Microplastic Contamination in Landfill Leachate and Surface Water: Assessment of Wastewater Treatment Efficiency at the Nonthaburi Waste Management Center, Thailand

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KEYWORDS
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ABSTRACT
Microplastics (MPs), plastic particles smaller than 5 mm, have emerged as a significant environmental concern, particularly as contaminants originating from landfills. Landfills can serve as a major source of MPs, potentially releasing them into surface water through leachate. This study aims to investigate the contamination of MPs in leachate and surface water, as well as to evaluate the efficiency of landfill wastewater treatment in removing these particles. The research was conducted at the Waste Management Center of the Nonthaburi Provincial Administrative Organization, Thailand, with samples collected in June 2023. Sampling included two leachate sources, influent and effluent from the treatment system and surface water. The abundance and characteristics of MPs in each sample were analyzed. Results indicated a significant presence of MPs in leachate, with an average concentration of 173.98 pieces/L, while concentrations in influent, effluent and surface water were 38.40 pieces/L, 10.80 pieces/L and 11.33 pieces/L, respectively. MPs in all samples were predominantly in the size range of 16-100 µm, corresponding to 71.28-93.75% of the total particles. Polypropylene was the dominant polymer in leachate (69.66%) and effluent (48.94%), whereas acrylate copolymer (96.53%) and polytetrafluoroethylene (44.12%) were the major types found in influent and surface water, respectively. The wastewater treatment system of the landfill demonstrated an overall removal efficiency of 71.88% for MPs in leachate. These findings highlight the extent of MP contamination in landfill environments and the importance of improving treatment processes to mitigate their release into surrounding ecosystems.

1. Introduction

Plastic is indispensable in contemporary daily life. The development of plastic has been increasing considerably since the 1950s. In the Year 2017, world plastic production reached 348 million tons [1]. Approximately 50% of plastics are used for single-use disposable products [2]. A large amount of abandoned plastics accumulating in the environment has been causing serious environmental problems [3].

Microplastics was defined as plastic particles <5 mm, it can be divided in to “primary MPs” (intentionally produced small plastic particles) and “secondary MPs” (formed from breakdown of larger plastic material) according to sources. Microplastics have become an exemplary indication of man-made waste and driver of environmental pollution [4]. Primary MPs are derived from a wide range of sources, including synthetic fibers from clothing, polymer manufacturing and processing industries, and personal care products [5], while secondary MPs originate from the breakdown of plastic debris [6]. Landfilling, as a widely applied strategy in the world for the disposal of waste, was estimated to store 21-42% of the global plastic waste production [6]. A large amount of plastic is buried in landfills. Microplastics could be generated by one or a combination of factors such as landfill fluctuating temperatures (reaching as high as 60-90 ºC), ranging pH values (4.5 to 9), Deep-seated fires, physical stress and compaction and microbial degradation, etc.

Some studies have shown that MPs can have negative effects on aquatic and terrestrial organisms. Therefore, the identification and quantification of major sources of MPs ought to be prioritized e.g., landfilling of waste should be considered one of the potential primary sources, in particular by the pathway of landfill leachates. Leaching of various contaminants from landfills, including plastic additives. Neither information on MP content in landfill leachates, nor on the potential impact of landfill leachate treatment on potential MP content has been

previously available. If landfills are indeed a significant source of MPs, which have detrimental effects in the environment, this should be addressed. In the report titled of Booklet on Thailand State of Pollution 2020, the number of solid wastes was 27.35 million tons [7]. These solid wastes were separated at sources for recycling as 11.93 million tons were correctly disposed as 11.19 million tons and were incorrectly disposed as 4.23 million tons. The top 5 of clean provinces in 2020 were Bangkok, Phuket, Lamphun, Rayong, and Nonthaburi, respectively. There is very little research into MPs at landfill sites, but since they are still a fundamental disposal option for plastic waste, they remain a possible reservoir of MPs from the breakdown of plastics [8]. Although there were many reports found that MPs can generate in water and leachate samples from the landfill [9], it exists many blanks there were many rooms to enhance. The purpose of this study is to examine abundance and characteristics of MP contaminations in water and leachate of solid waste landfills, and to acquire information on the comparison of solid waste in different landfills on the amounts of MPs both untreated and treated before releasing to public water sources.

2. Methods

A. Study Area

The Nonthaburi Provincial Administrative Organization (NPAO) Waste Management Center is located in Nonthaburi Province, Thailand (e.g. Fig. 1). This facility plays a pivotal role in managing the increasing amount of municipal solid waste generated by the province, which has seen a steady rise in recent years due to population growth and urbanization. The center employs a variety of waste management strategies, including waste-to-energy initiatives, landfill management, and innovative waste treatment technologies to tackle the escalating waste problem and minimize environmental impacts. One of the main challenges in Nonthaburi is the substantial increase in waste generation. The amount of waste recorded before disposal in the landfill area of NPAO in the year 2018 is 1,506 tons/day consisting of 1,436 tons/day of waste in Nonthaburi province and 70 tons/day of waste outside Nonthaburi province. The increase of waste from 2009 to 2018 has an average increase rate of 5.5 percentage, with the rate of waste per capita of 1.15 kg/person/day [10].

This significant amount of waste poses challenges in both proper disposal and resource recovery, and it underscores the necessity for comprehensive waste management systems. Landfill management is essential aspect of the center's operations. Nonthaburi has well-designed landfill structures with comprehensive odor control measures and post-landfill capping processes. Advanced reverse osmosis systems treat leachate to prevent groundwater contamination. These measures help the facility operate sustainably while mitigating environmental risks. The degradation of plastic waste within landfills, especially under anaerobic conditions and through mechanical processes such as waste compaction and landfill gas recovery, may produce MPs. However, there is little information on the rates and mechanisms of MP generation within such environments. Understanding the breakdown pathways of microplastics into MPs in landfills is essential for assessing the potential contribution of these sites to MP pollution.

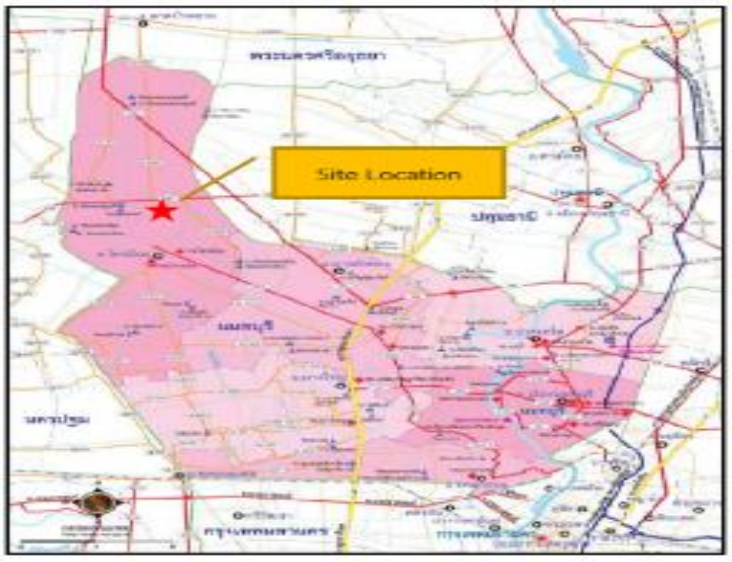

Fig. 1 The Nonthaburi Provincial Administrative Organization (NPAO) Waste Management Center, Sai Noi District, Nonthaburi Province. Approximately 500 rai (197 acres) 35 kms far from Bangkok, Thailand

B. Sampling and Sample Analysis

The main research gap regarding MP contamination in leachate and wastewater treatment at the Nonthaburi Waste Management Center lies in the limited understanding of the extent and mechanisms by which MPs are generated, transported, and removed during treatment processes. Additionally, the potential for treated water to release MPs into surrounding environments and the long-term environmental impacts of this contamination are largely unexplored. Addressing this gap is crucial for improving treatment efficiency and reducing pollution risks. For each leachate, several liters of sample were collected at four locations including of leachates, surface water, influent and effluent (e.g. Fig. 2) on Jun 30, 2023, using a metallic jar. Each sample was filtered through stacked stainless-steel sieves with mesh sizes of 5 mm to remove large debris, retaining the residue on the sieves. A total of four samples were collected from all sources, which were then transported to the laboratory for further MP extraction and analysis.

Fig. 2 Sampling Points of MPs across different water sources at leachate B (L-B1), leachate D (L-D1), surface water, influent and effluent.

At laboratory, MPs were extracted from the particulate samples using a combination of wet peroxide oxidation (WPO) and sodium chloride (NaCl) density separation, based on modified protocols from the National Oceanic and Atmospheric Administration's methods for analyzing microplastics in the marine environment. These methods, described by [11], provide guidelines for quantifying synthetic particles in water samples.

The particulate samples were placed in glass beakers, covered with aluminum foil, and dried at 60°C for 24–48 hours. Hydrogen peroxide (H_2O_2, Merck KGaA, Germany) and iron sulfate ($FeSO_4$, Ajax Finechem, Australia) were then added to the samples to digest organic contaminants [12]. Afterward, NaCl (Carlo Erba, France) was added to increase the solution's density. The samples were transferred to a separation unit and left to settle overnight. The MPs were then filtered from the solution using a 12 µm polycarbonate nucleopore track-etched membrane (Whatman, 110616, USA). The filters were placed in clean glass petri dishes and air-dried at room temperature before being examined under a microscope.

All MPs in the samples was quantified and confirmed by plastic identification. In brief, all collected particles were placed on a KBr window for polymer type analysis using a Fourier-transform infrared microscope (micro–FTIR: Bruker, Lumos II, Germany). The infrared (IR) spectra were obtained in transmission mode, within the wavenumber range of 4000–600 cm^{-1}, at an acquisition rate of 6 cm^{-1}/s. Background scans were conducted prior to each new sample to minimize background noise. The polymer composition of the MPs was determined by comparing the IR spectra against a spectral database for polymers and additives, using OPUS 8.5 SP1 software (Bruker, Germany). Results with a similarity of over 60% were considered valid. The number of reported MPs was the particles having the plastic similarity score more than 60%. Additionally, the MPs in this study, all larger than 16 µm, were well-suited for micro–FTIR analysis, which can detect particles as small as 10 µm. Finally, the photographs of MPs were captured simultaneously under a stereomicroscope (Shodensha, Trinocular Stereomicroscope NSZ405J3, Japan).

3. Results and Discussion

Microplastics in different sources of The Nonthaburi Provincial Administrative Organization (NPAO) Waste Management Center. Results of the present study showed that MPs were contaminated in various abundance and characteristics at all the sampling points (e.g. Fig. 3). All finding results were reported as follow:

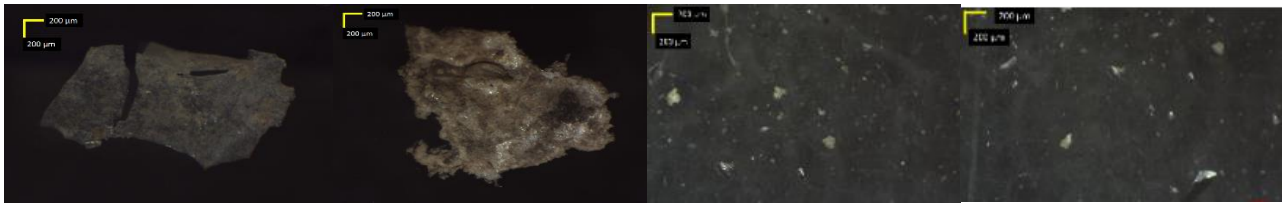

Fig. 3 Detection of MP photos in the environmental occurrences of The Nonthaburi Provincial Administrative Organization (NPAO) Waste Management Canter.

A. Microplastic Contaminations

The abundance of MPs in leachate, surface water and wastewater treatment were compared across different sources. Leachate from site D had the highest concentration, with approximately 283.14 pieces/L, followed by leachate from site B with 64.81 pieces/L. Influent contained 38.40 pieces/L, surface water (pond) had 11.33 pieces/L, and the lowest concentration was found in effluent, with 10.80 pieces/L. This study indicates that leachate, particularly from site D, had the highest volume of MPs, while the effluent had the lowest (e.g. Fig. 4). This pattern suggests a potential point source or higher MP accumulation at L-D1, which could be influenced by proximity to the waste management site or other localized factors, while the other sites show lower contamination levels. This observation aligns with studies showing that landfill leachates and industrial wastewater effluents can significantly contribute to MP pollution, with smaller particles (less than 100 µm) being more abundant due to fragmentation.

The concentration of MPs in leachate and wastewater in this study showed a 72% reduction when comparing untreated leachate (influent) to treated leachate (effluent). This reduction is comparable to the 76% reduction reported in municipal solid waste treatment in Fiflhot, Iceland [13]. It is higher than the 50% reduction observed in municipal solid waste in Shanghai, China [14], but lower than the 99% reduction reported for municipal solid waste treatment in Suzhou, China [15].

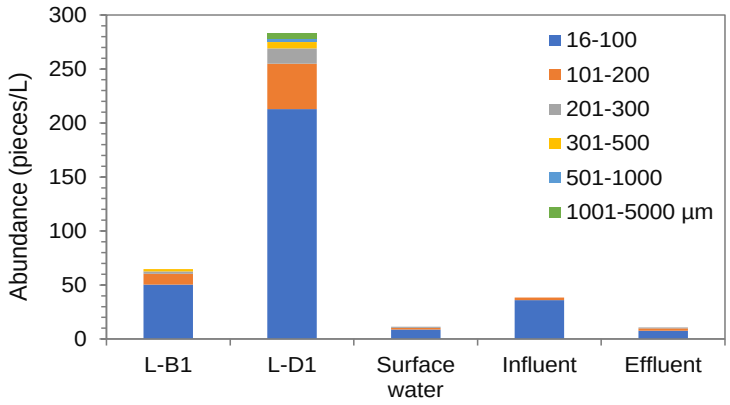

Fig. 4 Abundance of MPs across different water sources (L-B1, L-D1, surface water, influent, and effluent) categorized by size fractions.

B. Microplastic Characteristics

1) Size fractions*:* The size fraction of MPs in leachate and wastewater were analyzed and compared across different sources, including leachate, surface water, influent, and effluent (e.g. Fig. 3 and 4). The maximum size of MP particles was defined as 5,000 µm, with the minimal detectable size being 16 µm. Six distinct size ranges were identified in the samples: 16–100, 101–200, 201–300, 301–500, 501–1,000, and 1,001–5,000 µm. The 16-100 µm size range represented the highest percentage of MPs across all sources, with concentrations as follows: leachate B (77.71%), leachate D (75.21%), pond (77.45%), influent (93.75%), and effluent (71.28%). The second most abundant size range was 101–200 µm, with percentages as follows: leachate B (15.43%), leachate D (14.82%), surface water (13.73%), influent (6.25%), and effluent (19.15%). MPs in the 501-1,000 µm and 1,001–5,000 µm size ranges were not detected in leachate B. In leachate D, the 501–1,000 µm size range had the lowest percentage (1.25%). MPs in the 301–500 µm, 501–1,000 µm, and 1,000–5,000 µm size ranges were not found in the surface water and effluent sources. Additionally, MPs in the 201–300 µm, 301–500 µm, 501–1,000 µm, and 1,001–5,000 µm size ranges were absent in the influent samples (e.g. Fig. 5).

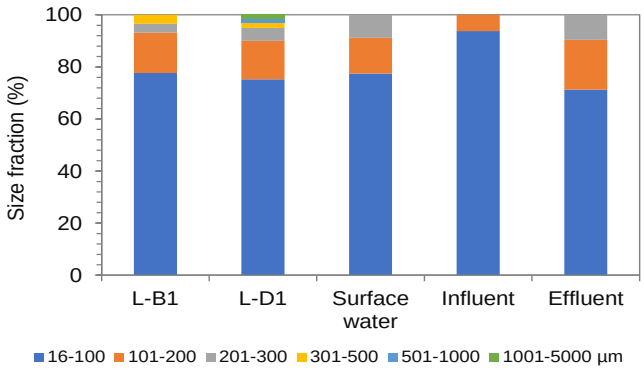

Fig. 5 Size fractions of MP in leachate and wastewater at Nonthaburi Province compared to sources at leachate B, leachate D, surface water, influent and effluent.

2) Chemical polymeric types: The first spectrum shows dominant peaks at around 2950 cm^{-1} and 2850 cm^{-1}, which correspond to the C-H stretching vibrations of the methylene ($-CH_2-$) and methyl ($-CH_3$) groups, indicating the presence of polypropylene (PP). The peaks around 1450 cm^{-1} and 1375 cm^{-1} further confirm the identification as PP (e.g. Fig. 6a). While another spectrum is characterized by prominent peaks near 2920 cm^{-1} and 2850 cm^{-1}, representing the C-H stretching vibrations. The additional peaks at 1456 cm^{-1} suggest the presence of polyethylene (PE), commonly used in packaging materials (e.g. Fig. 6b). The last spectrum shows key peaks that confirm the presence of PS. The peaks around 3025 cm^{-1} and 2923 cm^{-1} correspond to the C-H stretching vibrations of aromatic and aliphatic groups, respectively, which are commonly observed in aromatic polymers like PS. The distinct peak at 1601 cm^{-1} is due to the C=C stretching vibration of the aromatic ring, while additional peaks at 1493 cm^{-1} and 1451 cm^{-1} correspond to aromatic C-H bending vibrations. Finally, the sharp peak at 755 cm^{-1} is associated with the out-of-plane bending of the aromatic C-H bonds, further confirming the aromatic nature of the polymer (e.g. Fig. 6c).

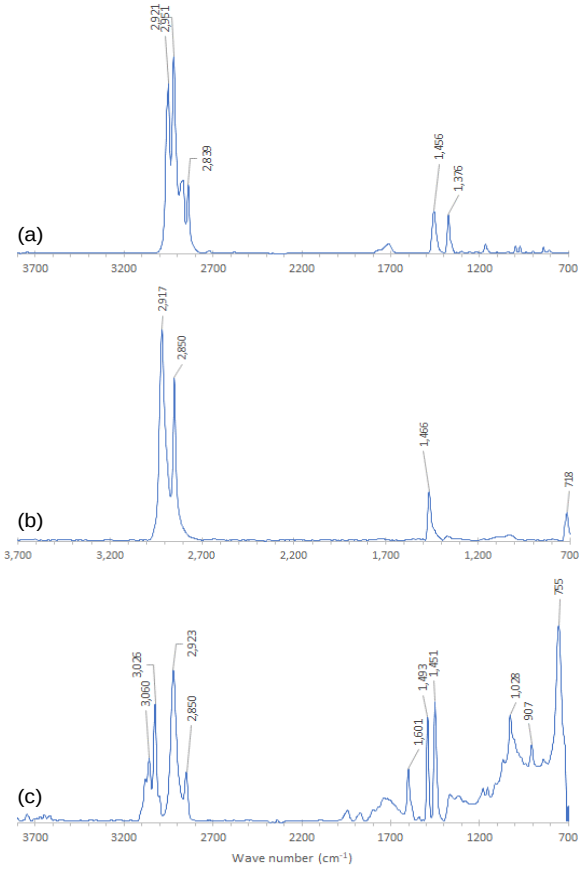

Fig. 6 Dominant FTIR spectra of MP samples from different sources.

In total, five main types of plastics were identified in all samples including Polypropylene (PP), Polyethylene (PE), Polystyrene (PS), Polyamide (PA), and Acrylate. In leachate B, Polypropylene (PP) and Acrylonitrile Butadiene Styrene (ABS) made up the highest proportion, accounting for 94.86% of MPs. In leachate D, PP and PE were the most prevalent, comprising 97.23% of MPs. In the surface water, PP and Polytetrafluoroethylene (PTFE) were the dominant types, representing 77.45% of MPs. For influent samples, PP and Acrylate were the only types identified, making up 100% of MPs. In effluent, PP and PA were the most abundant, accounting for 68.09% of MPs (e.g. Fig. 7). The comparative analysis of the polymeric composition across different environmental compartments highlights significant variability. Landfill leachates show a higher prevalence of PE and PP, possibly due to the disposal of plastic products, while surface waters exhibit a more varied mix of polymers. The composition in wastewater treatment systems reveals inefficiencies in removing certain polymers, emphasizing the need for improved treatment technologies. These findings are consistent with studies in similar environments, which have reported similar polymer distribution patterns in various aquatic and landfill-related samples [16].

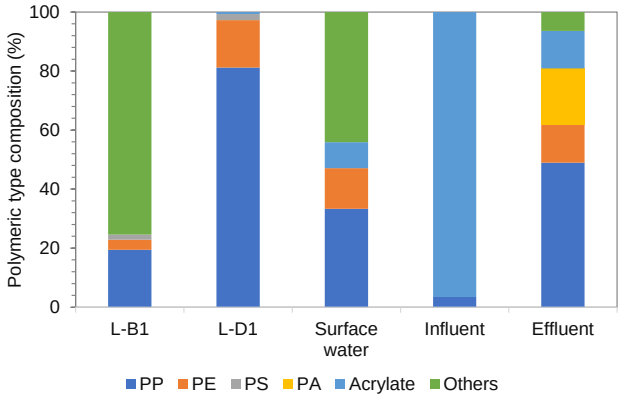

Fig. 7 Percentage of chemical polymeric identification of MP in leachate and wastewater at Nonthaburi Province compared to sources at leachate B, leachate D, surface water, influent and effluent.

4. Conclusions

The study of MP contamination at The Nonthaburi Provincial Administrative Organization (NPAO) Waste Management Center highlights significant findings regarding the presence and removal of MPs in landfill leachate and wastewater treatment systems. These findings emphasize the environmental risks associated with MPs and the need for improved waste management practices to mitigate their release into surrounding ecosystems. A major conclusion of the study is the considerable contamination of MPs in leachate, particularly in leachate D, which had the highest concentration of 283.14 pieces/L. Leachate B also showed a significant concentration of 64.81 pieces/L, indicating that leachate sources are major contributors to MP pollution. Influent and surface water samples had lower MP concentrations, at 38.40 pieces/L and 11.33 pieces/L, respectively, while effluent had the lowest concentration of 10.80 pieces/L. These results show that landfill leachate, particularly untreated, serves as a significant source of MP contamination, which can potentially enter water bodies and impact aquatic ecosystems. The study also revealed that the size range of 16-100 µm dominated MP contamination in all sources, accounting for 71.28-93.75% of the total particles across leachate, surface water, influent, and effluent. This prevalence of smaller MPs highlights the challenges in capturing and removing these particles in standard wastewater treatment processes. The second most abundant size range was 101-200 µm, but MPs larger than 500 µm were rarely detected, especially in influent, effluent, and surface water. This underscores the difficulty in filtering out smaller MPs, even in treated effluent. In terms of polymer composition, the study identified five main types of plastics: PP, PE, PS, PA, and Acrylate. PP was the dominant polymer in most samples, particularly in leachate D (97.23%) and leachate B (94.86%). Other polymers like Acrylate and Polytetrafluoroethylene (PTFE) were also present but to a lesser extent. The high prevalence of PP suggests its widespread use and persistence in landfill environments, making it a significant contributor to MP pollution.

The effectiveness of the wastewater treatment system at The Nonthaburi Provincial Administrative Organization (NPAO) Waste Management Center was also evaluated. The system demonstrated a 72% reduction in MP concentration when comparing untreated leachate (influent) to treated leachate (effluent). While this reduction is comparable to other studies, such as the 76% reduction reported in Fiflhot, Iceland, it

falls short of the 99% reduction observed in Suzhou, China. This suggests that there is room for improvement in the treatment system's ability to remove MPs, especially smaller particles that are more difficult to capture. In conclusion, the study highlights the significant contribution of landfill leachate to MP pollution and the challenges associated with removing MPs, particularly those in the smaller size ranges, through wastewater treatment processes. It underscores the need for enhanced treatment technologies to better capture MPs before they are released into the environment. Additionally, the study calls for further research into the long-term environmental impacts of MPs and the development of more effective strategies to control their release from waste management systems.

Acknowledgement

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