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A study on microplastics pollution and contamination from leachate and soil in open dumpsite in Pathum Thani province, Thailand

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ABSTRACT

Currently, open dumping remains the most common method of solid waste disposal in Thailand. However, most dumpsites are unsanitary, causing serious environmental pollution through leachate seepage into soil and groundwater. This study aimed to quantify and characterize microplastics (MPs) in leachate and soils at an open dumpsite, as well as to investigate the accumulation of associated toxins, specifically heavy metals and plasticizers. Heavy metals analyzed included Cu, Mn, Zn, Ni, Pb, Cd, Cr, Hg, and As, while plasticizers consisted of polycyclic aromatic hydrocarbons (PAHs), Bisphenol A (BPA), and phthalates. MPs were examined for abundance, morphology (shape, color), and polymer composition. The results showed that leachate quality parameters (DO, BOD, COD, EC, TS, and SS) at three sites before treatment and one site after treatment exceeded the industrial wastewater discharge standards set by the Ministry of Natural Resources and Environment (B.E. 2017). MPs contamination was highest in leachate around the dumpsite, followed by fresh leachate, untreated leachate, and treated leachate. MPs in soils within the dumpsite were also higher than in sediments. Morphological classification revealed five major forms: fragments (27%), fibers (40%), pellets (21%), films (7%), and flakes (8%). MPs occurred in seven colors: transparent, red, blue, black, pink, white, brown, and green. FTIR analysis identified polymers including polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), polyester (PL), and chlorosulfonated polyethylene (CSPE). Heavy metals detected in leachate included Ni (1.52 ± 0.40 mg/L), Cd (2.62 ± 0.02 mg/L), Cr (0.97 ± 0.70 mg/L), and Pb (0.97 ± 0.52 mg/L), with significant differences across sites ($p < 0.01$), all exceeding the Pollution Control Department's water quality standards. Plasticizers detected included dibutyl phthalate (DBP), di(2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), PAHs (acenaphthene, acenaphthylene, anthracene, pyrene), and Bisphenol A. These substances are known to be harmful to human health and ecosystems, with some classified as carcinogens. The findings demonstrate that open dumpsites are significant sources of MPs and associated toxic contaminants in leachate and soil, with potential risks to food chains and ecological systems. Effective waste separation, monitoring, and management are urgently needed to mitigate MPs pollution and toxic chemical contamination in Thailand.

Keywords: leachate, open dumping, microplastics, heavy metals, plasticizer.

INTRODUCTION

Solid waste disposal remains one of the most pressing environmental challenges in Thailand, where open dumping is still widely practiced due to low operational costs and insufficient infrastructure for sanitary landfills or incineration (Pollution Control Department, 2019). Open dumpsites are unsanitary by nature, lacking leachate collection and liner systems, which results in uncontrolled percolation of contaminated leachate into surrounding soils and groundwater [1]. Such

leachate is a complex mixture containing high levels of organic matter, inorganic salts, heavy metals, and more recently, emerging contaminants such as microplastics (MPs) and plastic additives [2].

Microplastics, defined as plastic particles smaller than 5 mm, are generated from the degradation of larger plastic debris and are increasingly recognized as persistent pollutants in both aquatic and terrestrial ecosystems [3]. Their small size, diverse morphology, and polymeric composition enable them to be widely dispersed and incorporated into soil and water matrices. MPs are not only pollutants themselves but also act as carriers of other contaminants, including heavy metals and plasticizers, due to their large surface area and high sorption capacity [4].

Previous studies have confirmed the presence of MPs in landfill leachate and adjacent soils, indicating that dumpsites may represent critical hotspots of MPs and associated chemical pollutants [5]. Soil, in particular, functions as a long-term sink for MPs transported by leachate infiltration and runoff, where they may accumulate and interact with co-contaminants such as polycyclic aromatic hydrocarbons (PAHs), phthalates, bisphenol A (BPA), and heavy metals [6]. These compounds are toxic, persistent, and in many cases carcinogenic, posing risks to ecosystems and human health [7].

In Thailand, studies on MPs have primarily focused on aquatic environments and marine litter [8]. While limited research has investigated MPs in dumpsite leachate and soils. Given that Pathum Thani Province is a rapidly urbanizing area where open dumping is still practiced, the potential risk of MPs and associated contaminants in leachate and soils is of particular concern.

Therefore, the objectives of this study were (i) to determine the abundance and characteristics of MPs in leachate and soil from an open dumpsite in Pathum Thani Province, and (ii) to analyze associated pollutants accumulated in MPs, leachate, and soil, including heavy metals and plasticizers. The results will provide baseline data on terrestrial MP pollution in Thailand and contribute to improved waste management and environmental protection strategies.

MATERIALS AND METHODS

The study area

The study was conducted in Khlong Sam Subdistrict, Khlong Luang District, Pathum Thani Province, Thailand (14°N, 100°E; 2.3 m a.s.l.), covering 48 km² with 16 villages and a population of 91,146 (civil registry, 2022). GIS was used to support site selection and sample collection of leachate, soil, and surface water from an open dumping site (Figure 1).

Soil sampling

Soil samples were collected systematically across the study area, with sampling points predetermined to ensure representative coverage. The

Figure 1. Schematic of the outdoor waste dumping area, Khlong Sam Subdistrict Administrative Organization 1. Front left waste dumping area 2. Front right waste dumping area 3. Rear left waste dumping area and 4. Rear right waste dumping area

coordinates of each site were recorded using a GPS device, and soil was excavated to a depth of 1–1.5 m. In situ measurements of soil pH and moisture content were conducted using a soil meter, and samples were stored in sample bottles for laboratory analysis. In the laboratory, soil samples were air-dried and subsequently oven-dried at 60 °C for 24 hours. A 5 g subsample was weighed and treated with 20 mL of 70% nitric acid (HNO_3) before digestion on a hot plate for approximately 30 minutes. After cooling, density separation was performed using a 1.2% (w/v) solution (200 mL), and the resulting suspension was filtered through 1 µm Whatman GF/B filter paper. The filter paper was then oven-dried at 60 °C for 5 hours prior to further analysis.

Analysis of physical and chemical characteristics of soil

The physical and chemical properties of the soil were analyzed following a modified protocol from the Soil Development Department (2010). Soil pH and electrical conductivity (EC) were measured using a 1:5 soil-to-water ratio (w/w), in which 4 g of soil was mixed with 20 mL of deionized water, allowed to equilibrate, and analyzed with a pH meter and an electrical conductivity meter, respectively. Moisture content and texture were determined according to standard laboratory procedures, and the samples were prepared for further analyses of microplastic contamination and heavy metal concentrations.

Analysis of microplastic contamination in soil samples

Microplastic contamination in soil samples was analyzed following a modified NOAA (2015) [9] protocol. Briefly, 200 g of wet soil was placed in a pre-weighed 600 mL beaker, oven-dried at 90 °C for 24 hours and treated with 200 mL of 56–60% meta-phosphoric acid. Samples were stirred with a magnetic bar for 1 hour and sieved to remove particles larger than 5 mm. The remaining material was transferred to a pre-weighed beaker and subjected to density separation using 150 mL of zinc chloride solution. Floating fractions were collected, washed with deionized water, oven-dried at 90 °C for 24 hours, and weighed. Organic matter was removed by sequential addition of Fe^{2+} solution and 30% hydrogen peroxide with controlled heating (≤75 °C). Finally, NaCl (≈5 M) was added for density separation over 24 hours, and microplastics were isolated, weighed, and identified under a stereomicroscope at 10–150×magnification.

Analysis of heavy metals in soil samples

The concentrations of 9 heavy metals in soil samples, including Pb, Cd, Cr, Cu, Ni, Mn, Zn, Hg, and As, were determined using inductively coupled plasma optical emission spectrometry (ICP-OES). Soil samples were prepared following a modified USEPA 3050B acid digestion method. Approximately 1 g of oven-dried and ground soil was placed in a 125 mL Erlenmeyer flask. Nitric acid (HNO_3) was added stepwise with intermittent heating to ensure complete digestion. Initially, 10 mL of 1+1 HNO_3 was added, and the mixture was heated at 90–95 °C for 10–15 minutes without boiling to partially oxidize organic matter and release loosely bound metals. An additional 10 mL of HNO_3 was then added, and heating continued for 30 minutes to dissolve more resistant metal compounds. A further 5 mL of HNO_3 was added, and the mixture was heated until the sample became pale (approximately 2 hours), indicating near-complete oxidation of organic matter. After cooling, 2 mL of deionized water and 3 mL of 30% hydrogen peroxide (H_2O_2) were added, and heating was resumed until the reaction ceased. Additional 1 mL portions of H_2O_2 were added if necessary (not exceeding 10 mL) to ensure complete oxidation. Finally, 5 mL of HCl and 10 mL of deionized water were added, and the mixture was heated for an additional 10–15 minutes to achieve full metal solubilization. The digested samples were then cooled, filtered through cellulose nitrate membrane filters, and diluted with deionized water to a suitable volume prior to ICP-OES analysis.

ANALYSIS OF LEACHATE SAMPLES

Leachate water sampling

Leachate water samples were collected from designated leachate collection points and surface water areas using the grab sampling technique. Samples were stored in 1 L glass bottles and maintained at 4 °C to preserve water quality prior to analysis. Each sample was filtered through a 5 mm mesh sieve to remove large debris. Subsequent analyses included determination of the

physical and chemical properties of the water, as well as quantification of microplastics and heavy metal contaminants [10].

Analysis of physical and chemical properties of leachate water

The physical and chemical characteristics of leachate water samples from each sampling point were analyzed. The parameters measured included pH, temperature, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TS), and electrical conductivity (adapted from Department of Industrial Works, 2011) [11].

Analysis of microplastic contamination in leachate samples

Leachate and surface water samples were first filtered through 5.6 mm and 0.3 mm sieves to remove macroplastics (>5 mm). The retained microplastics were transferred into preweighed beakers, dried at 90 °C for 24 h, and digested with 0.05 M Fe^{2+} solution and 30% hydrogen peroxide to remove organic matter. Density separation was performed by adding NaCl (≈5 M) and sodium iodide (1.5 g/cm³) to isolate microplastics, which were subsequently examined and characterized under a stereomicroscope at 10–150× magnification [12,13]. For the purification of leachate with high organic content, solid-phase extraction (SPE) using C18 cartridges was employed to selectively retain organic and inorganic compounds. The target analytes were adsorbed onto the sorbent and subsequently eluted with appropriate solvents to achieve efficient recovery [12,13].

Analysis of heavy metals in leachate samples

For heavy metal analysis, 100 ml of leachate and 20 g of soil samples were digested with concentrated nitric acid and 30% hydrogen peroxide on a hot plate within a fume hood until the volume was reduced to 5–10 ml. The digested solutions were filtered through GF/A filter paper into 100 ml volumetric flasks, rinsed with ion-free distilled water, and brought to volume. Calibration standards were prepared to generate a calibration curve using an inductively coupled plasma (ICP), plotting absorbance against concentration. Concentrations of heavy metals, including Pb, Cd, Cr, Cu, Ni, Mn, Zn, Hg, and As, were determined using ICP-OES and expressed in mg/L.

Analysis of contamination of plasticizers

Leachate samples that had undergone SPE were analyzed for plasticizer compounds, including Bisphenol A, phthalates, and polycyclic aromatic hydrocarbons (PAHs). The analytes retained on the C18 cartridges were eluted with appropriate solvents and concentrated as needed. The prepared extracts were then subjected to gas chromatography coupled with mass spectrometry (GC-MS) for identification and quantification. Analytical conditions, including column type, temperature program, and ionization mode, were optimized according to standard protocols to ensure accurate detection of the target plasticizer compounds.

Extraction and analysis of plasticizer contaminants from microplastics

20 grams of isolated microplastics were accurately weighed and sequentially soaked in prepared solvents of increasing polarity, hexane, dichloromethane, and methanol (1.2% w/v) to extract accumulated plasticizer contaminants. Each solvent was added to the microplastics in a beaker to fully immerse the sample, and the mixture was capped and left to stand for 24 h to allow thorough extraction. The liquid extracts were then filtered and concentrated to dryness using a vacuum evaporator, after which the residues were stored at 2–8 °C in vials.

For analysis, 10 µL of each prepared extract was injected into a GC-MS system equipped with a DB-5 column (5 µm), under controlled carrier gas flow. The analytes were identified and quantified by comparing retention times and mass spectra against NIST 14 library standards for plasticizer compounds, allowing assessment of potential contamination and associated hazards.

STATISTICAL ANALYSIS

This study employed IBM SPSS Statistics Subscription Version 28 for data analysis. A one-way analysis of variance (One-Way ANOVA) and an Independent-Samples T-Test were performed at a 95% confidence level ($p \leq 0.05$) to compare the quantity of microplastics as well as the concentrations of contaminants in soil and leachate.

RESULTS AND DISCUSSION

Study of physical and chemical characteristics

Study of the physical and chemical characteristics of natural water sources around the open dumpsite

The results of the study revealed that the detected temperature ranged between 32.60–33.20 °C. The pH values were within 6.94–7.13, which complied with the effluent standards for industrial estates and industrial zones dated March 29, 2016. The average electrical conductivity was 210.50 µm/cm. The average dissolved oxygen (DO) was 8.09 mg/L. The average BOD, representing the oxygen consumed by microorganisms to decompose organic matter, was 12.17 mg/L. The average COD, representing the oxygen required to chemically oxidize organic matter in water, was 115 mg/L. The average total solids (TS) were 115 mg/L, while the average suspended solids (SS) were 13.11 mg/L. It was found that all measured parameters were within the acceptable standard limits, as shown in Table 1.

The physicochemical characteristics of natural water sources surrounding the open dumpsite were found to be within the permissible limits set by the Notification of the National Environment Board No. 24 (B.E. 2547) [14]. The measured temperature (32.60–33.20 °C) reflects typical tropical environmental conditions and aligns with findings by Sangkham et al. [15], who reported similar temperature ranges (30–34 °C) in surface water near open dumpsites in northern Thailand, suggesting that waste decomposition and limited shading can slightly elevate water temperature. The pH values (6.94–7.13) were within the neutral range, indicating that the water was neither strongly acidic nor alkaline. This finding corresponds with Chiemchaisri et al. [16], who reported neutral pH values (6.8–7.5) in leachate-impacted surface waters, implying that buffering capacity of surrounding soils and dilution by rainfall may stabilize pH levels. The average electrical conductivity (210.50 µS/cm) was relatively low compared to values reported near active landfill sites (often exceeding 400 µS/cm; El-Salam and Abu-Zuid, [17]), indicating minimal ionic contamination and suggesting that leachate migration was limited. Similarly, the DO value of 8.09 mg/L exceeded the minimum threshold (≥5 mg/L), showing good oxygenation and moderate organic loading. This aligns with Ahmed et al. [18], who observed that open water bodies with adequate aeration maintain DO levels above 7 mg/L despite proximity to waste sites. The BOD of 12.17 mg/L and COD of 115 mg/L remained within the acceptable range. Although these values indicate the presence of some organic matter, they were significantly lower than those typically reported in leachate contaminated waters (BOD > 50 mg/L, COD > 250 mg/L) [19]. This suggests that the studied water sources were not directly impacted by leachate infiltration or that dilution effects were strong during sampling. Furthermore, TS and SS values (103.71 mg/L and 13.11 mg/L, respectively) were well below the standard limits, consistent with Rahman et al. [20], who found similar levels in uncontaminated rural surface waters. This indicates limited sediment or waste particle inflow from surrounding areas. Overall, the results suggest that despite being located near an open dumpsite, the natural water sources remain within safe physicochemical limits. However, continuous monitoring is recommended because environmental factors such as rainfall, waste accumulation, and leachate migration may alter water quality over time [21].

Table 1. Physical and chemical characteristics of natural water sources surrounding the open dumpsite

Area	Parameters								
	Trial	Temp (°C)	pH	EC (µs/cm)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	TS (mg/L)	SS (mg/L)
(W0)	1	32.60	6.94	210.00	7.94	11.96	117.00	105.00	12.50
	2	33.20	6.96	210.00	8.15	11.96	113.00	102.23	13.30
	3	33.10	7.13	211.00	8.18	12.38	117.00	103.90	13.55
	$\bar{x}$	32.96	7.01	210.50	8.09	12.17	115.00	103.71	13.11
Standard values[1/]	≤40		6.5-8.5	-	≥5	≤20	≤120	≤3.000	≤50
Comparison with standards		pass	pass	-	pass	pass	pass	pass	pass

Note: [1/] Notification of the National Environment Board No. 24 (B.E. 2547).

Study of physical and chemical characteristics of leachate

The analysis of leachate quality from sites W1–W4 (Table 2) indicated that all measured parameters exceeded the effluent standards, reflecting a high degree of pollution across the study area. However, the severity of contamination varied among sites. At W1, although values of BOD (39.51 mg/L) and COD (1,956.66 mg/L) already surpassed the standard limits, the overall concentrations were comparatively lower than other sites, suggesting moderate organic pollution. W2 and W3 demonstrated substantially higher BOD and COD levels (1,000.33 mg/L and 404.73 mg/L; 6,858.88 mg/L and 7,189.33 mg/L, respectively), accompanied by elevated total and suspended solids, indicating intense organic load and poor water quality. In particular, W3 exhibited consistently high electrical conductivity (6.282 µS/cm) and suspended solids (179.76 mg/L), which suggest a higher accumulation of dissolved salts and particulate matter. The most critical contamination was observed at W4, where extremely high EC (10,006 µS/cm), COD (9.229 mg/L), and TS (4,661.66 mg/L) were recorded, along with the lowest DO level (0.12 mg/L), reflecting severe organic and inorganic pollution as well as strong anaerobic conditions. These findings imply that leachate in W4 represents the most degraded water quality and poses the greatest environmental risk. The observed variation among sites may be attributed to differences in waste composition, leachate generation, and hydrological conditions within the dumpsite area [22].

Study of physical and chemical characteristics of soil

The analysis of soil samples collected from the dumpsite area (Table 3) revealed relatively stable physical properties. Temperature measurements for sediment (S1) and surface soils (S2) ranged narrowly between 35.10–35.40 °C, indicating minimal thermal variability across the site. Soil pH values were consistently neutral, with S1 averaging 7.21 and S2 averaging 7.32, and a narrow variation range of 7.18–7.37. Moisture content was low but relatively uniform, ranging from 4.03% to 4.49%, suggesting limited water retention in these soils. When compared with global soil quality standards, such as those from the FAO Global Soil Partnership (2020) [23], neutral pH values within 6.0–7.5 are generally considered optimal for microbial activity and nutrient availability in soils. The observed soil pH in the dumpsite falls within this recommended range, indicating that despite exposure to leachate, the soils maintain their buffering capacity and are

Table 2. Preliminary physical and chemical characteristics of leachate in the open dumpsite area

Area	Parameters								
	Trial	Temp (°C)	pH	EC (µs/cm)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	TS (mg/L)	SS (mg/L)
(W1)	1	34.20	7.61	3,244.00	4.88	39.06	1,956.00	2,662.00	62.50
	2	34.20	7.66	3,263.00	4.89	39.78	1,959.00	2,674.00	65.00
	3	33.80	7.66	3,249.00	4.88	39.70	1,955.00	2,669.00	69.20
	$\bar{x}$	34.00	7.63	3,252.00	4.88	39.51	1,956.66	2,668.33	65.56
(W2)	1	35.50	7.63	4,744.00	4.53	975.00	6,797.00	3,372.00	158.40
	2	35.30	7.61	4,744.00	4.53	1,005.00	6,899.00	3,370.00	162.33
	3	35.50	7.66	4,746.00	4.53	1,021.00	6,878.00	3,370.00	167.64
	$\bar{x}$	34.06	7.64	4,745.00	4.53	1,000.33	6,858.88	3,370.66	162.79
(W3)	1	35.50	7.67	6,282.00	4.62	405.60	7,199.00	3,486.00	179.30
	2	35.50	7.60	6,282.00	4.62	402.60	7,180.00	3,493.00	178.00
	3	35.60	7.66	6,282.00	4.67	406.00	7,189.00	3,502.00	182.00
	$\bar{x}$	35.40	7.64	6,282.00	4.64	404.73	7,189.33	3,493.66	179.76
(W4)	1	33.30	8.13	10,005.00	0.11	781.50	9,225.00	4,653.00	202.20
	2	33.30	8.18	10,007.00	0.13	808.50	9,233.00	4,660.00	207.90
	3	33.30	8.29	10,007.00	0.11	797.00	9,229.00	4,672.00	200.83
	$\bar{x}$	33.30	8.25	10,006.00	0.12	795.66	9,229.00	4,661.66	203.64
Standard values[1/]		≤40	5.5–9	150–300	≥2	≤20	≤120	≤3.000	≤50
Comparison with standards		Not compliant	Not compliant	Not compliant	Not compliant	Not compliant	Not compliant	Not compliant	Not compliant

Note: [1/] Ministerial Notification of Ministry of Natural Resources and Environment on the standards for control of industrial wastewater discharge from factories, industrial estates and industrial zones (B.E. 2563).

Table 3. Preliminary physical characteristics of soils in the dumpsite area (Khlong Sam Subdistrict Administration)

Soil sample	Trial	Temperature (°C)	pH	Moisture content (%)
(S1)	1	35.20	7.21	4.14
	2	35.10	7.25	4.49
	3	35.10	7.18	4.06
	$\bar{x}$	35.13	7.21	4.23
(S2)	1	35.40	7.33	4.03
	2	35.10	7.37	4.21
	3	35.20	7.28	4.19
	$\bar{x}$	35.23	7.32	4.14

not strongly acidified or alkalized. This may help limit the mobility of heavy metals and other contaminants that are sensitive to pH fluctuations.

International studies show similar patterns [24], reported that soils near uncontrolled landfill sites exhibited pH values ranging from acidic to neutral (4.42–7.35), with neutral zones associated with reduced contaminant mobility. Koda et al. [25], found landfill soils in Europe had pH ranges of 5.0–8.0, with median values near 7.3, reflecting a "neutral character" comparable to the current study. Likewise Madyiwa et al. [26], observed soils near landfills in Zimbabwe with an average pH around 6.5, facilitating the precipitation and adsorption of heavy metals onto soil particles and organic matter, thus reducing their environmental mobility.

Overall, the neutral pH values and uniform moisture content indicate that the soils within the dumpsite are relatively stable in terms of basic physical and chemical characteristics. Nevertheless, neutral pH does not necessarily imply absence of contamination. The accumulation of heavy metals, organic compounds, or other leachate-derived pollutants may still occur without significantly altering pH. Therefore, further chemical analysis, particularly of heavy metals and organic contaminants, is essential to fully assess the environmental risks posed by leachate infiltration into these soils.

Study of the quantity and morphology of microplastics

The study on the abundance of microplastic contamination in leachate and soil classified microplastics based on morphology into five categories: fibers, fragments, pellets, flakes, and films. The microplastic content was analyzed by randomly collecting samples of leachate and soil from the open dumpsite at the Khlong Sam subdistrict administrative organization, Pathum Thani province, in order to assess microplastic contamination.

The results of microplastic quantification in leachate and in soil are presented in Table 4. The quantification of microplastics in leachate and soil samples revealed significant variation in abundance across different sampling points. Treated leachate (W1) exhibited the lowest concentration (17 pieces/L), suggesting that treatment processes are effective in reducing microplastic levels. In contrast, untreated leachate (W2), fresh leachate (W4), and leachate surrounding the dumpsite (W3) showed higher concentrations (48, 51, and 64 pieces/L, respectively), indicating that landfill operations contribute substantially to microplastic release into the environment. Soil samples demonstrated even greater accumulation, with sediment soil (S1) containing 58 pieces/L and soil at the dumpsite (S2) reaching 74 pieces/L, reflecting long-term deposition and persistence of microplastics in terrestrial environments. These findings are consistent with previous studies. Yatim et al. [27] reported elevated microplastic levels in leachate and soil samples from unsanitary landfill zones in Malaysia, where untreated leachate contained up to 60 pieces/L and surrounding soils exceeded 70 pieces/L. Similarly, a study conducted

Table 4. Distribution and abundance of microplastics in individual leachate and soil samples

Sampling point	Microplastic abundance (pieces/L)
Treated leachate (W1)	17
Untreated leachate (W2)	48
Leachate around the dumpsite (W3)	64
Fresh leachate (W4)	51
Sediment soil (S1)	58
Soil at the dumpsite (S2)	74

near the Gulf of Thailand found comparable concentrations in landfill leachate, emphasizing the role of waste degradation and leachate migration in microplastic contamination. A global review by Zhang et al. [28] further supports these observations, noting that microplastic concentrations in landfill leachate can range from less than 10 to over 100 pieces/L depending on landfill age, waste composition, and treatment efficiency.

The relatively low microplastic abundance in treated leachate observed in this study aligns with findings from engineered landfills employing advanced filtration and sedimentation systems. This underscores the importance of effective leachate treatment in mitigating microplastic pollution. Moreover, the high concentrations found in soil samples suggest that microplastics not only persist but may also accumulate over time, posing long-term risks to soil health and potentially entering food chains through terrestrial organisms.

Overall, the results highlight the need for improved waste management practices, particularly in leachate treatment and landfill design, to reduce microplastic emissions and protect surrounding ecosystems.

Microplastic types in leachate and soil

Leachate samples were collected from four locations: W1, W2, W3, and W4, and soil samples were collected from two locations: S1 and S2. Six types of MPs were identified: fibers, fragments, pellets, flakes, and films.

The study found that the most abundant type of microplastic in both leachate and soil samples was fragments, followed by fibers, pellets, films, and flakes, which were the least abundant. The size of the microplastics ranged from 0.07 to 4.73 mm.

The analysis of MPs in soil samples from the study areas revealed differences in both abundance and type. Sediment soil (S1) contained a total of 58 pieces/kg, with fragments (26 pieces/kg) being the most abundant, followed by fibers (18 pieces/kg), films (4 pieces/kg), flakes (3 pieces/kg), and pellets (2 pieces/kg). In contrast, soil at the dumpsite (S2) had a higher total concentration of 74 pieces/kg, dominated by fragments (50 pieces/kg), followed by flakes (18 pieces/kg), films (12 pieces/kg), fibers (13 pieces/kg), and pellets (5 pieces/kg) consistent with Pratiwi et al. [29]. Overall, fragments were the predominant type in both study areas, while pellets and flakes were comparatively less abundant. The results indicate that soils within the dumpsite exhibit higher microplastic contamination compared to sediment soils. (Table 5).

Microplastic colors in leachate and soil

The analysis of microplastic (MP) colors in both leachate and soil revealed variations in color distribution across sampling areas (Table 6). In leachate, leachate around the dumpsite (W3) had the highest total MP abundance (74 pieces/L), followed by untreated leachate (W2, 49 pieces/L), fresh leachate (W4, 49 pieces/L), and treated leachate (W1, 26 pieces/L). Transparent MPs were the most commonly observed color in W1 and W3, while red and green MPs were more prevalent in W4. Other colors, including blue, black, pink, white, brown, and miscellaneous colors, were present in varying amounts across all leachate samples.

In soil samples, soil at the dumpsite (S2) contained a higher total MP abundance (49 pieces/kg) compared to sediment soil (S1, 26 pieces/kg). Transparent MPs were dominant in both soil types, followed by white, black, and green MPs, while pink, blue, brown, and other colors occurred in smaller quantities. Overall, the results indicate that MPs of various colors are widely distributed in both leachate and soil, with

Table 5. Distribution and microplastics types in individual leachate and soil

Sampling area	Microplastic types and abundance in leachate (pieces/L)					
	Fiber	Fragment	Pellets	Flake	Film	Total
Treated leachate (W1)	12	7	3	1	1	24
Untreated leachate (W2)	11	17	6	6	8	48
Leachate around the dumpsite (W3)	19	27	11	3	4	64
Fresh leachate (W4)	10	21	20	4	2	57
Sampling area	Microplastic types and abundance in leachate (pieces/kg)					
Sediment soil (S1)	18	26	2	3	4	53
Soil at the dumpsite (S2)	13	50	5	18	12	98

Table 6. Variation in color distribution and abundance of microplastics in individual leachate and soil samples

Sampling area	Microplastic colors and abundance in leachate (pieces/L)									
	Transparent	Red	Blue	Black	Pink	White	Brown	Green	Others	Total
Treated leachate (W1)	5	1	5	2	1	5	1	3	3	26
Untreated leachate (W2)	8	4	7	7	2	8	2	5	6	49
Leachate around the dumpsite (W3)	15	9	8	9	5	8	2	13	5	74
Fresh leachate (W4)	6	10	3	7	4	6	3	6	4	49
Sampling area	Microplastic colors and abundance in soil (pieces/kg)									
	Transparent	Red	Blue	Black	Pink	White	Brown	Green	Others	Total
Sediment soil (S1)	5	1	5	2	1	5	1	3	3	26
Soil at the dumpsite (S2)	9	4	3	7	2	8	2	5	6	49

higher contamination levels observed in areas closer to the dumpsite.

The colors of MPs varied across sampling areas, reflecting differences in type, category, and sources of plastic waste. The color of MPs originates from the addition of pigments during plastic manufacturing to enhance aesthetic appeal, increase value, and match the intended application of the plastic product. The diversity of MP colors may lead to contamination of the food chain, as the colors often resemble the natural appearance of food items, particularly for aquatic organisms such as fish, squid, crabs, shrimp, and turtles, increasing the risk of ingestion.

The study identified the following MP colors: transparent, red, blue, black, pink, white, brown, green, and others, with transparent being the most abundant across all leachate and soil samples. This was followed by white, blue, green, red, and other colors. The predominance of transparent and white MPs is mainly due to these being the base colors used in primary plastic production processes in the industry.

The analysis of microplastic composition at the dumpsite

The polymer composition of MPs in both leachate and soil was analyzed using Fourier transform infrared spectroscopy (FTIR). In leachate samples, including treated leachate, leachate around the dumpsite, fresh leachate, and untreated leachate, four major polymer types were identified: polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), and polyester (PL) (Table 7) [30]. The study area serves as the final disposal site for plastic packaging, where materials degrade into secondary forms and are transported through physical, chemical, and biological processes. The plastics primarily originate from daily-use items, such as food containers, children's toys, fertilizer bags, synthetic fibers, carpets, ropes, shopping and hot bags, beverage bottles, snack and coffee packaging, pipes, cable sheaths, and medical or laboratory plastics. Specifically, PP was common in food containers, hot cups, semi-processed food packaging, hot bags, bottle caps, labels, baskets, sacks, and PVC pipes used in molding or manufacturing.

In soil samples, the FTIR analysis revealed a wider range of polymers, including PE, PP, low-density polyethylene (LDPE), high-density polyethylene (HDPE), and chlorosulfonated polyethylene (CSPE). LDPE is commonly used in food packaging, cooling bags, shrink films, stretch films, and bottle caps, often in combination with other materials. HDPE is used in plastic packaging such as bottles, drums, and trays. CSPE was detected due to its high resistance to ozone, ultraviolet-induced discoloration, heat, chemicals, oils, abrasion, and corrosion, making it suitable for electrical insulation, chemical transport coatings, and industrial protective layers. The predominance of PP and PE in both leachate and soil reflects their widespread use in everyday plastic

Table 7. Polymer composition of microplastics in leachate and soil determined by FTIR

Polymer type in leachate	Polymer type in soil
Polypropylene: PP	Polypropylene: PP
Polyethylene: PE	Polyethylene: PE
Poly vinylidene chloride: PVC	Low density polyethylene: LDPE
Polyester: PL	High density polyethylene: HDPE
	Chlorosulfonated polyethylene: CSPE

packaging and highlights their persistence in the environment (Figure 2).

Morphological analysis of microplastics in leachate and soil

Morphological analysis using a micro-stereo microscope with a magnification of 10–150× revealed the types and colors of microplastics identified, including fibers, films, fragments, pellets, and flakes. The size of the detected microplastics ranged from 0.07 to 4.73 mm. The polymer composition of microplastics in leachate and soil was predominantly PE and PP, respectively.

The investigation of the types and distribution of microplastics in leachate and soil around the landfill area indicated the presence of fibers, fragments, pellets, flakes, films, and others. Notably, fragments were consistently detected across all sampling sites, likely due to the abundance of plastic waste in the landfill, such as plastic bags, packaging, and other synthetic materials. Since the landfill has been in operation for more than 30 years, continuous accumulation and compaction of plastic waste has occurred. Over time, exposure to air, ultraviolet radiation, sunlight, chemicals, and other environmental factors contributes to the degradation of larger plastics into smaller pieces [31]. These microplastics are subsequently transported and dispersed into leachate and soil through rainfall percolation and surface runoff. The previous studies reported that environmental microplastics mainly originate from the mechanical degradation of textiles and plastic packaging materials [32]. Recent findings further suggest that MPs can adsorb heavy metals such as Pb and Cu, serving as carriers that enhance their persistence and mobility in the environment [33]. This interaction explains the co-occurrence of MPs and metals detected in soil and leachate samples. FTIR analysis confirmed the presence of PP, PE, PVC, and PL polymers, which are commonly derived from household and packaging waste. The presence of plastics, wires, and synthetic fabrics mixed with municipal waste at the dumpsite further supports the link between poor waste segregation and microplastic metal contamination (Figure 3).

The analysis of heavy metal contamination and accumulation in leachate and soil was performed using inductively coupled plasma optical emission spectrometry (ICP-OES). Calibration curves were constructed by plotting concentration against intensity, where the X-axis represented intensity and the Y-axis represented concentration of heavy metals. The calibration yielded an R^2 value of 0.999 for all parameters, confirming the reliability of the measurement. When compared with the quality standards for effluent discharges, as specified by the Ministry of Natural Resources and Environment Notification on Standards for the Control of Wastewater Discharge from Industrial Factories, Industrial Estates, and Industrial Zones (March 29, 2016), the results indicated that heavy metal contamination in leachate varied across sampling sites. The differences in concentration levels were influenced by the amount, composition, and type of waste deposited in the landfill area. Among the detected heavy metals,

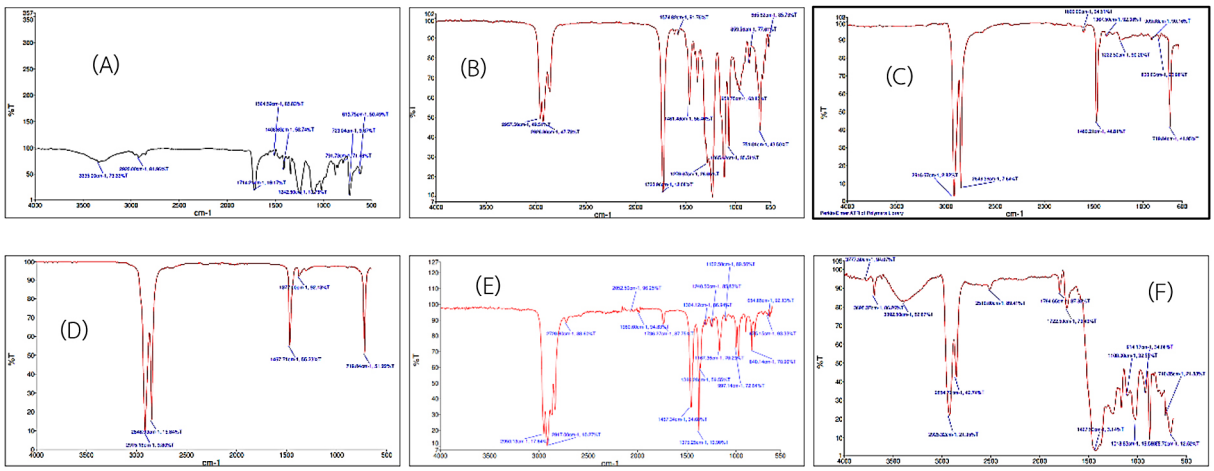

Figure 2. FTIR spectrum graph of MPs in the wastewater treatment system and sludge within the wave range of 400–4000 cm^{-1}: a) polyethylene, b) poly vinyl chloride, c) low-density polyethylene, d) high-density polyethylene, e) chlorosulfonated polyethylene, f) polypropylene

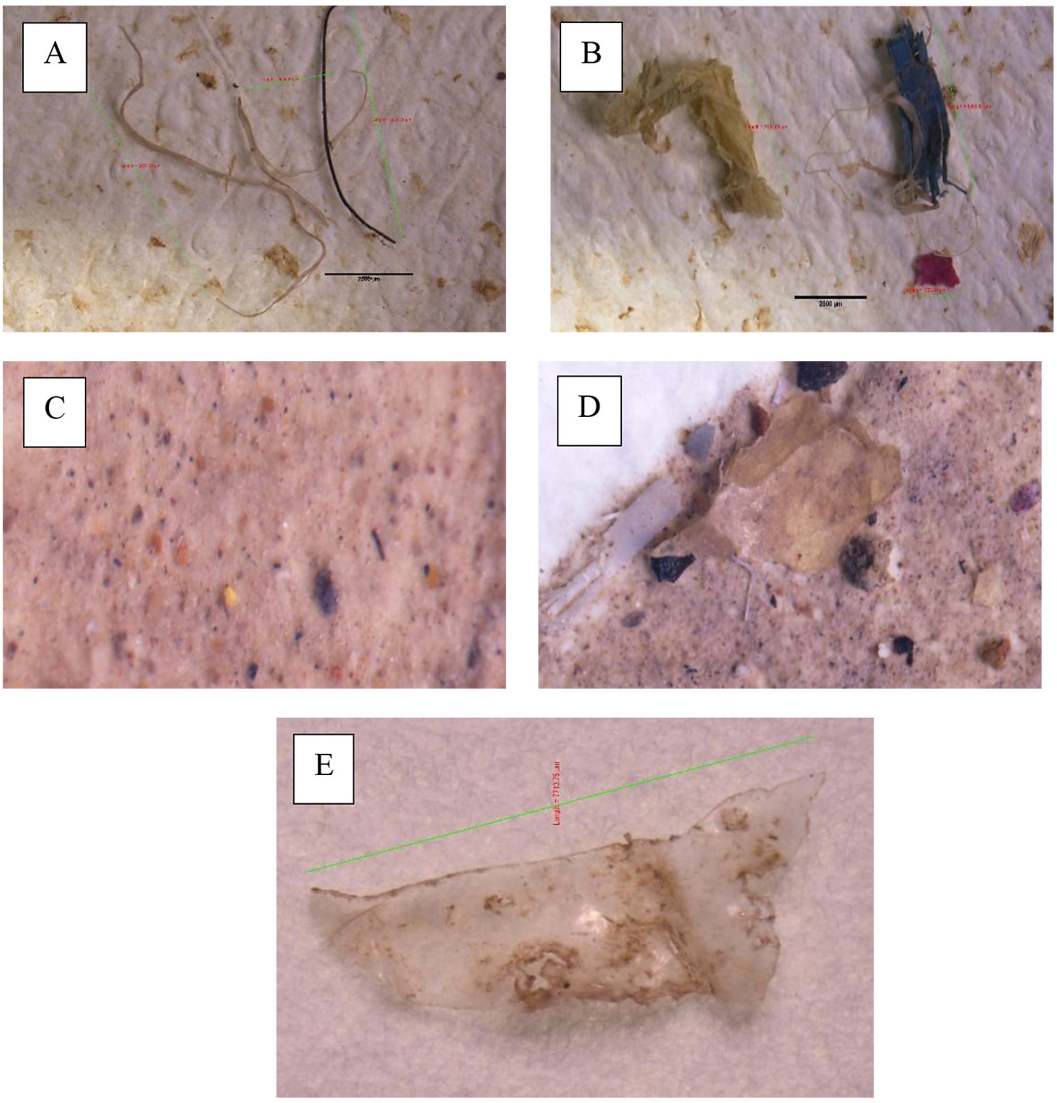

Figure 3. Examples of MPs shape are found in the study area: a) fiber, b) fragments, c) pellets, d) flake and e) film

copper (Cu) exhibited the highest concentration at 1.8 mg/L, whereas arsenic (As) was the lowest at 0.01 mg/L. In addition, nickel (Ni), cadmium (Cd), chromium (Cr), lead (Pb), and mercury (Hg) exceeded the permissible standard limits.

For soil samples, zinc (Zn) showed the highest concentration at 17.7 mg/kg, while Hg and As were the lowest at 0.01 mg/kg. However, the measured concentrations of heavy metals in soil samples did not exceed the regulatory standard limits. Waste management practices at the landfill site revealed that hazardous wastes were not separated from general waste, nor were they managed properly. Hazardous waste materials such as cans, electrical devices, wires, cables, electronic circuit boards, and batteries were disposed of in the landfill without appropriate treatment. These sources likely contributed to the presence of heavy metals in both leachate and soil consistent with [34]. Therefore, continuous monitoring of heavy metal contamination in leachate is recommended, along with the implementation of proper hazardous waste management strategies to prevent further environmental and ecological contamination. Furthermore, integrating assessments of MPs and heavy metals into national waste management frameworks would enhance pollution prevention and support sustainable environmental management in Thailand (Figure 4).

The Independent Samples t-test results showed significant differences ($p < 0.05$) in the concentrations of Cu, Mn, Ni, Zn, Cd, Cr, and Pb between sampling groups, indicating spatial heterogeneity in heavy metal contamination. Similarly, one-way

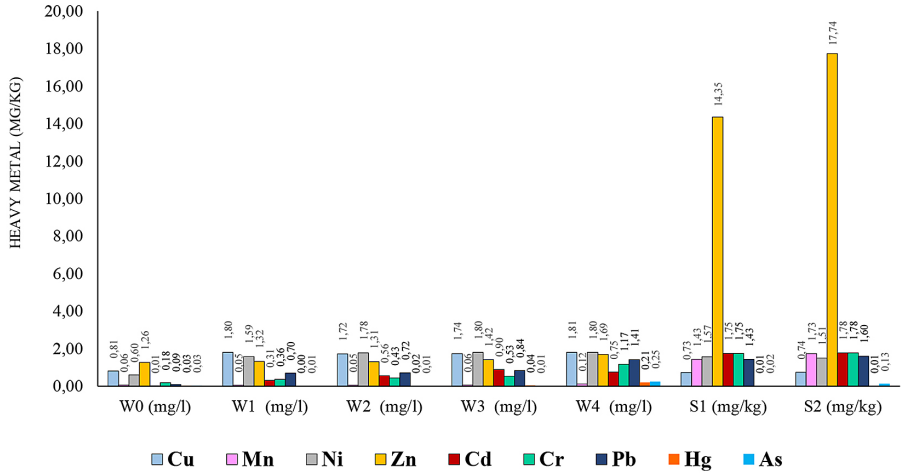

Figure 4. Heavy metal concentrations in leachate and soil

ANOVA analysis revealed that the concentrations of heavy metals varied significantly across the sampling sites, particularly Cu, Ni, Cr, and Pb, while Zn, Cd, Hg, and As showed no significant differences ($p > 0.05$) as shown in Table 8. This spatial variation suggests the influence of localized contamination sources such as waste accumulation, leachate infiltration, and surface runoff within the open dumpsite. Comparable findings have been reported in open dumping areas in Thailand, where uneven distributions of microplastics and heavy metals were attributed to uncontrolled waste deposition and leachate migration [35].

These results highlight the environmental risks associated with unsanitary waste disposal, which can lead to the accumulation of toxic metals in soil and leachate. Elevated concentrations of Cu, Ni, Cr, and Pb observed in this study are consistent with previous reports from landfill leachate and sediment environments [36], emphasizing potential ecological and human health impacts. Therefore, upgrading open dumpsites into engineered sanitary landfills with leachate treatment systems and implementing continuous monitoring of key contaminants are strongly recommended to mitigate pollution and support sustainable waste management practices.

Furthermore, integrating assessments of MPs and heavy metals into national waste management frameworks would enhance pollution prevention and support sustainable environmental management in Thailand.

Study of plasticizer and organic contaminant pollution in landfill area

The landfill area in Pathum Thani province has been identified as a significant source of plasticizer contaminants in microplastics, leachate, and soil. Analytical results indicate that the majority of pollutants belong to the plasticizer group, primarily phthalates, which include diethyl phthalate (DEP), dibutyl phthalate (DBP),

Table 8. Heavy metals concentrations and ANOVA results among sampling sites

Heavy metals	Mean±SD	*F*-value	*P*-value	Significance
Cu	1.334±0.509	4.82	0.004	$p < 0.01$
Mn	0.769±0.861	3.21	0.015	$p < 0.05$
Ni	1.524±0.402	5.60	0.002	$p < 0.01$
Zn	5.584±6.844	1.10	0.039	Not significant
Cd	2.624±0.002	0.05	0.900	Not significant
Cr	0.970±0.708	2.73	0.030	$p < 0.05$
Pb	0.979±0.520	3.00	0.020	$p < 0.05$
Hg	0.039±0.717	0.52	0.780	Not significant
As	0.024±0.043	2.20	0.060	Not significant

mono-(2-ethylhexyl) phthalate (MEHP), di-sec-butyl phthalate (DSBP), and di-cyclohexyl phthalate (DCHP).

These plasticizers are commonly added to polymer products to enhance flexibility, transparency, and mechanical strength. However, prolonged accumulation of plastic waste, coupled with environmental degradation caused by heat, UV radiation, sunlight, and mechanical stress, leads to fragmentation of plastics into microplastics (<5 mm). This degradation process facilitates the release of plasticizers and other additives into the surrounding environment, posing significant health and ecological risks [37].

Exposure to phthalates has been associated with adverse health effects. Inhalation can cause respiratory irritation, while chronic exposure may affect the central nervous system, resulting in headaches, dizziness, nausea, and vomiting. Direct contact with eyes can lead to mild irritation and tearing, and ingestion may induce gastrointestinal disturbances. Certain phthalates, particularly those with higher molecular weights such as DEHP and DINP, are known to interfere with endocrine function and reproductive health, and have been linked to carcinogenic potential in humans and experimental animals, although data remain limited.

Regulatory measures vary internationally. The European Union restricts six phthalates: DBP, BBP, DEHP, DOP, DINP, and DIDP, [38] whereas Thailand currently lacks comprehensive quantitative standards, though some phthalates are prohibited in cosmetic products under the Ministry of Public Health Notification (2008). The International Agency for Research on Cancer (IARC) classifies DEHP and DINP as Group 3 agents, indicating insufficient evidence for human carcinogenicity and limited animal data.

In addition to phthalates, polycyclic aromatic hydrocarbons (PAHs) such as Acenaphthene,

Table 9. Summary of plasticizer contaminants in landfill area, Pathum Thani province

Sample code	Compound	Group	Potential environmental/ health impact
W1 (Treated leachate)	Bisphenol A	Bisphenol A	Endocrine disruptor, reproductive toxicity
	Pyrene	PAHs	Carcinogenic, persistent organic pollutant
	Naphthalene	PAHs	Respiratory toxicity, carcinogenic potential
	Di-(2-Ethylhexyl) Phthalate (DEHP)	Phthalate	Endocrine disruptor, reproductive toxicity
W2 (Raw leachate)	Bisphenol A	Bisphenol A	Endocrine disruptor, reproductive toxicity
	Pyrene	PAHs	Carcinogenic, persistent organic pollutant
	Naphthalene	PAHs	Respiratory toxicity, carcinogenic potential
	Di-(2-Ethylhexyl) Phthalate (DEHP)	Phthalate	Endocrine disruptor, reproductive toxicity
W3 (Leachate around landfill)	Bisphenol A	Bisphenol A	Endocrine disruptor, reproductive toxicity
	Naphthalene	PAHs	Respiratory toxicity, carcinogenic potential
	Anthracene	PAHs	Carcinogenic, persistent organic pollutant
	Pyrene	PAHs	Carcinogenic, persistent organic pollutant
	Dibutyl Phthalate (DBP)	Phthalate	Endocrine disruptor, reproductive toxicity
	Diethyl Phthalate (DEP)	Phthalate	Endocrine disruptor, reproductive toxicity
	Di-(2-Ethylhexyl) Phthalate (DEHP)	Phthalate	Endocrine disruptor, reproductive toxicity
	Phthalic acid	Phthalate	Environmental persistence, moderate toxicity
W4 (Fresh leachate)	Bisphenol A	Bisphenol A	Endocrine disruptor, reproductive toxicity
	Pyrene	PAHs	Carcinogenic, persistent organic pollutant
	Naphthalene	PAHs	Respiratory toxicity, carcinogenic potential
	Di-(2-Ethylhexyl) Phthalate (DEHP)	Phthalate	Endocrine disruptor, reproductive toxicity
S1 (Sediment soil)	Naphthalene	PAHs	Respiratory toxicity, carcinogenic potential
S2 (Landfill soil)	Oxalic acid	Organic acid	Low toxicity, may affect soil pH
	Decane	Hydrocarbon	Flammable, toxic to aquatic organisms

Acenaphthylene, Anthracene, Benzo [a] fluoranthene, and Pyrene were detected in microplastics, leachate, and soil [39]. The total concentrations of phthalates (DBP, DEHP, DOP, DEP, BBP) ranged from 2.597–23.699 µg/L in leachate and 0.297–3.504 µg/kg in soil. Among the detected organic contaminants, Bisphenol A (BPA) showed concentrations ranging from 0.889–0.917 µg/L in leachate, making it one of the most abundant compounds. Other hydrocarbons, including 2-hydroxy-1-(hydroxymethyl) ethyl, 9-Octadecenoic acid, Oxalic acid, and Decane, were also present. While most of these compounds do not exhibit acute toxicity, their chronic effects include disruption of enzymatic activity, respiratory irritation, central nervous system effects, and potential mutagenicity (Table 9).

The findings highlight that microplastics serve as carriers for persistent chemical additives, such as phthalates and PAHs, which may accumulate over time and persist in the environment. The toxicological impact of these contaminants depends largely on the type and concentration of plasticizers released. Notably, phthalates such as DBP, DEHP, BBP, DEP, and MEHP are of particular concern due to their widespread use and potential for long-term health effects, including endocrine disruption, reproductive toxicity, and carcinogenicity [40].

This study emphasizes the necessity of monitoring microplastic pollution and associated chemical additives in landfill sites, as their accumulation represents a significant environmental and public health concern. The results underscore the importance of proper waste management and regulatory oversight to mitigate the release of toxic plasticizers and other hazardous substances into the environment.

CONCLUSIONS

This study investigated microplastic pollution and associated contaminants in leachate and soil from an open-air central landfill managed by the Khlong Sam subdistrict administrative organization, Pathum Thani province. The findings can be summarized as follows:

1. Leachate characteristics – physicochemical analysis indicated that temperature and pH values were within acceptable limits; however, parameters such as DO, BOD, COD, EC, TS, and SS exceeded the wastewater discharge standards for industrial sources.
2. Soil properties – samples near the landfill were mostly neutral in pH with low moisture content, showing limited variation in physical and chemical properties.
3. Microplastic pollution – were detected in all leachate and soil samples. Fragments were the most abundant type, followed by fibers, pellets, films, and flakes. Transparent microplastics were dominant in all samples. FT-IR analysis identified PP, PE, PVC, PL, and CSPE as the main polymer types.
4. Heavy metal contamination – ICP-OES analysis detected nine heavy metals in leachate, with Ni, Cd, Cr, Pb, and Hg exceeding regulatory limits, while soil concentrations were within acceptable standards.
5. Plasticizer and organic contaminants – GC-MS analysis revealed Bisphenol A (BPA), various phthalates (DBP, DEHP, DOP, DEP, BBP), PAHs, and other organic compounds. Although concentrations were generally low, the presence of these contaminants indicates potential environmental toxicity and health risks.
6. Implications – improper landfill management, including the lack of hazardous waste segregation, contributes to the release of microplastics, plasticizers, and heavy metals into leachate and soil. These pollutants pose long-term risks to human health and ecosystems, particularly through chronic exposure to phthalates and PAHs.

The study highlights the significant environmental impact of open-air landfill practices, particularly the accumulation of microplastics and chemical contaminants. Effective waste management strategies, including source separation of hazardous and plastic waste, proper landfill design, and regular monitoring of leachate and soil, are essential to mitigate environmental contamination and protect public health.

The findings from this study underscore the urgent need to strengthen waste management policies and practices in Thailand, particularly regarding open-air landfills and microplastic contamination. Although the landfill operated by the Khlong Sam subdistrict administrative organization functions as a central disposal site, its open dumping characteristics allow the continuous release of microplastics, heavy metals, and plasticizers into surrounding ecosystems.

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