# CHAPTER:2
# A REVIEW ON DIFFERENT METHODS OF THE DEGRADATION OF MICROPLASTIC FROM THE ENVIRONMENT

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**ABSTRACT**

Microplastic is a term used to describe microscopic plastic particles that are more common in the environment and are less than 5 mm in size. Due to their small size, these Microplastics have a negative impact on the environment, particularly aquatic life, which is inhaled, choked, and entangled. Due to the characteristics of plastic; it takes a thousand years for this microplastic to disintegrate, Therefore, it persists in nature.

Degradation is an efficient method for getting rid of plastic pollution, and since it is the result of several degradation methods working together in nature and taking future engineering applications into account, it is important to have a thorough understanding of how plastics degrade. It is clear that there are still a lot of difficulties to be solved in the degradation of microplastics, and there aren't any proven solutions that can be employed in engineering or in nature on a large scale. Research on the breakdown of microplastics is thus urgently needed.

Because of the severe harm they pose to biota, microplastic contamination has become a major global environmental concern. However, there have only been a few investigations on the removal of microplastic contamination. Due to their smaller size than plastic goods, microplastics were not suited for typical treatment methods. So many therapy options for microplastics have been researched. This study outlined the recently reported strategies for microplastic degradation, including direct photodegradation, photocatalytic oxidation, electrochemical oxidation, and biodegradation, as well as the relevant mechanisms of degradation and the present status of development. Each technique's traits and restrictions were thoroughly explained. We discovered that while almost all of them successfully degraded microplastics, most showed that under laboratory circumstances, microplastics can only be partially converted into valuable chemicals or even $CO_2$ and $H_2O$.

## 1. INTRODUCTION

Plastics are synthetic organic polymers that form when fossil fuel-based monomers polymerize. Due to their superior physical and chemical characteristics, durability, relative affordability, and ease of production in a wide range of shapes and sizes, plastics have a wide range of uses

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in many sectors. The term "microplastics," which was first used in 1968, refers to synthetic polymers with particle sizes of 5 mm or less. Primary and secondary Microplastics are the two main categories into which they fall. The term "primary microplastics" refers to tiny particles that have been created in tiny sizes for particular uses. However, secondary microplastics are created when large plastics, such as water bottles, ropes, and face masks, break apart due to a variety of environmental factors, including strain, waves, winds, tides, seawater aging, light irradiation (photo-oxidation), heat irradiation, and photo-oxidation. Plastic pollution is a recognized issue on a global scale. Absent the manufacturing of plastic fiber, its production in 2016 totaled 322 million metric tons. 90 million metric tonnes of textile fibers were produced during the same time period. More than 60% of this manufacturing is made up of plastic fibers. Cellulosic (6%) and natural fibers (27%) make up the remainder. Plastics are increasingly produced, long-lasting, and resistant to biodegradation; as a result, they accumulate to a large extent in the environment. Seas and oceans are the most affected and researched environmental compartments since it is predicted that by 2050, there will be more plastic in them than fish, with an estimated yearly input of between 4 and 12 metric tonnes. We cannot, however, ignore the fact that reports of the production, consumption, and disposal of plastics of various sizes in terrestrial and Nearby freshwater habitats have been widely published. (I) Polymer nanoparticles are produced for specific uses, such as cosmetic products, and ink for 3D printers. (ii) fragmentation of plastics due to UV photodegradation, mechanical actions, hydrolysis, or microbial degradation, as it is frequently the case in the marine environment. and (iii) wastewater treatment plants discharges, including biosolids and effluents, daily discharge. **[1]**

Recent estimates place the number of microplastic particles in the oceans at 4.85 trillion. With only 4% of studies being done in freshwater habitats, the majority of MPs research has been done in marine settings. According to the information available, freshwater microplastic concentrations are comparable to those in marine environments. The emphasis turned to investigating the effects of MPs on ecological processes and food webs after the widespread occurrence of MPs in aquatic ecosystems was demonstrated. Despite increased research efforts, little is known about how MPs impact aquatic ecosystems, particularly at lower trophic levels like phytoplankton. Numerous investigations have shown that aquatic microalgae can interact with MPs. Their futures are affected by this. Microplastic surfaces make good substrates for the growth of biofilms, and microalgae constitute an important part of the biotic communities that they colonize. Environmental aspects like water and soil quality have an impact on how

PE degrades. By adhesion and the growth of a microbial population on the PE surface, the polythene substrata deteriorate due to changes in its shape, hydrophilicity, crystallinity, mechanical characteristics, and molecular weight distribution. By secreting mucilaginous extracellular polymeric substances (EPS), algae, especially cyanobacterial species, have been observed colonizing artificial substrates such as polythene surfaces in sewage water. For polymer biodegradation to occur, extracellular and intracellular depolymerization must be active enzymatically**. [2]**

There are two key reasons why plastics and microplastics are serious environmental issues and current discussion points. First off, due to the longevity of the polymeric structures and the potential for easy transportation by winds and river currents, microplastics have the potential to absorb a variety of contaminants on their way to the atmospheric, terrestrial, and marine environments, which could pose risks to human health and the environment. Second, microplastics present in aquatic systems, for instance, have negative long-term environmental effects that endanger both human health and the health of other marine animals. As they move up and down the trophic chain, microplastics and their accompanying chemicals cause harm to a variety of creatures that ingest them. Consequently, even tiny creatures like Antarctic krill can ingest polyethylene microbeads and disintegrate them into nanoplastics. According to the reports, the average person uses 5 g, or about the weight of a credit card, of microplastics per week. Although the consequences of microplastics on the human body are not fully understood, one thing is for certain: the leaching of the chemical compounds included in microplastics (such as colors, fillers, additives, surfactants, and polymers) has an unquestionably negative influence on human health, especially that of the respiratory system. Therefore, effective technologies for removing or degrading microplastics as well as dye degradation procedures are urgently required for addressing these critical environmental concerns. **[3]**

**2.Origin of microplastics: -** How do oceanic microplastics get there? Two primary sources can be used to determine the origins of the microplastics: (a) direct runoff introduction and (b) weathering breakdown of meso- and macroplastic waste. Some microplastics, particularly the synthetic micro- and nanoparticles of plastic that are discharged into the oceans. These consist of the tiny plastic particles created in cosmetic manufacturing processes, those utilised as exfoliants in cosmetic formulas, and Utilizing respirometry, researchers replicate seawater exposure and assess the rate of carbon conversion. An incubation of a finely divided polymer in a biotic media, such as coastal sea sediment, allows for the measurement of the carbon dioxide gas produced during biodegradation. The medium is typically seeded with an active microbial culture and supplemented with urea (N)/phosphates (P) to speed up mineralization. Titrimetry is used to determine the carbon dioxide and to compute the percentage of carbon that is converted from the polymer phase to the gas phase. This serves as the foundation for the popular Sturm test for organic chemicals. Review of Polymer Biodegradation Assessment The rate of CO2 evolution from the biodegradation of polyolefins is so sluggish that 14C-labelled polymer was used to track the process, even under ideal laboratory conditions in soil seeded with activated sewage sludge consortia. **[4]**

According to recent data that are consistent with earlier rate assessments, carbon conversion decreased by 1.2% over a 3-month period. Pre-oxidized polymers biodegrade more quickly. Low-density polyethylene [LDPE] without and with pre-photodegradation have carbon conversion rates of 0.2% and 5.7% per ten years, respectively. Pre-photooxidized polystyrene will degrade in soil with growing plants at a rate of 5% over the course of six months. These findings, however, are probably overestimates because the hydrophilic oxygenated degradation products from substantial pre-degradation and the lower molecular weight polymer fraction are probably going to biodegrade quickly at first. In any case, the discovery has limited practical significance. When plastics are embrittled during beach weathering, their specific surface area increases by several orders of magnitude, which is believed to speed up biodegradation. However, this slight acceleration of an already extremely slow process will result in the mineralization of the entire deposit in a few years, which is a realistic amount of time. The findings from field exposures, such as HDPE, LDPE, and PP coupons immersed in the Bay of Bengal (India) and observed over a 6-month period in a recent study, are essentially similar with the laboratory results. Maximum shipbreaking industry and commercial abrasives in synthetic'sandblasting' media (acrylic and polyester beads). Runoff can easily transport these to the oceans. The in situ weathering of mesoplastics and bigger pieces of plastic trash in the beach environment, however, is the most plausible mechanism for the formation of the majority of microplastics**. [5]** Beaches, bodies of surface water, and deep ocean settings are all common locations for plastic trash, but as was already said, the rates of weathering at these three locations will be extremely different. Plastic waste lying on beaches is subjected to far higher temperatures than that which is floating in water. Sand-covered beaches can reach temperatures of 40 °C in the summer due to the comparatively low specific heat of sand (664 J/Kg-C). Its temperature may rise even further in areas where the plastic trash is darkly pigmented due to the heat buildup caused by solar infrared absorption. The light-initiated oxidative degradation is accelerated at higher temperatures by a factor depending on the activation energy of the process. Where the activation energy 50 kJ/mole for instance, the rate of degradation doubles when the temperature rises by only 10 °C**.** The importance of beach cleaning as a successful mitigation technique is highlighted by the realisation that microparticles (and consequently also nanoplastics) are most likely formed on beaches. The removal of bigger plastic waste from beaches before it becomes surface embrittled due to weathering can be very beneficial in lowering the amount of microplastics that enter the ocean. Therefore, beach cleanup can have ecological benefits beyond only enhancing the aesthetics of the beaches. By minimising microplastics, it also helps to maintain the health of the marine food chain**. [6]**

### 3. Fundamentals of plastics and microplastics

**3.1 plastics: -** The term "plastics" refers to a broad spectrum of synthetic or semi-synthetic materials that fall under the category of polymers. These polymers are composed of lengthy chains of carbon atoms, occasionally with oxygen, nitrogen, or Sulphur atoms added. Plastics can be shaped and pressed into solid objects of various sizes and shapes thanks to their flexibility. Plastics are also more affordable to produce, lightweight, resilient, and have a wide range of applications. However, businesses that use fossil fuels like coal, oil, and natural gas generally generate plastics. Leo Baekeland, a Belgian chemist, invented Bakelite, the first synthetic polymer to be commercialised as a coil insulator in place of shellac, beginning the history of plastic in 1907. Due to Baekeland's accomplishments, significant chemical corporations made investments in the study and creation of other synthetic polymers, which soon joined Bakelite in mass production. Polyvinyl chloride (PVC), polystyrene (PS), polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), and high-density polyethylene (HDPE) were first made available in 1912, 1932, 1933, 1941, and the early 1950s, respectively. The difficulty of cleaning and processing waste plastics, however, means that plastic collection and recycling are still ineffective. Due to the wave action and subsequent entanglement in the ocean current system, this resulted in significant plastic pollution in landfills, which finally found its way to significant bodies of water, causing garbage patches in all of the world's seas and poisoning terrestrial ecosystems simultaneously. Starting with inappropriate disposal, plastics travel a long way to become microplastics before being broken down into smaller particles (100 nm to 5 mm) by the sun, biological microbes, and waves. **[7]**

**3.2 Microplastics: -** In marine sediments in European seas, tiny bits of plastic called microplastics are collecting. The definition of MPs as plastic particles smaller than 5 mm was created in 2009 during the workshop titled "Occurrence, Effects, and Fate of Microplastic Marine Debris". The origin of the MPs, whether primary MPs (made in microscopic dimensions) or secondary MPs (degraded and fragmented plastic in the environment), was later added to the definition to further clarify it**.** To further clarify, the term "primary MPs" refers to the microbeads, fibres, nurdles or pellets that are produced in large quantities for use in personal care items, cosmetics, and other plastic production processes. Contrarily, secondary MPs are fragments of abandoned plastic waste that have broken apart into smaller pieces as a result of exposure to sunshine and other causes like microbial degradation and wave action. Since simulation studies have only considered two relevant pieces of information, namely (1) the type, volume, and mode of occurrence of plastics in the environment (ocean garbage patches and landfills), and (2) the process of degradation, physicochemical mechanisms, and duration, environmental conservationists have had difficulty quantifying secondary MPs in the environment. Although significant research has been done on experimental degradation in a lab-scale model, it is impossible to predict the real quantity, selectivity, and manner of degradation of MPs in the environment since they depend on so many different variables**. [9]**

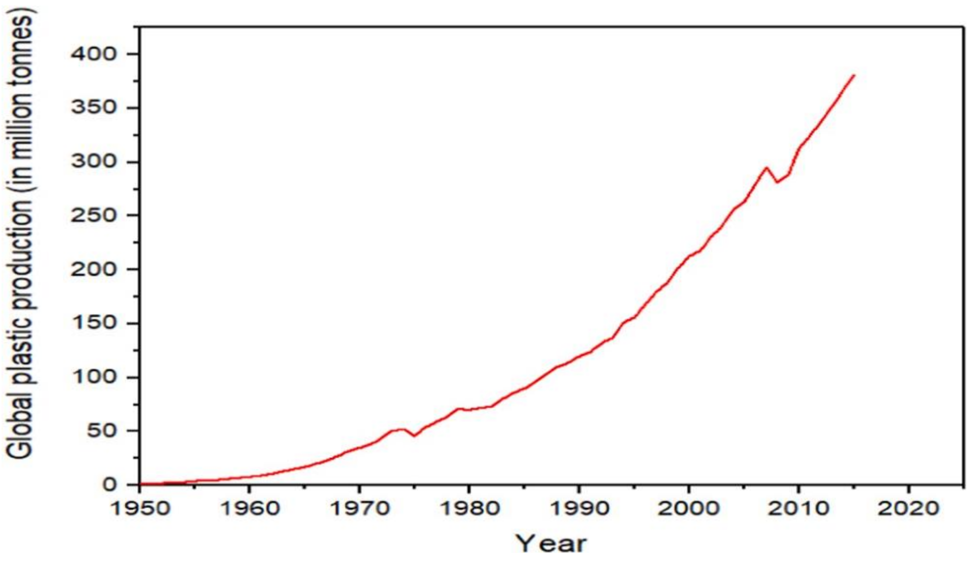


**Fig. 1.** The global production of plastics from 1950 to 2020 (in million tonnes). **[8]**

## 4. Types of Microplastics

Therefore, many types of microplastics are given below

**4.1 Primary microplastics:** - Primary MPs are the small, synthetic polymers that are produced by a variety of commercial and home cleaning products and are found in the ocean and other aquatic environments. Exfoliants like hand or mouth cleaners, such as toothpaste, which have high MP concentrations and can be used as exfoliants, are the most frequently reported primary MPs. The exfoliants, which have been employed as skin cleaners, have soft edges and amorphous features in MPs and range in size from 74 to 420 m. Other constituents, such as polyolefin particles frequently made up of PS, PE, and PP MPs, are also present and are US-patentable**.** Numerous additional product kinds, such as round clothing and uneven MPs, are moulded according on the plastic's size, shape, and color. MPs, for instance, are used in skincare products that contain PE and PS and come in a variety of colours. PE and PS granules and PS spheres less than 5 mm and 2 mm, respectively, can be present in a single cosmetic item. It was discovered that the individual care products sold on the European market had about 6% MPs. Typically, MPs range from 0.05% to 12% and have extents between 450 and 800 m in a variety of items. PE (93%) was the most prevalent MPs type discovered in cleaning supplies. MPs are produced by the petroleum industry in drilling fluids and abrasives. **[11]**

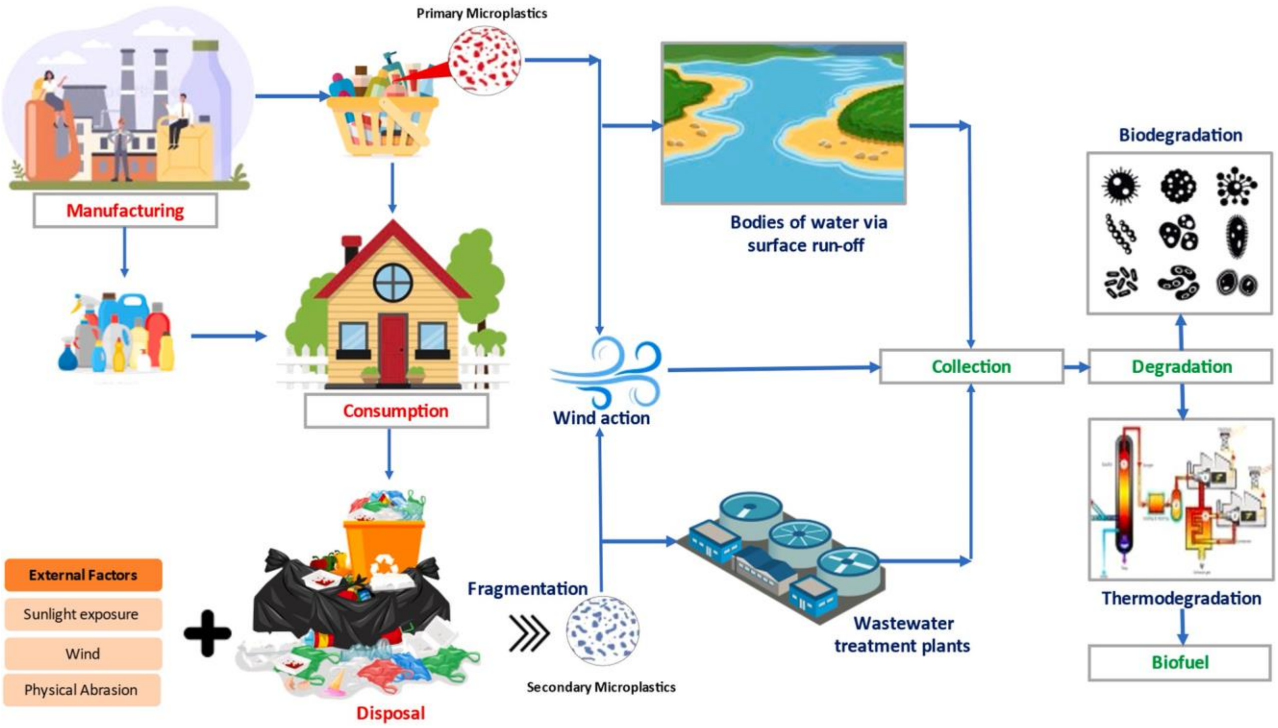


**Fig.2**.A schematic of the life cycle of microplastics. **[10]**

**4.2 Secondary Microplastics:** - Secondary or middle forms of MPs are described as large molecules of polymers that have broken down into minute pieces or trash. The enormous plastics of waste from land- and ocean-based resources can be blamed for secondary MPs of marine and aquatic habitats. According to estimates, freshwater ecosystems include between 75% and 90% and 10% to 25% respectively of plastic from terrestrial and oceanic sources. Wind-borne plastic can travel from garbage facilities to freshwater habitats. Additionally, during natural disasters like tidal waves, storms, and tornadoes, the debris of plastic can end up in the ocean, especially in developing nations without efficient control of landfilling. Although the longevity of plastics is unclear, they can persist for decades in ecosystems. Larger plastic waste gets broken up into smaller pieces after entering the ocean ecosystems by physical, chemical, or biological weathering processes. The weathering process, together with photodisintegration by sunlight, is the most important element in causing plastic to disintegrate. By breaking down chemical bonds through photo-radiative means, the polymer matrix oxidises. In comparison to beach or terrestrial environments, the pace of plastic degradation is slower in freshwater and oceanic eco-systems because of the low temperature. Additionally, surface foulants impede the oxidation reaction brought on by UV light and slow down weathering. The oxidation process in the environment and sediment is slowed down by the plastic reduction rate. Furthermore, because synthetic polymers are resistant to degrading, it has been found that open dumping of biodegradable plastics also produces secondary MPs that accumulate in the freshwater eco-system**. [12]**

**4.3 Nano Plastics: -** The most appropriate method for testing the effects of environmental pollutants like micro(nano)plastics depends on a number of factors, including the research question, the amount of information needed, and the model species chosen for the study. In vivo studies, which involve exposing an organism as a whole and allow for the evaluation of lethality, effects on behaviour, feeding, bioaccumulation, depuration, trophic transfer, and biochemical, physiological, and histopathological responses, can be used to assess the biological effects of micro(nano)plastics. Ecotoxicology is placing more and more emphasis on the evaluation of impacts on fish embryos after it was suggested as an alternative to adult in vivo experiments. Behaviour is one of the various methods that may be used to evaluate the effects of micro(nano)plastics because it can be seen as the product or goal of numerous intricate physiological and developmental processes. Though effects on behaviour parameters like mobility and avoidance may have ecological ramifications (e.g., altering the prey-predator relationship and diminishing competitive advantages), few research are addressing effects on these endpoints or primarily focusing on feeding impairment. Although data from in vitro approaches, such as primary cell culture and cell lines, do not provide information on the feedback loops involved in regulating organismal responses to environmental stress, they do allow the study of specific mechanisms of action. In vitro systems can be used to evaluate cytotoxicity, genotoxicity, dispersion within a cell, and molecular responses such the expression of genes involved in a metabolic process. These techniques have the advantage of enabling a high throughput approach to examine specific modes of action and species-specific responses (such as those of fish and humans), and are ethically advised anytime they may be used to substitute animal experiments. **[13]**

**4.4 Other Microplastics: -** Additionally, a number of compounds, including by-products and unreacted oligomers or monomers, can be discovered in plastic products. Plastics also have a better capacity for sorption processes including adsorption and absorption, which allows them to concentrate hydrophobic compounds made of carbon that are dissolved in water. As a result, the molecules left behind by plastics might constitute a "cocktail of chemicals" and harm the ecosystem.

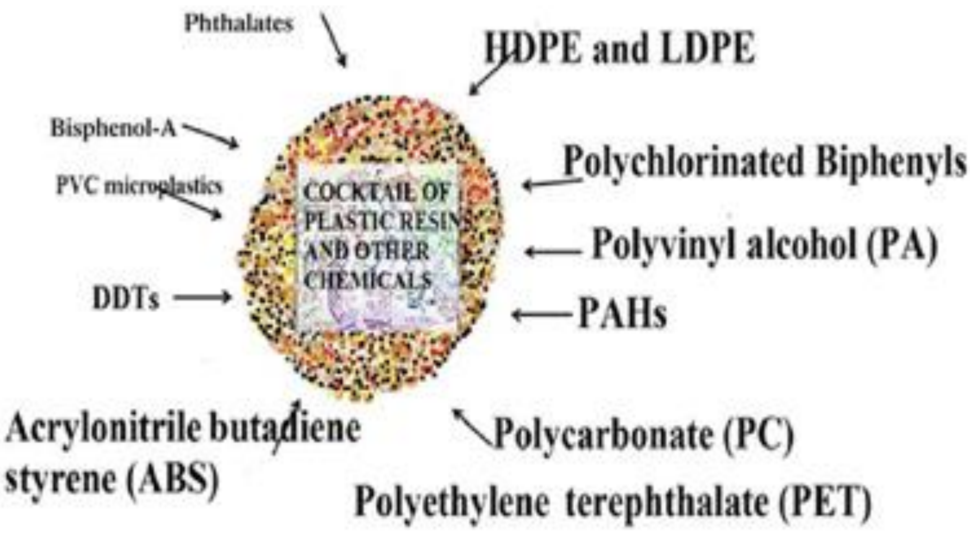


**Fig.3.** Microplastics and their associated sorbed and additive chemicals. **[14]**

**5. Degradation Processes of microplastics**

Recent hot themes include plastic pollution and the potentially dangerous effects of microplastics. There have already been a number of solutions put out, which essentially fall

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into three categories: containment, mitigation, and remediation. The containment strategy's main priorities are effective landfill management and recycling. The systematic separation of plastic trash at the landfill is the first step in proper waste disposal. Leaching in the landfill must be avoided as well because landfill runoffs are one of the main point sources of microplastics entering the environment. The containment technique does help to reduce plastic pollution, but it is not likely to be the greatest option. The purpose of these legislative strategies is to increase public awareness of the dangerous threats posed by MPs. In addition, initiatives supporting efficient waste management, recycling, organic farming, and clean-up campaigns are developed by many industries to help the growing plastic pollution issue. This method did reduce MP pollution, but it is thought to be ineffective for microplastics that come from properly disposed of wastes and from the deterioration of still-in-use objects. Therefore, environmental MP eradication requires remedial measures. Direct MP removal methods are also seen to be a more practical option. Strategies for remediation stop MPs from contaminating ecosystems. A significant potential for MP reduction through sewage matrix separation was seen in some WWTP unit operations. **[15]**

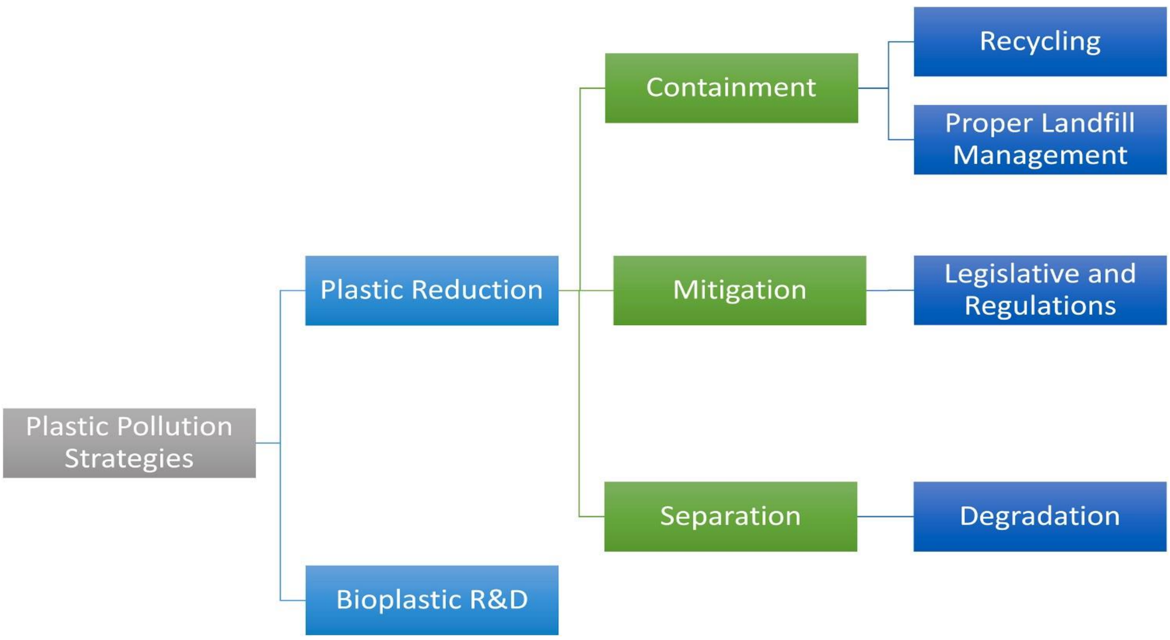


**Fig.4.** Microplastic pollution strategic map**. [16]**

Numerous research in recent years have described the ways in which MPs degrade. Physical and chemical techniques are among them.

**5.1 Physical Process: -** The three primary physical techniques are adsorption, coagulation filtering, and sol-gel. Sol-gel technique is used to create structural composite silica gel, which interacts with MPs to polymerize it. MPs are subsequently removed from the silica gel by removing the agglomerates using separation technology. To produce the separation effect, coagulation filtration makes MPs coagulate into bigger agglomerates. The sol-gel method is more suited for use in liquids since it displays a pH-induced response. The excessive usage of coagulants will harm organisms and result in secondary contamination hygroscopic nanocellulose network used to catch microplastics in the water column. Additionally, due to its porous structure and ease of production, biochar has long been considered the most promising adsorbent, and the adsorption of contaminants has been extensively researched. Through mechanisms like as electrostatic contacts, hydrogen bonding interactions, and - interactions, MPs can be absorbed by various adsorbent materials. The removal of MPs from aqueous solutions using a magnetic charcoal adsorbent with a maximum effectiveness of 99.46% was examined. A Zn-Al layered double hydroxide (LDH) can adsorb MPs in water with an efficiency of up to 164.49 mg/g, according to research on the interaction between MPs and LDHs. The researchers discovered that chitin and graphene oxide (ChGO) sponges may successfully adsorb several kinds of MPs. The development of MPs adsorbents will continue to be the main focus of attention because both magnetic and composite adsorbents have optimal removal efficiencies, but their material synthesis is complicated and expensive. In addition, further study is required to explore the adsorption process of MPs. **[17]**

**5.2 Chemical process: -**

various types of advanced oxidation degradation process of microplastic is given below-

**5.2.1. Electrochemical oxidation process: -** There are currently few investigations on the efficient oxidation-based electrochemical degradation of MPs. Consequently, a similar electro-Fenton degradation approach for MPs based on a $TiO2$/graphite ($TiO2/C$) cathode is needed. This method also produces free radicals through electrode redox to interact with the MPs and cause deterioration. The electrolytic intermediates produced by this process are unregulated, but it won't cause secondary pollution. Controlling the environmental impact of intermediates and final breakdown products should therefore be the main focus of future study. **[18]**

**5.2.2. Photocatalytic oxidation: -** Using free radicals produced by semiconductors to react with MPs to break the polymer chain and thereby start the MPs' degradation process, photocatalytic oxidative degradation is a redox process that uses solar energy as its energy source. By doing this, it can achieve the effect of removal. Numerous investigations have so far demonstrated that MPs can be degraded photocatalytically using nano-TiO2. A harder surface is produced as a result of the process, which also results in the formation of hydroxyl, carbonyl, and hydrocarbon groups. The TiO2 nanoparticle film showed the maximum degradation efficiency for PE after 36 hours and a high degradation efficiency of 98.40% for 400 nm PS within 12 hours**.** Additionally, a paper from 2021 mentioned that N-TiO2 materials produced using two different methods had good MP degradation effects. Zinc oxide (ZnO) nanorods (ZnO-Pt) have a positive impact on the breakdown of MPs in water in addition to nano-TiO2. The biggest benefit of photocatalytic oxidation is the use of solar energy as an energy source. A variety of MXene/ZnxCd1-xS photocatalysts that can degrade MPs and use light energy to catalyse hydrogen evolution have been created. The best visible-light photocatalyst is Cu2O because it has an ideal photocatalytic hydrogen evolution rate of 14.17 mmol/g/h, which simultaneously solves MPs' pollution and energy problems. **[19]**

## 6. Advanced process for degradation of microplastic

Photoreactors, which make up many crucial engineering components, have drawn a lot of interest. A floating photo-device (reactor) with photocatalysts is a new method for removing MPs, particularly for simultaneously collecting and eliminating MPs from the ocean. The MPs could be successfully removed using this design reactor, which is pulled by a boat roaming the sea, under an endless supply of sunshine. The biodegradable bag, however, has completely vanished from the aquatic environment for three months, while it is still unharmed in the soil 27 months later. These materials are biodegradable by the action of microorganisms (biodegradation), UV light (photodegradation), and water (hydrodegradation). Self-degradable materials have been modified with additives and plasticizers showing spontaneously dissolving capabilities. Some biodegradable bags weren't completely biodegradable; how quickly they degrade depended on their structure and chemical make-up. Comparing the tensile strength and surface area of several plastics used as carrying bags (including compostable, ordinary polyethylene, and oxo-biodegradable plastic) under various marine environmental conditions.

In contrast to the other plastics, which remained mostly intact after 40 weeks, the biodegradable plastic vanished between 16 and 24 weeks. Although they may completely degrade on their own and crumble into powder or microscopic pieces, this does not guarantee that the materials will ever function properly in nature again. The breakdown of the plastics is based on physical, chemical, and biological processes, and identifying the degradation of tiny fragment plastics (MPs level) is crucial to entirely removing plastics**. [20]**

**6.1. Biodegradation process: -** Biodegradation technology is thought to be the most likely technique to be used in the future to address MP pollution because of its high efficiency, environmental friendliness, affordability, and sustainable development. Studies have revealed that various bacteria and fungi can contribute to the destruction of MPs, despite the fact that MPs can remain in the environment and have a certain resistance to degradation due to their chemical stability. Animals also have a negative impact on MPs in a specific way.

**6.1.1. Animals: -** As a summary, the elimination of MPs in mammals can be accomplished through phagocytosis or enzymes released by microbes. According to certain studies, yellow mealworms can survive by consuming PS, which degrades the quality of PS. However, researchers also discovered that MPs were present in Lumbricus terrestris living in MP-contaminated soil and that the amount of particles in the hindgut was higher. Therefore, they investigated the invertebrate snail in soil and discovered that it had some capacity to break down PS. Only a small number of animals degrade through ingestion, whereas the majority of species degrade through the use of enzymes generated by their microbiota. The decomposition of three different types of polystyrene (PS), polyethylene (PE), and polyurethane (PU) by Zophobas atratus larvae (Coleoptera: Tenebrionidae) is correlated with alterations in the intestinal microbial ecology and digestive enzyme activity. The microorganisms in animals' bodies control most of their capacity for deterioration, hence microbial degradation merits our attention. **[21]**

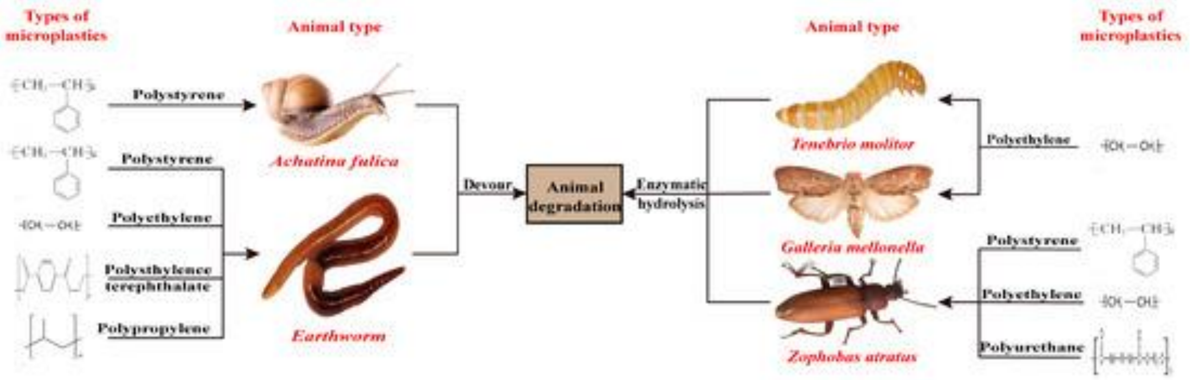


**Fig.** Pathways for animal decomposition of microplastics (MPs). **[22]**

**6.1.2. Bacteria: -** Bacteria are effective MP-degrading microorganisms. Microorganism-produced enzymes play a key role in the breakdown of MPs. By secreting enzymes, bacteria break down organic polymers into simple CO2, H2O, and inorganic compounds; this is the end result of combining enzymes with polymers and catalysing their hydrolysis. MPs are regarded as one of the crucial carbon sources required for bacterial viability throughout the degradation process. As a result of bacteria adhering to the MPs' surface and creating a biofilm, the MPs corrode and break. The MP structure continues to weaken as the bacteria continue to live and grow on the biofilm, eventually absorbing it to fulfil the removal goal. Different bacterial species release diverse enzymes, each of which affects and leaves behind different kinds of MP breakdown products. During the decomposition process, some bacteria may emit poisonous and hazardous compounds to stop their growth. Additionally, it can be challenging to destroy MPs, and the enzymes released by bacteria may not function on various kinds of plastic substrates. As a result, new strains of effective bacteria have been discovered continuously, increasing the rate at which MPs degrade**. [23]**

There has been a lot of interest in the microbial degradation of PE-MPs, PS-MPs, PP-MPs, PET-MPs, and PVC-MPs, among other materials. Animals' intestinal tracts are where most microorganisms congregate, and some research has shown that bacteria isolated from the intestines may efficiently breakdown MPs. Bacillus sp. strain NyZ451 and Acinetobacter sp. strain NyZ450 were isolated from Tenebrio molitor larvae. The PE quality declined by about 18% when the two were co-cultured for 30 days. Exiguobacterium sp. Strain YT2, a PS-degrading strain, was also isolated from Tenebrio molitor larvae. Incubation for 28 days led to the possibility of biofilm formation on PS membranes. Through testing, it was discovered that its strains' suspension cultures could reduce PS weight by 7.4% in just 60 days. Furthermore, isolated bacteria that degraded LDPE-MPs were found in the worms' guts. MPs can be used by microorganisms as a source of energy. Bacillus subtilis' ability to degrade was therefore studied using PE as the only carbon source, and the results revealed that after 30 days, its mass had decreased by 9.26%. **[25]**

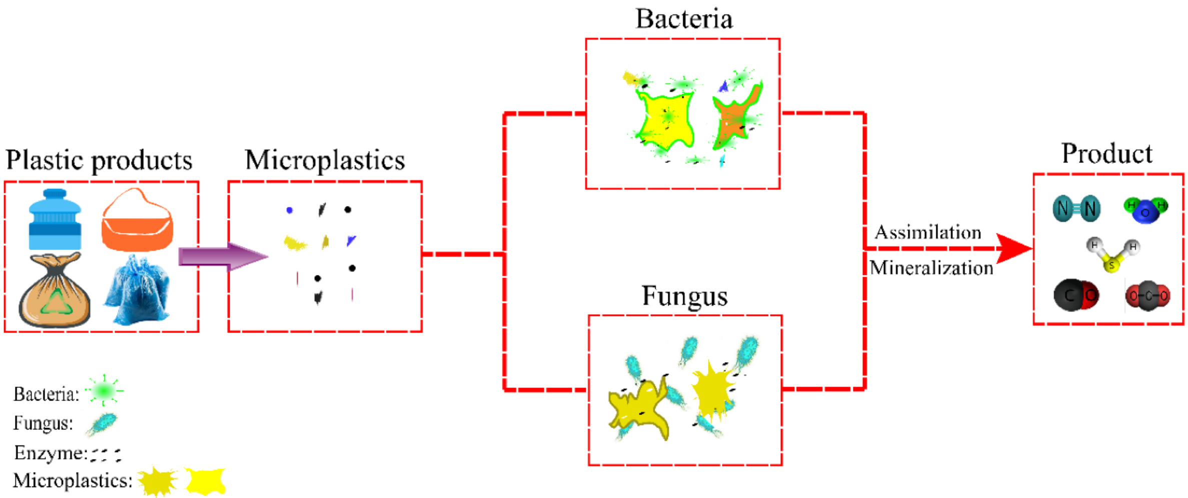


**Fig.** Pathways of bacteria- and fungi-degrading microplastics (MPs). **[24]**

The largest area of pollution is located in the soil, which is also nutrient-rich and serves as a haven for bacteria. As a result, numerous researchers have searched the soil for an effective MP-degrading bacterium. The waste site sediments were used as the basic growth medium (without a carbon source), mixed flora was added, and PE MPs were added to screen the viable strains. Finally, there was a 14.7% decrease in the weight of PE MPs due to the greater amount of Bacillus and Bacteroides isolates. In Malaysia, Bacillus cereus and Bacillus gottheili were isolated from the mangrove sediments. PE, PET, and PS were drastically reduced to 1.6% after 40 days of cultivation using Bacillus cereus. B. gottellii caused isolated mixed colonies from mangroves in various habitats to lose 6.6%, 7.4%, 3.6%, and 5.8% of their body weight, respectively, for PE, PET, PP, and PS. After adding PS and PET for 90 days, the weight loss increased to 18%. Bacillus sp. strain 27 and Rhodococcus sp. strain 36 were obtained from Peninsular Malaysia's Matang Mangrove area in Perak and the Cherating Mangrove area in Pahang in order to search for bacteria that are more effective at decomposing PP-MPs. Both bacteria were found to be capable of using PP-MPs for growth and reproduction in the study, and after 40 days in culture, their rates of weight loss were 4.0% and 6.4%, respectively. **[26]**

## 7. Marine microplastic degradation

Plastic surfaces and bulk phases underwent considerable disintegration as a result of prolonged immersion of microplastic pellets, foams, and fibres in marine surface waters; the extent of degradation varied depending on the polymer type and period. With few exceptions, weathering resulted in an increase in surface area, altered surface chemistry, biofouling, morphological and rheological alterations, decreased crystallinity of plastic polymers, and increased surface area. The model plastics were graded from 1 to 7 (highest to lowest) in accordance with the degree of degradation identified by each of the analytical methodologies, in order to establish a semi-quantitative assessment of plastic degradation. Using indicators of mechanical, chemical, and biological degradation, the degree of degradation was evaluated, and polymers exhibiting indicators of all three degradation pathways received a lower rank (more degradation) than others. Due to accelerated plastic surface degradation and a decrease in mean particle diameter, the model bioplastic PCL achieved the highest overall score (1/7) in this study. An increase in the BET surface area and a decrease in the intensity of the IR peaks, which indicate the release of low-molecular weight fragments into the environment, were evidence of the micronanoplastic particles detaching from the plastic surface. Out of all the popular plastic polymers, PVC showed the most degradation (2/7). Due to the release of potentially harmful MNPs into the environment, photooxidation in the presence of dissolved inorganic compounds in seawater caused significant surface degradation and a decrease in mean particle diameter. PVC pellet weathering poses a serious risk in maritime environments because of the poisonous properties of vinyl chloride monomer and phthalate plasticizers. Weathered PA fibres came in at number three out of seven plastic polymers and showed signs of oxidation, hydrolysis, and biodegradation. As a result of the crystalline coating on PA surfaces degrading and being exposed to the amorphous core, there was a decrease in crystallinity and an increase in the concentration of oxygen-containing functional groups. This suggests that PA may develop a stronger affinity for hydrophobic organic pollutants as a result of weathering. Over the course of the 12-month research, no signs of MNP development were seen. Low-molecular weight substances, such as MNPs, were lost to the marine environment as a result of PP surface degradation. This was corroborated by a notable rise in BET surface area and a decline in the intensity of the IR peak corresponding to the carbonyl compounds. In what is otherwise regarded of as a relatively robust polymer to UV exposure, the presence of chromophoric groups in the virgin material were supposed to have begun substantial photooxidation of the PP surface. The only plastic whose thermal stability decreased during marine incubation was weathered PET. Based on observations of the PET surface and proof of hydrolytic activity, this was predominantly attributed to microbial destruction. PET degrades at a rate of 5/7 among the model plastics in maritime environments. LLDPE pellets swelled as a result of prolonged weathering, as seen by a notable increase in the mean diameter and surface area of the plastic pellets. This was attributed to a combination of seawater penetration into the bulk phase of this low-density polymer and photooxidation of LLDPE pellets. Degradation was rated 6/7 for the type LLDPE, although there was no proof that plastic degradation products formed or that thermal stability decreased. **[27]**

Last but not least (7/7), aged ePS foam showed little indication of deterioration in marine surface waters. The large rise in crystalline content indicated that ePS surfaces have a strong affinity for dissolved chemicals and PIOM, even while an increase in surface heterogeneity and functional groups containing oxygen were suggestive of surface deterioration. Silica and dissolved metal(loid)s are examples of polar and non-polar molecules that can be found in PIOM remnants trapped by the intricate surface topology and high hydrophobicity of ePS foams, increasing the concentration of crystalline moieties. This was further reinforced by the absence of data indicating the development of plastic breakdown products or diminished bulk-phase heat stability. Therefore, even while the degradation of ePS in marine surface waters may be regarded as modest, the possibility that ePS will adsorb harmful metal(loid)s offers a serious risk in marine environments. To completely comprehend the dangers posed by marine plastic pollution, more investigation is required to ascertain the connection between weathering and chemical adsorption-desorption processes in actual ecosystems.

## 8. Future challenges

In the upcoming years, research findings on the sustainable breakdown of microscopic plastic fragments are suggested. The biodegradation and photodegradation systems continue to hold the most promise for the sustainable decomposition of plastics, despite the fact that the degradation efficiency is still low at this point. To achieve a breakthrough in the degrading efficiency, more research is required. In this regard, the following characteristics might be taken into account-

**a. Biodegradation: -** In order to create functioning microbes and increase the effectiveness of degradation through additional research, a thorough understanding of the mechanisms underlying plastics biodegradation is essential. Investigating the bioaccumulation of MPs by microorganisms in natural settings is crucial. It is necessary to address the insights influences on MP concentrations, volumes, kinds, forms, and compositions related to the biodegradation efficiency.

**b. Photodegradation: -** The most promising photocatalysts up to this point have traditionally been identified as TiO2-based compounds, which primarily restrict in the UV region. Therefore, the need for innovative visible-light-driven photocatalysts is critical. The photocatalytic device should also decompose single and many types of polymers efficiently. Given the complexity of the photodegradation mechanism of MPs, it is crucial to clarify the functions of element radicals, particularly (OH) hydroxyl radicals. Photoreactors, which make up many crucial engineering components, have drawn a lot of interest. A floating photo-device (reactor) with photocatalysts is a new method for removing MPs, particularly for simultaneously collecting and eliminating MPs from the ocean. The MPs could be successfully removed using this design reactor, which is pulled by a boat roaming the sea, under an endless supply of sunshine.

## 9. CONCLUSION:

Characterising MPs from landfills is crucial to comprehend MPs degradation processes and the most prevalent types of polymers that they include. Understanding the environmental effects of MPs from landfills will be aided by this. It will be important to conduct comprehensive multidisciplinary studies that address the migration and fate of MPs as well as their function in the spread and evolution of antibiotic resistance in order to better comprehend the indirect impacts of MPs pollution. It is important to identify the plastic waste components that are most likely to fragment and that may be lessened by better product design techniques, as well as ways to decrease consumption or boost recycling. Plastic waste should be diverted from landfills by putting trash reduction, recycling, and energy recovery measures first. Consumer behavior can also be changed by promoting the avoidance of single-use plastics and other disposable goods. Plastics continue to exist and cause pollution long after they have served their intended purpose, therefore their effects cannot be completely mitigated within a typical human lifespan. Depending on how it is used, plastic may, when it reaches the trash stage of its life cycle, constitute a serious threat to the environment and the climate. Due to the way landfills are administered, the effects of environmental processes like wind, flooding, leaching, and runoff, as well as the dispersal of trash by animals, landfills have a direct impact on the creation of MPs in the ecosystem. Although landfills have made efforts to lessen the severity of this issue, plastic debris surrounding current and former landfills continues to be a source of MPs. Due to the nano-/microparticle-containing nature of plastic waste and the defragmentation of plastic waste during landfilling, landfills have an indirect effect on the creation and spread of MPs. Leachate and air can carry fine particles or fibres from landfills to the surrounding area. When plastic waste ages in a typical environment, oxidative photodegradation processes trigger the production of dangerous volatile organic compounds. Additionally, MPs serve as chelators or transporters for a variety of co-contaminants, including hazardous pharmaceuticals, heavy metals, and brominated flame retardants. Due to their hydrophobicity, these co-contaminants bond to the microplastic surface readily. In order to increase plasticity during the synthesis of raw plastics, a wide range of chemical additives, including polybrominated diphenyl ethers, bisphenol A (BPA), and phthalates, are employed in MPs. These additives may have hazardous consequences when released because they are endocrine disruptors. Multi-annual studies will be required to develop, examine, and share an ever-increasing dataset on landfills that include details on the traits and variability of MPs, as well as changes through time.

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