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RESEARCH ARTICLE

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# Spatial Distribution and Ecological Risk of Microplastic Contamination in River Water Near a Landfill Leachate Disposal Area: A Case Study of Supit Urang Landfill, Malang City, Indonesia

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**ABSTRACT**

Microplastics (MPs) in landfill leachate are a critical environmental challenge due to their persistence in natural environment, where they resist degradation and pose long-term environmental risks, including harm to aquatic ecosystems and human health. Specifically, Supit Urang Landfill in Malang discharges leachate containing microplastics into the Sumber Beling River, which flows through the densely populated areas of Mulyorejo and Bandulan. This poses a significant risk, as public awareness of microplastic pollution remains low, and residents continue using the river for activities like fishing, washing, and bathing. This study examines the distribution and properties of microplastics in Sumber Beling River and assessed their ecological risk levels. Nine sampling points were chosen to represent pollution sources, upstream quality controls, and downstream sites impacted by pollution. We employed ATR-FTIR spectroscopy for its high accuracy in identifying microplastics, along with an ecological risk assessment using PHI, PLI, and PERI. The results revealed that microplastic abundance varied between 63 and 240 particles/L, with the highest concentration found in densely populated areas (TS.7). The predominant shapes of MPs were films (48.30%) and fragments (42.98%), with polypropylene (PP) and polyethylene (PE) being the most prevalent polymers detected. Although the overall ecological risk was low, site P5, located in the densely populated residential area of Mulyorejo, exhibited a high risk level. These findings underscore the urgent need for targeted interventions in densely populated areas to enhance waste disposal and raise community awareness regarding microplastic pollution.

## Introduction

Over the past half-century, single-use plastic consumption has become a basic need for human life, leading to the "plastic age”. In 2017, the increasing scale of plastic manufacturing worldwide reached 348 million tons [1]. The widespread use of plastics has been based on their benefits. Plastic is more durable and stronger than other materials, making it a commercially advantageous and profitable material for many industries [2]. However, its environmental impact has not been adequately considered, particularly when plastic degrades into microscopic particles ranging from 1 µm to 5 mm, commonly referred to as microplastics (MPs). MPs contamination is believed to threaten the environment, especially human health, as these particles do not degrade completely in nature for centuries [3]. MPs particles accumulating in the human body can potentially cause cancer due to their carcinogenic properties and health hazards [4]. These pollutants can also disrupt plant growth and soil health [5].

In recent years, research on MPs has attracted significant scientific interest. These contaminants can spread throughout all layers of the environment, both in freshwater systems like drainage [6], rivers, and lakes [7] as well as in landfill leachate [8]. Plastic decomposition into MPs at landfills can take about 20 years due to high temperatures, UV light, and oxygen [9]. Leachates discharged into rivers without treatment can become

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a significant source of water bodies, eventually reaching the ocean. This poses an ecological risk to aquatic environments that are affected by MPs contamination. Microplastics particles can slip through the digestive systems of aquatic organisms and subsequently be transferred to the human body via the ingestion of contaminated organisms [10]. However, MPs have not yet been a significant focus in leachate treatment [11].

In terms of waste management, Malang City is actively collaborating with Germany under the Emission Reduction in Cities - Solid Waste Management (ERIC-SWM) Project to enhance urban waste management practices. This initiative focuses on constructing sanitary landfills, implementing waste sorting, composting, and establishing leachate treatment plants. It is implemented at the Supit Urang Landfill, the largest waste management center in Malang City [12]. Although the quality of leachate released into the river meets the quality standards, the parameters used do not consider MPs contamination in the environment. This oversight highlights a significant gap in addressing the growing concern of microplastics in water systems. Leachate treatment at the landfill includes three steps: anaerobic ponds, membrane bioreactors with denitrification, nitrification, ultrafiltration processes, and wetland ponds. The treated leachate was discharged into the Sumber Beling River, north of Supit Urang Landfill.

The Sumber Beling River is the primary outlet for leachate discharged from the Supit Urang Landfill. Its upstreams originate in the valleys and hills west of the landfill, and the river flows through agricultural regions and densely populated residential areas such as the Mulyorejo and Bandulan Baru Subdistricts before merging with the Metro River. Leachate discharged into the river undergoes environmental transformations, including accumulation, breakdown, and dispersion under diverse ecological conditions. Over time, it can infiltrate the human body via multiple exposure pathways, such as inhalation, ingestion, and dermal absorption [13]. Public awareness of the hazards posed by MPs contamination in rivers due to leachate remains limited, as evidenced by the persistent behavior of residents who continue to use river water for activities such as fishing, washing, and bathing. Additionally, dedicated structures near the Cindelaras Dam at Mulyorejo residents were specifically used for washing and bathing. The more frequent the public's behavior of utilizing rivers, the lower the public's knowledge and awareness regarding MPs pollution [14].

Given these issues, this research was designed to assess the prevalence and properties of MPs in the Sumber Beling River contaminated by Supit Urang Landfill leachate. It will investigate variations in MPs abundance across sampling points to identify differences and sources of microplastic contamination. The hypothesis was that MPs abundance and characteristics will vary significantly based on proximity to the landfill, indicating a direct correlation with leachate discharge. Additionally, this study will evaluate the ecological implications of MPs to assess potential risks to the local community, thereby enhancing comprehension of microplastic contamination in freshwater ecosystems.

## Materials and Methods

### Study Area and Sampling Methods

The selection of MPs sampling sites was guided by the Indonesian Ministry of Environment and Forestry Regulation No. 27 of 2021 regarding the environmental performance assessment. Some criteria include representing pollution sources and sampling upstream water bodies that have not been affected by human activities. Therefore, based on the administrative map and catchment area of the Sumber Beling River, nine sampling locations were identified, including leachate before and after treatment (TS.1 and TS.2), upstream areas as quality controls (TS.3), leachate outlet points (TS.4), and polluted areas, according to the characteristics of the regions traversed by the river (TS.5, TS.6, TS.7, TS.8, and TS.9), as shown in Figure 1. Focusing solely on water samples allows researchers to identify suspended MPs easily exposed to humans and aquatic organisms. This study's sampling method follows the guidelines issued by Mississippi State University, which is titled "Microplastics Sampling and Processing Guidebook" [15]. Water samples were collected three times on January 17, 2024, during the rainy season, using glass containers with a volume of one liter and then filtered through layered steel mesh sieves with pores of 0.5 mm and 0.05 mm. The final MPs were determined by averaging the values from three water samples collected at each sampling site.

### Microplastics Identification

In this sample analysis process, we followed the guidelines issued by Masura et al. [16]. The analysis consisted of three stages: wet peroxide oxidation (WPO), microplastic particle separation, density separation, and subsequent MP identification. The identification process was divided into two parts: the first was microscopic identification to determine the shape and size using a binocular microscope (CX23LEDRFS1, Olympus, Japan), and observed using Image Raster software, followed by polymer type identification using chemical characterization with Attenuated Total Reflection (ATR) - Fourier Transform Infrared (FTIR) spectroscopy. MPs analysis results obtained through FTIR are presented in graphs showing the wavelengths absorbed by the MPs samples. Each type of polymer has distinct absorbed wavelength values [17]. It was then compared with data from the Primpke microplastics FTIR Library using SpectraGryph 1.2 software to assess the accuracy of polymer types within the samples against known MPs types.

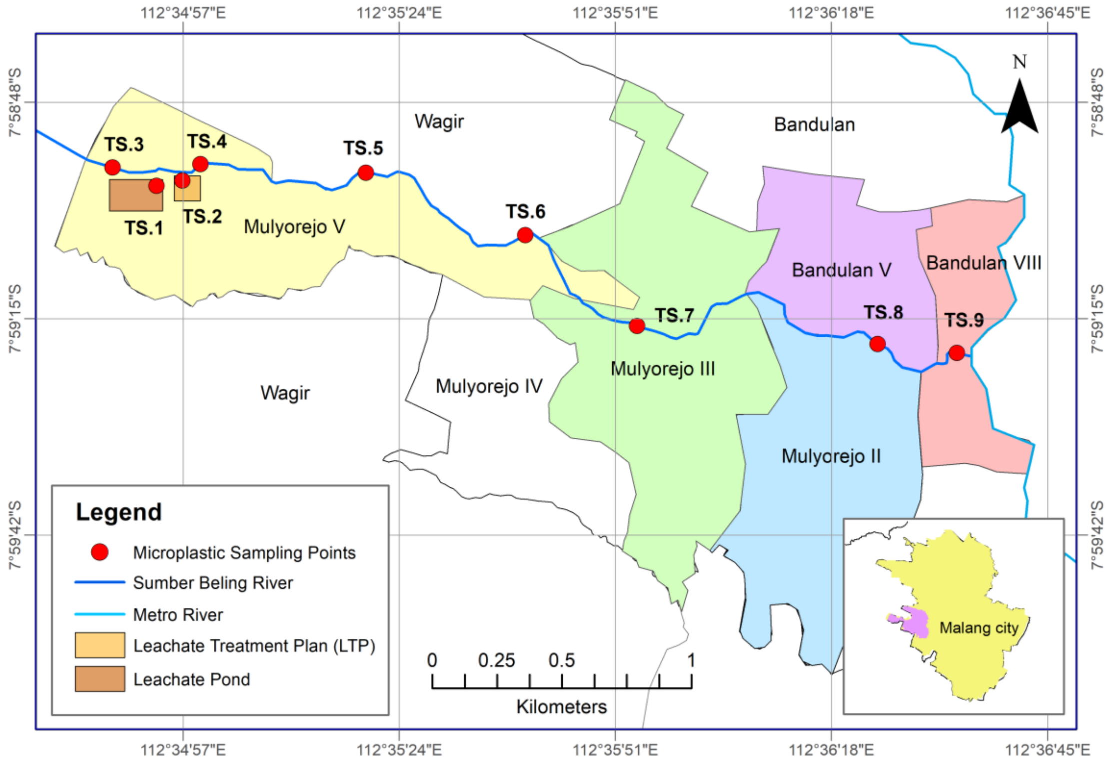


**Figure 1.** Location of MPs sampling points at Sumber Beling River.

**Quality Control**

Maintaining rigorous quality control throughout the entire research process, from initiation to completion, is essential to ensure the reliability and comparability of MPs data, encompassing procedures such as sample collection, extraction, and analysis. As highlighted by Wang et al. [18], all plastic materials must be thoroughly removed from laboratory surfaces and equipment. Stringent measures were essential for mitigating the risk of contamination. In this study, all fieldwork equipment and laboratory instruments were washed at least three times with purified water. To avoid external contamination, glass beakers were covered with aluminum foil and securely sealed. Additionally, cotton coats and gloves were worn as the main clothes during sampling and analysis to prevent contamination from plastic fibers. A control Petri dish containing distilled water was placed in a sterile laboratory cabinet to minimize potential airborne contamination during the study.

**Statistical Analysis**

We employed a One-Way ANOVA test assess variations in the average concentration of MPs across all sampling points, aiming to determine whether differences in MPs concentrations between various sites were statistically significant, aided by SPSS 16.0. This approach directly supports the objective of evaluating microplastic variations influenced by landfill leachate. Additionally, each observation in the ANOVA analysis must be independent [19]. To validate our analysis, the Shapiro-Wilk test was used to assess data normality, while Bartlett's test was conducted to verify variance homogeneity across groups. Ensuring that each observation remained independent was also critical for the validity of ANOVA. Subsequently, Tukey Honestly Significant Difference (HSD) test was then performed to determine which sampling locations exhibited significant variations in MPs abundance. Additionally, spatial maps of MPs distribution were created using the Inverse Distance Weighting (IDW) method in ArcGIS version 10.8. This visualization links our statistical findings to environmental sources, enhancing deeper insight into the ecological impact of MPs contamination while aligning our statistical methods with the objectives of the study.

**Ecological Risk Assessment**

At present, a standardized and systematic framework for evaluating the ecological risks associated with MP contamination in river ecosystems remains unavailable. Consequently, the risk evaluation in this study is based on models previously formulated by Wang et al. [18] and Lithner et al. [20]. These models are based on the MPs concentration, the variability in polymer structures, the threats and risks of each polymer. A Polymer Hazard Index (PHI) calculation for MPs is used to evaluate the possible impact of synthetic polymers on ecological systems and public health in the study area. MPs polymers' chemical toxicity is a critical indicator in assessing their ecological damage. $Pn$ indicates the percentage of every polymer category within a sample, and $Sn$ denotes the hazard value listed in the Hazard Ranking table for polymers compiled by Lithner et al. [20].

$$PHI = \sum_{n=0}^{n} Pn\ Sn \tag{1}$$

The Pollution Load Index (PLI) for MPs is a technique utilized to assess the extent of water environment contamination by MPs. It is a consistent framework for assessing and comparing pollution across various locations. The calculation for each sample is based on the MPs concentration factor ($CF_i$), which represents the proportion of MPs in each sample ($C_i$) to the minimal recorded MPs presence across various sites documented in prior research ($C_{0i}$) [20]. Since there are no prior studies on MPs at the study location, the lowest abundance found is $C_{0i}$ [21]. PLI is particularly effective in identifying microplastic pollution hotspots and can guide targeted interventions and monitoring efforts.

$$CF_i \ = Ci/C_{0i} \tag{2}$$

$$PLI_i = \sqrt{CF_i} \tag{3}$$

The Potential Ecological Risk Index (PERI) served as a metric to assess the environmental hazards of the polymers, individually and in combination with persistence. PERI incorporates several key factors, including the polymer concentration, the toxic properties of the polymers, and the extent of MPs contamination within the research location [18]. These are essential because the concentration of MPs in a given location indicates the severity of pollution, each polymer exhibits varying levels of toxicity, and the extent of MPs distribution significantly affects the environment.

$$T_r^i \quad = \sum_{n=0}^{n} \frac{P_n}{C_i} S_n \tag{4}$$

$$E_r^i \quad = T_r^i\ CF_i \tag{5}$$

$$PERI = \sum_{i=I}^{n} E_r^i \tag{6}$$

$T_r^i$ represents the risk factor for each MPs abundance, where $P_n$ indicates the percentage of each polymer category within a sample, $C_i$ is the average MPs concentration at the station, and $S_n$ is the toxicity rating to each polymer. $E_r^i$ quantifies the ecological risk associated with the abundance of microplastics with $T_r^i$ as the risk factors and $CF_i$ denoting the microplastic pollution load in the river area. Lithner et al. [20] provide a framework for evaluating hazard levels and MP risk categories, as illustrated in Table 1.

**Table 1.** Hazard levels and MP risk categories.

| Risk model | Range | Risk category |
|---|---|---|
| Pollution Load Index (PLI) | < 10 | I |
| | 10–20 | II |
| | 20–30 | III |
| | > 30 | IV |
| Pollution Hazard Index (PHI) | 0–1 | I |
| | 1–10 | II |
| | 10–100 | III |
| | 100–1,000 | IV |
| | > 1,000 | V |
| Potential ecological risk assessment (PERI) | < 150 | Minor |
| | 150–300 | Medium |
| | 300–600 | High |
| | 600–1,220 | Danger |
| | > 1,220 | Extreme danger |

## Results and Discussion

### Results

MPs, including leachate and river water, were detected at all sample locations. TS.1 and TS.2 represent the abundance in the leachate from Supit Urang Landfill, whereas TS.3 to TS.9 indicate the abundance levels in Sumber Beling River. The highest abundance was found at TS.7 in the Sumber Beling River, with 240.00 particles/L, characterized as dense residential settlements. The lowest abundance was at TS.3, with 63.00 particles/L, in an agricultural area (Figure 2). The mean concentration was recorded 126.21 particles/L.

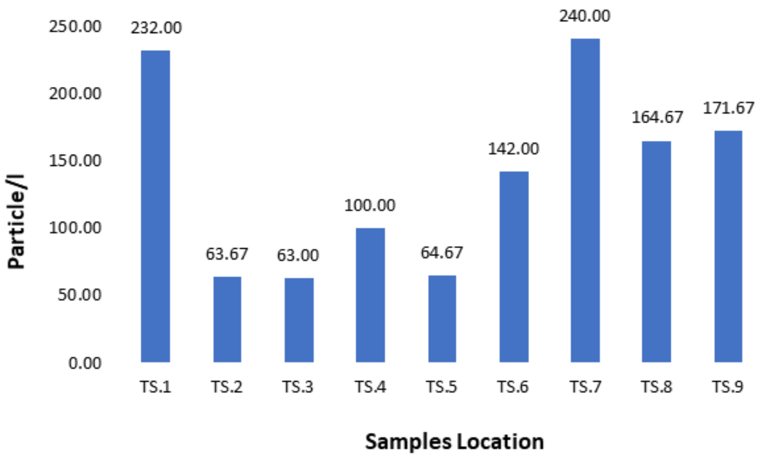


**Figure 2.** The abundance of MPs in landfill leachate and Sumber Beling River.

Based on the variance analysis of all samples, the significance level was shallow at 0.000, which is less than 0.05 (0.000 < 0.050). This indicated that the levels of MPs contamination varied considerably across various collection sites. The results of Tukey's HSD test (α = 0.05) further indicated that the samples could be grouped into three subsets based on MPs concentration. The first subset consisted of TS.2, TS.3, and TS.5, which had the lowest MPs concentrations (63–64.67). Meanwhile, the second subset included TS.6, TS.8, and TS.9, with higher concentrations (142–171.67), but no significant differences were observed among them. The third subset, which had the highest MPs concentrations, comprised TS.1 and TS.7 (232–240) and differed significantly from the other subsets.

**Table 2.** Results of MPs variance analysis using Tukey's HSD test.

| Sample | N | Subset for alpha = 0.05 | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| TS.2 | 3 | 63.6667 | | |
| TS.3 | 3 | 63.0000 | | |
| TS.5 | 3 | 64.6667 | | |
| TS.6 | 3 | | 142.0000 | |
| TS.8 | 3 | | 164.6667 | |
| TS.9 | 3 | | 171.6667 | |
| TS.1 | 3 | | | 232.0000 |
| TS.7 | 3 | | | 240.0000 |
| Sig. | | 1.000 | 0.581 | 1.000 |

In Figure 3, dark green areas represent regions with an abundance of 63.00–92.85 particles/L, found at TS.2, TS.3, and TS.5. These points have the same variance value, with a significance level of 1.000 (1.000 > 0.050), as shown in Table 2. A similar variance was noted at three other yellow-marked sites: TS.6, TS.8, and TS.9, with a significance level of 0.581 (0.581 > 0.050), categorized as having similar characteristics, being in suburban residential areas. TS.1 and TS.7 also share the same variance significance level of 1.000 (1.000 > 0.050). The variance is visualized in red, indicating the highest abundance compared with other locations, with an average abundance of 212.93–240.00 particles/L.

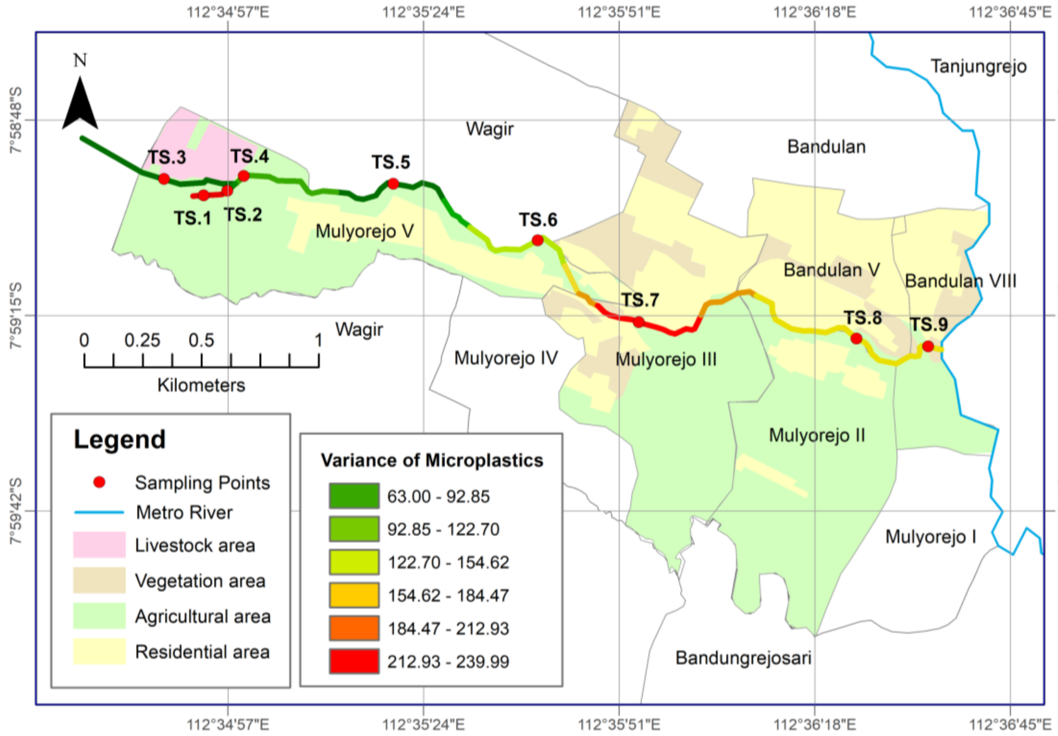


**Figure 3.** The spatial variance of MPs abundance at Sumber Beling River.

The highest percentage of large microplastics particles (LMP) with sizes ranging from 1 to 5 mm, was found at TS.6, comprising 5% with 142.00 particles/L (Figure 4). Although represented as the highest percentage, it remains relatively low, at less than 50%. Conversely, small microplastics particles (SMP) with sizes ranging from 0.05 to 1 mm, averaged over 90% across all samples, with TS.2 having the highest percentage at 100%.

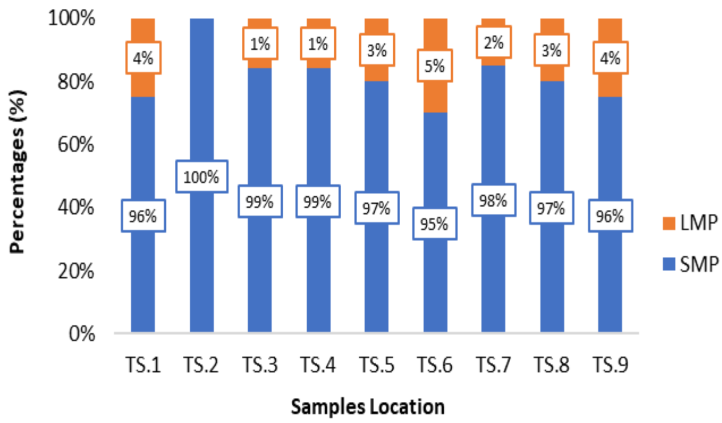


**Figure 4.** MPs abundance in each sample by size category.

Film-type MPs are the most dominant shape in the river, totaling 599.67 particles/L and making up 48.30%. TS.3, TS.6, TS.7, TS.8, and TS.9 were the most significant contributors (over 50%) (Figure 5). Fragments accounted for 533.67 particles/L or 42.98% of the total. The highest fragment percentages were at TS.2 (52.36%) and TS.4 (52.00%), representing treated leachate with a total of 33.33 particles/L and the accumulation point of leachate and river water with 52.00 particles/L, respectively. Foam microplastics were the least common, totaling 44.33 particles/L or 3.57%). The highest percentage of foam was found in TS.7, a densely populated residential area with 6.81% or 16.33 particles/L. It was not found at TS.2 (0.00%) or TS.4 (0.00%). Fiber was also the least common form of MPs, totaling 48.67 particles/L or 3.92%. The highest percentage of fiber was at TS.6, with 7.98% or 11.33 particles/L. Pellets had the lowest count, with only 15.33 particles or 1.23%. The identified microplastic shapes can be observed in Figure 6.

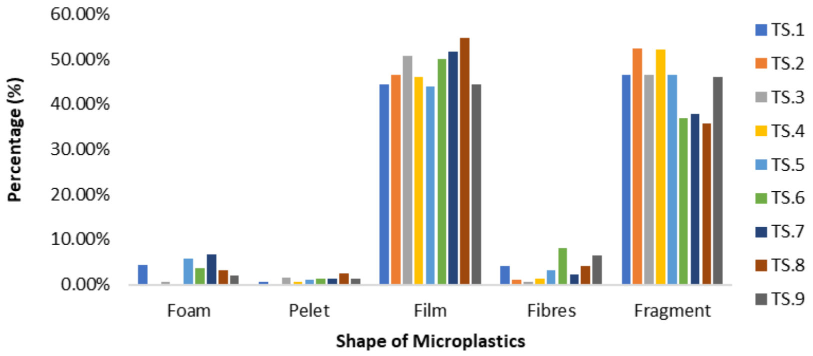


**Figure 5.** MPs abundance in each sample by shape category.

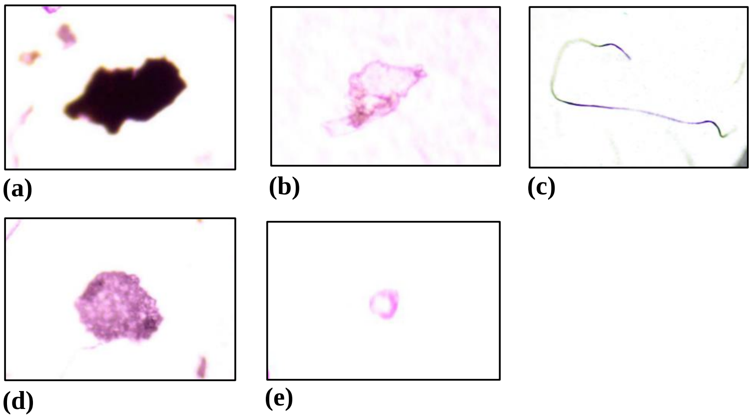


**Figure 6.** The shape of microplastics: (a) fragment, (b) film, (c) fiber, (d) foam, and (e) foam**.**

To improve the accuracy and validity of the samples, leachate and river water samples were collected according to the MPs sampling locations for ATR-FTIR analysis, considering the prevalence of SMP. The leachate sample before treatment, represented by P1, showed predominance of polyethylene (PE) at 53.48% and polypropylene (PP) at 46.52%. P2 (leachate after treatment) was dominated by PP at 55.41%. The polymer types in P3, which combined the control point (TS.3) and the pollution point (TS.4), were PP at 59.45% and PE at 40.55% (Figure 7). For sample P4 (agricultural pollution), the polymers were PE (53.39%) and PP (47.61%). In P5, representing residential area I (TS.6 and TS.7), PE was the dominant polymer at 48.00% and PP at 38.08%. Polyethylene terephthalate (PET) and polyurethane (PU) were found in lower amounts of 11.34% and 2.58%, respectively. P6 representing residential area II (combining TS.8 and TS.9), PP was 50.82%, and PE was 40.81%. PET was also found at a lower percentage (8.37%).

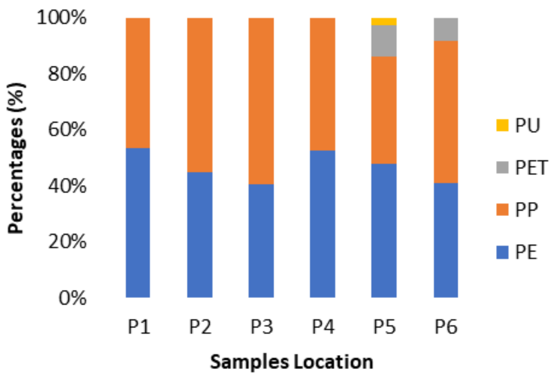


**Figure 7.** MPs abundance in each sample by polymer types.

In the leachate samples P1 and P2, the PHI values were 6.35 and 5.46 (< 1,000), respectively, which fall into Hazard Level II (Table 1). indicating a medium risk category. Similarly, river water samples P3, P4, and P6 also showed Hazard Level II (medium risk) with values of 5.06, 6.24, and 5.33 (< 1,000), as shown in Figure 8a. The highest PHI value in sample P5, from residential area 1, at 196.56 (< 1,000), is classified as Hazard Level IV, indicating a dangerous risk category. The PLI values for leachate samples P1 and P2 were 2.20 and 1.15 (<10), respectively, categorized as Risk Level I (low risk), as shown in Table 1. Besides, PLI values for all river water samples from Sumber Beling River varied: 1.33, 1.19, 2.04, and 1.91 categorized as Risk Level I (Figure 8b). The ecological risk values for MPs in the leachate (P1 and P2) were 13.96 and 6.29, falling into level I with low ecological risk (Figure 9). River water samples P3, P4, and P6 from the Sumber Beling River had ecological risk values of 6.73, 7.40, and 10.19 (< 150), categorized as level I with low risk. In sample P5 (residential area 1), the ecological risk was 400.53 (300–600), indicating Category III with high risk.

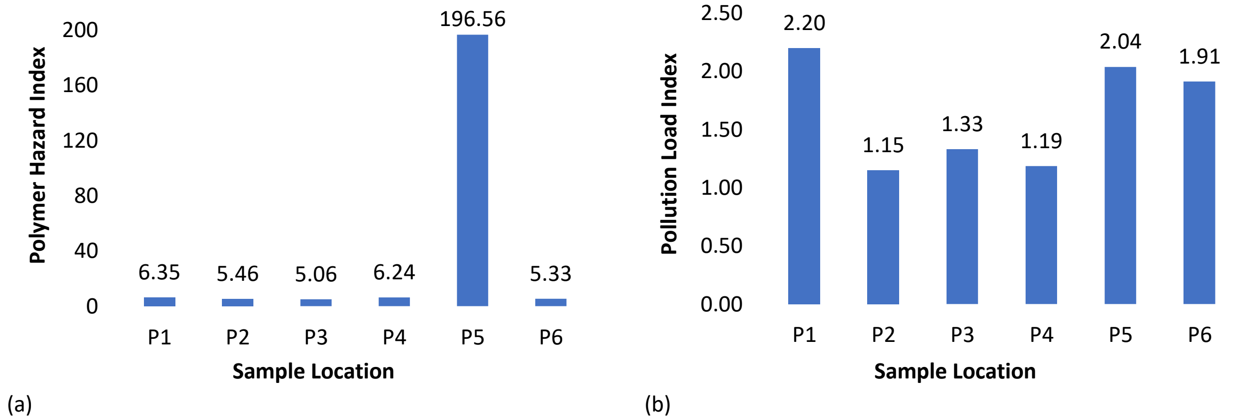


**Figure 8.** (a) Polymer Hazard Index and (b) Pollution Load Index in the study area.

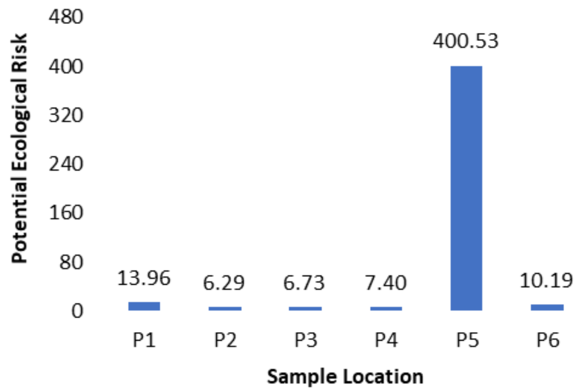


**Figure 9.** Potential Ecological Risk Index (PERI) in the study area.

**Discussion**

Microplastics (MPs) were detected at all sampling locations, including leachate from the Supit Urang Landfill and water from Sumber Beling River. The findings indicate that areas with high population density, such as TS.7, exhibit the highest MPs concentration, whereas agricultural regions like TS.3 show lower levels. This suggests that human activities significantly influence MPs distribution in aquatic environments. Regarding leachate, untreated samples at TS.1 exhibited a relatively high MPs concentration compared to other landfills, such as the Piyungan landfill, Yogyakarta [8]. This is likely due to plastic waste entering the landfill and the fragmentation or degradation of plastic materials. After treatment through the Membrane Bioreactor (MBR) system, MPs concentrations at TS.2 significantly decreased, highlighting the effectiveness of this technology in filtering microplastic particles, with an efficiency of up to 99% in leachate treatment [22]. In Sumber Beling River, the presence of MPs before leachate discharge (TS.3) indicates additional pollution sources, such as waste from upstream poultry farms. Feces and food remnants contaminated with plastic on the farm could enter the river system via runoff [23].

After the leachate discharge point (TS.4), MPs abundance increased but subsequently decreased at TS.5, which is situated further downstream, likely due to sedimentation processes. Most MPs abundance decreases in surface water 1 to 2 km from the contamination source downstream in urban wetlands due to sedimentation at TS.6 [24]. However, MPs levels increased again at TS.6, suggesting additional contributions from local activities such as waste disposal and laundry practices in the river. Other factors influencing MPs fluctuations include population density along the riverbanks. TS.7 with a high population, exhibited the highest MPs concentration. Higher population density correlates with increased human activities and waste generation [25]. Whereas subsequent locations (TS.8 and TS.9) showed a slight decline, which may be attributed to the 1.2 km distance between sampling points and interactions within the river ecosystem, such as organism [26]. These findings reinforce the notion that a combination of human activities, land use patterns, and natural processes influence MPs distribution dynamics in freshwater environments.

The variance analysis of all samples indicates a significant difference in MPs contamination across sampling locations, suggesting that variations are influenced by specific environmental factors such as pollution sources, land use characteristics, and population density [27]. The complexity of MPs distribution underscores the need for site-specific mitigation approaches, as areas dominated by agricultural and livestock activities generally exhibit lower MPs abundance, aligning with previous findings that these environments contribute less to microplastic contamination [23]. In contrast, densely populated residential areas and regions with untreated waste sources tend to have higher MPs concentrations, highlighting the role of urbanization and inadequate waste management in exacerbating pollution levels [25]. The presence of untreated leachate further intensifies MPs contamination, emphasizing the critical need for effective leachate treatment technologies to mitigate microplastic pollution in landfill effluents. Additionally, the distinct characteristics of locations situated at the confluence of multiple pollution sources illustrate the complexity of MPs transport and accumulation in freshwater systems. These findings highlight the necessity of integrating land use planning with pollution control measures to develop targeted monitoring and remediation strategies, ultimately minimizing the impact of MPs contamination on aquatic ecosystems and ensuring effective environmental management.

Large MPs were found in relatively low percentages, while small MPs dominated across all samples, likely due to their low density, which keeps them afloat. Environmental exposure, including UV radiation, waves, and climate variations, accelerates the fragmentation of large MPs into smaller particles over time [28], especially in low-flow conditions [29]. Among MPs types, films were the most prevalent, primarily originating from livestock operations and residential waste, including discarded plastic bottles, bags, and food packaging. Films are commonly used in food packaging [30]. Fragments were also abundant, particularly in areas influenced by leachate treatment plants (LTP), although their presence contrasts with Egea-Corbacho et al. [31], suggesting membrane bioreactors (MBRs) effectively prevent fragment release. This discrepancy may be attributed to airborne MPs contamination during the final treatment stages in the constructed wetland or atmospheric deposition near the landfill [32]. Foam MPs, mainly from styrofoam-based food packaging, were the least common and absent in LTP-affected locations, likely due to MBR efficiency. Fibers, primarily from laundry discharge, and pellets, potentially from cosmetic waste, were found in minor quantities. These findings highlight the role of anthropogenic activities, environmental conditions, and wastewater treatment processes in influencing MPs distribution in leachate and freshwater systems.

PE was the primary polymer in untreated leachate, suggesting that most plastic waste at the Supit Urang Landfill consists of PE, the most widely used plastic globally [30]. After treatment with the Membrane Bioreactor (MBR) system, PP became more dominant due to its lower density, making it more likely to pass through the treated leachate, whereas PE tended to accumulate during sludge sedimentation [33]. In contaminated locations, runoff from livestock operations and leachate discharge contributed to the presence of PP and PE, originating from various sources such as agricultural plastic packaging, household plastic bags, and detergent and shampoo waste [34]. Other polymers, such as PET and PU, were also detected in small quantities, particularly in residential areas, highlighting the influence of domestic activities on the composition of microplastics in aquatic environments, such as bottle caps, straws, and plastic toys [35]. These findings confirm that polymer distribution in leachate and freshwater systems is significantly influenced by wastewater treatment processes, anthropogenic activities, and the physical characteristics of each plastic type.

The low PHI values are due to the low hazard scores of the polymer types found in these samples, namely, PE and PP. However, it is essential to not overlook the potential environmental impact of these polymers, as their significance increases with higher abundance [36]. In contrast, a higher PHI value was observed in residential areas due to the presence of polyurethane (PU), a polymer with one of the highest hazard scores due to its carcinogenic monomers, posing risks to both humans and aquatic organisms [20]. Similarly, the PLI values for leachate samples indicated a low-risk classification, due to the minimal difference between the lowest MPs values ($C_{0i}$) and abundance values ($C_i$). This result contrasts with the study by Mohammadi et al. [37] on landfill leachate in Bushehr Port, Iran, which showed high PLI values. The difference is because the average lowest abundance ($C_{0i}$) in their study was relatively low compared with this study.

The ecological risk assessment also showed that MPs in the leachate and river water samples generally posed a low risk, except in densely populated residential areas with higher PHI values. Despite the low ecological risk, the presence of plastic additives—chemicals introduced during plastic manufacturing—should also be considered [38]. Furthermore, MPs have the potential to absorb and transport pollutants, such as heavy metals, increasing their toxicity and necessitating further investigation into their combined effects with other contaminants [39]. The presence of MPs in residential areas raises concerns regarding human exposure, particularly through activities such as washing, bathing and fishing, which can lead to direct contact with contaminated water. Consuming fish contaminated with MPs may cause short-term health issues, such as inflammation and digestive disorders [40], while prolonged exposure has been linked to tumor cell proliferation and damage to normal skin cells [41]. Understanding these risks is crucial for developing effective waste management strategies and public health initiatives to mitigate the impact of MPs pollution and enhance environmental safety.

## Conclusions

The abundance of MPs in leachate before treatment is notably high, but decreases significantly following treatment, which is attributed to the MBR system employed at the Supit Urang Landfill. However, further research is essential to assess the MPs abundance at each stage of the treatment process. Although the leachate discharged into the Sumber Beling River contributes to pollution, It does not serve as the main contributor to MPs pollution; rather, the main source stems from the activities of residents in densely populated areas. Evidence for this is the greater concentration of MPs found in densely populated areas compared to other regions. Across all sampling locations, MPs are predominantly small particles mainly appearing as films and fragments, with PP and PE being the most prevalent polymer types. The ecological risk assessment indicates a moderate hazard index level for most study areas, except for the densely populated residential area of Mulyorejo, which falls into the hazardous category. Additionally, all samples' PLI reflects a low danger level. Consequently, the PERI is generally low, except in Mulyorejo, which is a high-risk category. These findings emphasize the urgent need for targeted interventions in densely populated areas, where rivers are frequently used for washing, bathing, and fishing. Improving waste disposal systems and enhancing community education regarding the impact of plastic waste are essential steps to mitigate microplastic pollution and reduce ecological risks. Policymakers and environmental authorities should prioritize the continuous monitoring of MPs in water systems. Future research should explore how MPs interact with various contaminants and focus on developing more efficient removal technologies to protect ecosystems and public health.

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