HOW DANGEROUS MICROPLASTIC IN LANDFILL AFFECT THE ENVIRONMENTAL AND HUMAN HEALTH

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ABSTRACT

Microplastics, which have a diameter less than 5 mm and are derived from plastics, are one of the emerging contaminants of concern. Microplastics can be found in their virgin state in many items of use, or they can be generated as a result of the physical and chemical structure of bigger plastics changing over time. The aims of this study were to investigate the microplastic distribution along landfill soil, leachate, and ground water around the Cipayung Landfill in Depok City. This study is a descriptive study, with examines 3 soil sample, 3 leachate sample, and 1 ground water sample. The abundance and shape of microplastics were characterized using a microscope. The results showed that the average abundance of microplastics in landfill soil sample was 63,556.67 particles/kg, leachate sample was 12,266.67 particles/L, and ground water sample was 3,466.67 particles/L. With the largest percentage being fragments in both soil and leachate samples, and films in ground water samples. The differences in waste types entering the Depok Landfill caused variations in the number, shape, and type of microplastic samples, and this study provides a foundation for mitigating and biodegrading microplastics in the landfill to minimize environmental impact and protect public health.

Keywords: Impact, Landfill, Microplastic

Introduction

Concerning patterns in current situation is plastic production has surged more rapidly than any other material since the 1970s. Moreover, there is a troubling trend favoring the use of single-use plastic item that are designed to be discarded after a brief single use.[1] Globally, humans produced 335 million tons of plastic in 2016, a 4% increase from the previous year and 20% increase over the past five years.[2] After 10 years, it is estimated that the global plastic production in 2020 increased to 367 million tons of plastic, although it experienced a 0.3% decrease compared to the previous year due to the impact of the Covid-19 pandemic.[3] As a result, the amount of plastic waste generated is quite high.

Approximately 36% of all manufactured plastics are employed in packaging, encompassing single-use plastic items such as food and drink containers.[4] Unfortunately, roughly 85% of these items end up either in landfills or as unregulated wastes. Recycling represents a small portion of current plastic waste, with most plastics either discarded or sent to landfill. Plastic waste in the environment gradually breaks down and degrades into microplastics (MPs, defined as particles smaller than 5 mm) within the environment. Currently, the presence of plastic waste is widely detected in oceans, freshwater bodies, soil, and the atmospheric environment.

Landfill, as a universal waste disposal method worldwide, store significant amounts of plastic waste. It has been reported that landfills account for 21-42% of the world's plastic waste. The U.S. generated 40 million tons of municipal plastic waste in 2021, and at least 85% of it was sent to landfill. In 2017, China generated a total of 196.7 million tons of plastic waste, with 60% of this waste being disposed of in landfills[2]. An increase in plastic waste worldwide has also occurred in Indonesia. The composition of plastic waste in Indonesia in 2020 amounted to 67.8 million tons per year, with various types of plastics found, including Light Density Poly Ethylene (LDPE), Poly Propylene (PP), High Density Poly Ethylene (HDPE), Poly Vinyl Chloride (PVC), Polyethylene Terephthalate (PET), and Polystyrene (PS/Styrofoam). The majority composition includes PP, LDPE, and HDPE plastics[5].

Moreover, because of the intricate combination of physical, chemical, and biological factors within landfill, including landfill compaction machines, pH, temperature, and diverse microbial communities, discarded plastic material gradually undergo fragmentation and degradation, resulting in the formation of microplastics (MPs). These MPs can subsequently enter the environment through mechanisms such as leachate pathways and airborne dispersion from landfill sites. MPs act as carriers for the transportation of varous pollutants, including persistent organic compounds, heavy metals, pathogens, and genes associated with antibiotic resistance. This poses a substantial threat to both the environment and human health. Consequently, landfills have the potential to serve as significant sources of microplastics pollution[6].

Extensive research has been conducted on the presence of microplastics in the environment of Indonesia. In a study conducted at the Galuga Bogor Landfill, the average release of microplastics from the landfill into the river was found to be 80,640 ± 604.80 particles per day, with a microplastic concentration of 15.56 ± 3.33 particles/m^3[7]. Similarly, research at the Piyungan Yogyakarta landfill also identified the presence of microplastics in leachate, which has the potential to contaminate rivers and ground water around the landfill. The average abundance of microplastic in leachate at the inlet pond was 154.8 ± 21.22 particles/liter, and in the outlet pond, it was 135.60 ± 12.18 particles/liter[8].

Related research describes microplastics in Depok City, especially in samples of soil, leachate, and ground water around the Cipayung Landfill which are still limited, although Depok City is one of the 10 cities that contributes a large amount of plastic waste in Indonesia, reaching 21,36% of the total waste generated in Depok City. However, microplastics have been found in Lake Kenanga (1,766.6 ± 40.11 particles/L) and Lake Agathis (1,885.53 ± 106.27 particles/L) near

Universitas Indonesia, Depok[9]. Previous research examining the microplastic content in tap water in several cities in Indonesia, including Depok, also found microplastic contamination. Among the samples studied, contamination levels reached 10.8 particles per liter of water, with an average of 3.23 particles per liter. Initial studies were carried out to investigate the presence and prevalence of microplastic in samples of landfill leachate, waste/soil, and ground water.The aims of this study were to investigate the microplastic distribution along landfill soil, leachate, and ground water around the Cipayung Landfill.

Methods

This research represents a quantitative descriptive study with the primary objective of quantifying both the quantity and morphology of microplastic particles derived from samples obtained at the Cipayung Landfill site. Situated in Depok City, West Java Province, Cipayung Landfill serves as the final destination for household waste originating from a densely populated region comprising over 2 million residents. Despite its daily operational status, it is important to note that the landfill lacks interim covers and liners; however, it adheres to specific waste disposal procedures.

The sampling process involved collecting data from various sources, including:

1. Landfill Soil: Samples were taken from three distinct locations within the landfill, each at a depth of 10-20 cm.
2. Leachate: Sampling was conducted at three key points - at the inlet, in proximity to the waste generation area, and at the outlet from Cipayung Landfill.
3. Ground water: single ground water sample was collected from a location situated approximately 100 meters away from the landfill site.

This comprehensive sampling approach allowed for a thorough examination of microplastic presence and characteristics within the landfill's environment. The study aimed to shed light on the extent of microplastic contamination in landfill soil, leachate, and ground water, providing valuable insights into the potential environmental and health impact of waste disposal practices in this region.Table 1 shows the locations and coordinate point of the landfill sample collection.

Table 1. Sample Collection Points

Sample	Coordinate Point Latitude ; Longitude	Location Information
S1	-6,4201201 ; 106,78844	Landfill Hangar
S2	-6,4218376 ; 106,78943	Management Office
S3	-6,4236034 ; 106,78839	Old waste mound
L1	-6,4205343 ; 106,78893	Inlet, near landfill scale
L2	-6,420869 ; 106,78863	Landfill area
L3	-6,4206828 ; 106,78889	Outlet
GW1	-6,4221301 ; 106,78913	Ground water, near parking area

In this study, a variety of equipment and substances were employed to facilitate the examination of microplastics. These included:

1. Oven: used for sample drying or other heat-related procedures
2. Precision Balance: utilized for accurate measurement of sample weights
3. Beakers: available in 50 ml, 100 ml, and 500 ml capacities for sample handling and mixing
4. Glass Stirring Rod: employed for stirring and homogenizing solutions
5. Glass Bottle: available in 250 ml, 1000 mlcapacities for sample storage and preservation
6. Dropping Pipette: used for precise and controlled liquid transfers
7. Mortar and Pestle: applied for sample preparation and grinding
8. Sodium Chloride (NaCl): a chemical substance used for specific procedures within the study

The examination of microplastics, including both their quantity and morphology, was conducted at Marine Biology Laboratory of FMIPA UI (Faculty of Mathematics and Natural Sciences, University of Indonesia) using a microscope. This specialized laboratory provided the necessary equipment and expertise for the detailed analysis of microplastic particles, ensuring the accuracy and reliability of study's findings.

Sampling and Analysis Procedure

The procedure for sampling and analyzing the samples in this study adhered to established methodologies, which were guided by earlier research. The process involved several key steps[10]:

1. Sampling Collection

   In this study, soil samples were collected from specific locations using established protocols for sample collection. These protocols involve extracting soil adhered to plastic waste at a depth of 0-20 cm beneath the soil surface. Subsequently, 500 g of soil from each location was carefully placed in a 500 ml glass container. These samples were then preserved within an icebox containing dry ice, maintaining a temperature of 4°C, until transportation to the laboratory. Concurrently, environmental variables, such as temperature, soil moisture, and soil pH were directly measure at the site.

   For leachate and ground water sample, approximately 1000 ml of the leachate and ground water sample was stored in a 1000 ml glass bottle at 4°C to ensure preservation during immediate transportation (within 48 hour). The leachate samples were fully mixed immediately after their arrival at the laboratory. Environmental variable, including leachate/ground water pH, temperature, and Total Dissolved Solid (TDS) were directly measure at the site.

2. Sampling Preparation

The soil samples were subjected to drying at a temperature of 60°C for a duration of 72 hours, to remove moisture from the samples. This step followed by grinding the soil sample to separate larger particles and ensure uniformity in the sample. While for leachate and ground water sample, homogenization of sample water was carried out so that there was no sediment.

Afterward, a process of density separation was carried out to eliminate different organic minerals during the microplastic extraction phase from the soil, leachate, and ground water samples. This was accomplished by introducing saturated NaCl, and wait for 24 hours

3. Quantification or Data Analysis

   The soil, leachate, and ground water sample were analyzed descriptively. After the completion of the sampling preparation steps, the subsequent phase involved the quantification of microplastics. Following the 24 hour density separation, the number and morphology of microplastics within the soil, leachate, and ground water samples were meticulously determined. This examination was conducted using a microscope at a magnification of 10 x 10 [11]. The microscopic analysis allowed for a detailed assessment of microplastic particles within the samples, providing crucial data for the study.

This comprehensive procedure ensured the systematic collection, preparation, and analysis of samples, allowing for the accurate assessment of microplastic content in the studied environmental matrices

Results

Characteristics of Samples

In this study, the samples were categorized into three distinct types: landfill soil, leachate, and ground water. Based on the result, environmental variable measurements, including pH, temperature, TDS (total Dissolved Solid), and air humidity, it can be concluded that the average valueof these variables do not exhibit significant differences among the various samples, whether they are soil, leachate, or ground water samples.

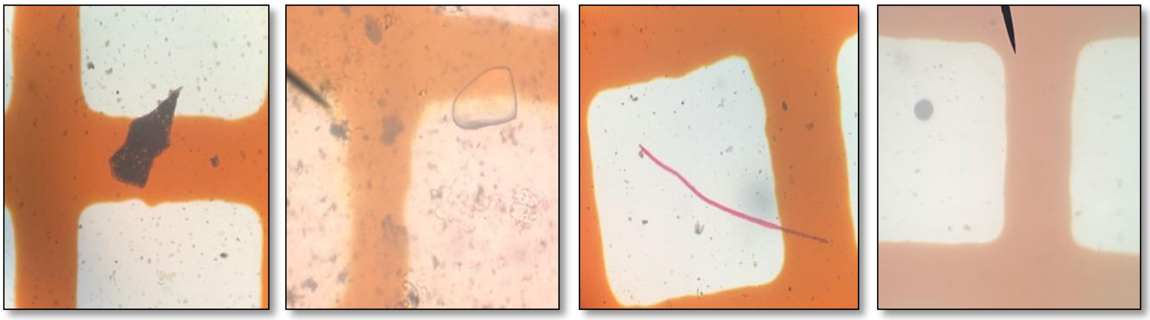
Table 1. Environmental Variable of The Cipayung Landfill Soil (S), Leachate (L), And Ground water (GW) Sample

Properties	Sample Code						
	S1	**S2**	**S3**	**L1**	**L2**	**L3**	**GW1**
pH	7	7	7	7	10	10	9
Temp (°C)	33	32	33	32.2	33.9	31.6	34.4
TDS (ppm)	-	-	-	143x10	135x10	244x10	249
Humidity	Dry	Wet+	Dry+	-	-	-	-

Microplastic Shape Analysis Results

Based on the analysis of microplastics discovered in the landfill soil, leachate and ground water samples obtained from the Cipayung Landfill in Depok City, the microplastics were categorized into four shapes: fibers, fragments, films, and pellets, is shown in Figure 1. Each of these shapes is indicative of different types of plastic particles:

1. Fibers: Fibers are characterized by their thin and thread-like appearance. They were observed in varying quantities in all sample types.
2. Fragment: Fragment are rectangular pieces of plastic with irregular shapes. They were dominant shape morphology in both soil and leachate samples.
3. Films: Microplastic films resemble thin plastic sheets. They were notably prevalent in ground water samples
4. Pellets: Pellets are round in shape and were identified in all sample types, though in lower percentages.



(a) (b) (c) (d)

Figure 1. Microplastics Shape from Depok City's Landfill: a) Fragment, b) Film, c) Fiber, d) Pellet

The study further revealed the distribution of microplastic shapes within each sample type. In soil samples, fragments were the most prominent shape morphology, constituting 64.33% of the total microplastics observed. Films accounted for 18.18%, fibers for 14.68%, and pellets for 2.79% of the microplastics. Leachate samples also exhibited fragment as the dominant shape morphology, making up 44.57% of the microplastics. Films comprised 28.26%, fibers 21.02%, and pellets 6.16% of the total. Ground water samples has a different distribution, with films as the most prevalent shape morphology, accounting for 38.46% of the microplastics. Fragments constituted 23.07%, fibers 34.61%, and pellets 3.84%.

These identified shape are common for microplastics and are often the result of plastic waste breaking down over time due to various environmental factors. The factors such as weathering, ultraviolet (UV) radiation exposure, and microbial activity can contribute to the fragmentation and transformation of plastics into these shapes[12,13].

It's important to note that while this study categorized microplastics into four primary shapes, microplastics can exhibit a wide range of shapes and sizes not specifically identified in this research. The variability in microplastic shapes underscores the complexity of microplastic pollution and highlights the importance of continued research and monitoring efforts to fully understand its environmental implications. In summary, the study revealed the prevalent shapes of microplastics in landfill soil, leachate, and ground water samples, with fragments being the most common shape in soil and leachate, and films dominating in ground water. These findings contribute to our understanding of microplastic pollution and its potential impacts on the environment.

The Abundance of Microplastics

The soil samples were collected from different age groups of waste piles within the study area. Samples 1 and 2 were sourced from waste piles that were less than 5 years old, whereas Sample 3 was extracted from piles exceeding 5 years in age. As depicted in Figure 2, the analysis of these samples revealed variations in the abundance of microplastics.

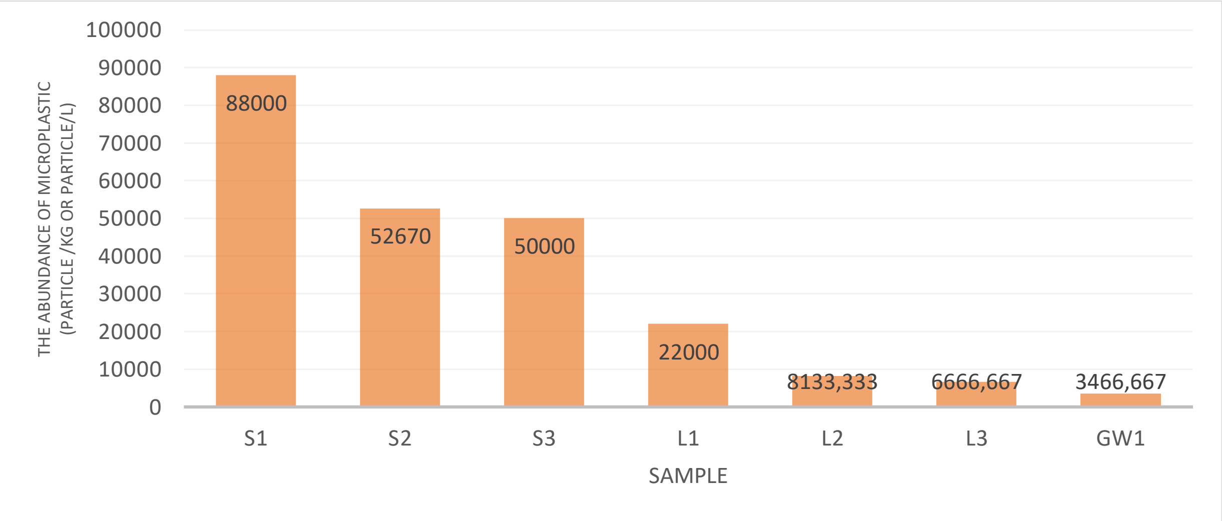


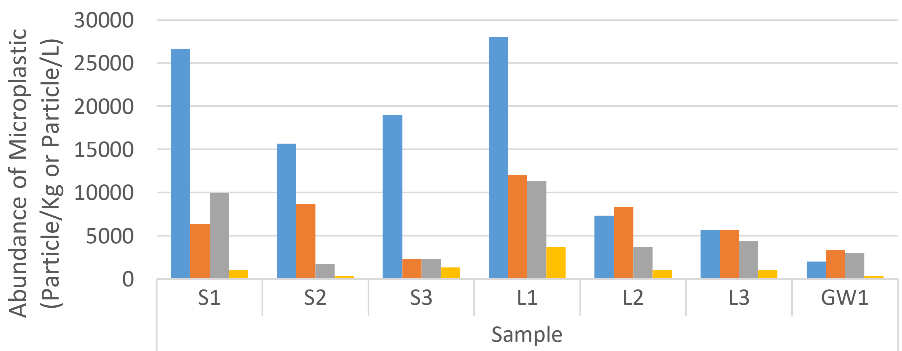
Figure 2. The Average Abundance of Microplastic by Soil, Leachate, and Ground Water Sample

Among the soil samples, Sample 1 exhibited the highest average microplastic abundance, with a measurement of 88,000 particles per kilogram (particles/kg). Conversely, Sample 3 displayed the lowest average microplastic abundance, totaling 50,000 particles/kg. When considering all the soil samples collected from the Depok City Landfill, the overall average abundance of microplastics was approximately 63,556.67 particles/kg.

Turning to the leachate samples, distinct abundance levels were observed among the various samples. Once again, Sample 1 had the highest average microplastic abundance in leachate, with a count of 22,000 particles per liter (particles/L), while Sample 3 exhibited the lowest average abundance, amounting to 6,666.67 particles/L. Overall, the leachate samples from the Depok City Landfill had an average microplastic abundance of approximately 12,266.67 particles/L.In contrast, ground water samples yielded an average microplastic abundance of approximately 3,466.67 particles/L.

The distribution of different microplastic types is illustrated in the bar chart in Figure 3. For each sample, fragments were identified as the most common microplastic type in both soil and leachate samples, with the highest abundance recorded in soil (26,666.67 particles/kg) and leachate (28,000 particles/L) samples. In ground water samples, fragments were also present but at a lower abundance (2,000 particles/L).

Microplastic films, on the other hand, were predominantly found in ground water samples, with the highest abundance in this sample type (3,333 particles/L). In soil and leachate samples, films were present but displayed varying abundances, reaching 8,666.67 particles/kg in soil and 12,000 particles/L in leachate.Additional microplastic types, such as fibers and granules, were also detected in the samples, each with its own level of abundance across soil, leachate, and ground water samples.



	S1	S2	S3	L1	L2	L3	GW1
Fragmen	26666,67	15666,67	19000	28000	7333,33	5666,66	2000
Film	6333,33	8666,67	2333,33	12000	8333,33	5666,67	3333,33
Fiber	10000	1666,67	2333,33	11333,33	3666,67	4333,33	3000
Pellet	1000	333,33	1333,33	3666,67	1000	1000	333,33

Figure 3. The Average Abundance of Microplastic by Type

In summary, this comprehensive analysis reveals significant variations in the abundance and types of microplastics across different sample categories, providing valuable insights into the microplastic composition within the Depok City Landfill environment.

Discussion

The increasing accumulation of plastic waste in the environmental has raised concerns, impacting both countries engaged in the import of plastic waste and those with high levels of plastic consumption. When plastic waste is not properly recycled and instead ends up being either illegally discarded or placed in landfills, it poses a significant risk to the environment. This risk encompasses pollution in various forms, ranging from macroplastics to microplastics and even nanoplastics. Notably, a substantial portion of plastic waste (approximately 75%) that enters landfills has the potential to contaminate the environment through the introduction of microplastics [6,14]. The sources of these microplastics in landfill are diverse and include household waste, industrial processes, and transportation activities. Furthermore, certain everyday consumer product, such as synthetic clothing and personal care items, can also contribute to the generation of microplastics when used and improperly disposed of [11]. This multifaced issue underscores the urgent need for effective plastic waste management and recycling practice to mitigate adverse impacts on ecosystems.

The lack of significant differences in environmental variables like pH, temperature, TDS, and humidity among different samples, such as soil, leachate, and ground water, can be attributed to several factor. Homogeneity of environmental conditions, it's possible that the study area or landfill site where the sample were collected had relatively uniform environmental conditions. When the environmental conditions are similar across the sampling locations, it can result in minimal variation in measured parameters like pH, temperature, TDS, and humidity[15,16].

The analysis of the results revealed important insights into the distribution and types of microplastic fragment within the landfill environment. Notably, it becomes evident that the highest concentration of microplastic fragments was predominantly present in soil and leachate samples originating from the landfill site. This prevalence can be attributed to the disposal of various plastic products, including bottles, food and beverage containers, broken water jugs, pipe fragments, and ruptured plastic bags, all of which undergo fragmentation over time[17].Furthermore, this study highlights the prevalence of film-type microplastics in ground water samples as well as in soil and leachate samples. This phenomenon is primarily linked to the degradation of plastic food packaging and shopping bags over time. The degradation process is gradual and is facilitated by various factors, such as exposure to sunlight-induced heat, physical forces such as friction and waste movement during stacking and compaction, and chemical, and biological processes [18,19].

The presence of fiber-type microplastics in the samples is attributed to synthetic fabrics and textiles, shedding tiny fibers that find their way into the landfill environment. Additionally, pellet or granule-type microplastics, often originating from factories that utilize plastic in beauty and cleaning products, known as microbeads, are also detected [18]. The dominance of specific microplastic types in the landfill site's samples may be influenced by the unique composition of plastic waste deposited and the decomposition processes occurring within the landfill environment [20]. These variations underscore the complexity of microplastic distribution and composition in landfill settings, influenced by both external factors and internal processes.Interestingly, these findings align with previous research conducted at the Laogang landfill, which also identified fragments as the dominant type of microplastics [21]. This consistency in results across different landfill sites highlights the potential for certain types of microplastics, such as fragments, to be prevalent in landfill environments, although specific contributing factors may vary from site to site.The results of this study shed light on the types and distribution of microplastics in landfill settings, underscoring the complex interplay of factors contributing to their presence. These findings have significant implications for understanding microplastic pollution in landfills and may inform strategies for waste management and environmental conservation.

The prevalence of microplastics within landfills can be attributed to a complex interplay of several key factors, including the sheer volume of plastic waste, the management practices employed for waste and leachate within the landfill, the age of the landfill itself, and various environmental factors such as temperature and humidity [6,13,22,23].The Depok City landfill, which has been operational since 1992, is a prime example of a landfill with a significant microplastic presence. This landfill receives an astonishing amount of waste, exceeding 850 tons per day, with the largest portion comprising organic waste (62.95%). However, plastic waste also represents a substantial component, constituting 21.36% of the total waste composition, making it the second-largest contributor to the landfill. This substantial input of plastic waste significantly contributes to the overall abundance of microplastics within the landfill [24].

Moreover, the management practices employed in waste and leachate management within the landfill are suboptimal, particularly concerning plastic waste recycling. This inadequacy in recycling processes results in the accumulation of plastic waste within the landfill, ultimately increasing the likelihood of degradation and the subsequent release of microplastics [6,13,22,25].The prevalence of microplastics in the Depok City landfill is reminiscent of the conditions observed in South China's landfills, where microplastic abundance ranges from 590 to 10,308 particles per kilogram [20]. This similarity underscores the global nature of the issue, with microplastics being a common concern in landfills worldwide.

Furthermore, previous studies have established that the abundance and characteristics of microplastics in landfills are closely linked to the age of the waste generation within the landfill site. Newer waste deposits tend to exhibit higher microplastic abundances, while older waste deposits often have elevated levels of secondary microplastics resulting from environmental degradation processes [6]. This pattern is consistent with the findings of the current study, where soil samples from newer waste deposits (e.g., samples 1 and 2) demonstrated higher microplastic abundance values compared to soil samples from older waste deposits (e.g., sample 3).

Additionally, the abundance of microplastics in leachate samples followed a similar trend, with sample 1, originating from a newer waste deposit, exhibiting higher microplastic abundance compared to samples 2 and 3, which had undergone treatment processes.

Microplastics can be released into ground water around landfills primarily due to the leaching of these tiny plastic particles from the disposed waste. When rainwater infiltrates landfill sites, it percolates through layers of waste, picking up suspended microplastics in the process. This contaminated liquid, known as leachate, can carry microplastics with it as it moves through the landfill, eventually seeping into the surrounding soil and, subsequently, into the underlying ground water. Additionally, the physical degradation of plastic waste within landfills over time contributes to the generation of microplastics, further enhancing their presence in leachate and their potential to infiltrate ground water. This phenomenon underscores the need for improved waste management practices and monitoring to mitigate the environmental and health risks associated with microplastic contamination in ground water near landfill sites [26–28]. The presence and abundance of microplastics within landfills are influenced by a multitude of factors, including the volume and composition of plastic waste, waste management practices, landfill age, and environmental conditions. Understanding these factors is crucial for developing effective strategies to mitigate microplastic pollution within landfill environments and for addressing this global environmental challenge.

Microplastics, minute plastic particles measuring less than 5mm, exert substantial and interrelated impacts on both the environment and human health. In the environment, microplastics disrupt ecosystems, threatening wildlife through ingestion and entanglement and altering habitats. They act as vectors for toxic chemicals, potentially entering the food chain and endangering human health through seafood consumption. Meanwhile, human exposure to microplastics, through ingestion and inhalation, raises concerns about gastrointestinal and respiratory effects[29]. The long-term health consequences of chronic microplastic exposure remain a subject of ongoing study, while the particles' capacity to absorb and release harmful chemicals adds an additional layer of complexity to their potential health impacts. Consequently, addressing the microplastic crisis requires comprehensive efforts to mitigate environmental pollution at its source and to better understand and manage the associated risks to human health[30–32].

Conclusion

The study has provided valuable insights into the characteristics, distribution, and abundance of microplastics in a landfill environment. Environmental variables such as pH, temperature, TDS, and humidity showed no significant differences among soil, leachate, and groundwater samples, suggesting relatively uniform conditions within the study area. Microplastics were categorized into four primary shapes: fibers, fragments, films, and pellets, with fragments being the most common shape in soil and leachate samples, while films dominated in groundwater.

The abundance of microplastics varied among soil samples, with newer waste piles exhibiting higher concentrations. Leachate samples also showed distinct abundance levels, with the highest in Sample 1. Groundwater samples had lower microplastic abundances overall. The distribution of microplastic types revealed that fragments were prevalent in both soil and leachate samples, while films were dominant in groundwater. The study highlighted the role of factors such as plastic waste volume, waste management practices, landfill age, and environmental conditions in influencing microplastic presence in landfills. It emphasized the urgent need for improved waste management, recycling practices, and monitoring to address the growing concerns related to microplastic pollution in landfill environments.

Furthermore, the broader implications of microplastics on the environment and human health were discussed, underscoring their potential ecological and health risks. Microplastics disrupt ecosystems, threaten wildlife, and act as carriers of toxic chemicals, potentially affecting both the environment and human health. Addressing the microplastic issue requires concerted efforts to reduce plastic pollution, enhance waste management, and conduct ongoing research to better understand and mitigate its impacts. Overall, this study contributes to our understanding of microplastic pollution in landfill environments, shedding light on its complexities and implications for both the environment and human well-being.

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Conflict of Interest

The authors declare no conflict of interest.

Reference

1. United Nations Environment Programme. Beat Plastic Pollution. *UNEP* https://www.unep.org/interactives/beat-plastic-pollution/?gclid=Cj0KCQjw1aOpBhCOARIsACXYv-f7ZYgBYFJwdwpR0KZX03F4MCrd6dQIZChpt3AMyRIEMha013VrEb8aAvJ0EALw_wc

B (2022).

2. Lin, X. *et al.* A landfill serves as a critical source of microplastic pollution and harbors diverse plastic biodegradation microbial species and enzymes: Study in large-scale landfills, China. *J. Hazard. Mater.***457**, 131676 (2023).
3. Tiseo, I. Global Plastic Production 1950-2020. *Statista* (2022).
4. UNEP. *Plastics: A Roadmap for Sustainability*. *Single-use Plastic: A Roadmap for Sustainability* (2018).
5. Ministry of Environment and Forestry Republic of Indonesia. *National Plastic Waste Reduction Strategic Actions for Indonesia*. *Ministry of Environment and Forestry, Republic of Indonesia* https://wedocs.unep.org/bitstream/handle/20.500.11822/32898/NPWRSI.pdf (2020).
6. Upadhyay, K. & Bajpai, S. Microplastics in Landfills : A Comprehensive Review on Occurrence , Characteristics and Pathways to the Aquatic Environment. (2021).
7. Nurhasanah, Cordova, M. R. & Riani, E. Micro- and mesoplastics release from the Indonesian municipal solid waste landfill leachate to the aquatic environment: Case study in Galuga Landfill Area, Indonesia. *Mar. Pollut. Bull.***163**, 111986 (2021).
8. Utami, I. & Agustina, R. Deteksi Pencemaran Mikroplastik pada Air Lindi di TPA Piyungan Yogyakarta Indonesia. *E-Journal.Unipma.Ac.Id***9(1)**, 24–32 (2022).
9. Hasibuan, A. J., Patria, M. P. & Nurdin, E. Analisis kelimpahan mikroplastik pada air, insang dan saluran pencernaan ikan Mujair Oreochromis mossambicus.(Peters, 1852) di Danau Kenanga dan Danau Agathis, Universitas Indonesia, Depok, Jawa Barat. *Pros. Semin. Nas. Apl. Sains Teknol. 2021* 1–10 (2021).
10. Al Hamra, A. J. & Patria, M. P. Microplastic in Gonggong snails (Laevistrombus turturella) and sediment of Bintan Island, Kepulauan Riau Province, Indonesia. *AIP Conf. Proceedings, Int. Conf.***2202**, 020079, 1–6 (2019).
11. Afrin, S., Uddin, M. K. & Rahman, M. M. Microplastics contamination in the soil from Urban Landfill site, Dhaka, Bangladesh. *Heliyon***6**, (2020).
12. Bajt, O. From plastics to microplastics and organisms. *FEBS Open Bio***11**, 954–966 (2021).
13. Wang, C. *et al.* Microplastic Pollution in the Soil Environment: Characteristics, Influencing Factors, and Risks. *Sustain.***14**, 1–14 (2022).
14. Monkul, M. M. & Özhan, H. O. Microplastic contamination in soils: A review from geotechnical engineering view. *Polymers (Basel).***13**, (2021).
15. Sallam, G. A. H. & Elsayed, E. A. Estimating relations between temperature, relative humidity as independed variables and selected water quality parameters in Lake Manzala, Egypt. *Ain Shams Eng. J.***9**, 1–14 (2018).
16. Saalidong, B. M., Aram, S. A., Otu, S. & Lartey, P. O. Examining the dynamics of the

relationship between water pH and other water quality parameters in ground and surface water systems. *PLoS One* **17**, 1–17 (2022).

17. Sari Dewi, I., Aditya Budiarsa, A. & Ramadhan Ritonga, I. Distribusi mikroplastik pada sedimen di Muara Badak, Kabupaten Kutai Kartanegara. *Depik* **4**, 121–131 (2015).
18. Octarianita, E., Widiastuti, E. L. & Tugiyono, T. Analisis Mikroplastik Pada Air Dan Sedimen Di Pantai Teluk Lampung Dengan Metode FT-IR (Fourier Transform Infrared). *J. Sumberd. Akuatik Indopasifik* **6**, 165–172 (2022).
19. Mallakpour, S. & Nouruzi, N. Polycaprolactone/metal oxide nanocomposites: an overview of recent progress and applications. in *Biodegradable and Biocompatible Polymer Composites: Processing, Properties and Applications* 223–263 (Elsevier Ltd, 2017). doi:10.1016/B978-0-08-100970-3.00008-0.
20. Wan, Y. *et al.* Informal landfill contributes to the pollution of microplastics in the surrounding environment. *Environ. Pollut.* **293**, 1–6 (2022).
21. Su, Y. *et al.* Occurrence of microplastics in landfill systems and their fate with landfill age. *Water Res.* **164**, (2019).
22. Zhou, C., Fang, W., Xu, W., Cao, A. & Wang, R. Characteristics and the recovery potential of plastic wastes obtained from landfill mining. *J. Clean. Prod.* **80**, 80–86 (2014).
23. Yang, L., Zhang, Y., Kang, S., Wang, Z. & Wu, C. Microplastics in soil: A review on methods, occurrence, sources, and potential risk. *Sci. Total Environ.* **780**, 146546 (2021).
24. Ardiyani, Q. T. Sistem Pengelolaan Sampah di TPA Cipayung Kota Depok. (Sekolah Vokasi Institut Pertanian Bogor, 2022).
25. Guo, J. J. *et al.* Source, migration and toxicology of microplastics in soil. *Environ. Int.* **137**, 105263 (2020).
26. Wang, W., Yuan, W., Chen, Y. & Wang, J. Microplastics in surface waters of Dongting Lake and Hong Lake, China. *Sci. Total Environ.* **633**, 539–545 (2018).
27. Kabir, M. S., Wang, H., Luster-Teasley, S., Zhang, L. & Zhao, R. Microplastics in landfill leachate: Sources, detection, occurrence, and removal. *Environ. Sci. Ecotechnology* **16**, 100256 (2023).
28. Zhou, Y. *et al.* Microplastics in soils: A review of methods, occurrence, fate, transport, ecological and environmental risks. *Sci. Total Environ.* **748**, 141368 (2020).
29. Li, Y. *et al.* Potential Health Impact of Microplastics : A Review of Environmental Distribution , Human Exposure , and Toxic Effects. (2023) doi:10.1021/envhealth.3c00052.
30. Ageel, H. K., Harrad, S. & Abdallah, M. A. E. Occurrence, human exposure, and risk of microplastics in the indoor environment. *Environ. Sci. Process. Impacts* **24**, 17–31 (2022).
31. Khalid, N. *et al.* Linking effects of microplastics to ecological impacts in marine environments. *Chemosphere* **264**, 128541 (2021).

32. Ya, H. *et al.* Recent advances on ecological effects of microplastics on soil environment. *Sci. Total Environ.***798**, 149338 (2021).