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CHARACTERIZATION OF AIRBORNE MICROPLASTICS PARTICLES ON URBAN ROADS: TYPES, SIZES, AND TOTAL PARTICLES

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Abstract

Introduction: *Airborne microplastics are part of air pollution that can enter the body orally, through direct contact with the skin and inhalation. Microplastic pollution raises concerns about health and environmental impacts, especially in urban areas with high activity. This study aims to characterize microplastic particles suspended in the air on urban roads by identifying the type, size, and total number of particles.* ***Methods:*** *Sampling method was carried out systematically in four strategic locations with high traffic levels. Laboratory analysis using a combination of spectroscopy and optical microscopy techniques were carried out to identify the type of polymer contained in the particles and to measure the particle size distribution in detail.* ***Results and Discussion:*** *This study identified a total of 223 airborne microplastic particles across four urban sites, dominated by fiber types (>80%), likely from synthetic textiles. Particle sizes ranged from 0.2 mm to 4.8 mm, with Small Microplastics (<1 mm) comprising over 60% and posing potential respiratory health risks. The highest concentration was found at Point 2 (63 particles), influenced by high traffic and nearby industry.* ***Conclusion:*** *Microplastics, which are predominantly in the form of fibers, especially small (<1 mm) in size, which are easily dispersed by the wind and have the potential to endanger health through inhalation, are thought to come from tire friction and industrial and household activities.*

INTRODUCTION

State of Global states that air pollution caused 8.1 million deaths in 2021, air pollution is the 2nd risk factor that can cause premature death (1). Deaths due to air pollution in Indonesia in 2021 will be 222,000 (2). In recent decades, air pollution related to microplastics has become a global concern due to its wide-ranging impact on the environment and human health. The absorption of microplastics through air and food increased six-fold from 1990 to 2018 in several countries such as Asia, Africa, China and the United States (3). Indonesia is a country in Southeast Asia that is in the top ranks of global microplastic consumption per capita, with an estimated consumption of polluted oral products of around 15 grams/month (4). Microplastic particles in the air, especially in urban environments, raise new concerns regarding human exposure and the potential accumulation of toxins from chemicals that are absorbed or added during the plastic production process.

The city of Gresik ranks second out of five cities in East Java with the highest microplastic content in the air at 26.21 particles/hour (5). One of the main sources of microplastics in urban environments is road dust generated from traffic and transportation activities. Road dust generally refers to fine particles generated from the abrasion of vehicle components, road surfaces, and the resuspension of particles previously deposited on the road. Traffic-related abrasive material particles dominate around 90% of the aerosol volume around busy roads (6). Tire abrasion accounts for up to 28% of the total microplastic particles in urban air, with a dominant size between 10–100 μm (7-8). The particles produced

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from tire abrasion contain various chemicals that can have a negative impact on the environment. Other vehicle components such as brakes also contribute to microplastic emissions into the environment (9).

Microplastics are not only local in nature, but also have the potential for long-distance transportation through wind and weather systems (10). This shows that even though the main source comes from urban areas, these particles can spread to surrounding areas and even to rural areas. The characteristics of microplastics, such as shape and size, affect how long the particles last in the atmosphere and their ability to stick to other particles or absorb harmful organic pollutants (11). Research conducted in several major cities has found variations in the types of microplastics ranging from synthetic fibers, fragment particles, to homogeneous polymer granules, each of which has a different source and transportation mechanism. This study aims to fill the knowledge gap by conducting a comprehensive characterization of airborne microplastics on urban roads, including identification of polymer types, particle size distribution, and estimation of total amount. These findings will provide a scientific basis for understanding the dispersion mechanism, potential health risks, and strategies for reducing microplastic emissions from urban activities. Airborne microplastic particles tend to accumulate on road surfaces before being resuspended by wind or traffic, so interventions such as routine street cleaning or the use of alternative materials in vehicle tires could be potential solutions (12). By combining field data and laboratory analysis, this research is expected to support urban policies that are more sustainable and responsive to microplastic pollution.

METHODS

Sampling Area

This research was conducted along Driyorejo Street in Gresik City, a designated industrial zone characterized by a high density of factories and companies. The area hosts more than ten industrial facilities, including those that are likely to contribute to airborne microplastic emissions such as textile, plastic manufacturing, and packaging industries. Air sampling was conducted at four purposively selected points, spaced approximately 500 meters apart, with three replicates per point. The sampling locations were: point 1 (-7.367789°S; 112.603490°E), point 2 (-7.367663°S; 112.608392°E), point 3 (-7.362904°S; 112.603371°E), and point 4 (-7.362898°S; 112.608270°E) (Figure 1). Instantaneous ambient air sampling was used at each site during peak daytime hours to capture representative particle concentrations. Intensive industrial activity along Driyorejo Street has the potential to contribute to microplastic pollution, particularly due to the use and handling of plastic materials in production, packaging, and waste management processes. This area is home to a variety of industries, including food and beverage manufacturing (e.g., PT. Mega Global Food Industri, PT. Garudafood), rubber processing (PT. Indotama Megah Indah Rubber), textile manufacturing (PT. Mitra Saruta Indonesia), and bicycle production (PT. WIM Cycle). These types of industries are known for using plastic-based materials in their operations whether in raw materials, packaging, or logistics which may release microplastics into the surrounding environment through atmospheric dispersion, surface runoff, or improper waste handling. Other plastic waste sources from vehicle related materials such as tire wear and synthetic brake dust can release very small microplastic particles into the environment. The high traffic on Driyorejo Street, as the main route for the transportation of goods and worker mobility, is also a source that contributes to the release of microplastics into the air. These microplastic particles, which come from road dust, vehicle tires, or industrial production, can then be carried away by the wind and pollute the surrounding air.

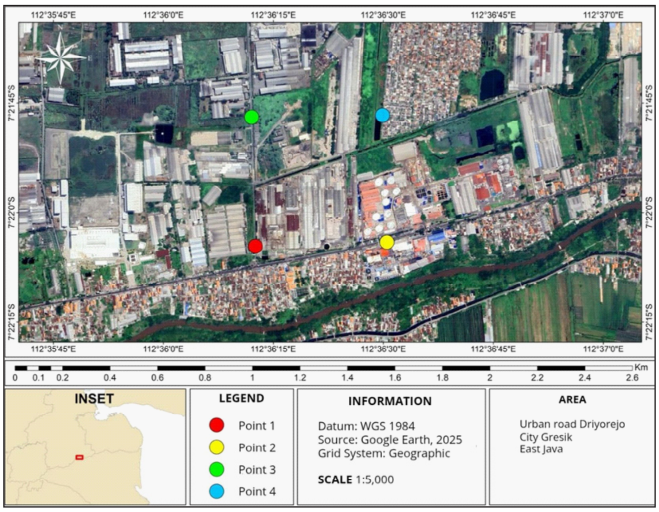

Figure 1. Research Area in Driyorejo Street, Gresik City, with the Four-Sampling Location of This Study

Sampling Method

The process of sampling microplastics in the air uses the passive deposition method, which relies on gravity or wind to deposit particles on the surface of the collector (13). Method works by placing a whatman filter on a plate and dripping it with aquades to more effectively capture microplastic particles. Placing the whatman filter at a predetermined point at a height of ± 1.6 meters above ground level, which is the average height of the human respiratory tract when standing. The filter was placed and left open from 8:00 a.m. to 1:00

p.m. for 6 hours, because at that time community activity was high, public transportation and industry were busy, and factories around the location were operating at full capacity, so the chances of microplastics in the air were higher. Sampling was carried out in September 2024, when the weather conditions were hot and scorching. The wind speed at the time of sampling was recorded at 23.4 km/h, which can affect the distribution and movement of microplastic particles in the air. Over the course of the 6-hour sampling period, the filter was exposed to ambient air and allowed to dry naturally. After the sampling period, the filter was carefully removed and placed in a sterile envelope to prevent contamination.

Visual Observation

Visual identification of airborne microplastics was conducted at the Ecological Observation and Wetlands Conservation (ECOTON) laboratory. Samples were prepared by placing the Whatman filters containing deposited particles into petri dishes and moistening them with distilled water (aquadest) to enhance particle visibility. Observations were carried out using a Ways GSM-SOURCES digital microscope at 100x magnification, with real-time imaging displayed and analyzed via the Opticlab Viewer software. Captured images were saved in raster format for further digital analysis using ImageJ. Pre-processing steps such as cropping, contrast adjustment, and filtering were applied to enhance image quality. Microplastic particles were then identified, counted, and categorized based on type (fragments, filaments, fibers, and pellets) and size: Large Microplastics (LMP, 1–5 mm) and Small Microplastics (SMP, <1 mm) (14–17). The total number of particles detected per sample was recorded to assess the level of microplastic pollution in the study area.

RESULTS

Types of Microplastics

Figure 2 describes the relative composition of various types of microplastics (fiber, filament, and fragment) at four observation points (Point 1 to Point 4). This graph presents the proportion of each type of microplastic to the total microplastic at each point, with the X-axis showing the percentage from 0% to 100%. Each observation point is displayed as a horizontal bar divided into three sections: fiber (blue), filament (green), and fragment (red). Each bar shows how the proportion of each type of microplastic contributes to the total at that point, with the total number of particles at each point always reaching 100%.

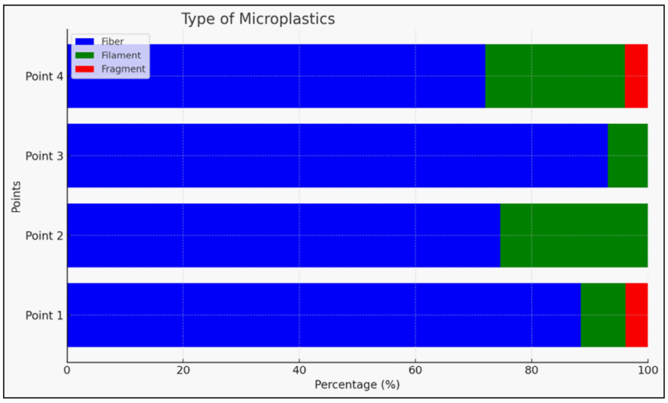

Figure 2. Stacked Horizontal Bar Chart about the Relative Proportions of Different Types of Microplastics Across the Four Points of Observation

In Point 1, the microplastic composition consists mainly of fiber, which dominates about 85% of the total particles, followed by filament which accounts for about 7%, and fragments about 4%. In Point 2, although the number of fibers is almost the same, the proportion of filaments is higher, so that more space on the bar is taken up by filaments than in Point 1, although fragments are not found. Point 3 shows a higher dominance of fibers, but with fewer filaments and fragments, the proportion of fibers reaches almost 93%, while filaments are only around 7%. At Point 4, although the number of fibers is lower than at the other points, the proportion of filaments is higher, with fragments still accounting for a small part of the bar. This graph provides insight into the variation in the distribution of microplastics types at different locations, which can be used to understand the factors influencing the spread of microplastics in the area. Details of the microscope captures for the three microplastics types can be seen in Figure 3.

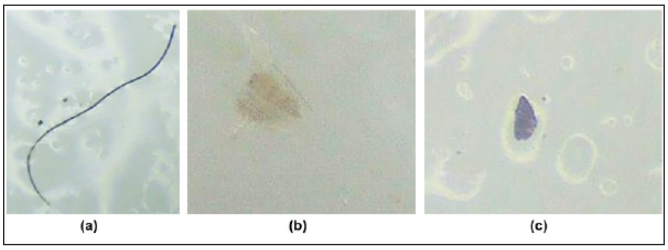

Figure 3. Microplastics Types Captured by Microscope: (a) Fiber; (b) Filament; (c) Fragment

Sizes of Microplastics

The distribution of microplastics by size (Large Microplastics: 1-5 mm, and Small Microplastics: <1 mm) at four observation points can be seen in Figure 4. Each point (Point 1 to Point 4) shows the number of large and small microplastics, with numbers displayed in each cell. The color on the heatmap illustrates the frequency of microplastics, with darker colors indicating higher numbers. At Point 1, 23 large microplastics and 30 small microplastics were found, while at Point 4, the number of small microplastics reached 41, while large microplastics only amounted to 11.

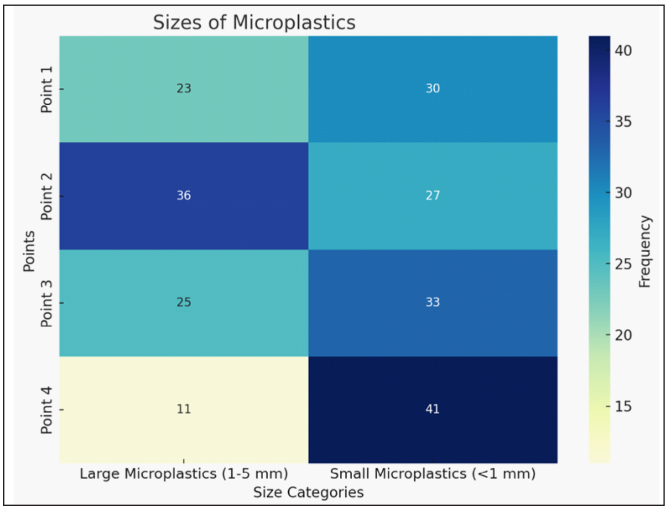

Figure 4. Distribution of Microplastics by Size at Four Observation Points

The results of this heatmap make it possible to visually compare the differences in distribution between large and small microplastics at each point. Points that show more small microplastics (such as Point 4) indicate a higher concentration of small sizes, while other points such as Point 2 have a more balanced distribution between the two sizes. The colors on the heatmap provide a clear picture of this difference, with high concentrations of small microplastics appearing darker, while large microplastics appear lighter at relevant points. With this visualization, we can get faster and easier information about the prevalence of microplastic sizes, which is important for further research related to the management and mitigation of microplastic pollution in the environment.

Total of Microplastics

The total amount of microplastics detected at four observation points, namely Point 1, Point 2, Point 3, and Point 4 is depicted in Figure 5. Each point is represented by a corner on the chart, and the length of the line connecting the point indicates the total amount of microplastics found at that point. Point 2 shows the highest number of 63 microplastics, which looks longer compared to other points, while Point 4 has the lowest number of 50 microplastics. The high level of microplastics at Point 2 is an indicator of an area that requires immediate intervention, such as routine monitoring or the implementation of plastic waste reduction policies. The low value at Point 4 reflects the effectiveness of environmental management practices at the location.

Visualization of the research results provides a clear picture of the variation in the amount of microplastics between different observation points. The amount of microplastics varies spatially, with points that have more microplastics located further from the center, while points that have fewer microplastics are closer to the center. There is consistency or fluctuation in the amount of microplastics at these locations. The patterns or trends in the research results are related to environmental factors or human activities that can affect the amount of microplastics in these areas. The results of this study are very useful in research aimed at analyzing microplastic pollution in greater depth and designing more efficient mitigation strategies.

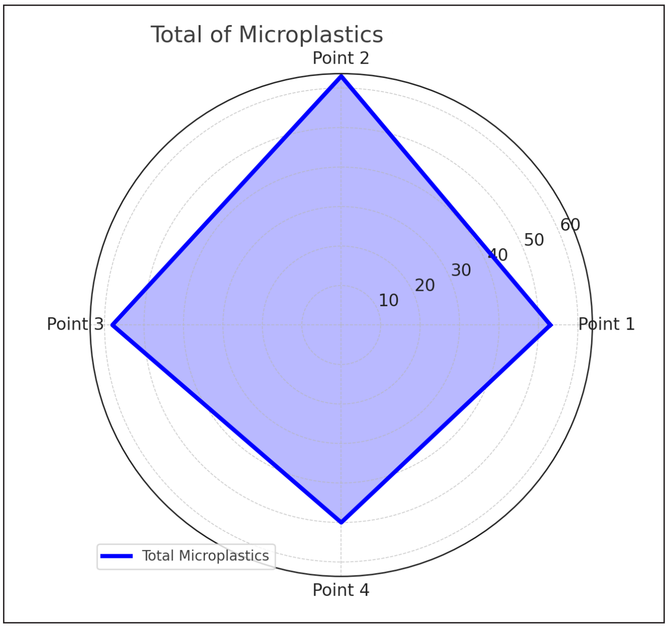

Figure 5. Total of Microplastics at Four Observation Points

DISCUSSION

Dominance of fiber-type microplastics at all urban road observation points, with significant variations in spatial distribution. Fiber accounts for more than 85% of the total microplastics detected, indicating a different source of pollution from previous studies that often found fragments to be the dominant type in the road environment (18). This distribution pattern highlights the importance of understanding the dynamics of transportation and the sources of microplastics in the urban context for the development of effective mitigation strategies. The finding of fiber dominance (83.4% of total microplastics) shows a different pattern from previous literature on microplastics in urban road environments. Fragments and fibers are the dominant forms of microplastics in all urban areas studied, with fragments often dominating road dust samples (19). Research in Yushan District, Ma'anshan City shows that film (66.64%), granules (16.14%), and fibers (14.13%) are the main forms of microplastics in road dust, with fibers only occupying third place (20). This difference indicates the possibility of variations in pollution sources or microplastic transport dynamics that are unique to this research location. The dominance of fiber can be linked to population density, human activity, and land use patterns around the observation point. Fiber generally comes from textile sources, such as synthetic clothing, carpets, and other textile products that can be shed through daily activities and transportation (21-22).

The high concentration of fibers can be explained through several potential mechanisms. Microplastic fibers can enter the road environment through atmospheric deposition, where fiber particles detached from synthetic textiles and consumer products are carried by the wind and eventually settle on the road surface. Fibers can come from the clothes of road users or materials transported by vehicles. In contrast to the dominance of fiber in this study, studies on microplastics on highways often emphasize the significant contribution of tire abrasion as a major source of microplastics (23-24). Tire wear plays a major role in the release of microplastics into the environment (25). Road-associated microplastic particles (RAMPs) mainly come from tire wear, with an estimate that up to 85% of the microplastics that end up in the environment come from roads (26). The substantial accumulation of microplastics on urban roads poses significant ecological concerns. Microplastics deposited on urban roads are often carried into water bodies through untreated drainage systems, and the concentration of microplastics in road runoff may be very high (27). During rainy episodes, the concentration of microplastics in the initial runoff of roads is particularly high, with the median abundance of microplastics in runoff samples (185 particles/L) 4.6 times higher than in rainwater (40 particles/L) (28). The risk assessment using the Polymer Risk Index (PRI) categorizes the majority of road locations within pollution classes II to III (PRI = 13.3–138.0), suggesting a moderate to high level of ecological risk (29). The dominance of fibers in this study may have ecological implications different from other types of microplastics, given the specific characteristics of fibers such as a high surface-to-volume ratio and the potential to contain harmful additives.

Distribution of microplastics at four observation points on urban roads, with small microplastic particles (<1 mm) dominating at 57% of the total samples. The analysis shows significant spatial variation, with the fourth point showing the highest concentration of small microplastics. These findings are consistent with the global trend that smaller microplastic particles tend to be more abundant in urban environments due to continuous fragmentation and different transportation mechanisms. A study in southern Xinjiang, China found that microplastic particles <500 μm in size were the most common size found, accounting for 48-91% of the total microplastics detected in samples of urban road dust, agricultural soil, and desert areas along highways (30). The study also noted that the minimum size of microplastic particles in urban road dust samples was 51.8 ± 2.2 μm, confirming the presence of microplastics in a very small size range in the road environment. Another study in northern coastal waters of Surabaya found that microplastics in sediments were dominated by fragments with a size of 300-500 μm (31). Although this study did not specifically focus on urban roads, it provides insight into the size of microplastics commonly found in urban environments, given that sediments often receive input from urban road runoff through drainage systems. The dominance of the 300-500 μm size in the study is consistent with the findings of this study, which show the prevalence of small (<1 mm) microplastics.

The size distribution of microplastics on urban roads is influenced by various environmental and anthropogenic factors. Fragmentation is one of the key factors influencing size distribution, where large microplastics can break down into smaller particles through physical, chemical, and biological processes. In urban road environments, fragmentation can be accelerated by mechanical pressure from vehicles, UV radiation, temperature fluctuations, and interactions with chemicals such as road salt and pollutants. Traffic intensity and vehicle type can also affect the size distribution of microplastics. Vehicles release microplastics through tire abrasion, vehicle paint, and other plastic components. Vehicle volume can explain 50.1% of TSP concentration, although it does not have a significant effect on the amount of microplastics (32). This indicates that the relationship between traffic and microplastics may be more complex and involve other factors such as vehicle type, speed, and road conditions. Temperature and humidity, as meteorological factors, can influence the size distribution of microplastics, although their impact on the overall quantity of microplastics remains minimal (33). Temperature can only explain 0.01% of the amount of microplastics, while humidity also shows an insignificant effect. However, meteorological factors may affect size distribution through fragmentation and transportation mechanisms.

Significant amounts of microplastics at four urban road observation points, with a total of 224 particles detected. The spatial distribution shows variation with the highest concentration at the second point (63 particles) and the lowest at the fourth point (50 particles). These findings are in line with global trends that show urban roads as the main reservoir of microplastics that contribute to the contamination of the urban environment and have the potential to affect human health through direct or indirect exposure. The microplastics detected on urban roads come from various anthropogenic sources. A major source of microplastic pollution worldwide is tire wear particles (TWPs), which are recognized as one of the most significant contributors to environmental contamination. Microplastic particles generated from tire wear play a substantial role in urban environmental contamination (34). These particles are released during vehicle use and mostly remain on the road surface or curb before being carried away by rainwater or wind. Another important source is brake wear particles (BWPs), which also contribute significantly to the total microplastics in the road environment. Global modeling results indicate that tire and brake wear particles, in both $PM_{2.5}$ and PM_{10} size ranges, are extensively deposited through wet and dry processes. The highest concentrations are found in densely populated urban regions and areas with heavy road traffic (35). These particles can persist for a long time in the road environment before being degraded or carried into the water system. In addition, road markings also contribute to microplastic contamination due to road wear. Although it is still a relatively new area of research, studies show that road markings containing synthetic polymers can break down into microplastic particles through mechanical abrasion by traffic and exposure to weather (36). Estimates in Sweden show that road marking wear results in microplastic emissions of 40-570 tons/year, equivalent to the contribution from ship anti-fouling paint (30-300 tons/year) (37).

The spatial distribution of microplastics on urban roads is influenced by various environmental and anthropogenic factors. Research conducted in Nanjing, China, indicates substantial spatial differences in microplastic concentrations within urban road dust, averaging 143.3 ± 40.8 particles/m². The highest levels of microplastic pollution are observed in commercial and heavy industrial zones compared to other urban functional areas (38). These findings are in line with the data from this study, which show variations in the amount of microplastics at various observation points. Weather conditions also significantly influence the spread of microplastics on urban roads. Redundancy analysis and variation partitioning indicate that urban functional zones, accumulated rainfall over seven days, and monthly $PM_{2.5}$ levels are the main factors influencing the presence and characteristics of microplastics in urban road dust (39). In cold climates, snow and ice on and around roads can temporarily trap microplastics and other traffic-related pollutants, forming a reservoir that releases these contaminants into runoff water or nearby soil as melting occurs (40). Road maintenance operations, such as cleaning and skid control in winter, can also affect the redistribution of microplastics. Microplastic concentrations originating from tire wear (rubber polymers) are generally higher within and near vehicle lanes, whereas other types of plastics exhibit a less distinct correlation with traffic levels (41). These results highlight the intricate nature of the factors that impact the distribution of microplastics in the roadway environment.

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AUTHORS' CONTRIBUTION

MSW: Formal Analysis, Investigation, Methodology, and Writing – original draft. AYPA: Finding Acquisition, Investigation, Validation. MZ: Supervision and Validation. EAW: Conceptualization, Writing - review and editing.

CONCLUSION

The results of research on the type, size, and total microplastics on urban roads show that fiber types dominate the microplastics found at all observation points. These fibers are likely sourced from a combination of synthetic textile particles released during industrial processing, as well as from traffic-related sources such as tire wear, brake pad dust, and airborne particles from vehicle upholstery and road dust. The prevalence of fibers indicates that both industrial emissions and high vehicle mobility contribute significantly to microplastic pollution in urban roadside environments. In addition, although large microplastics (1–5 mm) were detected at some points, small microplastics (< 1 mm) were found at most points, reflecting that small microplastics are more easily dispersed in the air and soil.

The total amount of microplastics also varies between points, with Point 2 recording the highest total amount of microplastics, which is due to factors such as higher traffic intensity and industrial activity around the point. Although traffic density was not measured quantitatively, field observations during sampling indicated that Point 2 was located near a busy intersection with frequent vehicular flow, including trucks from nearby factories and public transportation vehicles.

To reduce airborne microplastic pollution in urban environments, it is essential to improve the management of plastic and synthetic textile waste. Industrial facilities especially those involved in textile manufacturing or plastic processing should implement effective air pollution control technologies, such as scrubbers, electrostatic precipitators, or high-efficiency particulate air (HEPA) filters, to minimize the release of synthetic fibers into the atmosphere. These interventions, along with household level strategies such as installing fiber catching filters in washing machines, can collectively help reduce the presence of microplastics in the air. In addition, it is important to introduce stricter policies on the use of single-use plastics and encourage the use of more environmentally friendly materials in the textile and automotive industries to reduce the accumulation of microplastics in urban environments.

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