Jurnal Sains dan Teknologi Lingkungan
p-ISSN:2085-1227 dan e-ISSN:2502-6119
Volume 18, Number 2, June 2026 Hal. 235-246

MICROPLASTICS AND HEAVY METALS CONTAMINATIONS IN AGRICULTURAL SOILS NEAR THE LANDFILL: A CASE STUDY IN YOGYAKARTA, INDONESIA

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Abstract

The Piyungan landfill in Yogyakarta, Indonesia, is a potential source of environmental pollution, releasing contaminants such as microplastics and heavy metals that can accumulate in the nearby soils. Agricultural soil surrounding the landfill has been found to contain both types of pollutants. The coexistence of microplastics and heavy metals may influence their environmental mobility and toxicity, potentially posing risks to ecosystems and human health. This study investigates the co-occurrence of microplastics and heavy metals (Pb and Cd) in agricultural soils near the Piyungan landfill. Soil samples were collected from four different points around the site. Microplastic extraction involved wet peroxide oxidation (WPO) using 30% H_2O_2, followed by density separation with saturated NaCl. The isolated microplastics were analyzed under a microscope, and polymer types were identified using Fourier Transform Infrared Spectroscopy (FTIR). Concentrations of Pb and Cd, both within the soil matrix and associated with microplastics, were measured using Atomic Absorption Spectrophotometry (AAS). The abundance of microplastics in the soil ranged from 3450 to 5110 particles/kg, consisting of fragments, films, foams, fibers, and pellets in various colors. Detected polymers included polypropylene (PP) and polyethylene (PE). Lead concentrations ranged from 5.1 to 8.4 mg/kg, while cadmium concentrations ranged from 0.6 to 1.4 mg/kg. These levels were significantly higher than those found in the reference soil, indicating the contamination of both microplastics and heavy metals in the agricultural soils near the landfill. Both heavy metals were also detected in microplastics. The observed co-contamination underscores the potential for complex interactions between microplastics and heavy metals in the soil near landfill, which may enhance their transport and combined toxicity.

Keywords: agricultural soil, heavy metals, landfill, microplastics, pollution.

1. INTRODUCTION

Plastics are ubiquitous, as they are used in nearly all aspects of our lives including packaging, clothing, household items, automotive, electronics, constructions, cosmetics, and other (Oehlmann et al., 2009; Pan et al., 2020). Plastic manufacturing has increased dramatically from almost no production in the 1950s to more than 460 million tons annually in 2019 (Jambeck et al., 2015; Geyer et al. 2017). Despite the massive production of plastics, plastic recycling and waste management are still limited in many countries, especially in the developing countries (OECD, 2022; Fei et al., 2023). In the developing countries, such as Indonesia, plastic garbage is frequently mismanaged and primarily ends up in landfills or is subjected to open burning and open dumping, which are economical and easy methods (Jambeck et al., 2015). In 2018, the amount of plastic waste ended up in landfills counted 42% of the global plastic waste (Hahladakis et al., 2018).

In landfills, plastic waste undergoes various degradation processes that will break down plastic into smaller fragments known as microplastics (plastic particles between 1μm to 5 mm) or

P-ISSN: 2085-1227 I E-ISSN: 2502-6119

nanoplastics (particles smaller than 1 μm), which are persistent and mobile in the environment (Kershaw, 2015; Zaini et al., 2024). In addition to plastics, landfills are also known as a source of various pollutants including toxic heavy metals lead (Pb) and cadmium (Cd), which originate from batteries, electronic wastes, and industrial waste (Trabelsi et al., 2009). As a result, both microplastics and heavy metals may co-exist and interact in landfill environments, influencing their environmental transport and behavior (Lestari, et al., 2025).

Several recent studies have found that microplastics in soils can adsorb heavy metals, potentially increasing their detrimental effect on plants and animals (Groh et al., 2019; An et al., 2023). Although plastics are hydrophobic, they are capable of adsorbing heavy metals due to their enhanced surface adsorption capacity and the formation of biofilms during their weathering and environmental exposure (Wagner et al., 2014). The accumulation of heavy metals on microplastics enhances the likelihood of their bioavailability and bioaccumulation. The accumulation of these metals in organisms has been reported in both aquatic and terrestrial environments. Thus, microplastics may serve as vectors for the transfer of heavy metals to the organisms from the contaminated environment (Khalid et al., 2021).

Most landfills in Indonesia are characterized as uncontrolled landfills where appropriate bottom liners and leachate collection and treatment system are lacking. In such condition, various contaminants in the landfill will easily escape into the surrounding soil and groundwater. The transport of these pollutants into the nearby agricultural soils is of environmental concerns. The transport of microplastics and heavy metals into the surrounding environment can occur through wind dispersion, surface runoff, or percolation of the landfill leachate.

Despite the environmental risks posed by both microplastics and heavy metals, studies on their co-occurrence in agricultural soils near landfill remain limited. Existing literature often treats them separately, without investigating their potential interactions or combined distribution patterns. Moreover, site-specific data from high-load landfills in tropical developing countries like Indonesia are still scarce. This study aims to identify and quantify the co-occurrence of microplastics and heavy metals Pb and Cd in agricultural soils near the Piyungan landfill, thus, providing empirical data on both pollutants interactions and distribution in landfill-affected soils.

Introduction contains background of research, similar research that has been available in order to explain the position of current research (novelty) and research objectives to be achieved.

2. MATERIALS AND METHODS

2.1. STUDY AREA AND SAMPLING LOCATIONS

Soil samples were collected from agricultural fields located near the Piyungan landfill in Yogyakarta, Indonesia. The Piyungan landfill serves as the main waste disposal facility the province. The Piyungan landfill implements an open and semi-controlled landfill system, which has the potential to pollute the surrounding environment through leachate percolation. The Piyungan landfill has a leachate treatment facility, where the treated effluent is discharged into the Opak river. The Opak river is the primary source of irrigation water for the surrounding agricultural areas. Soil samples were collected from agricultural areas that are potentially affected by the landfill through the irrigation water flow. Four sampling points (S1 – S4, Figure 1) were selected along the irrigation path flowing from the Piyungan landfill to capture the spatial variation of pollutant distribution. In addition, one reference soil was taken from the agricultural soil, which was assumed to be unaffected by the irrigation flow of the landfill.

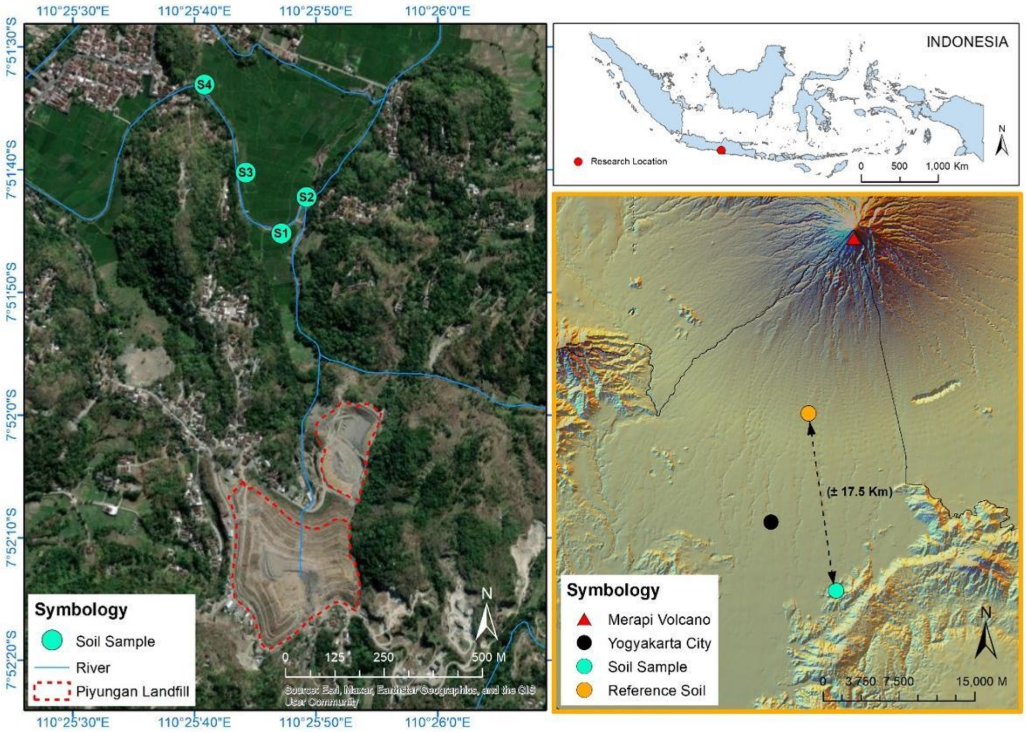

Figure 1. The map of study area and soil sampling locations.

Sampling was conducted on May 13th, 2024, during the dry season using purposive sampling technique. At each sampling point, composite topsoil samples were collected from a depth of 0–20 cm using clean, non-plastic tools using a soil auger. Each sample was immediately sealed in aluminum foil bags to prevent contamination and stored at 4°C prior to laboratory analysis.

2.2. MICROPLASTICS ANALYSIS

Prior to microplastics and heavy metals analysis, the soil samples were dried at 40°C for 24 hours to remove moisture while avoiding the degradation of microplastics in the samples. After drying, the soil samples were sieved using a 2 mm-mesh sieve to remove large debris and non-soil particles. Microplastics were extracted using density separation with a saturated sodium chloride (NaCl) solution (density 1.20 g/mL, Sigma Aldrich, Germany). The floating fraction, potentially containing microplastics, was subjected to wet peroxide oxidation using 30% hydrogen peroxide (Sigma Aldrich, Germany) to digest organic matter. The mixture was vacuum-filtered using a Whatman GF/B filter (47 mm diameter, 0.45 μm pore diameter). Microplastics captured on the filter paper were visually observed using a microscope (Olympus BX53 Trinocular) to identify their types based on morphology, including fibers, fragments, films, foams, and pellets. The abundance of microplastics was calculated by counting the number of particles using a calibrated grid. A subset of particles that could be physically retrieved from the filters was further analyzed for polymer identification using Attenuated Total Reflectance–Fourier Transform Infrared Spectroscopy (ATR-FTIR, Shimadzu IRTracer-100). To minimize the risk of plastic contamination throughout preparation and analysis, all equipment used was non-plastic and pre-cleaned with pre-filtered distilled water, dried, and wrapped in aluminum foil prior to use. All chemical reagents were also filtered through Whatman GF/C filters before usage.

2.3. HEAVY METALS ANALYSIS

Analysis of lead (Pb) and cadmium (Cd) in soil samples was conducted according to the procedure outlined in the Indonesian National Standard (SNI) 8910:2021. Soil samples were dried in at a temperature of 105°C for 2 hours to remove moisture, then ground and sieved using a 40-mesh sieve to obtain homogeneous soil particles. One gram of sample was mixed with 10 mL of HNO_3 (1:1 v/v of HNO_3:H_2O, Sigma Aldrich, Germany) and heated at 95°C for 10 min. After cooling, concentrated HNO_3 was added dropwise until the solution was clear. To ensure a complete extraction, the solution was gradually added with H_2O_2 to oxidize the remaining organic matter as well as 10 mL of $HClO_4$ (Sigma Aldrich, Germany) and reheated for 15 min. The final extract was filtered using a Whatman filter paper, then analyzed for Pb and Cd using an atomic absorption spectrophotometer (GBC Avanta, Australia).

3. RESULTS AND DISCUSION

3.1. ABUNDANCE AND CHARACTERISTICS OF MICROPLASTICS

Soil samples were taken from an agricultural area near the Piyungan landfill which were irrigated and planted with paddy. The texture of soil samples is clayey with dark brown color, indicating a high content of organic matter. The reference soil is agricultural soil with similar color only lower moisture content. Microplastics abundance in each soil sample is shown in Figure 2. The abundance of microplastics ranged from 3450 to 5110 particles/kg. All soil samples from the irrigation-affected area (S1 to S4) show significantly higher microplastic abundance than the reference soil. This indicates that the irrigation channel is likely contribute for microplastic pollution in the soil. The microplastic particles in irrigation water may originate from the landfill leachate or surface runoff. Microplastics abundance increased with the distance from the Piyungan landfill. Microplastics may accumulate downstream due to reduced water velocity and sediment trapping. In addition, other sources of microplastic pollution may contribute more significantly in the farther area from the landfill. The microplastic abundance in reference soil (1980 particles/kg) may reflect the regional contamination from atmospheric deposition, agricultural practices, or irrigation from other water sources.Contains a discussion of research results along with tables, figures, equations and other supporting data. The results are brief and clear. Show clear differences between the results of research with previous studies.

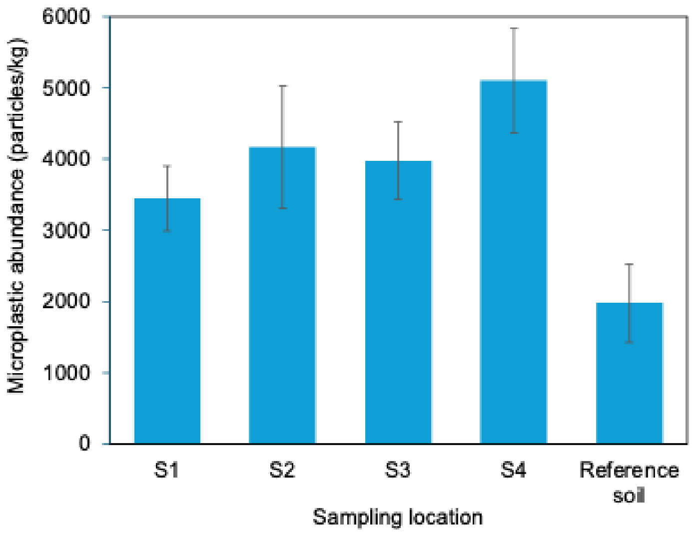

Figure 2. Microplastics abundance in each sampling location.

The shape of microplastics is an important factor that influence their environmental ability to adsorb pollutants, toxicity and transport (Qiao et al., 2019; Rozman et al., 2023). Figure 3 shows the percentage of five category of microplastic shapes (film, foam, fiber, fragment, pellet) in each soil sample. All soil samples, including the reference soil, showed the predominance of fragments shape (48 to 63%), which primarily originates from the degradation of larger plastic waste (Cole et al., 2011). Film type microplastics were also prevalent, contributing 27 to 46% of the total microplastics in each sample. Film type microplastics may originate from single use plastic bags or agricultural mulching sheets (Li et al., 2022). It is worth noting that fiber type was almost absent in the landfill-affected soils but appeared more prominently in the reference soil which suggested different pollution pathways. The fiber type of microplastics in the reference soil may be associated with domestic wastewater and atmospheric inputs (Adhikari et al., 2024).

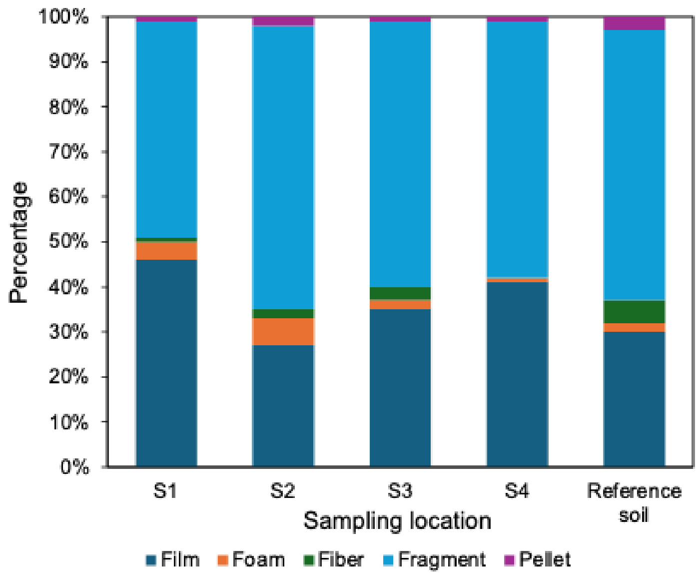

Figure 3. Shapes of microplastics in each sampling locations.

The color of microplastics may affect the adsorption, release, and degradation of pollutants of microplastics (Zhao et al., 2022). The color distribution of microplastics found in each location is given in Figure 4. The dominant color of microplastics in the soil samples was black (35-57%), followed by red (19-25%) and transparent (10-18%) microplastics. The dominance of black microplastics is attributed to the significant use of black plastic materials in various sectors such as food packaging, kitchen utensils, toys, electronics, etc. (Turner, 2018). Most of these black plastics end up in landfills, causing their accumulation in the environment. Other observed plastic colors included red, transparent, blue, yellow, and green. These colors are added into the plastic polymer as required during the plastic production process (Chen et al., 2020) and these original colors may change or diminish due to various factors such as weather conditions, photoaging from sunlight, thermal radiation, physical abrasion, and biodegradation (Li et al., 2023). Figure 5 presented some colored microplastics found in this study.

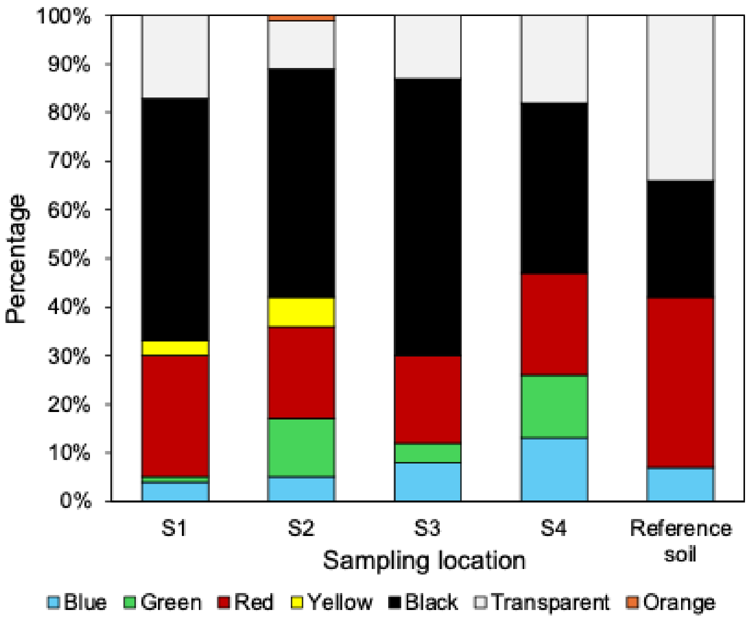

Figure 4. Color of microplastics in each sampling locations.

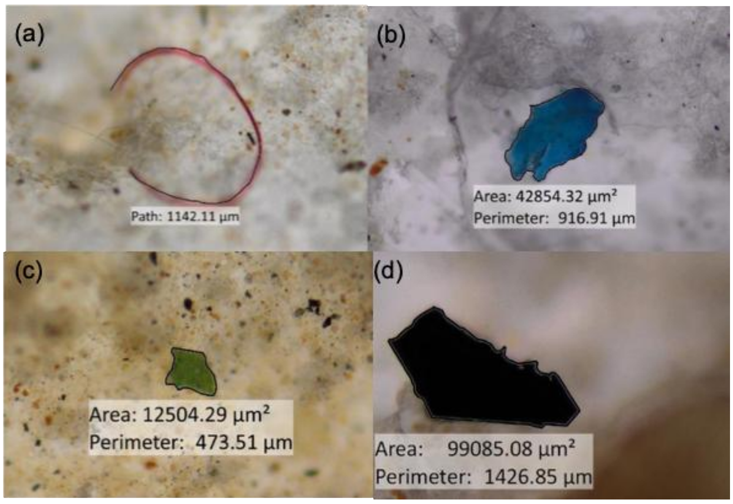

Figure 5. Some detected microplastic particles: red fiber (a); blue (b); green (c); black (d) fragments.

A total of five microplastic particles were manually recovered from the filter paper and analyzed using FTIR spectroscopy. The identified polymers included polyethylene (PE), and polypropylene (PP) (Figure 6). PE and PP are among the most frequently detected microplastic polymers in soil due to their extensive use and persistence. It is important to note that the FTIR analysis was limited to particles large and rigid enough to be handpicked, which likely introduced a detection bias toward more visible or structurally stable particles. As a result, smaller microplastics and flexible fibers may be underrepresented in this study.

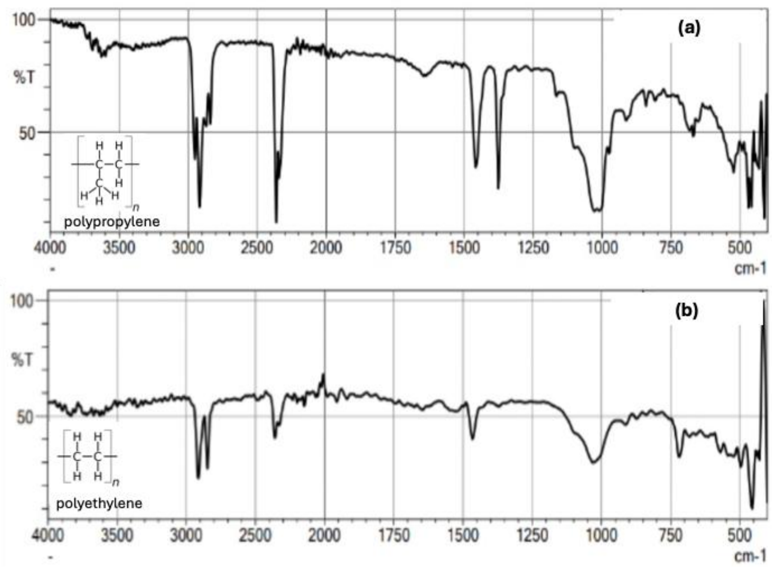

Figure 6. FTIR spectra of microplastics polymers found in soil samples: polypropylene (a) and polyethylene (b).

3.2. HEAVY METALS CONCENTRATIONS

The concentrations of Pb and Cd were analyzed both in bulk soil and in microplastic particles. Table 1 presented the concentrations of Pb and Cd in the soil samples and in microplastic particles. The total concentrations of Pb and Cd in soil ranged from 5.1–8.4 mg/kg and 1.1–1.4 mg/kg, respectively. The concentrations of Pb and Cd in reference soil are generally lower than those in the landfill-affected soils, indicating the enrichment of Pb and Cd in the soils. It is worth noting that the concentrations of Pb and Cd on microplastics were significantly elevated, suggesting the enrichment of both heavy metals on microplastic particles. Studies have shown that weathered microplastics can significantly adsorb heavy metals from their environment (Mao et al., 2020).

Table 1. Concentration of heavy metals Pb and Cd in agricultural soils near the Piyungan landfill and in microplastics found in the soils.

Sample	Concentration in soil (mg/kg)		Concentration in microplastics (mg/kg)	
	Pb	Cd	Pb	Cd
S1	8.2	1.4	2.7	1.4
S2	6.9	1.1	33.5	5.1
S3	8.4	1.2	246.3	14.8
S4	5.1	1.2	195.2	15.1
Reference soil	6.3	0.6	50	2.97

4. CONCLUSION

This study confirms that the Piyungan landfill in Yogyakarta, Indonesia, is a source of environmental contamination, contributing both microplastics and heavy metals to surrounding agricultural soils. The elevated concentrations of microplastics, lead (Pb) and cadmium (Cd), highlight the landfill's role in the release and distribution of persistent pollutants to the surrounding environment. In addition, Pb and Cd were also found adsorbed onto microplastic surfaces, indicating the potential for microplastics to act as carriers or vectors of toxic elements. The combined presence of microplastics and heavy metals emphasize the need for integrated monitoring of both types of pollutants in terrestrial systems and for the development of effective waste management strategies to mitigate pollutant release from landfill sites.

5. ACKNOWLEDGEMENT

The authors would like to thank Environmental Quality Laboratory of Universitas Islam Indonesia for providing the facilities necessary to carry out this research.

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