Ecotoxicological perspectives of microplastics

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ABSTRACT

Plastic pollution has been in discussion from last few decades. However, in the recent days, microplastic (MP) contamination has become an additional issue of concern for ecotoxicologists as extensive research on MP toxicity revealed serious effects on the environment, chronically. Global data on the production and usage of plastic compounds, demonstrated a steady exponential increasing pattern over time, thus creating an elevated threat to the ecosystem health. There are certain unavoidable anthropogenic sources of microplastics (MP) in our planet and it is necessary to understand how and at what level, MP particles are spreading in several ecosystems and thus an explicit global mapping of the environmental risk assessment is pivotal. Through this article, we are comprehensively elucidating the ecotoxicological standpoint of microplastics in recent days.

KEYWORDS: Microplastics, Ecotoxicology, Environmental contamination

INTRODUCTION

Over the past 70 years, the manufacturing of durable and convenient synthetic plastic materials has led to the spread of microplastic (MP) particles in the environment. Because of its widespread dispersion and detrimental impact on the living organisms, contamination through microplastics (MP) is a topic of concern on a global scale. MP have been found and quantified in freshwater, marine, and terrestrial inhabitants (**Aragaw and Mekonnen, 2021**). Starting from 1950s, there is an exponential growth in the global plastic production. According to **Geyer et al., (2017)** global plastic waste generation is predicted to reach around 25,000 million metric tons. The gross data on the global scientific production off MP stated that Europe (excluding Germany) is leading, followed by China and then Asia (excluding China) **(Orona-N´avar et al., 2022)**.

Plastics also typically includes thermoplastics, thermosets, polyurethanes (PURs), elastomers, coatings, and sealants. The most common resins and fibres are polyester, polyamide, and acrylic (PP&A) fibres, high density polyethylene (PE), low-density and linear low-density PE, polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyethylene terephthalate (PET), and PUR resins **(Geyer et al., 2017)**. MP (less than 5 mm), which are categorized according to primary or secondary sources, are extensively present in the environment and have a substantial impact on aquatic life forms. According to several research, MP concentrations seen in these kinds of settings are higher than the 6650 buoyant particles/m3 safe concentration level. It has been demonstrated that MP with a large specific surface area, low polarity, and hydrophobic qualities can absorb heavy metals, antibiotics, bisphenol A (BPA), polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT), polycyclic aromatic hydrocarbons (PAHs), and polyfluoroalkyl substances (PFAS). MP derived from polystyrene (PS), polypropylene (PP), and polyvinyl chloride (PVC) are more harmful to aquatic life and have an impact on the reproductive, neurological, endocrine, and immunological systems (**Vo and Pham, 2021**). All sizes of marine life can eat microplastic-containing prey or mistake plastic for food. This can have harmful, toxic consequences on muscles and cells. The most prevalent polymers, with diameters ranging from 1 to 100 µm, were found to be polyethylene (PE), polypropylene (PP), and polystyrene (PS). Interestingly, plastic appears to be more of a sink than a vector for non-additive contaminants. The most prevalent pollutants identified were persistent organic pollutants (POPs). Mortality, reproductive consequences, genotoxicity, accumulating, and behavioural effects were among the biological impacts and adverse effects. The interaction of plastic polymers, additives, and non-additives in causing hazardous consequences requires more to be investigated (**Palmer and Herat, 2021**). The growing incidence of persistent organic pollutants (POP) exacerbates their environmental issues. POPs tend to concentrate when they are absorbed by MP, alter their and this process has been shown to change or raise the toxicity and environmental risk of MP. It implies that a larger variety of environmentally important POPs might be the subject of future research. Future research might potentially use a variety of artificially aged and naturally aged MP in various environmental settings to unravel their interaction with POPs in respect to their ecological concerns (**Tang et al., 2021**).

Up to 14 million tons of plastic debris are believed to reach the ocean each year, and millions of tons of MP are generated each year and startlingly end up in the environment. Its unstable outcomes reveal a serious imbalance in the natural ecology of many organisms. Such a destructive and poisonous impact on our environment necessitates a sustainable solution to protect its people. Furthermore, research has demonstrated that a wide range of species eat MP. The notion that MP may affect the availability and toxicity of co-contaminants, that are naturally existing as well as those that are introduced from the outside, is supported by the combination of ingestion and chemical contact. An emerging technique for reducing environmental microplastic contamination is microbial remediation, primarily by bacterial and fungal populations (**Das et al., 2024**).

Since they affect rivers, lakes, oceans, and even the polar regions, MP, which have been found in large quantities in the world's water, have drawn a lot of attention and might represent a serious danger to the ecosystem as a whole. Few research have examined their ecological consequences on freshwater creatures, despite the fact that several have documented direct negative effects on marine organisms. A comprehensive knowledge of the possible ecological repercussions and a rigorous assessment of the harmful effects and processes of MP on aquatic species are still lacking in this sector. The physicochemical characteristics of MP were examined in the light of toxicological worries about their environmental influence and bioavailability (**Li et al., 2023**).

Through mechanisms like improving microplastic adsorption/desorption capacities for these contaminants and facilitating horizontal gene transfer of antibiotic resistance genes, the soil plastisphere may increase the ecotoxicological risks posed by co-existing contaminants (such as heavy metals, organic contaminants, pathogens, and antibiotic resistance genes), changing their environmental behaviours **(Zhang et al., 2025)**. The widespread presence of MP contamination in terrestrial settings have detrimental effects on microbial populations, soil health. MP complicate their effects on ecological systems by acting as vectors for a variety of environmental contaminants, such as pesticides, heavy metals, antibiotics, and persistent organic pollutants, in addition to being physical pollutants **(Ullah et al., 2025)**. There is a wide range of MP abundance in inland waters, from 0.00 to 4,275,800.70 items m^{-3} (mean: 25,255.47 ± 132,808.40 items m^{-3}), according to the extensive dataset of MP in worldwide inland waters. MP levels in water were shown to be primarily influenced by agriculture, land surface runoff, evapotranspiration, and the human development index. While MP abundance was reasonably high across Asia, Europe, Africa, and the eastern United States, it was especially high in China, according to a predictive analysis **(Jin et al., 2025)**. Findings demonstrated that the distribution and amount of MP in surface waters varied by oceans, with a mean abundance of 2.76 items/m^3, the total concentration of MP in all five oceans varied from 0.002 to 62.50 items/m^3. The Southern Ocean had the lowest mean concentration of MP (0.04 items/m3), whereas the Atlantic had the highest (4.98 items/m^3) **(Mutuku et al., 2024)**. The global ocean's MP varies from 0.002 to 62.50 items/m3, with an average size of 2.50 to 2.63 mm and an abundance of around 2.76 items/m3. Untreated plastics enter aquatic habitats where they are broken down into smaller pieces by bacteria, mechanical breakdown, and photodegradation **(Narwal and Kakakhel, 2025)**.

This article elucidates the recent paradigms of MP contamination in our environment. We have summarised the article depending on the current scenario of the MP ecotoxicity and have indicated the seriousness of the same.

OVERVIEW OF THE MICROPLASTIC TOXICITY ON OUR ECOSYSTEM

Numerous compounds, including plasticizers, colorants, fillers, and stabilizers, have been added to plastics throughout manufacture; some of these chemicals are known to be harmful to biota. MP may also come into contact with chemical pollutants when they are discharged into the environment, such as medicines, trace metals, and hydrophobic organic contaminants, all of which can adhere to plastic surfaces (**Khan et al., 2022**). After being thrown out and subjected to physical and chemical forces that break down their plastic structure into smaller fragments known as MP and nanoplastics (NP), plastics can remain in different environmental compartments for years. Through trophic transmission, these persistent particles in the environment may bioaccumulate in living organisms and then undergo biomagnification. The behaviour of micro- and nanoplastics (M/NP) in terrestrial ecosystems has, however, received very little consideration (**Rose et al., 2023**). The majority of research on the toxicity of MP in aquatic environments has been carried out in lab settings, despite the fact that several studies have documented that MP may be transported through food webs at higher trophic levels, where they may accumulate causing harmful effects. This indicates a formidable knowledge gap regarding the ecotoxicological effects of MP on aquatic animals and higher trophic level consumers (including humans) as there are insufficient research conducted throughout whole ecosystems or at ecologically relevant concentrations (**Rakib et al., 2023**). MP can act as a sink and supplier of these related chemical pollutants, possibly altering their toxicity, bioavailability, and destiny by absorbing different ambient chemical contaminants and releasing harmful plastic additives. (**Huang et al., 2021**). The generation of M/NPs has grown as a result of biodegradation, thermo-oxidative degradation, thermal and hydrolysis processes, as well as photodegradation. MP impacts on marine life have been thoroughly studied. However, because there is a lack of data on freshwater species, there is relatively little literature on their consequences. Therefore, compared to marine systems, freshwater systems are severely contaminated, and further study is needed to determine the ecotoxicological consequences of M/NPs on freshwater species. To enable the detection, identification, and quantification of polymers in environmental matrices, it is becoming increasingly crucial to develop analytical techniques for M/NPs and standardize them. Developing effective mitigation methods, influencing policy choices, and protecting aquatic ecosystems and human health from the effects of micro and nano-plastic pollution all depend on addressing these constraints and closing these knowledge gaps. Additionally, new approaches are needed to investigate the effects of M/NPs on people and the biota (*in vitro*) (**Naz et al., 2024**).

Numerous findings from investigations on the temporal and spatial fluctuations of MP in freshwater and saltwater ecosystems support the idea that harmful contaminants adsorb to the surface of MP. Furthermore, because phytoplanktonic organisms, small-sized polymer fragments have become more involved in the food chain, the growth and/or development of such aquatic organisms may be severely restricted as a result of this circumstance. These decisions are influenced by a number of aspects, including the organism's simplicity of use, the test methods' clarity, their comparability, and the goal of the conducted investigations. The accumulation of pollutants in an organism is influenced by the mobility and dynamics of MP in water, the resemblance of MP colour to nutrients for the organism, or the absorption of pollutants owing to surface load. Furthermore, polymer type has been found to play a significant role in determining the toxicity of MP. Although polypropylene (PP) is the most prevalent type of microplastic in detection and analysis studies, toxicology and MP studies have revealed that there are a lot of studies on polyethylene (PE) and polystyrene (PS) (**Sönmez et al., 2022**).

The harmful impact of MP in freshwater habitats is not as well studied as it is in marine ecosystems. Although some species have shown signs of toxicity, such as decreased growth in photoautotrophs, higher mortality in certain invertebrates, genetic alterations in amphibians, and internalization of MP and NP in fish, other research indicates that it is unclear whether MP can have harmful long-term effects on ecosystems. The negative interactions between MP and freshwater organisms will probably be worsened by a number of additional stressors, such as environmental change (temperature increases and invasive species) and anthropogenic contaminants (antibiotics, metals, pesticides, and endocrine disruptors). These factors could have serious negative effects on freshwater ecosystems and food webs (**Castro-Castellon et al., 2022**). Ecotoxicological research examined the effects of MP on aquatic creatures, namely fish and algae, etc. MP have been shown to have a number of negative consequences, including oxidative stress, immunotoxicity, neurotoxicity, reproductive toxicity, and a reduction in photosynthetic efficiency. In order to have a more comprehensive understanding of this new environmental problem, it is becoming increasingly necessary to do extensive study using MP of various sizes, shapes, varieties, and colours, expanding the range of studied (micro)organisms. Ecotoxicological research examined the effects of MP on aquatic creatures, namely fish and algae. The size, shape, and type of MP have a significant impact on the harmful consequences, even if some of the published results are conflicting. As a result, it appears that little is known about MP's existence in the environment and the negative consequences they cause. In order to have a more comprehensive understanding of this new environmental problem, it is becoming increasingly necessary to do extensive study using MP of various sizes, shapes, varieties, and colours, expanding the range of studied (micro)organisms (**Miloloža et al., 2020**).

The mechanism of harmful effects of MP on aquatic species in the aquatic environment is investigated at the level of cells and genes in addition to the level of individual organisms, depending on the various qualities of the various plastic materials. Additionally, environmental elements like temperature, pH, light intensity, salt, etc., relate to the toxicity of MP. They have the ability to leak additives into the aqueous environment or absorb heavy metals, persistent organic pollutants, etc., which together have a detrimental effect on aquatic life. To further understand the cumulative harmful effect of MP, it is necessary to investigate their adsorption and release mechanisms (**Ma et al., 2019**). MP can alter soil properties (such as bulk density, porosity, chemical composition, pH, or EC) and negatively impact the structure, enzymatic activity, population, and diversity of soil biota as well as other living organisms. Plastics have been demonstrated to be able to hold onto pesticides, particularly the more hydrophobic ones, which decrease their immediate availability for leaching, breakdown, plant uptake, or ingestion by other soil organisms. As a result, pesticides will not be able to reach the intended pests at the recommended dosages, plastics containing pollutants may be consumed or absorbed by organisms that are not the intended target, or polluted plastics may gradually desorb the pesticides, creating a time-dependent release of pesticides into the environment. Therefore, depending on the specific MP/pesticide system, the co-existence of MP and pesticides in soils may result in medium- and long-term disruptions that negatively impact soil organisms. Because aging causes new functional groups or microcracks to form in plastics that promote pesticide retention, aged MP often have greater impacts than pristine MP on the destiny of environmental pesticides and the toxicity of pesticides to living beings. Depending primarily on the characteristics of both pesticides and MP, environmental soil variables like pH, DOM, salinity, etc., appear to have little or fluctuating effects on the interactions between MP and pesticides. Pesticides may enter terrestrial animals via MP, and the likelihood of harmful consequences will rely on how well the pesticide interacts with the organism's biosystem. In order to completely comprehend the mechanisms involved in pesticide absorption and translocation by crops grown in soils polluted with MP (**Peña et al., 2023**). Heavy metals and organic contaminants are both adsorbed by MP, resulting in combined contamination. Antibiotic adsorption behaviour on MP has drawn more attention recently. In order to comprehend their ecological and environmental risk assessments, it is crucial to investigate the sorption behaviour of contaminants on MP. Results indicate that the physical and chemical characteristics of antibiotics, MP, and the water environment all influence how antibiotics adsorb onto MP. Physical and chemical interactions, such as hydrophobic interaction, partitioning, electrostatic contact, and other non-covalent interactions, are how antibiotics are adsorbed on MP. The physicochemical characteristics of MP and antibiotics (such as particle size, state of dispersibility, and morphology) will be influenced by the fundamental aqueous environment physicochemical properties (such as pH, salinity, ionic strength, soluble organic matter content, and temperature), resulting in variations in the kind and intensity of their interactions (**Abdurahman et al., 2023**).

One of the major theories behind the perceived risk and hazard of plastic in the marine environment is that microplastic will transfer hazardous hydrophobic organic chemicals (HOC) to marine animals. The majority of microplastic that lies in the seas, HOC microplastic-water partitioning may be presumed to be at equilibrium. Consistency between (a) measured HOC transfer from microplastic to organisms in the lab, (b) measured HOC desorption rates for polymers in artificial gut fluids, (c) simulations using plastic-inclusive bioaccumulation models, and (d) HOC desorption rates for polymers inferred from first principles is shown (**Koelmans et al., 2016**). These ubiquitous microplastic particles have been shown to harm fish's liver, gills, endocrine system, neurological system, and gastrointestinal tract in addition to interfering with their normal metabolic processes. Stopping excessive use, raising awareness and influencing human behaviour, improving waste segregation technology, enhancing recycling, and reusing plastic waste are the simplest and most considerate ways to lessen microplastic contamination. Plastic waste may be transformed into a sustainable and useable energy source as non-recyclable plastics can provide electricity. Thus, reducing plastic or microplastic contamination is urgently needed. By implementing appropriate waste management procedures, extending the shelf life of plastic items, and raising public awareness, the discharge of plastic litter in ecosystems may be significantly decreased, leading to the restoration of the marine environment (**Mallik et al., 2021**).

MP are persistent and harmful, and because they may act as a vector for several legacies and emerging contaminants, therefore their presence in aquatic habitats has raised concerns worldwide. MP have detrimental effects on aquatic life and are released into aquatic habitats from a variety of sources, particularly wastewater facilities (WWPs). The majority of the microalgae species showed signs of growth inhibition and reactive oxygen species (ROS) production. Accelerated premature moulting, growth retardation, increased mortality, eating behaviour, fat buildup, and lower reproductive activity were all possible effects in zooplankton. MP may also have toxicological effects on polychaetes, such as neurotoxicity, cytoskeleton instability, decreased growth, feeding rate, survival and burrowing ability, weight loss, and elevated mRNA transcription. Coagulation and filtration, electrocoagulation, advanced oxidation, primary sedimentation/Grit chamber, adsorption removal technique, magnetic filtration, oil film extraction, and density separation are among the various chemical and biological treatments for MP that have been shown to have high removal rates (**Ahmed et al., 2023**). There are MP everywhere in the world. It's possible health risks have been largely regarded as a typical emerging contaminant. Humans may come into touch with MP through their skin, mouth, or lungs. Oxidative stress, DNA damage, organ malfunction, metabolic disorders, immunological response, neurotoxicity, and toxicity to reproduction and development are some of these impacts. Furthermore, epidemiological data indicates that exposure to MP may be linked to a number of chronic illnesses (**Li et al., 2023**).

In the aquatic environment, MP act as substrates for the colonization of biofilms, which improves the adsorption of hazardous pollutants on MP surfaces. The mechanism behind MP biofilm development, microbial colonization, and the strong elements affecting the process in the aquatic ecosystem. The effect of MP-biofilm on the adsorption of both organic and inorganic pollutants is next investigated. Understanding the climate danger requires a thorough discussion on the ecological importance of the MP-biofilm related pollutant combination for boosting greenhouse gas (GHG) emissions from aquatic ecosystems. When colonized bacteria produce protective extracellular polymeric substances onto MP during biofilm development, the MP surface becomes sticky, allowing for the quick adsorption of chemicals and microbes to form heteroaggregates. MP with functional aromatic groups help bacteria adhere to surfaces, but also have an impact on biofilm development. Conversely, MP-biofilm encourages the development of Mn and Fe hydrous oxides, which can co-precipitate with heavy metal ions and aid in remediation procedures. However, freshwater ecosystems produce comparatively greater greenhouse gas emissions per unit mass via MP biodegradation than do marine ecosystems. Given its toxicity, MP-biofilm causes fish to undergo an oxidative reaction, which results in their agonizing demise and obliterates aquatic biodiversity (**Mishra et al., 2024**). MP have recently been shown to aid biofouling by genetically different species, which leads to the development of biofilms. However, biofilms may alter the physicochemical characteristics of MP, including their roughness and buoyancy. Several researchers believe that the relationship between MPand biofilms had more serious repercussions, citing evidence of its impact on aquatic life, the environment, and nutrient cycles. Furthermore, because microplastic-associated biofilms act as carriers of heavy metals, hazardous compounds, and genes that confer resistance to antibiotics, causing detrimental effects on human health (**Okeke et al., 2022**).

Crops based on their observed reactions, and talk about a number of theoretical soil function processes. The model demonstrates that the effects of MP on crops might be either beneficial, harmful, fatal, or non-existent. Generally speaking, microfibers of various diameters can benefit crops. However, at varying sizes, the harmful effects of MP with or without other contaminants are more prevalent. The deadly effects of biodegradable plastic raise doubts about their environmental friendliness. Although less common, no influence on crops is also conceivable. Only onions appear to be resistant to MP, in contrast to other crops including wheat, maize, and beans. To guarantee food safety, crop absorption of M/NP requires a precise standard. The biogeochemistry of nutrients and organic matter can be impacted by changes in soil enzymes and litter breakdown. It is possible to create hydrophobicity by increasing evaporation (**Iqbal et al., 2021**).

Although the majority of research on this topic has focused on the aquatic environment, microplastic contamination also affects terrestrial ecosystems. For the majority of terrestrial ecosystems, insects are essential (**Lee et al., 2023**). The issue of soil MP contamination is worsening every year. Since polyvinyl chloride (PVC) is a substance used extensively, PVC MP may be a major source of pollution, particularly in industrial soils. In addition, PVC often contains a wide variety of chemical additives that can move to the surface as it ages. There is proof that PVC-MP have a negative impact on the soil environment; they release toxic compounds as they age, impacting microbial populations, enzymatic activity, plants, some soil animals, and biogeochemical cycles. However, more study is required because there is not enough evidence on this topic. The analytics processes for soil containing PVC-MP can be approached in a variety of ways, and while choosing a protocol, considerations such as the complexity of the soil matrix and the characteristics of PVC and its aging must be considered. Standardization of the protocol and similar data must be the goal (**Nosova and Uspenskaya, 2023).**

DISCUSSION

Based on analysis, seven research goals are outlined that are crucial to advancing our knowledge of plastics. These goals may be addressed by identifying pertinent activities to accomplish each goal and by learning from research on natural sediments. These objectives encompass (1) the description of microplastic particles, (2) how MP interact with environmental materials, (3) how MP are distributed vertically, (4) how MP erode and deposit, (5) how biota affects microplastic transport, (6) sampling techniques, and (7) microplastic toxicity. However, significant information gaps remain, regarding the function of transport modes, the impact of biota on microplastic transport, and the significance and application of microplastic dynamic behaviour due to time-dependent changes in particle characteristics in numerical models. It is necessary to distinguish between the impacts of the polymers themselves, their physical shape, the compounds connected with plastic, and the attached contaminants in order to fully evaluate the ecotoxicology of MP (**Waldschläger et al., 2022**). Plastic waste from land and the sea gradually fragments, biodegrading at the micro and nanoscales. The Atlantic, Pacific, and Indian subtropical gyres are home to up to 2.41 million tons of MP, according to oceanographic model studies. MP throughout the environment from primary (such exfoliating cleansers) and secondary (chemical degradation) sources. As the number of cases of ingestion and entanglement rises over time, this man-made problem threatens both terrestrial and aquatic ecosystem flora and wildlife. The following key elements are included in the impact of MP across taxa at indicated environmentally relevant concentrations, which lays the foundation for future ecotoxicological-based research on MP: (i) the adherence of chemical pollutants (like PCBs); (ii) biological effects in aquatic and terrestrial organisms (like bioaccumulation, biomagnification, and bio-transportation); (iii) physico-chemical properties (like polybrominated diphenyl ethers) and environmental biodegradation pathways (like heat stress and chemical stress); and (iv) an ecotoxicological prospect for optimal impact assessments (**Vazquez and Rahman, 2021**).

Small particle sizes, poor photodegradability, and excellent environmental transporters are characteristics of MP. They have the ability to chemically react or physically adsorb organic, inorganic, and bio-pollutants to produce complex binary pollutants or alter the way these pollutants behave in the environment. The following aspects of MP should be reviewed: (i) Adsorption of MP organic pollutants and heavy metals, as well as the important environmental factors that influence adsorption behaviours; (ii) MP enrichment and release of antibiotic-resistant genes (ARGs) and their effects on ARG migration in the environment; (iii) MP formation of "plastispheres" and interactions with microorganisms; and (iv) MP ecotoxicological effects and co-exposures of MP with other pollutants. Lastly, a summary is provided of the scientific knowledge gaps and prospective research areas related to MP, including the standardization of study methodology, the ecological consequences, the hazards to human health, and the mixing of MP with other pollutants (**Song et al., 2022**).

A wide variety of aquatic biota are vulnerable to microplastic exposure due to the MP widespread dispersion throughout the world's seas. Studies conducted in the field and in the lab have shown that aquatic species at various trophic levels of the frequently consume MP. Exposure to MP cs can have a range of negative impacts on aquatic biota, including humans, apex predators, and primary producers. The potential negative effects of ingested MP (including the related toxicants) on aquatic species, particularly the marine taxa, are the primary focus of MP toxicity research to date. However, little is known about the effects of exposure to MP on aquatic primary producers, the trophic transfer process of MP and related compounds, and the health risks connected with ingesting aquatic goods. Furthermore, the majority of the research on the consequences of MP that is now accessible was carried out in lab settings, which may make it less applicable to real-world settings. Several study goals are suggested below to gain a better understanding of the ecological concerns that MP pose to people and aquatic organisms: (1) When conducting research on microplastic exposure, use doses that are ecologically appropriate. (2) Conduct more research to determine the impact of MP on aquatic primary producers and contributing variables. (3) Give greater consideration to the ecotoxicological impacts of MP on freshwater creatures and higher order predators. (4) Determine the part that MP play in the trophic transmission of environmental pollutants and thoroughly assess the synthetic impacts of MP and environmental toxicants. (5) Carry out more research on the variables influencing MP selectivity by aquatic creatures as well as the toxicity and destiny of MP that are consumed by aquatic species. (6) To determine the quantity of MP that humans are exposed to through the consumption of aquatic goods, conduct comprehensive monitoring programs on the abundance of MP in aquatic products that are at the point of human consumption. (7) Put greater attention into examining the toxicity and prevalence of nanoplastics in aquatic life as well as the potential health effects on humans (**Wang et al., 2019**). International surveys and scientific investigations have amply proven the pervasiveness of MP in the aquatic environment. One potentially significant concern has been identified as the further deterioration and fragmentation that leads to the production of nanosized plastic particles, or NP. Both MP and NP may have direct ecotoxicological consequences in the environment. They may also act as vectors by adsorbing co-contaminants. Aquatic creatures may suffer negative consequences from the leakage of plastic additives and monomers from the polymer matrix. Although there is currently little information on the ecotoxicological effects of NP and MP, their small size raises concerns about the negative effects and dislocation of these particles inside organisms, which is similar to the problems that are frequently raised for engineered nanomaterials. Similarly, leaching of soluble chemicals and transport of co-contaminants are hotly contested topics in the ecotoxicology of nanoparticles (**Rist and Hartmann, 2017**).

MP can be directly or indirectly ingested by aquatic species at different trophic levels, and then passed on via aquatic food chains, which can have a variety of effects on ecosystems and organisms. Furthermore, MP can release dangerous plastic additives and absorb a variety of chemical pollutants from the environment **(Ramasre et al., 2025)**. MP effects are monitored in terms trophic transfer dynamics, bioaccumulation patterns, and the overall effects on ecosystem stability and food web structure. Numerous aquatic species physiological, metabolic, and reproductive processes have been demonstrated to be hampered by MP. Recent biomonitoring investigations have demonstrated that these effects spread to human populations through inhalation, nutritional intake, and perhaps prenatal transmission. These issues are particularly noticeable in low- and middle-income areas, where exposure hazards are disproportionately high and monitoring is insufficient. Policies must support sustainable alternatives, encourage equitable solutions across areas, and incorporate ecological and public health issues **(Sunny et al., 2025)**.

A healthy environment, livelihoods, and human well-being depend on clean water in order to meet the Sustainable Development Goals (SDGs) of the UN after 2015. Water quality should be improved by lowering pollution and minimizing the release of dangerous chemicals and materials, among other things, according to SDG Goal 14 and Aim 6, Objective 6.3. The prevalence of emerging micropollutants (EMP) in water, however, continues to be a significant obstacle to reaching SDG Aim 6, Objective 6.3, and the 2030 Agenda for Sustainable Development. To put it another way, there is a significant challenge in achieving the potential to improve water quality by lowering pollution, removing discharge and minimizing the release of hazardous chemicals and materials, halving the amount of untreated wastewater, and dramatically increasing recycling and safe reuse worldwide by 2030. Biodegradable polymers stand out as a crucial and essential part of this plan. Although it is not a permanent solution to plastic pollution, using biodegradable polymers (BP) in place of conventional plastic trash has major positive effects on the environment. They can so take the place of non-biodegradable plastics and play a significant role in the breakdown of these materials in soil ecosystems **(Özgenç et al., 2025)**. BP are marketed as environmentally beneficial substitutes for traditional plastics. Nevertheless, they break down more quickly than traditional MP to produce biodegradable microplastics (BMP), which might result in a greater buildup of BMP in the environment. They have a shorter migration distance across various matrices than MP because they are more susceptible to environmental changes including photodegradation and biodegradation **(Yan et al., 2025)**.

To address the threats that MP represent to soil-mediated ecological services, multidisciplinary research combining ecology, material sciences, and environmental policy is crucial. In the end, detecting MP and preventing their spread need thorough scientific research and integrated management strategies. In turn, this will help protect biodiversity, maintain the integrity of our terrestrial ecosystems, and guarantee the maintenance of essential soil processes in an era where plastic is becoming more and more prevalent. Maintaining ecological balance and fostering a healthy environment for future generations depend critically on protecting land-based ecosystems from the growing danger of MP. To comprehend the long-term impacts of MPs on soil health and ecosystem functioning, longitudinal research is crucial. To successfully reduce MP pollution, new waste management approaches must be investigated, such as bioremediation methods and regulations meant to lower the manufacturing and use of plastic **(Ullah et al., 2025)**.

Conclusion and future directions

The nature of plastic pollution is very dynamic which started from over usage of non-biodegradable plastic wastes which were basically obtained from daily used products. Microplastic or nanoplastic contamination is the latest form of plastic pollution in our environment which has created significant challenges for the ecosystem health, animal health and public health. With the constant increase in the plastic waste production and emission into the environment, the living world and the corresponding ecosystems are in constant threat to the anthropogenic (artificial) unwanted compounds. It is a fact that at this point of time, despite of the urgent need to remove the plastic wasters from our environment, we are unable to do so, due to several reasons which broadly encompass lack to remedial information and obviously some unavoidable industrial and commercial reasons. Ecologists and toxicologists are constantly warning about the issues regarding the ecological risk indexing and organismal risk indexing due to microplastic contamination, where researcher involved in public health issues are cautioning us with the health hazards. Future direction should address remediation and scientific waste management to mitigate this complicated threat to the globe. Through this article, it is an appeal to the policymakers to look this ecotoxicological issue with extreme urgency, where eco-friendly industrial policies should help the planet to respire in this toxic environment.

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