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Accumulation of Microplastics in the Food chain: Recent advances, Key issues, Human Health Implications, and Preventive measures

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ABSTRACT

Synthetic polymer particles with a diameter of less than 5 mm, or microplastics, are widely used in numerous industries and have a long lifespan. These are termed as pollutants because of their widespread application in a variety of industries and long lifespan. The manufacture of plastics has increased significantly since 1950, causing serious environmental contamination, particularly in aquatic environments where rivers carry 70–80% of these plastics into the ocean. Their distribution is influenced by wind, tides, and wave currents; plastic makes up 75% of oceanic waste. Urban runoff, plastic waste, cosmetics, synthetic textiles, and industrial abrasives are the main sources of microplastics. They enhance immunological reactions, oxidative stress, and other health problems in both people and wildlife. Reducing single-use plastics, enhancing waste management, creating substitute materials, and developing microbial degradation strategies are all necessary to control microplastic pollution.

Keywords: Microplastics, pollutants, aquatic environments, ecological risks, waste management.

1. INTRODUCTION

Microplastics are often insoluble in water manufactured solid particles or polymeric matrices [1]. Their size ranges from 1μm to 5 mm, and their shape can be either regular or irregular. The physical characteristics of plastics, like their resistance to corrosion, low weight, and durability, illustrate why these materials are used extensively in industries and everyday life. The plastics industry has grown significantly since 1950, and in 2017 348 million tons of plastic were produced worldwide [2], and 33 billion tons are expected to be made by 2050 [3]. However, because of their widespread usage, high manufacturing, effective disposal, and resistance to disintegration, they have been dispersed throughout both land and water ecosystems, where they will remain for decades. Most plastics are transported by rivers, It finally results in a significant amount of plastic waste finds its way into the world's oceans [4].

2. GEOGRAPHICAL OVERLAP OF MICROPLASTICS

Microplastic pollution shows wide regional variation, with environmental and anthropogenic factors being the primary determinants of abundance and distribution [7]. On the other hand, external factors might have a greater impact on the dispersion of microplastics. The dispersion of these particles is greatly influenced by wind directions, river hydrodynamics, cyclones, wave currents, and tides. About 75% of trash at the oceans is plastic, mostly in the form of microplastics (less than 5 millimeters in size), which harm marine and coastal ecosystems worldwide. North America (12%), South America (7%), Asia (36%), and Europe (38%), have carried out the majority of the study on microplastics. Since 2010, the countries of Europe, North America, Asia, India, and China have produced the greatest advances in the study of microplastics. Conversely, the continents of Africa (2%), Antarctica (1%), and Australia (4%), on the other hand, have seen relatively

Figure 1. Microplastics collected from a sandy shoreline in Europe [5]

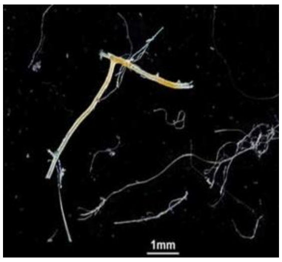

Figure 2. Microplastic filaments found in the deep-sea sediments [6]

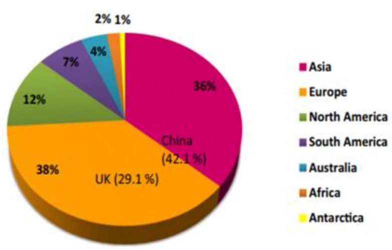

Figure 3. Percentage of studies on microplastics carried out worldwide between 2010 and 2019 based on our scope [9]

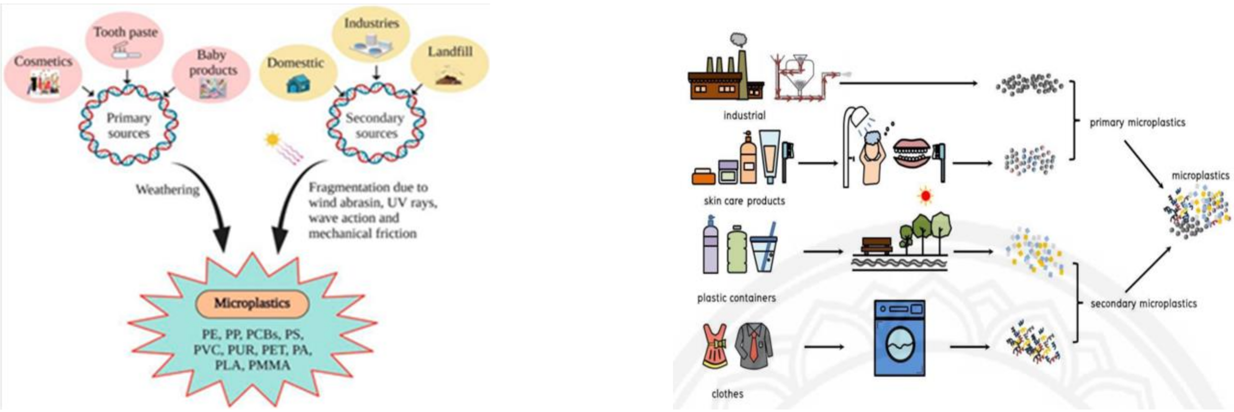

Figure 4. Types, origins, and mechanisms of primary and secondary MP formation [23, 24]

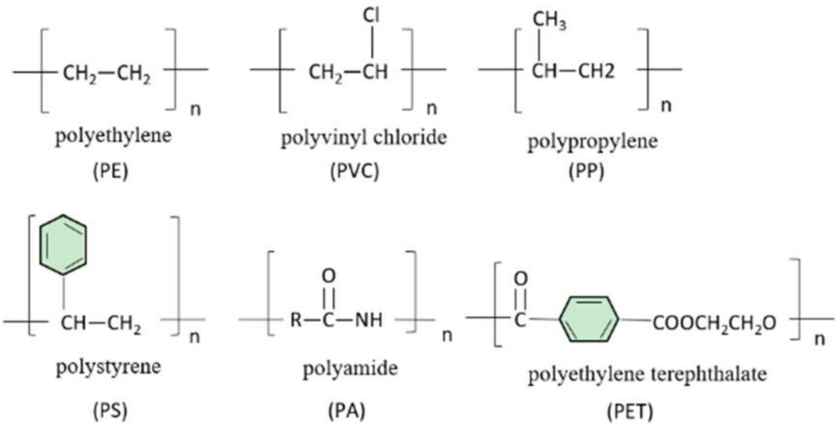

Figure 5. Structure of Microplastics [27]

little research [8].

3. ORIGIN OF MICROPLASTICS

The basic origin of plastic pollution is urban and suburban regions, where runoff gradually contaminates rivers, lakes, seas, oceans [10]. Additional sources of microplastic include tires and rubber products, toothpaste, cosmetics, deformed and abandoned vessels, exploring detergents in toiletries, and synthetic clothing washing. Misused plastic waste finds its way onto land, into rivers, streams, and coastal seas, adding to the worldwide contamination of beaches and oceans caused by an increase in marine litter. An estimated 7–17 million tons micro plastics, or 3–5% of overall global output, are released. Approximately 80% of marine litter originates on land, from places like waste and litter disposal (mostly plastic) [11].

4. PRODUCTION, TYPES, AND PROPERTIES OF MICROPLASTIC

4.1. Origin and Production

There are two main possible sources of microplastics: (a) runoff which releases microplastics directly into the environment (b) weather-induced degradation meso- and plastic detritus. Runoff releases some microplastics into the ocean, including nano and microplastic particles found in consumer goods [12]. This includes industrial abrasives used in synthetic "sandblasting" media, which are frequently utilized as exfoliates in cosmetic formulations (beads of acrylic polymers and polyester), and micron-sized plastic particles produced by the ship-breaking business [13]. Runoff can easily carry these to the oceans.

4.2. Types of microplastics

Microplastics are plastic fibers, debris, or particles that range in diameter from 1 to 5 mm [14]. Because they have a tendency to collect in the environment, microplastics pose a major threat to ecosystems everywhere [15]. Secondary microplastics are produced indirectly by breaking up bigger plastic leftovers, whereas primary microplastics are produced directly in the industry [16]. The two primary categories of microplastic sources are as follows [17]. Some possible sources of primary microplastics are plastic pellets used in manufacturing, scrubbers, commercial cleaning abrasives, plastic powder, plastic resin flakes, and plastic fluff used to create plastic items [18–21]. Primary microplastics can also originate from volatile particulate pollutants such as nano-polyester, nano-Fe3O4, and SiO2 from printing toners. Secondary microplastics are created when bigger polymers fragment into nano, micro, and macro sizes, much as primary microplastics. Secondary microplastics can come from a number of causes, including exposure to wind, wave action, photo degradation, biodegradation, hydrolysis, and UV light from sunshine, before they are released into the environment as a result of weathering [22].

5. PROPERTIES

Because of the vast amount of plastic particles that have accumulated in the natural environment, the density and texture of microplastics differ greatly based on the polymeric characteristics and manufacturing method [25]. Microplastics exhibit heterogeneous behaviors that vary based on their physical attributes, including size, shape, and density of particles. Water columns and floating water may include microplastics because of differences in particle and fluid densities (the buoyancy effect) [26].

6. OCCURRENCE, SPATIAL DISTRIBUTION, AND FATE OF MICROPLASTICS

In our daily lives, plastic product is everywhere, and the annual production of plastics is dramatically rising [28]. By 2050, 33 billion tons and 67.8 million metric tons [29] of plastic garbage, respectively, are predicted to

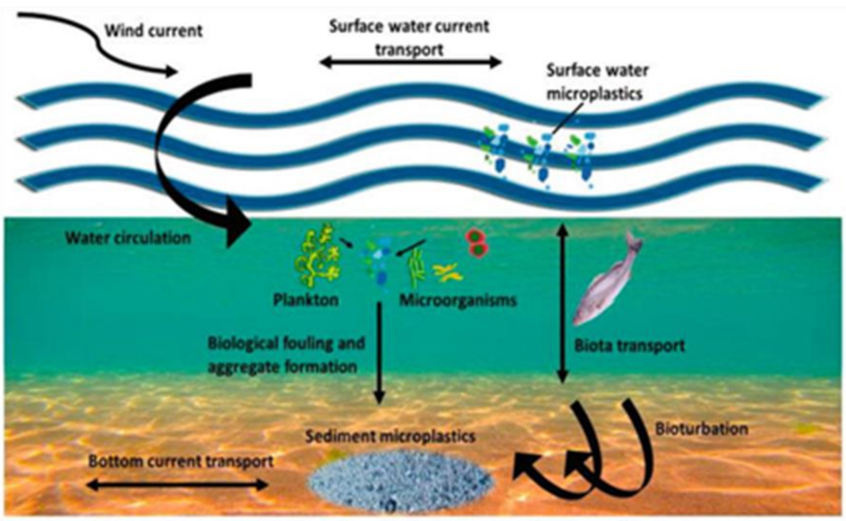

Figure 6. Fate or routes of microplastics' distribution in the marine environment [31]

end up in the environment. Microplastics are present everywhere since they are found in all components of ecosystems.

7. TRANSPORT PATHWAYS

Plastic waste on terrestrial lands subsequently carries on with the runoff due to rainfall; it is estimated that almost 44% of the total microplastics discharged into the marine ecosystem are transported via surface runoff. It can be transported by wind, which carries atmospheric currents and plastic waste from the terrestrial zone to the seas and oceans. The wind transports 15% of the total microplastics deposited into the marine ecosystem as wastewater discharge, responsible for 37% of the total microplastics released and through which they can enter receiving water bodies. Lastly, 4% of the total release of microplastics is caused by the direct disposal of this waste to the marine and oceans [30].

8. MICRO PLASTICS BIOLOGICAL TRANSPORT

TRANSFER OF MICROPLASTICS INTO THE FOOD CHAIN

Microplastics can be produced in a variety of ways, disperse over the environment, or into the food chain and then human body [32]. Microplastic enters marine food webs when marine species ingest it, become entangled, or breathe it in. Microplastics are easily consumed accidentally or intentionally by various aquatic species due to their small size. The concentration, size, form, distribution, chemical make-up (i.e., chemical signal), and animal feeding habits all impact the ingestion of microplastic particles. In animals with well-developed organs for detecting prey, plastic polymers might not be determined, or they might be rejected if they are undesirable or if alternative prey is available [33].

9. FACTORS AFFECTING THE BIOAVAILABILITY OF MICROPLASTICS

Different factors affect the bioavailability of microplastics.

- Occurrence
- Properties of plastic
- Zooplankton transformation and selectivity

9.1. Occurrence

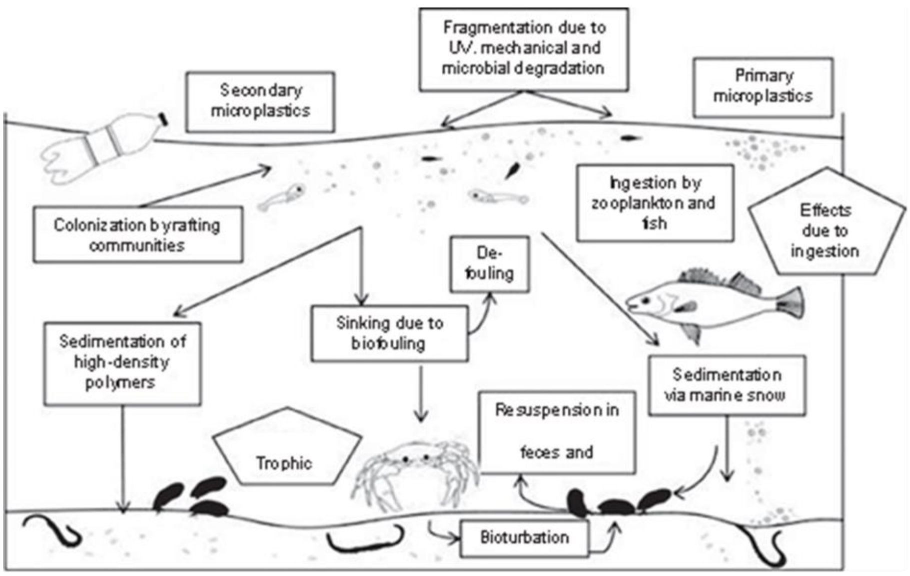

Figure 7. Possible routes for the movement of microplastics and the biological interactions they have [34]

Degradation and fragmentation of microplastics will increase the number of microplastics consumed by various organisms [35]. Microplastics are less common in marine gyres than in shelf-sea regions because of the low primary productivity and organism abundance in these areas [36]. Ingestion rises when microplastic quantity is large [37].

9.2. Properties of plastic

Microplastics may be mistaken for a species' natural prey due to their similar size, or they may be inadvertently swallowed during routine feeding activities. Numerous zooplankton species have been shown to contain microplastics in their stomachs, with sizes varying from 0.5 to 816 mm [38]. Microplastics' color may make them easier for raptorial species to identify and consume, increasing the possibility that other organisms will also eat them [39].

9.3. Transformation

Some chemical and physical characters of microplastics in the aquatic life can be altered by natural aging processes, including weathering and bio fouling [40]. These processes will make microplastics smaller and more asymmetrical in surface and form, which will increase their overall surface area [41].

9.4. Selectivity of zooplankton

Table 1. Microplastics' in vivo toxicological effects on typical aquatic species

Aquatic organisms	Size/exposure time	Toxicity	References
Zebrafish	Five µm 0-7 days	Fish liver inflammation and accumulation of lipids	[18]
Carcinus maenas	<5 mm 14 and 21 days	Lipid accumulation and inflammation in fish liver	[45]
Carassius auratus	<5 mm 1.5 h-6 days	Accumulate in the gut	[34]
Scleractinian coral	1.0 µm 6, 12 and 24 h	Repress detoxification and immune system	[49]
Daphnia magna	<5 mm 48 h	CAT, GST, and MDA level activities	[50]
Paracentrotus lividus	<5 mm 24 h	Decrease of larval length	[45]
Seals, sea lions, dolphins, and Sea Snake	<5 mm Long exposure	Increase in morbidity and mortality	[51]
Lemna minor	<5 mm 48 h	Inhibited root growth	[32]
Myriophyllum spicatum	20-500 µm 0-24 h	Inhibited shoot growth	[21]
Skeletonema costatum	1 mm 96 h	Suppression of both growth and photosynthesis activity	[46]
Chlorella pyrenoidosa	0.1 and 1.0 µm 0-35 days	Inhibition of growth and decreased photosynthetic activity	[13]
Tetraselmis chair	5 nm 96 h	decreased the particular growth rate on average	[23]
Chlorella pyrenoidosa and Microcystis	0.1 and 5.0 µm 0-72 h	impeded expansion	[43]
Hyalella azteca	71.43 microplastics/mL Ten days	Decreased growth and reproduction	[2]

Zooplankton may consume in different ways based on their species, life stage, as well as how easy it is for them to find food [42]. The predator's size relative to the prey, the prey's moving style, and how easily the predator may capture each type of prey all shape the selection of prey. Additionally, a mix of mechano- and chemo-receptors helps animals determine appropriate food [43]. Animals that can see well, like fish larvae, tend to take the biggest, most obvious food because they are more likely to become susceptible after an encounter. Non-visual suspension feeders, on the other hand, like copepods, eat smaller species that are easier to avoid and the growing stages of larger species [44].

10. MICROPLASTICS UPTAKE IN ORGANISMS

Microplastics can get into the body in a number of ways, such as through eating [45], breathing [46], or touching the skin [47]. The physiochemical characters of the environment contribute to each of these exposure pathways. Microplastics might potentially harm human health, including secondary genotoxicity [48] and inflammation, or accumulation may trigger and strengthen immunology response [49]. We have only recently discovered about how microplastics affect sea life [50]. Marine organisms may be hurt by microplastics because they can physically block or damage feeding parts or the digestive system, or they can cause other kinds of harm to the body. Microplastics can also transport toxic chemicals (additives, monomers, sorbed compounds) into marine species.

11. EFFECT OF MICROPLASTICS ON AQUATIC BIOTA AND HUMAN FOOD SAFETY

11.1. Possible threat to flora and fauna

Animals that remain in water are directly or indirectly exposed to MPs when they swim in bodies of water. This is a common way for aquatic animals like zooplankton, mussels, crabs, marine worms, and fish to take in MP [53]. When there is an abundance of these MPs in the ocean or river, they get into bodies of marine fauna and build up into their organ system. Marine animals are mostly exposed to MPs through eating. Physical,

Table 2. In vivo toxicological effects of microplastics on typical terrestrial species

Terrestrial species	Size/exposure time	Toxicity	References
Collembolan	<5 mm 0-24 days	Inhibited growth and reproduction	[47]
Earthworms	250 and 1000 g 28 days	Histopathological injury	[4]
Folsomia candida	<500 µm 28 days	Induced avoidance behaviors and inhibited reproduction ability	[48]
Mice	5 and 20 µm 17 days	Accumulated in the liver, kidney, and gut	[47]
Mice	5 and 20 µm Six weeks	Change of the gut microbiota composition	[19]
Wheat	50, 500, 4800 nm 24, 48, 72 h	Disturbed growth	[48]
Lettuce	0.2 and 1.0 µm 0-30 days	Accumulated in tissue	[45]
Folsomia candida	80 -250 µm Seven day	Change the physical properties of soils	[21]

chemical, and biological effects on the environment may occur because of MP. Ingesting MPs has led to many adverse effects, including starvation, problems with digestion and eating, and more deaths and illnesses. When larger plastic remnants are consumed by aquatic creatures, the plastic inhibits their digestive tracts, resulting in malnourishment and illness. Entanglement and ingestion can have a physical impact on animals, with entanglement occurring far more frequently. When plastic waste gets tangled in plastic tires, rings, or fibers, it generally causes drowning, asphyxia, or strangulation in aquatic creatures [54].

11.2. Possible threat to land flora and fauna

The basic origin of plastic contamination that seep into soil include fertilizers, abandoned plastic trash, mulch from agricultural land, and domestic sewage [55] MP particle size had a significant influence on liver, kidney, and gut of mice, as well as on tissue accumulation kinetics and distribution patterns. It is likely that MP particle size affects the hazardous kinetic/toxic dynamic behavior in mice. Induced dysbiosis of the intestinal microbiota, decreased intestine mucus secretion, and MPs' interactions with bacteria and their role as a microbial habitat [56].

12. IN VITRO TOXICOLOGICAL STUDY OF MICROPLASTICS

Ecotoxicology experiments conducted in vitro provide evidence in favor of initiatives to design and use animal testing for reasons related to science, ethics, and the economy. Numerous toxicity endpoints have been measured using cell lines. MPs are absorbed by cells and have a major biological impact on tissues. As an important indicator of MP toxicity, aquatic plants are crucial to preserving the equilibrium of the marine ecosystem. In Chaetoceros neo gracile, MPs can decrease algal cell bioavailability, cellular esterase activity, and neutral lipid content. In Chlorella vulgaris, MPs may inhibit cellular photosynthesis. Even so, it's very possible that terrestrial and aquatic plants will interact with MPs in the ocean. Regretfully, data from in vitro MP toxicity investigations are currently insufficient.

13. INFLAMMATION AND IMMUNE RESPONSES

Pollution from microplastics (MP) is pervasive and posing a growing risk to aquatic biota. Although their harmful effects on cells and organisms have been documented in recent scientific papers, it is still unknown what chemical mechanism underlies their

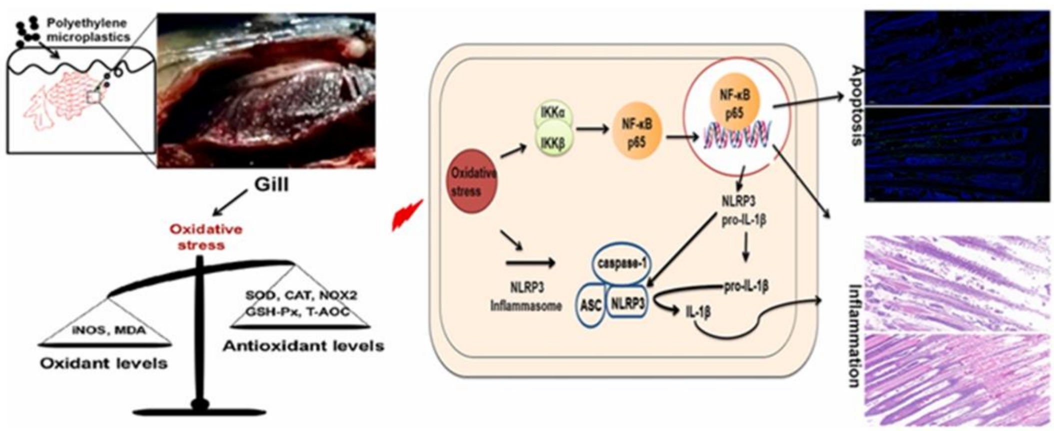

Figure 10. Microplastic pollution is threat to aquatic biota [58]

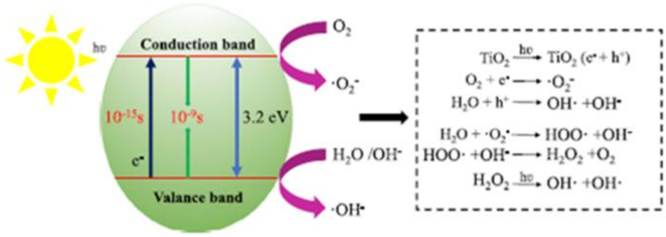

Figure 11. Engineered nanomaterial is the proposed mechanism for the photo catalytic elimination of contamination over TiO2 ENM (Reproduced with permission from Ref. [68]

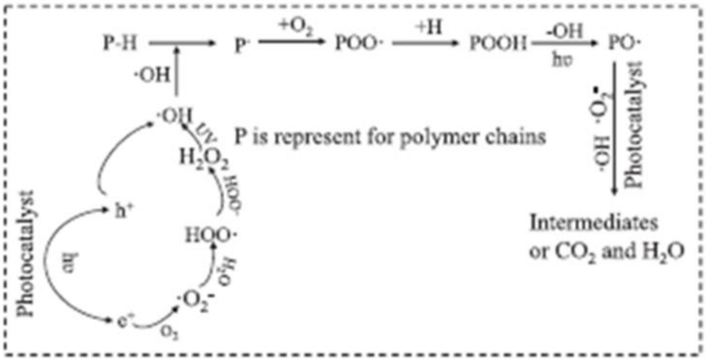

Figure 12. Mechanisms of photo degradation of plastics [69]

toxicity [57].

14. CURRENT TRENDS IN MP DEGRADATION

Large plastics break down into smaller ones, which increases bioavailability and pose a major hazard to the ecosystem [59]. Due to their minor weight and inert qualities, these are exceedingly difficult to eliminate from the aquatic environment [60]. Massive MP particles can remove the majority of microplastics from wastewater treatment plants (WTPs) during primary or secondary treatment. Some MPs, however, may have stayed in the biosolid, while other small-sized MPs were discharged with the final waste and went directly into urban rivers and lakes and rivers [61].

15. MPS DEGRADATION METHODS

15.1. Advanced oxidation processes

Based on the generation of various reactive oxygen species (ROS), such as sulfate radical (SO4•¡, E0 = 3.1 V versus NHE) and hydroxyl radical (•OH, E0 = 2.7 V vs. standard hydrogen electrode [NHE]) for Fenton, AOP, an efficient chemical elimination method, performs exceptionally well in degrading persistent organic contaminants in aqueous matrices [62]. Plastic wastes may be effectively transformed into valuable compounds by the Fenton procedure [63]. Additionally, sulfate radical (SR)-based activated organic pollutants (AOPs) have been proposed as "systems" to break down a variety of refractory organic pollutants in a complex aquatic environment [64]. The MP breakdown process was directly driven by these produced species, which resulted in chain termination, the creation of valuable products, or even complete MP mineralization [65].

15.2. Photochemical oxidation

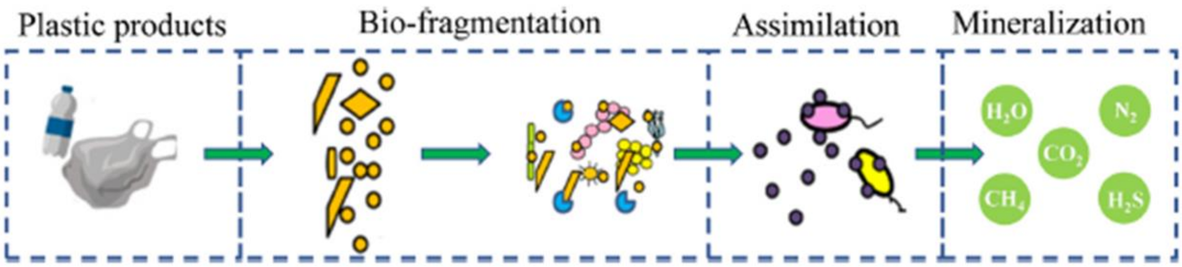

Figure 14. Biodegradation pathway of MPs (Reproduced with permission from Ref. [73]

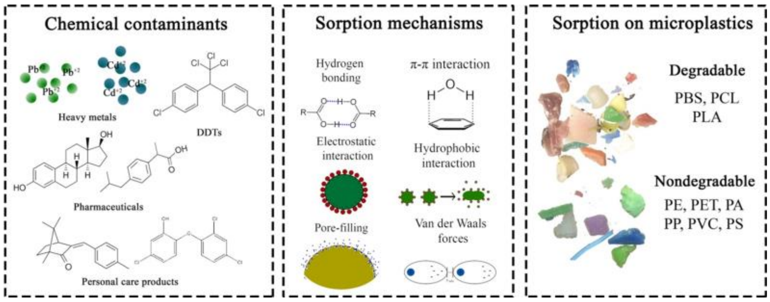

Figure 15. Chemical pollutants absorbing into both biodegradable and non-biodegradable micro plastics [79]

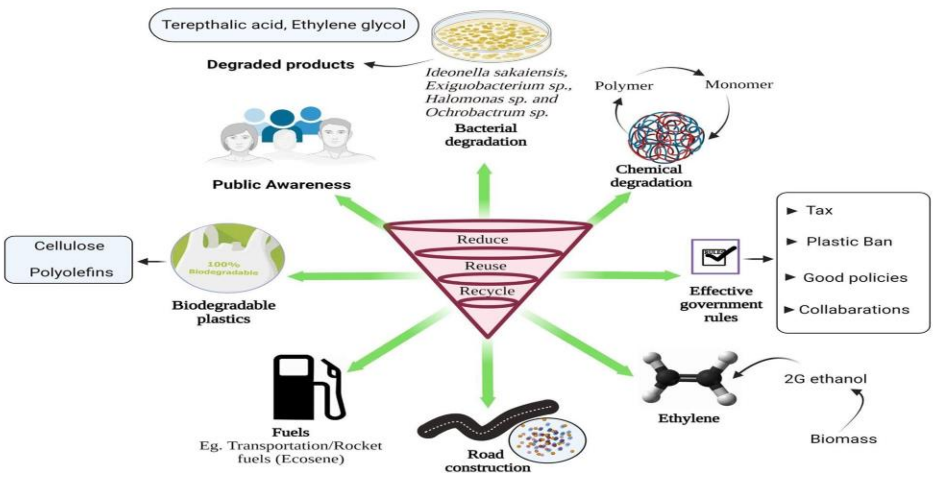

Figure 16. Pathways of microplastics controlling techniques [94]

One of the key processes in the breakdown of polymers is thought to be photo degradation [66]. When it comes to MPs, extended exposure to UV-enriched sunlight can cause morphological changes like flakes and cracks as well as environmental free ion production, by adding oxygen, hydrogen elimination and chemical cleavage or cross-linking. The most significant factor thought to be impacting this process was UV radiation. MPs' spontaneous photo degradation was uncontrollable [67].

15.3. Electrochemical oxidation

There are two types of electrochemical oxidation: anodic oxidation and indirect cathodic oxidation. Figure 3 illustrates the most often utilized process, which is known as anodic oxidation (AO). It involves either the indirect oxidation of pollutants by •OH or reagents

Table 3. Analysis and Assessment of Microplastics

Method	Microplastic removal Efficiency (%)	Comments	References
Sand filtration	74–97	Less Cost	[75]
Disc filtration	40–99	Comparatively minimal energy use, clogged filter cloth	[75]
Membrane bioreactors	Up to 100	Extremely high MP removal efficiency result in minimal sludge output, high volumetric loading, and high-quality effluent, all of which lower the cost of sludge treatment and disposal.	[75]
Conventional activatedsludge	91–98	Dependable, economical, adaptable, and capable of handling a broad variety of influent concentrations Extended periods of storage, elevated energy expenses, and the handling and elimination of sludge	[76]
Dynamic membranes	ND	Cheap, simple to clean, and energy-efficient only micro particles other than MPs were tested	[44]
Coagulation	17–99	Ideal for removing tiny MPs, low-power consumption, basic mechanical components, Large volumes of sludge and significant chemical requirements	[77]
Electrocoagulation	99	Energy-efficient, economical, automatable, suitable for the removal of small MPs, less sludge, and no need for chemical coagulants Cathode passivation and the sacrificial anode's repeated need for replacement	[78]
Sol-gel agglomeration	99	A substitute for conventional flocculants. The MP particle's surface characteristics and chemical makeup has a significant impact on removal efficiency.	[79]
Bio agglomeration (bio-flocculation)	50–80	Microbes and jellyfish create bioflocculants; only bench-scale experiments are described.	[80]
Retention ponds	85	Used in stormwater management	[81]
Bio retention systems	70–84	There is currently a dearth of research on MP removal efficiency. In order to manage stormwater	[82]

(active chlorine, H_2O_2, O_3, and peroxymonosulfate) in aqueous solution, or the direct oxidation of organic pollutants on the anode surface through charge transfer. Indirect cathodic oxidation is thought to be an electro-Fenton (EF) process. The Fenton reaction, which generated •OH or other reactive oxygen radicals from the breakdown of H_2O_2 by the catalytic action of Fe^{2+}, was the source of free radicals that led to the oxidation of organic pollutants in EF [70].

15.4. Biodegradation

Scientists have discovered MPs in the natural environment remain stable for lengthy span, certain microbes continue to destroy them [71]. Microbes can break down a variety of organic contaminants, including MPs, and are very adaptable, allowing them to survive in nearly any environment [72]. MPs were utilized as growth substrates for biofilms during the MP breakdown process.

16. MICROORGANISMS PARTICIPATING IN THE DEGRADATION OF MICROPLASTICS/PLASTICS

Microplastics (MPs) degrade in various environments through an intricate procedure involving physicochemical and microbiological factors [74]. Despite being less vulnerable to microbial invasion than other materials, microbial deterioration significantly impacts MP transformation [75]. Researchers have isolated these organisms from several habitats to investigate the capacity of different microorganisms, such as fungi and bacteria, to degrade MP. Numerous bacteria in soil, water, and the atmosphere have demonstrated encouraging results in the breakdown of MP in lab settings, enabling in-depth observation of metabolic pathways and environmental impacts. Similarly, fungi, which are widely distributed and can reproduce, can break down MPs by reducing their hydrophobicity through the creation of chemical bonds and by using them as a source of carbon [76].

17. SORPTION

The prevalence of microplastics (less than 5 mm) as pollutants is a growing problem. These were discovered in a variety of environmental settings, including isolated areas devoid of human habitation. Microplastics interact with a wide range of ecological compounds that are categorized as heavy metals or organic contaminants once they are released [77]. Due to certain sorption mechanisms, certain contaminants have an affinity for microplastics and can become carriers of dangerous substances. Here, we concentrated on field and lab studies that examined the sorption behavior of both biodegradable and non-biodegradable microplastics [78].

18. CURRENT GLOBAL STATUS AND CHALLENGES OF THE MICROPLASTICS INDUSTRY

Controlling the massive global production of plastic presents significant difficulties. Source management is the most acceptable strategy for reducing microplastic contamination [80]. Society must, in the short term, restrict the use of unnecessary single-use plastic products like straws, shopping bags, water bottles, and utensils. To lessen environmental waste, the government should prioritize waste collection and recycling initiatives. The government should concentrate on garbage collection and recycling programs to reduce environmental waste. It is necessary to create standardized analytical techniques to accurately detect and measure microplastics and nanoplastics in various matrices [81]. Developing cost-effective and environmentally friendly alternatives to plastics is essential; in the long term, researchers must consider ways to break down plastics into their parts so they can be remodeled into new materials [82]. Researchers have found a mutant enzyme that breaks down plastic drink bottles far more quickly than in oceans, which can take centuries [83]. These are the typical actions we can take to prevent plastic troubles. Recent studies have shown the effectiveness of bacteria in decomposing plastic [84-93]. The existence of heavy metals in plastic-derived samples from aquatic environments has been an increasingly pressing issue in recent years.

19. CONCLUSION

To deal with microplastic contamination, global cooperation in waste management, plastic production reduction, biodegradable alternative development, and novel microbial degradation methods is urgent. Comprehensive laws, public education campaigns, and interdisciplinary research ought to take precedence in any future initiatives to lessen the harm that microplastics cause to the environment and public health. In addition to protecting ecosystems and human populations, we may contribute toward a cleaner environment by embracing sustainable practices and advancing scientific understanding.

20. ACKNOWLEDGEMENT

NA

21. CONFLICT OF INTEREST

The authors have declared that there is no conflict of interest.

22. SOURCE/S OF FUNDING

NA

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