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Regional Case Study

Atmospheric Microplastic Particulate Matter in an Urban Roadside: Case of Bandar Lampung City, Indonesia

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Abstract

Atmospheric microplastics (AMPs) have become a growing concern in recent years, although research remains limited. This study investigated AMPs in Bandar Lampung City, Indonesia, by roadside particulate sampling using a High-Volume Air Sampler (HVAS) over eight hours in industrial zones, residential areas, busy roads, and city centers. AMPs were identified through visual analysis for their abundance and physical characteristics. Certain samples were further examined with Raman spectroscopy. Total Suspended Particulate (TSP) levels ranged from 16.96 to 427.8 µg/m^3, with the highest concentrations in industrial areas. Microplastic concentrations ranged from 0.0021 to 0.0199 particles/m^3, with fibrous microplastics most common. Blue and grey (faded black) microplastics were the most prevalent, with particles between 500-1000 µm making up 42% of the total. Raman analysis detected Polyethylene terephthalate (PET). In S4 (city center), the highest vehicle count was 3,388±270 vehicles/day, while S2 (residential area) recorded the lowest at 1,166±99 vehicles/day. No significant relationship was found between TSP levels, microplastic concentrations, or vehicle numbers. However, Northern area may be potential sources of AMPs along traffic flow.

Keywords: Atmospheric Microplastics (AMPs); roadside; particulate matter; Bandar Lampung City

1. Introduction

Plastic pollution, specifically caused by microplastics (MPs), has become an escalating worldwide issue as a result of the rising manufacturing and disposal of plastic products (Eriksen et al., 2014; Geyer et al., 2017; Patrício Silva, 2021). In the last seventy years, there has been a significant increase in worldwide plastic production, with a total of 359 million tonnes being produced (Osman et al., 2023). Plastic pieces smaller than 5 mm in size are recognised as microplastics (Gaston et al., 2020) and are further broken down into nanoplastics, which have diameters less than 1 µm (Gigault et al., 2018). The majority of microplastics originate from sources on land, making up 80-90% of pollution, while the remaining 10-20% come from the ocean (Osman et al., 2023). Microplastics, such as fibres, fragments, and films, have been extensively found in the atmosphere (Zhang et al., 2020). Airborne microplastics are commonly produced by the fragmentation or degradation of plastic debris or items such as clothes, furniture, automotive tyres, and toys. These microplastics have low densities (Dris et al., 2017; Wright et al., 2020).

Characterizing airborne microplastics or nanoplastics is challenging due to their small sizes and the limitations of available equipment, especially when analyzing aerosol samples (Zheng et al., 2024). Airborne microplastic deposition rates are dependent on aerodynamic parameters (O'Brien et al., 2023) and atmospheric elevation (Liu et al., 2019). According to (Sobhani et al. (2020), Microplastics present in the atmosphere may possess diverse structures, such as fibres, films, and fragments. Exposure to sunlight can cause airborne microplastics to undergo photochemical reactions, resulting in the release of chemical additives and monomers that may represent a risk to human health (Prata et al., 2020; Shuo et al., 2021). Microplastics and $PM_{2.5}$ may include polycyclic aromatic hydrocarbons (PAHs), which increase the probability of developing cancer (Akhbarizadeh et al., 2021).

Airborne microplastics are becoming more common in various environments, particularly in urban areas and megacities like Paris, France (Dris et al., 2017) London, United Kingdom (Wright et al., 2020) and Dongguan, China (Cai et al., 2017). The information regarding their occurrence is limited and still in the early stages (Hidayat et al., 2024; Jahandari, 2023a) In Indonesia, the abundance of microplastics in the air has been detected and reported in some studies. For example, the presence of microplastics has been documented in Surabaya city (Syafei et al., 2019) and in the Greater Bandung Region (Hidayat et al., 2024; Syafina et al., 2022). However, the number of studies conducted is comparatively low compared to other environmental studies (Cahya Alam and Rachmawati, 2020; Mulyasari et al., 2023). Besides, microplastic study in Sumatera was relatively rare in comparison to other islands (Cahya Alam and Rachmawati, 2020), notably in Bandar Lampung. Research regarding the presence of MPs in bodies of water such as rivers, marine surfaces and drainage systems (Alam et al., 2024; Alam Firdha et al., 2023; Sari et al., 2023), as well as in sediment (Satiyarti et al., 2022; Alam et al., 2024), and biota (Ledy Melindo et al., 2022; Riani and Cordova, 2022), has been detected. However, their presence in the air remains undetected. Therefore, airborne microplastics in the urban roadside areas of Bandar Lampung City, are characterized in this study.

The research aims to examine the size of Atmospheric Microplastics (AMPs) in Bandar Lampung City, Indonesia. Furthermore, the study investigates the correlation between particulate concentrations and the abundance of microplastics. Additionally, the research seeks to analyze the estimated daily intake of microplastics from AMPs. The samples of AMPs were collected at various locations in Bandar Lampung City, Indonesia, spreading different areas. Considering the scarcity of global research on AMPs (Zhang et al., 2020), this study's findings can contribute to bridging the knowledge gap regarding the extent of AMPs emissions. In addition, this research lays the groundwork for future efforts to detect, monitor, and prevent atmospheric microplastics in Bandar Lampung, Indonesia. This study makes a valuable contribution to creating a healthier environment for humankind by helping to identify the risks associated with exposure to AMPs pollution. By supporting United Nations Sustainable Development Goal (UN SDG) number 3, which specifically relates to the presence of (micro)plastics in humans, inhalation, and air, this helps in detecting these risks (Walker, 2021).

2. Methods

2.1 Sampling Area

The research area was situated in Bandar Lampung City, Indonesia, as shown in Figure 1. Data was collected in four locations and four times for each site. The sampling period was from July to early September 2023, during the dry season. The dry season is associated with peak pollution events compared to the wet season (Syafei et al., 2015). Sampling at each site was conducted with a minimum interval of two days to capture diverse environmental condition as well as logistic consideration. Sampling could not be conducted simultaneously due to the limited availability of instruments. The sampling points were selected based on several conditions, including compliance with the Indonesian National Standard 19-7119.9-200 regarding the determination of sampling locations for roadside air quality monitoring. Specific criteria for this research included the availability of an electricity source, proximity to roads, and representation of certain activities. The sampling equipment required a high-capacity electricity supply, and the roadside air quality had to meet specific criteria (BSN, 2005).

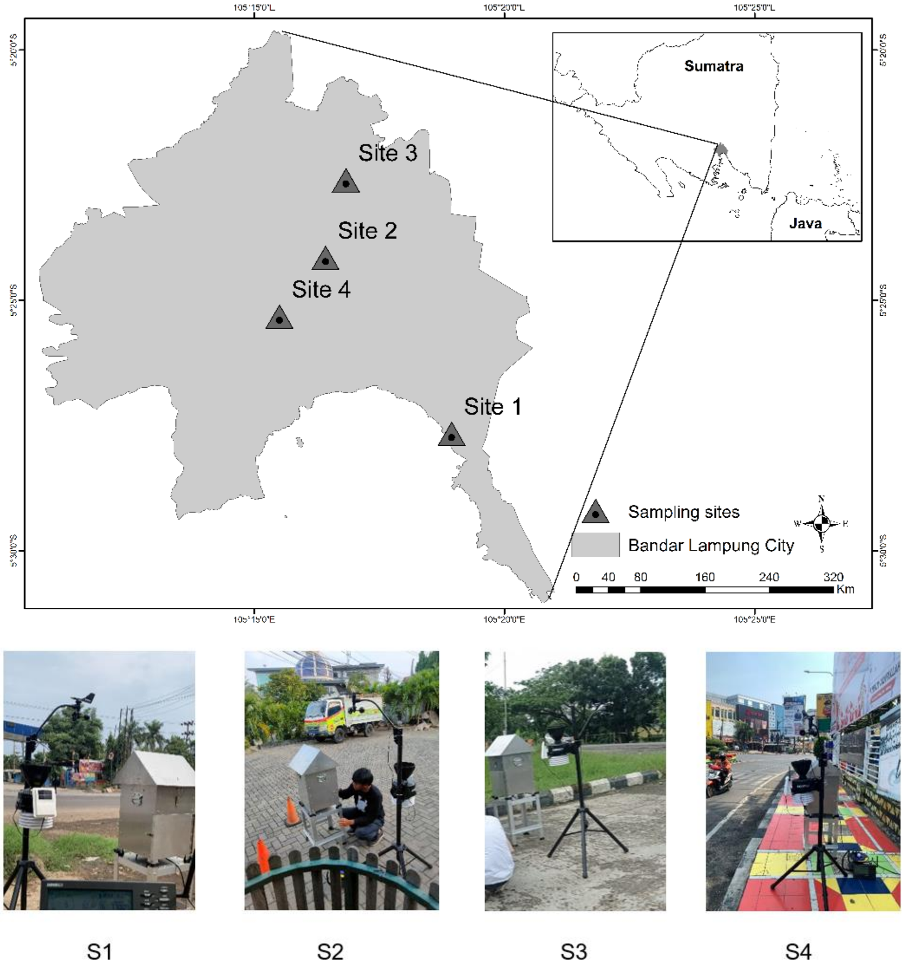


Figure 1. Sampling site location

The four selected locations were representative of areas potentially emitting microplastics, namely industrial zones, busy roads, residential areas, and the city center. Due to cost limitations and restricted permits, the purposive sampling was employed. Besides, the period and sampling location were also referenced to the previous study by Alam et al. (2024). The roadside air quality sampling would have done in these four sites. The first location (S1) was representative of industrial area (coordinate: 5°27'39.87"S, 105°18'56.69"E). This location contains many types of industries that are also frequented by heavy vehicles. The second location (S2) was residential (coordinate: 5°24'9.05"S, 105°16'25.42"E). This location is a residential area. The traffic condition in this area is dominated by light vehicles and motorcycles, and heavy vehicles are rarely found. The third place (S3) was a busy roads/province road (coordinate: 5°22'35.93"S, 105°16'50.01"E). The sampling area is located near the inter-provincial highway in Sumatra, which is always busy with traffic and frequented by various types of vehicles. The fourth location (S4) a city center (S4, coordinate: 5°25'19.46"S, 105°15'30.24"E). This location is also a densely populated city center area with heavy traffic and business activities.

2.2 Roadside Air Sampling and Vehicle Counting

Roadside data was using HVAS (High Volume Air Sampler) (BSN, 2005; Gaston et al., 2020) for eight hours from 08.00-16.00. The previous study showed that an eight-hour sample duration could guarantee a sufficient particulate load for analysis (Gaston et al. 2020). The sampling duration was also refered to NIOSH (National Institute for Occupational Safety & Health) recommendation time average to collect a sample (Leidel, 1977; Limsiriwong and Winijkul, 2023). Specification of the HVAS was MSInstrument MS001 type with a flowrange 0-1950 LPM and operating at 220 volts. The filter had characterization as a glass microfiber filter (GF/A Whatman Filter) EPM 2000 with size of 203 mm x 254 m and porosity of 1,6 um. By Indonesian National Standard of 19-71119.9:2005, the selection of roadside air quality monitoring requires four specific conditions as follows (See Figure S1):

(1) The placement of the sampling instrument should be close to an electricity source and should be situated in flood free area;
(2) The instrument must be positioned in a location without any disturbance and secure environment for data collection;
(3) The equipment should be at considerable distance from any building to avoid potential interference;
(4) The placement of appliance is about 1-5 meter away from the roadside and positioned at a height of 1.5 to 3 meter above the ground.

To support the roadside air quality sampling analysis, wind speed and direction measurements were taken deploying a TSI 5725 Anemometer. The vehicle counts were recorded three times a day for an hour in each sampling site. The time was limited to a range of 07.00-10.00 WIB (Western Indonesian Time) in the morning, 12.00-14.00 in the afternoon; and 16.00-18.00 in the evening. The vehicle counts were categorized by the type of truck, passenger car, and motorcycle.

2.3 Laboratory Analysis

The laboratory analysis conducted involved identifying the concentration of TSP and detecting microplastics. Particulate concentration on the filter can be measured by subtracting the weight of the collected filter from to initial blank filter according to the gravimetric method (BSN, 2005). The balance used was the analytical balance Kern ABJ 220-4NM with a readout accuracy of 0.1 mg. The samples were determined by dividing the weight obtained from collection by the volume of air (Fingas, 2011). To identify microplastics using microscopy techniques (traditional and fluorescent), the following pre-treatment steps were performed:

(1) The filter was initially cut into a size of 4.2 cm x 10.1 cm to fit the microscope base, and the total number of each filter was 12 pieces (Syafina et al., 2022);
(2) A filter is then placed using tweezers in a glass petri dish and covered to reduce microplastic contamination in the room (Dris et al., 2017; Syafina et al., 2022);
(3) Three ml of 30% H_2O_2 solution was poured into the filter to remove the organic pollutan for around a minute. The organic content in the filter can bias the observation of suspected microplastic (Alam et al., 2019);
(4) The filter was then dried at 105°C using Memmert UN110 for a half of hour to ease the observation (Alam et al., 2019).

Furthermore, visual analysis was conducted to observe the physical characterization analysis for microplastic in 4x and 10x levels of magnification. This can be called as traditional microscopy technique (Gaston et al., 2020). Entire samples was observed using trinocular microscope olympus CX23LEDRFS1. This method is widely used in visual analysis of suspected microplastic because it is simple to operate, cost-effective, and has minimal chemical hazards (Karlsson et al., 2020). In order to ensure the identification of suspected microplastic under optical microscopy, a needle test was performed on all samples. This would minimize the uncertaintes found in observation. Microplastics exhibited various responses following a brief exposure to heat. The microplastic becomes melting, culting, deforming, or becoming sticky or adhering to the needle (Beckingham et al., 2023).

Physical characterization analysis of microplastic was determined by the particle size, color, and shape. The observation provides initial information on how the microplastic forms and its fate. The size of the microplastic was further identified using ImageJ 1.54 version software. Image analysis is a tool that could measure small differences in the size of MPs and reduce background noise (Cowger et al., 2020;

Valente et al., 2023). Picture of suspected microplastic was then calibrated depending on the level of magnification. The 4x level of magnification would be calibrated in size of 5 mm and the 10x level of magnification would use 2 mm calibration.

Four microplastic particles were detected and identified using Raman spectroscopy as fluorescent microscopy technique (Gaston et al., 2020), which is a test conducted by a third party to analyze the polymer composition. The microplastic was taken using an infinity-X camera and thereafter subjected to light with a wavelength of 785 nm and a power of 10 mW. The integration time for the exposure was around 20 seconds. The measured wave numbers range from 100 to 3000 cm-1. The acquired Raman spectra were subsequently adjusted for background interference and automatically compared to the reference polymer plastic spectrum (Hager et al., 2018).

2.4 Quality Assurance and Quality Control

Maintaining the stringent quality controls and ensuring the analysis quality during the sampling process were implemented in various restrictions. Several precautions were taken to minimize potential contamination from plastic materials, both in the sampling stage and throughout the laboratory testing (Michida et al., 2019; Prata et al., 2020). The laboratory analysis utensils were also washed with distilled water before use (Michida et al., 2019). During laboratory observations, the researcher wore a cotton laboratory coat and utilized sterile gloves, as detailed in Prata et al. (2020) Furthermore, it was imperative to promptly cover the petri dishes both before and after visual observations for contaminant prevention purposes.

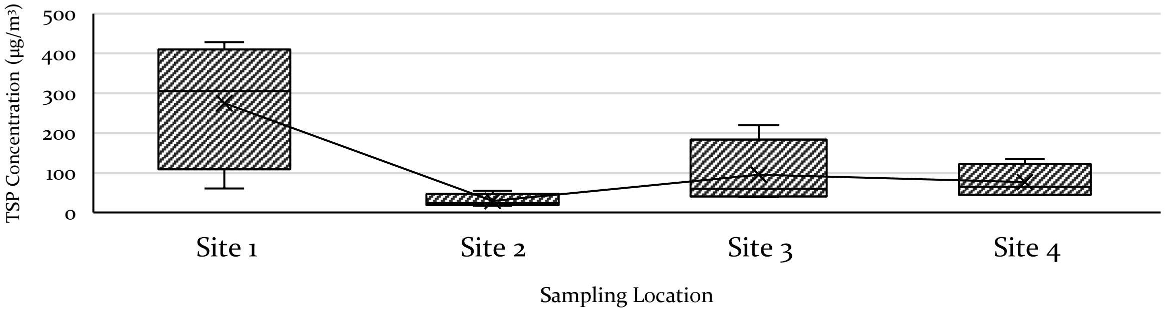
2.5 Data Analysis

The Spearman analysis was performed for nonparametric correlation using Rstudio version 4.3.2 to evaluate the relationship among TSP measurements, vehicle numbers, and microplastics concentration at the sampling sites (p-value<0.05) since the analysis categorized as non-parametric data. The Meteorology data were analyzed using WRPLOT version 8.0.2 to identify the prevailing wind direction coming from in order to be initial assessment (Gunawan et al., 2018) of AMPs sources. The Kruskal Wallis (>2 parameters) and wilcoxon test (p-value<0.05) was further conducted to determine significant differences in the microplastic abundance (Sari et al., 2023). Besides, the differences in TSP concentration and vehicle numbers were also analyzed for mean differences using a similar statistical analysis method (p-value<0.05).

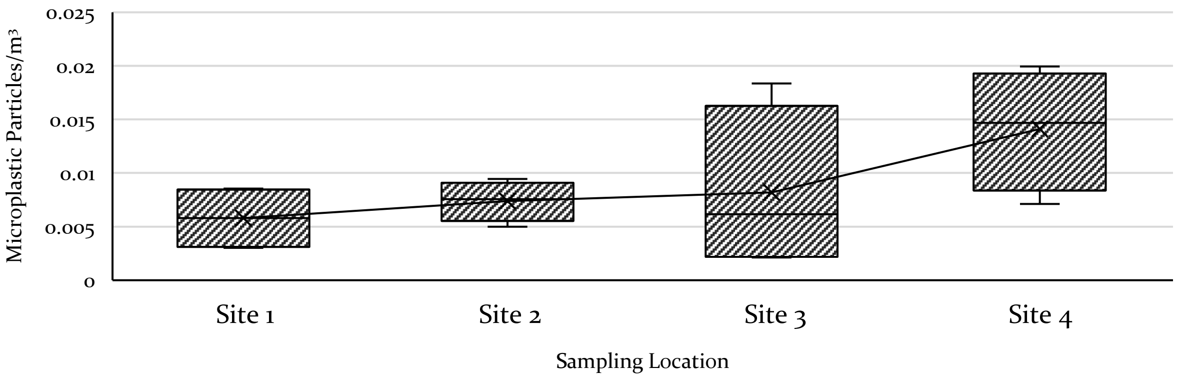
3. Result and Discussion

3.1 Particulate Concentration Profile

Microplastics (MPs) in roadside sampling were described by collecting particulates and then identifying the MPs in the laboratory. Sixteen samplings were done across four sites sequentially. The overall concentration of total suspended particulates was found to fluctuate within a range of 16.96 – 427.8 μg/m^3. The S1 measurement resulted in higher TSP concentration compared to other locations. The average of TSP concentration was 274±159.7 μg/ m^3. The S2 site had the lowest concentration due to no industrial and lower activities releasing pollutants near the area. The variation is visually represented in Figure 2 (A). Statistical analysis indicated a significant difference (p-value < 0.05) across the various sampling sites. Further analysis using the wilcoxon test revealed that the greatest differences were observed between S1 and S2 (p-value < 0.05). The TSP concentration differed by as much as 21 times between S1 and S2. The S2 site was typically categorized as a medium-to-high-income residential area, while the S1 site was a busy road close to an industrial area with many trucks crossing. This means that the TSP concentration could be varied on each site depending on the activities and traffic near the site as well as meterological factor in the location (Kole et al., 2017; Sivaramasundaram and Muthusubramanian, 2010).



(a)



(b)

Figure 2. Concentration of (a) TSP (Total Suspended Solid) and (b) AMP (Atmospheric Microplastic Pollutant) among sample locations

3.2 Microplastic Abundance

The average abundance of microplastics obtained from four locations with four measurements in Bandar Lampung City is estimated in the range 0.0021-0.0199 particles/ m³ with an average of 0.008 ± 0.005 particles/ m³ of air or 49.812 ± 31.435 particles/day. Based on the sampling results at four locations, the highest average abundance of microplastics comes city center, specifically at S4, with 0.014 ± 0.006 particles/m³ of air or 40-112 particles/day, followed by S3 (0.008 ± 0.008 particles/ m³ or 12-103 particles/day), and S2 (0.007 ± 0.002 particles/ m³ or 28-53 particles/day). However, the lowest average abundance of microplastics came from the industrial area (S1) with 0.006 ± 0.003 particles/ m³ of air or 17-48 particles/day. Concerning the concentration of Atmospheric Microplastics (AMPs) across different land-use types (residential, busy road, city center, and industrial area), AMP concentration in area S4 was significantly exceeded rather than those S1 and S2 site. Nevertheless, samples obtained from the industrial area exhibited a relatively low concentration, nearly on par with the residential areas. The abundance of microplastics across sampling sites did not show any significant differences (p-value > 0.05). The average results for each location along with the microplastic quantity for each sample analysis are listed in Figure 2 (B). All sampling sites had AMPs concentration of 0.0021-0.0199 particles/m³ where the contamination of AMP was much lower than in other cities in Indonesia (Hidayat et al., 2024; Syafei et al., 2019; Syafina et al., 2022), provided in Table 1. The comparison might be underestimated since the sampling duration was still not standardized nationally or globally (Cahya Alam and Rachmawati, 2020; Torres-Agullo et al., 2021). It becomes an urgent issue to standardize the techniques these days (Shuo et al., 2021).

The presence of MPs in roadside areas requires attention. AMPs can be easily transported by wind into the human respiratory system through inhalation, risking negative impact to human health. To reduce the release of MPs into the environment in urban areas, strategies may include lowering traffic volume and speed, implementing street sweeping, using filtration chambers, and installing stormwater bioretention systems or settling ponds (Mierzyńska et al., 2024).

Table 1. Comparison of data with other studies

Study area	**Sampling duration**	**Result**	**Site type**	**Microplastics type**	**Dominant Size (μm)**	**Identification Polymere Method**	**Identified Polymere**	**Source**
Indonesia (Bandung)	3 hours	0.43 ± 0.15 items/m^3 (urban) 0.2 ± 0.07 items/m^3 (suburban)	Outdoor	Fiber	500-1000 μm;1000-1500 μm	-	-	(Syafina et al., 2022)
	Not informed	1.03-14.27 particles/m^3	Outdoor (top of building)	Fiber, granule, fragment	1-20 μm; 20-40 μm	μFTIR	PE (>95%), EVA, PBR, PCL, PDAP, PE, PET, PVA	(Hidayat et al., 2024)
Indonesia (Surabaya)	6 hours, 13 hours	55,93-174,97 particles/m^3	Outdoor (roadside)	Fiber, film, foam	1000-1400;600-1000	FTIR	PET, PE, cellophane	(Syafei et al., 2019)
Indonesia (Bandar Lampung)	8 hours	0.008 ± 0.005 particles/m^3	Outdoor (roadside)	Fiber, Fragment	500-1000 μm; 100-500 μm	Raman	PET (samples)	Present study
Southern California	8 hours	0,6 ± 0,6 fibers/m^3 and 5,6 ± 3,2 fragments/m^3	Outdoor, indoor	Fiber, fragment	101-300 μm ; 301-500 μm	μRaman, FTIR, μFTIR	PVC (dominant), PS, polymeric	(Gaston et al., 2020)
Thailand (Bangkok)	24 hours	201,72 to 581,9/m^3	Outdoor (Ambient and roadside included)	Fiber, Fragment, film, and sphere	10-100; 2,5-10; 2-2,5	FTIR	PE, PU, PP, PS, and cellophane	(Sarathana and Winijkul, 2023)
Japan (Osaka)	Not informed	0.63-3.29 particles/m^3	Outdoor	Fiber, granule, fragment granule, and fragment	1-20 μm; 20-40 μm	μFTIR	PET (dominant), EVA, PE, PP, PEMA, PET, PMMA, PP, PS, and PVC	(Hidayat et al., 2024)
France (Paris)	10-40 hours	0.3-1.5 fibers/m^3	Outdoor (top of building)	Fiber	50-250 μm 250-450 μm	-	-	(Dris et al., 2017)

3.3 Microplastic Morphology

Microplastic morphology was characterized by its shape, color, and size. The microplastics were predominantly characterized by fibers, with the longest dimension measuring 4704 µm. In this study, fewer than 10% particles were categorized as fragments. Previous research has shown that fibers are a common type of microplastic found in the atmosphere. The data presented in Table 1 reveals a similar prevalence of microplastic types in some cities of Indonesia and other cities (Hidayat et al., 2024; Syafei et al., 2019; Syafina et al., 2022), including Paris, Dongguan, and Osaka with fibers as dominant form (Cai et al., 2017; Dris et al., 2017; Hidayat et al., 2024). However, findings may vary in other locations. For example, in Hamburg, the prevailing type of atmospheric microplastics is fragments, comprising 95% of the total particle count, while only 5% are fibers (Klein and Fischer, 2019). The morphology of microplastics is frequently employed to explore their source and route, as specific shapes might be more commonly released from certain products (Helm, 2017; Rochman et al., 2019). In the context of urban atmospheric deposition in Shanghai, fibers are the predominant shape identified, likely linked to the increasing production of synthetic fibers used in clothing, upholstery, or carpeting (Zhang et al., 2020) while microplastics may potentially arise from the exposure of larger plastic items to strain, fatigue, or UV light (Liu et al., 2019).

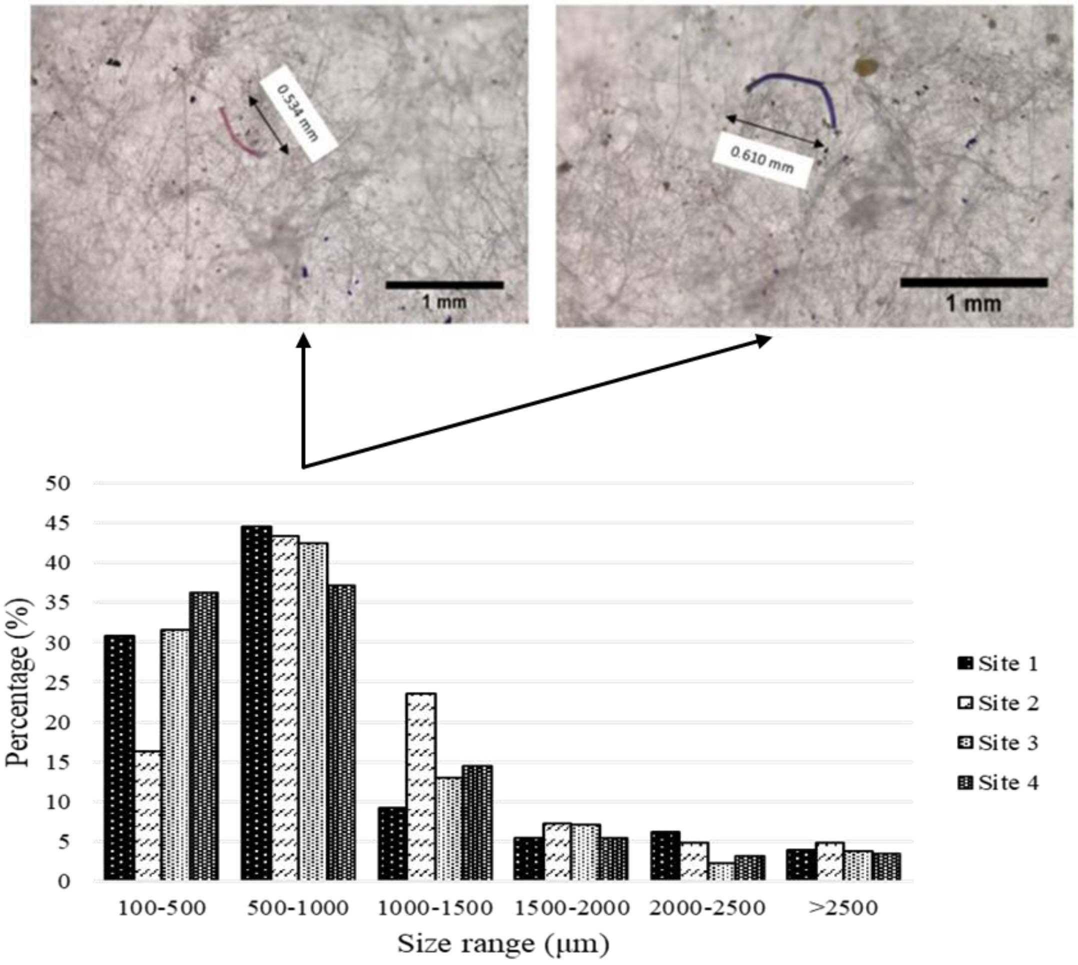


Figure 3. Microplastic size measured on filters.

The sizes of atmospheric microplastics detected at 4 locations range from 121 to 4704 µm for fibers and 105 to 1470 µm for fragments. The average size of microplastics showed the highest percentage in the range of 500-1000 µm (42%), followed by 100-500 µm (29%), 1000-1500 µm (15%), 1500-2000 µm (6%), 2000-2500 µm (4%), and >2500 µm (4%), as shown in Figure 3. The distribution of microplastic sizes across various size ranges at all sampling locations is consistent. More than 98% of Atmospheric

Microplastics (AMPs), comprising the majority, had sizes less than 100 µm. AMPs ranging in size from 500-1000 µm were predominantly discovered in industrial (45%) and residential (43%) areas. These findings suggest a likely connection between nearby shipping sectors and the prevalence of microplastics in landfills. Thus, the transportation and shipping sectors must look into possible sources of AMPs (O'Brien et al., 2023).

The distribution and concentration of AMPs and microplastics (MPs) can be influenced by urban topography, defined as dense building in constrained communities. The airflow patterns and the dispersal of pollutants in the atmosphere can be influenced by the geography of a city (Huang et al., 2023; Ng and Obbard, 2006). Large volumes of plastic will be discarded as trash in settlement centers, where they will degrade and generate microplastics (MPs), categorizing the sources of MPs into three groups. The first category includes goods and personal items such as fabric and apparel, cigarette filters, food containers, single-use plastic shopping bags, wrappers, and self-defense items like face masks, sunscreen lotions, and so forth. Construction and landscaping materials and activities, such as geotextiles, artificial grass, ropes, paints and coatings, insulation, and building finishes, are linked to the second-largest source of MPs waste. Thirdly, the main applications for pipes, such as PVC (Polyvinyl chloride pipes), are in welding and drainage systems due to their low cost and chemical and corrosion resistance (Jahandari, 2023b).

Microplastic fibers vary in thickness and/or width from 1 to 500 µm (Cole, 2016; Napper and Thompson, 2016). It should be noted that for small-sized microplastics, identifying whether a particle is a fiber can be challenging. This difficulty arises because mechanical and/or chemical degradation of the material can result in a reduction in fiber length, causing the fiber width and length to become similar. Therefore, differentiating between fibers and fragments for smaller microplastics may not be effective (Sarathana and Winijkul, 2023).

3.4 Color Variation of Microplastics

Microplastic particles were detected in various colors such as blue, gray, black, brown, red, green, purple, pink, light blue, yellow, orange, and transparent. The color composition can be seen at Figure S2. The primary color composition of microplastics at the four research locations consisted mostly of blue (30-41%), followed by grey (21-30%) and black (7-15%). The amount of blue color found in microplastic studies on aerosols is also frequently identified as the dominant color in studies conducted in Paris and China (Cai et al., 2017; Dris et al., 2015). The remaining portion accounted for less than 15% for each identified color. Colors can function as a first means of identifying potential types of plastic. The color of transparent and clear products is associated with polypropylene (PP), white with polyethylene (PE), and opaque colors with low-density polyethylene (LDPE) (Zhang et al., 2020). Color can also indicate the photodegradation and residence time of microplastics (Hidalgo-Ruz et al., 2012). Unfortunately, the treatment using 30% H_2O_2 to digest the organic material could cause discoloration of microplastics (Habibi et al., 2022).

3.5 Vehicle Numbers

The measurement of motor vehicle volume was conducted at four sampling locations, with samples taken from various types of vehicles such as cars, trucks, and motorcycles. The motor vehicle volume at each location can be observed in Figure 5. It is evident that the motor vehicle volume for the three types of vehicles was the highest in S3 (province road), with an average of 3747 ± 323 vehicles/day. The subsequent order is S4 (3,388 ± 270 vehicles/day) in the city center, followed by the industrial area (S1: 2,264 ± 350 vehicles/day), and the lowest volume was observed in the residential area (S2: 1,166 ± 99 vehicles/day). The dominant types of vehicles at each location in order are motorcycles > passenger cars > trucks.

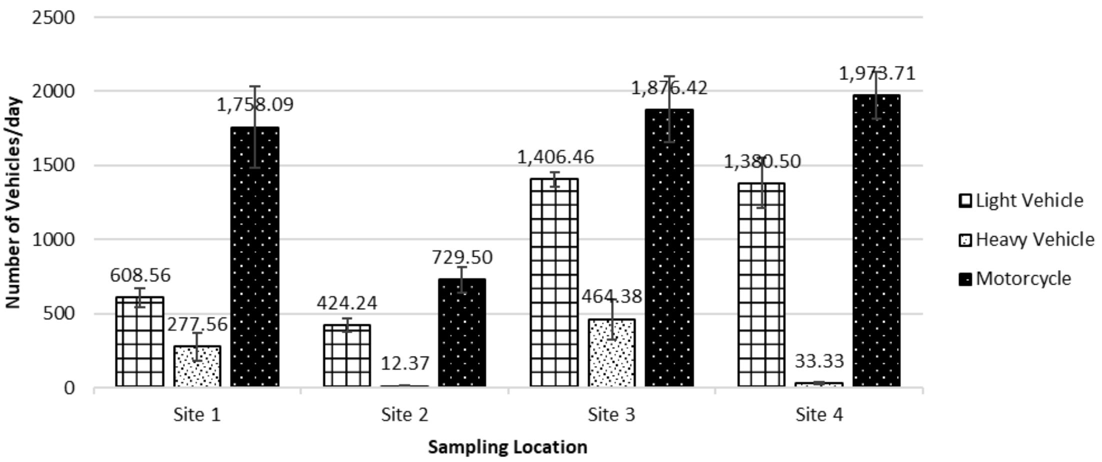


Figure 5. Average number of vehicles in each sampling location

3.6 Polymer Analysis

Some samples of microplastics (n=4) with fiber morphology were subjected to Raman analysis to determine their polymer composition. The limited number of samples analyzed was due to resource constraints and equipment availability. The Raman spectra obtained were plotted on a line graph and are available for reference in Figure S3. The samples were confirmed to be plastic polymers, specifically Polyethylene terephthalate (PET), based on characteristic peaks at wavelengths of 1614 cm^{-1} and 1725 cm^{-1} observed in all selected samples. PET is a commonly used polymer in various applications such as bottles, strapping, food packaging, thermal insulation, and microbeads (Coyle et al., 2020). Additionally, PET is utilized in the production of polyester fiber, fabric, and cording for textiles (Kuczenski and Geyer, 2010). PET-AMPs have adsorption energies ranging from 6 to 20 kcal/mol per molecule. This polymer can also serve as a medium for the simultaneous absorption of air contaminants in the environment, with absorption occurring through either an inner or outer process, depending on the molecular polarity and electronegativity of the gaseous molecules (Ortega & Cortés-Arriagada, 2023). This polymer had a specific gravity about 1,34-139 (Coyle et al., 2020).

3.7 Relationship MPs, TSP, and Vehicle Numbers

The vehicular exhaust was commonly the primary source of total suspended particulate (Alnawaiseh et al., 2015; Lin et al., 2008). Fugitive road dust and industrial emissions are also potential sources of TSP (Lin et al., 2008). The study revealed a strong correlation (r: 0,8), yet insignificant (p-value 0,33>0,05) between the number of vehicles and TSP levels at S2, which is located near a dwelling area. On the other hand, findings at other sites were different, with lower correlation (r<0.3) and not significant (p-values > 0.05). The lack of statistical significance suggests that the relationship is weak and may not be meaningfull and the chance or other factors could be cofounding. The indication of the value showed the vehicular numbers were not aligned with the TSP concentration. The reasons for these differences can vary, as the sources of TSP may include road dust, industrial emissions, domestic burning, and other factors (Ashrafi et al., 2018; Shakya et al., 2017). All these correlation results were provided in Table S1.

TSP concentration and MPs also did not correlate across all sites (p-values: 0.3-0.9, p > 0.05). A negative correlation was observed in S1 and S4 (higher TSP associated with lower MPs), while a positive relationship was observed in S2 and S3, although it was not significant (r: 0-0.8; p-values: 0.3-0.9, p > 0.05). It can be concluded that there is no significant relationship between TSP and MPs. It means that sources of MPs and TSP may be different (Sarathana & Winijkul, 2023). A similar study was conducted in Bandung by Syafina et al. (2022) and in five locations in the Bangkok Metropolitan Region in Thailand by Sarathana & Winijkul (2023), likely yielding with the same result indicating no relationship between the two. It was indication the sources of MPs and TSP are not similar. MPs could be released from human activities related to plastic degradation before suspension in the air, whereas TSP concentrations can be more varied.

We attempted to elucidate the association between vehicular activities and the presence of AMPs. Some researchers have stated that microplastics from tire wear significantly contribute to airborne pollution (Aatmeeyata et al., 2009; Kole et al., 2017; Tamis et al., 2021). The findings revealed that there was no statistically significant correlation between the number of vehicles and microplastic abundance at all sampling sites. The lack of correlation may be attributed to the size of microplastics detected in the air. The smallest size of microplastics found in the air was 105 μm. Particles larger than 10 μm in size could not remain suspended in the air for long periods. Particles within the size range of 1-10 μm tend to stay in the air for minutes to hours, depending on particle characteristics and meteorological conditions (Kole et al., 2017). However, particles released from tire wear were found to be in the size range of 6-562 nm (Mathissen et al., 2011) while other studies also reported tire wear microplastics to be less than 100 μm (Kole et al., 2017).

3.8 Preliminary Microplastics Distribution

Figure 6 illustrates the frequent distribution of wind direction at each sampling site. Utilizing a windrose could serve as a preliminary tool to estimate the source of the measured particulate matter (Gunawan et al., 2018). The prevailing wind speeds were generally calm, ranging between 0 to 1 m/s, with a distribution of more than 50%. The wind was predominantly influenced by traffic direction. Since the sampling locations were situated near roadways, the prevailing winds were likely stronger from the nearest roads. For example, at Site 1 (S1), the prevailing wind direction was from the Northwest, blowing towards the Southeast. Additionally, winds from the West were also observed. S1 is in proximity to the sea, a jetty, and industrial areas. At Site 2 (S2), winds were observed blowing from the Northeast and Southeast. S2 is situated near residential areas and busy roads. Similarly, at Site 3 (S3), the prevailing wind direction was from the Northwest, possibly due to nearby busy roads and commercial activities along Soekarno Hatta Street. Finally, at Site 4 (S4), winds were observed coming from the Northeast, combined with winds from the Northeast and Southeast. These prevailing wind directions could be influenced by the presence of a busy four-way intersection and characteristics of a commercial area with busy roads. All the prevailing wind direction was influenced by traffic flow. This can be indication that the MPs was mobilized by wind from other places and accumulated on the road surface or rundoff into drainage (Goßmann et al., 2022; Ziajahromi et al., 2023).

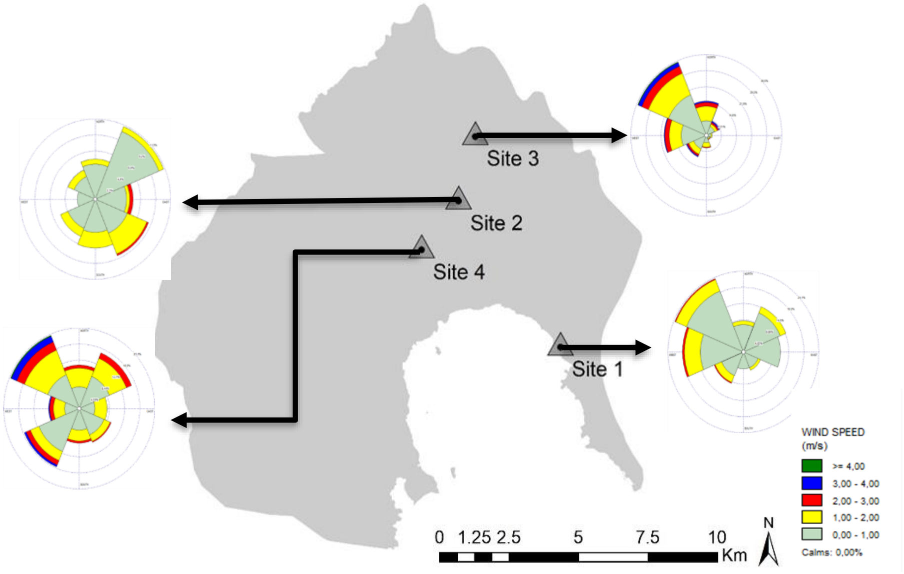


Figure 6. Windrose in sampling sites

4. Conclusion

The study explored the characteristics of AMPs and their correlation with roadside vehicle and also their distribution. The result concluded as follows: (1) Total Suspended Particulate (TSP) concentrations ranged from 16.96 to 427.8 μg/ m^3, with industrial areas exhibiting the highest levels. Conversely, outdoor AMPs were least prevalent in industrial zones and most abundant in roadside areas of the city center. Microplastic abundance varied between 0.0021 and 0.0199 particles/m^3. There was no correlation observed between MPs and TSP; (2) Microplastics were primarily fibrous, with fragmentary forms being relatively scarce. Blue and grey (faded black) were the most prevalent colors across all sampling locations. Microplastic size distribution indicated that the 500-1000 μm category was predominant (42%), followed by the 100-500 μm range (29%). Raman analysis identified PET (Polyethylene terephthalate) in some samples; (3) The highest vehicle count was recorded at Site 2 (city center), with 3,388±270 vehicles/day, while Site 4 (residential area) had the lowest vehicle count of 1,166±99 vehicles/day. No significant correlation was observed between MPs and vehicle numbers. Additionally, the Northwest and Northeast directions were identified as common sources of microplastics at almost all sites, likely following the direction of nearby traffic flow. This suggests that MPs were transported along the traffic flow, which may be a potential source of microplastics in roadside areas.

The findings of this study can provide valuable insights into the occurrence and concentration levels of airborne microplastic particles (AMPs), particularly in Bandar Lampung City. This information can support future research efforts aimed at better understanding the transport and deposition of AMPs. It is recommended that future studies include simultaneous sampling in various locations, including ambient microplastic pollution and indoor environments and also all polymeres. Additionally, there is an urgent need to standardize the techniques used for AMPs sampling and characterization in laboratory settings. This standardization would facilitate comparisons of AMPs occurrence, particularly in Indonesia.

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References

Aatmeeyata, Kaul, D. S., dan Sharma, M. 2009. Traffic generated non-exhaust particulate emissions from concrete pavement: a mass and particle size study for two-wheelers and small cars. Atmospheric Environment, 43, 5691–5697.

Akhbarizadeh, R., Dobaradaran, S., Amouei Torkmahalleh, M., Saeedi, R., Aibaghi, R., dan Faraji Ghasemi, F. 2021. Suspended fine particulate matter (PM2.5), microplastics (MPs), and polycyclic aromatic hydrocarbons (PAHs) in air: their possible relationships and health implications. Environmental Research, 192.

Alam, F. C., Fajar, M., Patricia, E. B. S., Novelina, A., Mawaddah, N., dan Sari, N. K. 2024. The relationship of microplastic abundance, flow rate discharge and drainage profile in Bandar Lampung City, Lampung Province, Indonesia. Indonesian Journal of Geography, 56, 307–316.

Alam, F. C., Sembiring, E., Muntalif, B. S., dan Suendo, V. 2019. Microplastic distribution in surface water and sediment river around slum and industrial area (case study: Ciwalengke River, Majalaya district, Indonesia). Chemosphere, 224, 637–645.

Alam Firdha, C., Sari Novi, K., Anggraini, R., dan Setiawan Faradila, R. 2023. Microplastic distribution in surface water and sediments of Way Belau River, Lampung, Indonesia.

Alnawaiseh, N. A., Hashim, J. H., dan Md Isa, Z. 2015. Relationship between vehicle count and particulate air pollution in Amman, Jordan. Asia Pacific Journal of Public Health, 27, NP1742–NP1751.

Ashrafi, K., Fallah, R., Hadei, M., Yarahmadi, M., dan Shahsavani, A. 2018. Source apportionment of total suspended particles (TSP) by positive matrix factorization (PMF) and chemical mass balance (CMB) modeling in Ahvaz, Iran. Archives of Environmental Contamination and Toxicology, 75, 278–294.

Beckingham, B., Apintiloaiei, A., Moore, C., dan Brandes, J. 2023. Hot or not: systematic review and laboratory evaluation of the hot needle test for microplastic identification. Microplastics and Nanoplastics, 3.

BSN. 2005. Standar nasional indonesia. Udara ambien- bagian 9: penentuan lokasi pengambilan contoh uji pemantauan kualitas udara roadside (No. 19-7119.9–2005). National Standardization Agency of Indonesia.

Cahya Alam, F., dan Rachmawati, M. 2020. Development of microplastic research in Indonesia. Presipitasi, 17, 344–352.

Cai, L., Wang, J., Peng, J., Tan, Z., Zhan, Z., Tan, X., dan Chen, Q. 2017. Characteristic of microplastics in the atmospheric fallout from Dongguan city, China: preliminary research and first evidence. Environmental Science and Pollution Research, 24, 24928–24935.

Cole, M. 2016. A novel method for preparing microplastic fibers. Scientific Reports, 6.

Cowger, W., Gray, A., Christiansen, S. H., DeFrond, H., Deshpande, A. D., Hemabessiere, L., Lee, E., Mill, L., Munno, K., Ossmann, B. E., Pittroff, M., Rochman, C., Sarau, G., Tarby, S., dan Primpke, S. 2020. Critical review of processing and classification techniques for images and spectra in microplastic research. Applied Spectroscopy, 74, 989–1010.

Coyle, R., Hardiman, G., dan Driscoll, K. O. 2020. Microplastics in the marine environment: a review of their sources, distribution processes, uptake and exchange in ecosystems. Case Studies in Chemical and Environmental Engineering, 2.

Dris, R., Gasperi, J., Mirande, C., Mandin, C., Guerrouache, M., Langlois, V., dan Tassin, B. 2017. A first overview of textile fibers, including microplastics, in indoor and outdoor environments. Environmental Pollution, 221, 453–458.

Dris, R., Gasperi, J., Rocher, V., Saad, M., Renault, N., dan Tassin, B. 2015. Microplastic contamination in an urban area: a case study in Greater Paris. Environmental Chemistry.

Eriksen, M., Lebreton, L. C. M., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., Galgani, F., Ryan, P. G., dan Reisser, J. 2014. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PLoS One, 9.

Fingas, M. 2011. An overview of in-situ burning, dalam Oil Spill Science and Technology. Elsevier, halaman 737–903.

Gaston, E., Woo, M., Steele, C., Sukumaran, S., dan Anderson, S. 2020. Microplastics differ between indoor and outdoor air masses: insights from multiple microscopy methodologies. Applied Spectroscopy, 74, 1079–1098.

Geyer, R., Jambeck, J. R., dan Law, K. L. 2017. Production, use, and fate of all plastics ever made. Science Advances, 3.

Gigault, J., Halle, A. ter, Baudrimont, M., Pascal, P.-Y., Gauffre, F., Phi, T.-L., El Hadri, H., Grassl, B., dan Reynaud, S. 2018. Current opinion: what is a nanoplastic? Environmental Pollution, 235, 1030–1034.

Goßmann, I., Süßmuth, R., dan Scholz-Böttcher, B. M. 2022. Plastic in the air?! - spider webs as spatial and temporal mirror for microplastics including tire wear particles in urban air. Science of The Total Environment, 832, 155008.

Gunawan, D., Agustine, I., dan Yulinawati, H. 2018. Spatial dispersion of particulate matters to ambient air in Jakarta and Palembang, dalam IOP Conference Series: Earth and Environmental Science. Halaman 012005.

Habibi, N., Uddin, S., Fowler, S. W., dan Behbehani, M. 2022. Microplastics in the atmosphere: a review. Journal of Environmental Exposure Assessment.

Hager, E., Farber, C., dan Kurouski, D. 2018. Forensic identification of urine on cotton and polyester fabric with a hand-held Raman spectrometer. Forensic Chemistry, 9, 44–49.

Helm, P. A. 2017. Improving microplastics source apportionment: a role for microplastic morphology and taxonomy? Analytical Methods, 9, 1328–1331.

Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., dan Thiel, M. 2012. Microplastics in the marine environment: a review of the methods used for identification and quantification. Environmental Science and Technology, 46, 3060–3075.

Hidayat, N. A. A., Kitano, K., Tani, Y., Lestari, P., Iriana, W., Fujii, Y., Okochi, H., dan Niida, Y. 2024. Airborne microplastics in Bandung and Osaka: concentration and characteristics. E3S Web of Conferences, 485, 06004.

Huang, Z., Hu, B., dan Wang, H. 2023. Analytical methods for microplastics in the environment: a review. Environmental Chemistry Letters, 21, 383–401.

Jahandari, A. 2023b. Microplastics in the urban atmosphere: sources, occurrences, distribution, and potential health implications. Journal of Hazardous Materials Advances, 12, 100346.

Karlsson, T. M., Kärrman, A., Rotander, A., dan Hassellöv, M. 2020. Comparison between manta trawl and in situ pump filtration methods, and guidance for visual identification of microplastics in surface waters. Environmental Science and Pollution Research, 27, 5559–5571.

Klein, M., dan Fischer, E. K. 2019. Microplastic abundance in atmospheric deposition within the metropolitan area of Hamburg, Germany. Science of The Total Environment, 685, 96–103.

Kole, P. J., Löhr, A. J., Van Belleghem, F., dan Ragas, A. 2017. Wear and tear of tyres: a stealthy source of microplastics in the environment. International Journal of Environmental Research and Public Health, 14, 1265.

Kuczenski, B., dan Geyer, R. 2010. Material flow analysis of polyethylene terephthalate in the US, 1996-2007. Resources, Conservation and Recycling, 54, 1161–1169.

Melindo, H. L., Riani, E., Wiradika, M., dan Sinambela, C. 2022. Mikroplastik dalam budidaya teripang pasir (Holothuria scabra): studi kasus Pulau Pasaran, Bandar Lampung. Coastal and Ocean Journal, 6, 73–80.

Leidel, N. A. 1977. Occupational exposure sampling strategy manual (No. 77-173).

Limsiriwong, K., dan Winijkul, E. 2023. Exploring personal exposure to airborne microplastics across various work environments in Pathum Thani Province, Thailand. International Journal of Environmental Research and Public Health, 20, 7162.

Lin, H. Y., Hung, C. H., Yuan, C. S., Chen, C. J., Chen, W. C., dan Chiang, S. W. 2008. Characteristics and source identification of roadside suspended particles. Transportation Research Part D: Transport and Environment, 13, 531–538.

Liu, K., Wang, X., Fang, T., Xu, P., Zhu, L., dan Li, D. 2019. Source and potential risk assessment of suspended atmospheric microplastics in Shanghai. Science of The Total Environment, 675, 462–471.

Mathissen, M., Scheer, V., Vogt, R., dan Benter, T. 2011. Investigation on the potential generation of ultrafine particles from the tire-road interface. Atmospheric Environment, 45, 6172–6179.

Michida, Y., Chavanich, S., Sanae, C., Cordova, M. R., Cózar, C. A., Galgani, F., Hagmann, P., Hinata, H., Isobe, A., Kershaw, P., Kozlovskii, N., Li, D., Lusher L, A., Martí, E., Mason A, S., Mu, J., Saito, H., Shim, Won Joon, Syakti, A. D., Takada, H., Thompson, R., Tokai, T., Uchida, K., Vasilenko. Katerina, dan Wang, J. 2019. Guidelines for harmonizing ocean surface microplastic monitoring methods, technology.

Mierzyńska, K., Pol, W., Martyniuk, M., dan Zieliński, P. 2024. Traffic intensity as a factor influencing microplastic and tire wear particle pollution in snow accumulated on urban roads. Water (Basel), 16, 2907.

Mulyasari, T. M., Mukono, J., dan Sincihu, Y. 2023. The presence of microplastics in the Indonesian environment and its effects on health. Journal of Public Health in Africa.

Napper, I. E., dan Thompson, R. C. 2016. Release of synthetic microplastic plastic fibres from domestic washing machines: effects of fabric type and washing conditions. Marine Pollution Bulletin, 112, 39–45.

Ng, K. L., dan Obbard, J. P. 2006. Prevalence of microplastics in Singapore's coastal marine environment. Marine Pollution Bulletin, 52, 761–767.

O'Brien, S., Rauert, C., Ribeiro, F., Okoffo, E. D., Burrows, S. D., O'Brien, J. W., Wang, X., Wright, S. L., dan Thomas, K. V. 2023. There's something in the air: a review of sources, prevalence and behaviour of microplastics in the atmosphere. Science of the Total Environment.

Ortega, D. E., dan Cortés-Arriagada, D. 2023. Atmospheric microplastics and nanoplastics as vectors of primary air pollutants - a theoretical study on the polyethylene terephthalate (PET) case. Environmental Pollution, 318, 120860.

Osman, A. I., Hosny, M., Eltaweil, A. S., Omar, S., Elgarahy, A. M., Farghali, M., Yap, P. S., Wu, Y. S., Nagandran, S., Batumalaie, K., Gopinath, S. C. B., John, O. D., Sekar, M., Saikia, T., Karunanithi, P., Hatta, M. H. M., dan Akinyede, K. A. 2023. Microplastic sources, formation, toxicity and remediation: a review. Environmental Chemistry Letters.

Patrício Silva, A. L. 2021. New frontiers in remediation of (micro)plastics. Current Opinion in Green and Sustainable Chemistry.

Prata, J. C., Castro, J. L., da Costa, J. P., Duarte, A. C., Rocha-Santos, T., dan Cerqueira, M. 2020. The importance of contamination control in airborne fibers and microplastic sampling: experiences from indoor and outdoor air sampling in Aveiro, Portugal. Marine Pollution Bulletin, 159.

Riani, E., dan Cordova, M. R. 2022. Microplastic ingestion by the sandfish Holothuria scabra in Lampung and Sumbawa, Indonesia. Marine Pollution Bulletin, 175, 113134.

Rochman, C. M., Brookson, C., Bikker, J., Djuric, N., Earn, A., Bucci, K., Athey, S., Huntington, A., McIlwraith, H., Munno, K., De Frond, H., Kolomijeca, A., Erdle, L., Grbic, J., Bayoumi, M., Borrelle, S. B., Wu, T., Santoro, S., Werbowski, L. M., Zhu, X., Giles, R. K., Hamilton, B. M., Thaysen, C., Kaura, A., Klasios, N., Ead, L., Kim, J., Sherlock, C., dan Ho, A. 2019. Rethinking microplastics as a diverse contaminant suite. Environmental Toxicology and Chemistry, 38, 703–711.

Sarathana, D., dan Winijkul, E. 2023. Concentrations of airborne microplastics during the dry season at five locations in Bangkok Metropolitan Region, Thailand. Atmosphere (Basel), 14.

Sari, N. K., Yuniar, D., dan Alam, F. C. 2023. Exploring marine surface microplastic around Pasaran Island, Lampung Province, dalam IOP Conference Series: Earth and Environmental Science. Halaman 012033.

Satiyarti, R. B., Wulan Pawhestri, S., dan Adila, I. S. 2022. Identifikasi mikroplastik pada sedimen Pantai Sukaraja, Lampung. Jurnal Kelautan Tropis, 25, 329–336.

Shakya, K. M., Peltier, R. E., Shrestha, H., dan Byanju, R. M. 2017. Measurements of TSP, PM 10, PM 2.5, BC, and PM chemical composition from an urban residential location in Nepal. Atmospheric Pollution Research, 8, 1123–11

Shuo, W., Weiyu, D., Huanming, L., Rui, S., dan Xu, Z. 2021. The pollution of atmospheric microplastics and their potential risks to humans, dalam IOP Conference Series: Earth and Environmental Science. IOP Publishing Ltd.

Sivaramasundaram, K., dan Muthusubramanian, P. 2010. A preliminary assessment of PM10 and TSP concentrations in Tuticorin, India. Air Quality, Atmosphere & Health, 3, 95–102.

Sobhani, Z., Lei, Y., Tang, Y., Wu, L., Zhang, X., Naidu, R., Megharaj, M., dan Fang, C. 2020. Microplastics generated when opening plastic packaging. Scientific Reports, 10, 4841.

Syafei, A. D., dan Fujiwara, A. 2015. Temporal and spatial analysis of peak-concentration times for NO and NO2 in morning and evening events: a case study of Surabaya City. Procedia Environmental Sciences, 28, 509–518.

Syafei, A. D., Nurasrin, N. R., Assomadi, A. F., dan Boedisantoso, R. 2019. Microplastic pollution in the ambient air of Surabaya, Indonesia. Current World Environment, 14, 290–298.

Syafina, P. R., Yudison, A. P., Sembiring, E., dan Irsyad, M. 2022. Identification of fibrous suspended atmospheric microplastics in Bandung Metropolitan Area, Indonesia. Chemosphere, 308.

Tamis, J. E., Koelmans, A. A., Dröge, R., Kaag, N. H. B. M., Keur, M. C., Tromp, P. C., dan Jongbloed, R. H. 2021. Environmental risks of car tire microplastic particles and other road runoff pollutants. Microplastics and Nanoplastics, 1.

Torres-Agullo, A., Karanasiou, A., Moreno, T., dan Lacorte, S. 2021. Overview on the occurrence of microplastics in air and implications from the use of face masks during the COVID-19 pandemic. Science of The Total Environment, 800, 149555.

Valente, T., Ventura, D., Matiddi, M., Sbrana, A., Silvestri, C., Piermarini, R., Jacomini, C., dan Costantini, M. L. 2023. Image processing tools in the study of environmental contamination by microplastics: reliability and perspectives. Environmental Science and Pollution Research, 30, 298–309.

Walker, T. R. 2021. (Micro)plastics and the UN Sustainable Development Goals. Current Opinion in Green and Sustainable Chemistry, 30, 100497.

Wright, S. L., Ulke, J., Font, A., Chan, K. L. A., dan Kelly, F. J. 2020. Atmospheric microplastic deposition in an urban environment and an evaluation of transport. Environment International, 136, 105411.

Zhang, Y., Kang, S., Allen, S., Allen, D., Gao, T., dan Sillanpää, M. 2020. Atmospheric microplastics: a review on current status and perspectives. Earth-Science Reviews.

Zheng, K., Wang, P., Lou, X., Zhou, Z., Zhou, L., Hu, Y., Luan, Y., Quan, C., Fang, J., Zou, H., dan Gao, X. 2024. A review of airborne micro- and nano-plastics: sampling methods, analytical techniques, and exposure risks. Environmental Pollution, 363, 125074.

Ziajahromi, S., Lu, H.-C., Drapper, D., Hornbuckle, A., dan Leusch, F. D. L. 2023. Microplastics and tire wear particles in urban stormwater: abundance, characteristics, and potential mitigation strategies. Environmental Science & Technology, 57, 12829–12837.