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Distribution of microplastics in soil by types of land use in metropolitan area of Seoul

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Abstract

Plastic pollution is becoming a significant problem in urban areas due to excessive use and careless disposal. While studies on microplastics are increasingly being conducted across various environments, research on microplastics in soil is limited compared to other areas. Microplastics entering the soil through various routes can stay there for a long period of time, threatening soil organisms and eventually humans. Therefore, this study was carried out to investigate the distribution characteristics of microplastics according to types of land use. For this purpose, a total of 54 soil samples were collected from agricultural land, residential areas, roadsides, parks, and forests. The analysis of microplastics in the soil by stereo microscopy showed that the average numbers of microplastics (particles/kg) in agricultural land, residential areas, roadsides, parks, and forests were 5047, 3646, 4987, 2673, and 1097, respectively. Various colors (black, red, green, blue, yellow, white, and transparent) and shapes (fragment, fiber, film, and sphere) of microplastics were found in soils. The combination of black x fragment plastics showed the highest frequency. Microplastics in soil samples from agricultural land, roadside, and residential areas with sizes between 20 µm and 500 µm were determined using Fourier transform infrared spectrometer (FT-IR) and analyzed by MP finder. The number of microplastics detected in the soil with sizes ranging between 20 µm and 500 µm was in the order of roadside > residential areas > agricultural land, which was different from the results by stereomicroscopy. Polyethylene (PE), polypropylene (PP), and polymethyl methacrylate (PMMA) were detected in soils from roadsides. Polyurethane (PU), cellulose acetate (CA), polyethylene terephthalate (PET), PP, and polystyrene (PS) were detected in soils from residential areas, with PU being the most frequently detected.

Keywords Microplastic, Seoul, Land use type, Roadside, Plastic pollution

Introduction

Plastic is widely used due to its low production cost and high durability, bringing convenience to people. However, its extensive use and improper disposal have led to it being considered a new environmental pollutant. Annually, 320 million tons of plastic are produced worldwide, with a total waste amount of 6–9.9 billion tons [1]. Plastic waste usually decomposes physically and chemically through biodegradation or photodegradation. However, biodegradation or photodegradation takes a considerable amount of time, thus increasing the time it remains in the environment [2, 3]. Various plastic materials take tens to hundreds of years to fully decompose depending on the type of plastic. During this period, plastic waste remains in marine, water, air, and soil environments, and microplastics created during this stage can come back to humans through various pathways [4].

The definition of microplastics was first mentioned by NOAA (National Oceanic and Atmospheric Administration, USA) in 2008 during an international research workshop on the occurrence, effects, and fate of marine debris. Microplastic can be categorized into nanoplastic (< 1 µm), small microplastic (1 µm–1 mm), large

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microplastic (1–5 mm), meso-plastic (5 mm ~ 2.5 cm), and macroplastic (> 2.5 cm) [5].

As problems related to microplastics in marine environments have become more prominent, microplastics have become recognized as a significant pollutant. Today, research on microplastics is being conducted not only in marine and aquatic environments but also in various other environmental fields, including water, atmosphere, and soil [6–11]. However, research on microplastics in soil is insufficient compared to research in other fields. Among all research papers on microplastics published in the Web of Science from 2010 to 2020, the majority were focused on microplastics in marine and biological contexts. Only 7.3% of the papers dealt with issues of microplastics in soils [12].

Microplastic contamination in soil mainly occurs through agricultural and industrial activities, with industrial activities being the main contributor in urban areas. Sources of microplastics in urban areas include tire dust, asphalt, various types of paint on buildings, road safety signs, artificial turf, sports facility flooring, household plastic waste, and microplastics that fall from the air. In agricultural areas, microplastics can originate from agricultural machinery, plastic film waste from mulching, greenhouses, discarded pesticide bottles, discarded fishing nets, insulated covers, sewage sludge containing micro-plastics, fertilizers, organic fertilizers, and slow-release fertilizers, which can be transferred to the soil [13–26].

Likewise, microplastic in soils has various negative effects and can be ingested by organisms during the decomposition process [21]. Microplastic on the surface of the soil can be transported to rivers or oceans through wind or water, while river floods can also deposit microplastic from the river onto the soil [27, 28]. Physical friction, ultraviolet rays, and temperature changes can weather microplastic in soil, and soil organisms like earthworms can digest it, resulting in even smaller microplastic particles that can travel through soil pores and contaminate groundwater [29–31]. When microplastic ends up in soil, it can be stored, moved, eroded, weathered, and leached into groundwater, posing a threat to soil organisms and ultimately passed up the food chain to humans, creating a negative impact [21].

Activities carried out by humans mostly occur on soil. As a result, soil is exposed to various pollutants through different pathways. Although soil can store, transfer, decompose, and interact with other pollutants and cause secondary damage, research on micro-plastics in soil is still in its early stages. Among various countries, China, being the largest producer and consumer of plastic goods, is leading research on microplastics in soil, followed by the United States and Europe in terms of publication numbers [12, 13, 15, 27–29, 32–34]. It should be noted that the accumulation of microplastics in soil can affect soil functions and organism diversity [30]. Investigations and research have been conducted in various regions over the past five years to determine the physicochemical properties of soil and its impact on terrestrial life.

Compared to other countries, there has been insufficient research conducted in Korea on the distribution of microplastics in soil, the types of microplastics present, and the distribution of microplastics across different types of land use. Therefore, the objective of this study was to determine the distribution of microplastics in roadside, agricultural land, forests, residences, and parks in the metropolitan area of Seoul in order to understand the characteristics of microplastic distribution based on land use.

Materials and methods

Research area

Research areas were selected based on various types of land use. The Gangdong District of Seoul was selected for this study because it had agricultural, residential, roadside, park, and forest area in the region. A total of 54 spots (10–12 test spots per land type) were selected. Traffic amount was considered when sampling roadside soils, either high traffic (more-than-6-lane-road) or low traffic (less-than-3-lane-road). Green spaces in apartment complexes were used for collecting soil samples for residential areas. The apartment complexes for soil sampling were selected based on their age, old and new. Three samples per apartment complex were collected. Parks account for 8.75% of Gangdong-gu's areas. We selected Gildong Ecological Park, Chunho Park, and Gwangnaru Hangang Park because people visited them often. For agricultural sites, seven spots and four spots were selected from conventional agricultural land and community gardens, respectively. Finally, Ilja mountain and Godeok mountain were selected as test spots for forest area (Fig. 1).

Soil sampling

Soils near street trees or roadside green spaces were collected as roadside soil samples. For agricultural lands, soils near crops or near greenhouses were collected. Soils near playground, gardens, and parking lot of the apartments were selected for residential areas. For park and forest areas, spots close to hiking trail were selected for sampling (Fig. 2). At each sampling point, a composite sample was prepared by mixing three top soil samples at a depth of 0–5 cm. A hand auger of 10 cm in diameter

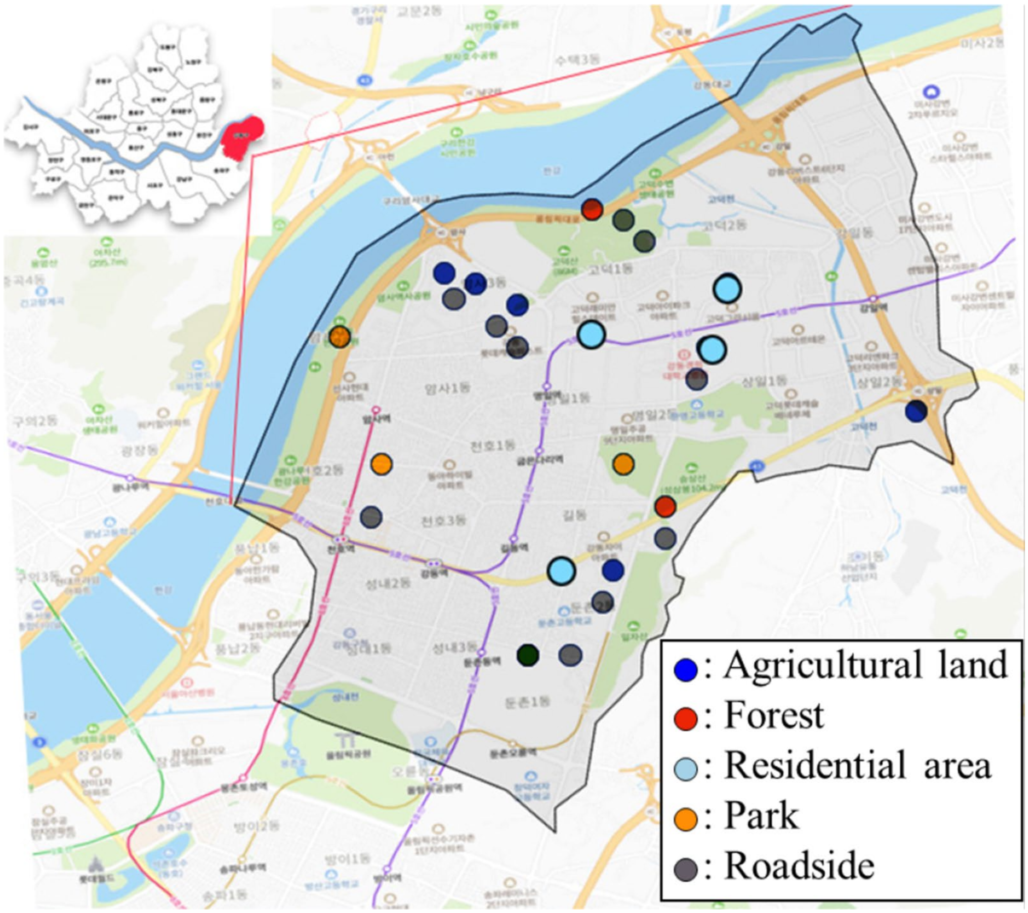

Fig. 1 Sampling sites for this study

Fig. 2 Hand auger and soil sampling sites for this study: **a** Hand auger; **b**, **c** Agricultural land; **d** Roadside; **e** Residential area; **f** Park

and 5 cm in height was used. Collected samples were carried to the laboratory for analysis.

Analysis

Sample preparation

Microplastic analysis was carried out after selecting an appropriate test method to analyze microplastic in soil through review of related documents [35–37]. Test samples brought to lab were put into a drying oven at 60 °C for 48 h. Dried soil samples were separated into large and small samples by sieving with a 5 mm sieve. After separation, samples above 5 mm in size were visually classified as mesoplastic and were analyzed quantitatively. Samples of 5 mm or smaller in size were stored for further analysis. For quantitative analysis of microplastic, density separation method was used. Since a mineral soil in general has a density of 2.65 g cm^{-3}, which is heavier than plastic, a NaCl solution with a density of 1.2 g cm^{-3} was used for analysis [38]. Loder and Gerdts [39] have recommended $ZnCl_2$ with a density of 1.7 g cm^{-3} for density separation considering its efficiency and economic feasibility. Thus, $ZnCl_2$ was used for this experiment. After 50 g soil sample gathered through 5 mm sieve was placed in a 250 mL Erlenmeyer flask, 100 mL of $ZnCl_2$ was added. The solution was then stirred at 300 rpm for 5 min. Afterwards, the Erlenmeyer flask was filled with $ZnCl_2$ and placed in a stable place for more than 24 h. After that, the floating matter (microplastic and organic matter) in the upper layer was transferred to a glass beaker. This process of density separation was repeated more than three times until microplastics were sufficiently separated from the test soil. For de-composition of organic matter from the sample transferred to the beaker, 20 mL of 0.05 M $FeSO_4{\cdot}7H_2O$ solution and 20 mL of 30% H_2O_2 were added. All reactions were carried out in a fume hood. After completion of reactions, a glass beaker containing the sample was placed on a hot plate at 70 °C and heated. When bubbles were generated in the glass beaker, it was immediately removed from the hot plate. In case reaction was extreme, distilled water was then added to the beaker. The beaker was left standing at room temperature for more than a week [38]. For easier microplastic analysis, pre-treated samples were sieved by stacking 1 mm, 300 µm and 100 µm sieves, respectively. Separated samples were washed well with distilled water and then filtered under vacuum filtration using a filter paper (CHMLAB, Ø 47 mm, pore size 0.45 µm) with a grid scale of 3.1 × 3.1 mm. Filtered sample was then dried and stored in a petri dish.

Quantitative analysis

For quantitative analysis, we analyzed microplastic and mesoplastic separately. First, during a microplastic pretreatment process, we visually selected mesoplastics (> 5 mm) filtered with a 5 mm sieve. For quantitative analysis of microplastic, we took pretreated samples and counted the number of microplastics with a digital stereo microscope (scmos05000KPB, SCMOS, China) at 20-800 magnification. All microplastics were classified by shape (piece, film, fiber, and sphere) and color (black, red, green, blue, yellow, white, and transparent).

FT-IR analysis

For qualitative analysis, a small amount of soil sample was taken from roadside, agricultural land, or residential area where the distribution of microplastic was greater than 5000 particles kg^{-1}. Samples were filtered through the same pre-treatment process as described above, vacuum filtered through filter papers (WHATMAN, anodiscTM, Ø 25 mm, pore size 0.2 µm), dried, and stored in petri dishes. Microplastics with sizes of 500 µm or below were analyzed using FT-IR (Bruker FT-IR Microscope LUMOS II IMG, USA). Measurements were made at 16 cm^{-1} resolution/scan using a multi-point ultrafast mapping detector. It is a fast-mapping method that can measure 1024 spectra simultaneously per scan by composing each pixel of an image as a full IR spectrum. For results after the measurement, OPUS and MP finder (Bruker vibrational spectroscopy software, USA) of the instrument were used. Samples were quantitatively and qualitatively analyzed for PE, PP, polyvinyl chloride (PVC), PS, and PMMA.

Statistical analysis

To find out statistical difference of microplastics in soil, SPSS (IBM SPSS Statistics, 2020, Version 27, Korea) was used for all statistical analyses. One-way ANOVA (analysis of variance) was performed to find out differences in microplastics by size and type of land use. T-test was used to compare difference in the average number of microplastics in the soil by the type of land use.

Results and discussion

Distribution of microplastic by land use

Mesoplastic

Table 1 and Fig. 3 show results of mesoplastic analysis categorized by land use. In agricultural lands, packing string, fertilizer bags, and pieces of plastic mulching were found. Various garbage, plastics, and mesoplastics from household wastes were found on roadside, parks, and apartment complexes, respectively. On roadside and agricultural land, there were a lot of plastic bags and plastics such as PVC, with detection frequency being higher than in parks and forests. Their results confirmed that the frequency of agricultural and anthropogenic activities was a major factor affecting plastic contamination.

Table 1 Number of mesoplastics in soils (particles/kg) according to types of land use

Land use type site No.	Roadside	Agricultural land	Forest	Residential area	Park
1	6	1	ND	1	ND
2	7	6	ND	2	ND
3	ND	12	ND	1	ND
4	38	2	ND	ND	ND
5	6	ND	1	ND	ND
6	ND	5	ND	1	ND
7	ND	5	ND	ND	ND
8	12	3	ND	2	ND
9	2	1	ND	ND	1
10	5	ND	3	1	1
11	–	ND	–	ND	1
12	–	–	–	1	–

ND not detected

Microplastic

As a result of analyzing microplastics in soil, 4987 particles kg^{-1} were detected in roadside, 5047 particles kg^{-1} in agricultural lands, 1097 particles kg^{-1} in forest, 3646 particles kg^{-1} in in residential areas, and 2673 particles kg^{-1} in parks, respectively. Results showed that microplastics in the soils from agricultural land and roadside were significantly higher than those in residential areas and parks. Microplastic was not detected in many points in the forest (Table 2). Various colors and forms of microplastics such as black fragments, green fibers, and white spheres (Fig. 4) were detected depending on the type of land used. Amounts of microplastics detected in soils on roadside and in agricultural land showed statistically significant differences compared to those in forest soils, whereas amounts of microplastics in parks and residential areas were in the mid-range (Fig. 5).

Compared to Choi's [40] microplastic survey results of Seoul, the results for parking lots and roadsides were similar in this study. However, the detected amounts for agricultural and residential areas in this study were higher than those found by Choi [40]. This seems to be due to the selection of sampling locations with higher level of human activities and vehicle access for residential areas in this study. As for the agricultural areas, Choi's study included rice paddy where generation of plastic is

Fig. 3 Mesoplatstics in soil

Table 2 Number of microplastics in soils (particles/kg) according to types of land use

Land use type site No.	Roadside	Agricultural land	Forest	Residential area	Park
1	16,325	5050	ND	1325	525
2	9300	3300	2250	2525	575
3	1025	1575	ND	1400	4925
4	2825	12,325	ND	9375	ND
5	2600	2950	ND	1125	ND
6	7750	2000	ND	9825	775
7	2275	9200	2975	5250	7775
8	1250	7650	2350	3575	550
9	675	2500	425	275	7250
10	5850	3925	2975	4325	5075
11	–	8625	–	1775	1950
12	–	–	–	2975	–
Total	49,875	59,100	10,975	43,750	29,400
Average	4987	5047	1097	3646	2673

ND not detected

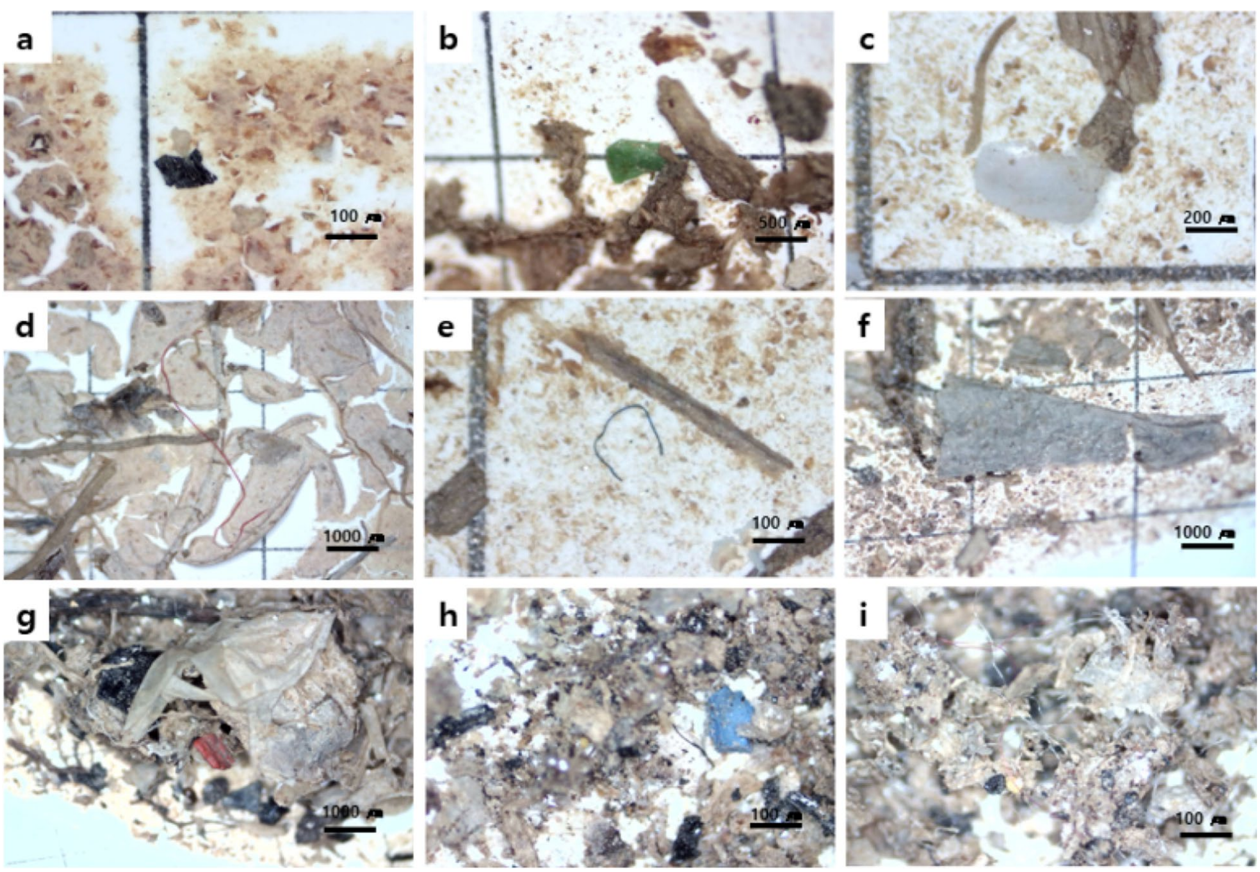

Fig. 4 Microplatstics in soil: **a**–**c** fragment; **d**, **e** fiber; **f** film; **g**–**i** Images of microplastics attached to soil organic matter

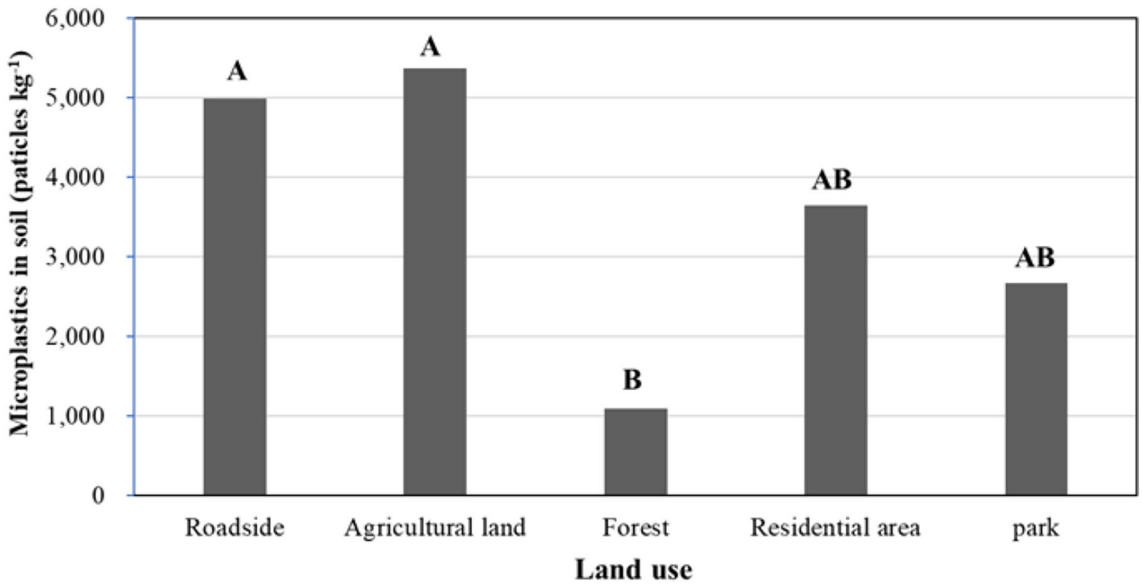

Fig. 5 Numbers of average microplastics in soils (particles/kg) according to types of land use: (**A**) Roadside, Agricultural land; (AB) Residential area and Park; (**B**) Forest

relatively low, whereas the main sampling points in this study were plastic film houses and community gardens.

After analyzing microplastics in road dust of city M, Korea, Kim et al. [41] have re-ported that over 90% of microplastics are debris created from tires. It has been reported that up to 3100 particles/kg of microplastics are present in roadside samples collected from Tehran, Iran [13, 40]. Fuller and Gautam [42] have also reported that 0.03–6.7% of plastics are present in soils of roadside trees in industrial areas. Chen et al. [32] have found out that areas near busy thoroughfares in central China have 1.8 times more microplastic pollutants than residential areas. Microplastic pollutants on roads can be from tire debris, road paint, asphalt, paints on road and buildings, and material used for traffic safety facilities [16, 43]. In the present study, areas near busy thoroughfares with 6 lanes or more had twice as much microplastics as areas near narrow roads in residential areas with less vehicle traffic (7020 particles kg^{-1} vs. 2955 particles kg^{-1}). In addition, this might be the result of correlation between traffic amount and emission of pollutants mentioned above [32].

Agricultural land can be contaminated by microplastics from mulching film, farm waste, controlled-release fertilizer, and agricultural machine use [13, 17, 21]. The amount of microplastics detected in the soil from agricultural land in this study was similar to that in the soil from Chinese agricultural land reported by Wang et al. [44], which was 2783–6366 particles kg^{-1}. The soil from agricultural land in Shanxi Province had 1430–3410 particles kg^{-1} [34]. Additional research is needed on microplastic contamination in agricultural land caused by plastic film waste considering that distribution of microplastics is high in agricultural land where plastic film is used for mulching and for greenhouses.

For soils in forest, microplastics were found only in soils near facilities such as walking trails, hiking trails, and around outdoor gym. For soils in parks, microplastics were detected in trails, parking lots, and soil near trees around shops. However, they were not detected in soils from areas where people never or seldom visited (Table 2). These results show that the occurrence of microplastic is greatly affected by human activities. Zhang and Liu [45] have compared distributions of microplastic in soils adjacent to agricultural land and forest areas and found that the concentration of microplastics in the soil of forest area is lower. This was because introduction of soil amendments and irrigation made the microplastic in soil increase and accumulate more in agricultural land soil.

Distribution of microplastic by land use

Distribution characteristics by size of microplastics

Figure 6 shows plastics detected in samples for each land use divided by size: 100–300 μm, 300 μm ~ 1 mm, and over 1 mm. The proportion of microplastics larger than 1 mm was the highest in roadside and agricultural land soils at 20% and 17%, respectively, whereas it was only 1% in forest soils. It appears that microplastics generated by humans on roadside, agricultural land, residential areas,

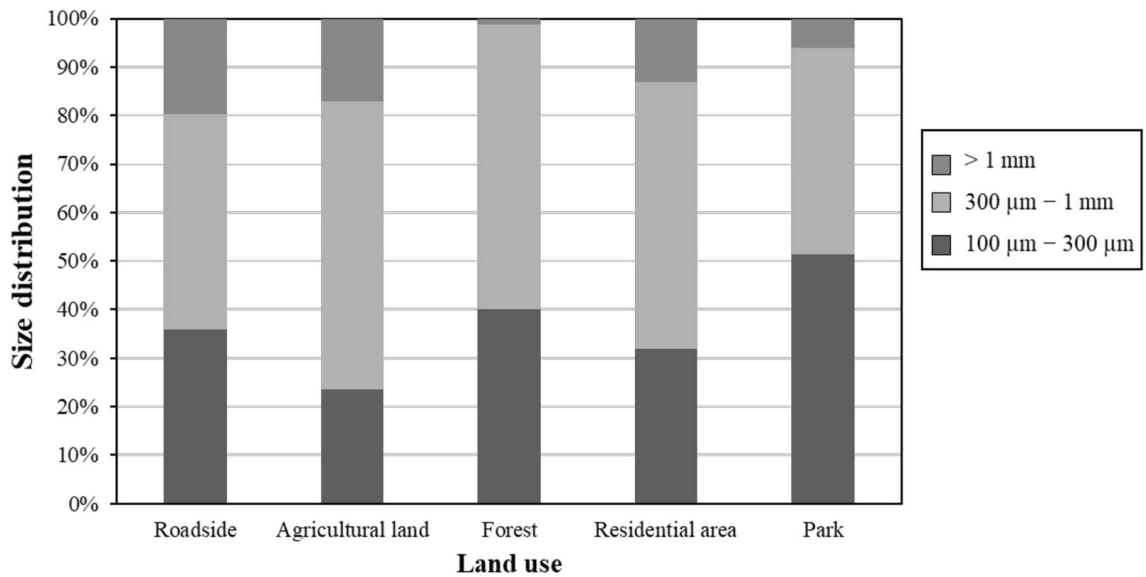

Fig. 6 Size distribution (%) of microplastic particles in soils according to types of land use

and parks are broken down into smaller pieces due to physical force such as compaction and friction or influence of the environment in a rather short time. In forest soils areas seldom visited by people, plastics with sizes over 1 mm had a small amount because input of waste was small. Although small particles of plastic had a high percentage, they were originated from plastic fallout or plastic that was already there and decomposed over a long period of time.

Wang et al. [44] reported that more than 80% of microplastics found in agricultural land soils in China were less than 1 mm in size, with microplastics ranging from 0.02 to 0.2 mm in size having the largest proportion, which is similar to the findings of the pre-sent study. The authors also noted that in rice paddies, larger microplastics (1–5 mm) had the highest proportion, while smaller microplastics (0.02–0.2 mm) were most abundant in orchards. They attributed these distribution characteristics to the specific agricultural practices used in each type of land use, such as the use of plastic film for mulching, irrigation, and plastic fallout.

Choi et al. [19] analyzed the distribution of microplastics according to land use in Yeoju, Korea and found that the largest number of microplastics was detected on roadside, with particles of 1 mm or less in size having a higher proportion in roadside soil than in soils from forests, residential areas, and agricultural land. However, this study observed a different trend where particles with sizes between 300 µm and 1 mm were not observed in parks, soils near roadside, agricultural land, forest, or residential areas. In this study, soils in parks and forests showed a small yet significant amount of microplastics with a size under 300 µm. It is estimated that the size of microplastics decreases and the number of individual pieces increases in forests and parks because there are relatively fewer human activities compared to roadside, residential areas, and agricultural land. Thus, plastics in forests and parks can decompose for a longer time without disturbance after being put into the soil.

Distribution characteristics of microplastic by shape and color

Table 3 shows a list of microplastics detected in the collected soil, divided into four shapes and seven colors. Regardless of land use, detected microplastics had a significantly higher proportion of fragments and black color. This was similar to the findings of Kim et al. [41], who reported that more than 92% of roadside microplastics were black fragments. In Yeoju, Choi et al. [19] found that 65.5% of microplastics were black. Black fragments found on roadside were predicted to be mostly from tires and flooring of cars using the road and shoe soles of pedestrians [43]. Black fragments found in agricultural land were from mulching film, use of farm machinery, and fertilizers. Wang et al. [44] reported that 54.05% of microplastics found in agricultural land soil were fragments, with the majority of microplastics found in rice paddies and orchards showing fiber and fragment forms, respectively. The fiber form is highly associated with the increased use of various synthetic fibers (ropes, clothing, upholstery, or carpets) [46]. Furthermore, there are previous studies similar to this research result where fragment and fiber forms are mainly distributed, leading to the assumption that the occurrence forms of microplastics are similar for each form [47]. In the present study, the proportion of microplastics in forest soil was 87% in fragment form, 5% in film form, and 8% in fiber form. However, Zhang and Liu [45] reported that 92% of soil microplastics in forest areas were in fiber form, with only 8% in fragment and film forms. The distribution by color was 90.2% black, 6.1% white, 2.9% green, 0.4% red, 0.2% blue, 0.1% yellow, and 0.1% transparent. White fragments were the second highest after black in roadside, forest, and residential areas, while in parks and agricultural lands, green was the second highest after black. The reason for the different distribution patterns according to land use is due to the different patterns of plastic use in each area. It is presumed that the use of green plastic and various farm machineries in parks and agricultural lands resulted in higher numbers than other colors [19].

FT-IR analysis of microplastic by land use

FT-IR was used for qualitative analysis of microplastics using fast-mapping method. A disadvantage of this method was that only microplastics with a size of 500 μm or less could be measured. Therefore, samples bigger than 1 cm had to be individually measured. Tables 4, 5 and 6 show the number of microplastics detected in 10 g of soils from roadside, agricultural land, and residential area by the method explained above. The number of

Table 3 Number of average microplastics by shape and color in soils (particles/kg) according to types of land use (BL: Black; R: Red; G: Green; B: Blue; Y: Yellow; W: White; T: Transparent)

Land use type	Fragment						Film							Fiber							Sphere						
	BL	R	G	B	Y	W	BL	R	G	B	Y	W	T	BL	R	G	B	Y	W	T	BL	R	G	B	Y	W	T
Roadside	3980	3	98	13	0	638	0	0	40	0	0	13	0	133	13	18	3	0	25	0	0	3	0	0	8	0	0
Agricultural land	5264	27	20	2	0	0	0	0	0	0	0	0	0	32	14	2	0	0	0	0	0	0	0	0	0	0	0
Forest	748	0	0	0	0	198	0	0	38	0	0	23	0	78	0	0	3	0	3	0	0	0	0	0	0	0	0
Residential area	3185	0	81	8	0	156	0	0	0	4	0	0	13	131	8	25	0	0	0	0	0	2	2	0	0	0	0
Park	2300	9	170	2	16	18	0	0	2	0	0	0	2	111	0	16	0	0	0	0	0	0	0	0	0	0	0

Table 4 Numbers of microplastics less than 500 μm in 10 g roadside soils (particles/kg)

	Microplastics									
	Total	PE	PP	PS	PET	PA	PMMA	PVC	CA	PLA
> 500	10	0	8	0	0	0	2	0	0	0
300–500	0	0	0	0	0	0	0	0	0	0
100–300	16	2	2	0	0	0	2	4	2	4
50–100	12	0	4	0	2	0	6	0	0	0
20–50	4	0	2	0	0	0	2	0	0	0
Total	42	2	16	0	2	0	12	4	2	4

PE polyethylene, *PP* polypropylene, *PS* polystyrene, *PET* polyethylene terephthalate, *PA* polyacrylate, *PMMA* polymethyl methacrylate, *PVC* polyvinyl chloride, *CA* cellulose acetate, *PLA* polylactide

Table 5 Numbers of microplastics less than 500 μm in 10 g agricultural land soils (particles/kg)

	Microplastics					
	Total	PE	PP	PS	PET	PU
> 500	2	0	0	0	2	0
300–500	2	0	0	0	0	2
100–300	0	0	0	0	0	0
50–100	0	0	0	0	0	0
20–50	0	0	0	0	0	0
Total	4	0	0	0	2	2

PE polyethylene, *PP* polypropylene, *PS* polystyrene, *PET* polyethylene terephthalate, *PU* polyurethane

Table 6 Numbers of microplastics less than 500 μm in 10 g residential area soils (particles/kg)

	Microplastics						
	Total	**PP**	**PS**	**PET**	**PMMA**	**PU**	**CA**
> 500	0	0	0	0	0	0	0
300–500	1	1	0	0	0	0	0
100–300	17	0	1	1	0	14	1
50–100	15	1	0	2	1	9	2
20–50	3	0	0	0	0	3	0
Total	36	2	1	3	1	26	3

PP polypropylene, *PS* polystyrene, *PET* polyethylene terephthalate, *PMMA* polymethyl methacrylate, *PU* polyurethane, *CA* cellulose acetate

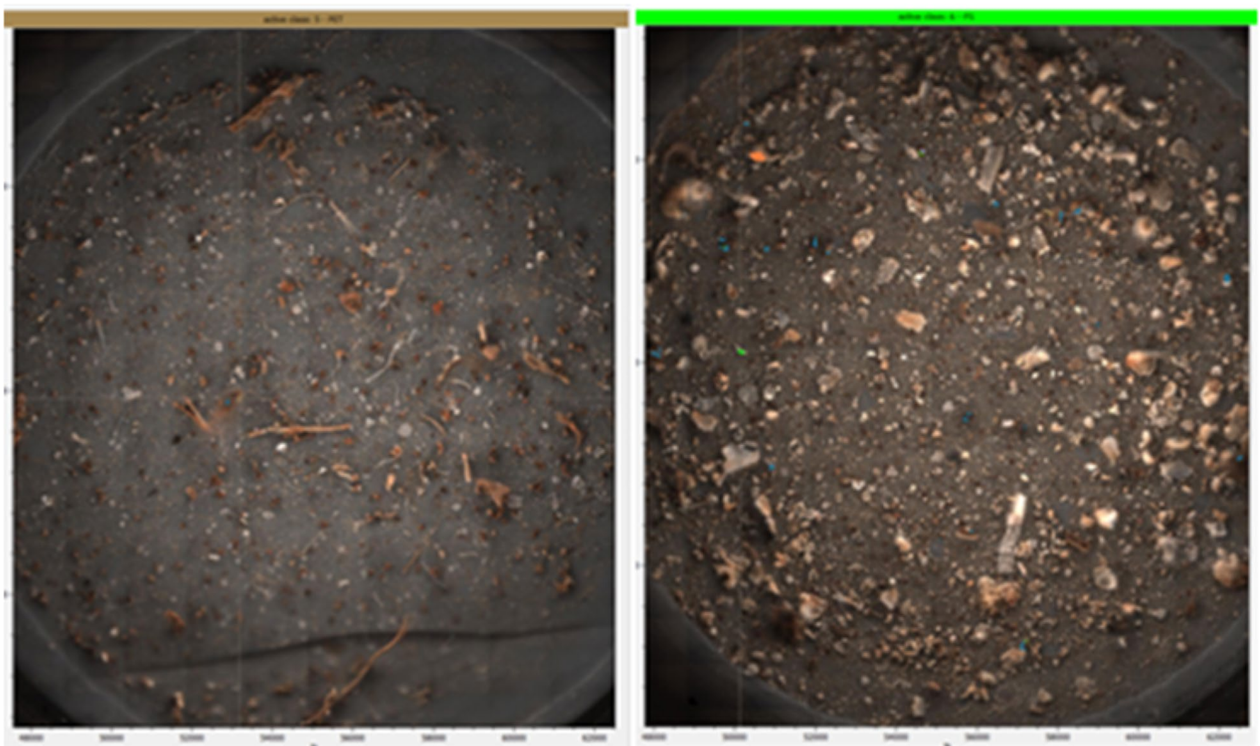

Fig. 7 Microplastic measurement images for an agricultural soil (left) and a residential soil (right) samples

microplastics was in the order of roadside > residential area > agricultural land. These results were different from those obtained with a digital stereo microscope. Such results might be due to distribution characteristics of microplastics. A large deviation can occur even with the same soil sample depending on the test method. Plastics larger than 1 cm were not analyzed by fast mapping in the FT-IR analysis.

In roadside soil, PE and PP were detected. Acrylates based PMMA particles were also found in roadside soil in a large number. PMMA is a material often used for paints, sign-boards, furniture, and automobile exterior. PP is also a material found in road maintenance materials and parking blocks. It is commonly encountered on roads. Although in this study, styrene-butadiene rubber (SBR) generated from automobiles was not detected in the soil because the road was well maintained, the ground level of roadside was higher than the road, and a location with a good drainage system was selected., Sommer et al. [17] have reported that SBR is a commonly used material in the tire industry, accounting

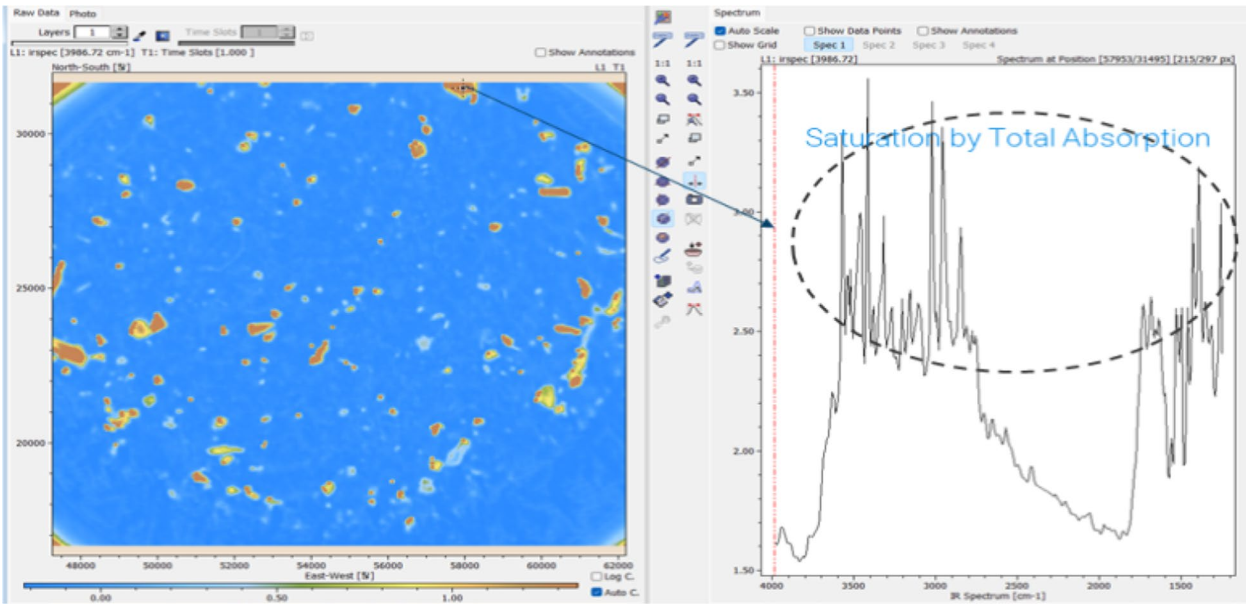

Fig. 8 "Total absorption" that cannot be measured during FT-IR analysis of microplastics

for more than half of black microplastic fragments detected in urban areas such as roadside and residential areas. Their report also showed an increase in SBR around highways, roadside, or parking lots due to continued use and wear of car tires. Choi et al. [19] have reported that PE, PP, PS, and polyvinyl chloride (PVC) account for the majority of microplastics found in Yeoju soil, whereas PU accounted for 72% in the present study. PU is used mostly as a synthetic leather material because it has higher elasticity and flexibility than hard PVC, making PU a preferred alternative. Therefore, PU detected in soil was presumed to be fragments from worn out shoe soles, insulation materials, cushioning materials, gloves and artificial leather [48]. PE and PP are preferred materials widely used for mulching in agricultural land [49]. However, due to their low density, they can be easily washed away along with soil erosion. PS, PE, PP, HDPE (high-density polyethylene), PVC, and PET have been detected in agricultural land soils in Shanxi province [34]

However, in this study, only small amounts of PET and PU particles were detected in agricultural land soils. Judging from image analysis, the agricultural land soil of this study contained a lot of large organic matters, which might interfere with fast mapping in the FT-IR analysis (Fig. 7).

As the diameter of the Anodisc used for FT-IR analysis was small, it was necessary to remove most of the soil organic matter or moisture during pretreatment and use a smaller soil sample than what is typically used for analysis with a stereo microscope. FT-IR analysis of soils from roadside, agricultural land, and residential areas resulted in distortion or saturation of the IR spectrum (Fig. 8). This was likely due to the presence of large particles in high quantities, which overlapped with fine particles below, causing wavelengths to travel through all the overlapping particles. As a result, it was found that there were areas where the counting of microplastics was impossible, thereby reducing the accuracy of the analysis.

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Author contributions
Conceptualization: J.H.Y., and K.H.K.; methodology: J.H.Y. and B.H.K.; formal analysis: B.H.K.; visualization: J.H.Y., and B.H.K.; original draft writing: J.H.Y., and B.H.K.; review and editing: J.H.Y., and K.H.K.; supervision: K.H.K. All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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