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Review Article

Plastic Pollution and Global Sustainability: A Deep Dive into Environmental, Health, and Economic Challenges

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ABSTRACT

Plastic pollution is one of the most pressing environmental challenges of the 21st century, leaving lasting impacts on ecosystems, human health, and economies. Since the mid-20th century, the widespread use of artificial polymers has led to plastics and their by-products macroplastics, microplastics, and nanoplastics contaminating every corner of the planet. Due to their resistance to decomposition, plastics accumulate in terrestrial and aquatic environments, polluting freshwater sources, choking marine ecosystems, and disrupting wildlife. Many organisms ingest plastic fragments, affecting their feeding, reproduction, and survival. Additionally, persistent organic pollutants (POPs) like PCBs, BPA, and phthalates bioaccumulate in food chains, posing risks to biodiversity and human health. Studies confirm that plastics harm various species, from seabirds to whales, while their presence in soil affects microbial populations and contributes to degradation. Water pollution worsens due to plastic waste, reducing quality and threatening aquatic life. Humans are exposed through ingestion, inhalation, and dermal contact, with research linking plastics to endocrine disruption, reproductive issues, and diseases. Economically, plastic waste burdens fisheries, tourism, and waste management industries. Natural forces such as wind and water spread plastics worldwide, creating a global plastic cycle. Efforts to mitigate the crisis include regulatory measures, alternative materials, and public awareness campaigns. Coordinated international action is essential, requiring collaboration among experts to assess health impacts and develop sustainable solutions. Addressing plastic pollution necessitates scientific policies, technological advancements, and behavioral changes, framing it alongside climate change and biodiversity loss as a "triple crisis" demanding urgent intervention.

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INTRODUCTION

Environmental pollution has emerged as a major global concern, driven by rapid industrialization, modern agricultural practices, and urbanization. It involves the introduction of harmful contaminants into the environment, leading to ecological imbalance, discomfort, and damage to ecosystems (Liaqat *et al*., 2022; Ramzan *et al*., 2022; Zahra *et al*., 2023; Zahra *et al*., 2024). However, in the current decade, plastic pollution has become a greater concern. Traces of polymer synthesis and various related chemicals, both overtly added, such as additives and plasticizers, and covertly present as by-products and impurities, belongs to the category of synthetic polymers that form plastic pollution (Schmidt *et al*., 2024). Evolving since the 1950s, the plastic industry has seen exponential growth and further exacerbated societal issues by capitalizing on improper disposal methods and resulting devastation from pollution. Due to being durable, versatile, and low-cost, plastic has found its way into every aspect of modern society. These unprecedented benefits, however, obstruct plastic's dangerous environmental impact and long-term hazards, most notably, undying degradation throughout nature. The worst of all consequences looming on the horizon is the destructive weathering of larger plastic materials, leading to the formation of microplastics (MPs) and nanoplastics (NPs). These minuscule ogres, most of which are 5 mm or less, are now infiltrating our atmosphere, soil, freshwater, and even the bodies of humans (Bashir *et al*., 2024).

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Expansion of microplastics: The ND threat

One issue of specific interest is the proliferation of tiny plastic pieces, with microplastics. In some marine environments, parts as small as 1.6 mm have been located, and it appears probable that there are smaller bits beneath current detection levels. A recent workshop convened in the USA by the National Oceanic and Atmospheric Administration (NOAA) concluded that microplastics should be defined as pieces 5 mm with a suggested lower size boundary of 333 micrometers to focus on microplastics that will be captured using conventional sampling approaches (Arthur *et al*., 2009). Nonetheless, it remains the responsibility of those defining microplastics not to overlook the vast abundance of smaller fragments. It seems likely that plastic fragments arise from some form of mechanical and chemical breakdown of larger plastic items. Alternative ways for microplastics to enter the environment include the outright dumping of litter, abrasively used plastic in industrial and household cleaning, such as in shot blasting and scrubbers in proprietary hand cleansers, and spillages of feedstock plastic pellets and powders from which most plastic products are manufactured. Shore data combined with data from open oceans and sea bird debris indicate that the volume of plastic fragments is increasing over time. Some coastal regions have reported worrying amounts of plastic debris, over 10% by mass of strandline material, as reported by Barnes *et al*. (2009).

Laboratory experiments demonstrate this phenomenon, showing that tiny fragments are indiscriminately swallowed by smaller marine organisms devoid of backbone creatures, including filter, deposit, and detritivore feeders (Thompson *et al*., 2004) while also showcasing the retention of plastic for over 48 days by mussels (Browne *et al*., 2008). The scale of microplastic consumption, particularly amongst natural populations, remains an enigma. Beyond the physical dangers that plastic waste incurs, there is much conjecture that ingestible plastic could relatively easily, if not seamlessly, contaminate the food chain by transferring poisons (Teuten *et al*., 2009).

The plastic debris from oceans in forms of pellets, fragments and microplastics have shown presence of organic contaminants such as polychlorinated biphenyls (PCBs), in addition to hexachlorinated hexane (HCH), polybrominated diphenylethers (PBDEs), alkylphenols, and BPA, at concentrations from ng g^{-1} to µg g^{-1}. There are subsets of these chemicals, some of which are deliberately added to the manufacture of plastics, while the others are attracted onto plastic debris as they encounter environmental conditions. Research in Japan has shown how plastics are capable of accumulating and retaining persistent organic pollutants produced in other parts of the environment. These contaminants may accumulate thousands of fold higher concentrations on plastic debris than are available in the contiguous seawater (Mato *et al*., 2001).

In the 2009 study, Teuten and colleagues focused on learning how these contaminants transfer from plastic waste into seabirds and other marine animals. The quality of the transport processes depends on the properties of the pollutants and the specific types of polymers that are affected. It may also be influenced by the physical state of the plastic debris after exposure to the environment. Recent modeling work has shown that even low levels of plastics can enhance the uptake of contaminants since, as they are ingested, they are transferred from the plastic to animals. Such a transfer could form a direct and critical way of getting chemicals into upper marine species like seabirds (Teuten *et al*., 2009), but it depends on things like the type of habitat, amount, and quality of plastic debris. In illustration, the contribution of plastic particles to total contaminant accumulation in organisms is largely determined by interactions with other particles that compete for the sorption and transport of contaminants. There are increasing amounts of plastic fragments found in regions all over the world. Microscopic fragments smaller than the 333 µm threshold of the NOAA have a great surface-to-volume ratio that improves the movement of contaminants, while their minuscule size allows for ingestion by various organisms. It has, therefore, given rise to an important problem of the capacity of plastics to deliver and expose wildlife to chemical contaminants. Extra discussion is required to come to terms with the magnitude of contribution by plastics to the movement of contaminants in natural settings and the extent these contaminants could be passed through food webs. However, chemicals associated with plastic threaten wildlife. The findings of laboratory-based research, which are the roots of this summary, are based on Oehlmann *et al*. (2009). These studies show that phthalates and bisphenol A (BPA) affect reproduction in all examined animal groups and stymie development in crustaceans and amphibians. These chemicals adversely affect molluscs and amphibians disproportionately. On the other hand, most observable impacts on fish are seen under increased concentrations. Most of these plasticizers seem to affect hormone function in a variety of ways, based on research conducted by Hu *et al*. (2009).

Plastic pollution is now one of the stubborn and widespread environmental problems. The consequences of plastic pollution extend both into the environment and our health, and even have economic implications, and therefore, an urgent need to identify the full extent of its impact on our planet is in order.

ENVIRONMENTAL IMPACTS OF PLASTIC POLLUTION

Terrestrial ecosystems: Silent contamination beneath our feet

Though it is rather invisible in soil than it is in oceans, plastic's impact is just as important. Agricultural land has increased risks driven by plastic mulching and the use of wastewater irrigation, sewage sludge. Small plastic fragments confound the structure of the soil and create an issue regarding the movement of air and water storage. Such changes distort the useful microbial populations required for nutrient processing and plant vitality. Also, microplastics in the soil are prone to dissolve in solutions containing toxins such as phthalates and BPA, polluting edible plants and aquifers. Both public health and the future ability to farm are put at risk by these contaminants. Although less spotlighted, terrestrial effects are equally harmful. Plastic contamination within farming areas develops a variety of chemical and physical impacts that wear the earth down over time (Rillig *et al*., 2019).

Fig. 1. The adverse implications of plastic pollution in coastal and marine areas (photo credit J.D.M. Senevirathna).

Marine ecosystems: An ocean choked in plastic

Plastic pollution in beaches and marine environments reduces aesthetic value and ecosystem health, leading to a significant decline in tourism (Fig. 1). It is estimated that approximately 14 million tons of plastic get into the world's oceans every year (Jambeck *et al*., 2015). Plastic fragments are regularly confused for food by marine creatures, causing damage through ingestion-related injuries, reproductive problems, or even death. Rodrigues *et al*. (2019) show that plastics allow for the transportation of persistent organic pollutants, invasive species, and pathogens to marine environments. The interactions level off downstream effects into marine ecosystems, which ultimately reduce the well-being of both fish populations and coral reefs. Plastic breakdown makes bioavailable toxins more dangerous to marine life (Massos and Turner, 2017). Damage to scenic values and maritime services like fishery and tourism, among others, constitutes the effects of marine plastic waste (Moore, 2008; Gregory, 2009). Residual fishing nets called ghost fishing gear result in improperly caught fish and severe harm to commercial fisheries (Moore, 2008; Brown and Macfadyen, 2007). Plastic pollution has extended in the marine realm from the surface toward the deep waters of the ocean, threatening biotic diversity, which is Earth's most fragile ecological system.

Freshwater systems: Rivers and lakes

People's living areas, such as freshwaters, are at the cut-off point of plastic consumption. Plastic debris occupies significant rivers, lakes, and streams. The extensive contamination of freshwater habitats by microplastics (MPs) threatens filter feeders like mussels and fish, as well as decreases the performance of municipal water treatment plants. This presents major threats to people's safe access to clean water and the overall public good. Tropical ecosystems transcend ecological boundaries with disparate ecological histories that link terrestrial sources of plastic to freshwater ecosystems and then to the ocean; they are transitional corridors linking terrestrial sources of plastic to the ocean. Along this way, these water bodies collect pollutants and endanger both wildlife and societies dependent on them (Bhardwaj *et al*., 2024).

WILDLIFE HARM: THE INFLUENCE ON SPECIES AND THEIR TERRITORIES

Some of the cases where terrestrial debris is consumed by wildlife include situations where endangered California condors (*Gymnogyps californianus*) were discovered to take such objects (Mee *et al*., 2007). Marine creatures can rapidly attach to floating plastic debris, and since they stay in the sea for extended periods, they can transport non-native species across oceans (Barnes *et al*., 2009; Gregory, 2009). However, the wildlife problems that remain the most media and public favorites are ingestion and entanglement. Many species, including invertebrates, turtles, fish, seabirds, and mammals, have been reported to have ingested or been entangled in plastic debris, thereby impairing their movement and feeding, reducing reproductive success, and causing injuries and death (Laist *et al*., 1997). Monitoring data that already exist indicates an increasing number of animals entangled over time (Ryan *et al*., 2009).

Many species that use various methods of feeding, such as filter feeding, deposit feeding, or detritivory, have been accounted for in ingesting plastics. It is possible for those species that have intentionally selected plastic debris as a food source to be particularly susceptible to ingestion. As such, the number of persons ingesting plastic can at times be extremely high in specific groups. For instance, 95% of dead fulmars in the North Sea. Reliable and substantial figures about debris consumed by seabirds can be drawn by looking at the carcasses of dead birds. Using this strategy, scientists have managed to measure temporal and spatial plastic debris concentration in European seas (Van Franeker *et al*., 2005). The negative impacts of plastic pollution on wildlife have increased, most obviously in terms of ingestion, entanglement, and loss of critical habitats. There are between 260 and several hundred species of invertebrates, fish, seabirds, turtles, and marine mammals whose populations have been impacted by plastic interactions (Derraik, 2002). For example, the examination of fulmars found dead on North Sea shores showed that 95% had plastic in their stomachs. Sperm whales are among the most hit, with some even being found with copious ingestion of plastics and stomach rupture (Jacobsen *et al*., 2010).

Entanglement is equally alarming. Fishing nets and different plastic waste remain to entangle marine wildlife, leading to injuries, and heightening the possibility of infection or death as the priority for seabirds and marine mammals (Macfadyen, 2007; Stelfox *et al*., 2016, Fig. 2). These interact ions threaten local ecosystems and result in considerable economic damage for coastal inhabitants who rely on fisheries and tourism as their main source of income. Consistent recording of entanglement patterns indicates a worsening of the problem, which threatens the milieu of marine ecosystems, as indicated by Ryan *et al*. (2009).

Fig. 2. Effects of plastics on coastal and marine biota: (a) Plastics ingestion by a blueshark: Priona ceglauca of Carlos Canales-Cerro (Thiel *et al*., 2018; photo authorship: Dr. Carlos Canales-Cerro), (b) Attachment on plastic debris by Goose Barnacle, *Lepas anserifera* (photo authorship: J.D.M. Senevirathna), (c) Partial cover of macroplastic pollutants on Rock Oyster: *Saccostrea forskalii* colony (photo authorship: J.D.M. Senevirathna), (d) Entanglement of nestling in a synthetic plastic string (photo authorship: Townsend and Barker, 2014).

Bioaccumulation and trophic transfer

When microplastics are consumed by organisms, they are transferred up the food chain. As reported by Setälä *et al*. (2016), trophic transfer has been recorded in both controlled and natural settings. In addition, the contaminants, such as BPA and heavy metals, bind to plastics, penetrating organisms, and increasing the risk of toxicity (Bakir *et al*., 2016).

HUMAN EXPOSURE AND HEALTH RISKS

As far as public exposure to plastics, it comes about by consuming seafood and salt, breathing plastic-based particles, and skin contact with plastics. It is believed that the average individual consumes around 70,000 to 120,000 micrometer-sized plastic pieces per annum (Cox *et al*., 2019). Nanoplastics have been found to react with human cells, causing inflammation, oxidative stress, and endocrine disruption (Lehner *et al*., 2019). Despite the absence of long-term epidemiological research, the current data indicate the possibility of severe health risks forcing professionals to call for plastic waste to be regarded as a dangerous pollutant (Rochman *et al*., 2013). Impacts of plastics do not only extend past the environment, but are also specifically emerging as threats to human health as well. Evidence is building on the ground that highlights the problems associated with the wide use of chemical compounds in plastics, such as that plastics can be toxic or hormone-like in their effects. Investigations by biomonitoring methods detected residues of phthalate additives, bisphenol A (BPA), and tetrabromobisphenol A (TBBPA) in humans. With these approaches, scientists can assess the overall exposure, including ingestion, direct skin contact, and air inhalation (Talsness *et al*., 2009).

Existing data imply that this substance exposure is widespread and associated with various unwanted health outcomes. Studies reveal that exposure to phthalates and BPA triggers developmental defects related to reproduction, especially among males. According to reports, an inverse relation exists between maternal urinary concentrations of Di(2-ethylhexyl) phthalate (DEHP) metabolites and indices of male genital development, viz, anogenital distance, penile width, and testicular descent (Swan, 2005). Research has also identified that exposure to phthalates is linked with poor semen quality in adults and reduced levels of testosterone in persons working in factories that produce high levels of phthalates, such as in PVC flooring factories. While average levels of these chemicals appear similar for global populations, large disparities occur among individuals and even in the same individual over time (Meeker and Sathyanarayana, 2008).

According to Koch and Calafat (2009), average exposure to di-ethyl phthalate and di-butyl phthalate is, in general terms, below the reference dose of the U.S. Environmental Protection Agency as well as the tolerance daily dose of the European Union but in some cases there are individuals located at the variability observed in the finding points to the fact that the current notion of "safe" levels of exposure (based on outdated assessments) can dramatically misestimate the actual risks, especially for sensitive groups like children, pregnant women or infants.

People encounter PHIPs by eating contaminated food, breathing in dust, or absorbing chemicals through their skin (Adibi *et al*., 2003). The main source of DEHP and comparable compounds in households appears to be food, according to Wormuth *et al*. (2006), while exposure via house dust is especially notable. Although fewer studies have focused on BPA, it appears that it enters the body using routes similar to those of phthalates and may remain in the system for a long time. Taking into account recent research by Lang *et al*. (2008), BPA concentrations in urine appear connected to the risk of cardiovascular disease, type 2 diabetes, and liver enzyme abnormalities. The high degree of exposure found in premature infants under care in neonatal intensive care units is of special concern because of the potential for acute and damaging contact with BPA and phthalates from these medical devices (Calafat *et al*., 2009). Even though studies are needed to determine how plastics contribute to the spread of these toxic compounds, it is obvious that existing toxicological models fail to capture all relevant aspects of risk. Current understanding questions the earlier assumption that toxicity occurs in a straight, increasing fashion with increasing dosage. Conventional toxicological methods frequently fail to pick up hormonal activities that occur at very low doses associated with endocrine disruption (Myers *et al*., 2009). Cellular programming by these disruptions in critical growth times may result in persistent physiological disruptions. Talsness *et al*. (2009) point out that developing alternative methods and standards for risk evaluation is now essential, especially since they must reflect endocrinological aspects, handle chronic low-level exposures, and model complex mixtures.

Animal experiments continue to be an essential source of information. The male reproductive tract, for example, appears particularly affected by phthalates not because of the parent compounds, but owing to the formation of biologically active monoester metabolites in the liver. While rats have been the primary model organism in these studies, there are uncertainties about how well results can be applied to humans, however, the basic hormonal processes are very relevant. Taken together, the growing body of research implies that human health may face serious and probably underestimated risks from prolonged, low-dose exposures as well as occasional, high-dose contacts with chemicals from plastic. The need to develop more refined toxicological evaluation approaches and adapt current regulatory strategies is now of great importance (National Research Council, 2009).

SOCIO-ECONOMIC IMPLICATIONS OF PLASTIC POLLUTION

Economic sectors, as well as ecosystems and human health, are all affected by the severe costs associated with plastic pollution. Its consequences are most evident in coastal districts, fishery operations, the tourism sector, and waste disposal arrangements.

Impacts on fisheries and livelihoods

Plastic in the oceans creates severe difficulties for both industrial and local fishing enterprises. Declining fish numbers caused by ingestion and environmental modification lower the overall productivity and net income of fisheries. In addition, consumer trust in seafood is eroded by contamination, which reduces participation in global seafood transactions. Communities and small-scale fishers who mainly live off fishing are particularly sensitive to such economic fluctuations (Galgani *et al*., 2010).

Impact on tourism

Tourism along the coast suffers important consequences from the environmental damage and sight pollution caused by plastic waste. Large quantities of plastic on shorelines serve to exclude tourists, hence lowering the income and job creation in tourism. On several occasions, local administrations, together with private successful policies result from responsible for addressing the issue of cleanup. Each year, according to the UN Environment Programme, cleaning up plastic from Caribbean beaches can require as much as $10 million in funding. Therefore, the ongoing degradation of coral reefs because of plastic endangers ecotourism initiatives in places with diverse underwater species (Reddy *et al*., 2020).

Waste management and infrastructure costs

An increase in plastic waste levels in some nations puts heavy stress on waste management operations like collection, processing, and landfilling, especially where poverty levels are high. Weak infrastructure for managing waste in many countries allows plastics to repeatedly enter natural settings, repeatedly damaging ecosystems and exacerbating mismanagement. Constructing effective plastic management systems in such contexts is expensive. Still, achieving long-term environmental stability depends on this. Attaining international environmental standards is more challenging for countries whose major sources of wealth are aid or tourism, as plastic pollution grows (Koelmans *et al*., 2019).

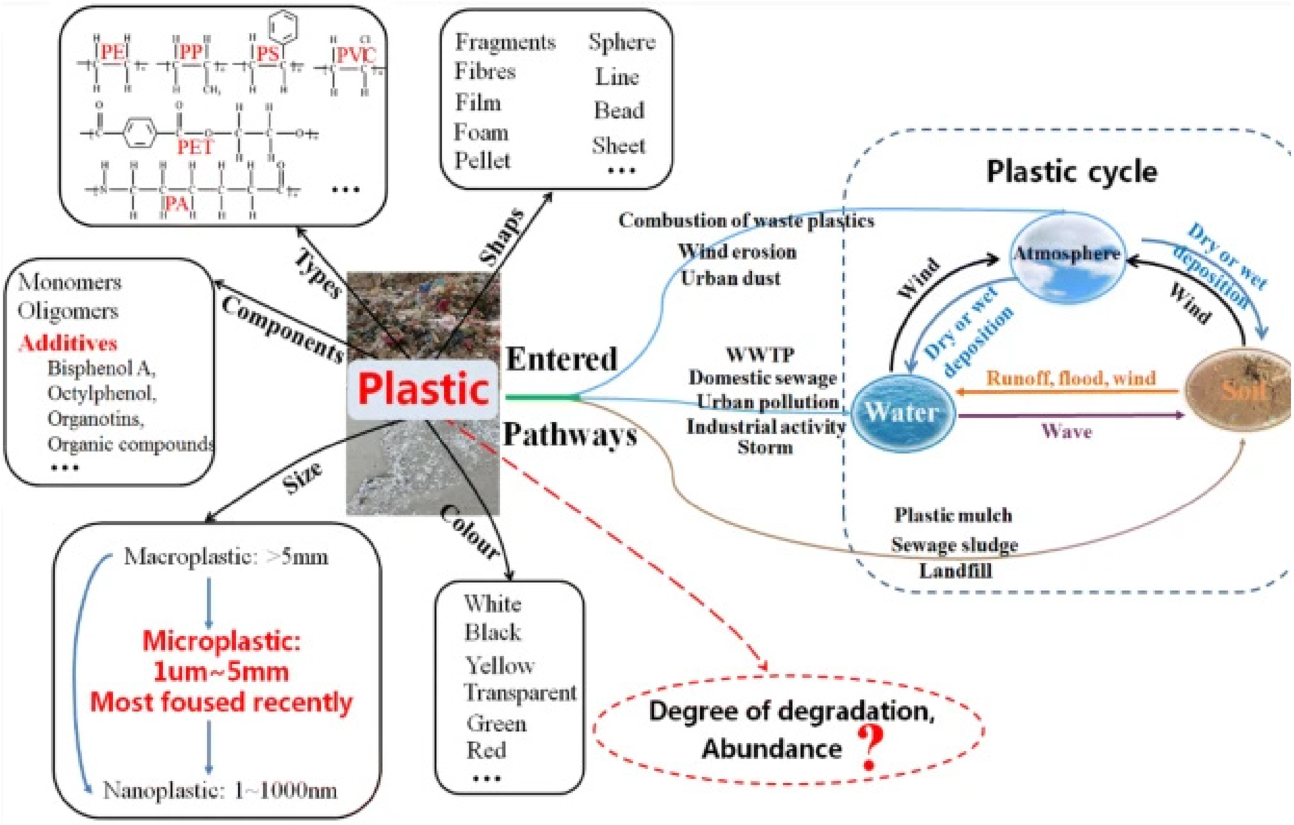

Fig. 3. Diversity of plastic pollution and cycles of plastic in the environment. (Based on Refers Teuten *et al*., 2009; Geyer *et al*., 2017; Koelmans *et al*., 2019).

GLOBAL DISSEMINATION AND PLASTIC CYCLE

Plastic pollution is now a global problem because plastics last a long time, can move easily, and are found almost everywhere. Most substances that pollute the environment either break down or settle, yet plastics can move over long distances because of wind, water, and animals (Fig. 3).

Ubiquity in environmental compartments

Samples from the seemingly untouched areas of both the Arctic Sea ice and the Mariana Trench have yielded traces of plastic. Atmospheric transfer, riverine runoff, and global ocean transport all help to drive the worldwide motion of plastics among land, water, and air systems (Allen *et al*., 2019). A global cycle of plastics, analogous to carbon and nitrogen cycles, is possible now due to human actions, according to Bjerrum and Canfield (2011). Reports found that polyethylene and polypropylene are present in rainwater, alpine soils, as well as in polar snow (Peeken *et al*., 2018).

Plastics in agricultural and urban areas

In land-based ecosystems, plastic litter predominantly is a result of Sewage sludge used as fertilizer, plastic mulch films in agriculture, urban runoff and industrial discharges, and improper landfill practices. These additions ultimately cause plastic to gather in soils and waterways, which has the potential to harm urban health and the safety of food (Zhu *et al*., 2019).

MAINTENANCE AND PRESERVATION OF THE MARINE ENVIRONMENT

Biodiversity hotspots and ecosystem services

Biodiversity hotspots in marine and coastal settings, for example, coral reefs, estuaries, and seagrass meadows, play a major role in the provision of environmental services. Safeguarding marine and shore environments is important in conservation. Biodiversity hotspots and ecosystem services coral reefs, estuaries, and seagrasses, along with other marine and coastal systems, are hotspots of biodiversity, supplying essential ecological services. Such services include the provision of food, the storage of carbon, the regulation of local climate, and the support of tourism (Reddy *et al*., 2020).

Approximately three-quarters of the global surface is ocean, home to many species for which taxonomic details are still incomplete. Problems caused by plastic debris are evident in the damage it inflicts on ecosystem structures and in the interference with different species' interactions. Filter feeders' feeding and reproductive ability are shown to be reduced by the presence of microplastics, as found by Cole *et al*. (2015).

Emerging threats

Rising levels of development on coasts, together with less effective tourism management, have resulted in more plastics entering these fragile environments. Because plastics have natural stability and buoyancy, they spread effortlessly and are tough to regulate. Given that salinity has a major impact on plastic resilience, strategies for conserving the marine environment must combine environmental care with pollution reduction (Matavos-Aramyan, 2024).

Call for integrated management

Proper safeguarding of marine and coastal ecosystems is contingent upon teamwork between governments at different levels.

1. MARPOL and the Basel Convention are two international agreements that create standards that help determine effective policies (Julian, 2000).
2. Developing national regulations for both the manufacturing and handling of plastic materials is very important.
3. Initiatives such as beach cleanups and resident education are both essential measures in local areas.
4. According to Law's (2017) report, successful policies result from combining public awareness efforts and the direct participation of stakeholders.

MITIGATION STRATEGIES AND RECOMMENDATIONS

Policy measures and international cooperation

Various countries have embarked on the ban of single-use plastics, promoting the use of biodegradable plastics and introducing extended producer responsibility (EPR) schemes. Policy enforcement, however, is usually lax. Nevertheless, a major challenge remains due to the considerable variations and lack of sufficient adoption of these strategies. Having the UN plastics treaty in place, together with parallel international commitments, can make rules more even and inspire higher levels of responsibility. Very recently, the basel convention brought particular plastic waste forms under its international trade regulations (Leal-Filho *et al*., 2019).

Innovations in material science

Both bioplastics and real biodegradable materials are becoming more widely appreciated (Chek *et al*, 2020). Although this is the case, considerable testing remains necessary to ensure these materials do not cause new kinds of harm to the environment. Both circular systems and chemical recycling have received increased attention in research studies recently (Moshood *et al*., 2022).

Public awareness and behavior change

Promoting public awareness about plastic consumption is of great importance. Educational campaigns on reducing plastic use at the consumer end are necessary. Source-based reduction of plastic leakage can be achieved by promoting reusable packaging measures, deposit return schemes, and corporate responsibility initiatives (Kumar *et al*., 2021).

Scientific monitoring and research

Addressing plastic pollution requires the establishment of a unified global system for monitoring contamination across multiple locations, ensuring consistent tracking and analysis. Research focusing on the health impacts of micro- and nanoplastics on humans should be prioritized, as their long-term effects remain largely uncertain. Additionally, studies exploring the interconnectedness of ecological, health, and economic factors are essential to fully understand the broader consequences of plastic waste. Cox *et al*. (2019) and Li *et al*. (2024) emphasize that comprehensive data accessibility plays a pivotal role in facilitating effective problem-solving, reinforcing the need for open and extensive research collaborations.

CONCLUISON

Plastic pollution results in interconnected problems for both natural environments and the health and development of human society. Even after years of expert caution, plastic is still building up in every region of the world. All environments, from agricultural soils to deep marine regions, are experiencing plastic pollution, with most of the accompanying hazards incompletely understood. Because of the complexity involved, multiple types of action, ranging from international control to inventive technology, community programs, and changed personal habits, are all required. If plastic pollution continues unchecked, it would endanger both natural biodiversity and ecosystem functions, as well as the resilience of future economic and social systems. A radical change in how we think about and handle this problem is required immediately, from a throwaway lifestyle to a model of regenerative design, from merely reacting to contamination to anticipating and avoiding it, and from disconnected regulations to science-supported overall action plans.

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Data availability

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Statement of conflict of interest

The authors have declared no conflict of interest.

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