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DISPERSION AND ATMOSPHERIC DEPOSITION OF MICROPLASTICS DURING EXCAVATION IN LANDFILLS

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ABSTRACT

Landfills are recognized as important reservoirs of microplastics (MPs), which may be remobilized and dispersed into the atmosphere through anthropogenic activities. In the context of landfill mining, excavation operations can intensify dust generation and promote the release of previously buried microplastics, yet this pathway remains poorly investigated. This study evaluated the influence of landfill mining excavation on the atmospheric dispersion and deposition of microplastics under distinct operational and spatial conditions at a landfill located in northeastern Brazil. Atmospheric particles were collected using passive atmospheric deposition sampling at five sampling points representing distinct excavation and operational scenarios. Putative microplastics were visually identified and quantified using stereomicroscopy without polymer confirmation. The highest deposition rates were observed near the excavation of older waste deposits, indicating that prolonged burial plays an important role in plastic degradation and the generation of secondary microplastics. Lower deposition rates were recorded at locations less directly influenced by excavation, suggesting contributions from routine landfill activities such as waste transport and leachate management. Fibers and fragments with light coloration predominated, consistent with advanced weathering of plastic materials. Overall, the results indicate that excavation during landfill mining may enhance atmospheric microplastic remobilization and dispersion. These findings highlight the importance of including atmospheric microplastic monitoring in environmental assessment and management frameworks for landfill mining projects.

1. INTRODUCTION

Solid waste management (SWM) has traditionally been guided by the sustainability R's, including reduce, reuse, repurpose, and recycle. In the context of landfills, however, this framework must be expanded to incorporate long-term resource management and recovery strategies (Roque, 2018; Wille et al., 2022). From this perspective, landfills should no longer be regarded solely as final disposal sites, but as components of sustainable materials management systems.

This paradigm shift is embodied in landfill mining (LFM), which redefines landfills as temporary storage systems from which deposited waste can be excavated and valorized as secondary raw materials (Van Passel et al., 2013). Resource recovery through LFM may involve material recycling, energy recovery, and the optimization of landfill space in both area and volume (Faitli et al., 2019; Marella & Raga, 2014). Accordingly, landfills are increasingly recognized as repositories of secondary resources that can be reintegrated into production chains, aligning waste management with the principles of the circular economy (Hermann et al., 2014; Jani et al., 2016).

Landfill mining operations typically involve a sequence of stages, including the removal of vegetation and topsoil, site preparation, waste excavation, material separation and processing, treatment and/or recycling of recovered materials, and post-mining site rehabilitation (Danthurebandara et al., 2015; Frändegård et al., 2013). These activities have been associated with significant emissions of particulate matter, with total releases estimated to range from 1.61 to 5.04 tons over the operational period (Zari, Smith & Ferrari, 2023).

Due to the high proportion of plastic materials in municipal solid waste, landfills have become important reservoirs of microplastics (MPs), which can be transferred to surrounding environments via atmospheric, hydrological, and soil pathways (Golwala et al., 2021; Jambhulkar et al., 2024). Recent estimates suggest that microplastic emissions at the soil–air interface may reach up to 48 kilotons

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per year for particles smaller than 100 µm, underscoring the significance of atmospheric transport as a pathway for microplastic dispersion (Yang et al., 2024).

Microplastics are defined as synthetic polymer particles smaller than 5 mm, while nanoplastics are generally below 1 µm in size. These particles are now recognized as ubiquitous contaminants, occurring across diverse natural and urban environments (Habibi et al., 2022). While primary microplastics are intentionally produced at the microscale, secondary microplastics originate from the fragmentation and degradation of larger plastic items, processes driven by ultraviolet radiation, chemical interactions with leachates, and thermomechanical stresses in landfill environments (Goli & Singh, 2023). Consequently, landfill matrices often contain large amounts of microplastics, with reported concentrations reaching up to 83 particles.g^{-1}, and may be incorporated into the dust generated during excavation (Sholokhova et al., 2023).

Once mobilized, microplastics can be transported through the atmosphere by wind-driven processes, enabling their redistribution across ecosystems. Following atmospheric transport, particles may be removed from the air column via dry deposition or wet deposition, depending on meteorological conditions such as precipitation and humidity, as well as particle size and density (Büks & Kaupenjohann, 2020; Montagner et al., 2021). Experimental studies further demonstrate that microplastics, including aged particles, may induce adverse effects in soil organisms, including oxidative stress and metabolic disturbances (Jiang et al., 2023). In addition, inhalation of microplastic-associated particulate matter has been linked to inflammatory and genotoxic responses in humans (Habibi et al., 2022).

Habibi et al. (2022) and Huang et al. (2020) described the main characteristics of the two main approaches used for atmospheric microplastic sampling. Active sampling uses suction pumps to draw a known volume of air through filters or collection substrates. This method allows the measurement of airborne microplastic concentrations per unit volume of air (MPs/m^3) and is widely used in air quality, human exposure, and health risk studies. It also enables the rapid collection of relatively large air volumes (2 to 23.93 m^3), producing data that can be compared across different locations and time periods.

Although passive sampling does not measure airborne MP concentrations per unit volume of air, it enables the estimation of atmospheric deposition rates per unit area (particles/m^2/day) and is particularly useful for evaluating particle dispersion, transport, and environmental accumulation over a long period (Habibi et al., 2022; Huang et al., 2020). While active samplers allow controlled airflow and high collection efficiency, passive samplers offer operational simplicity and lower costs, making them suitable for long-term monitoring and multi-site assessments (Torres-Agullo et al., 2021).

Methods for microplastic (MP) identification range from visual inspection under stereomicroscopy to advanced spectroscopic techniques, such as FTIR and micro-Raman analysis. Although visual identification is widely used in atmospheric MP studies because it is simple and low-cost, it has important limitations and may lead to particle misclassification, especially in complex environmental matrices (Habibi et al., 2022). Therefore, results based solely on visual identification should be interpreted with caution, particularly when polymer confirmation is not performed.

In Brazil, among the 80 studies evaluated, 60% relied exclusively on visual inspection for MP identification, while 23.75% employed microscopic examination without subsequent chemical confirmation using analytical techniques. Nevertheless, in an effort to reduce the subjectivity associated with visual analyses, the number of studies incorporating chemical characterization methods to confirm the polymeric composition of MPs has increased since 2020. (Montagner et al., 2021).

In this context, Le et al. (2023) emphasized the importance of developing analytical approaches for atmospheric MP monitoring that are not only accurate and reliable but also simple, efficient, and economically accessible. In this regard, visual analysis using stereomicroscopy combined with complementary procedures, such as the hot-needle test to exclude certain organic particles, has been widely applied and can provide relevant preliminary information regarding particle abundance and morphology (Dong et al., 2023; Hidalgo-Ruz et al., 2012; Jarosz et al., 2022; Lusher et al., 2020; Sharaf Din et al., 2024).

Despite increasing evidence of microplastic contamination in landfill matrices, limited attention has been paid to their atmospheric dispersion under landfill mining (LFM) conditions. Gupta et al. (2025) and Zhang et al. (2025) highlighted that most studies have focused on MPs in leachates and mined materials, particularly in the fine fraction of excavated waste, whereas no studies or risk assessments specifically addressed airborne MP generation during LFM activities. According to Yang et al. (2025), only two studies reported airborne MPs associated with landfill operations, neither of which directly investigated landfill mining.

In this context, Lou et al. (2025) emphasized that effective landfill mining projects should include quantitative assessments of MP contamination in fine mined fractions and dust-control measures to reduce atmospheric dispersion. This highlights the need for studies on the dispersion and atmospheric deposition of MPs during landfill excavation, as these activities may resuspend and transport contaminant particles into surrounding environments.

This study tests the hypothesis that excavation activities during landfill mining operations represent a relevant source of atmospheric microplastic dispersion, with spatial patterns shaped by waste age, proximity to excavation zones, and operational conditions. Accordingly, the objective of this study is to evaluate the atmospheric deposition of microplastics within a landfill undergoing landfill mining activities, using passive sampling to (i) characterize spatial variations in microplastic deposition, (ii) assess the influence of excavation activities relative to other routine landfill operations, and (iii) provide baseline information to support future risk assessments and mitigation strategies for landfill mining projects.

2. MATERIALS AND METHODS

2.1 Study area

The study was conducted at a landfill located in the Reconcavo region of Bahia, northeastern Brazil. The site operated as a controlled landfill between 2000 and 2011 and was later converted into a sanitary landfill under a concession agreement with a private company, which remains responsible for its operation (Martins, Silva & Carneiro, 2017). Except for the criterion related to minimum distance from population centers, which could not be fully assessed due to the absence of historical imagery, the landfill complies with Brazilian regulatory requirements regarding terrain slope, soil characteristics, distance from water bodies, and absence of occupation in legally protected areas (Santos, De Souza & Vaz, 2018).

From 2016 to 2022, the landfill received an average of approximately 168 tons of municipal solid waste per day, according to the Brazilian National Information System on Sanitation (SNIS), a national database of solid waste management statistics (SNIS, 2021; SNIS, 2022). Based on the average gravimetric composition reported by Alfaia et al. (2017), the landfill is estimated to contain at least 64,386 tons of plastic waste.

This site was selected because it was undergoing pilot-scale landfill mining activities at the time of the study, which allowed for the evaluation of excavation-induced remobilization and atmospheric dispersion of microplastics under pilot-scale operational conditions.

2.2 Sampling design and experimental rationale

To test the hypothesis that excavation activities during landfill mining prospecting act as a significant driver of atmospheric microplastic dispersion, a spatially distributed passive sampling design was adopted. Five sampling points were selected to represent distinct operational and spatial conditions within the landfill (Figure 1), including areas directly influenced by excavation, zones affected by routine operational activities, and locations more distant from active mining fronts.

The spatial arrangement of the sampling points was designed to capture gradients of influence from distinct landfill operational areas, including excavation zones, access roads, leachate lagoons, and waste handling areas (Table 1). Sampling points were positioned to represent proximity to these specific operational sources. This spatial design, combined with the identification of potential interference sources, allowed the assessment of (i) spatial variability in atmospheric microplastic deposition, (ii) the relative contribution of excavation activities compared with routine landfill operations, and (iii) the influence of proximity to the excavation area associated with the older mined waste, consistent with the objectives defined in the Introduction.

2.3 Atmospheric microplastic sampling

Sampling devices were strategically oriented to maximize exposure to the prevailing wind direction, thereby increasing the likelihood of capturing wind-driven particle transport. Sampling was conducted on 14 May 2024 under stable and sunny conditions to reduce short-term meteorological variability. The sampling period was preceded by eight consecutive days of rainfall, which likely enhanced wet deposition and atmospheric washout of suspended particles, potentially resulting in reduced background concentrations of airborne microplastics.

FIGURE 1: Spatial distribution of sampling points for atmospheric deposition of microplastics at the landfill located in the city of Santo Antônio de Jesus, Bahia (Brazil), with indication of excavation area of the older mined waste.

TABLE 1: Characterization of sampling points and potential sources of interference in the atmospheric deposition of microplastics.

Sampling point	Topographic elevation (m)	Location	Potential sources of interference
P1	172.34	Area near the work front, corresponding to the receiving point of newly collected waste.	Dust generation associated with daily covering of waste and presence of larger plastics, potentially subject to mechanical fragmentation.
P2	188.34	Landfill plateau, in the third vertical layer	Less direct influence from dust sources; proximity to the main access road for collection trucks, with possible resuspension of particles.
P3	188.53	Landfill plateau, third vertical layer, near the first excavation trench.	Direct influence from an excavation area associated with waste approximately two years old.
P4	183.9	Berm, located at the base of the landfill, near the second excavation trench.	Direct influence from an excavation area associated with waste approximately ten years old, potentially more degraded and fragmented.
P5	182.39	Area near the leachate lagoons.	Absence of relevant dust sources; possible influence of aerosols generated by the drainage and movement of leachate.

Wind direction data from the Brazilian National Institute of Meteorology (INMET, n.d) climatological normals indicated a prevailing southeast (SE) wind regime (SE-NW transport). This wind field governs atmospheric advection of particulate matter, including microplastics, and was used as the reference for interpreting exposure conditions and guiding the sampling design. However, the absence of concurrent in situ wind measurements (speed and direction) limits a more detailed characterization of short-term atmospheric transport dynamics and deposition variability.

At sampling points P1, P2, P3, and P5, collection began immediately prior to the initiation of landfill excavation operations near P3 and continued for approximately six hours, encompassing two landfill excavation operations cycles and the subsequent waste sorting and packaging operations. This sampling period was designed to capture the cumulative effect of particle emissions associated with landfill mining operations on microplastic deposition.

Due to restricted access to P4 during the morning shift, sampling at this location was conducted in the afternoon for a total duration of three hours, including approximately two hours of excavation followed by an additional hour to allow the gravitational settling of lighter particles. The absence of sampling during the initial excavation phase constitutes a relevant methodological limitation of the present study, as emissions generated between 10:00 and 12:00 were not captured at P4, potentially leading to an underestimation of particle deposition.

Differences in exposure time were normalized in the estimation of deposition rates (particles/m²/day). However, this normalization does not fully account for potential temporal variations in microplastic emissions across different stages of the excavation process. Therefore, results from P4 should be interpreted with caution when compared with those from other sampling locations.

Microplastics were collected using a passive dry deposition method to characterize spatial deposition fluxes. Due to operational and logistical constraints associated with landfill excavation, sampling was conducted in a single campaign. To account for local environmental variability and improve the representativeness of the measurements, three replicate collectors were deployed at each sampling point.

Specifically, 100 mm glass Petri dishes containing qualitative filter paper (80 g m^{-2}) were placed on platforms positioned 30 cm above ground level (Cui et al., 2022). The three Petri dishes were exposed simultaneously and treated as independent replicate samples of atmospheric deposition. Results are presented as mean ± standard deviation (n=3). Accordingly, the standard deviation reflects the variability among replicate deposition samples collected at the same site and during the same exposure period, rather than solely analytical uncertainty.

To minimize contamination during sampling, the Petri dishes were pre-washed with deionized water, wrapped in aluminum foil during transport from the laboratory to the landfill, and handled without latex gloves to avoid the introduction of synthetic particles. Following exposure, the dishes were immediately covered, wrapped in aluminum foil to minimize contamination during handling and transport (Sivalingam et al., 2024), and transferred to the LAQUA/UFRB laboratory for analysis.

2.4 Microplastic identification and quality assurance

Microplastics were identified and quantified by visual analysis using a WF10X binocular stereomicroscope (Sharaf Din et al., 2024). The visual identification procedure was performed sequentially: (i) selection of particles <5 mm; (ii) assessment of uniform thickness, colors, and surface gloss; and (iii) mechanical testing with a cold needle to evaluate particle flexibility, with brittle particles considered likely to be of organic or mineral origin (Lusher et al., 2020; Yang et al., 2021). When uncertainty remained, (iv) a hot-needle test was applied, in which a heated needle was pressed against the particle and melting was used as a diagnostic criterion for microplastics (Loppi et al., 2021). Despite its low cost, this technique does not allow for the determination of polymers, is subject to analyst subjectivity, and destroys the particles, preventing subsequent reanalysis.

In the present study, spectroscopic or chemical confirmation of polymer identity (e.g., FTIR or Raman spectroscopy) was not performed, representing an important methodological limitation. Consequently, some visually identified particles may correspond to non-plastic anthropogenic or

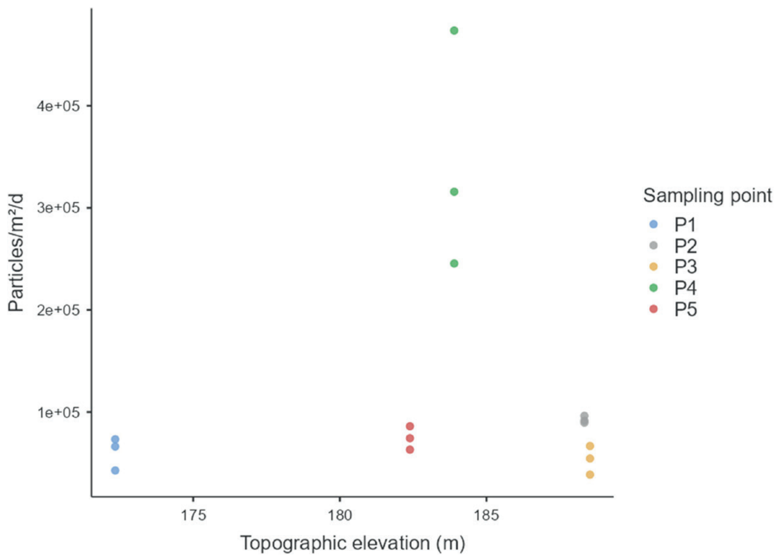

FIGURE 2: Mean number of microplastic particles deposited at the different sampling points of the landfill located in Santo Antônio de Jesus, Bahia (Brazil).

natural materials, potentially leading to false positives and overestimation of MP abundance. Therefore, the identified particles should be interpreted as visually classified putative microplastics, and some degree of false-positive classification cannot be excluded.

To minimize particle loss and cross-contamination during sample handling, Petri dishes and filter papers were rinsed with deionized water inside a laminar flow hood, and the resulting rinsates were filtered under vacuum conditions (Habibi et al., 2022). To evaluate potential laboratory contamination and support data quality assurance, three procedural blanks consisting of Petri dishes with filter paper were prepared and processed following the same protocol as the exposed samples (Cui et al., 2022). All filters, including blanks, were subsequently analyzed under the stereomicroscope.

3. RESULTS AND DISCUSSION

3.1 Microplastic identification and quality assurance

Figure 2 and Table 2 show the mean atmospheric microplastic deposition at each sampling point. A descriptive analysis showed that P4 exhibited the highest mean particle deposition (344,963.03 particles/m²/day), indicating elevated particulate loading at this site. In addition, the standard deviation at P4 was higher than at the other sampling points, suggesting greater variability in the collected samples (SD = 116,851.30 particles/m²/day).

The Shapiro-Wilk test indicated that the data were normally distributed at all sampling points ($p > 0.05$), supporting the use of parametric statistical approaches. Tukey's post-hoc test (Table 3) indicated that P4 differed significantly from all other sampling points ($p < 0.001$), whereas no significant differences were observed among P1, P2, P3, and P5.

Despite the observed normality, non-parametric analyses were additionally performed due to the small sample size and the presence of extreme values at P4. The Kruskal–Wallis test indicated statistically significant differences among sampling points ($p = 0.019$). However, pairwise comparisons using the Dwass-Steel-Critchlow-Fligner post-hoc test (Table 4) did not identify significant differences between individual pairs of sampling points.

Overall, Tukey's test indicated a significant effect associated with P4, whereas the Dwass-Steel-Critchlow-Fligner procedure did not detect significant pairwise differences. These differences reflect methodological sensitivity to extreme values and distributional assumptions, as well as the influence of small sample size on rank-based procedures.

TABLE 2: Summary of descriptive statistics and Shapiro-Wilk normality test for spatial deposition fluxes at each sampling point (P1-P5).

Sampling point	Mean	SD	Minimum	Maximum	Shapiro-Wilk	
					W	p
P1	60775.97	15986.81	42781	73339	0.91340	0.430
P2	92522.07	3391.06	89636	96257	0.95301	0.583
P3	53306.30	14043.40	38706	66718	0.99463	0.860
P4	344963.03	116851.30	245481	473645	0.95317	0.583
P5	74526.95	11460.10	63153	86071	0.99984	0.975

TABLE 3: Post-hoc Tukey HSD test results for pairwise comparisons of particle deposition rates (particles/m²/day) among sampling points (P1-P5), including mean differences and significance levels.

		P1	P2	P3	P4	P5
P1	Average difference	—	-31746	7469.7	-284187***	-13751
	p-value	—	0.945	1.000	<.001	0.997
P2	Average difference		—	39215.8	-252441**	17995
	p-value		—	0.891	0.001	0.993
P3	Average difference			—	-291657***	-21221
	p-value			—	<.001	0.987
P4	Average difference				—	270436***
	p-value				—	<.001
P5	Average difference					—
	p-value					—

*Note: * p < .05, ** p < .01, *** p < .001*

3.2 Spatial patterns and operational influences

The highest values were recorded at P4, located adjacent to the excavation area containing older waste, which is consistent with previous findings indicating that prolonged burial enhances plastic degradation and fragmentation, thereby increasing the generation of secondary microplastics (Canopoli, Coulon & Wagland, 2020).

Previous studies on landfill mining have reported strong associations among microplastic abundance, landfill age, excavation depth, and the fine fraction of mined waste (FFM < 4 mm), suggesting that both degradation stage and waste stratification influence microplastic availability for remobilization (Jambhulkar et al., 2024; Sholokhova et al., 2023). In the present study, areas influenced by older waste showed consistently higher atmospheric deposition, reinforcing burial time as a key factor controlling secondary microplastic generation and dispersion during excavation.

P2 (mean = 92,522.07 particles/m²/day ± 3,391.06) and P5 (mean = 74,527.95 particles/m²/day ± 11,460.10) show intermediate values, which are less directly influenced by excavation activities. At P2, the proximity to the access road suggests a contribution from vehicle-induced resuspension, given that one of the main sources of microplastic (MP) contamination is tire abrasion, which generates particles that further degrade into fibers and fragments (Gupta et al., 2025). At P5, deposition may be partly associated with aerosolization processes at leachate ponds (Le et al., 2023; Liu & Zheng, 2025).

TABLE 4: Dwass-Steel-Critchlow-Fligner post-hoc pairwise comparisons of particle deposition rates (particles/m²/day) among sampling points (P1-P5) following a Kruskal-Wallis test.

		W	P
P1	P2	2.77746	0.284
P1	P3	-0.92582	0.966
P1	P4	2.77746	0.284
P1	P5	1.54303	0.811
P2	P3	-2.77746	0.284
P2	P4	2.77746	0.284
P2	P5	-2.77746	0.284
P3	P4	2.77746	0.284
P3	P5	2.16025	0.545
P4	P5	-2.77746	0.284

Note: p > 0.05 indicates no statistically significant differences between sites

P1 (mean = 60,775.97 particles/m²/day ± 15,986.81) and P3 (mean = 53,306.30 particles/m²/day ± 14,043.40) showed comparable deposition rates and likely represent background levels of atmospheric microplastic transport within the landfill area. Despite its higher elevation and greater distance from the landfill's routine operational area, P3 may primarily reflect the influence of excavation trench 1. The short residence time and high humidity conditions (resulting from the rainy period preceding the sampling date) may have contributed to the observed lower particulate matter flux.

In Brazil, until now, only two studies have reported atmospheric microplastic deposition in landfill environments using passive methods, neither of them addressing landfill mining. Deposition rates reported by Oliveira et al. (2022) during routine landfill operation (57,845.94 particles/m²/day ± 10,890.45) are comparable to baseline values observed in this study (P1 and P3), whereas Rezende et al. (2020) reported substantially lower levels (mean = 14,323.94 particles/m²/day ± 1,555.28). In a Chinese landfill, the deposition rate was considerably lower, at 6,164.0 ± 532.0 particles/m²/day (Yang et al., 2025). Differences may reflect operational intensity, landfill age, site characteristics, and methodological variability.

Several authors highlight the need for standardization of microplastic collection and identification procedures to support the development of stricter regulations aimed at mitigating pollution associated with these contaminants (Habibi et al., 2022; Kabir et al., 2023; Singh et al., 2023; Sivalingam et al., 2024). To improve the reliability of the results, it is recommended to increase the number of samples per sampling point and to adopt varying sampling durations, including periods equivalent to the excavation time as well as longer intervals, such as 24 or even 48 hours (Choi et al., 2024).

Although passive deposition methods may underestimate total airborne microplastic concentrations compared with active sampling approaches (Dong et al., 2023), the method was suitable for the comparative objective of this study. The spatial distribution of particle deposition, with higher values observed at P4, suggests the presence of a localized hotspot in the study area. This pattern may be associated with landfill mining activities occurring at or near this sampling point.

These results are consistent with the possibility that excavation activities influence microplastic dynamics in the surrounding environment, potentially through direct emissions and/or the resuspension of previously deposited particles from the landfill surface. However, the present data do not allow for a direct distinction between these mechanisms, and the observed patterns should be interpreted as indicative of increased atmospheric availability of microplastics in areas influenced by excavation activity.

3.3 Morphology and color distribution of MPs

The predominance of lightly colored particles at this point supports this interpretation (Figure 3), as weathering processes promote pigment loss in plastics over time (Kabir et al., 2023). This pattern is environmentally relevant, given the higher likelihood of ingestion of white and transparent microplastics by aquatic organisms (Bharath, Muthulakshmi & Natesan, 2023).

The results demonstrate the occurrence of microplastics at all sampled points (P1–P5), with a significant predominance of fibers compared to fragments. Among the evaluated points, P4 showed the highest percentages of microplastics, especially in the fiber category, suggesting a possible contribution or accumulation of these particles associated with the second excavation trench. A similar pattern was observed at P5, which may be related to its proximity to the leachate lagoon.

Fragments showed lower percentages than fibers at all sampling points. This difference may indicate either a lower contribution from degraded rigid plastics or a greater environmental persistence and transport capacity of fibers. Studies indicate that fibers have a high dispersion potential due to their low weight and elongated shape, which favor their suspension in the atmosphere and subsequent deposition (Yang et al., 2024).

The heterogeneous composition observed in the graphs, represented by the different colors of the stacked bars, suggests a diversity of microplastic sources. The predominance of certain color classes may reflect specific patterns of plastic consumption and disposal in the region. Furthermore, the simultaneous presence of several categories indicates that the detected microplastics originate from multiple handling, degradation, and transport processes.

Representative microplastic particles are shown in Figure 4, predominantly composed of fibers and fragments with light coloration. This morphology and color distribution are consistent with advanced weathering processes and have been widely reported as dominant features in atmospheric microplastic deposition (Habibi et al., 2022; Kabir et al., 2023; De Souza, Parolin & Crispim, 2024).

Mineral particles and biological fragments were also observed in the samples, reflecting the complex composition of atmospheric fallout in the study area. Microplastic identification was confirmed using the needle test, which has proven effective in distinguishing synthetic materials from natural ones based on physical response to mechanical probing. Only particles confirmed as microplastics were included in the morphological analysis.

Overall, the findings demonstrate that landfill mining excavation constitutes a relevant pathway for atmospher-

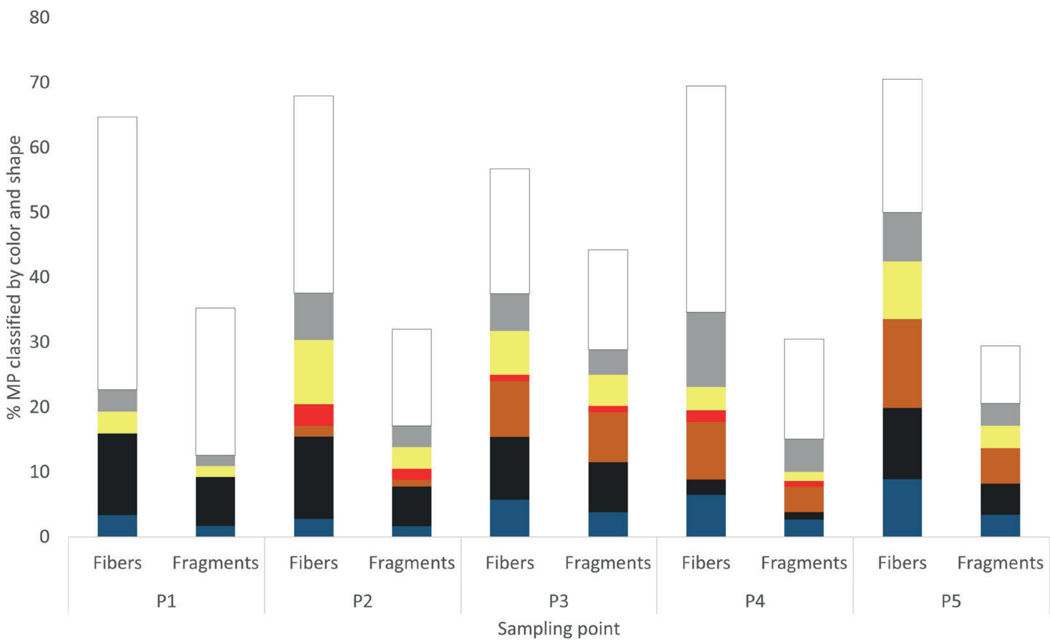

FIGURE 3: Percentage distribution of microplastic (MP) colors among sampling points P1–P5.

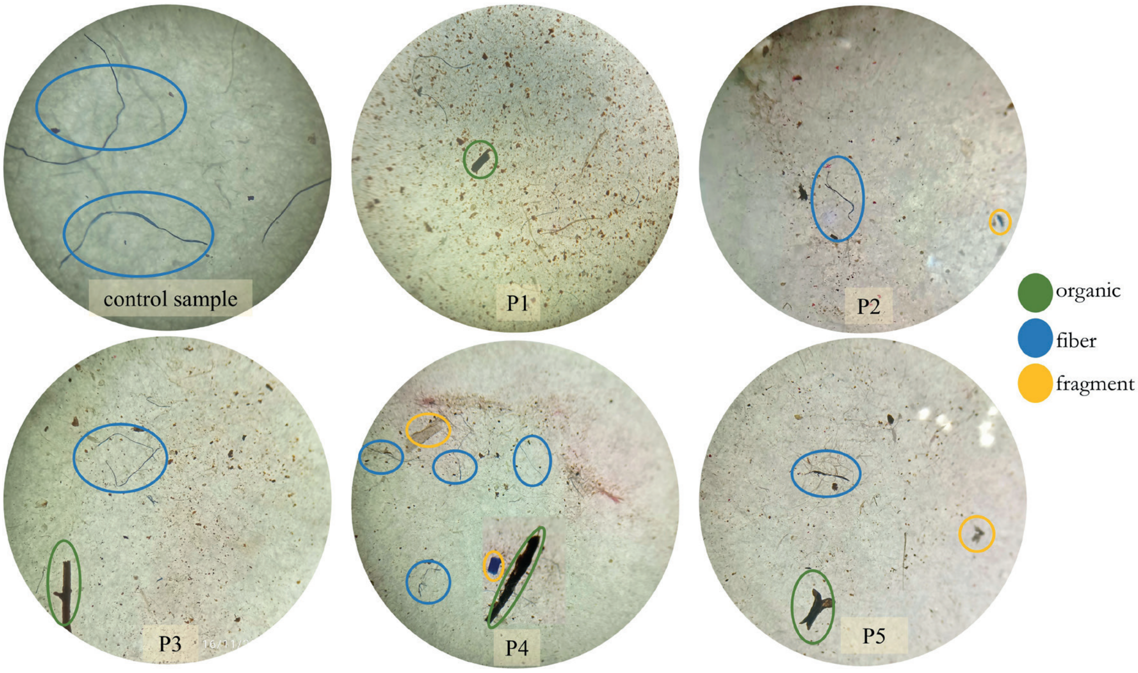

FIGURE 4: Representative examples of microplastics and co-occurring particulate materials identified in atmospheric deposition during excavation of the mined material.

ic microplastic dispersion, modulated by waste age, operational conditions, and particle characteristics. These results support the inclusion of atmospheric microplastic monitoring in environmental assessments and risk management frameworks for landfill mining projects.

4. CONCLUSIONS

Passive atmospheric deposition during landfill mining revealed a predominance of fibrous and fragmented putative microplastics with light coloration, consistent with advanced weathering and fragmentation of long-buried plastic waste. These characteristics suggest that the detected particles were predominantly secondary microplastics generated through degradation processes within the landfill mass.

Atmospheric deposition exhibited marked spatial variability, with the highest deposition rates recorded near the excavation of older waste deposits. Greater variability in particle deposition was also observed at this location, indicating heterogeneous particulate release associated with excavation activities and waste characteristics. Parametric analyses indicated significant differences involving P4; however, the small sample size and the influence of extreme values reduced the consistency between parametric and non-parametric statistical comparisons.

Overall, the observed spatial pattern suggests that prolonged burial enhances plastic degradation and increases the generation of secondary microplastics. The presence of microplastics at locations distant from active excavation fronts further indicates that atmospheric dispersion is influenced not only by excavation activities but also by routine landfill operations, including waste handling and vehicle traffic.

Visual identification combined with hot-needle testing enabled a preliminary distinction between synthetic and non-synthetic particles; however, the absence of spectroscopic confirmation remains an important limitation of this study. Some natural or anthropogenic particles may have been visually misidentified as microplastics, potentially leading to overestimation of particle abundance. Therefore, the reported values should be interpreted as indicative estimates of atmospheric microplastic deposition rather than absolute deposition rates.

Direct human health risks were not evaluated in this study. However, the presence of airborne microplastics during excavation activities raises concerns regarding occupational exposure and particle deposition in surrounding environments. These findings indicate that landfill mining may contribute to atmospheric microplastic emissions, particularly during excavation and material handling stages. Therefore, atmospheric microplastic monitoring and mitigation measures should be incorporated into environmental management and impact assessment frameworks for landfill mining projects.

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REFERENCES

Alfaia, R. G. D. S. M., Costa, A. M., & Campos, J. C. (2017). Municipal solid waste in Brazil: A review. Waste Management & Research: The Journal for a Sustainable Circular Economy, 35(12), 1195–1209. https://doi.org/10.1177/0734242X17735375

Bharath, M. K., Muthulakshmi, A. L., & Natesan, U. (2023). Microplastic contamination around the landfills: Distribution, characterization and threats: A review. Current Opinion in Environmental Science & Health, 31, 100422. https://doi.org/10.1016/j.coesh.2022.100422
Büks, F., & Kaupenjohann, M. (2020). Global concentrations of microplastics in soils – a review. SOIL, 6(2), 649–662. https://doi.org/10.5194/soil-6-649-2020
Canopoli, L., Coulon, F., & Wagland, S. T. (2020). Degradation of excavated polyethylene and polypropylene waste from landfill. Science of The Total Environment, 698, 134125. https://doi.org/10.1016/j.scitotenv.2019.134125
Choi, D., Jung, S., Lee, J., & Kwon, E. E. (2024). Analysis of microplastics distributed in the environment: Case studies in South Korea. Energy & Environment, 0958305X241230616. https://doi.org/10.1177/0958305X241230616
Cui, J., Chen, C., Gan, Q., Wang, T., Li, W., Zeng, W., Xu, X., Chen, G., Wang, L., Lu, Z., Li, J., & Jin, B. (2022). Indoor microplastics and bacteria in the atmospheric fallout in urban homes. Science of The Total Environment, 852, 158233. https://doi.org/10.1016/j.scitotenv.2022.158233
Danthurebandara, M., Van Passel, S., Vanderreydt, I., & Van Acker, K. (2015). Assessment of environmental and economic feasibility of Enhanced Landfill Mining. Waste Management, 45, 434–447. https://doi.org/10.1016/j.wasman.2015.01.041
De Souza, T. L., Parolin, M., & Crispim, J. Q (2024). Sobre as pesquisas de microplásticos na atmosfera, o que sabemos? Observatorium: Revista Eletrônica De Geografia, 15(1), 360-387. https://doi.org/10.14393/OREG-v15-n1-2024-73349
Dong, H., Wang, X., Xu, L., Ding, J., & Wania, F. (2023). A Flow-through Passive Sampler for Microplastics in Air. Environmental Science & Technology, 57(6), 2362–2370. https://doi.org/10.1021/acs.est.2c07016
Faitli, J., Nagy, S., Romenda, R., Gombkötő, I., Bokányi, L., & Barna, L. (2019). Assessment of a residual municipal solid waste landfill for prospective 'landfill mining.' Waste Management & Research, 37(12), 1229–1239. https://doi.org/10.1177/0734242X19881197
Frändegård, P., Krook, J., Svensson, N., & Eklund, M. (2013). A novel approach for environmental evaluation of landfill mining. Journal of Cleaner Production, 55, 24–34. https://doi.org/10.1016/j.jclepro.2012.05.045
Goli, V. S. N. S., & Singh, D. N. (2023). Extraction and characterization of microplastics in Landfill-Mined-Soil-like-Fractions: A novel methodology. Chemical Engineering Journal, 452, 139217. https://doi.org/10.1016/j.cej.2022.139217
Golwala, H., Zhang, X., Iskander, S. M., & Smith, A. L. (2021). Solid waste: An overlooked source of microplastics to the environment. Science of The Total Environment, 769, 144581. https://doi.org/10.1016/j.scitotenv.2020.144581
Gupta, A., Verma, A., & Atri, R. K. (2025). Landfills as a potential source and origin of microplastics: Formation, composition, and environmental risks. Frontiers in Environmental Science, 13, 1689154. https://doi.org/10.3389/fenvs.2025.1689154
Habibi, N., Uddin, S., Fowler, S. W., & Behbehani, M. (2022). Microplastics in the atmosphere: A review. Journal of Environmental Exposure Assessment. https://doi.org/10.20517/jeea.2021.07
Hermann, R., Baumgartner, R. J., Sarc, R., Ragossnig, A., Wolfsberger, T., Eisenberger, M., Budischowsky, A., & Pomberger, R. (2014). Landfill mining in Austria: Foundations for an integrated ecological and economic assessment. Waste Management & Research: The Journal for a Sustainable Circular Economy, 32(9_suppl), 48–58. https://doi.org/10.1177/0734242X14541168
Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. Environmental Science & Technology, 46(6), 3060–3075. https://doi.org/10.1021/es2031505
Huang, Y., Qing, X., Wang, W., Han, G., & Wang, J. (2020). Mini-review on current studies of airborne microplastics: Analytical methods, occurrence, sources, fate and potential risk to human beings. TrAC Trends in Analytical Chemistry, 125, 115821. https://doi.org/10.1016/j.trac.2020.115821
Jani, Y., Kaczala, F., Marchand, C., Hogland, M., Kriipsalu, M., Hogland, W., & Kihl, A. (2016). Characterisation of excavated fine fraction and waste composition from a Swedish landfill. Waste Management & Research, 34(12), 1292–1299. https://doi.org/10.1177/0734242X16670000
Jambhulkar, R., Sharma, N., Kundu, D., & Kumar, S. (2024). Unveiling the composition of bio-earth from landfill mining and microplastic pollution. Environmental Monitoring and Assessment, 196(11). https://doi.org/10.1007/s10661-024-13229-2
Jarosz, K., Janus, R., Wądrzyk, M., Wilczyńska-Michalik, W., Natkański, P., & Michalik, M. (2022). Airborne Microplastic in the Atmospheric Deposition and How to Identify and Quantify the Threat: Semi-Quantitative Approach Based on Kraków Case Study. International Journal of Environmental Research and Public Health, 19(19), 12252. https://doi.org/10.3390/ijerph191912252
Jiang, X., Cao, J., Ye, Z., Klobučar, G., & Li, M. (2023). Microplastics - Back to Reality: Impact of Pristine and Aged Microplastics in Soil on Earthworm Eisenia fetida under Environmentally Relevant Conditions. Environmental Science & Technology, 57(44), 16788–16799. https://doi.org/10.1021/acs.est.3c04097
Kabir, M. S., Wang, H., Luster-Teasley, S., Zhang, L., & Zhao, R. (2023). Microplastics in landfill leachate: Sources, detection, occurrence, and removal. Environmental Science and Ecotechnology, 16, 100256. https://doi.org/10.1016/j.ese.2023.100256
Le, V.-G., Nguyen, M.-K., Nguyen, H.-L., Lin, C., Hadi, M., Hung, N. T. Q., Hoang, H.-G., Nguyen, K. N., Tran, H.-T., Hou, D., Zhang, T., & Bolan, N. S. (2023). A comprehensive review of micro- and nano-plastics in the atmosphere: Occurrence, fate, toxicity, and strategies for risk reduction. Science of The Total Environment, 904, 166649. https://doi.org/10.1016/j.scitotenv.2023.166649
Liu, J., & Zheng, L. (2025). Microplastic migration and transformation pathways and exposure health risks. Environmental Pollution, 368, 125700. https://doi.org/10.1016/j.envpol.2025.125700
Loppi, S., Roblin, B., Paoli, L., & Aherne, J. (2021). Accumulation of airborne microplastics in lichens from a landfill dumping site (Italy). Scientific Reports, 11(1), 4564. https://doi.org/10.1038/s41598-021-84251-4
Lou, F., Wang, J., Sima, J., Lei, J., Zhu, C., & Huang, Q. (2025). Microplastic contamination in different aged landfill mineralization. Waste Management, 204, 114930. https://doi.org/10.1016/j.wasman.2025.114930
Lusher, A. L., Bråte, I. L. N., Munno, K., Hurley, R. R., & Welden, N. A. (2020). Is It or Isn't It: The Importance of Visual Classification in Microplastic Characterization. Applied Spectroscopy, 74(9), 1139–1153. https://doi.org/10.1177/0003702820930733
Marella, G., & Raga, R. (2014). Use of the Contingent Valuation Method in the assessment of a landfill mining project. Waste Management, 34(7), 1199–1205. https://doi.org/10.1016/j.wasman.2014.03.018
Martins, L. O. S., Silva, L. T., & Carneiro, R. A. F. (2017). Análise da Viabilidade EconômicaeE Financeira da Implantação de Usina de Geração de Energia a Partir de Resíduos Sólidos Urbanos no Município de Santo Antônio de Jesus – BA. Revista Livre de Sustentabilidade e Empreendedorismo, 2(2), 25.
Montagner, C., Dias, M., Paiva, E., & Vidal, C. (2021). Microplásticos: Ocorrência Ambiental e Desafios Analíticos. Química Nova. https://doi.org/10.21577/0100-4042.20170791
National Institute of Meteorology (INMET). (n.d.). Climatological normals: prevailing wind direction (VTDIRPRE) [Dataset]. Ministry of Agriculture and Livestock. https://portal.inmet.gov.br/uploads/normais/Normal-Climatologica-VTDIRPRE.xlsx
National Information System on Sanitation (SNIS). (2022). Thematic diagnostic: Urban solid waste management. Overview. Ministry of Cities, Brazil. https://www.gov.br/cidades/pt-br/acesso-a-informacao/acoes-e-programas/saneamento/snis/produtos-do-snis/diagnosticos-sni.
National Information System on Sanitation (SNIS). (2021). Previous SNIS diagnostics: Solid waste (2002–2021). Ministry of Cities, Brazil. https://www.gov.br/cidades/pt-br/acesso-a-informacao/acoes-e-programas/saneamento/snis/diagnosticos-anteriores-do-snis/residuos-solidos-1
Oliveira, M. M. C., Queiroz, L. de A., Santos, N. de S., & Valentim, C. S. (2022). Determinação de microplásticos no ar e no lixiviado de um aterro sanitário. GEAMA – Ciências Ambientais e Biotecnologia. 9(2), 11–19. https://www.journals.ufrpe.br/index.php/geama/article/view/5417
Rezende, V. E., Ferreira, G. T. F., Silva Filho, C. R. R., Araujo, L., & Caixeta, D. S. (2020). Dispersão de microplásticos pelo ar em aterro sanitário. In: XIX SILUBESA - Simpósio Luso-brasileiro de Engenharia Sanitária e Ambiental. Anais do XIX Simpósio Luso-Brasileiro de Engenharia Sanitária e Ambiental (SILUBESA) https://abes-dn.org.br/anaiseletronicos/46_Download/TrabalhosCompletosPDF/III-025.pdf

Roque, A. J. (2018). Ambiente e sustentabilidade: Desafios e perspetivas para a geotecnia. Geotecnia, (143), 55–83. https://doi.org/10.24849/j.geot.2018.143.04

Santos, P. F., de Souza, A. C., & Vaz, C. B. (2018). Avaliação da localização dos pontos de disposição final dos resíduos sólidos urbanos no Recôncavo Baiano.

Sharaf Din, K., Khokhar, M. F., Butt, S. I., Qadir, A., & Younas, F. (2024). Exploration of microplastic concentration in indoor and outdoor air samples: Morphological, polymeric, and elemental analysis. Science of The Total Environment, 908, 168398. https://doi.org/10.1016/j.scitotenv.2023.168398

Sholokhova, A., Pitak, I., Denafas, G., Kalpokaitė-Dičkuvienė, R., Praspaliauskas, M., & Burlakovs, J. (2023). An In-Depth Analysis of Physical, Chemical, and Microplastic Parameters of Landfill Fine Fraction for Biocover Construction. Sustainability, 15(24), 16914. https://doi.org/10.3390/su152416914

Singh, B., Srivastava, G., Kala, D., Gill, M., Kaushal, A., & Gupta, S. (2023). Microplastics as an emerging threat to human health: Challenges and advancements in their detection. Applied Chemical Engineering, 6(2), 2103. https://doi.org/10.24294/ace.v6i2.2103

Sivalingam, S., Priya, P. G., Lakshmi, D. S., & Srimath, S. T. G. (2024). Microplastics in Asia: Overcoming sampling, analysis, and regulatory challenges to protect the ecosystem – a review. Environmental Science: Atmospheres, 4(12), 1331–1351. https://doi.org/10.1039/D4EA00100A

Torres-Agullo, A., Karanasiou, A., Moreno, T., & Lacorte, S. (2021). Overview on the occurrence of microplastics in air and implications from the use of face masks during the COVID-19 pandemic. Science of The Total Environment, 800, 149555. https://doi.org/10.1016/j.scitotenv.2021.149555

Van Passel, S., Dubois, M., Eyckmans, J., de Gheldere, S., Ang, F., Tom Jones, P., & Van Acker, K. (2013). The economics of enhanced landfill mining: Private and societal performance drivers. Journal of Cleaner Production, 55, 92–102. https://doi.org/10.1016/j.jclepro.2012.03.024

Wille, E., Isenborghs, C., Lamair, L., Neculau, C., & Derijdt, R. (2022). Cedalion and Orion: A two-step decision support tool to allow smart ELFM project planning, prioritisation and sustainable interim use (rawfill project). Detritus, (18), 85–94. https://doi.org/10.31025/2611-4135/2022.15165

Yang, L., Zhang, Y., Kang, S., Wang, Z., & Wu, C. (2021). Microplastics in freshwater sediment: A review on methods, occurrence, and sources. Science of The Total Environment, 754, 141948. https://doi.org/10.1016/j.scitotenv.2020.141948

Yang, S., Lu, X., Peng, Y., Wang, Z., Yang, X., & Wang, X. (2024). Microplastic Emission from Soil-Air Interface. Environmental Science & Technology Letters, 11(11), 1207–1213. https://doi.org/10.1021/acs.estlett.4c00189

Yang, Y., Lü, F., Zhang, H., & He, P. (2025). Evolution and associated environmental pollution risks of micro- and nanoplastics through landfill processes. Emerging Contaminants, 11(4), 100593. https://doi.org/10.1016/j.emcon.2025.100593

Zari, M., Smith, R., & Ferrari, R. (2023). Evaluation Of Dust Emission Rate From Landfill Mining Activities. Detritus, (25), 78–89. https://doi.org/10.31025/2611-4135/2023.18328

Zhang, L., Zhao, W., Yan, R., Lyu, S., & Sui, Q. (2025). Occurrence, sources, and ecological risk of microplastics in groundwater: Impacts by agricultural activities and atmospheric deposition. Water Research, 281, 123585. https://doi.org/10.1016/j.watres.2025.123585