Tropical Environment, Biology, and Technology

Review
Volume 3(2), 2025, 76–85
https://doi.org/10.53623/tebt.v3i2.713

Emerging Global Threat of Microplastics and Their Impact on Soil Sustainability: A Case of Southeast Nigeria

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SUBMITTED: 5 June 2025; REVISED: 2 July; ACCEPTED: 22 July 2025

ABSTRACT: Plastics became an integral part of daily life from food packaging to water bottles, but their environmental and health impacts raised significant concerns. Microplastics (MPs), defined as plastic particles smaller than 5 mm, originated primarily from the fragmentation of larger plastic materials. These particles not only disrupted endocrine signaling but also caused cellular damage, making their ecological impact a critical area of study. A recent review examined water-soluble polymers, a rapidly growing class of materials found in cosmetics, paints, food packaging, and water purification systems. Despite their utility, these materials posed serious environmental risks due to their chemical composition and resistance to biodegradation. In some cases, their degradation products were even more hazardous and persisted in soil for extended periods. Studies showed that water-soluble plastics, such as polyethylene, posed significant threats to the environment. While they might not have appeared immediately harmful, their breakdown products had severe long-term effects on terrestrial ecosystems. Among the many global challenges to soil sustainability, MPs-induced soil perturbations were especially concerning in regions referred to as the "Global South." In soil, MPs stressed beneficial microbial populations by blocking digestive tracts or altering biological processes, thereby weakening the overall soil ecosystem. Since soil biomes played a crucial role in decomposition and nutrient cycling, particularly the nitrogen cycle, their disruption profoundly affected soil health. Therefore, by disrupting vital natural processes essential for maintaining soil health, the presence of MPs demonstrated the potential to physically alter both the biological and physicochemical configuration of the soil. The continuous rise in plastic pollution and the emerging threats posed by MPs to soil sustainability worldwide remained urgent concerns. This study highlighted the risks that MPs posed to the physical, chemical, and biological components of the soil ecosystem.

KEYWORDS: Microplastics; soil sustainability; soil health; microbial degradation; environmental contamination

1. Introduction

MPs are small plastic particles ranging from 0.1 µm to 5 mm and have been recognized as an emerging environmental contaminant [1]. They originate from the fragmentation of larger plastic debris and are now considered a major global concern due to their widespread presence and persistence in the environment, which may adversely affect ecosystem services and functions. The extensive use of plastic across industries such as manufacturing, healthcare, and agriculture has led to increased MP contamination in agricultural soils [2], raising concerns about potential disruptions to soil structure and function.

Although agricultural soils are a known sink and potential source of MPs, particularly due to human activities, limited knowledge exists regarding the impacts of MPs on the soil's biophysical environment. Despite rising global concern, the Nigerian context especially southeastern Nigeria, remains largely unexplored, with no known field-based investigations characterizing MP presence, sources, or ecological impacts in soil. This study seeks to fill that gap by examining local practices such as informal waste disposal, land use pressure, and weak waste management systems that may contribute to MP accumulation in soils.

The accumulation of plastic in the environment is driven by low degradation rates, unsustainable usage, and poor disposal practices. A report by [3] showed that only a small fraction of plastic waste is recycled or converted to energy. Most plastic waste ends up in landfills, where it can persist for up to 1,000 years, polluting both soil and water with MPs. Similarly, [4] demonstrated that approximately one-third of all plastic waste enters soil or freshwater systems. In 2016 alone, a significant portion of the 322 million metric tons of global plastic production was used for packaging, further contributing to environmental burden [5]. A previous study concluded that the continued accumulation of discarded plastics due to their long durability and poor recycling practices demands urgent attention to mitigate their long-term impacts [6]. It is now widely acknowledged that MP pollution represents a significant global change factor with far-reaching implications for ecosystem services and functionality.

MPs contamination in the soil is a globally emerging issue. Several studies have documented its presence in different ecosystems, and results consistently indicate that soil is increasingly impacted by this form of pollution. A study in China, for example, investigated the distribution of MPs across four agricultural sites and one forest buffer zone. Soil samples collected at a depth of 0–10 cm revealed higher MPs concentrations in agricultural soils compared to the buffer zone [7]. Similarly, [8] studied MPs contamination in three agricultural sites in Ontario, Canada, sampling soils at a depth of 0–15 cm and found significant variation in MP concentrations across sites.

In Spain, soil samples from 16 agricultural sites showed average MPs concentrations of 930 ± 740 particles/kg for low-density MPs and 1100 ± 570 particles/kg for high-density MPs [9]. Another investigation along the Spanish Mediterranean coast revealed that marine soil contamination by MPs was negligible prior to 1975 but has increased significantly since [10]. These studies indicate that MPs' presence and concentration in soils vary with geographical location, agricultural practices, economic factors, and the extent of plastic usage.

Other research has shown that MPs can migrate through soil. For instance, [11] found that smaller-sized MPs exhibited greater vertical mobility in soil. Column experiments conducted in China with polystyrene nanoplastics demonstrated that soil pH and mineral composition significantly influence migration patterns [12]. In Hawaii, [13] analyzed plastic residues from five beach soil sites on Kauai Island and concluded that MPs formed from macroplastic disintegration persist in the environment for extended periods. [14] further reported that synthetic polymers resist biodegradation and therefore contribute substantially to long-term soil contamination.

However, studies on MPs contamination in African soils are sparse and virtually nonexistent in Nigeria. Currently, there are no national-level datasets, regional field surveys, or standardized soil MP monitoring frameworks in place. This study aims to address that knowledge gap by synthesizing available information and conceptualizing potential MP input pathways that may be unique to southeastern Nigeria's soil environments. Table 1 summarizes the characteristics and key challenges associated with MPs pollution in soil ecosystems.

Table 1. Key characteristics and challenges of MPs pollution in soil environment.

Aspect	Soil Environment	Reference
Dominant sources	Plastic mulch, sewage sludge, synthetic textiles, informal waste dumping	[2]
Data availability	Limited, especially in Africa; few long-term or spatially extensive studies	[2]
Research focus	Soil structure alteration, microbial activity disruption, nutrient cycling	[3]
Ecological impacts	Less known effects on microbes, earthworms, nematodes; indirect effects on plant health	[6]
Sampling methods	Soil core extraction, density separation, sieving, spectroscopy	[7]
Detection challenges	Soil heterogeneity and organic matter interfere with recovery and identification	[16]
Key knowledge gap	Fate of MPs in different soil types, interaction with soil microbiome, response to climate variables	[17]

Despite advances in science, research on MPs in soil environments remains limited compared to studies in marine and freshwater systems, warranting urgent attention [15–17]. This research gap may be attributed to the lack of multidisciplinary approaches to studying MPs in soils, as noted by [18]. MPs are highly persistent in soil ecosystems, and commonly detected polymers include polypropylene, polyethylene, polystyrene, and polyvinyl chloride. Soil contamination by MPs and its impact on the biophysical properties of soil are cause for concern. Therefore, to better understand the implications of MPs on soil ecosystems particularly in agricultural land, it is crucial to first identify and characterize their sources.

2. Source of MPs Contamination on Soil Ecosystem

2.1. Living quarters.

In many homes in southeastern Nigeria, people obtain potable drinking water from local vendors who typically package the water in plastic bottles. These empty bottles, which eventually degrade into smaller particles, often end up in the soil environment. Over time, their accumulation may negatively affect indigenous soil decomposers and other autochthonous organisms essential for soil sustainability. Additionally, synthetic materials such as nylon and polyester are widely used in households [19]. Many common household items including cosmetics, food containers, toothpaste, plates, and cutlery serve as major sources of MPs contamination. However, there is a lack of quantitative data estimating the annual volume of plastic waste generated from household sources in southeastern Nigeria. Including such data would enhance the understanding of local input sources and inform the prioritization of waste management strategies.

2.2 Landfills and industrial discharge.

The soil in Owerri and its surrounding areas in southeastern Nigeria falls within the acid sand category, as described by [20]. This naturally fragile soil structure is increasingly threatened by the proliferation of landfills across major cities in the region. In Owerri, for example, plastics constitute a major component of local landfills. During periods of heavy rainfall, these plastics are frequently washed into nearby rivers such as the Nworie and Otamiri, posing significant risks to aquatic ecosystems. Open landfills also serve as major reservoirs of MPs, with approximately 80% of the annual 6,300 tons of plastic waste accumulating in these sites [21]. A similar issue is observed with industrial discharge. Untreated wastewater from industrial cities like Aba and Onitsha commonly contains MPs, originating from laundering synthetic fabrics and personal care products such as exfoliants and shampoos [22]. Given the informal and largely unregulated nature of waste disposal and industrial discharge in the region, MPs are likely to accumulate disproportionately, exacerbating both environmental degradation and public health risks. These challenges underscore the urgent need for targeted policy interventions, increased community awareness, and improved waste governance to reduce MP inputs.

2.2. Sewage treatment plants.

A major pathway through which MPs enter the soil environment is the application of sewage sludge as fertilizer to boost crop productivity [23, 24]. During wastewater treatment, MPs are retained in the sludge, which is subsequently applied to agricultural lands, thereby inadvertently introducing MPs into terrestrial ecosystems [25]. A study by [26] found that sewage sludge can contain up to 15,385 MPs particles per kilogram. Despite the widespread use of sewage sludge in southeastern Nigeria, there is currently little to no data on the MPs load in local sludge or the extent of its application on farmland. This represents a critical knowledge gap that this study seeks to address.

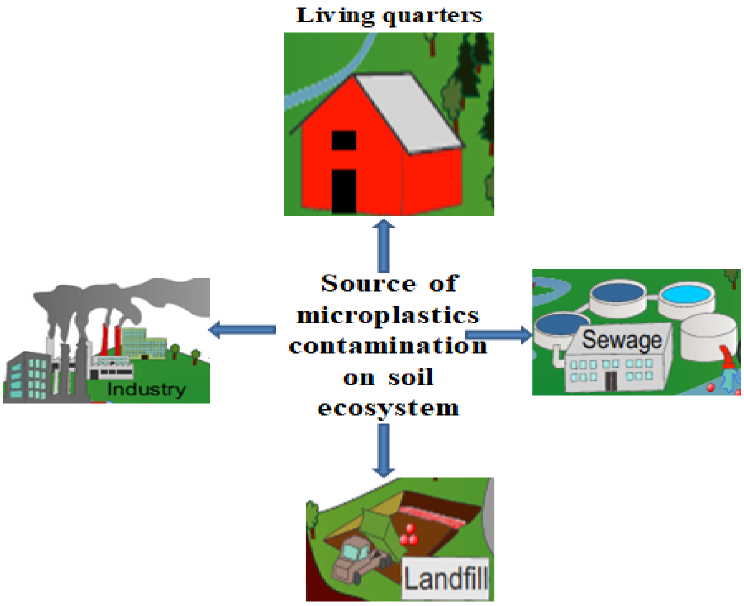

Figure 1. Infographic depicting sources of MPs contamination in the soil ecosystem.

3. Effects of MPs on Soil pH.

MPs alter soil chemistry by directly interacting with various organic and inorganic components, including cations and protons [27, 28]. For example, [29] examined the effects of MPs on soil chemistry and found that MPs disrupt soil pH. Their findings demonstrated that MPs tend to lower pH in acidic soils such as those found in Owerri and its environs in southeastern Nigeria, while increasing pH in alkaline soils [30]. However, the mechanisms underlying these changes remain unclear, highlighting the need for further investigation. Recent research in soil chemistry suggests that MPs may act as electron donors or acceptors, bind with soil colloids, or interfere with cation exchange capacity. Nonetheless, these interactions are still poorly understood under real-world soil conditions. Integrating established principles of soil chemistry and incorporating schematic models would help clarify the mechanisms of interaction and better explain the implications of MPs for soil health.

4. Effects of Exposure to MPs on Soil Organisms.

Autochthonous soil organisms play a critical role in sustaining soil ecosystem functions and supporting agricultural productivity. However, the presence of MPs in soil has been shown to negatively impact these organisms [31], including a decline in essential bacterial and fungal populations that are vital to nutrient cycling and soil structure [32].The impact of MPs on microbial behavior varies depending on the type of plastic involved. For example, a study by [33] revealed that polyester and polyacrylic MPs suppressed microbial diversity and activity, particularly in acidic soils like those found in Owerri. Currently, there is no comprehensive data on the interactions between MPs and soil organisms in field conditions. Further studies are necessary to investigate how MPs affect microbial communities and broader ecosystem functions.

These studies should also consider the potential effects of MPs on neurological processes, immune responses, and reproductive health in soil fauna. For instance, [34] highlighted negative impacts on earthworms, such as impaired sperm health, increased oxidative stress, and reduced coelomocyte viability. Moreover, a laboratory investigation revealed that a combination of MPs and toxic metals such as cadmium slowed growth and increased mortality rates in earthworms [35]. MPs also disrupt digestion, energy metabolism, development, and reproduction in other soil organisms, including *Caenorhabditis elegans* (nematodes) and terrestrial snails [36]. However, much of this evidence is based on laboratory-controlled conditions, and real-world field studies are needed to accurately assess the broader ecological impacts on soil ecosystems. Expanding the scope of future research to include microbial diversity, enzymatic activity, and the potential for horizontal gene transfer under MP stress could provide deeper insights into long-term soil health risks. In addition, comparing microbial responses under aerobic versus anaerobic soil conditions could reveal differential effects. Table 2 presents a summary of the effects of MPs on soil physicochemical and biological properties.

Table 2. Summary of MPs effects on soil physicochemical and biological properties.

Soil Property / Process	Observed Effect of MPs	Reference
Soil microbial community	Decreased microbial diversity and enzymatic activity; disruption of microbial networks	[2]
Soil structure/aggregation	Decreased bulk density and increased porosity; disrupted soil aggregation	[3]
Water retention and infiltration	Reduced water holding capacity and altered hydraulic conductivity	[4]
Mycorrhizal fungi	Negative effects on arbuscular mycorrhizal colonization and symbiotic function	[6]
Plant growth	Root development impeded; reduced biomass and nutrient uptake	[6]
Nutrient cycling (e.g., nitrogen)	Potential disruption of nitrogen transformation and microbial-mediated nutrient turnover	[23]
Soil pH	Alteration of pH (acidic soils tend to become more acidic; alkaline soils may show increased pH)	[29]
Earthworms and soil fauna	Growth inhibition, oxidative stress, immune disruption, and increased mortality	[34]

5. Critique of Previous Studies on MPs in Soil.

Many studies have reported on the presence and effects of MPs in soils globally and within Africa. However, a critical evaluation of this body of research reveals important limitations. For instance, many investigations are constrained by limited spatial and temporal coverage, reducing the ability to generalize findings across ecosystems or seasons. Furthermore, polymer identification techniques vary significantly among studies, affecting data reliability and comparability. Some rely solely on visual identification methods, which are prone to misclassification, while others employ spectroscopic techniques such as FTIR or Raman spectroscopy,that offer greater accuracy but are less frequently used due to high cost and technical expertise requirements. Local studies in Nigeria are particularly sparse, thereby limiting insight into MPs pollution under region-specific conditions.

6. Influence of Climate and Land Use on MPs Mobility and Degradation

Changing Environmental factors such as temperature, rainfall, and land use have significant but underexplored effects on the mobility and degradation of MPs in soils. Climate change may exacerbate MPs leaching and transport by increasing rainfall intensity and variability, leading to greater soil erosion and the migration of MPs into surface waters and deeper soil layers. Elevated temperatures may accelerate certain abiotic degradation pathways; however, they may also disrupt microbial communities that mediate the biodegradation of plastics. Moreover, land use changes such as the conversion of forests to agricultural or urban areas, could alter soil structure, permeability, and organic content, all of which influence MP retention, breakdown, and movement. Despite their importance, these dynamic interactions are rarely addressed in the current literature. Including this dimension in MPs research would better contextualize MPs contamination within broader environmental change trends.

7. Local Plastic Use, Waste Management, and Policy Gaps

The dynamics of MPs pollution in southeastern Nigeria are closely linked to regional patterns of plastic consumption, waste handling practices, and the effectiveness of policy enforcement. The area faces systemic challenges such as informal dumping, limited recycling infrastructure, and weak regulatory oversight of plastic production and disposal. Common community practices such as open burning of plastic waste and poorly managed landfills, further contribute to MPs contamination in soils. Addressing these issues requires more than technical solutions. Stakeholder engagement, community-based education, and coordinated policy interventions are essential. Facilitating dialogue among regional authorities, environmental agencies, and local communities will be crucial for strengthening waste management systems and mitigating MPs pollution.

8. Conclusions

The environmental and ecological threats posed by MPs are profound and increasingly urgent. Beyond disrupting soil ecosystems, recent studies have also linked MPs to human health issues, such as inflammation and bone density disorders, including osteoporosis. This study highlights the severe knowledge gaps surrounding MPs contamination in southeastern Nigeria, where plastic usage patterns and inadequate waste management systems amplify the problem. To address this emerging threat to soil sustainability, there is an urgent need for a bold new vision that integrates cutting-edge innovations with local realities. Recommendations include Strengthening waste collection and recycling infrastructure; Implementing region-specific policy enforcement; Encouraging community engagement and awareness campaigns; Promoting interdisciplinary research to understand the long-term ecological consequences of MPs. Given that household items constitute a major source of MPs contamination, increasing public awareness and stakeholder involvement is critical to reducing plastic input into the environment. This study calls for collective and sustained action to end plastic pollution and ensure soil health and sustainability for future generations.

Acknowledgments

The authors thank Prof Peter Okorie for his insightful contributions in the writing of the manuscript.

Author's Contribution

Conceptualization and original draft by Joseph Ekenwosu. Literature review was done by Joseph Ekenwosu and Peter Nzenwa while editing and proofreading was done by Chidinma Ikpeama. Authors read the manuscript and approved it for publication.

Competing Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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