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FROM SOILS TO OCEANS: A COMPARATIVE REVIEW OF MARINE AND TERRESTRIAL MICROPLASTICS AND THEIR MICROBIAL INTERACTIONS

Mayuri Wakade and Sushmitha Baskar*

*Discipline of Environmental Studies
School of Interdisciplinary and Trans – disciplinary Studies
Indira Gandhi National Open University, New Delhi - 110068

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Abstract
Microplastics are recognized as a global environmental crisis due to their increasing production, persistence and high mobility across ecosystems. They are continuously transported between terrestrial, aquatic and atmospheric systems through processes such as runoff, ocean currents and atmospheric deposition. This highlights global distribution of microplastics beyond their original sources. Beyond physical transport, microplastics act as active ecological substrates which supports the formation of distinct microbial communities referred to as plastisphere. The formation and structure of these communities are governed by both intrinsic polymer properties and extrinsic environmental factors, with early colonization driven by deterministic selection of generalist microorganism and later stages shaped by temporal succession and stochastic processes. In addition to their ecological role, microplastics act as vectors for a wide range of contaminants and microorganisms. Their surfaces can adsorb and transport heavy metals, persistent organic pollutants and antibiotics. This influences their mobility and bioavailability in the environment. These interactions raise concerns regarding their impacts on environmental and human health where microplastics enter biological systems through ingestion and inhalation and induce adverse effects. Despite increasing research, most studies address these aspects independently, which leads to fragmented understanding. This review provides an integrated understanding of microplastic by linking their transport pathways, plastisphere ecology and vector role, highlighting their impact on environmental and human health.

Keywords
Microplastic, Microbial interactions, Plastisphere, Deterministic and stochastic processes.

INTRODUCTION

The growing dependence on plastics in daily human activities has led to increase in their production and significant accumulation in the environment. Recent global studies by Zong (2021) have demonstrated a strong positive correlation between global plastic production and the accumulation of macro and microplastic debris in marine oceans. Further estimations by model predicts that plastic production may reach approximately 2134 million tons by 2050 with more than 15.6 million tons of total plastic particles entering the oceans annually. In addition to increasing plastic production, waste mismanagement plays a significant role in leakage of plastic into the natural environments. Pottinger et al. (2024) highlighted that integrated strategies such as reduction in plastic use, improved waste management and recycling systems are essential to address this issue. Their study further indicates plastic pollution is not only an environmental issue but also linked to climate change due to its contribution in greenhouse gas emissions (Pottinger et al. 2024). Over time, plastics get fragmented into small sized particles (<5 mm) called microplastics due to their recalcitrant nature and long persistence in environment. A recent study by Liro and Zielonka (2025) suggests the

CONTACT *Corresponding author: *sushmithab@ignou.ac.in; Orcid ID: 0000-0003-3839-5557*
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fragmentation is governed by complex interplay of intrinsic (human-controlled) factors, such as polymer type, shape and usage patterns and extrinsic environmental processes including ultraviolet radiation, wind, water dynamics and biological activities. Microplastics are now ubiquitous in nature and have been detected in soil, freshwater, marine systems and even in the atmosphere (Tang 2024, Liu et al., 2019). Due to their small size and high mobility, microplastics can move easily across terrestrial, aquatic and atmospheric systems. In terrestrial systems, microplastics accumulate in soil which functions as a major sink and as a transport media where different processes enable the movement of microplastics into groundwater and nearby water bodies (Wei et al., 2024; Severe et al., 2025; Rilig et al., 2017). These travel through rivers and freshwater systems into marine environments. Atmosphere plays a crucial role as a connecting link between these systems, which facilitates their long-range transport and widespread distribution in environment (Rashid et al., 2025; Wang et al., 2022; Kane et al., 2020; Liu et al., 2019). This continuous movement highlights microplastics as globally distributed pollutant which move across boundaries and not limited to one system. Beyond their physical transport, microplastics have gained attention as active ecological substrates. Microplastics function as novel anthropogenic habitats, where their surface is colonized by diverse microbial communities termed as plastisphere (Zettler et al., 2013). The assembly and structure of these communities are governed by a combination of intrinsic polymer properties and extrinsic environmental factors. These interactions result in selective colonization, where certain microorganisms are favored over others (Ramsperger et al., 2020; Wang et al., 2023). Although these processes are common to environmental systems but they exhibit distinct behavior in terrestrial and aquatic systems due to differences in soil characteristics, water dynamics and environmental conditions. Over time, these microbial communities evolve from generalist as early colonizer to more specialized and structured communities through both deterministic and stochastic processes which makes plastic as a dynamic and evolving substrate (Yang et al., 2023; Sun et al., 2021).

In addition to their ecological role, microplastics also function as vectors for a wide range of contaminants and microorganisms. Their surfaces can adsorb heavy metals, persistent organic pollutants and antibiotics through various physiochemical interactions, which influences the transport, mobility and bioavailability of these contaminants (Chen et al., 2023; Wang et al.,2020; Wang et al., 2024). Moreover, microplastics provide favorable conditions for microbial growth and interactions, which can promote the development and spread of antibiotic resistance. Further, microplastics can also act as carriers of pathogenic microorganisms which enables their persistence and long-range transport across environmental systems (Zhang et al., 2025). This raises concern regarding the potential impact of microplastics on ecosystem functioning and human health particularly through trophic transfer and different environmental pathways.

Despite growing research most researchers have examined microplastics transport, plastisphere formation, vector and health risks in isolation. A comprehensive understanding that integrates these interconnected processes across terrestrial and marine systems remains limited. Therefore, this review aims to provide a holistic synthesis of microplastics transport pathways, plastisphere ecology and vector functions, highlighting their combined role in contaminant dynamics and potential health implications. By linking these aspects, this review contributes to an integrated framework for understanding the environmental behavior and risks associated with microplastics.

Transport and Distribution of Microplastics Across Terrestrial and Aquatic Systems

(I) Terrestrial Systems: Tyre-road interactions generate significant quantities of microplastic particles, as tyres consist of synthetic polymers such as styrene - butadiene rubber. These particles accumulate in the surrounding soils, released from vehicle movement. Similarly, microplastics accumulate in agricultural soils due to the usage of plastic materials in mulch films and irrigation components (Rashid et al., 2025). This highlights soil as a major sink in terrestrial environments. Further, the modeling approaches by Wei et al. (2024) demonstrated the vertical transport of microplastic from surface soil to ground water. Particle properties such as size, shape and density along with soil characteristics and flow conditions, play a crucial role in controlling their dispersion and retention. These highlight soil not just as sink but also as a transport medium of microplastics. The study by Severe et al. (2025) highlights splash erosion and surface runoff as key mechanisms for the transportation of microplastics. Splash erosion is caused by the detachment of microplastic particles from the soil surface by raindrops while the surface runoff transports these particles to adjacent water bodies. Moreover, the particle properties influence this transport, smaller and lighter particles move more easily with the water flow. This facilitates the transport of microplastics from soil system to aquatic systems. Further physical transport processes, biological activity also contributes to the redistribution of microplastics in soil. Rilig et al. (2017) demonstrated that earthworms can ingest microplastics along with soil particles and transport them to deeper layers through burrowing and casting activities. This facilitates the vertical movement and mixing of microplastics within the soil profile. Atmosphere also plays a significant role in distribution of microplastics from terrestrial to marine systems. Long range transport of microplastics through atmosphere enable them to reach remote marine regions far from the terrestrial source. There is continuous deposition of microplastic from air into the marine systems, making atmosphere act as bridge between terrestrial and marine systems (Liu et al., 2019).

(ii) Marine Systems: Microplastics are transported from terrestrial environments to aquatic systems through multiple pathways. Rivers play a significant role in transferring plastic debris from land to oceans. The mismanaged plastic waste from terrestrial environments is a major source for riverine microplastics. Kumar et al. (2021) reviewed the factors influencing transport and deposition of microplastics in riverine systems. Hydrodynamic conditions such as flow velocity, turbulence and physical characteristics of plastic such as size, shape and density determine whether particles remain suspended or settle. Processes such as biofouling, where microorganisms attach to plastic surfaces, increases the weight of the particles and promote settling of microplastics in river sediments, in contrast, fragmentation of large plastics can produce smaller particles that remain suspended in water for longer periods. The study by Watkins et al. (2019) highlights anthropogenic structures such as dams as sink for microplastic. Their study reported higher microplastic abundance in reservoir sediments compared to the reservoir water. The reduced flow velocity near dams enhances microplastic sedimentation due to increased retention time. These findings help in mitigation strategies too.

Estuarine fronts are identified as a hotspot for microplastic accumulation and fragmentation due to convergent circulation patterns (Wang et al., 2022). The mixing and turbulence in these areas can move microplastics from surface to deeper parts of water columns. When the frontal systems weaken or breaks, the accumulated microplastics can be released into the adjacent coastal waters. Hence estuaries not only traps plastics but are important for transferring river borne plastics into the marine environment. A numerical modeling study by Golubeva and Gradova (2024) demonstrated that low density microplastics transported by rivers can be carried toward the continental shelf by ocean currents due to their suspension in surface waters. Their study also highlighted the trapping of microplastics in sea ice which accelerates the long-range transport during melting.

In addition to riverine and estuarine transport, the atmosphere has recently been identified as another major pathway for transporting terrestrial microplastics to marine systems. The field-based study by Liu et al. (2019) reported the presence of microplastics in the marine atmosphere suggesting long range transport through atmospheric circulation. Additionally, these microplastics accumulate in the ocean through processes like precipitation and dry deposition. Their study highlights the role of atmosphere in global transport of microplastics (Liu et al. 2019).

After reaching marine environments through rivers, estuaries and atmospheric transport, microplastics are not limited to the ocean surface, they show significant vertical distribution within the water column. A study by Zhao et al. (2022) reported that microplastics are present from the surface waters to the deep ocean, including the abyssal region. The findings from the South Atlantic Gyres demonstrated that microplastics concentrations were higher at deeper water levels compared to the surface. This suggests deeper ocean accumulation of microplastics due to vertical mixing and biofouling. Kane et al. (2020) identified microplastic hotspot in Tyrrhenian Sea, part of the Mediterranean Sea with concentration reached up to 1.9 million particles per square meter. This is the highest recorded concentration in the ocean. The study further suggested the role of bottom sea currents in accumulating the microplastics in deep sea sediments making it a global sink for microplastics.

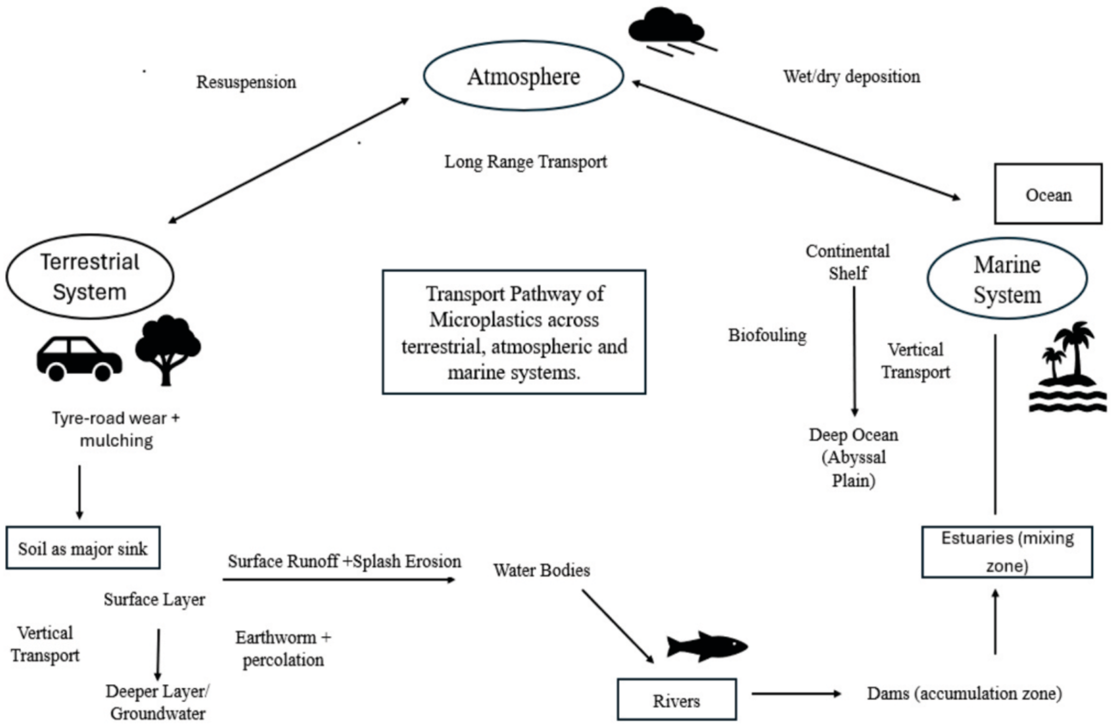

Fig. 1: Transport pathways of microplastics across terrestrial, atmospheric and marine systems. The diagram illustrates the movement of microplastics from terrestrial sources through freshwater and atmospheric pathways to marine systems, with final accumulation at deep sea sediments.

As shown in Figure 1, microplastics are continuously transferred between environmental systems through interconnected pathways. Beyond these transport processes, it is important to understand that microplastics do not remain passive during their movement but instead act as active ecological substrates that support microbial colonization which is discussed in the subsequent section.

Plastisphere Ecology

The concept of the plastisphere was first introduced by Zettler et al. (2013) to describe the diverse microbial communities colonizing plastic debris in aquatic environments. Microbial communities on plastic surfaces were taxonomically distinct from those in surrounding surface seawater, suggesting selective habitat formation and highlighting plastic debris as a unique anthropogenic ecological niche in the open ocean (Zettler et al. 2013). This makes plastic not simply inert pollutant but as an active substrate that can shape unique biofilm communities. This raises the question of why selective colonization occurs on plastic surface? A subsequent study by Bhagwat et al. (2021) demonstrated that biofilm development on plastic surfaces is initiated by rapid physiochemical modifications resulting from the establishment of a conditioning layer. Adsorption of dissolved biomolecules modifies the surface properties such as hydrophobicity, charge and roughness. This facilitates the development of early plastisphere. Further study by Ramsperger et al. (2020) showed that interactions between polymer surface properties and environmental chemistry, where ionic strength and surface charge influence the early biofilm structural diversity across freshwater and marine systems. This was supported by Ober Beckmann et al. (2014) that microbial structure and diversity vary with geographical location, season and polymer type. Together, these studies suggest that plastisphere is shaped by both intrinsic surface properties of plastic and extrinsic environmental factors, which selectively favors certain microorganisms over others (Wang et al. 2023).

The selective colonization of plastic surfaces marks the beginning of early microbial succession. Wallbank et al. (2022) demonstrated that early plastisphere succession is dominated by generalist biofilm-forming microorganisms. These pioneer microbes are selected based on their ability to attach and rapidly colonize rather than plastic specific metabolic utilization. This suggests that surface availability and environmental conditions play a greater role in shaping pioneer communities. A study of spatiotemporal succession in the lacustrine plastisphere by Yang et al. (2023) highlighted the dominance of bacterial generalist during early stages, favoured by deterministic environmental selection. As biofilm development progresses, temporal succession plays a more dominant role, leading to the establishment of more specialized and structured microbial community. This suggests that polymer properties and environmental selection influences initial colonization while temporal succession shapes long term community composition. In addition to these deterministic factors, stochastic processes also play a crucial role in plastisphere assembly. The study by Sun et al. (2021) reported that random processes such as ecological drift and dispersal limitation result in the formation of heterogenous microbial niche on microplastic surfaces. Together these findings indicate that plastisphere development is governed by both deterministic selection and stochastic processes leading to the development of unique microplastic associated microbial habitat. Although plastisphere formation occurs across different environments, but its characteristics differs between terrestrial and aquatic systems due to changes in physical, chemical and biological factors.

(I) Terrestrial Plastisphere: Recent studies have demonstrated that microbial communities associated with soil microplastics are taxonomically distinct from those in the surrounding bulk soil. Sun et al. (2024) reported that fungal communities colonizing soil microplastics differ significantly from those in surrounding soil. The study further identified certain fungal genera such as Penicillium and Alternaria as plastisphere associated fungi indicating that these species may prefer plastic surfaces for colonization in soil. This pattern is consistent with observations in marine environments, where microbial communities associated with plastic debris were also found to differ from surrounding seawater communities as described by Zettler et al. (2013). This highlights the selective nature of plastisphere formation on microplastics. Further experimental evidence provided by Rohrbach et al. (2023) demonstrated that different polymer types can support distinct microbial communities indicating that polymer chemistry acts as a deterministic factor in influencing the microbial community assembly. In addition, the formation of eco-corona through the adsorption of organic molecules on the plastic surface, further modifies the surface properties and influences the microbial colonization in soil. Moreover, the environmental conditions such as temperature may also influence composition of microbial community in soil microplastics as reported by Sun et al. (2022). Although, the microorganisms colonizing microplastics originate from the surrounding soil but the plastic surface selects specific taxa which makes plastic surfaces function as the ecological filters. This selective process leads to species turnover where some soil microorganisms replaced by other microbes that grow on plastic surfaces has been identified as the key reason for explaining the differences between the plastisphere and bulk soil microbial communities. Together these findings indicate the contribution of both substrate properties and environmental factors in the assembly of microbial community in soil microplastics. In addition to deterministic selection, stochastic processes may also contribute to development of unique microbial niches in soil microplastics. Interestingly, the recent findings by Deng et al. (2025) suggested microplastic particles may act as microbial hotspot for organic carbon metabolism in soil ecosystems as the microbial communities associated with microplastic show greater potential for organic carbon degradation when compared with surrounding soil. This indicates that metabolically active plastisphere communities are capable of influencing carbon cycling and contribute to plastic degradation. Moreover, the bacterial communities have been reported to dominate the soil plastisphere when compared with fungi highlighting their significant role in microplastic colonization and degradation processes. The study by Li et al. (2021) reported environmental factors such as soil pH exerting stronger influence on shaping the plastisphere communities than contaminants levels such as arsenic. Further the microbial communities associated with soil microplastics show active role in pollutant transformation processes such as arsenic methylation. This finding indicates the microplastics function not only as carriers of contaminants but also as active microbial reactor that can influence the toxicity and mobility of pollutants in soil systems.

(ii) Marine Plastisphere: Similar to terrestrial plastisphere, microplastics in marine ecosystems also serve as substrates for microbial colonization leading to the formation of distinct plastisphere communities. However, in contrast to soil systems, marine plastisphere development is strongly influenced by continuous interaction with water and hydrodynamic conditions (Tang, 2024). Consistent with terrestrial ecosystems, microbial communities on marine microplastics are taxonomically distinct from the surrounding seawater indicating selective colonization of plastic surfaces (Zettler et al. 2013). Huang et al. (2024) described the sequential processes of marine plastisphere formation which includes the development of conditioning layer on plastic surface, followed by microbial attachment, microcolony formation and the establishment of a mature biofilm. Similar processes occur in soil systems, while biofilm formation in marine environments are rapid due to continuous exposure to water and nutrients. The study by Kingsburg et al. (2025) highlighted the role of physicochemical properties of plastic surface in influencing the early stages of marine plastisphere formation. Plastic surface properties such as roughness, polymer composition and hydrophobicity act as deterministic factors which governs the early microbial attachment and community structure. This pattern is consistent with terrestrial systems where polymer properties determine the early-stage microbial selection. Microplastics are continuously exposed to marine conditions, where environmental factors play significant role in shaping the marine plastisphere communities. Hydrodynamic forces such as turbulence, water mixing and currents influence the microbial attachment. The study by Nguyen et al. (2023) highlights the degree of resilience to storm induced disturbances in plastisphere communities. The temporary shift in microbial composition followed by recovery and re-establishment of original plastisphere communities was observed. Similar to terrestrial systems, the study suggests that both deterministic environmental selection and stochastic processes such as dispersal and recolonization contribute to community assembly and recovery. This highlights the stable nature of marine plastisphere community under fluctuating environmental conditions. Similar to terrestrial systems, where plastisphere communities influence the carbon cycling, the study by Fortin et al. (2025) demonstrated the genetic potential of marine plastisphere in plastic degradation and nitrogen cycling. Microbial genes are associated with nitrogen transformation processes such as nitrification and denitrification. Together these findings highlight the function role of microplastics in regulating biogeochemical processes across terrestrial and marine systems. In addition, the plastisphere communities have shown to participate in the transformation of pollutants. Interestingly the study by Liu et al. (2024) demonstrates the metabolic potential of marine plastisphere for processes such as organohalide respiration which enables the degradation of recalcitrant contaminants in marine systems. This indicates the microplastics support specialized microbial communities capable of utilizing and transforming complex compounds. These studies are consistent with terrestrial studies, where microbes contribute to arsenic methylation. This highlights the role of plastisphere communities in both biogeochemical cycling and pollutant transformation across both terrestrial and marine systems. Beyond these roles, microplastics also act as vector for the transport of contaminants.

Table 1: Comparative characteristics of terrestrial and marine plastisphere and their influencing factors.

S. No.	Characteristics	Terrestrial Plastisphere	Marine Plastisphere	References
1.	Initial colonization	Influenced by soil properties and surrounding microbial pool	Strongly influenced by polymer physio-chemical properties and continuous inter-action with water.	Tang (2024), Kingsburg et al. (2025)
2.	Conditioning Layer/ Eco-corona	Adsorption of organic molecules on plastic surface	Formed by dissolved organic matter in water.	Bhagwat et al. (2021), Rohrbach et al. (2023)
3.	Influencing Factors	Soil pH, moisture, temperature	Hydrodynamic (current, turbulence) Salinity, temperature	Tang (2024),
4.	Deterministic Vs Stochastic Processes	Initially deterministic (soil conditions), later influenced by stochastic processes	Strong influence of stochastic processes due to high dispersal and mixing.	Sun et al. (2021), Yang et al. (2023).
5.	Microbial Community	Distinct from bulk soil, influenced by soil microbial pool	Distinct from surrounding sea water	Zettler et al. (2013), Sun et al. (2024)
6.	Biogeochemical Role	Microbial hotspot for carbon cycling	Microbial hotspot for nitrogen cycling	Fortin et al. (2025)
7.	Pollutant Transformation	Metal transformation (arsenic methylation)	Organic Pollutant degradation (organ-ohalide respiration)	Liu et al. (2024), Li et al. (2021)
8.	Resilience to disturbances	Influenced by soil stability and	High resilience to disturbances like storms due to recolonization.	Nguyen et al. (2023)
9.	Overall nature	More structure and niche driven communities	More dynamic, dispersed and heterogenous communities.	Tang (2024)

The comparative characteristics highlighted in Table 1 demonstrate how environmental conditions shape plastisphere development and function across systems. In addition to their ecological role, microplastics also act as vector for contaminants and microorganisms.

Microplastics as Vector

(i) ***Heavy Metals:*** Microplastics can act as vectors for heavy metals in the aquatic and terrestrial environments. The adsorption of heavy metals on microplastics is governed by multiple interacting factors including metal ion concentration, polymer properties such as surface area, aging of the material, functional groups and environmental conditions like pH and ionic strength (Chen et al., 2023). Environmental ageing enhances the surface roughness and introduces functional groups; this increases the adsorption capacity of microplastics. Beyond environmental interactions, their study reported the ingestion of metal loaded microplastics by aquatic organisms, which may highlight bioaccumulation and heavy metal transfer across trophic levels. Further the study by Brennecke et al. (2016) demonstrated that polystyrene and PVC particles in sea water can adsorb copper and zinc released from antifouling paints used for ship coatings, which makes microplastics as mobile vectors linking point source pollution to large scale contaminant distribution within marine ecosystems. However, these adsorbed metals are not permanently bound and may be released back into the surrounding environment. The study by Zhou et al. (2024) highlighted that aged microplastics not only exhibit higher adsorption capacity for mercury (Hg^{2+}) but can also influences its chemical transformation by promoting the formation of gaseous elemental mercury (Hg), which affects its environmental cycling. In terrestrial systems, microplastics similarly influence the behavior of heavy metals in soil. Shikhorshidi et al. (2023) reported microplastics can enhance the sorption of lead by providing additional binding sites especially after environmental ageing, however desorption can occur under changing soil conditions. These findings suggest that microplastics not only transport heavy metals but also play an important role in modifying their chemical behavior in marine and terrestrial systems. Microplastics can act as both sink and source of heavy metals depending on the environmental conditions which temporarily bind and release contaminants under changing physiochemical conditions.

(ii) ***Persistent Organic Pollutants:*** Microplastics also act as vectors for organic contaminants, particularly hydrophobic compounds such as persistent organic pollutants. Wang et al. (2020) highlighted the sorption of organic contaminants onto microplastics is primarily driven by hydrophobic interactions, along with other mechanisms such as pi-pi interaction, electrostatic forces and pore filling processes. These interactions enable microplastics to accumulate high concentrations of organic pollutants such as polycyclic aromatic hydrocarbon (PAHs) and Polychlorinated dibenzo-p-dioxin and furans (PCDD/ Fs) relative to surrounding environment. Conesa (2022) reported that these hydrophobic compounds exhibit a strong affinity for microplastic surfaces. The adsorption process is influenced by polymer type, ageing and environmental conditions with weathered microplastics showing enhanced sorption capacity. Similar to heavy metals, these contaminants are not permanently bound and may be release under changing environmental conditions, thereby increasing their bioavailability and potential toxicity.

(iii) ***Antibiotics:*** Microplastics can also act as a vector for antibiotics which facilitates their transport and persistence in the environment. According to the recent study by Wang et al. (2024), microplastics are capable of absorbing various antibiotics through mechanisms such as electrostatic interactions, hydrogen-bonding and hydrophobic interactions. The adsorption process is influenced by polymer characteristics, ageing of microplastics and environmental conditions. Similar to heavy metals and persistent organic pollutants, these antibiotics are also not permanently bound and may be released under changing environmental conditions, thereby increasing their bioavailability. Salinity and temperature are key environmental factors that regulates the adsorption and desorption behavior between antibiotics and microplastics (Kuang et al., 2023). For instance, the experimental study by Ma et al. (2020) demonstrated the synergistic effect of microplastics and antibiotics. The combined presence of both can enhance the enrichment of antibiotic resistance genes in soil microbial communities. In addition, the metagenomic study by Zhang et al. (2025) further revealed the synergistic impact of microplastics and antibiotics at the molecular level which can significantly alter the microbial community structure and function. This leads to the enrichment of antibiotic resistance genes and changes in metabolic pathways. Further the microplastics are identified as vector for pathogenic microorganisms in aquatic environments. They can attach to the plastic surface and be transported across long distances through water currents. This facilitates the spread of potentially harmful microorganisms across ecosystems and increases the risk of their transfer to higher trophic levels

including humans which may pose risk to human health.

Impacts of Microplastics on Human Health: The small particle size and persistence of microplastics allow them to be easily consumed by organisms across different levels of the food chain. These particles may accumulate within tissues of organisms or be transferred through food webs and eventually reaching humans. An experimental study by Kangas et al. (2023) demonstrated that littoral predators accumulate higher number of microplastics when they consume previously exposed prey as compared to direct ingestion from the surrounding water. Their study confirmed the transfer of microplastic in three trophic level systems tested on zooplankton, shrimp and prawns. Similar evidence has been previously reported by Nelms et al. (2018), which indicates the presence of microplastics in fish and marine mammals such as seals with ethylene propylene being one of the most frequently detected polymer types. Together these findings provide strong evidence that microplastics can move through different trophic levels of marine ecosystems. Such transfer may lead to the accumulation of microplastics in higher trophic organisms and potentially reaching humans through seafood consumption. Similarly, microplastics may also enter the human diet through terrestrial food sources. A study by Conti et al. (2020) detected the microplastics and nano-plastics in edible fruits and vegetables such as apples, carrots, lettuce, potatoes, and broccoli indicating the entry of the microplastics through agricultural systems in terrestrial food chain. After ingestion, microplastics may interact with the human digestive system. *In vitro* gastrointestinal digestion model was used by Chen et al. (2022) reported the partial release of the heavy metals associated with the microplastics under simulated gastric and intestinal conditions. Results showed that the acidic conditions of the gastric phase enhanced the release of heavy metal with lead showing highest bio accessibility. After passing through the stomach, it can reach the small intestine, where absorption may occur into the body. A recent study by Leonard et al. (2024) identifies the presence of different polymer types such as polyethylene terephthalate and polystyrene in the human blood samples. This indicates the transportation of these particles in human blood through circulatory system and potentially reaching different tissues and organs, including the placental barrier. Interestingly the study by Ragusa et al. (2020) reported the first evidence of microplastic particles in human placental tissue including the maternal and fetal sides. This important finding suggests that these particles may potentially cross biological barriers and poses the threat to the developing fetus. In addition, microplastics further influence the cellular processes and increase viral infection. Experimental studies by Wang et al. (2022) reported that exposure to polystyrene microplastics significantly enhanced Influenza A virus infection in host cells by facilitating viral entry and replication. Further interaction of microplastics with mitochondria reduces the ATP production, this leads to oxidative stress that damages the cell and exhibit inflammatory responses. Additives on plastics such as Bisphenol A and phthalates are endocrine disrupting chemicals which interferes with hormonal regulations and can induce infertility, metabolic problems and increased cancer risk (Kovacs et al., 2025). Together these findings indicate the combined toxic effect of microplastics in human body. Further the study by Zhao et al. (2024) detected the presence of microplastics particles in various types of human tumor tissues indicating that these particles can accumulate in human organs following circulatory processes. Further experimental evidence provided by Rafazi et al. (2024) demonstrated that microplastics can increase the cancer cells growth in 2 D model and enhances the cell survival in 3D tumor like environment. These findings suggest the microplastics may influence tumor behavior by promoting cell growth and survival. However, direct relationship between microplastics exposure and cancer development in humans needs to be further investigated.

Conclusion

Microplastics have changed from being just a pollutant to an important component of modern ecosystems. This review highlights that microplastics are not inert particles but active substrates that interacts with microorganisms, contaminants and environmental processes. Their continuous transport across terrestrial, atmospheric and aquatic systems highlights their global presence, even in remote regions. Beyond their physical mobility, microplastics play an active ecological role through the formation of the plastisphere, where their surface supports distinct microbial communities. The structure and function of these communities are governed by the influence of polymer characteristics and environmental conditions. This represents microplastics as dynamic substrate connecting abiotic and biotic component of ecosystem. In addition, the microplastics adsorb and transport the contaminants such as heavy metals, organic pollutants and antibiotics highlights their f unction as vector. The sorption and desorption processes of contaminants on microplastics further influences their bioavailability and transformation. Moreover, the detection of microplastics in food, water and air indicates its entry into biological systems including human tissues highlights the possible health risks associated with it. The multifunctional characteristics of microplastics emphasizes the need for an integrated approach to understand its environmental behavior. Future research should focus on bridging the existing knowledge gap, effective plastic management strategies and mitigate their long term environmental and health risks.

REFERENCES

1. **Bhagwat, G., O'connor, W., Grainge, I., & Palanisami, T.** (2021). Understanding the fundamental basis for biofilm formation on plastic surfaces: role of conditioning films. *Frontiers in Microbiology*, *12*, 687118. https://doi.org/10.3389/fmicb.2021.687118

2. **Brennecke, D., Duarte, B., Paiva, F., Caçador, I., & Canning-Clode, J.** (2016). Microplastics as vector for

heavy metal contamination from the marine environment. *Estuarine, Coastal and Shelf Science*, *178*, 189-195. https://doi.org/10.1016/j.ecss.2015.12.003

3. **Chen, Q., Zhao, H., Liu, Y., Jin, L., & Peng, R.** (2023). Factors affecting the adsorption of heavy metals by microplastics and their toxic effects on fish. *Toxics*, *11*(6), 490. https://doi.org/10.3390/toxics11060490

4. **Chen, X. J., Ma, J. J., Yu, R. L., Hu, G. R., & Yan, Y.** (2022). Bioaccessibility of microplastic-associated heavy metals using an in vitro digestion model and its implications for human health risk assessment. *Environmental Science and Pollution Research*, *29*(51), 76983-76991. https://doi.org/10.1007/s11356-022-20983-8

5. **Conesa, J. A.** (2022). Adsorption of PAHs and PCDD/Fs in microplastics: A review. *Microplastics*, *1*(3), 346-358. https://doi.org/10.3390/microplastics1030026

6. **Conti, G. O., Ferrante, M., Banni, M., Favara, C., Nicolosi, I., Cristaldi, A., & Zuccarello, P.** (2020). Micro-and nano-plastics in edible fruit and vegetables. The first diet risks assessment for the general population. *Environmental research*, *187*, 109677. https://doi.org/10.1016/j.envres.2020.109677

7. **Deng, W., Wang, Y., Fu, M., Wang, Z., Di, X., Wang, J., & Liu, W.** (2025). The spatiotemporal successions of bacterial and fungal plastisphere communities and their effects on microplastic degradation in soil ecosystems. *Environmental Science & Technology*, *59*(29), 15408-15419**.** https://doi.org/10.1021/acs.est.5c06662

8. **Fortin, S. G., Uhlig, K., Hale, R. C., & Song, B.** (2025). Microplastic biofilms as potential hotspots for plastic biodegradation and nitrogen cycling: a metagenomic perspective. *FEMS Microbiology Ecology*, *101*(5), fiaf035. https://doi.org/10.1093/femsec/fiaf035

9. **Golubeva, E., & Gradova, M.** (2024). Numerical study of the riverine microplastic distribution in the Arctic Ocean. *Water*, *16*(3), 441. https://doi.org/10.3390/w16030441

10. **Golubeva, E., & Gradova, M.** (2024). Numerical study of the riverine microplastic distribution in the Arctic Ocean. *Water*, *16*(3), 441. https://doi.org/10.3390/w16030441

11. **Huang, H., Wang, F., Ma, S., Yuan, X., Li, J., Chen, H., ... & Gai, N.** (2024). The aquatic plastisphere: methodology, biofilm formation mechanism, and microbial diversity. *Reviews of Environmental Contamination and Toxicology*, *262*(1), 15. https://doi.org/10.1007/s44169-024-00063-3

12. **Kane, I. A., Clare, M. A., Miramontes, E., Wogelius, R., Rothwell, J. J., Garreau, P., & Pohl, F.** (2020). Seafloor microplastic hotspots controlled by deep-sea circulation. *Science*, *368*(6495), 1140-1145. 10.1126/science.aba5899

13. **Kangas, A., Setälä, O., Kauppi, L., & Lehtiniemi, M.** (2023). Trophic transfer increases the exposure to microplastics in littoral predators. *Marine Pollution Bulletin*, *196*, 115553. https://doi.org/10.1016/j.marpolbul.2023.115553

14. **Kingsbury, J. M., Laroche, O., Pochon, X., Zaiko, A., Lear, G., Weaver, L., & Pantos, O.** (2025). Plastic physico-chemical properties shape the early marine plastisphere. *Environmental Pollution*, 127532. https://doi.org/10.1016/j.envpol.2025.127532

15. **Kovacs, K., Bodis, J., & Vass, R. A.** (2025). Microplastics, Endocrine Disruptors, and Oxidative Stress: Mechanisms and Health Implications. *International Journal of Molecular Sciences*, *27*(1), 399. 10.3390/ijms27010399

16. **Kuang, B., Chen, X., Zhan, J., Zhou, L., Zhong, D., & Wang, T.** (2023). Interaction behaviors of sulfamethoxazole and microplastics in marine condition: Focusing on the synergistic effects of salinity and temperature. *Ecotoxicology and Environmental Safety*, *259*, 115009. https://doi.org/10.1016/j.ecoenv.2023.115009

17. **Kumar, R., Sharma, P., Verma, A., Jha, P. K., Singh, P., Gupta, P. K., & Prasad, P. V.** (2021). Effect of physical characteristics and hydrodynamic conditions on transport and deposition of microplastics in riverine ecosystem. *Water*, *13*(19), 2710. https://doi.org/10.3390/w13192710

18. **Leonard, S. V., Liddle, C. R., Atherall, C. A., Chapman, E., Watkins, M., Calaminus, S. D., & Rotchell, J. M.** (2024). Microplastics in human blood: Polymer types, concentrations and characterisation using μFTIR. *Environment International*, *188*, 108751. https://doi.org/10.1016/j.envint.2024.108751

19. **Li, H. Q., Shen, Y. J., Wang, W. L., Wang, H. T., Li, H., & Su, J. Q.** (2021). Soil pH has a stronger effect than arsenic content on shaping plastisphere bacterial communities in soil. *Environmental Pollution*, *287*, 117339. https://doi.org/10.1016/j.envpol.2021.117339

20. **Liro, M., & Zielonka, A.** (2025). Towards a geography of plastic fragmentation. *Microplastics and Nanoplastics*, *5*(1), 12. https://doi.org/10.1186/s43591-025-00120-1

21. **Liu, J., Xu, G., Zhao, S., & He, J.** (2024). Plastisphere microbiomes respiring persistent organohalide pollutants. *Environmental Science & Technology*, *58*(33), 14740-14752. https://doi.org/10.1021/acs.est.4c02251

22. **Liu, K., Wu, T., Wang, X., Song, Z., Zong, C., Wei, N., & Li, D.** (2019). Consistent transport of terrestrial microplastics to the ocean through atmosphere. *Environmental science & technology*, *53*(18), 10612-10619. 10.1021/acs.est.9b03427

23. Ma, J., Sheng, G. D., & O'Connor, P. (2020). Microplastics combined with tetracycline in soils facilitate the formation of antibiotic resistance in the Enchytraeus crypticus microbiome. *Environmental Pollution*, *264*, 114689. https://doi.org/10.1016/j.envpol.2020.114689

24. **Nelms, S. E., Galloway, T. S., Godley, B. J., Jarvis, D. S., & Lindeque, P. K.** (2018). Investigating microplastic trophic transfer in marine top predators. *Environmental pollution*, *238*, 999-1007. https://doi.org/10.1016/j.envpol.2018.02.016

25. **Nguyen, D., Masasa, M., Ovadia, O., & Guttman, L.** (2023). Ecological insights into the resilience of marine plastisphere throughout a storm disturbance. *Science of The Total Environment*, *858*, 159775. https://doi.org/10.1016/j.scitotenv.2022.159775

26. **Oberbeckmann, S., Loeder, M. G., Gerdts, G., & Osborn, A. M.** (2014). Spatial and seasonal variation in diversity and structure of microbial biofilms on marine plastics in Northern European waters. *FEMS microbiology ecology*, *90*(2), 478-492. https://doi.org/10.1111/1574-6941.12409

27. **Pottinger, A. S., Geyer, R., Biyani, N., Martinez, C. C., Nathan, N., Morse, M. R., & McCauley, D. J.** (2024). Pathways to reduce global plastic waste mismanagement and greenhouse gas emissions by 2050. *Science*, *386*(6726), 1168-1173. 10.1126/science.adr3837

28. **Rafazi, P., Haghi-Aminjan, H., Bagheri, Z., & Rahimifard, M.** (2024). Microplastics and cancer progression: A comparative study of 2D and 3D gastric cancer models using ISOCompliant protocols. *Results in Engineering*, *24*, 103329. https://doi.org/10.1016/j.rineng.2024.103329

29. **Ragusa, A., Svelato, A., Santacroce, C., Catalano, P., Notarstefano, V., Carnevali, O. & Giorgini, E.** (2021). Plasticenta: First evidence of microplastics in human placenta. *Environment international*, *146*, 106274. https://doi.org/10.1016/j.envint.2020.106274

30. **Ramsperger, A. F., Stellwag, A. C., Caspari, A., Fery, A., Lueders, T., Kress, H., & Laforsch, C.** (2020). Structural diversity in early-stage biofilm formation on microplastics depends on environmental medium and polymer properties. *Water*, *12*(11), 3216. https://doi.org/10.3390/w12113216

31. **Rashid, S., Majeed, L. R., Mehta, N., Radu, T., Martín-Fabiani, I., & Bhat, M. A.** (2025). Microplastics in terrestrial ecosystems: sources, transport, fate, mitigation, and remediation strategies. *Euro-Mediterranean Journal for Environmental Integration*, *10*(4), 2633-2659. https://doi.org/10.1007/s41207-025-00766-6

32. **Rillig, M. C., Ziersch, L., & Hempel, S.** (2017). Microplastic transport in soil by earthworms. *Scientific reports*, *7*(1), 1362. https://doi.org/10.1038/s41598-017-01594-7

33. **Rohrbach, S., Gkoutselis, G., Hink, L., Weig, A. R., Obst, M., Diekmann, A., & Horn, M. A.** (2023). Microplastic polymer properties as deterministic factors driving terrestrial plastisphere microbiome assembly and succession in the field. *Environmental microbiology*, *25*(12), 2681-2697. https://doi.org/10.1111/1462-2920.16234

34. **Severe, E., Surridge, B. W., Fiener, P., Coogan, M. P., Platel, R. H., James, M. R., & Quinton, J.** (2025). The transport of microplastics from soil in response to surface runoff and splash erosion. *Environmental Science & Technology*, *59*(27), 14063-14074. https://doi.org/10.1021/acs.est.5c04795

35. **Shirkhorshidi, B., Ghanatghestani, M. D., Moeinpour, F., & Parvaresh, H.** (2023). Exploring the interaction between microplastics and heavy metals: unveiling the impact of microplastics on lead sorption and desorption in soil. *Environmental Monitoring and Assessment*, *195*(9), 1017. https://doi.org/10.1007/s10661-023-11640-9

36. **Sun, Y., Shi, J., Wang, X., Ding, C., & Wang, J.** (2022). Deciphering the mechanisms shaping the plastisphere microbiota in soil. *Msystems*, *7*(4), e00352-22. https://doi.org/10.1128/msystems.00352-22

37. **Sun, Y., Zhang, M., Duan, C., Cao, N., Jia, W., Zhao, Z., & Wang, J.** (2021). Contribution of stochastic processes to the microbial community assembly on field collected microplastics. *Environmental Microbiology*, *23*(11), 6707-6720. https://doi.org/10.1111/1462-2920.15713

38. **Tang, K. H. D.** (2024). Terrestrial and aquatic plastisphere: formation, characteristics, and influencing factors. *Sustainability*, *16*(5), 2163. https://doi.org/10.3390/su16052163

39. **Wallbank, J. A., Lear, G., Kingsbury, J. M., Weaver, L., Doake, F., Smith, D. A., & Pantos, O.** (2022). Into the plastisphere, where only the generalists thrive: early insights in plastisphere microbial community succession. *Frontiers in Marine Science*, *9*, 841142. https://doi.org/10.3389/fmars.2022.841142

40. **Wang, J., Pan, Z., Yu, J., Zhang, Z., & Li, Y. Z.** (2023). Global assembly of microbial communities. *Msystems*, *8*(3), e01289-22. https://doi.org/10.1128/msystems.01289-22

41. **Wang, K., Guo, C., Li, J., Wang, K., Liang, S., Wang, W., & Wang, J.** (2024). A critical review of the adsorption-desorption characteristics of antibiotics on microplastics and their combined toxic effects. *Environmental Technology & Innovation*, *35*, 103729. https://doi.org/10.1016/j.eti.2024.103729

42. **Wang, T., Zhao, S., Zhu, L., McWilliams, J. C., Galgani, L., Amin, R. M., & Chen, M.** (2022). Accumulation, transformation and transport of microplastics in estuarine fronts. *Nature Reviews Earth*

& Environment, *3*(11), 795-805. https://doi.org/10.1038/s43017-022-00349-x

43. **Watkins, L., McGrattan, S., Sullivan, P. J., & Walter, M. T.** (2019). The effect of dams on river transport of microplastic pollution. *Science of the Total Environment*, *664*, 834-840. https://doi.org/10.1016/j.scitotenv.2019.02.028

44. **Wei, Y., Chen, Y., Cao, X., Yeh, T. C. J., Zhang, J., Zhan, Z., ... & Li, H.** (2024). Modeling of microplastics migration in soil and groundwater: insights into dispersion and particle property effects. *Environmental Science & Technology*, *58*(34), 15224-15235. https://doi.org/10.1021/acs.est.4c05202

45. **Yang, Y., Suyamud, B., Liang, S., Liang, X., Wan, W., & Zhang, W.** (2023). Distinct spatiotemporal succession of bacterial generalists and specialists in the lacustrine plastisphere. *Environmental Microbiology*, *25*(12), 2746-2760. https://doi.org/10.1111/1462-2920.16400

46. **Zettler, E. R., Mincer, T. J., & Amaral-Zettler, L. A.** (2013). Life in the “plastisphere”: microbial communities on plastic marine debris. *Environmental science & technology*, *47*(13), 7137-7146. https://doi.org/10.1021/es401288x

47. **Zhang, X., Li, M., Xiao, Y., Yang, X., Zhou, H., Qu, Y., & Zhan, J.** (2025). Metagenomics reveals combined effects of microplastics and antibiotics on microbial community structure and function in coastal sediments. *Marine Pollution Bulletin*, *218*, 118153. https://doi.org/10.1016/j.marpolbul.2025.118153

48. **Zhao, S., Zettler, E. R., Bos, R. P., Lin, P., Amaral Zettler, L. A., & Mincer, T. J.** (2022). Large quantities of small microplastics permeate the surface ocean to abyssal depths in the South Atlantic Gyre. *Global Change Biology*, *28*(9), 2991-3006. https://doi.org/10.1111/gcb.16089

49. **Zhao, J., Zhang, H., Shi, L., Jia, Y., & Sheng, H.** (2024). Detection and quantification of microplastics in various types of human tumor tissues. *Ecotoxicology and Environmental Safety*. 283, 116818. https://doi.org/10.1016/j.ecoenv.2024.116818

50. **Zhou, X., Wang, Y., Liu, R., Mo, B., Li, D., He, L., ... & Li, F.** (2024). Adsorption and desorption of Hg (II) by four aged microplastics and its effects on gaseous elemental mercury production in seawater. *Ecotoxicology and Environmental Safety*. *272*, 116036. https://doi.org/10.1016/j.ecoenv.2024.116036

51. **Zong, H.** (2021). A correlation analysis between global plastic production and floating macro-and micro-plastic waste in the ocean. *International Journal of High School Research*, *3*(6), 51.