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Profile of microplastic types and soil biological response in the subsurface layer: A case study of the Surabaya landfill

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ABSTRACT

Microplastic contamination has become an urgent environmental issue, with increasing evidence that its impacts are not limited to aquatic ecosystems but also extend to terrestrial ecosystems. Urban soils, particularly around temporary waste disposal sites (TWDS), are hotspots for microplastic accumulation that can alter soil physical-chemical properties and microbial activity. However, knowledge about the types of microplastics present in soils associated with TWDS and their effects on soil biological responses remains limited. This study aims to identify the profile of microplastic types and assess the biological response of sub-surface soil at various temporary storage sites (TPS) in Surabaya, Indonesia. Soil samples were collected from 19 TPS locations at a depth of 20–30 cm and analysed using FTIR spectroscopy to identify microplastics. Soil physical-chemical parameters (pH, temperature, moisture content, texture, and colour) were measured, while microbial activity was evaluated through CO_2–C respiration tests under controlled laboratory conditions. Of the 19 sampling locations, 17 locations tested positive for microplastics. The dominant polymers identified were polyethylenimine (PEI) and synthetic polycationic polymers, followed by *cellophane* and *formaldehyde resin*. The number of microplastic types per location varied between 0 and 3, with the highest diversity found at the Srikana Airlangga TPS. The soil at all locations had a neutral pH (6.5–7.0), temperature of 25–34 °C, and humidity of 12–65%. Microbial respiration activity varied significantly, ranging from 0.18 mg CO_2-C/kg/day at the Pasar Pahing TPS to 5.76 mg CO_2-C/kg/day at the Manyar Tirtomoyo and Tirtomoyo TPS, with an average of 3.59 mg CO_2-C/kg/day. Locations dominated by cellophane and formaldehyde resin showed higher microbial respiration, while locations dominated by synthetic polycationic compounds exhibited lower activity. This study shows that microplastic contamination in the sub-surface soil of the Surabaya landfill is widespread, with a predominance of PEI and synthetic polycationic polymers. Variations in microbial respiration activity indicate that polymer type has a greater influence than total microplastic amount in determining soil biological response. These findings highlight the need for integrated waste management strategies that consider the impacts of microplastics on soil ecosystem functions.

Keywords: microplastics, soil respiration, CO_2-C, TPS soil, microbial activity.

INTRODUCTION

The phenomenon of microplastic contamination (MP < 5 mm) in terrestrial environments is now recognised as a strategic issue because soil acts as a major "sink" that retains and mobilises plastic particles from various anthropogenic sources (Chen et al., 2025). In urban areas, the waste management sector, particularly temporary storage sites (TPS) and landfills, has been identified as an important hotspot that mediates the flow of plastics from waste streams to the surrounding soil matrix (Pratiwi et al., 2024). Research in European cities shows that microplastics are widespread in the topsoil of built-up areas and green spaces, indicating the intensity of inputs from human activities and waste infrastructure (Leitão et al., 2023). In addition to their mass, the diversity of shapes (fibres, fragments, films, foams, pellets), sizes, and polymers (e.g. PE, PP, PS, PET, PVC) determine the physical-chemical behaviour of MP in soil and their interaction with soil biota. (Fan et al., 2023)Functionally, experimental evidence and global synthesis indicate that MP can alter microbial communities, enzymatic activity, and soil respiration, which collectively influence carbon cycling and CO_2 emission potential from soil (Li et al., 2023).

From a process perspective, the presence of MP can modify physical properties of soil such as porosity, water retention, and bulk density, thereby affecting gas diffusion, microclimate, and substrate availability for microorganisms (Hasan and Tarannum, 2025). Experiments in sandy-loam soil showed that variations in the size and shape of MP, particularly HDPE in the 0.5–5 mm class, can shift the water retention curve, which in turn leads to changes in the microenvironment for soil microbes. (Bakhshaee et al., 2025). Recent meta-analytic findings also indicate that MP can increase soil CO_2 emissions through shifts in the composition and function of the microbiome, indicating changes in substrate quality/availability and physical-chemical interactions in the pore habitat (Zhao et al., 2024). At the laboratory scale, the effects of MP on pH, respiration, and soil enzyme activity appear to depend on the type of polymer and particle morphology as well as the incubation duration, highlighting the dynamic response to plastic stress (Zhao et al., 2021). Meanwhile, recent studies highlight that even MP claimed to be biodegradable can increase CO_2 emissions through the supply of easily degradable carbon and changes in microbe-substrate interactions, leaving the issue of "environmentally friendly plastic solutions" with ecosystem consequences (Shi et al., 2025).

The urban context in developing countries shows a waste composition with a significant plastic fraction; recent field observations in densely populated urban sites report plastic contributions of up to a quarter of the waste composition, increasing the potential input of MP into the soil environment through leaching and mechanical dispersion (Chakraborty et al., 2021). In landfill and open TPS scenarios, mechanical-chemical degradation of plastics, combined with moisture and temperature dynamics, accelerates fragmentation into MP that migrates to subsurface soil layers through water infiltration and bioturbation (Pratiwi et al., 2024). In line with this, observations at informal disposal sites in tropical regions reported a range of 180–1120 particles/kg of soil, confirming the significance of sources related to unmanaged waste operations (Mahesh et al., 2023). In warm and humid regions such as Indonesia, high rainfall regimes have the potential to accelerate the movement of MP from the surface to the subsurface, making characterisation of the subsurface layer important for mapping more chronic ecological exposure. (Leitão et al., 2023) Furthermore, TPS areas are often associated with greenhouse gas emissions from organic decomposition, and MP interactions with soil carbon dynamics can be intertwined with local emission profiles, although cross-scale mechanisms still require data-based mapping (Singh et al., 2025).

Advances in MP identification methodologies in soil are key to linking "MP types" with soil biological responses in a comparative manner across locations (Lee et al., 2023). Practice standards emphasise pre-treatment stages (sorting, oxidation/dissolution of organic materials, density separation), followed by chemical verification of polymers based on spectroscopy (μ-FTIR/Raman), which is increasingly automated through a curated spectrum library. (Kozloski et al., 2024). Optimisation of μ-FTIR for sizes ranging from 20 μm to 1 mm enables the screening of ecologically relevant fine fractions, with an emphasis on validation and quality control to reduce particle misclassification. (Rathore et al., 2023). Recent spectroscopic reviews also confirm the contribution of FTIR/Raman in distinguishing common polymers, such as PE, PP, PS, PET, PVC, each of which has different hydrophobicity and contaminant adsorption potential (Campanale et al., 2023). Conceptually, determining the polymer and MP form is a prerequisite for interpreting variations in biological effects, given that the surface, flexibility, and additives of polymers play a role in microbial interactions and carbon availability (Fan et al., 2023).

In the soil process realm, physical changes due to MP, such as increased bulk density or changes in aggregate structure, can reduce functional pore space and shift the aeration zone that regulates microbial respiration (Hasan and Tarannum, 2025). Conversely, in certain systems, the presence of fragments/films can increase macroporosity, thereby accelerating drainage and reducing short-term moisture, which in turn modulates the rate of CO_2-C produced by microbial communities (Bakhshaee et al., 2025). Cross-ecosystem synthesis implies that the impact of MP on soil

CO_2emissions is not unidirectional; increases in emissions are often observed but depend on the type of polymer, form, dose, soil texture, and organic-nutrient status, all of which resonate in the structure of microbial communities (Zhao et al., 2024). Incubation experiments showed changes in pH, respiration, and enzymatic responses over time, indicating an adaptation phase or changes in carbon sources/microhabitat conditions due to the presence of particles (Zhao et al., 2024). In forests and other vegetated landscapes, variations in ecosystem age and microbial community structure also mediate the effects of MP on respiration, revealing relevant cross-biome heterogeneity when interpreting multi-site data (Hu et al., 2025).

Although many studies focus on topsoil, the sub-surface layer plays a role as a more stable intermediate accumulation zone, where the rate of organic matter renewal is slower and oxygen/moisture gradients are different, so that biological responses to MP may deviate from surface patterns (Leitão et al., 2023). In the context of TPS, mechanical activities such as compaction, vehicle movement, and rainwater runoff can drive particle migration to greater depths, making subsurface surveys crucial for assessing chronic exposure to soil microbiota and the potential for sustained CO_2 flux (Pratiwi et al., 2024). Meanwhile, spatial mapping of disposal facilities in developing areas shows sharp heterogeneity between sites, requiring a multi-site study design to capture the variability of MP shape/polymer and its relationship to soil function (Mahesh et al., 2023). In many Asian cities, waste management backlogs and high plastic fractions increase the likelihood of MP leakage from the waste chain into soil media, so field evidence linking MP type profiles and local biological responses will enrich the policy database (Lu et al., 2024). Thus, there is an urgent need for simultaneous characterisation of MP attributes (type/shape/polymer/size) and soil biological function indicators (CO_2-C respiration) in the sub-surface layer of tropical urban landfills (Chen et al., 2025).

However, further research is needed, particularly in tropical urban ecosystems with TPS hotspots, as there is a lack of field studies that simultaneously map the profile of MP types/forms/polymers in the sub-surface layer and directly link them to biological function indicators such as CO_2-C rates. In Indonesia, multi-location spatial databases capturing heterogeneity between TPS, including gradients of activity and local management, are still limited, so generalisations of MP effects on soil respiration at the city scale are not yet robust. Most global studies focus on topsoil or laboratory conditions, so the subsurface dynamics that are more representative of chronic exposure and long-term interactions with microbial communities are poorly understood. Additionally, the separation of the roles of "MP types" (form/polymer/size) on CO_2–C variation is rarely analysed comparatively across locations with soil covariate controls (moisture, organic carbon, bulk density), despite these factors potentially confounding the MP–respiration relationship (Hasan and Tarannum, 2025). In turn, without a database that integrates MP profiles and biological functions in the subsurface, it is difficult to formulate site-based risk indicators and intervention priorities for urban TPS systems (Chen et al., 2025).

Based on this framework, the objective of this study is to profile the types of microplastics in the sub-surface soil layer at 19 TPS sites in Surabaya, including classification of shape, size, and polymer, as well as to measure the biological response of the soil through CO_2-C respiration rate (mg/kg/day) indicators at each location. This study also aims to analyse the relationship between MP characteristics and soil biological responses, considering relevant soil physical covariates, to test whether specific compositions/polymers correlate with increases or decreases in respiration. Specifically, this study seeks to identify locations with high MP loads and extreme CO_2 -C for understanding potential mechanisms involving interactions between pore structure, moisture, and microbial substrate availability. Thus, this study is expected to fill knowledge gaps regarding the relationship between MP type profiles and soil biological functions at the urban scale in tropical environments, while providing a scientific basis for location-based MP risk management in urban TPS systems. This contribution is not only relevant for soil ecology and local carbon cycling but also for urban waste management policies targeting the prevention of plastic leakage and the reduction of its ecological impacts on soil and the atmosphere.

METHODS

Research design

This study utilised an exploratory observational design with a laboratory analysis approach to profile microplastic types and assess soil biological responses through microbial respiration parameters. The primary objective of this design is to identify the distribution of microplastic types in the subsurface soil layers of temporary waste storage sites in Surabaya, as well as to evaluate how the presence of these particles is related to soil physical characteristics and biological activity. An observational approach was chosen because it provides a realistic picture of the diverse field conditions across different TPS locations, while laboratory analysis allows for precise characterisation of microplastics and measurement of soil biological activity.

Research location and time

Sampling was conducted at 19 polling stations spread across the city of Surabaya. The locations were selected based on variations in waste management characteristics, daily waste generation volumes, and geographical positions that reflect the heterogeneity of the urban waste management system. The selection of locations also considered representation from the eastern, western, northern, and southern areas of Surabaya. Sampling was conducted from February to April 2025, a relatively stable period in terms of rainfall, thereby minimising excessive soil moisture bias. Each sampling point was geographically documented using GPS coordinates to ensure positional accuracy and enable replication of the study in the future.

Soil sampling

Soil samples were collected from the sub-surface layer at a depth of 20–30 cm using a manual soil drill made of stainless steel to avoid additional plastic contamination. At each TPS, sampling was carried out at three different points within a radius of 10–20 metres from the centre of the landfill, then samples from each point were mixed homogeneously into a single composite. This approach was chosen to represent the overall soil conditions at each location. The soil obtained was placed in clean glass containers with aluminium foil lids and stored at 4 °C prior to analysis in the laboratory to prevent further degradation and cross-contamination.

Analysis of microplastics

The identification of microplastic types was carried out through a series of pre-separation and characterisation procedures. First, soil samples were dried at 40 °C until they reached a constant weight, then filtered to separate particles larger than 5 mm. The finer soil fraction is extracted using a high-density solution (saturated NaCl, density 1.2 g/cm^3) to float plastic particles. The floating particles are then filtered using a 0.45 µm microporous membrane and dried. Polymer identification is performed using Fourier transform infrared spectroscopy (FTIR) and Raman spectroscopy. The obtained spectra are compared with a standard polymer library to determine the type of microplastic. This study identified several dominant polymers, including polyethylenimine (PEI), cellophane, formaldehyde resin, and synthetic polycationic polymers. The analysis results were recorded in terms of frequency of occurrence per location and proportion of total positive samples.

Analysis of soil physical properties

The physical properties of soil are measured to evaluate the environmental conditions where microplastics are distributed. The parameters observed include soil pH, temperature, moisture content, colour, and texture. pH measurements are taken using a digital pH meter on a soil-water suspension with a ratio of 1:2.5. Soil temperature is measured in situ with a digital soil thermometer, while moisture content is measured using the gravimetric method by drying in an oven at 105 °C until a constant weight is achieved. Soil texture was determined using the international texture triangle method based on the distribution of sand, silt, and clay fractions after dispersion. Soil colour was determined using the Munsell soil colour chart as a visual reference. All parameters were recorded for each location to identify potential correlations with microplastic distribution.

Analysis of soil biological activity

Soil biological activity is measured using a microbial respiration test based on CO_2-C release. This method was chosen because it is widely used as an indicator of soil health and microbial activity. A 50 g soil sample was placed in a sealed incubation container connected to a 0.1 M NaOH trap to absorb the CO_2 released. Incubation was carried out for seven days at a constant temperature of 25 °C with soil moisture maintained at 60% field capacity. After incubation, the NaOH solution is analysed by titration with 0.1 N HCl using phenolphthalein as an indicator to determine the amount of CO_2 bound. Respiratory results are expressed in units of mg CO_2–C per kg of soil per day. The procedure is repeated three times for each sample to enhance data reliability.

Analisis data

The results of microplastic identification, physical properties, and microbial respiration were analysed descriptively and comparatively. Descriptive analysis was used to describe the distribution of microplastic types and physical characteristics of soil between temporary disposal site of locations. Comparative analysis was conducted by comparing CO_2 respiration values between locations and correlating them with variations in the identified microplastic types. For visualization purposes, the data were presented in tabular form.

RESULTS

Profile of microplastic types in subsurface soil

Analysis of 19 temporary disposal sites in Surabaya revealed the presence of various types of microplastics, including polyethylenimine, cellophane, formaldehyde resin, and synthetic polycationic. Out of the total sampling points, 17 locations tested positive for microplastics, while two locations (temporary disposal site of Manyar Tirtoyoso and Gubeng Lama station) showed no indication of microplastic presence. PEI and synthetic polycationic were more frequently found in the samples, while formaldehyde resin and cellophane were detected at specific locations.

Table 1 shows the dominance of PEI and synthetic polycationic compounds, indicating that the main sources are synthetic materials from urban areas and domestic waste. Cellophane and formaldehyde resin are less commonly found and tend to be associated with specific industrial and household waste. Variations between locations indicate heterogeneity in waste inputs at each temporary disposal site.

Physical characteristics of soil

The physical characteristics of the soil at the 19 temporary disposal sites varied relatively. All locations had neutral pH (6.5–7), while soil temperature ranged from 25–34 °C. Soil texture included clay, loam, sand, and stony soil with moisture varying between 18–65% (Table 2).

Neutral soil pH supports microbial activity in general, while differences in temperature and humidity affect the rate of microbial respiration.

Table 1. Distribution of microplastic types in subsurface soil of Surabaya landfill

Sample location	Identified types of microplastics
Temporary Disposal Site of Manyar Tirtomoyo Street	*Polyethylenimine (PEI), Formaldehyde resin*
Temporary Disposal Site of Mojoarum	*Cellophane, Formaldehyde resin*
Temporary Disposal Site of Dharmahusada	*Cellophane, Formaldehyde resin*
Temporary Disposal Site of Manyar Tirtoyoso	*Not detected*
Temporary Disposal Site of Tirtomoyo	*Cellophane, Formaldehyde resin*
Temporary Disposal Site of Wonorejo (Rungkut)	*Polyethylenimine (PEI), Formaldehyde resin*
Temporary Disposal Site of Jagir Wonokromo	*Formaldehyde resin*
Temporary Disposal Site of Srikana Airlangga	*Polyethylenimine (PEI), Formaldehyde resin, Cellophane*
Temporary Disposal Site of. Kejawan Putih Tambak	*Polyethylenimine (PEI), Formaldehyde resin*
Temporary Disposal Site of Menur	*Polyethylenimine (PEI), Cellophane*
Temporary Disposal Site of Old Gubeng Station	*Not detected*
Temporary Disposal Site of Kalibokor	*Polyethylenimine (PEI), Cellophane*
Temporary Disposal Site of Gebang Putih	*Polyethyleneimine (PEI), synthetic polycation*
Temporary Disposal Site of Tambak Wedi	*Polyethyleneimine (PEI), synthetic polycation*
Temporary Disposal Site of Pahing Market	*Polyethyleneimine (PEI), synthetic polycation*
Temporary Disposal Site of Buktong Menur	*Polyethyleneimine (PEI), synthetic polycation*
Temporary Disposal Site of Kejawan Putih Tambak	*Polyethyleneimine (PEI), synthetic polycation*
Temporary Disposal Site of Wonorejo Selatan (Rungkut)	*Polyethyleneimine (PEI), synthetic polycation*
Temporary Disposal Site of Jagir	*Polyethyleneimine (PEI), synthetic polycation*

Table 2. Physical characteristics of subsurface soil at the temporary disposal site in Surabaya

Parameter	Value range	Mean
Soil pH	6.5–7	6.97
Temperature (°C)	25–34	30.2
Humidity (%)	18–65	39.05
Dominant texture	See, clay, sand, rocky	-
Soil colour	Dark brown – dark brown	-

Sandy or rocky soil textures are found in some locations and have the potential to affect microplastic infiltration and distribution. The dominant brownish-black soil colour indicates a relatively high organic matter content.

Soil biological activity (microbial respiration)

Microbial respiration measured in terms of CO_2 production showed significant variation between locations. Respiration rates ranged from 0.16 to 5.76 mg CO_2/kg/day. The locations with the highest respiration rates were Temporary Disposal Site of Manyar Tirtomoyo and Tirtomoyo (5.76 mg/kg/day), while the lowest values were found at Temporary Disposal Site of Pasar Pahing (0.18 mg/kg/day) (Table 3).

Variations in respiration values reflect differences in the adaptation of microbial communities to the presence of microplastics and soil physical conditions. High values at sites dominated by cellophane and formaldehyde resin indicate the potential role of microplastics in facilitating certain microbial activities. Conversely, sites dominated by synthetic polycationic compounds tend to show low respiration, possibly due to toxic effects on microbial metabolism.

DISCUSSION

The results of this study reveal the dominant distribution patterns of microplastics, primarily Polyethylenimine (PEI) and synthetic polycationic polymers, along with the presence of cellophane and formaldehyde resin in several locations, indicating variations in contamination sources and differences in the intensity of plastic input into the soil. The dominance of PEI and synthetic polycationic types is consistent with findings related to the accumulation of synthetic plastics in urban areas, as reported by Kang (2025) in a study indicating that intense anthropogenic activities in urban areas form a distinctive local contaminant profile (Kang et al., 2025). In this context, Temporary Disposal Site of with different waste characteristics contribute to varying microplastic compositions between locations. For example, *cellophane* and *formaldehyde resin*, which are more commonly found in certain locations, suggest the presence of industrial waste management or specific household residues, consistent with the subsequent explanation that plastic polymer sources reflect both domestic and industrial waste streams (Sajjad et al., 2022).

The findings of neutral soil pH, varying moisture content, and different textures indicate highly variable environmental conditions. Interestingly, these results are consistent with global studies showing that microplastics can alter soil structure, modify water retention and porosity, although the effects depend on the shape and size of MP particles, such as fragments or fibres (Wang et al., 2023). The findings of Bakhshaee et al. (2025) indicate that HDPE fragments can increase water holding capacity (WHC) by up to 36%. This factor triggers the hypothesis that similar physical changes may occur in locations with high PEI concentrations, although in other contexts such as respiration, this is checked differently (Bakhshaee et al., 2025).

In terms of soil biological activity, the maximum CO_2 respiration rate (> 5 mg/kg/day) was found at locations dominated by cellophane and formaldehyde resin, indicating stimulation of microbial activity under these conditions. A similar phenomenon has been reported by Xiang (2024) through a global analysis concluding that microplastics can increase CO_2 emissions from soil by triggering shifts in microbial communities and enhancing the role of organic decomposition functions (Xiang et al., 2024). Meanwhile, Zhao et al. (2024) also showed that MP caused a significant increase (25%) in CO_2 production, microbial biomass, and dissolved substrate (DOC), even though microbial diversity decreased (Zhao et al., 2024). This supports the interpretation that

Table 3. Respiratory activity of subsurface soil microbes at the Surabaya landfill

Sample location	Respirasi CO_2-C (mg/kg/hari)
Range	0.16–5.76
Mean	3.92
Highest location	Manyar Tirtomoyo & Tirtomoyo (5.76)
Lowest location	Pasar Pahing (0.18)

MP, especially certain types, can serve as a microbial substrate or modulate the microhabitat for heterotrophic microbes, thereby accelerating respiration. However, the lowest results at sites dominated by synthetic polycationic plastics, with respiration as low as 0.18 mg/kg/day, indicate the possibility of toxicity effects or microbial metabolic inhibition. This aligns with a meta-analysis by Zhou et al. (hg.), which found that plastic types such as PET, PE, and PS can reduce soil enzyme activity by 5–13% (Liu et al., 2023). Thus, low respiration data at synthetic polycationic sites may reflect an inhibitory effect on the microbial community rather than stimulation.

Comparisons between locations indicate that locations with higher numbers of microplastic types do not always have higher respiration activity, suggesting that polymer types and characteristics are more critical than quantity alone. This supports the findings of Boctor (2025), who found that although microplastics can disrupt soil fauna, microbial activity can be enhanced under certain conditions, particularly when microplastics become a source of microbial carbon (Boctor et al., 2025). This means that the non-linear relationship between microplastic quantity and respiratory dynamics requires further testing of microbial community structure, in addition to particle quantification alone.

The mechanism behind this variation likely originates from the microplastic surface-dwelling microbial community, which is known to have a different composition from that of common soil microbial communities and plays a role in carbon, nitrogen, and phosphorus cycles (Rillig et al., 2024). This community may be more adaptive to microplastic carbon substrates and produce higher respiration rates. At certain temporary disposal site, the plastisphere may develop more intensively due to PEI or cellophane inputs, thereby accelerating CO_2 production. From a management perspective, these results suggest that the type of polymer behaviour, particularly those that are friendly to microbial activity or toxic to it, is important to consider in pollution mitigation. For example, the use of biodegradable alternatives may alter microbial ecosystem interactions, as demonstrated in various restoration studies such as biochar, which can enhance soil aggregation and aid in MP remediation (Ji et al., 2025).

Although this study successfully identified the types of microplastic polymers in the subsurface layer of soil at various landfills, it should be noted that the concentration of microplastics in particles per kilogram of soil was not measured quantitatively. The focus of this study was on the polymer type profile, so the relationship between particle number and soil biological response could not be directly evaluated. This is an important limitation of the study, given that many previous studies have emphasised that both the type and amount of microplastics play a role in determining the intensity of the impact on microbial activity and soil respiration (Li et al., 2023; Zhao et al., 2024). Therefore, further research needs to integrate quantitative measurements of microplastic concentrations to obtain a more comprehensive picture.

In addition, this study only assessed some of the physical and chemical parameters of the soil, namely pH, moisture content, texture, and temperature, without covering other properties such as bulk density, water retention capacity, and porosity. However, several studies have reported that changes in these properties can be mediated by the presence of microplastics, thereby affecting gas diffusion, moisture dynamics, and substrate availability for microorganisms (Bakhshaee et al., 2025; Hasan and Tarannum, 2025). Thus, expanding the parameters for measuring soil properties in future research will be very helpful in explaining the mechanism of microplastic interaction with soil ecosystem functions.

The variations in temperature (25–34 °C) and soil moisture (12–65%) observed in this study also have the potential to be important environmental factors that modulate microbial responses to microplastics. Previous studies have confirmed that microbial respiratory activity is greatly influenced by temperature and moisture conditions, as these two factors determine oxygen diffusion, the rate of organic decomposition, and the metabolism of microbial communities (Xiang et al., 2024; Hu et al., 2025). Although an in-depth analysis of the interaction between these factors was not conducted in this study, we would add that differences in respiration values between locations are likely influenced by a combination of the presence of certain polymers and varying temperature and humidity conditions. Further research specifically examining the interaction between types of microplastic polymers, particle concentrations, and environmental factors would strengthen our understanding of the underlying mechanisms.

Furthermore, this study supports the expansion of research into soil-water-MP dynamics, as changes in physical properties (porosity, WHC) can have implications for the hydrological cycle and vegetation, as observed by Bakhshaee et al. (2025). Temporary disposal site offices in areas prone to flooding or slope changes may impact MP transportation to deeper layers.

CONCLUSIONS

This study reveals that microplastic contamination in the sub-surface layer of soil at 19 temporary waste storage sites in Surabaya is quite widespread, with 17 locations showing positive results. The dominant types of microplastics are polyethylenimine and synthetic polycationic, followed by cellophane and formaldehyde resin. Variations in distribution between locations reflect differences in waste source characteristics and the intensity of anthropogenic activities in the surrounding areas. In terms of environmental parameters, the soil at all locations was relatively neutral with a pH of 6.5–7.0, temperature of 25–34 °C, and humidity varying between 12–65%.

Soil biological activity measured through microbial respiration (CO_2 -C) showed a fairly wide range, from 0.18 mg/kg/day to 5.76 mg/kg/day, with an average of 3.59 mg/kg/day. High respiration activity at sites dominated by cellophane and formaldehyde resin indicates microbial stimulation, while low respiration at sites with synthetic polycationic polymers suggests potential toxic effects on the microbial community. These results confirm that the type of microplastic polymer is more influential than the total amount in determining soil biological responses.

These findings reinforce the importance of considering the ecotoxic effects of microplastics in urban waste management, particularly in temporary disposal site of systems that have the potential to become entry points for contaminants into soil ecosystems. Further research should focus on analysing soil microbial community structures using molecular approaches to understand the interactions between the plastisphere and native microorganisms. Additionally, long-term studies on the cumulative effects of microplastics on soil ecosystem functions, carbon cycles, and plant health are also needed. Exploring mitigation strategies, such as the use of biodegradable materials or biochar as soil remediation agents, could be a direction for future applied research.

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