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Abundance and Characteristics of Microplastics in the Soil of a Higher Education Institution in China

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ABSTRACT: While microplastics have been detected in various spheres of the environment, there are few studies examining their abundance in higher education institutions, where their exposure to students and staff could raise concern. This study aims to quantify and characterise the microplastics in the soil of a higher education institution in China. Surface soil samples were collected in triplicate from nine sampling sites distributed evenly across teaching, recreational, and residential areas on campus. The soil samples were sieved with a 5 mm screen, and the fractions passing through the sieve were digested with 30% hydrogen peroxide. Microplastics were density-separated from the digested soil and observed under the microscope. ATR-FTIR was used to determine their compositions. This study reveals a higher abundance of microplastics in teaching and residential areas (150–700 items/kg and 50–650 items/kg, respectively) as compared to recreational areas (0–450 items/kg), with the highest mean abundance (516.7 items/kg) recorded for residential areas. Fibrous and fragment microplastics (31.5% and 33.3%, respectively) were most common in the soil samples, with the former more prevalent in residential areas. There were more black microplastics (36.4%) and white microplastics (29.1%) than those of other colors. Microplastics ≤ 0.5 mm constituted the largest fraction (64.3%) of total microplastics recovered and polyethylene microplastics were most abundant (35.2%). This study contributes to a better understanding of microplastic pollution in the compounds of higher education institutions, which could be positively linked to the human activities within those institutions.

KEYWORDS: Abundance; concentration; human activities; particle size; polyethylene; residential

1. Introduction

Plastics have the desirable properties of good stability, flexibility, corrosion resistance, thermal stability, and versatility, making them indispensable in construction, manufacturing, agricultural production, and daily life [1]. Due to the increasing demand for plastics in various economic sectors, the global annual output of plastics has increased from 2 million metric tons in 1950 to 348 million metric tons in 2019 [2]. Correspondingly, as of 2019, a total of 9.5

billion metric tons of plastics had been produced globally, of which about 22% of plastics were improperly discarded, posing a huge threat to the ecosystems [2]. Through the effects of light, high temperatures, oxidation, physical corrosion, and microbial degradation, these plastics in the environment undergo fragmentation, forming smaller plastic particles called microplastics [3]. The term "microplastics" was first proposed by Thompson et al. in 2004 to describe plastic particles in water bodies and sediments with small sizes [4]. With further development of plastic particle size classification, Arthur and Baker defined plastic particles smaller than 5 mm as microplastics (Figure 1) [5]. Figure 1 shows the classification of plastics based on size.

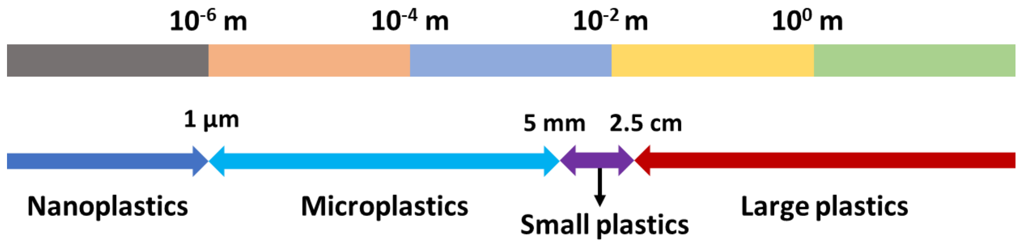

Figure 1. Size classification of plastic debris [5].

Microplastics have been detected in various spheres of the environment, including the freshwater, marine, and terrestrial ecosystems. While recent studies have turned attention to the prevalence of microplastics in freshwater and marine environments, it is noteworthy that a large amount of microplastics still remains in the soil [6–8]. Nizzetto et al. warned that the abundance of microplastics in terrestrial ecosystems could be 4-23 times that of the ocean [9]. The annual input of microplastics into agricultural soil is much higher than that of the ocean [10]. A study on microplastics in agricultural soil in the suburbs of Wuhan found that the abundance of microplastics was as high as 12,560 pieces/kg [11]. Fuller et al. reported that the contents of microplastics in the soil of Australian industrial areas ranged from 0.03% to 6.7%, and believed that human activities are the main contributor of microplastic pollution [12].

Compositional analysis of microplastics in the environment showed that the main polymer types are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyamide (PA), and polyethylene terephthalate (PET) [3, 13, 14]. Microplastics are hard-to-degrade organic pollutants with strong hydrophobicity and high specific surface areas, which make them good adsorbents of persistent organic pollutants (POPs), such as polyaromatic hydrocarbons, polybrominated diphenyl ethers, and polychlorinated biphenyls [15, 16]. Therefore, they also act as carriers to transport these pollutants from the polluted ecosystem to other ecosystems. The adsorption capacity of microplastics is affected by their shapes, particle sizes, polymer compositions, and surface structures [17]. Compared with those in the marine environment, plastics in the terrestrial environment are more strongly affected by weathering and solar radiation, resulting in a higher degree of ageing and fragmentation, hence a larger specific surface area and a better ability to adsorb toxic and harmful substances [18].

Terrestrial microplastics may be ingested by soil organisms and transmitted along the food chain, causing adverse impacts on organisms at various trophic levels [19]. Researchers have discovered that microplastics have an inhibitory effect on the growth and development of certain soil organisms. After being ingested, microplastics could accumulate and block the digestive tracts of the organisms. This could affect their feeding ability, resulting in delayed growth and development and even death in severe cases [20]. For instance, PE microplastics have been shown to reduce the motility of springtail (*Folsomia candida*), an organism widely present in the soil [21]. Besides, PE microplastics were able to damage the guts and trigger immune system responses in epigeic earthworms (*Lumbricus terrestris*) fed with the microplastics [22].

Microplastics normally enter the soil through the degradation of waste plastic products, surface water irrigation, the application of sludge and organic fertilizers, atmospheric deposition, etc. [23]. Polyethylene is the most common raw material in the manufacturing of plastic shed films and mulching films used in the agricultural sector to retain soil moisture and prevent the growth of weeds, thus increasing agricultural yields [10]. Over time and upon continuous exposure to the elements, the plastic films covering the soil undergo fragmentation, chemical decomposition, and biodegradation to form microplastics [24]. Microplastics are also trapped in the sludge of industrial and domestic sewage treatment facilities [25]. Application of the sewage treatment sludge, called biosolids, as fertiliser is permitted in certain countries, and this causes the entry of microplastics into the environment [26, 27]. A study reported up to 1.4×10^4 microplastics in biosolid samples and estimated that application of the biosolids to agricultural soil introduced up to 1.3×10^{12} microplastic particles into the soil annually [28]. There is a tendency for microplastics to build up with each soil application of biosolids, particularly the fibrous microplastics [28]. A review estimated that 26,042, 21,249, and 13,660 metric tons of microplastics had entered agricultural soil due to biosolids application in the United States, China, and Canada, respectively [26]. A proportion of microplastics in soil is contributed by the settlement of airborne microplastics [1]. It was reported that atmospheric deposition is an important pathway for the entry of microplastics into the soil environment [1, 29]. Improper disposal of plastic waste also constitutes a source of microplastics in soil, where degradation of the plastic waste releases microscale plastic pieces [30].

In view of the multiple pathways that microplastics could enter the soil environment and the fact that soil contamination with microplastics is becoming more prevalent and severe, this study aims to examine the abundance of microplastics in the soil of a higher education institution located in China. This is crucial as universities are places with high human activity, and understanding the concentrations and distribution of microplastics in universities sheds light on the exposure of students and staff to microplastics. Besides, while there are numerous studies quantifying the amount of microplastics in soil, not many of them were conducted in the compound of a university. This study serves to fill in the knowledge gap about the extent of microplastic pollution in the soil of a higher education institution.

2. Methods

The study was conducted within the confines of a higher education institution located in southern China (Figure 2). The site of the institution is generally flat, surrounded by hills in the east, hence receiving runoff from the hills which are largely forested. Soil sampling was conducted in the compound of the institution between September 28 and October 2, 2021, to determine the concentrations and distribution of microplastics in the soil therein. The weather during the sampling period was sunny in the daytime and there was no rain. The mean temperature was about 26^{o}C.The sampling locations are shown in Figure 2 and Table 1. The locations cover areas for different purposes in the institution, particularly for teaching, recreation, and residence. This permits comparison of the microplastics contents based on the land uses of the institution [31].

Surface soil samples were collected from the teaching area, residential area, and recreational area, respectively, using a stainless-steel shovel that had been carefully cleaned to minimise microplastic contamination. The soil sampling depth was 5 cm. Three sampling sites were selected from each of the areas, giving a total of nine sampling sites. Three samples of 1 kg each were collected from each sampling site for triplicate analysis. A total of 27 samples were collected. All the soil samples were put into separate Ziplock bags and stored in the refrigerator prior to analysis.

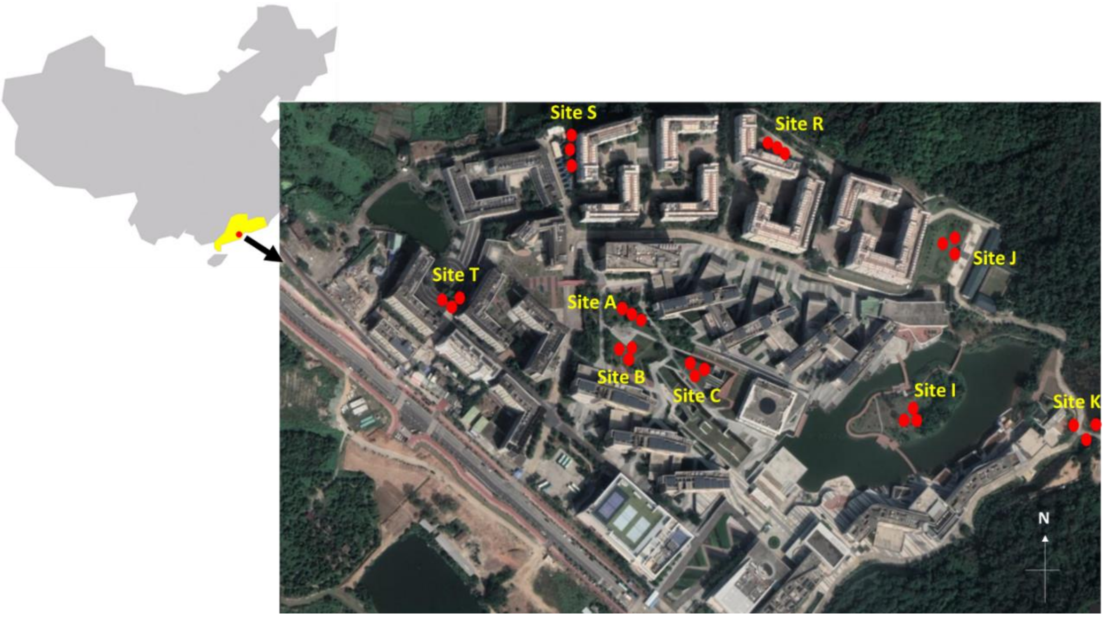

Figure 2. Soil sampling locations for microplastics with three samples collected from each location.

Table 1. Soil sampling locations and observation of the respective human activities.

Area	Sampling site	Longitude	Latitude	Observed human activities
Teaching area	A	113°31′9.08″	22°21′1.09″	High
	B	113°31′10.47″	22°21′41.73″	High
	C	113°43′12.36″	22°62′58.44″	High
Recreational area	I	113°31′8.64″	22°21′25.27″	Moderate
	J	113°31′41.65″	22°81′26.48″	Moderate
	K	113°31′22.79″	22°20′49.20″	Low
Residential area	R	113°31′13.26″	22°21′3.62″	High
	S	113°30′10.18″	22°21′6.62″	High
	T	113°29′19.12″	22°21′1.99″	High

2.1. Pretreatment of soil samples.

Visible large plastic fragments (particle size > 5 mm), crop roots, stones, and other impurities were removed from the soil samples by tweezers. The soil samples were then oven-dried at 40 °C until a constant weight was attained. The samples were subsequently sieved through a 5 mm filter screen to remove impurities and larger particles.

2.2. Separation of microplastics from soil samples.

The pre-treated soil from each sample was placed in a 1000-ml beaker, which was labelled accordingly. The soil sample was digested with 30% hydrogen peroxide to remove organic impurities. To prepare NaCl flotation solution with a density of 1.2 g/cm^3, 250 g of sodium chloride was dissolved in 1000 ml of deionized water. To prepare $ZnCl_2$ flotation solution with a density of 1.6 g/cm^3, 600 g of zinc chloride was dissolved in 1000 ml of deionized water.

NaCl flotation solution was added to the digested soil samples, and the mixtures were left to stand for 48 hours. After that, the supernatant of each mixture was transferred to the vacuum filtration device containing a membrane filter for suction filtration. Upon completion of filtration, the membrane filter with residue was removed and placed in a petri dish to dry at room temperature. The residue was subjected to second flotation using $ZnCl_2$ flotation solution. The mixture was left to stand for 48 hours and underwent vacuum filtration, with the residue left to dry at room temperature.

2.3. Quantification and characterization of microplastics.

The membrane filter with filtration residue was placed under a microscope with 10x and 100x magnification for observation of microplastics. The abundance, sizes, colors, and shapes of the microplastic particles on the filter membrane were visually inspected and recorded. Microplastics of the sizes 0–0.1 mm, 0.1–0.5 mm, 0.5–1.0 mm, and 1.0–5.0 mm were counted. The shapes of the microplastics, namely fiber, film, and granular, were also identified. The concentration of microplastics in the soil was reported as units per kilogramme (n/kg). The microplastic particles observed under the microscope were picked up with a fine needle and fixed on a glass slide. The attenuated total reflectance (ATR) mode of Fourier transform infrared spectroscopy (FTIR) was used to identify the functional groups of the microplastics. The obtained infrared spectra of the microplastics were compared with the standard spectra to determine their compositions.

3. Results and Discussion

3.1. Concentrations of microplastics.

According to Table 2 and Figure 3, sampling site S had the highest concentration of microplastics (516.7 ± 104.1 n/kg), followed by T (483.3 ± 152.8 n/kg), and C (433 ± 275.4 n/kg). Sites S and T are residential areas, while site C is a teaching area (Table 1). All three sites were observed to have high human activity with frequent movement of students and staff members (Table 1). Sampling site J recorded the lowest concentration of microplastics (50.0 ± 50.0 n/kg), whereas that at site K was 100.0 ± 50.0 n/kg (Table 2). Both sites are recreational areas that are less frequented by students and staff members. The latter, with fewer observed human activities than the former, had a relatively higher microplastics concentration, probably owing to its proximity to an internal road passable by vehicles. Nonetheless, the microplastics concentration at site K was lower than all other sites except J (Figure 3). Site R within a residential zone with high human activities was found to contain relatively low levels of microplastics (116 ± 76.4 n/kg), indicating the presence of other factors that could influence the prevalence of microplastics besides human activities.

Generally speaking, human activities are still an important determinant of soil microplastics concentrations on campus, with areas of higher human activities, particularly the teaching areas (sites A, B, and C), characterised by a constant flow of people, having higher soil concentrations of microplastics (Figure 3). Residential areas (sites R, S, and T) also contained high abundances of soil microplastics, with sites S and T being the most prominent.

The variability of microplastics in the residential sampling sites on campus could be influenced by the population density therein. The recreational areas on campus (sites I, J, and K) usually have less human movement, which might correspond with the lower abundance of soil microplastics therein. Site I was an exception, and this might be attributed to its surrounding features, such as a cafeteria in the north and classrooms in the south, with substantial human activities. The trends of microplastics concentrations are in agreement with other studies that show sampling sites near residential areas are often linked to higher abundances of microplastics reported [14, 32].

Table 2. Microplastics concentrations in soil samples.

Sample	Concentration of microplastics (n/kg)	Mean concentration of microplastics (n/kg)	Standard deviation of concentration of microplastics (n/kg)
A1	450		
A2	300	316.7	125.8
A3	200		
B1	300		
B2	350	400.0	132.3
B3	550		
C1	150		
C2	700	433.3	275.4
C3	450		
I1	450		
I2	300	333.3	104.1
I3	250		
J1	50		
J2	0	50.0	50.0
J3	100		
K1	150		
K2	100	100.0	50.0
K3	50		
R1	200		
R2	50	116.7	76.4
R3	100		
S1	400		
S2	550	516.7	104.1
S3	600		
T1	450		
T2	650	483.3	152.8
T3	350		

The mean abundances of microplastics in the soil samples are within the commonly reported ranges; for instance, a mean abundance of 740.1 n/kg was reported by Zhou et al., 273.33 n/kg by Han et al., and 593 n/kg by Scheurer et al. [33–35]. Some studies have revealed even higher soil microplastic abundances in the range of thousands to tens of thousands [36]. The risk of microplastics exposure on campus is, therefore, deemed to be low, and it remains largely uncertain how microplastics could affect humans in the long run. Almost all current studies on the risks of microplastics focus on microorganisms, animals, and plants, and in most instances, the receptors are exposed to much higher levels of microplastics. Earthworms exposed to a maximum of 200,000 n/kg PE microplastics were observed to have altered acetylcholinesterase activity, while nematodes exposed to $2.21 \times 10^5 – 16.9 \times 10^5$ particles/ml of HDPE microplastics had their transforming growth factor-beta (TGF-b) signaling pathway affected [20]. As such, it can be deduced that humans would have a higher tolerance to microplastics than the soil organisms and that the microplastics concentrations reported in this study are not likely to pose a significant concern. However, cumulative human exposure to microplastics from different sources could have long-term implications. Besides, climate change might affect the chemistry and distribution of microplastics in the environment, adding another layer of uncertainty to the risk of microplastics [37].

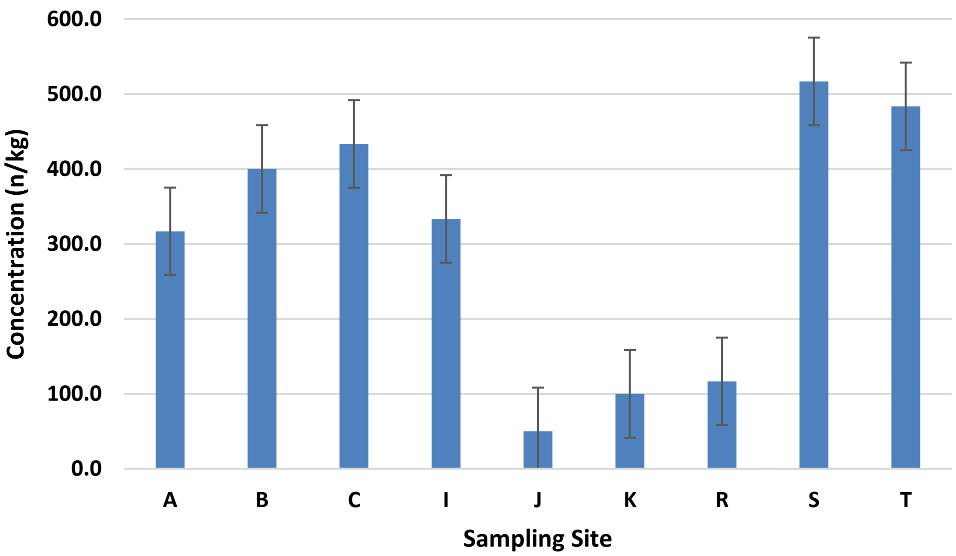

Figure 3. Concentrations of microplastics at different sampling sites on campus.

3.2. Shapes of microplastics.

Fragment microplastics were most abundant in the soil samples, constituting 33.5% of the total microplastics (Figure 5). Fibrous microplastics were the second most abundant microplastics (31.5%), whereas film microplastics were the third (18.8%). In terms of their distribution, fibrous and fragment microplastics seem to be the most abundant in nearly all sampling sites (Figure 4). Fibrous microplastics were found to be most abundant in the soil of residential areas, particularly at sites R and T, which might be associated with the fabrics used by the occupants. Typically, washing a piece of cloth could shed 1900 fibres into water [3]. Film microplastics were generally more abundant in recreational areas except site K, where no film microplastics were found (Table 3, Figure 4).

Table 3. Percentages of microplastics by shape at different sampling sites.

Sampling site	Percentage by shape (%)			
	Fibrous	**Fragment**	**Film**	**Granular**
A	36.8	26.3	21.1	15.8
B	33.3	37.5	8.3	20.8
C	26.9	42.3	19.2	11.5
I	20.0	25.0	40.0	15.0
J	0.0	66.7	33.3	0.0
K	50.0	16.7	0.0	33.3
R	42.9	57.1	0.0	0.0
S	25.8	41.9	12.9	19.4
T	41.4	17.2	24.1	17.2

Figure 6 shows the shapes of microplastics as observed under the microscope. The fact that fibrous and fragment microplastics were most abundant in this study aligns with a study revealing fragment microplastics were predominant in the soils in the Daliao River Basin [34]. Fragment microplastics as the predominating microplastics detected in this study are in agreement with the findings of Yu et al. that they were most prevalent in the agricultural soils of Shouguang City, China [38]. This is in contrast to other studies revealing fibrous microplastics as the most prevalent [39–41]. A study conducted on coastal beach soils found the largest fraction of microplastics detected was microplastic flakes, followed by foams and fragments, indicating the variability of the shapes of microplastics across sample types and sampling sites [42].

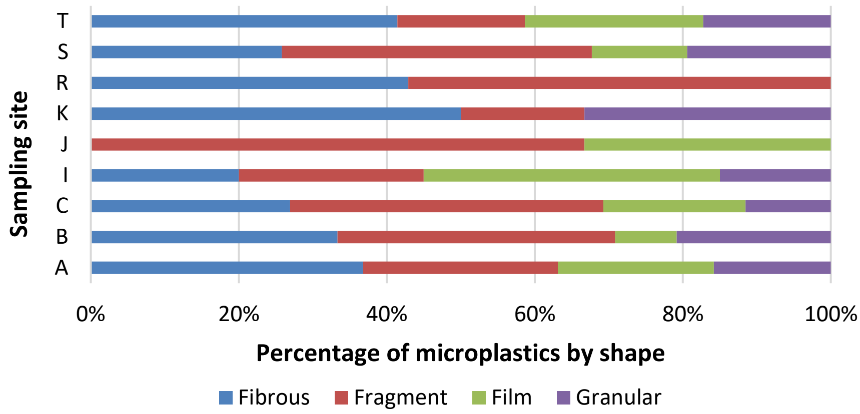

Figure 4. Percentages of microplastics of different shapes at different sampling sites on campus.

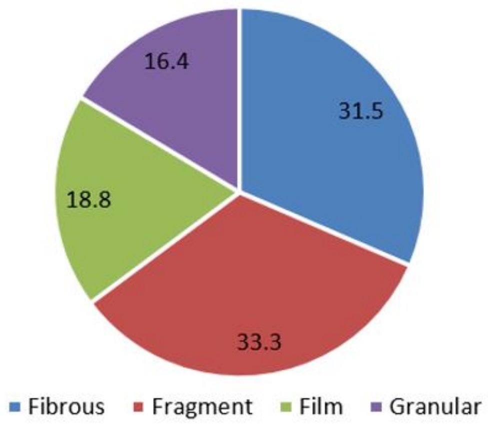

Figure 5. Percentages of total microplastics in all samples by shape.

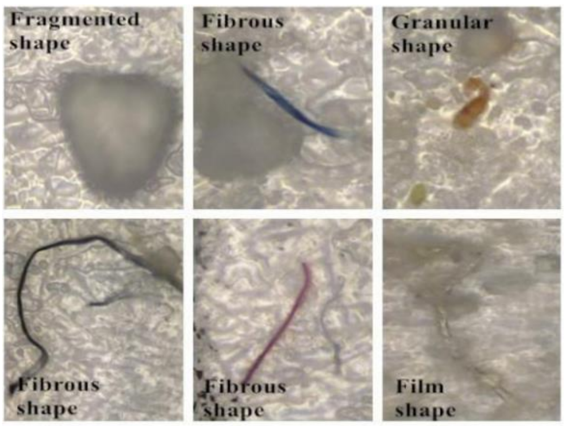

Figure 6. The shapes of microplastics detected and observed under the microplastics.

3.3. Colors of microplastics.

Five colors of microplastics, namely black, green, red, blue, and white, were observed. These are the colors of microplastics most commonly reported [3, 14, 39]. Black microplastics were the most abundant, comprising 36.4% of the total microplastics, while white microplastics were the second most abundant with 29.1% (Figure 8). Microplastics of all five colors were found at all the sampling sites except J, K, and R. J and K, falling within recreational areas, only contained microplastics of two and three colors respectively, with black and white microplastics being the most prevalent (Table 4 and Figure 7). Significant numbers of green and red microplastics were observed in soil samples taken from residential areas, which might be partly contributed by laundry activities and the fabrics used by the occupants (Figure 7). White microplastics were prevalent in recreational areas. The predominant colors of microplastics tend to vary geographically. Yu et al. found that transparent or translucent microplastics constituted the largest proportion of microplastics in the agricultural soils in Shouguang City, followed by white microplastics [38]. White microplastics were reported to be the most abundant microplastics in other studies [40, 43]. In those studies, white microplastics were deemed to have come from plastic bags and plastic packaging.

Table 4. The color distribution of soil microplastics on campus.

Sampling site	Percentage by color (%)				
	Black	Green	Red	Blue	White
A	47.4	15.8	10.5	0.0	26.3
B	45.8	4.2	16.7	16.7	16.7
C	30.8	19.2	7.7	15.4	26.9
I	20.0	5.0	5.0	5.0	65.0
J	66.7	0.0	0.0	0.0	33.3
K	16.7	0.0	16.7	0.0	66.7
R	28.6	28.6	14.3	0.0	28.6
S	45.2	16.1	12.9	9.7	16.1
T	27.6	6.9	24.1	20.7	20.7

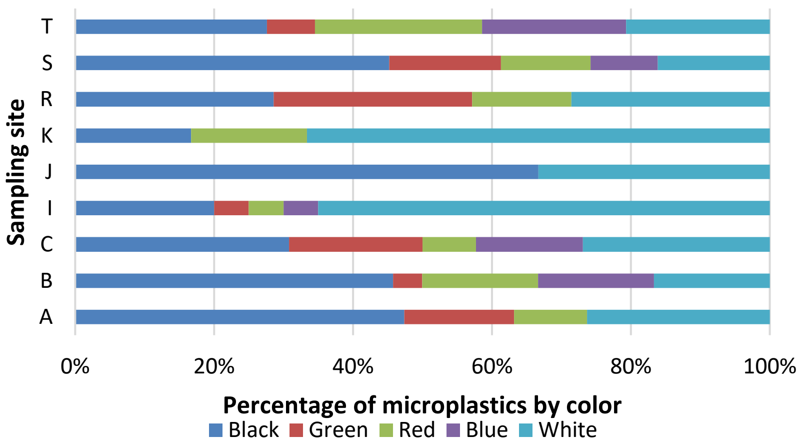

Figure 7. Percentages of microplastics of different colors at different sampling sites on campus.

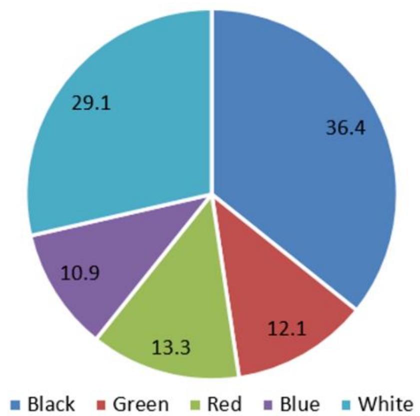

Figure 8. Percentages of total microplastics in all soil samples by color.

3.4. Particle size distributions and compositions of microplastics.

In terms of particle size, microplastics with sizes ≤ 0.1 mm were most predominant in the soil of the institution (35.8%), followed by those with sizes ranging from > 0.1 mm to 0.5 mm (28.5%) (Figure 10). The rest was almost equally divided between the size ranges of > 0.5–1.0 mm and > 1.0–5.0 mm, respectively (Figure 10). Microplastics of ≤ 0.1 mm were most prevalent in recreational areas whereas those of > 0.1 mm to 0.5 mm were most prevalent in residential areas. Microplastics of sizes > 1.0 mm to 5.0 mm could more commonly be found in teaching areas (Table 5 and Figure 9). This study resonates with the findings of Yu et al. that microplastics less than 0.5 mm were the most abundant of all microplastics recovered [38]. Similar to the findings of Yu et al. and Zhou et al., a positive skew in the microplastics particle size distribution was observed where the numbers of microplastics were inversely proportional to the particle sizes [33, 38]. This was thought to result from the degradation of microplastics [42, 43].

Table 5. Particle size distributions of microplastics at different sampling sites

Sampling site	Particle size distribution (%)			
	0 – 0.1 mm	**>0.1 – 0.5 mm**	**>0.5 – 1.0 mm**	**>1.0 – 5.0 mm**
A	31.6	21.1	26.3	21.1
B	33.3	33.3	12.5	20.8
C	34.6	15.4	26.9	23.1
I	40.0	35.0	15.0	10.0
J	66.7	0.0	33.3	0.0
K	50.0	16.7	16.7	16.7
R	28.6	57.1	0.0	14.3
S	19.4	38.7	22.6	19.4
T	51.7	24.1	13.8	10.3

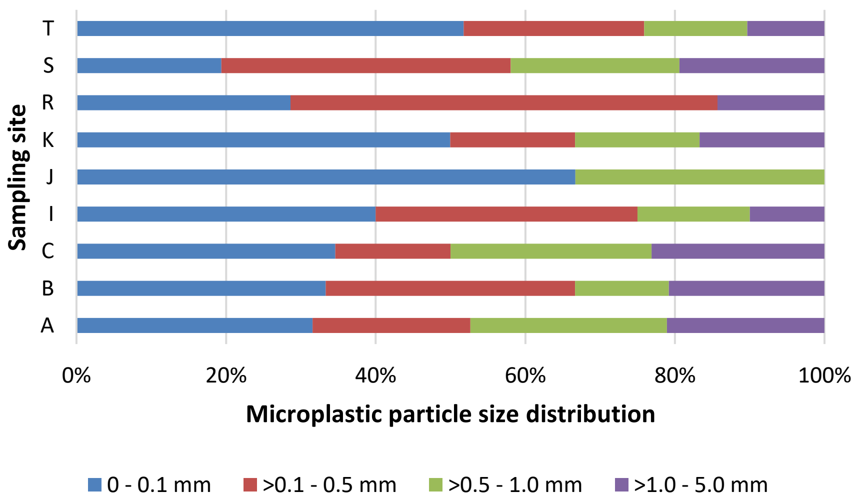

Figure 9. Particle size distributions of microplastics in soil samples from different sampling sites.

Microplastics detected in the soil samples were mostly PE (35.2%), a polymer commonly used for packaging and plastic bags (Figure 11) [44]. A significant proportion of PS (21.4%) was also detected in the soil samples and PS is widely used as food packaging (Figure 11). Besides, there were substantial PP (19.5%) and PVC (14.4%) detected in the soil samples. Small amounts of polyacrylonitrile (PAN) and an unidentifiable copolymer were reported.

PAN is a synthetic resin used for the production of synthetic fabrics [45]. In the study of Yu et al., the abundance of PE microplastics was second to PP and ethylene-propylene copolymer (EPC) microplastics [38]. However, it aligns with the study of Piehl et al. showing that PE microplastics were most prevalent in the agricultural farmland in southeast Germany, and PE, PS and PP types of microplastics had the highest predominance of all microplastics types [43]. PE, PS and PP microplastics were also the most abundant microplastics in the coastal soils near the Bohai Sea and the Yellow Sea while PE and PET microplastics were most common in the water, sediment and soil samples taken from a tropical Indian river [40, 42].

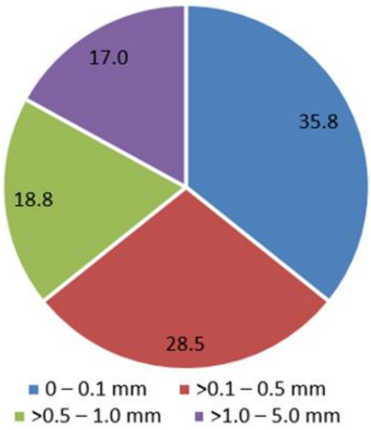

Figure 10. Overall microplastic particle size distribution.

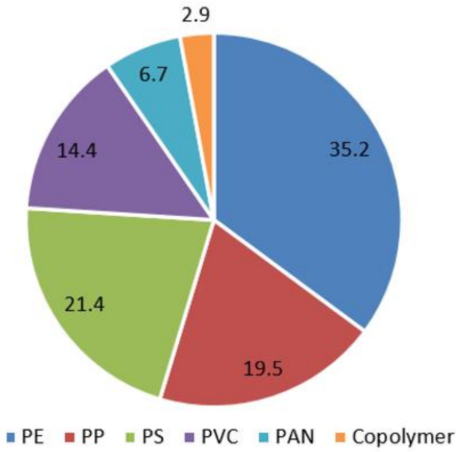

Figure 11. Compositions of the total microplastics in all soil samples.

4. Conclusions

This study further shows that microplastics are ubiquitous and are found in the soil of a higher education institution. Areas on campus with higher human activities, particularly the teaching and residential areas, tended to have higher amounts of microplastics in comparison to areas with lower human activities, such as those for recreation. Fibrous and fragment microplastics were most found on campus. Among all the microplastics detected, white and black microplastics were most prevalent. Microplastics with sizes smaller than 0.5 mm made up the largest fraction of the total microplastics, while PE and PP microplastics were most abundant in the soil samples. This study contributes to the understanding of the prevalence and characteristics of microplastics in the soil of higher learning institutions, which have not been thoroughly studied. It reveals the presence of significant amounts of microplastics in the soil of a higher education institution in China, thus the potential risk of exposure of the people in the institution to microplastics. It also highlights the potential association between human activities on campus and the levels of microplastics in the soil.

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Competing Interest

The authors declare that there is no competing interest.

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