. SOURCES OF MICROPLASTICS BY USAGE SECTORS

6.1 Land-Based Sources of Microplastics

Land based sources are the major sources of microplastics and includes plastic fragments from household plastic containers, beauty and cosmetic products, detergents and gels, along with synthetic fibers and single use products.

6.2 Ocean-Based Sources of Microplastics

Ocean based sources include fishing components, marine vessels and offshore wastes formed due to marine recreation and tourism (Fig. 2, Table 5).

Table 4. Sources for microplastics (Source: Duis and Coors [11])

Types	Sources
Primary microplastics	Production of plastics, accidental losses, and surface run-off
	Industrial abrasives
	Drilling fluids for oil and gas exploration
	Specific medical applications (e.g. dentist tooth polish)
	Personal care products containing microplastics as exfoliants /abrasives
Secondary microplastics	Plastics released from sites of waste depots, landfill and recycling facilities
	Abrasion from car tyres, household plastics and synthetic fibres.
	General littering, dumping of plastic waste
	Losses of plastic materials during natural disasters
	Material lost or discarded from fishing vessels and aquaculture facilities
	Material lost or discarded from merchant ships, recreational boats, oil and gas platforms
	Paint coating and abrasion during use and paint removal

Table 5. Sources of microplastics by usage sectors [23]

Category	Source sector	Description
Individual consumers	Food & drink single-use packaging	Containers, plastic bags, bottles, caps, cups, plates, straws, spoons.
	Cosmetics & personal care products	Microbeads, packaging, toothbrushes, etc.
	Textiles & clothing	Fibres
Producers/Converters	Plastic Producers, Fabricators & Recyclers	Pellets & fragments
Sectorial consumers	Agriculture	Greenhouse-sheets, pots, pipes, nutrient prills
	Aquaculture	Buoys, lines, nets, PVC pipes
	Construction	EPS, packaging
	Fisheries	Fishing gear, packaging
	Shipping/Offshore industry	Paints, pipes, clothes, cargo, miscellaneous, plastic-blasting,
	Sport	Synthetic turf
	TerrestrialTransportation	Pellets, tyres, tyre dust
	Textile industry	Fibres
	Tourism industry	Consumer goods, packaging, Micro-beads, textile fibres
Waste management	Solid waste	Unmanaged or poorly managed waste disposal
	Water & wastewater	Microbeads, fragments, fibres
Entry points to the ocean	Rivers, Coastline, Marine, Atmosphere	Paints, pipes, clothes, miscellaneous, plastic-blasting, cargo, Containers, plastic bags, bottles, caps, cups, plates, straws, spoons,

Fig. 2. Sources of microplastics from household or commercial activities
(Source: Boucher and Friot [3])

7. KEY SOURCES OF MICROPLASTICS

Boucher and Friot [3] reported that, the main known sources of primary MPs are city dust, marine coatings, personal care products, plastic pellets, road markings, synthetic textiles, and tyres.

7.1 City Dust (Weathering, Abrasion and Pouring)

City dust includes losses from the abrasion of objects and infrastructure, and blasting of abrasives and intentional pouring. The type of loss is mainly unintentional.

7.2 Marine Coatings (Weathering and Incidents During Application, Maintenance and Disposal)

From marine coatings, primary microplastics are released from boats during building, maintenance, repair or use. Activities like surface pre-treatment, coating application and equipment cleaning lead to releases of MPs. Here the type of loss is purely unintentional.

7.3 Personal Care Products: (Pouring During Product Use)

Use of personal care products results in the direct introduction of the plastic particles into wastewater streams from households, hotels, hospitals, and sport facilities including beaches. The type of loss is intentional.

7.4 Plastic Pellets: (Incidents During Manufacturing, Transport and Recycling)

Due to processing, transport and recycling, plastic pellets are released into the environment through small or large incidents. Pellets are also formed during primary plastic production, transport and plastic recycling, resulting into unintentional loss (Fig. 3).

7.5 Road Markings: (Weathering and Abrasion by vehicles)

Weathering or abrasion of the road markings which are made from paint, thermoplastic, preformed polymer tape and epoxy releases the microplastics into the environment, causing heavy smog and air pollution, affecting the human health. Weathering or from abrasion by vehicles results in loss of MPs. Such microplastics were washed off by the surface runoff and finally end up into the ocean.

7.6 Synthetic Textiles: (Abrasion During Laundry)

Abrasion of polymer clothing in professional laundries and household washing machines results in shedding of small plastic fibres, which are also non-degradable and discharged into nearby water bodies and finally to ocean. Type of loss is unintentional.

7.7 Tyres: (Abrasion While Driving)

Vehicle tyres due to their continuous use, are get eroded and releases plastic particles from the outer parts. Tyre dust will then be spread by the wind or washed off the road by rain. Such MP particles were then transferred from tyres to the world's oceans. Type of loss is unintentional.

8. CHARACTERISATION OF MICROPLASTICS

Microplastics were characterized according to their type, shape, colour, and erosion [22] (Table 6).

Fig. 3. Plastic pellets
(Source: UNEP [24])

Table 6. Characterisation of microplastics (Source: Yuan et al [22])

Class	Sub-class	Description
Shape	Fibers	Filaments, microfibers, strands, threads.
	Foams	Polystyrene, expanded Polystyrene.
	General	Irregular, elongated, degraded, rough, broken edges flakes
	Particles	Resin pellets, nurdles, pre-production pellets, nibs.
	Spheres	Beads, grains, micro-beads, microspheres, cylinder, disc, flat, ovate, pellet, ellipse.
Colour	Black, Multicolour, Transparent, White	Crystalline, clear-white-cream, red, orange, blue, opaque, grey, brown, green, pink, tan, yellow, pigmented.
Erosion	---	Fresh, un-weathered, initial change, degree of cracking, weathering, grooves, surface irregularity, jagged fragments, linear fractures, sub-parallel ridges, degradation.

9. METHODS FOR ANALYSIS OF MICROPLASTICS

Methods used for the analysis of MPs as suspended solids in water samples, beach samples, and bed samples are wet sieving, transfer sieved solids, wet peroxide oxidation, density separation, microscope examination, and gravimetric analysis [22].

10. FATE OF MICROPLASTICS IN THE AQUATIC ENVIRONMENT

After the release, MPs are transported and further environmental proceeds. Buoyancy, durability, and wind-driven mixing is an important factor for the fate of plastic particles. Inputs of plastics from land, riverine, and marine sources reach temporary reservoirs on beaches, tidal wetlands, and marine sediments [25,7,1].

10.1 Environmental Transportation

Microplastics were transported from land to freshwater and at the last to marine environments. MPs may undergo degradation during transportation and distributed to various environment compartments, which results in formation of biofilms in marine settlement [26].

10.2 Environmental Persistence and Degradation

Degradation of plastic occurs by photo-, thermal, or bio-degradation. Environmental exposure conditions, polymer properties, and quantity of chemical additives will influence MP degradation and fragmentation. Environmental degradation processes involve MP fragmentation into increasingly smaller particles/nanoplastics.

10.3 Interactions with Other Compounds

In the ocean, microplastics concentrate on DDT, polychlorinated biphenyl (PCBs), dioxins, pharmaceuticals, personal care products, flame retardants, and industrial chemicals.

11. CONTROL MEASURES FOR MICROPLASTICS

Practices such as to avoid air dry and use of the dryer, use of non-synthetic and eco-friendly clothes, use of paper bags, reduce and recycle plastic, cleaning of water bodies, and use of public transport should minimize the hazards of microplastics up to certain extent [27].

12. RESEARCH GAPS AND NEXT STEPS

This study identifies many research gaps regarding the microplastics. Gaps like fate of MPs ingested by commercial species and seafood products remain unexplored, along with the time of retention of microplastic in the gut and/or its translocation to the tissues that may be consumed by humans is also not known. Further, how to determine and risks posed by microplastics for food safety and potentially food security was not fully understood.

13. CONCLUSION

Results of this study indicate that, microplastics are produced as a result of an enhanced incidence of plastics debris and microplastics, in the aquatic environment. Number of research gaps need to be filled to better assess the risk of microplastics in aquatic environment and inform management actions. Targeted, well-designed and quality-controlled investigative studies should be carried out to better understand microplastics with respect to their occurrence, numbers, shapes, sizes, composition and sources. Research is also needed to understand the significance of treatment-related waste streams as contributors of microplastics to the environment [8]. Also, the public should take action to minimize plastics released into the environment for the benefits of the environment and human well-being.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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