
Microplastics Formation, Distribution, Impact, and Mitigation Strategy: A Review

Yohanna Anisa Indriyani^{1*}, Rustam Efendi²

¹ Alumni of Soil Science Study Program, Faculty of Agriculture, IPB University, Indonesia

² Department of Mechanical Engineering, Faculty of Technique, Universitas Sulawesi Tenggara, Indonesia

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Abstract

The use of plastics in this modern era has become an inevitable necessity, due to its favorable properties such as lightweight, corrosion resistance, good plasticity and flexibility, thermal and electrical insulation, and low cost. Unfortunately, the production and use of plastics, which is increasing year by year, is being realized more as a hazard to the environment and living beings, especially due to microplastic contamination. Microplastics, defined as plastics less than 5 mm in size and the result of abiotic and biotic degradation of plastic polymers, have been reported to pollute various aquatic and terrestrial ecosystems, and are found in various plants, animals, and human tissues, as well as biological samples. The global concern for microplastic contamination makes it important to have an understanding of how microplastics are formed in the environment and what mitigation strategies can be done. This paper reviews recent articles on issues related to microplastics from the Scopus database, Google Scholars, and other web sources from the period covering 2017-2024, and focuses on understanding the formation of microplastics in the environment, microplastics in aquatic and terrestrial ecosystems (sources, distribution, and environmental impacts), the impacts of microplastics on living organisms (plants, fauna, and human health), and microplastics mitigation strategies.

Keywords:

Degradation, health risk, impact, mitigation strategy, pollution

1. Introduction

Plastic, a man-made long-chain polymer, has become an essential and indispensable part of modern human life. Today, there is hardly a single item that is not made of or does not contain plastic. Plastics have been used in almost all branches of industry, due to their characteristics of being lightweight, corrosion resistant, having good plasticity and flexibility, being thermally and electrically insulating, and being relatively inexpensive [1]. The origins of plastics date back to the first synthetic plastic, known as Bakelite, which was produced in 1907 and marked the beginning of the global plastics industry. Global plastic production increased rapidly, reaching 359 million tonnes in 2018. According to the OECD Global Plastics Outlook Database, almost two-thirds of plastic waste comes from short-lived products such as textiles, packaging, and consumer products [2].

Due to improper management and disposal practices, large amounts of plastic waste enter the environment through various pathways and cause serious problems. Despite their high

durability, under various physical, chemical, and biological processes, plastics can break down into smaller particles less than 5 mm in size. These small particles are called microplastics [3], a term used for the past few decades. Microplastics, based on their origin, can be divided into primary and secondary microplastics. Primary microplastics are plastics produced in particle form (commonly used in the paint and varnish industry, cosmetics, automotive, construction, etc.). In contrast, secondary microplastics arise as a result of the fragmentation of plastic polymers under various environmental influences [4].

Microplastic pollution is a global issue of concern and a threat to the environment and living organisms. Microplastics are reported to have polluted various ecosystems and are even found in various plant and animal species, human tissues, and biological samples. Some studies have found that cancer, intestinal, lung, cardiovascular, infectious, and inflammatory diseases are caused or mediated by microplastics [5]. Their hydrophobic nature, particle size, surface morphology, abundance, and ability to absorb and transport various contaminants (such as pesticides and other harmful agents) to organisms and their digestive systems, make microplastic contamination considered harmful.

Microplastics are also reported to be vectors for heavy metals (such as Ag, Al, Cu, Fe, Mn, Pb, Zn) and many POPs (persistent organic pollutants) such as HOCs (hydrophobic organic contaminants), OCPs (organochlorine pesticides), PAHs (polyaromatic hydrocarbons), and PCBs (polychlorinated biphenyls) [6]. These chemical compounds can be bound to microplastics through various types of bonds and interactions, such as hydrogen bonds, halogen bonds, hydrophobic interactions, π - π interactions, electrostatic attraction or repulsion, Vander Waals forces, and partitioning effects [7]. The interaction of heavy metals and POPs with microplastics is harmful as they exhibit mutagenic, carcinogenic, and teratogenic effects on organisms [8]. In humans, these compounds can cause impairments in immune function and metabolism, oxidative stress, and cytotoxicity, as well as neurotoxicity and neurodegenerative diseases [9].

The global concern for microplastic contamination makes it important to have an understanding of how microplastics are formed in the environment and what mitigation strategies can be done.

2. Material and Methods

This study presented a review focused on the formation, distribution, impact, and mitigation strategies of microplastics. Literature used in this review was obtained from the databases of Scopus, Google Scholars, and other web sources using keywords such as 'microplastic formation', 'microplastic in terrestrial ecosystems', 'microplastic in aquatic ecosystems', 'microplastic impact on plant', 'microplastic impact on animal or fauna', 'microplastic impact on human', 'microplastic mitigation', for the period spanning 2017-2024.

3. Results and Discussion

3.1 From Plastic to Microplastic: Understanding Microplastic Formation in the Environment

The large amount of plastic waste is partly because most plastics (both processed and manufactured plastics) are produced for single use, so they will be discarded when their function or life span has expired. Improper waste management and processing have made single-use plastics a major contributor to municipal solid waste in most developing countries. Plastic, due to the influence of certain abiotic and biotic processes, can be degraded into various smaller sizes: (i) >20 mm size which is termed macroplastic, (ii) 5-20 mm size which is termed mesoplastic, (iii) <5 mm size which is termed microplastic, and (iv) <1 μm size which is termed nanoplastic [10]. Microplastics, based on their origin, can be divided into two types namely primary microplastics, and secondary microplastics. The distinction between these two is based on whether the microplastics were originally produced at particle size (the size dimension of the plastic fits the criteria for the term microplastics) or whether the microplastics originate from the degradation and/or breakdown of larger polymers. Microplastics, based on their shape, can be categorized into fragments, fibers, foam, pellets, and films [11].

Secondary microplastics can be formed through abiotic and biotic processes, including (i) photodegradation, (ii) mechanical degradation, (iii) thermo-oxidative or thermal degradation, (iv) chemical degradation, and (v) biodegradation [3]. Microplastic degradation will occur, as long as abiotic and biotic factors are present, until the formation of smaller particles and subsequent mineralization into CO₂, H₂O, and biomass through biotic processes [12]. The degradation process and the time required to completely degrade plastics depend on external factors (abiotic and biotic) and internal factors (plastic polymer type, material thickness, etc.). Figure 1 summarizes the classification of microplastics.

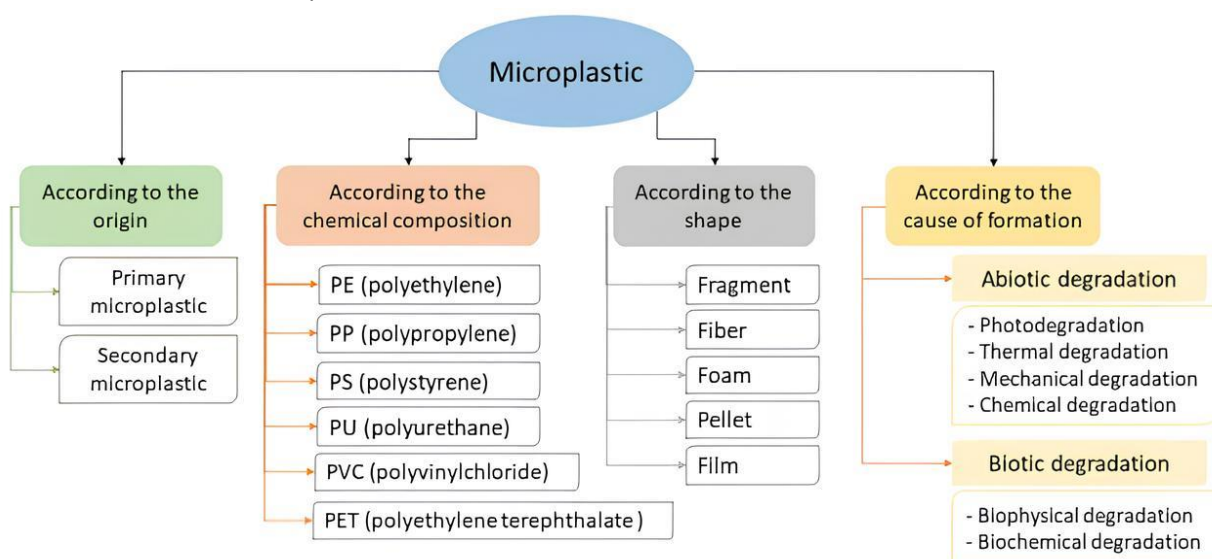


Figure 1

Classification of microplastics according to origin, chemical composition, shape, and formation related to the type of degradation. (Adapted from [5] and [13]).

3.1.1 Microplastic Formation Due to Abiotic Degradation

Plastic can be degraded into smaller particles by abiotic factors such as temperature, light, water, air, or mechanical forces, resulting in physical and chemical changes in the polymers. Abiotic

degradation of plastic polymers can occur through several mechanisms including photodegradation, thermal degradation, chemical degradation, and mechanical degradation [3].

Photodegradation of plastic occurs due to ultraviolet (UV) irradiation on the plastic surface, which then drives the degradation of plastic in three steps: (i) initiation, where polymer chain breakage occurs at the carbonyl group (polymer backbone) to release alkoxy and hydroxyl free radicals, (ii) oxidation, which occurs at the plastic surface, and (iii) termination, where inert compounds are formed through disproportionation and recombination reactions [14]. Thermal degradation of plastic occurs due to energy input from high temperatures, causing the plastic polymer to undergo thermo-oxidative reactions [3]. This degradation is similar to photodegradation, but the initiation process occurs due to heat absorption from the environment [14]. The amount of heat energy absorbed by the plastic polymer will drive the breaking of carbon bonds in the polymer chain, and generate free radicals that can react with oxygen to form hydroperoxides. Thermal degradation, as well as photodegradation, can result in changes to the size, color, shape, and properties of the polymer.

Chemical degradation of plastic occurs due to the presence of chemical compounds such as ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and volatile organic compounds (VOCs), which can directly attack plastic polymers or catalyze the formation of free radicals through photochemical reactions [15]. Ozone can attack the unsaturated C=C double bonds of plastic polymers and cause the breakage of polymer chains. SO_2 can generate O_3 through photochemical reactions with O_2 in the atmosphere. SO_2 can also be excited by UV radiation and generate reactive singlet or triplet states, which can directly react with the unsaturated C=C of plastic polymers. NO_2 can also generate O_3 through photochemical reactions. NO_2 is a highly reactive compound that can easily react with unsaturated C=C double bonds in plastic polymers [3].

Mechanical degradation of plastics occurs due to external forces, such as impact/friction by wind, water/waves, sand, wind, etc., in both terrestrial and aquatic environments. The effect and extent of degradation by these external forces depend on the mechanical properties of the plastic polymer. The fracture strain reflects the ability of the plastic to withstand a change in shape without crack formation. Fracture strain can vary for different plastic polymer types, ranging from 1%-900% [15].

3.1.2 Microplastic Formation Due to Biotic Degradation

Biotic degradation (biodegradation) of plastics occurs due to the influence of organisms that cause fragmentation of plastic polymers, either biophysically (through biting, chewing, or breaking activities) or biochemically (through enzymatic activities) [14]. Microorganisms can perform biophysical degradation by attaching and growing on the surface of the plastic and then breaking it down into oligomeric fragments through hydrolysis, ionization, or protonation. Meanwhile, biochemical degradation of plastics is carried out through the secretion of enzymes that can break down polymer chains into oligomers, dimers, or monomers [14]. Plastics generally have very low bioavailability, so only a small part of the plastic polymer chain has the potential for biotic degradation. Therefore, abiotic degradation of plastics that produce degradation products with lower molecular weight can accelerate the biodegradation process [16].

Plastics, based on the presence or absence of ester or amide groups, can be categorized as hydrolyzable plastics (such as PET, PA, PUR) or non-hydrolyzable plastics (such as PE, PP, and PVC) [3]. Hydrolysable polymers are generally more susceptible to biodegradation by extracellular hydrolase enzymes, while non-hydrolysable plastic polymers are relatively more challenging. Some

enzymes that have been reported to degrade hydrolysable plastic polymers include (i) PETase (an enzyme capable of hydrolysing PET), (ii) lipase, kunitz, serine esterase, and nitro-benzyl-esterase; involved in PET hydrolysis, (iii) amidase, hydrolase, kunitz, and protease; involved in PA hydrolysis, and (iv) esterase and polyester hydrolase; allegedly involved in PUR hydrolysis. The structure of the non-hydrolysed plastic polymer resembles the structure of lignin [3]. Several enzymes involved in lignin biodegradation are reported to contribute to the biodegradation of non-hydrolysable plastics, including (i) laccase; involved in PE degradation, and (ii) hydroquinone peroxidase; involved in PS degradation.

Biodegradation of plastics through hydrolytic or oxidative processes by various extracellular enzymes results in the breakdown of long-chain polymers into short-chain polymers or small molecular fragments (oligomers, dimers, or monomers). The small molecular weight products of degradation can be taken up by microbes or undergo intracellular metabolism within microbial cells. Ultimately, through microbial extracellular and intracellular processes, plastic polymers can be mineralized to CO₂ and H₂O under aerobic conditions and to CH₄, CO₂, organic acids, H₂O, and NH₄ under anaerobic conditions [3].

3.2 Microplastic in Environments: Source, Distribution, and Its Impact

Under the influence of certain abiotic and biotic factors, plastic degrades into microplastics and undergoes translocation from one soil layer to a deeper soil layer, including penetrating the groundwater. Microplastics can also be transported to waters (rivers, oceans, etc.) because they are carried by wind (microplastics on the soil surface or atmospheric microplastic particles) or water (rainwater runoff on the soil surface or subsurface water flow).

3.2.1 Microplastic in Terrestrial Ecosystems (Soils/Sediments)

Several studies confirm that soil health parameters are becoming threatened by plastic contamination [17]. Microplastics enter the soil environment through various pathways, including the improper disposal of plastic waste, the application of soil amendments (compost or sludge), the use of plastic mulch, the use of microplastics-contaminated water for irrigation, or the deposition of microplastic particles from the atmosphere [18]. Soils are one of the main reservoirs of microplastic accumulation in terrestrial ecosystems; and their abundance in each soil can vary depending on the type of land use (i.e. agricultural land, industrial land, urban land, etc.), as well as the composition, shape and size, and source of microplastic pollution [19]. Table 1 depicts the abundance of microplastics in some terrestrial environments, either natural ecosystems or anthropogenic ecosystems.

In wet agricultural land, such as paddy fields, irrigation and application of microplastic-coated urea fertilizer are identified as the main origins of microplastics. In dry agricultural land, such as sweet potato farming, sewage sludge application and the use of plastic mulch are identified as the main origins of microplastics in the soil [29]. When microplastics accumulate on the soil surface, they can be transported vertically to the subsurface and deeper layers, through uptake by soil organisms, root absorption, water leaching, etc. Microplastics that enter the soil can, in turn, travel to the groundwater system through penetration into soil pores or leaching into aquifers.

Microplastic contamination can alter soil physical properties such as water holding capacity, soil mass density, soil structure, hydraulic conductivity and soil particle size distribution, and soil chemical properties such as soil organic carbon content, soil nutrient content such as phosphorus and organic phosphate, organic nitrogen, and ammonium nitrogen [30]. The relatively high

accumulation of microplastics that clog soil pores can reduce the infiltration capacity of the soil, which will affect the nutrient cycling in the soil, the diversity of soil microbial communities and abundance, and ultimately the growth, development, and productivity of crops [30].

Table 1
Inventory of microplastic abundance in sediment/soil environments

Ecosystem	Location	Identification method	Abundance (particle kg ⁻¹)	Type of microplastics	Ref.
Coastal sediment	Muaro Lasak, Indonesia	Microscope, FTIR	13.23	Fiber, film, and fragment. PE, PP, PA	[20]
Bay sediment	Banten Bay, Indonesia	Stereomicroscope, FTIR	267 ± 98	Foam, fragment, granule, fiber. CP, PP, PE, diphenyl sulfide, PET.	[21]
Mangrove sediment	Todos Santos Bay, Brazil	Stereomicroscope, spectrometer	7735 - 8417	Fiber, fragment. -	[22]
Lake sediment	Turkey Susurluk Basin, Turkey	Stereomicroscope, ATR-FTIR	276 particles m ⁻²	Fiber, fragment, film. PET, PP, PS, PVC, polyacrylates.	[23]
River sediment	Alaknanda River, Uttrakhand	Stereomicroscope, SEM	955	Fragment, film, pellet. PP, PS, PT, HDPE, PVC, LDPE.	[24]
Estuary sediment	Changjiang Estuary, China	Stereomicroscope, FTIR	121 ± 9	Fiber, fragment, pellet. PS, PET, rayon, polyester, acrylic.	[25]
Agricultural soil	Iran (south-central Iran)	Stereomicroscope, Raman spectrometer	40 - 1100	Fiber, film, fragment. PET, PP, PS, nylon, PS-nylon.	[26]
Farmland soil	Suburbs of Shanghai, China (shallow soil [S], deep soil [D])	Stereomicroscope, FTIR	78.00 ± 12.91 [S], 62.50 ± 12.97 [D]	Fiber, fragment, film, pellet. PP, PE, polyester.	[27]
Dumping site soil	Bantar Gebang, Indonesia	Microscope, FTIR	10929 ± 13547	Fragment, film, fiber. PE, PP, PET, PU, PS, PVC, PDAP.	[28]
	Cambodia		26749 ± 67488	Fragment, film, fiber. PE, PP, PET, PS, PU, PVC, PDAP.	
	Laos		8402 ± 7872	Fragment, film, fiber. PE, PP, PS, PET, PU, PVC.	
	'Smoky Mountain', Philippines		20333 ± 12897	Fragment, film, fiber. PP, PE, PU, PET, PMMA, PVC, PDAP.	
	Vietnam		20608 ± 23633	Fragment, film, fiber. PET, PE, PP, PDAP, PS, PVC, PU, PMMA.	
	Chennai and Bangalore, India		3519 ± 4382	Fragment, film, fiber. PE, PET, PP, PVC, PDAP, PU, PS.	

Note: PE: Polyethylene, PET: polyethylene terephthalate, PP: polypropylene, PA: polyamide, PVA: polyvinyl alcohol, PVC: polyvinyl chloride, PU: polyurethane, PS: polystyrene, PTFE: polytetrafluoroethylene, PDAP:

poly diallyl phthalate, PMMA: Polymethyl methacrylate, HDPE: high-density polyethylene, LDPE: low-density polyethylene, CP: cellophane

3.2.2 Microplastic in Aquatic Ecosystems

Microplastics have been reported to be distributed in all freshwater systems (lakes, rivers, wetlands, and groundwater), as well as in marine ecosystems. Most microplastics released into terrestrial ecosystems will end up in marine ecosystems. In coastal areas, these terrestrial microplastics are a major contributor to marine plastic debris, with 1.15-2.41 million tonnes of plastic waste being transported to the ocean annually from rivers [32]. Rivers are estimated to transport 70-80% of the plastics that eventually reach the oceans, with major inputs being unmanaged plastic waste, agricultural waste, and wastewater treatment plant effluent [33].

In the marine environment, microplastics dispersed on the sea surface or suspended in the water column can be transported from their release zone to remote areas, or accumulate in mid-oceanic regions (so-called 'gyres', oceanic current systems that flow in a circular pattern). The highest concentration of microplastics is found in the middle of the water column, which indicates that microplastics are distributed vertically due to the influence of wind and currents that produce turbulent water regimes [34]. The sinking speed of microplastic fragments is influenced by shape and density, including the biofouling phenomenon. Biofouling is the phenomenon of microorganisms aggregating and forming biofilms on the surface of plastic fragments [35].

3.3 The Impact of Microplastic on Living Organisms

Microplastics can bioaccumulate in biological systems and have toxic effects, such as damaging the immune and digestive systems of organisms and even causing cytotoxic effects on human brain cells [5]. The large surface area of microplastics makes them potential carriers of toxic chemicals, and adsorbers/absorbers of various contaminants. Microplastics also harm plants, including inhibiting plant growth and development, which in turn can reduce crop productivity. This will certainly threaten the survival of humans, who depend on plants as one of their food sources. The impacts of microplastics on soil productivity and living organisms are summarized in Figure 2.

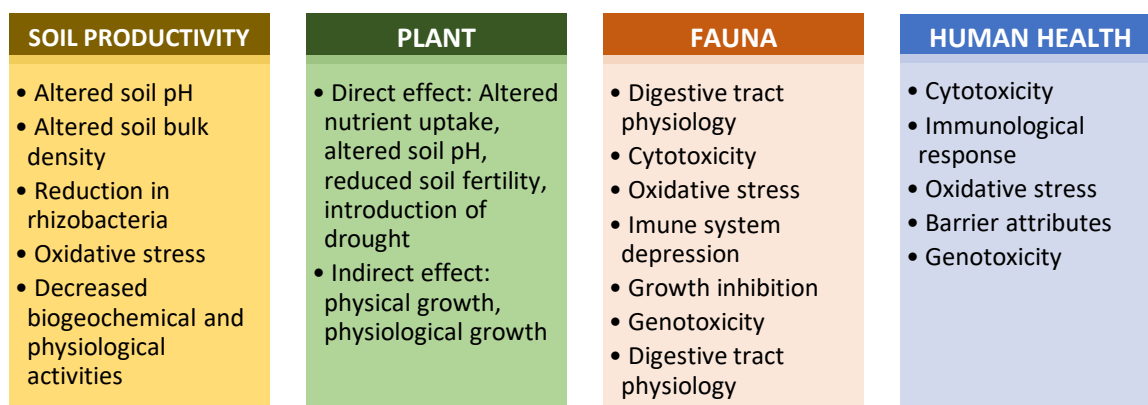


Figure 2
Impact of microplastic on soil productivity, plant, fauna, and human health.
(Adapted from [10] and [19]).

Microplastic contamination can inhibit plant growth and development, both directly (causing physical and physiological obstacles to plants) and indirectly (causing a decrease in soil health, which in turn affects plant productivity). Microplastic contamination can directly affect seed germination, root growth and activity, shoot and leaf growth, and overall crop yield. This physical

growth inhibition will be accompanied by changes in several physiological mechanisms, such as photosynthesis, ionic homeostasis, redox regulation, and hormonal regulation. The indirect impact of microplastic contamination on plants can occur, for example, due to changes in soil physical-chemical-biological properties in contaminated soils, which in turn affect plant growth and development. Microplastic stress can alter the community structure and diversity of soil biota including soil bacteria, resulting in changes in the activity of soil biota. PE stress, for example, changes the diversity of nitrogen-fixing microbes [37] and can cause changes in soil NH_4^+ and soil pH [19].

In vivo studies using marine organisms show that microplastics have significant toxic effects through various routes of exposure, such as intravenous, intraperitoneal, subcutaneous, dermal, and oral exposure. Exposure to microplastics can be both direct and indirect exposures, where the effects vary depending on the route of exposure. Direct exposure occurs when microplastics come into direct contact with an organism and generally cause short-term acute toxicity, while indirect exposure occurs when microplastics are integrated into the food web and generally cause chronic organ toxicity. In addition to the route of exposure, the size, concentration, and duration of exposure to microplastics have also been investigated by in vivo studies. Several studies have reported that microplastics can accumulate in the digestive tract, muscles, and gills of fish; as well as cause changes in digestive tract physiology, cytotoxicity, oxidative stress, immune system depression, growth inhibition, and differential gene expression in marine animals [5].

Clinical trials on the effects of microplastic accumulation have also been investigated from human samples, including feces, colectomy, placenta, and meconium samples. In vitro studies have been conducted by utilizing several human cells, such as human dermal fibroblasts and peripheral blood mononuclear cells, human lung epithelial cells, human adenocarcinoma cell lines, etc. This is due to the absence of epidemiological data [5]. Danopoulos et al. [38] evaluated microplastic exposure using quantitative meta-regression analysis of secondary data from various in vitro studies on human cells. The toxic effects of microplastic exposure on human cells can be categorized as cytotoxicity, immunological response, oxidative stress, barrier attributes, and genotoxicity.

3.4 Mitigation Strategies of Microplastic

3.4.1 Mitigation Strategies of Soil or Groundwater Microplastic

Research on the mitigation of microplastics from soil or groundwater environments is still limited. Most research on this topic has focused on indirectly mitigating soil/groundwater microplastics by reducing the amount of microplastic contamination released from sources into both environments [39]. Sewage sludge, which is one source of soil/groundwater microplastics, can be reduced through pyrolysis, but the drawback of this method is the possibility of other microplastics forming in the process [39]. Other mitigation recommendations in plastic reduction, particularly plastic mulching as another major source of soil/groundwater microplastics, are suggested by Qi et al. [40]. The use of biodegradable plastics is also one of the recommendations to reduce the use of conventional plastics, given that plastics cannot be fully replaced [40]. Wong et al. [41] suggested an environmental microplastic extraction method (through filters or pumps) followed by chemical/biological degradation in a reactor. However, this method is difficult to implement on a large scale [39]. Several strategies suggested to stakeholders that could be useful for soil and groundwater microplastic mitigation, including control of plastic production and

consumption, use of recycled plastics, use of renewable energy, and garbage management approaches (Figure 3).

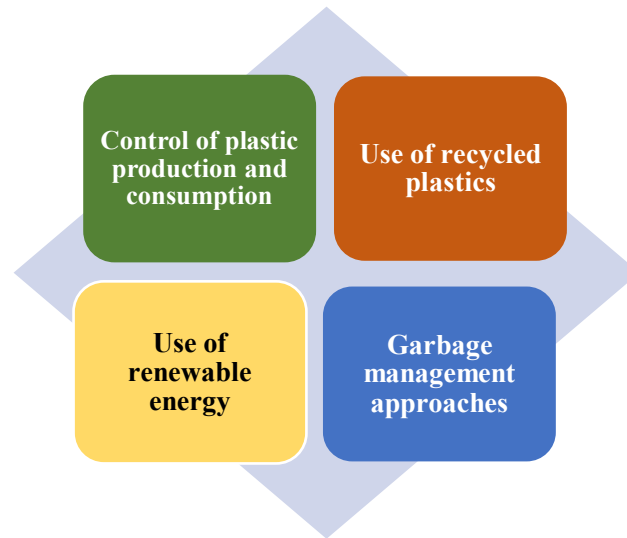


Figure 3
Mitigation of soil and groundwater microplastics.

3.4.2 Mitigation Strategies of Aquatic Microplastic

There are two strategies to mitigate microplastics in aquatic ecosystems, as follows [5]:

(1) Conventional treatment techniques

- a. **Coagulation:** This method utilizes chemical coagulants (such as aluminum-based and iron-based coagulants) to destabilize dissolved and suspended particles to enable their removal through sedimentation. Coagulation methods have several disadvantages, including high sludge volume, the potential for coagulated sludge to contain hazardous substances, and relatively high costs due to the use of additives to increase coagulation efficiency and the need to optimize various reaction parameters to address diverse contaminants.
- b. **Adsorption:** This method utilizes adsorbents (such as graphene oxide, chitin, and layered double hydroxides) to remove microplastics from wastewater. The disadvantage of the adsorption method is the non-selective nature of the adsorption pathway.
- c. **Membrane bioreactor technology (MBT):** MBT is commonly used for the treatment of wastewater containing various contaminants (including microplastic) with varying concentrations, such as industrial and municipal wastewater. The advantages of this technique are high effluent quality and good removal efficiency with a high rejection potency towards target pollutants. The disadvantages of this technique are membrane fouling, aeration limitations, and relatively high cost due to the need to add nutritious materials to microbes.
- d. **Rapid sand filtration:** This method is known to remove various contaminants, such as suspended solids of clay particles, viruses, and also microplastics from wastewater. The advantages of this method are the relatively small land requirement, low sensitivity to water quality parameters, and high flow rate. The disadvantages of this method include limited effectiveness (the need for flocculating agents), frequent maintenance, and relatively high cost.

(2) Innovative treatment techniques

- a. **Electrocoagulation:** This method combines coagulation and electrochemical techniques, producing flocs of cations formed by metal electrodes under electric current. Electrocoagulation is considered to be more efficient than conventional coagulation as it does not use chemical coagulants, reducing costs and operating time
- b. **Electrochemical oxidation:** These methods include anode oxidation and indirect cathode oxidation. It is proven to effectively degrade various organic pollutants (i.e. antibiotics, antipyretics, dyes, and microplastics) into non-toxic products (such as CO₂ and H₂O) without the need for chemical additives.
- c. **Photocatalytic degradation:** This method utilizes photocatalytic semiconductor materials that can absorb visible or ultraviolet light and during the process will produce free radicals which degrade the microplastics. The disadvantage of this method is that it requires proper handling in the disposal of the residual sludge.
- d. **Magnetic separation:** This method utilizes magnetic materials (known as magnetic seeds), such as iron nanoparticles and magnetic carbon nanotubes, for the removal process of contaminants including microplastics. The magnetic separation method has been applied to remove microplastics from sediment and aquatic (freshwater and marine water) samples. The drawbacks of this method include its selectivity and separation efficiency which are affected by the presence of other pollutants, as well as the shape and size of microplastics.

The two mitigation treatment techniques of aquatic microplastics are summarized in Figure 4.

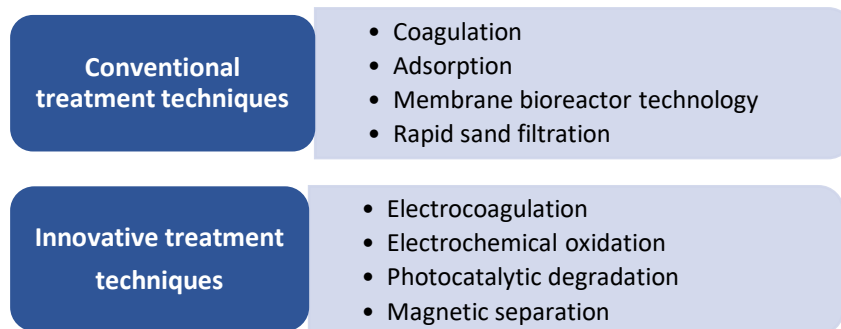


Figure 4

Conventional and innovative treatment techniques to mitigate microplastics in aquatic ecosystems.

Microplastics can be degraded through physical, chemical, and biological processes. The process of biological degradation of microplastics involves a variety of enzymes and includes the degradation of plastic polymers into oligomers, dimers, and monomers, which will then be mineralized into final products in the form of CO₂ and H₂O under aerobic conditions and to CH₄, CO₂, organic acids, H₂O and NH₄ under anaerobic conditions [3]. Microplastic biodegradation can be mediated by algae, bacteria, or fungi.

Algal biodegradation occurs mainly in different processes such as corrosion, fouling, hydrolysis, or penetration. Microalgae degrade plastics by producing several enzymes, such as ligninolytic and exopolysaccharide enzymes. Various fungi (mostly saprotrophs, opportunistic, or obligate parasites) are able to degrade plastic polymers into environmentally acceptable compounds due to the large number of intracellular and extracellular enzymes produced (such as oxidase and hydrolase enzymes), and a number of natural biosurfactants (i.e. hydrophobins). Fungi produce several intracellular and extracellular enzymes that can catalyze diverse types of

biochemical reactions to degrade petroleum-based polymers. Meanwhile, bacterial biodegradation of microplastics involves the role of several enzymes such as hydrolase, lipase, esterase, carboxylesterase, laccase, amidase, and kunitinase enzymes.

4. Conclusion

Microplastics can be formed through abiotic degradation or biotic degradation and it have been reported to contaminate both aquatic and terrestrial environments. Microplastic contamination can alter the chemical-physical-biological properties of soil, which in turn can affect plant growth, development, and yield. The impact of microplastics has been reported to be harmful to humans (causing cytotoxicity, immunological responses, oxidative stress, barrier attributes, and genotoxicity). Reducing the use of plastics, managing plastic waste at source, and mitigating the contaminated-environments is important. The study of mitigation strategies for microplastic-contaminated environments is still limited, thus opening up opportunities for further research on this topic.

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