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16. Impact of Microplastics on Soil Hydraulic Characteristics

Dr Atanu Patra

Department of Environmental Science,
Mankar College, Mankar,
West Bengal, India.

Prof. Apurba Ratan Ghosh

Department of Environmental Science,
The University of Burdwan, Burdwan, Golapbag,
Purba Bardhaman, West Bengal, India.

Abstract:

Microplastics, small plastic particles measuring less than 5 mm in size, becoming ubiquitous in the environment due to their widespread use and improper waste management. While considerable research has focused on their effects on aquatic ecosystems, their impact on the terrestrial environment, particularly on soil hydraulic characteristics, remains a topic of emerging concern. This study presents the major research findings and existing literature on soil hydraulic character affected by microplastic. In the hydrological cycle infiltration and water retention capacity are key components that also influence water availability, fertility of the soil and overall ecosystem health. The common sources of microplastic in soil are the use of plastic-based mulches in agricultural fields, sludge, urban runoff and municipal solid waste that have the potential to alter the hydraulic character of soil through physical, chemical and biological aspects. Microplastics introduced in soil, physically cause blockages of the pore that reduce the flow of water and increase surface runoff and soil water infiltration rates. Moreover, they may be able to also alter soil structure, bulk density and porosity which influences the nutrient cycling, movement and storage of water in the soil profile. Chemically microplastics interact with the various constituents of soil and hamper soil water interaction, nutrient availability and overall soil health. Furthermore, the introduction of microplastics in the soil can stimulate shifts in microbial population, and interact with soil biota activities which ultimately affect the soil hydraulic properties, changing in soil aggregation process and stability which ultimately affect the soil's capacity to retain and transport the water. It's vital to understand the consequences of microplastic contamination on soil hydraulic characteristics to measure the potential threats to terrestrial ecosystems, agricultural productivity and water resources. A comprehensive knowledge of these impacts is required for effective mitigation strategies and management practices. This study emphasizes the need for further research to address the effect of microplastics on soil hydraulic characteristics among various types of soil, land-use practices, and environmental conditions. Various methodologies should be developed to detect, quantify, and track microplastic levels in soils accurately.

Further research requires examining the interactions between microplastics and soil biota and the underlying mechanisms driving changes in soil hydraulic characteristics. The presence of microplastics in soils can create a significant threat to soil hydraulic properties, alterations in water availability, nutrient cycling and overall ecosystem health. Addressing these emerging environmental challenges requires a multidisciplinary approach, incorporating soil science, hydrology, ecology, and waste management to develop effective strategies for mitigating the impacts of microplastics on soil health and maintaining sustainable terrestrial ecosystems.

Keywords:

Microplastics, Soil ecosystems, Hydraulic, Terrestrial ecosystems.

16.1 Introduction:

Microplastics, tiny plastic particles less than 5 mm in size, garnered significant attention due to their adverse effects on aquatic as well as terrestrial ecosystems (Horton et al., 2017). Soil hydraulic characteristics refer to the properties of soil that describe its ability to retain, transmit, and release water. These characteristics are essential in understanding how water moves through the soil, which is crucial for various applications, including agriculture, civil engineering, environmental science, and hydrology (Wösten et al., 2001; Andry et al., 2009). Microplastics originated from plastic substances, which have been used for various purposes due to their diversity, durability, lightweight, water resistance, and low cost (Ghayebzadeh et al., 2020). Modern practices of the use of plastic films in the agricultural field to maintain moisture, microclimate for plants, control weeds and increase productivity and automobile tire residue and other activities of humans dramatically increased the concentration of microplastics in the terrestrial environment over the last fifty years (Mbachu et al., 2021). However, in recent years, research has started to shed light on another crucial aspect of microplastic pollution and its impact on soil hydraulic characteristics.

Soil, being a vital component of the terrestrial ecosystem, plays a crucial role in water retention supporting plant growth and water uptake capacity, regulating water flow, and maintaining overall environmental stability (Haygarth et al., 2023). The infiltration and retention of water within the soil are fundamental processes influenced by its hydraulic properties (Bens et al., 2007). Microplastics can find their way into soils through various pathways, such as the application of plastic-containing agricultural mulches, sewage sludge, or even atmospheric deposition (Piehl et al., 2018). Once present in the soil, microplastics can interact with soil particles, organic matter, and microorganisms, potentially altering the soil's hydraulic behavior. These alterations can have far-reaching consequences for water availability, nutrient transport, and overall ecosystem health (Machado et al., 2020). Microplastic detection in soil is a crucial area, microplastics in soil involve a range of scientific methods and techniques to quantify and characterize these minuscule plastic particles (Bharath et al., 2022). The presence of microplastics in soil can significantly affect its hydraulic characteristics, which are essential for the movement and retention of water within terrestrial ecosystems (Jin et al., 2022). This study tries to discuss different sources of microplastic in soil, detection techniques, and effects on the hydraulic characteristics of soil and also enlighten the future aspects of the study.

16.2 Different Detection Techniques of Microplastics:

Detecting microplastics in soil can be challenging due to their small size and the complex matrix of soil. Various techniques are developed to identify and quantify microplastics in soil. Some are as follows

16.2.1 Visual Inspection:

The easiest method to identify microplastic in soil is the microscopic observation, although it’s difficult to separate particles and fibers. Moreover, it can separate microplastics through color, shape and size and also infer the origin of microplastics.

The process of identification through a microscope can be easier by using different staining processes such as Nile red, eosin B, rose Bengal, *etc.* However, sometimes this commonly used staining method give unsatisfactory result due to the confounding impact of staining on biogenic material and the affinity of different stain to plastic.

16.2.2 Density Separation:

It is a simple technique of separation that involves making a solution with soil samples with a known density, generally a salt solution or a heavy liquid like sodium polysulfate. The density of microplastics is less than most of the soil particles, which will float on the surface of the solution and can be collected for analysis.

16.2.3 Sieve Filtration:

This is a physical method for the detection of microplastics with the help of a series of sieves with different mesh sizes, generally, microplastics are smaller than most of the soil particles they can be separated and deposited on the finer mesh sieves. The collected material can be analyzed under the microscope.

16.2.4 Fourier-Transform Infrared (FTIR) Spectroscopy:

Fourier-transform infrared (FTIR) spectroscopy is a useful method for the chemical characterization of microplastic particles. It works by changing in dipole moment under the infrared spectrum; it can also differentiate between different types of plastic particles based on their spectra. It is a useful tool for confirming the presence of plastic polymers in soil samples.

16.2.5 Raman Spectroscopy:

Raman spectroscopy is another alternative method for determining the chemical composition of the microplastics. It can provide information about the origin of microplastics present in soil samples with the help of molecular fingerprints on the polarizability of bonds.

16.2.6 Microscopic Imaging:

Microscopic imaging, especially electron microscopy is an effective tool for the detailed study of the size, shape, and surface features of microplastics. With the help of transmission electron microscopy (TEM) and scanning electron microscopy (SEM) capture of high-resolution images of microplastics in soil samples provides detailed information about it.

16.2.7 Pyrolysis-Gas Chromatography-Mass Spectrometry (Py-GC-MS):

With the help of this technique heating of the soil sample breaks down the organic material and converts it into volatile compounds, which are then measured by gas chromatography-mass spectrometry. In this process, we can identify and quantify various types of plastic polymers present in soil samples.

16.2.8 Fluorescent Staining:

In this process to stain microplastics various types of fluorescent dyes are used to bind with microplastic present in soil samples then examined under fluorescence microscopy and stained microplastics emit fluorescence that can be easily distinguished from natural soil particles.

16.2.9. X-Ray Microtomography:

This method is a non-destructive imaging technique used for 3D imaging of microplastics present in soil samples to understand the distribution of microplastics within soil with the help of.

16.2.10 Ultraviolet (UV) Radiation:

Some microplastics have a special property to fluoresce under UV light, by the help of this property microplastics can detect and quantify from soil samples. Soil samples are exposed to UV light and the emitted fluorescence.

Sometimes it is important to note that for better accuracy different techniques are used in combination for the characterization of microplastics in soil samples. However, the methods are applied depending on the specific research objective and availability of resources.

16.3 Impact of Microplastics on Soil Hydraulic Characteristics (*Figure 16.1*):

16.3.1 Water Retention and Infiltration:

Water retention refers to the ability of a substance, typically soil, to hold water within its pores and spaces. It is a crucial property of soil that determines its capacity to store water for plant use, groundwater recharge, and other purposes (Liu et al., 2023). Microplastics can modify soil pore structure and particle aggregation, affecting water retention and infiltration rates.

Their presence can lead to changes in soil macroporosity and microporosity, impacting the movement of water through soil layers. There was a relation between soil partial size and the effects of microplastics on water retention generally greater particle size reduces the effects, further more clay soil had a greater impact due to contamination in comparison with sand and loam (Guo et al., 2022).

16.3.2 Hydraulic Conductivity:

The ability of soil to transmit water, known as hydraulic conductivity (Ks) **(Figure 2)**, can be influenced by microplastics. They might clog pores and interstitial spaces, reducing the rate of water movement within the soil profile (Shafea et al., 2023). When microplastics are present in soil, they can create physical barriers that hinder water infiltration and storage in the soil.

This can lead to decreased soil moisture levels, which can change the soil's pore structure, reducing the connectivity of pores that allow for water flow (Botyanszká et al., 2022). This altered pore structure can increase the risk of waterlogging in some areas and decrease water availability in others.

16.3.3 Runoff and Erosion:

Altered soil hydraulic properties due to microplastics could increase surface runoff and soil erosion. This can have implications for water quality, sediment transport, and downstream ecosystems (Rehm et al., 2023).

16.3.4 Plant-water relations:

Microplastics may affect the availability of water to plants, potentially impacting their growth, nutrient uptake, and overall health. Changes in soil water dynamics could lead to water stress in plants. Microplastic not only affects crop growth and plant productivity but also negatively impacts the quality of production (Dainelli et al., 2023).

16.3.5 Contaminant Transport:

Microplastics can adsorb various pollutants and chemicals such as pesticides, heavy metals, antibiotics and persistent organic pollutants from the environment that may act as a medium to transfer contaminants in the terrestrial environment (Dissanayake et al., 2023). Changes in soil hydraulic properties could also influence the transport of these contaminants through the soil, potentially affecting groundwater quality (Hüffer et al., 2023).

16.3.6 Microbial Activity:

Soil microorganisms play a crucial role in nutrient cycling and organic matter decomposition. Microplastics might interfere with microbial habitats and activity, indirectly influencing soil hydraulic properties through changes in soil organic matter content (Zhao et al., 2021; Lin et al., 2020).

16.3.7 Long-Term Soil Health:

Accumulation of microplastics in soil over time could lead to persistent alterations in hydraulic characteristics, impacting soil structure, fertility, and overall ecosystem functioning (Zhou et al., 2023).

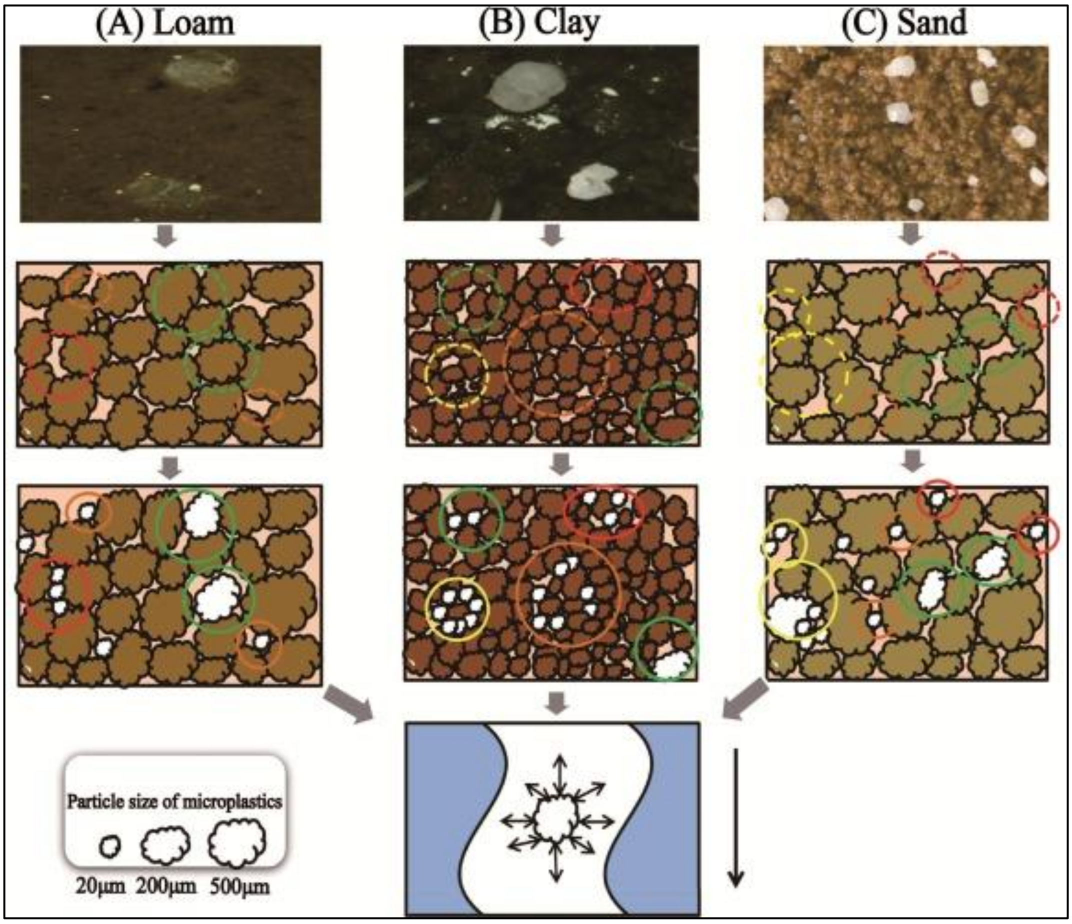

***Figure 16.1*: Presence of microplastics depending on soil characteristics**

16.4 Different mitigation techniques to reduce microplastics in soil (*Figure 16.2*):

Mitigating the presence and effects of microplastics in soil is a challenging task, as these tiny plastic particles are widespread and can persist in the environment for a long time.

However, several strategies and techniques can be employed to reduce microplastic contamination in soil such as

16.4.1 Reduce Plastic Usage:

One of the most effective ways to mitigate microplastic pollution in soil is to reduce overall plastic usage. This includes less use of single-use plastic products and opting for reusable alternatives. Encourage the use of biodegradable or compostable plastics when necessary, as they may break down more readily in the environment.

16.4.2 Proper Waste Management:

Improve waste management practices are essential to minimize plastic litter and ensure that plastic waste is properly disposed of and recycled. The foremost key to reducing microplastic contamination is preventing the entry of plastic into the environment

16.4.3 Filtering and Sediment Control:

Implementing effective storm water management systems with sediment basins and filtration techniques can help capture and remove of microplastics from runoff before they reach soil and water bodies.

16.4.4 Bioremediation:

Certain microorganisms, such as bacteria and fungi, have been found to have the ability to degrade plastics to some extent. Research is ongoing to develop and optimize bioremediation techniques for microplastics in soil.

16.4.5 Soil Amendments:

Adding organic matter to soil, such as compost or organic mulch, can help to improve the soil structure and may facilitate the entrapment of microplastics and reduce mobility in soil.

16.4.6 Soil Erosion Control:

Reducing the movement of microplastics through soil erosion can be achieved by putting erosion control measures in place, such as putting in erosion control blankets and growing cover crops.

16.4.7 Innovative Technologies:

Researchers and developers are investigating novel technologies, like electrostatic techniques and sophisticated filtration systems, to eliminate microplastics from soil. It's critical to understand that microplastic pollution is a complicated, multifaceted problem that calls for a range of approaches, from small-scale initiatives to large-scale legislative changes. Governments, businesses, academics, and the general public must work together to reduce the amount of microplastics in soil, safeguard ecosystems, and preserve human health.

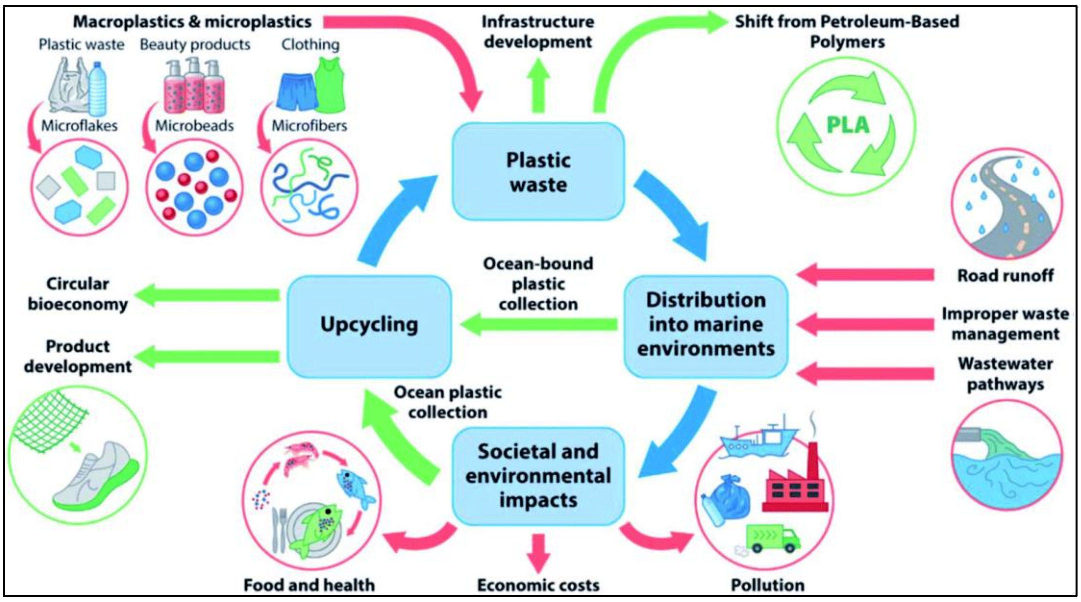

Figure 16.2: **Pathways and mitigation techniques of microplastic in soil**

16.5 Future Aspects:

An area of research that was just getting started examined how microplastics affected the hydraulic properties of soil. There might have been further advancements in this field since then. Quantifying the precise effects of microplastics on soil hydraulic characteristics is likely to be the main focus of future study. To learn more about how different types of microplastics affect soil permeability, drainage system, and moisture retention, this could entail researching the sizes, concentrations, and varieties of microplastics.

16.6 Conclusion:

The presence of microplastics in soil can interfere with natural processes and soil hydraulic properties. Protecting soil health and maintaining ecosystems need both identifying and reducing their presence. The issues presented by microplastics in soil require ongoing research, cooperation, and proactive interventions at all levels, from individual acts to global policy changes. The impact of microplastics on the hydraulic properties of soil is a developing field that has broad ramifications for ecosystems on land. For effective methods to be developed to reduce the negative effects of microplastics on soil water dynamics and overall ecosystem health, it is imperative to comprehend the processes and degree of these consequences. It is noteworthy that the field of research on the precise impacts of microplastics on soil hydraulic properties is still in its infancy, and the degree of their influence may differ based on variables including soil type, concentration, size, and kind of microplastic. To gain a deeper understanding of the causes, consequences, and long-term impacts of microplastic contamination on soil health and ecosystem function, more research is required. To lessen these effects, mitigation measures like cutting plastic pollution at its source and enhancing waste management are crucial.

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