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Microplastic Pollution in Residential Soils

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ABSTRACT: The presence of microplastics (MPs) in soil has the potential to cause detrimental impacts to the environment and living organisms. These include alterations to soil characteristics, changes in microbial activity, damage to fauna, and effects on plant growth. However, the existing body of research on microplastics (MPs) in residential soils remains limited. Consequently, the present study sought to identify, quantify the abundance of, and characterise MPs in dense, medium, and low-density residential soils in Sukolilo District Surabaya City, Indonesia. Surface soil samples were collected from three locations, sieved with a 5 mm sieve, and subjected to wet peroxide oxidation (WPO) and filtration in order to separate MPs from the solution. MPs were identified by visual inspection or microscopy, and by Fourier Transform Infrared (FTIR) spectroscopy. The results demonstrated that the highest abundance of MPs was observed in dense residential soils (120.59 n/kg), followed by medium (67.10 n/kg) and low (80.64 n/kg) residential soils. The most prevalent type of microplastic observed was fragments (78.65%), particularly in areas characterised by high population density. The transparent (54.02%) and blue (50.66%) MPs were found to be more abundant than other colours. The most abundant microplastic (MP) size category was the small microplastic (SMP) (< 1 mm), representing 99.91% of the total MP abundance. The most abundant MP type was polypropylene (PP), representing 65.73% of the total MP abundance. This study offers a more nuanced understanding of MP in residential soils, which is related to human activities.

KEYWORDS: Characteristics, Abundance, Microplastics, Settlement, Soil

I. INTRODUCTION

Plastics are synthetic or semi-synthetic organic polymers composed primarily of carbon and hydrogen atoms. Although they can be synthesized from various organic polymers, the majority of industrial plastics are derived from petrochemical sources. The term "plastic" originates from the material's intrinsic property known as plasticity (the capacity to deform under stress without breaking). Plastics are often formulated with various additives such as colorants, plasticisers, stabilisers, fillers, and reinforcing agents to enhance performance and functionality (Helmenstine, 2020).

The recycling rate of plastic products continues to increase, but most plastic waste still ends up in the environment. Plastic waste in nature will experience a weathering process due to exposure to ultraviolet light, wind, and water abrasion, which causes plastic to degrade into micro-sized particles known as microplastics (He et al., 2018). Microplastics (MP) are defined as plastic fragments measuring <5 mm made of synthetic or semi-synthetic polymers. The term "microplastic" was first introduced by Thompson in 2004 to describe these small particles in the environment. The term 'microplastic' was first coined in 2004 to describe the smaller plastic particles that were recorded. However, there is still no comprehensive definition that accurately encompasses all the criteria that could potentially describe microplastic (He et al., 2019). Based on the sizes, plastics can be classified as macroplastic (MaP), mesoplastic (MeP), dan microplastic (MP), and nanoplastic (Jabeen et al., 2017) (Figure 1). According to (Blettler et al., 2017), macroplastics (MaP) are plastic materials measuring between 2.5 and 10 centimeters. Mesoplastics (MeP) are plastic particles measuring between 5 mm and 2.5 cm, which are generally formed as a result of the decomposition of larger plastic particles (Jabeen et al., 2017). while microplastics (MP) are defined as plastic particles with a diameter of 1 um - 5 mm (Blettler et al., 2017 and Peng et al., 2018).

Characteristics of microplastics can be identified by shape, color, and polymer type (Free et al., 2014). The identification of the shape of MPs is carried out in order to ascertain its effect on the particle distribution of soil samples. In soil samples, fragment MPs were identified as the most prevalent type of microplastic, representing 33.5% of the total MPs content. MP fibres represent the second most prevalent form of microplastic (31.5%), while microplastic film is the third most prevalent (18.8%) (Tang and Luo, 2023). In accordance with its dimensions, the MPs can be classified into two distinct size categories: namely large (LMPs) and small (SMPs). The dimensions of large microplastic particles range from 1 to 5 mm, while those of small microplastic particles range from 1 µm to 1 mm (Figure 1).

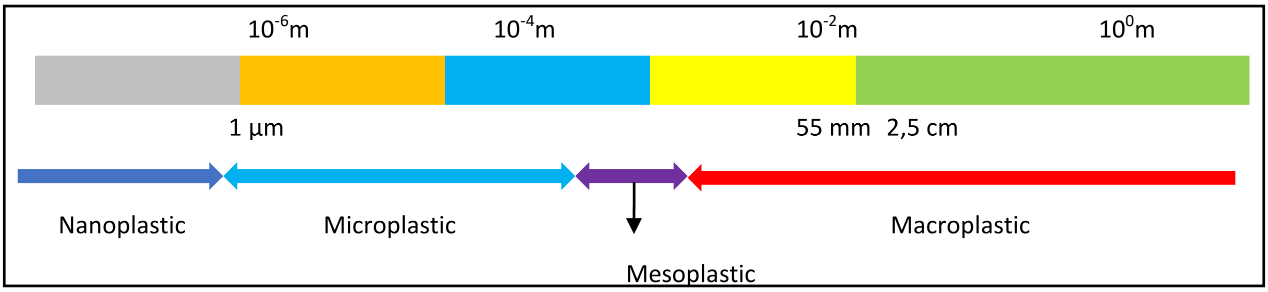

Figure 1: Classification Size of Plastic Waste (Tang and Luo, 2023)

It is important to acknowledge the potential environmental impacts of high concentrations of MPs in soil. MPs in high concentrations in the soil environment pose ecological problems. As explained by (Li et al., 2020), such accumulation can change soil characteristics, inhibit soil microbial processes, disrupt soil fauna, and consequently disrupt plant development. The potential toxicity and long lifespan and persistence of MPs represent a significant threat to soil ecology and ecosystems (Ruz et al., 2012). The presence of MP in the soil can trigger the degradation of soil physical properties, inhibit rainwater infiltration and irrigation, and reduce the soil's ability to retain water (Liu et al., 2014). The migration, erosion, degradation and leaching of MPs into the soil will result in the contamination of groundwater, which will in turn have a detrimental impact on the health of organisms and humans (Sajjad et al., 2022). Therefore, many studies have been conducted on the distribution of MPs in soil, especially in residential (Tang and Luo, 2023) and urban (Zhou et al., 2022) soils. Until now, knowledge related to soil pollution in urban residential areas by microplastics is still relatively minimal. The rapid urbanization process, accompanied by population migration from rural areas to urban areas, contributes to the increasing intensity of anthropogenic activities in urban areas (Wu et al., 2019). This study aims to measure the abundance and characteristics of MPs in soil in a densely populated residential area in Sukolilo District, Surabaya City, Indonesia.

II. METHODS

A. Soil Sampling

Soil samples were collected in Sukolilo District, Surabaya City (Figure 2 dan Table I). The sampling locations were selected from three sub-districts with different population densities, namely: (a) Nginden Jangkungan (K1), the most dense populated village, (b) Klampis Ngasem (K2), the medium dense village, and (c) Keputih (K3), the least dense area. The sampling campaigns were conducted in January, when the weather was clear and no rain. Soil sampling was conducted on vacant lots, main roads, and intersecting roads. These are busy zones with many human activities. Soil samples were collected from 3 sites in each selected sub-district. The samples were taken by digging top soil layers from holes of 20 cm (l) x 20 cm (w) x 5 cm (h) dimension.

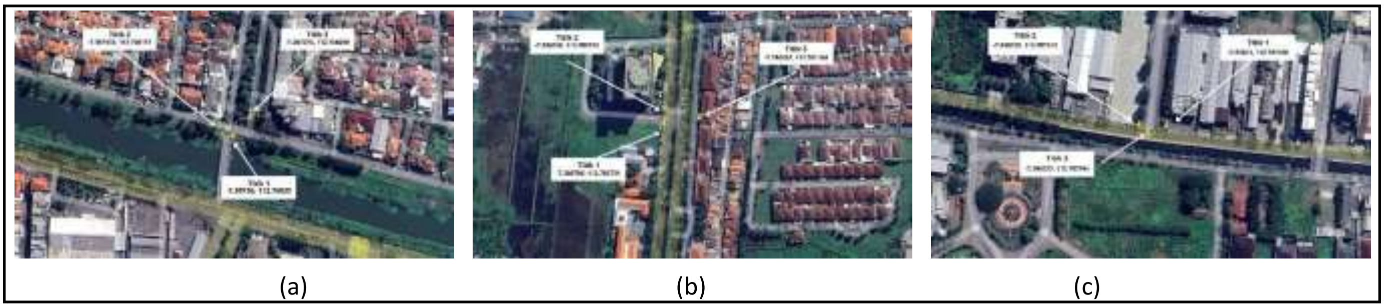

Figure 2: Sampling Locations: (a) Densest Settlement; (b) Medium Dense Settlement; and (c) Least Dense Settlement.

Table I Residential Soil Sampling Locations

No.	Sub-district	Population Density (People/km^2)	Sample Code	Latitude	Longitude
1	Nginden Jangkungan (K1)	14,194	K1-1	7°18'26.7"	112°46'06.9"
			K1-2	7°18'26.8"	112°46'05.4"
			K1-3	7°18'26.9"	112°46'06.0"
2	Klampis Ngasem (K2)	10,800	K2-1	7°17'11.9"	112°46'50.7"
No.	Sub-district	Population Density (People/km^2)	Sample Code	Latitude	Longitude
			K2-2	7°17'11.8"	112°46'50.7"
			K2-3	7°17'11.9"	112°46'51.5"
3	Keputih (K3)	1,264	K3-1	7°17'24.5"	112°47'14.5"
			K3-2	7°17'24.6"	112°47'14.2"
			K3-3	7°17'24.8"	112°47'14.4"

B. Sample Treatment

The soil samples were separated from plant debris, stones, other non-plastic matters. Large visible plastic fragments were also removed from the samples. Soil samples used for extraction of macro-, meso-, and microplastics without any treatment. Then the samples were dried in an oven at 70°C (to avoid deformation of the MP) (Hurley and Nizzetto, 2018). Soil samples should be dried prior to analysis to increase the recovery of MP bound to organic matter (Rani et al., 2023). The samples were then sieved through a graded stainless-steel sieve with mesh sizes of 5.6 mm and 0.3 mm (Lestari et al., 2022).

C. Removal of Microplastics from Soil Sample

Sieved soil samples were placed in 1000 mL beakers and labeled. The soil samples were processed using the density separation method procedure. In density separation, the soil was placed in a NaCl solution with a higher density than the plastic density (so that it floats). A saturated NaCl solution was prepared and heated to 75°C. The NaCl solution was added to the soil sample and allowed to settle for ± 24 hours. The supernatant from each mixture was transferred to a vacuum filtration device containing a filter (size 0.3 mm) for suction. Then, the filtration was repeated using filters measuring 10 and 20 µm. After filtration, the membrane filter with the residue was removed and placed in a Petri dish to be dried in a desiccator at room temperature (Lestari et al., 2022). Then the filtration results suspected of being MP were subjected to the Wet Peroxide Oxidation (WPO) procedure, this was done to remove organic impurities. The WPO process is to add 20 mL of 30% H_2O_2 to the beaker glass. then add 20 mL of 0.05 M $FeSO_4$ and the MP sample. then left at room temperature for five minutes. The stir bar is inserted into the beaker glass and covered with aluminum foil. The mixture is heated to 75ºC on a hotplate. A mercury thermometer is inserted into the beaker glass to facilitate observation. If gas bubbles are seen on the surface, the beaker glass is immediately removed from the hotplate and placed in a fume hood until it subsides. If the reaction is likely to overflow from the glass, distilled water is added to slow down the reaction. The mixture is heated again to 75ºC on a hotplate for 30 minutes or can be repeated with the same procedure until no organic material is visible (Noaa, 2009).

D. Characteristics of Microplastics

The filtered MP particles were observed under a digital microscope at 10x, 25x, and 45x magnifications. MP was counted according to its size (0-0.1, 0.1-0.5, 0.5-1.0, and 1.0-5.0 mm). The filtered MP particles were observed under a microscope (5MP Bio Digital Microscope 107BN) equipped with a camera and computer connection, for identification and subsequent photography (Zhou et al., 2022). The MP forms identified according to Peng (2018) categories include fragments, fibers, films, and granular. The MP shapes were identified according to (Peng et al., 2018) category (fragment, fiber, film, and granular). The concentration of MP in soil was expressed in units per kilogram (n/kg). Polymer types of the MPs were identified by Fourier Transform Infrared (FTIR) spectroscopy with a Agilent Cary 630. The polymer was determined if the FTIR spectrum showed at least 60% similarity with the reference.

III. RESULTS AND DISCUSSION

A. MP Distribution

MP particles (<5 mm) were found in the soil at the three study sites. The highest MP abundance was found in the densest human settlement (K1) (120.59, particles (p)/kg or 8,900 p/m²), followed by least dense (K3) (80.64 p/kg, or 6,016 p/m²) and middle dense (K2) (67.10 p/kg, or 4,925 p/m²) (Table II and Figure 3). Of the three sites, it was observed that the high human activities were observed in densest and least dense human settlements, such as trading or buying and selling food, burning waste, and unmanaged waste disposal. The middle dense human settlement was indicated by busy traffic. High levels of human activity and vehicle access in residential areas affect the number of MPs. (Zhou et al., 2020) investigated that the average MP abundance in residential soil samples was 50-650 items/kg, while Scheurer and Bigalke (2018) were 740.1 p/kg and 593 p/kg in floodplain soil. Some studies indicated that the abundance of MPs in soil is even higher, ranging from thousands to tens of thousands (Mendoza et al., 2021). In addition, based on the study of (Tang and Luo, 2023), less human movement led to lower MP abundance in soil.
The concentrations of MPs in various studies generally differed. This might caused by differences in land use, waste management performance, MP movement routes, sampling techniques, and analysis conditions used (Nematollahi et al., 2022).

Table II Average MP abundance

No.	Sampling Location	Dry Weight of Sample (kg)		Total Number of MPs (p)		Sampling Area (cm²)	MP Abundance in Top Soil	
		Each	Average	Each	Average		p/kg	p/m²
1	K1	2.95	2.95	362	356.00	400	120.59	8,900
		2.96		348				
		2.95		358				
2	K2	2.81	2.94	190	197.00	400	67.10	4,925
		2.97		197				
		3.03		205				
3	K3	3.09	2.98	234	240.67	400	80.64	6,017
		3.01		263				
		2.86		225				

B. MP Color

MPs in densest human settlement (K1) were dominated by blue color (50.66%), followed by green (20.60%), yellow (8.61%), white (7.87%), red (6.37%), transparent (3.56%), and black (2.34%) (Figure 4). Meanwhile, in the middle settlement (K2), transparent color was the most dominant (44.67%), followed by black (19.80%), blue (12.86%), white (11.00%), yellow (10.49%), green (1.02%), and red (0.17%). In the low settlement (K3), the transparent color also dominated (54.02%), followed by black (20.64%), green (8.17%), white (6.09%), blue (5.96%), yellow (4.99%), and red (0.14%). In all three settlements, the most common MP color was transparent, especially in the low settlement (K3). This finding suggested that the color distribution of MPs tended to vary by human settlement type and was likely influenced by geographic factor. In addition, this variation was caused by different distribution patterns according to land use and plastic use patterns in each area (Tang and Luo, 2023).

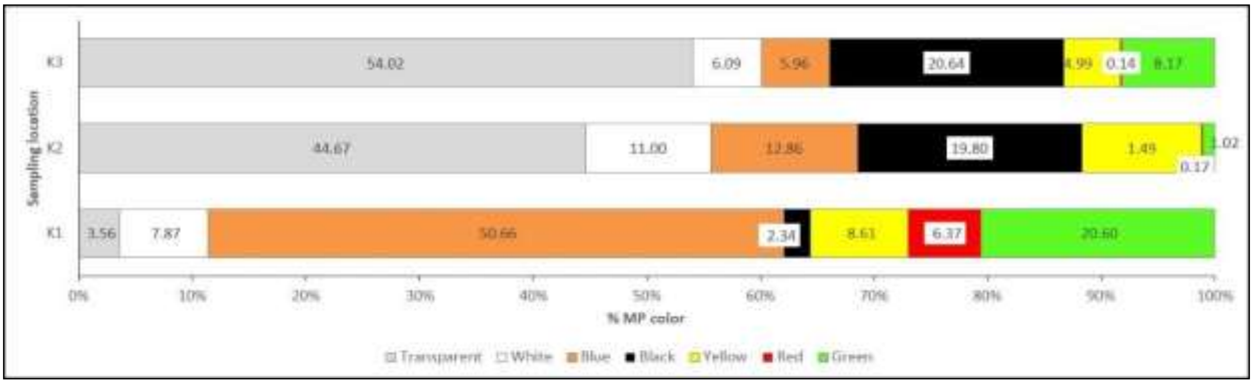

Figure 3: Average Percentage of Microplastics by Color at Study Sites

C. MP Shape

Different forms of MP such as fragments, fibers, films and pellets were found in densest (K1), middle (K2) and least dense (K3) human settlements (Figure 5). The distribution of MP forms in K1 was dominated by fragments (78.65%), followed by fibers (15.92%), films (5.06%), and pellets (0.37%) (Figure 6). Fragment was the most dominant MP form in K2 (48.73%), followed by film (44.16%) and fibers(7.11%) (Figure 6). In K3 the dominant form of MP was film (64.54%), followed by fragment (28.67%), pellet (4.43%), and fiber (2.35%) (Figure 6). Based on these data, it can be concluded that fragments are the most common form of MP found in human settlement (K1 and K2), followed by film. This finding was consistent with the investigation of (Tang and Luo, 2023), who found that MP fragments were the most common MP in soils.

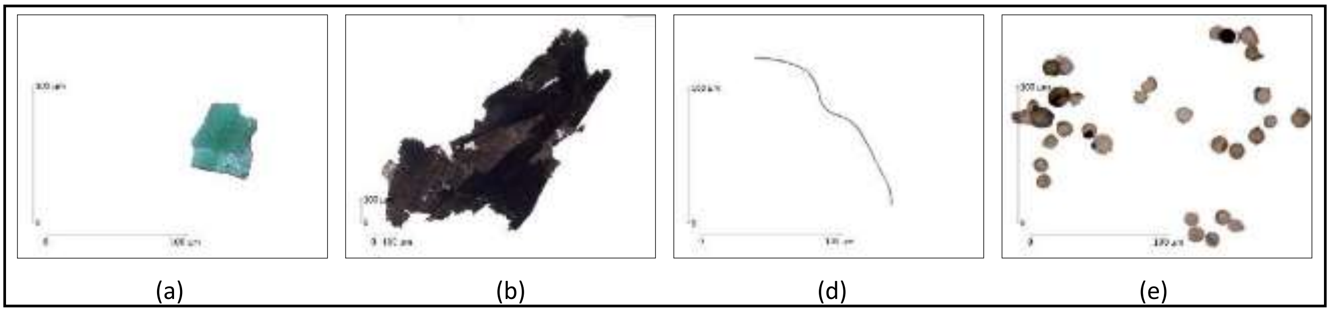

Figure 4: Forms of Microplastics in Soil Samples: (a) Fragments, (b) Films, (c) Fibers, and (d) Pellets

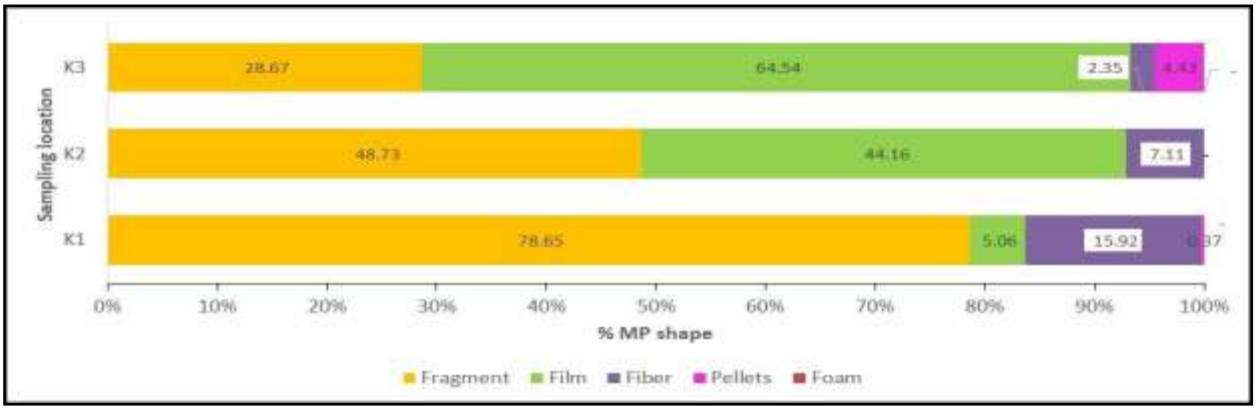

Figure 5: Average Percentage of Microplastics by Shape at All Sampling Sites

D. MP Types

Identification of the MP samples using FTIR resulted in the presence of PETE, ABS, LDPE, PP, and PS (Figure 7). The FTIR results showed that the MP samples contained transmission peaks of PETE at λ 1095.8, 69.095 (Figure 7.a1), ABS at λ 2922.2, 81.257 (Figure 7.b1), LDPE at λ 2914.8, 82.148 (Figure 7.c1), PP at λ 1371,7, 76.685 (Figure 7.d1), and PS at λ 1028.7, 75.927 (Figure 7.e1). This shows that the degradation of plastics has occurred with the decrease of OH group at λ. Under hot conditions and the presence of oxygen, polyolefins can form hydroperoxide groups. These groups then experience O–O bond cleavage to produce hydroxyl radicals and alkoxy groups. The subsequent degradation process takes place through an auto-oxidation reaction that produces compounds such as lactones and esters (Chiellini et al., 2006).

In dense settlements (K1), the dominant polymer type was PP (65.73%), followed by PETE (11.24%), HDPE (8.80%), ABS (7.40%) and LDPE (6.84%) (Figure 8). In medium settlements (K2), the highest polymer type was PP (42.47%), followed by HDPE (29.27%), LDPE (21.15%), ABS (5.41%) and PETE (1.69%) (Figure 8). At low settlement (K3), the dominant polymer type was LDPE (54.02%), followed by PP (33.80%), HDPE (9.70%), PETE (1.39%) and ABS (1.11%) (Figure 8). It can be concluded that PP is the dominant polymer type. The variation of MP polymer type depends on the density of the settlement. Settlements with less human activity but relatively higher MP concentrations may be due to their location near internal roads that can be traveled by vehicles. Conversely, residential areas with high human activity but relatively low MP levels suggest that factors other than human activity influence MP prevalence (Tang and Luo, 2023). This is likely related to preferences and usage habits of polymers in packaging, accessibility, and other environmental and economic factors that influence polymer use in society. By performing a mapping linking the polymer type, shape, and color of the identified MPs, we can easily see the differences in MP composition as well as their common relationships in different types of land use (Zhou et al., 2022).

E. MP Size

MP concentrations in the three human settlement sites showed the dominance of small microplastics (SMP) (<1 mm) and large microplastic (LMP) (1 - 5 mm) particles (Table III). In dense settlements (K1), the majority of MP particles were SMP (355.67 particle; 99.91%), while LMP accounted for only 0.33 particle (0.09%). In medium settlements (K2), the highest concentration of SMP reached 189.67 particle (99.48%), with LMP at 0.52 particle (0.52%). Meanwhile, in low settlements (K3), MP was mainly SMP (239.33 particle; 99.45%) with a slightly higher LMP of 1.33 particle (0.55%) (Table III). According to Yu et al. (2021), the main size category of MPs was < 0.5 mm in agricultural soil. The SMPs with < 0.5 mm size were in higher abundance in the 10-25 cm layer of the agricultural soil than in the top 0-5 cm layer. This phenomenon indicated that SMPs tended to migrate to deeper soil layers.

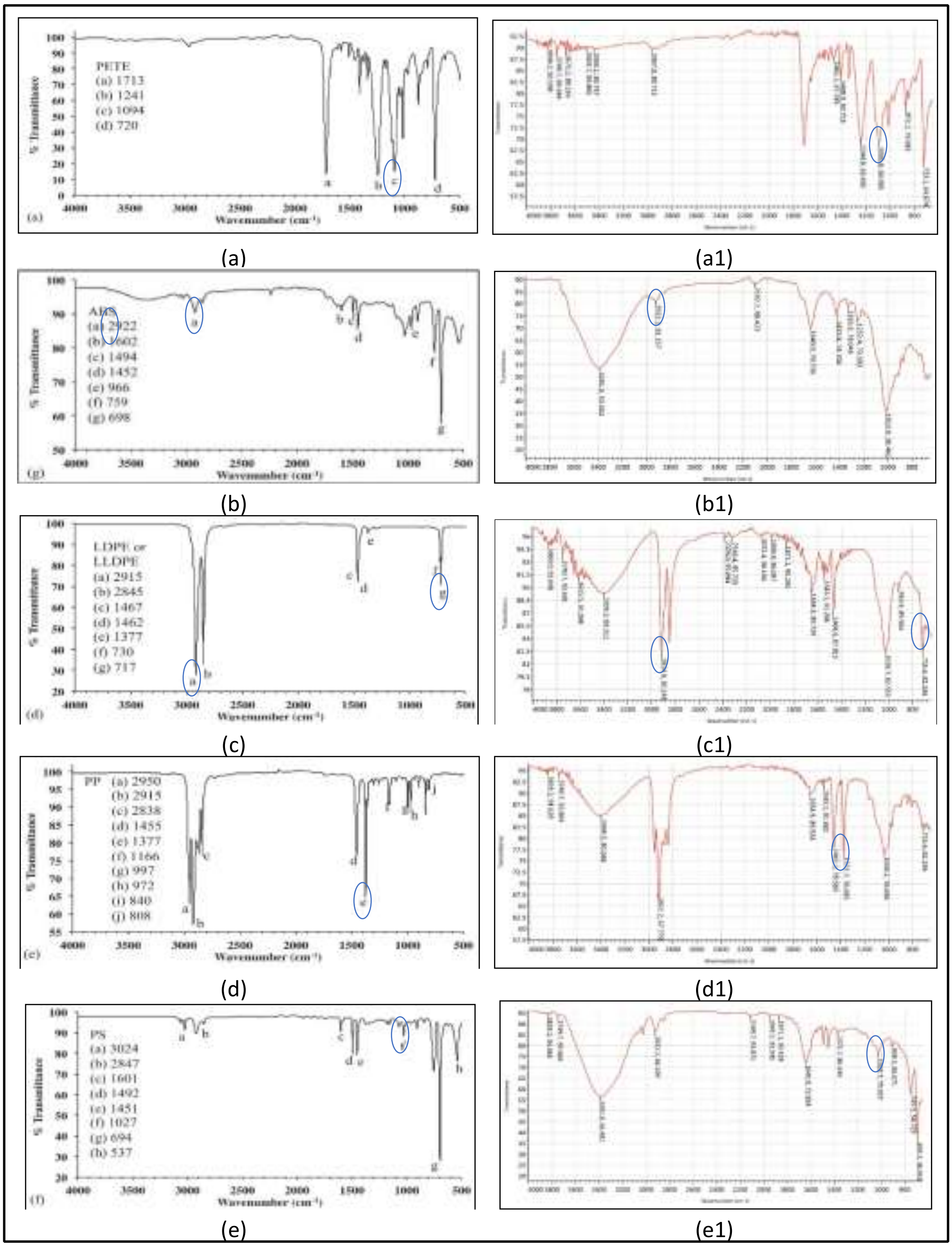

Figure 6: FTIR Spectra of Reference Polymers and Samples: (a, b, c) are Reference PETE, ABS, LDPE, PP, and PS Spectra, Respectively, According to Jung et al. (2018), (a1, b1, c1, d1, e1) are: PETE Blue Fiber Sample, ABS Black Fragment Sample, LDPE Black Film Sample, PP Blue Fragment Sample, PS Red Fragment Sample, Respectively

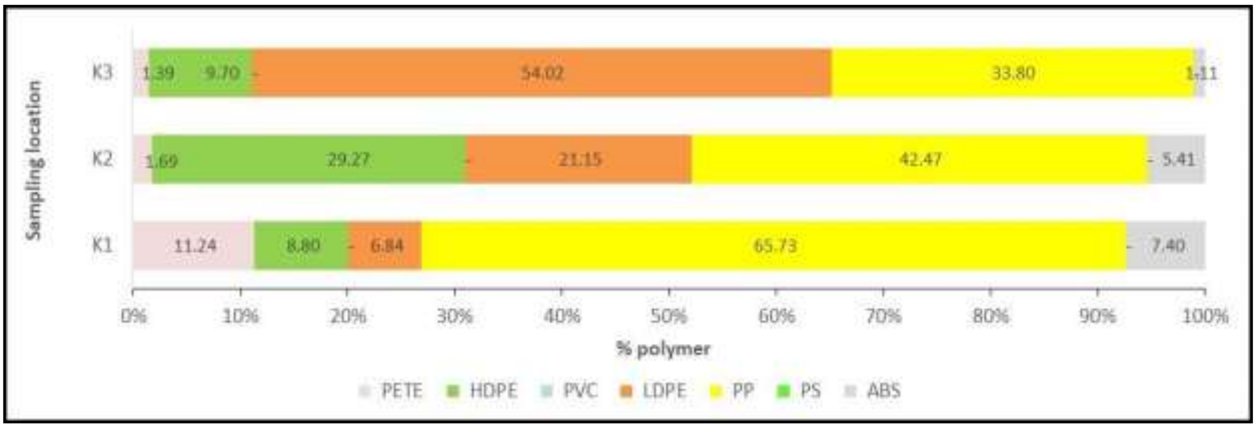

Figure 7: Average Percentage of Microplastics by Type at Study Sites.

Table III Average Percentage of Microplastics By Size at Study Sites

Size	MP Abundance (Particle)			Average Particle Number of MP (%)		
	K1	K2	K3	K1	K2	K3
SMP (< 1 mm)	355.67	189.67	239.33	99.91	99.48	99.45
LMP (1 - 5 mm)	0.33	1.00	1.33	0.09	0.52	0.55
Total	356.00	190.67	240.67	100.00	100.00	100.00

The results above indicate that the top soil in the study area has been contaminated by small microplastic particles (SMP). The source of MP is estimated to come from human activities. The growth of urban areas is one of the main causes of the increasing release of MP into the environment (Celis et al., 2024). In addition, there are factors that may be related to MP pollution in soil in Indonesia, namely based on data from the Initial Draft of the National Medium-Term Development Plan (RPJMN) 2020-2024, it states that household access to domestic waste management in urban areas only covers 61 percent of households. This is due to the still low application of the principle of waste reduction and limited waste reduction infrastructure, such as Integrated Waste Processing Sites (TPST) and Reuse, Reduce, Recycle Waste Management Sites (TPS 3R). In addition, waste transportation efforts in urban areas face challenges due to the lack of transportation fleets and geographical challenges.

This condition makes MP pollution in the soil must be addressed immediately with strategic solutions. This study is the first study on MP pollution in Surabaya soil. In comparison, a study conducted in the green space of Nanjing urban area, eastern China, recorded that the average abundance of MP in soil reached 461 ± 222 p/kg. The most common types of MP were fibers (39.1%) and fragments (37.7%). MPs measuring less than 250 μm accounted for about 38.1% of the total findings, with little difference in size distribution between urban and suburban areas (UF), and relatively uniform size patterns across functional zones. White color dominated most areas, between 20.5% and 34.8%, except for the education and culture area (SCH). Each area was generally dominated by three colors of MP with a cumulative amount of > 60%. In terms of polymer composition, the most common ones were PET (32.0%), PP (20.5%), and ABS (9.9%) (Zhou et al., 2022).

High concentrations of MP in soil are of a serious concern because they can cause various negative impacts on the environment. They can potentially change the physical properties of the soil, disrupt the activity of microorganisms, damage soil organisms, and inhibit plant growth (Li et al., 2020). In addition, because it is toxicity and durability, MPs may cause a real threat to the ecological balance of the soil and ecosystem function (Hidalgo et al., 2012). Several studies have also shown that MPs damaged soil structure, reduce the ability of the soil to absorb rainwater, irrigation, and reduce the capacity of the soil to store water (Liu et al., 2014).

IV. CONCLUSIONS

The MP abundance in the soils varied, depending on the density and human activities in each area. The dense settlement (K1) showed the highest MP abundance both in number per kilogram of soil and per square meter of area, which was most likely influenced by intensive human activities and high vehicular access. Meanwhile, the medium human settlement (K2) had high vehicular activity, yet the MP abundance was lower than that of K1. However, the lowest dense residential area (K3), showed MP abundance somewhat higher than that of K2. Analysis of MP shape showed that fragments were the most common form found in K1, whereas in K2 and K3 the dominant polymer types and MP shapes differed, reflecting usage preferences and local environmental factors. These results illustrate the complexity of MP distribution in soil, which is influenced by various factors including land use, waste management practices and environmental conditions.

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