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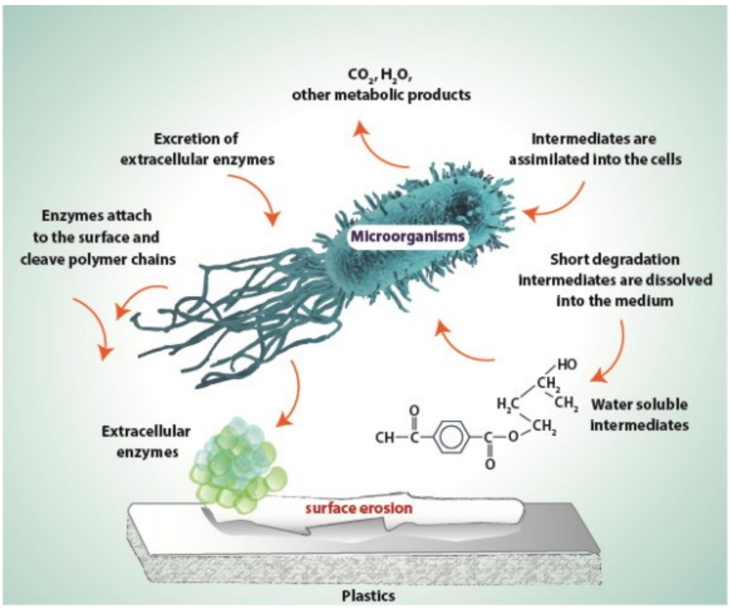
The Great Plastic Plague: From Pollution to Solution



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Waseem Hassan, Neha Naqee, Muhammad Adeel Akram

Department of Soil and Environmental Sciences, Muhammad Nawaz Shareef University of Agriculture, Multan

Plastic is a single word for a multifaceted reality, encompassing a wide variety of polymers and additives with different chemical and physical properties. The end products range from single-use plastic bags, food wraps and plastic bottles, to fishing lines, buoys, and synthetic fibres used in the clothing or fishing industries.As plastic waste accumulates in the ocean at alarming rates, the need for efficient and sustainable remediation solutions is urgent. One solution is the development and mobilization of technologies that either (1) prevent plastics from entering waterways or (2) collect marine and riverine plastic pollution. Plastic production has sharply increased over the last 70 years. In 1950, the world produced just two million tonnes. It now produces over 450 million tons. Plastic has added much value to our lives: it's a cheap, versatile, and sterile material used in various applications, including construction, home appliances, medical instruments, and food packaging.

However, when plastic waste is mismanaged (not recycled), incinerated, or kept in sealed landfill, it becomes an environmental pollutant. One to two million tonnes of plastic enter our oceans yearly, affecting wildlife and ecosystems. Plastic pollution is found globally from deserts to farms, from mountaintops to the deep ocean, in tropical landfills and in Arctic snow. Emissions of plastic are increasing and will continue to do so even in some of the most optimistic future scenarios of plastic waste reduction. Estimates of global emissions of plastic waste to rivers, lakes, and the ocean range from 9 to 23 million metric tons per year, with a similar amount emitted into the terrestrial environment, from 13 to 25 million metric tons per year as of 2016. Between 1970 to 2019, an estimated 30 million metric tons of plastics had accumulated in the ocean, while more than 100 million tons had accumulated in rivers and lakes. Such large amounts of plastic waste pollution in waterways can have devastating impacts on marine life and ecosystems. .Global plastics production has doubled since the beginning of the century, to almost 400 million metric tons per year in 2021. Following business-as-usual scenarios, these estimated emission rates will be approximately doubled by 2025. Asia accounts for more than 80 percent of global plastics waste emitted to the ocean. Pakistan produces approximately 3.9 million metric tons of plastic waste each year, with a per capita generation of 18 kg.Punjab generates around 1,600 to 1,800 metric tons of plastic waste daily. This is a rough estimate based on the state's population, industrial activity, and urbanization levels.This would amount to roughly 0.58 to 0.66 million metric tons of plastic waste annually.Less than 0.3 million metric tons of plastic are estimated to be currently circulating on the ocean surface, which represents a small fraction of the estimated 9 million to 23 million metric tons of plastic that are emitted annually into rivers, lakes, and the ocean

Plastic is also deliberately introduced to agricultural soils through plastic mulching with polyethylene films and increasingly also so-called “biodegradable” plastic films, compost, and sludge-derived biosolids that contain plastic residues, as well as by the application of polymeric stabilizers against soil erosion). Current plastic fractions in soils can reach up to 0.1% of soil organic carbon. Recently, there have been reported, that small plastic particles can be taken up from the gastrointestinal tract into tissues, and small plastic particles have been shown to penetrate biological membranes. Plastic pollution can influence the global carbon cycle both directly and indirectly. The direct effect is due to the small but non-negligible fraction of the 280 million to 360 million metric tons of fossil carbon converted into plastic per year , that degrades or is industrially converted (e.g., by incineration or landfilling) to carbon dioxide, methane, and other greenhouse gases. Wildlife encounters with macroplastic debris have been widely reported. A recent analysis listed 914 marine megafaunal species (including 226 species of seabirds, 86 species of marine mammals, all species of sea turtles, and 430 species of fishes) affected through entanglement and/or ingestion. For endangered species, not more than a few encounters are required to threaten population-level consequences. Entanglement and ingestion of plastic jeopardizes 17% of the 693 species on the International Union for Conservation of Nature Red List

Degradation of plastic wastes

Plastic wastes can be degraded by either physicochemical (abiotic) processes or through biodegradation (biotic). Breaking down of the polymeric material by physical forces of mechanical nature is usually considered the first step that plays a vital role in any degradation process. Approximately 60% of plastic enters the environment as plastic waste .recycling 1 ton of plastic waste will save up to 130 million kJ of energy.Plastics can be degraded in the environment by following Methods.

1. **Aerobic biodegradation (aerobic respiration)**

In this type of degradation, microorganisms break down large organic compounds into smaller compounds by using oxygen as an electron acceptor. By-products of this process are carbon dioxide and water

Carbon plastic + Oxygen carbon dioxide + water + Carbon residual

Bacteria: Common aerobic bacteria involved in degradation include Pseudomonas, Bacillus, Streptomyces, and Mycobacterium species.

Fungi: Fungi, such as Aspergillus and Penicillium, also play a significant role, especially in the breakdown of complex organic compounds like cellulose and lignin.

Aerobic degradation by microorganisms plays a crucial role in the natural recycling of organic matter and offers significant environmental benefits.Additionally, aerobic degradation contributes to soil health by producing humus, a nutrient-rich material that enhances soil fertility and structure. This natural process also minimizes the production of harmful byproducts, such as methane, which is a potent greenhouse gas.

2. **Anaerobic biodegradation**

In anaerobic biodegradation, oxygen is not necessary for the breakdown of compounds by the action of microorganisms. Oxygen is an important component for the natural attenuation of contaminants at sites of hazardous waste. Anaerobic bacteria use nitrate, iron, sulphate, manganese and CO_2 as an electron acceptor in place of oxygen to break down large organic compounds into smaller compounds.

Carbon (plastic) $\rightarrow$ methane + carbon dioxide + water + Carbon residual

All polymers are not directly transported into the cells of microorganisms through their cell walls because they are large in their size and are not water soluble. Microorganisms can use these polymers as a source of energy by secreting extracellular enzymes. Polymers are depolymerized by these enzymes outside the bacterial cells. Enzymes play their role in polymers biodegradation both by intra-cellularly and extra-cellularly. Depolymerization and mineralization are the two processes that are involved in biological degradation of plastic polymers.This process is particularly useful in managing organic waste in landfills, wastewater treatment facilities, and agricultural settings. One of the key advantages is the production of biogas, primarily composed of methane and carbon dioxide, which can be captured and used as a renewable energy source. This not only helps reduce reliance on fossil fuels but also mitigates greenhouse gas emissions by preventing methane from being released directly into the atmosphere.

3. Enzymatic degradation of plastics

Due to the absence of hydrolysable groups in the carbon–carbon backbone, the degradation of plastic by microbial enzymes is a very difficult task. The reduction of molecular weight is the first step that is achieved by the action of both biotic and abiotic factors. By UV light exposure, the carbonyl group of polymer is easily attacked by microbial enzymes. For polymers degradation different enzymes are used e.g. laccase, manganese-dependent enzymes (lignin degrading enzymes), urease, lipase, and protease. Thermostable laccase can degrade the polyethylene (PE) in 48 h of incubation at 37 $^{\circ}$C .Enzymatic degradation of plastic waste presents a promising and environmentally friendly approach to addressing the global plastic pollution crisis. The primary advantages is its potential to accelerate the degradation of plastics, which traditionally take hundreds of years to decompose. Secondly, enzymatic degradation can potentially convert plastics into useful byproducts, such as monomers or biofuels, which can be repurposed in various industrial applications.

Summary

Environmental issues are a priority and cannot be ignored. Plastic waste are continuously increasing due to our changing lifestyle, convenience, and modernisation. Unregulated accumulation and improper disposal of plastic waste lead to severe health impacts on humans and animals. Furthermore, these wastes can also cause environmental hazards as they contain toxic substances capable of leaching into the soil and water, thereby leading to environmental pollution. Plastics have found widespread use because of their unique properties and are thus considered one of the most essential materials in our life. Nevertheless, plastic waste hazardous effects are proportionally related to their utilization and accumulation in the environment. Correspondingly, the plastic material characteristics are considered a real challenge for microbial degradation or even colonization on their surface.