RESEARCH ARTICLE

Microplastic pollution in urban green-belt soil in Shihezi City, China

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Abstract
The problems are associated with microplastic (MP) pollution of global concern. However, little is known about the pollution characteristics and sources of MPs in urban green-belt soils. Therefore, this study investigated MP pollution in 11 sampling sites (22 green belts) in Shihezi City. The results showed that the abundance of MPs (0.02–5.00 mm) ranged from 287 ± 100 items/kg dw to 3227 ± 155 items/kg dw (mean + SD). Fibers (69.9%) accounted for the majority of MPs, and the MPs were mainly black (36.7%) and 0.02–0.5 mm (64.8%). The main types of MPs were polystyrene (PS) and polyethylene (PE). Compared with agricultural soil, the color and composition of green-belt soil MPs are diverse, which means that the source of green-belt soil MPs is more diverse. In different types of green-belt soil, MP pollution of industrial green land is more serious. Through cluster analysis and spatial distribution, fragments and fibers were found to have similar sources, mainly originating from food and textile industrial activities. This study provides important information for revealing MP pollutions in urban green-belt soils.

Keywords Microplastics · Urban green-belt soil · Pollution · Polystyrene · Potential sources · Spatial distribution

Introduction

Plastics are widely produced and used in various industries. In 2018, the global production of plastics was approximately 360 million tons, of which China accounted for 30%. Of this plastic, only 25% was recycled (PlasticsEurope 2019). Because of their unique physical and chemical properties, such as ultraviolet resistance, high-temperature resistance, and corrosion resistance, plastics have a long degradation time in the environment. As a result, it leads to the accumulation in the environment of those microplastics that have been broken down through physical, chemical, and biological activities (Wright et al. 2020). Plastic particles with a particle size of < 5 mm are known as microplastics (MPs) (Arthur et al. 2009).

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MPs have been widely reported in the agricultural soil environment; however, little is known about MP pollution in urban green-belt soils. When MPs enter the soil environment, they can change the soil properties, thereby affecting plants and animals and harming the ecosystem. For example, studies have shown that MPs can change the bulk density, water holding capacity, and water-stable aggregates (de Souza Machado et al. 2018) and cause degradation of organic matter in soil (Liu et al. 2017), which means that MPs in the soil can affect plant growth. In addition, MPs can absorb organic pollutants (Laganà et al. 2019) and heavy metals (Brennecke et al. 2016) owing to the large specific surface area of MPs. MPs can be mistakenly regarded as food and eaten by organisms, which leads to contamination of organisms by MPs and their adsorbed contaminants. Studies have shown that ingestion of MPs can lead to false satiation, thereby causing biological harm such as clogging or abrasion of the digestive tract and reduced feeding rates (Guo et al. 2020). Luo et al. (2019) reported that exposure of female rats to polystyrene MPs increased the risk of metabolic disorders in their offspring. MPs have been found in many small soil invertebrates, such as snails (Panebianco et al. 2019) and nematodes (Kim and An 2019). Some MPs that accumulate in organisms are transferred to the food chain (Nelms et al. 2018; Sarker et al. 2020). For example, studies have reported the transfer of microscopic and

macroscopic plastics between soil and chicken in a family garden in southeastern Mexico (Lwanga et al. 2017) and the intake of plastics by sheep from agricultural soil in Spain (Beriot et al. 2021). The study of soil MPs has attracted the attention of researchers because the exact extent of MP contamination and its possible practical effects on soil ecosystems are not yet fully understood.

The main object of the current research on soil MPs is farmland. For example, researchers have detected MPs in agricultural soil in Shanghai suburbs, revealing the pollution characteristics of MPs in typical agricultural soil (Liu et al. 2018). The analysis of pollution and potential sources of MPs in other soil types is insufficient. Because of the different uses of soils, the main ways in which MPs enter the soil are different. Urban soil, described as "anthropic soil," are a mixture of natural soil-forming factors and anthropogenic activities, which is fundamentally different from natural soil (Tresch et al. 2018). Urban green space, as a substitute for natural soil, provides a large number of ecosystem services, rainwater interception, and purification, provides habitat for countless microorganisms, plants, and animals, and provides entertainment places for urban residents (Delgado-Baquerizo et al. 2021; Francini et al. 2018). According to the United Nations, 68% of the world's population will live in cities by 2050 (Delgado-Baquerizo et al.). However, relevant studies show that urban green space is not only the repository of pollutants, but also the second source of pollutants (Li et al. 2018). In view of the importance of urban green-belt soils and the harm of MPs, researchers need to consider the pollution characteristics and potential sources of MPs in urban green-belt soils.

Shihezi City, which won the United Nations Dubai Award for "the best example of improving the living environment" in 2000, is a garden city built on the Gobi wasteland, with a green coverage rate of 42%. Therefore, Shihezi City is an ideal city for investigating MP pollution of urban green-belt soil in remote areas. We investigated the pollution characteristics and spatial distribution of soil MPs in the green space of Shihezi City. The aims of this study were as follows: (1) to investigate the pollution characteristics of MPs in the green-belt soil of Shihezi City; (2) to study the differences in the distribution of MPs in soils taken from different types of green-belts; and (3) to analyze the sources of MPs using cluster analysis, spatial analysis, and related information.

Materials and methods

Sampling sites and sampling

Taking Shihezi City as the research area, 11 sampling points (Fig. 1) were selected and divided into six categories, namely, park green space (A1 and A2), residential green space (B1 and B2), industrial green space (C1 and C2), commercial green space (D1 and D2), road green space (E1 and E2), and green buffer (F1) (Table S1).

Soil sampling was conducted in October 2020. Each sampling point was divided into three sampling surfaces at a distance of three meters, and three subsamples were collected and mixed thoroughly. Before collecting duplicate soil samples, the branches and leaves were removed from the soil surface of the selected sampling area (an area of 20 ×

Fig. 1 Sampling sites in Shihezi City. (**A**, park green space; **B**, residential green space; **C**, industrial green space; **D**, commercial green space; **E**, road green space; **F**, green buffer)
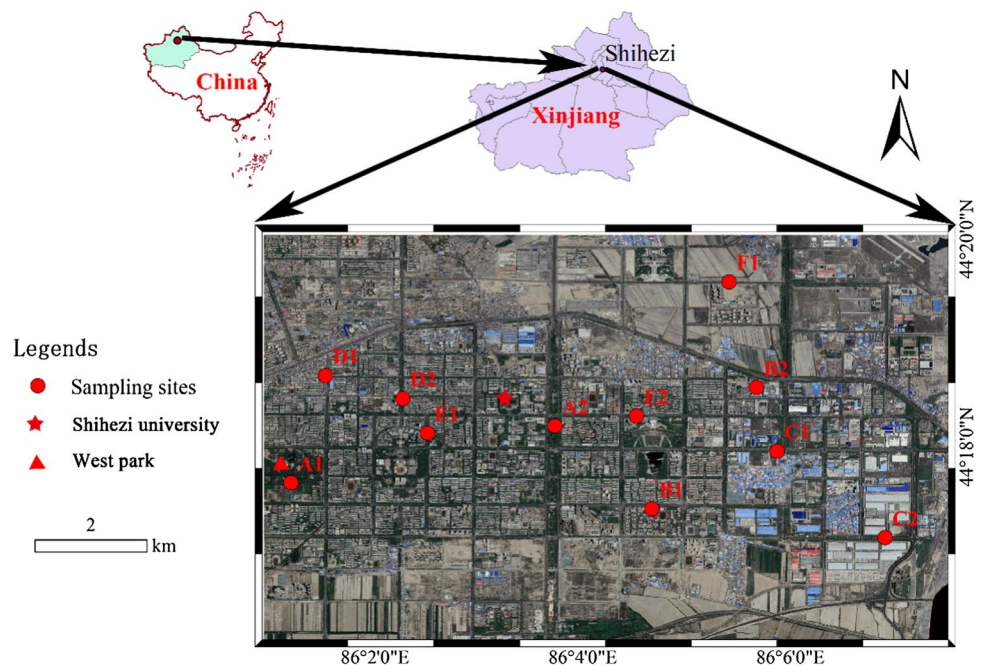
20 cm and depth of 0–5 cm), and the soil was collected with a stainless-steel shovel. Approximately 1 kg of soil sample at each sampling point was stored in aluminum boxes and transported to the laboratory.

Sample preparation

MP extraction

The extraction method was modified from Liu et al. (2019). A portion of the stored sample was weighed and dried in an oven at 50 °C for 24 h to a constant weight. When the soil weight remained constant, 100 g of soil samples was weighed into a clean and dry glass bottle, 200 mL of saturated sodium bromide was added, and the solution was stirred for 5 min and set overnight. The supernatant was then poured into a conical bottle and density separation was repeated three times for the lower layer for each sample. Finally, the supernatant was filtered with a Whatman filter (GF/F, 0.45μm). The surface material of the filter membrane was gently scraped repeatedly with a clean small steel sheet, and then the material was rinsed into a conical flask with 30 mL of 30% hydrogen peroxide (used filter membranes were examined under a microscope for MPs), which was then placed in a shaker (120 rpm, 50 °C) for digestion for 72 h. After digestion, the digestive fluid was turbid, which might have been due to the soil attached to the particles falling off; therefore, density separation was required. The digested liquid was filtered through a filter membrane and washed with saturated sodium bromide, added into a centrifuge tube, and centrifuged at 4000 rpm for 10 min (Carr et al. 2016). Centrifugation was repeated three times for each sample. Finally, the supernatant was filtered, and the MP particles on the surface of the filter membrane were washed with anhydrous ethanol and placed in a clean glass petri dish. The petri dish was then dried at room temperature.

Observation and identification of MPs

The concentration, size, and type of all observed substances were determined, and the substances were observed using a stereomicroscope (SZX16, Olympus) equipped with a camera. Suspected MPs were first distinguished under the microscope according to the classification criteria developed in a previous study (Mohamed Nor and Obbard 2014) and thermal needles. Four characteristics were recorded, namely, abundance, size (0.02–5 mm), color, and shape. Seventy suspected MPs (particles so fine that they could not be tested with a heating needle) were then removed with tweezers for further confirmation by micro-Fourier transform infrared (μ-FTIR) spectroscopy (Bruker Vertex 70v, Germany) under the transmittance mode. Each spectrum was obtained in a wavenumber range of 4000–400 cm^{-1} and scanned 32 times with a resolution of 4

cm^{-1}. The KnowItAll 2020 software was used to compare the obtained spectra with the built-in polymer library, and only results with matching degrees > 70% were accepted. Among the 70 selected suspecteds particles, 56 were identified as plastics (80%). According to the test results, non-MPs were removed from the statistical analysis.

Quality assurance and quality control

All utensils were rinsed with distilled water three times and were covered with an aluminum film when not in use. All the solutions were filtered before use. In order to reduce errors, all used filter membranes were scanned for MPs under the stereomicroscope. Three parallel experiments were conducted for each sampling site. Gloves and cotton laboratory coats were used for all experimental steps. During the experiment, two groups of blank samples were set: the first group was operated without soil to evaluate whether there was pollution during the operation process; the second group had a filter device placed around the microscope to filter the surrounding air for 2 h to evaluate the presence of air pollution in the environment. As observed through the microscope, 0.83 ± 0.75 fibers were found in both groups. Therefore, contamination during the analysis process was negligible.

Data analysis

SPSS version 25 was used for all statistical analyses and Origin version 2021 and ArcMap version 10.2 were used for mapping. The Kruskal–Wallis *H*-test was used to compare the differences in abundance between different sampling sites and between different functional areas. All sampling sites and shapes of MP were classified by systematic clustering to determine which study areas had similar pollution characteristics and similar sources of pollution by the method of the cluster analysis. To infer the source of MPs based on the shape distribution of MPs, a four-variable PCA was used. The inverse distance weight interpolation method was used in ArcGIS to study the spatial distribution of MPs in Shihezi City. Statistical significance was accepted when $p < 0.05$, and the values were expressed as the mean ± standard deviation.

Results and discussion

Abundance and distribution characteristics of MPs

In this study, MPs were found in the urban green-belt soil at each sampling point. The abundance of MPs at each sampling point is shown in Fig. 2a. There was a significant difference in the abundance between the different sampling sites ($p < 0.05$) (Table S2). The concentration

of MPs ranged from 287 ± 100 items/kg dw to 3227 ± 155 items/kg dw, with an average of 1303 ± 926 items/kg dw; this shows lower abundance of MPs in the urban green-belt soil at each sampling point than that detected in agricultural soils. For example, an average abundance of 2116 ± 1024 items/kg MPs was detected on a farm in southeastern Spain (Beriot et al. 2021). It is worth noting that in the Spanish study, distilled water was used as the density solution and the MPs were observed based on the overall image changes before and after heating without size information, while the present study used a high-density separation solution ($\rho = 1.55$) and was carefully observed under a microscope, so the present study is much lower than the Spanish study on MP contamination in agricultural fields. The average content of MPs in the vegetable soil in southwest China was 18,760 items/kg (Zhang and Liu 2018), which better proves the high MP contamination in farmland areas. In their study, $ZnCl_2$ ($\rho = 1.5$) was used as separation solution, similar to the present study, and the size range of statistical MPs was consistent. There was a significant difference in the content of MPs between C2 and E1 (Table S3). Among the 11 sampling sites, the highest abundance of MPs was detected in C2 (3227 ± 155 items/kg dw), with fiber-shaped MPs up to 2400 ± 176 items/kg dw. This might have occurred because there are textile mills around

C2, which pollutes the surrounding green-belt soil with MPs. A previous study of water and sediment samples from a textile industrial zone in Shaoxing City, China, showed that the textile industry has a high degree of MP pollution to local fresh water and sediments (Deng et al. 2020), which further verifies our results. Therefore, the surrounding soil may also be contaminated by MPs. This finding is similar to the highest concentration found in typical farmland soils in Shaanxi Province (3410 items/kg) (Ding et al. 2020). This shows that MPs in soil have other sources besides agricultural activities, which are dependent on the surrounding environment. The lowest concentrations were 287 ± 100 items/kg dw and 593 ± 68 items/kg dw at E1 and A1, respectively. E1 is in an area with high traffic flow, but the MP content was the lowest. This might have been due to tillage activities prior to E1 sampling; however, tillage activities mainly result in the migration of surface-enriched soil MPs to deeper soils by overturning the topsoil and deeper soils (Rillig et al. 2017). The MPs content of A1 might have been low because it is in the forest of West Park, which has lush trees and is less affected by human activities and atmospheric deposition; therefore, it is less polluted by MPs. This result is similar to that detected in soil samples from the Swiss Nature Reserve (593 items/kg) (Scheurer and Bigalke 2018).

Fig. 2 Abundance (**a**), shape distribution (**b**), color distribution (**c**), and size distribution (**d**) of microplastics in Shihezi City (A, park green space; B, residential green space; C, industrial green space; D, commercial green space; E, road green space; F, green buffer)
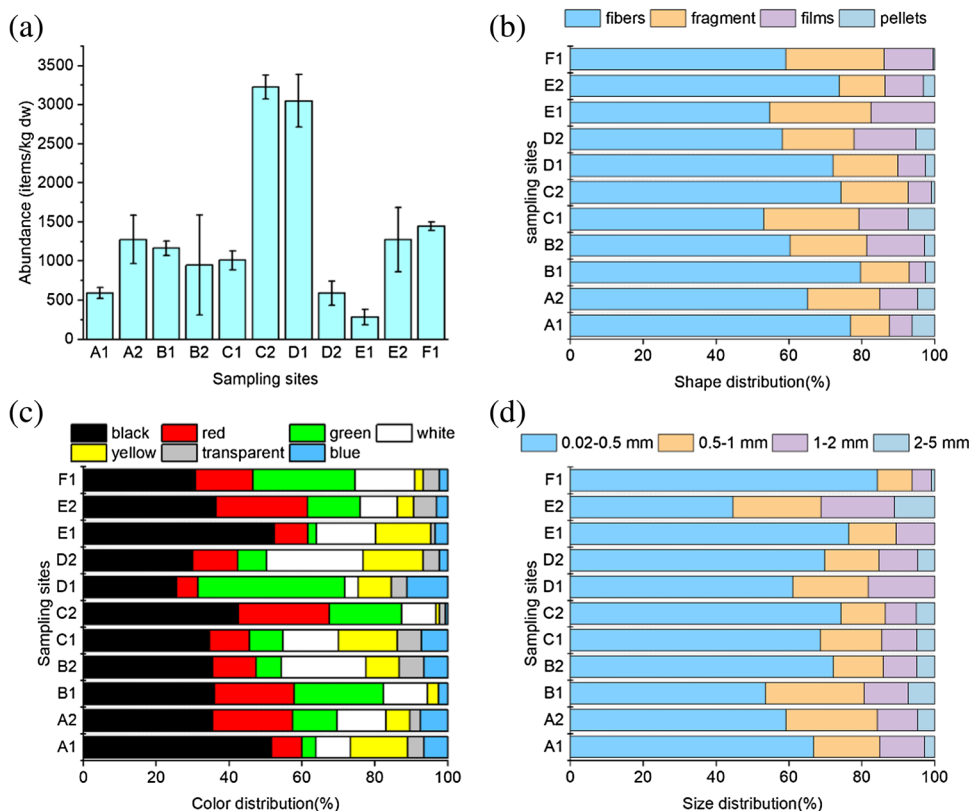
Characteristics of MPs in urban green-belt soil

In this study, the shapes of MPs were divided into fibers, fragments, films, and pellets, and the images obtained using the stereomicroscope are shown in Fig. 3. As shown in Fig. 2b and Fig. S1a, fibers are common MPs, accounting for 67.9% of MPs, followed by fragments and films, accounting for 19.3% and 10.0% of MPs, respectively. The smallest proportion was of pellets, accounting for only 2.8% of MPs. This result is similar to that of a study of cultivated soil in Southwest China (Zhang and Liu 2018). It has also been reported that MPs are mainly fiber-shaped in farmland in the suburbs of Shanghai, China (Liu et al. 2018). Owing to the characteristics of climate drought in Shihezi City, the use of a dust-proof net in the early stage of green-belt soil development led to fiber pollution (Chen et al. 2021). In addition, the erosion of synthetic textiles and synthetic rubber (Prata 2018) and atmospheric deposition are other important sources (Dris et al. 2016). In 2014, the global synthetic fiber output reached 65.2 million metric tons with the highest proportion being from Asia (52.5 million metric tons) (Chemical et al. 2015). When exposed to sunlight, these fiber products undergo photooxidation and exert thermal effects to decompose and degrade into microfibers, thereby resulting in high fiber contamination in the environment (Song et al. 2017). Fragmented MPs usually originate from the breakdown of plastic containers, cutlery, furniture, and toys (Peng et al. 2018; Zhao et al. 2015). Most MP films originate from the decomposition of large plastic bags (Mohamed Nor and Obbard 2014). During sampling, some aged plastic bags were found in the soil, which supported this finding. To further analyze the distribution of soil MP morphology, four variable principal component analyses were performed (Fig. S2). Ninety-two percent of the total data variance was explained by factors 1 and 2, explaining 65.6% and 24.6% of the total variance, respectively. Factor 1 was mainly determined by the load of fragments, fibers, and films (0.60, 0.56, and 0.56, respectively). Factor 2 represented particles (0.99). Except for the samples from C1 and E2, the characteristics of all samples were significantly different. These results reflect the heterogeneity of soil MP distribution in the green-belt soil of Shihezi City.

The proportions of different colored MPs at each sampling point and the proportions of total color are shown in Fig. 2c and Fig. S1b. Black was the main color, accounting for 37.1%, followed by red and green, accounting for 18.0% and 17.8%, respectively. A study by Wang et al. (2021) on MP color distributions in soils of different land-use types found that yellow was the main MP color (32.05%), and only four colors were found in total. They studied the soil of the largest greenhouse vegetable production base in northern China and found that transparent/translucent (27.1%) was the main MP color, followed by white (24.2%), and multiple colors were observed (Yu et al. 2021). The color diversity of MPs indicates the diversity of MP sources. As shown in Fig. S1b, 46.5% of MPs had bright colors. This result is similar to that detected in agricultural farmland in Southeast Germany (40%) (Piehl et al. 2018). Colorants have been widely added to the production of consumer plastics to increase the attractiveness of plastic products (Thetford
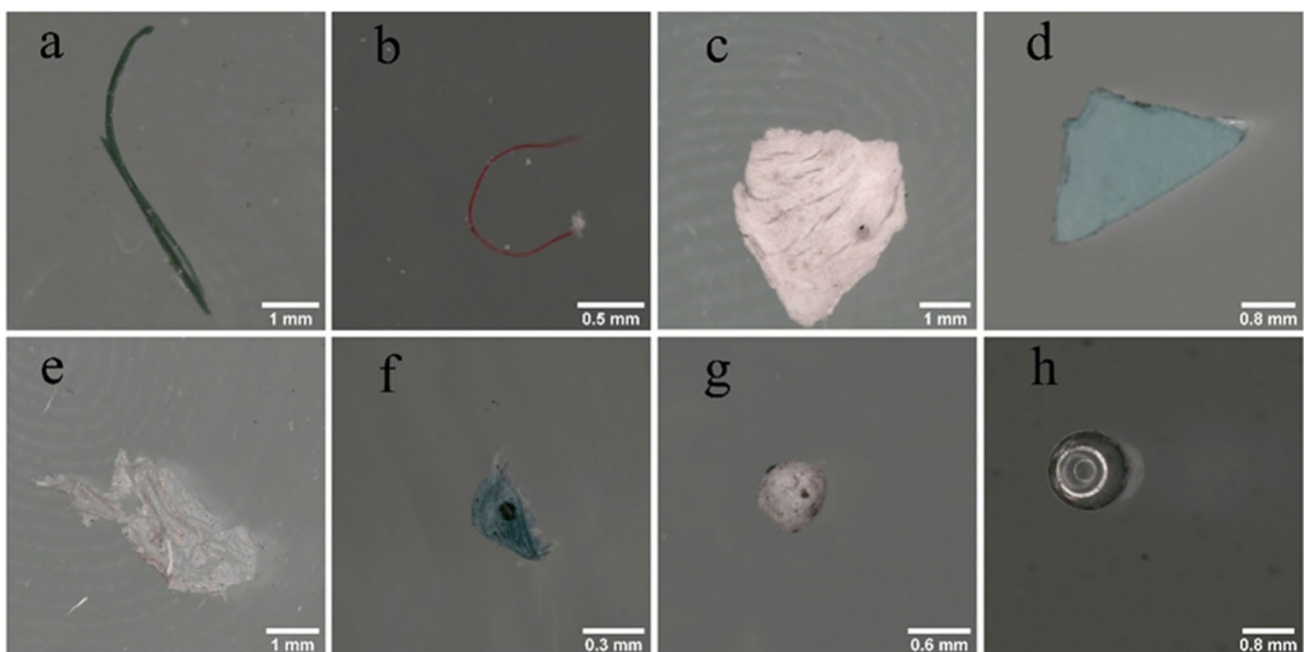

Fig. 3 Images of microplastics obtained using stereomicroscope, namely, fibers (**a, b**), fragments (**c, d**), films (**e, f**), and pellets (**g, h**)

et al. 2003; Xu et al. 2020). However, colored plastics are created by adding colorants (Muller 2011) which can be released into the environment during decomposition (Gewert et al. 2015). Therefore, the high percentage of brightly colored MPs found in this study is of even greater concern to researchers.

According to Ding et al. (2020), the size of MPs is divided into four ranges, namely, 0.02-0.5, 0.5–1.0, 1.0–2.0, and 2.0–5.0 mm. The distribution is shown in Fig. 2d and Fig. S1c. The content of MPs decreased as the MP size increased, which is consistent with the results of other studies (Imhof et al. 2016; Yu et al. 2021). In addition, most MPs in other environmental media are < 0.5 mm in size, such as the atmosphere (Szewc et al. 2021), water (Bertoldi et al. 2021), and water sediment (Peng et al. 2017). The sources of small MPs can be divided into two categories, the first produced from large-sized plastics via photodegradation, wind corrosion, and physical wear (Gewert et al. 2015) and the second being man-made tiny plastic particles released directly into the environment, such as the former production of face wash, toothpaste, and shampoo containing microbeads (Cole et al. 2011). Owing to the typical climate characteristics of Xinjiang (long light period, windy, and dry year-round), the decomposition of large-sized MPs into small-sized MPs is accelerated.

Among the 70 randomly selected particles, 56 were identified as MPs, which were mainly composed of 12 polymers (80%), namely, polystyrene (PS), polyethylene (PE), polypropylene (PP), polyurethane (PU), polyvinyl alcohol (PVA), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyfluoroethylene (PVF), amino plastics (AF), polyamide (PA), polyacrylonitrile (PAN), and phenol-formaldehyde resin (PF). The infrared spectra of major MPs are shown in Fig. 4a. More types of polymers were detected than those detected in several other environmental media, such as a researcher identified three (PP, PE, and PS) and

five (PP, PE, PS, PVC, and PET) types of MPs by attenuated total reflection Fourier transform infrared spectroscopy in surface water and sediment, respectively, in the lower Xijiang River in southern China (Huang et al. 2021). In addition, more types of polymers were detected than those in agricultural soils; for example, in a study of MPs in Shanghai farmland by (Liu et al. 2018), three types of MPs (PP, PE, and polyester) were identified by μ-FTIR. Similarly, a researcher studied the contamination of microplastics in six different types of agricultural soils and identified a total of seven types of microplastics by μ-FTIR, namely PVC, PA, PE, PP, PS, polyester, and acrylic (Wang et al. 2021). The results of our study differ from those of previous studies, thereby indicating that the sources of MPs in urban greenbelt soil are more complex than those in other environmental media. Among the 12 types of polymers, PS (28.6%) and PE (21.4%) were the most abundant (Fig. 4b). PE is commonly used in environmental protection bags, pallets, plastic containers, agricultural films, food packaging films, toys, and bottles, whereas PS is commonly used in the dairy industry, fishery food packaging, building insulation materials, and other industries (PlasticsEurope 2019). PE and PS are two of the four most versatile thermoplastic resins (Wang et al. 2020), which may be one of the main reasons for their serious pollution. It is urgent to regulate the use of plastics and the recycling and treatment of plastic waste, considering the wide use and serious pollution of the two dominant polymers.

Distribution characteristics of MPs in different green-belt soils

Because there are many types of urban greenbelts, this study divided the sampling points into park green space, residential green space, industrial green space, commercial green space, road green space, and green buffer to study the
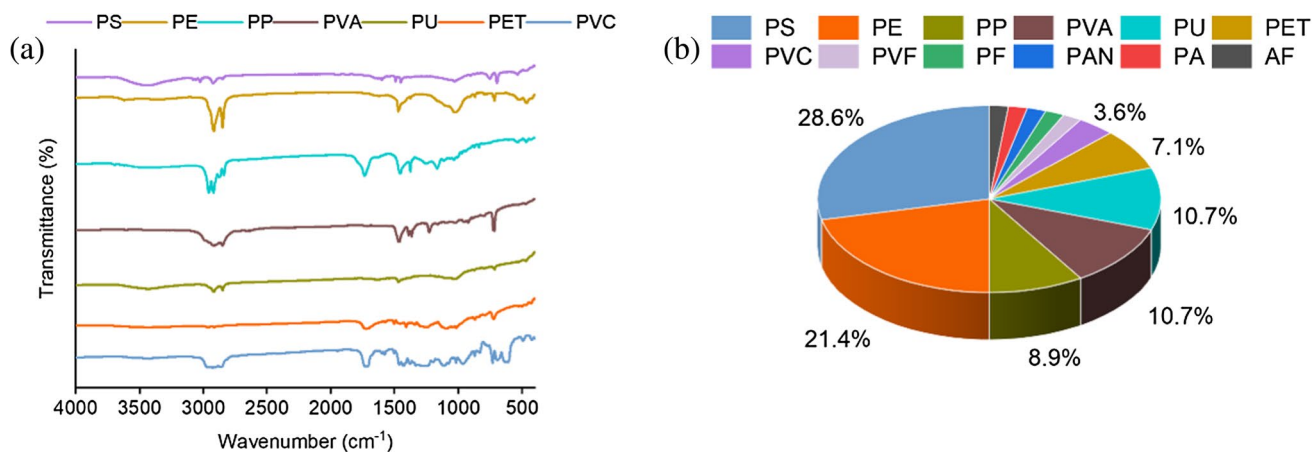

Fig. 4 Micro-Fourier transform infrared spectra of the selected microplastics (**a**) and proportion of selected items (**b**)

influence of different green belt types on the distribution of MPs. According to Fig. 5, the abundance of MP was the highest on the industrial green space (2118 ± 1220 items/kg), followed by commercial green space (1574 ± 1362 items/kg), green buffer (1446 ± 55 items/kg), residential green space (1036 ± 470 items/kg), park green space (935 ± 425 items/kg), and the lowest in the road green space (780 ± 602 items/kg). However, there were no significant differences in the distribution of MPs in the different types of green-belt spaces (Table S4). In addition, the abundance of MPs of < 5 mm in size in the green buffer soil was higher than that of other types in green-belt soil, whereas the abundance of MPs of 2–5 mm in size in the of green buffer soil was lower than that of other types in green-belt soil. Because there are no tall buildings at the edge of the city, it is possible that the green buffer is susceptible to pollution from strong winds carrying dust and sand. Moreover, strong light radiation can accelerate the decomposition of MPs. Therefore, natural factors are the main factors affecting the distribution characteristics of MPs in greenbelt soil, whereas human factors mainly affect abundance.

Sources of MPs

According to relevant studies, there is a link between the shape of microplastics and potential sources (Maghsodian et al. 2021). In this study, fibers were observed as the predominant shape, which may be closely related to synthetic fiber production and use, while infrared analysis indicated the presence of PET and PA microplastics, and the breakage or abrasion of these textiles may be the source of PET and PA microplastics (Geyer et al. 2017). In addition, another important source of fibers in urban green belts was found in this study, namely the use of dust screens. Fragments are also more common, and microplastic fragments have some association with plastic packaging and plastic waste (Yang et al. 2021), suggesting that the decomposition of bulk plastic and litter may be a key source of microplastics in the urban greenbelt of Shihezi City.

In this study, clustering analysis and spatial distribution of MP shapes were used to further understand the sources of MPs. Based on cluster analysis results (Fig. 6a), it was observed that the shapes of MPs were divided into three main categories. The three main types are fragments and fibers, pellets, and films. The fibers and fragments were grouped together, which means that fiber and fragment–shaped MPs have similar origins. The spatial distribution of fiber and fragment MPs in Shihezi City (Fig. 6b and c) further indicates that the pollution characteristics of fiber and fragment MPs are similar, and the pollution is more serious in the east of Shihezi City, which is mainly concentrated in sampling site C2; thus, industrial activities are one of the main sources of fiber and fragment MPs. It can be seen from Fig. 6d that in addition to the serious pollution in the industrial area, the MPs in the shape of films also have more serious pollution around F1, which is due to the fact that the

Fig. 5 Abundance (**a**), shape (**b**), and size (**c**) distribution of MPs in soils at green-belt sites in Shihezi City (A, park green space; B, residential green space; C, industrial green space; D, commercial green space; E, road green space; F, green buffer)
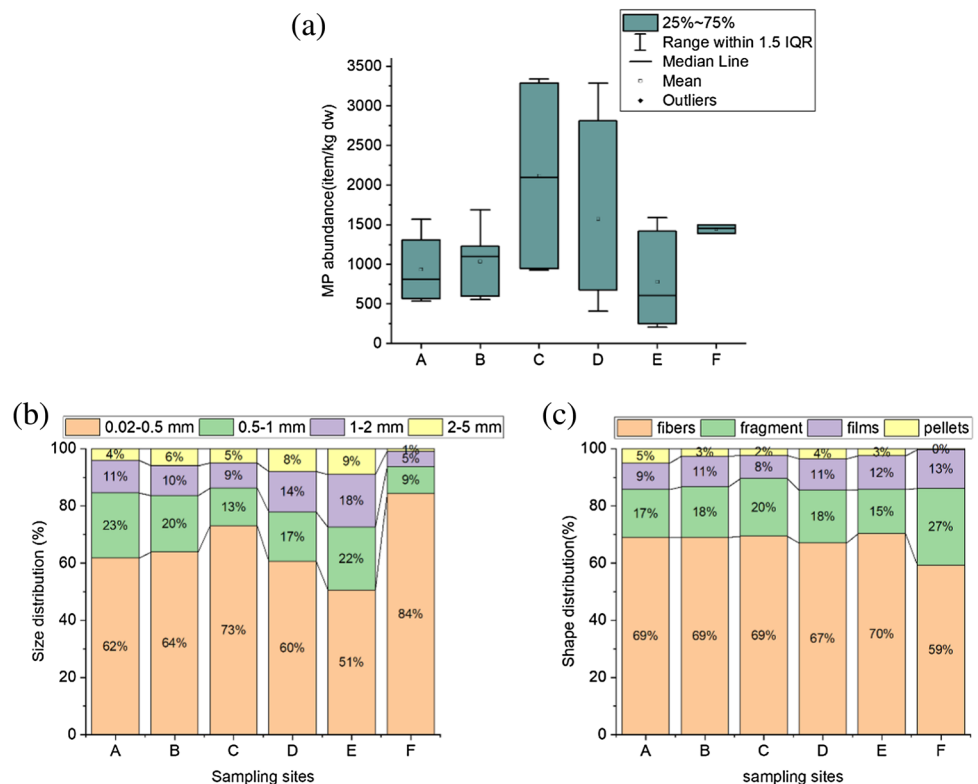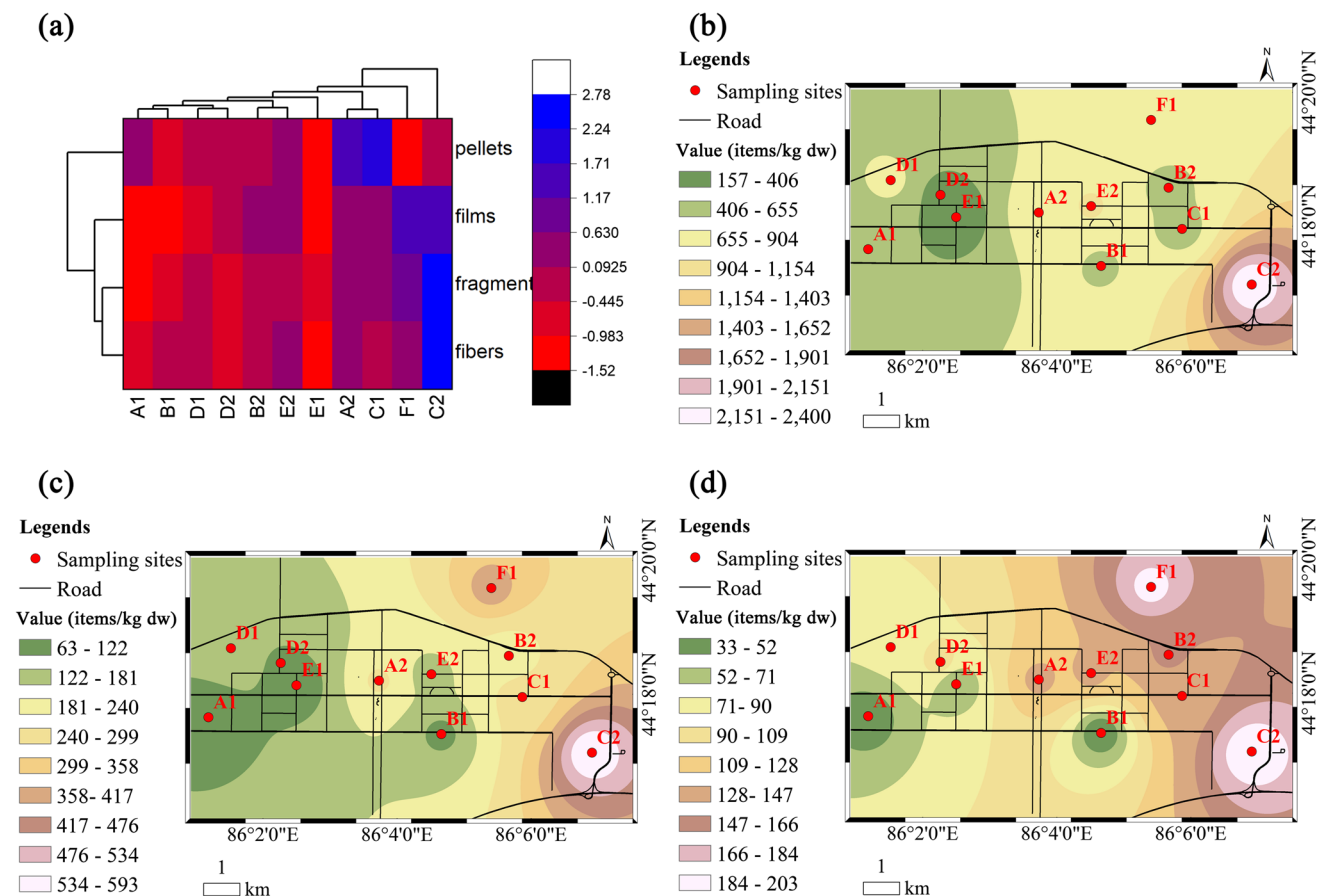
Fig. 6 Clustering of sampling sites according to the shape distribution based on a heat map (**a**) and spatial distribution of microplastics in the shape of fibers (**b**), fragments (**c**) and films (**d**)

area around F1 is all agricultural and plastic films which are widely used to cover farmland in arid areas of Northwest China (Li et al. 2020). However, plastic film is usually not recycled and is left in the field, thereby resulting in film MP contamination (Huang et al. 2020). Therefore, in addition to industrial activities, the surrounding agricultural activities are also one of the main sources of film MPs. The pellet MPs at each sampling point had low pollution; therefore, no spatial analysis was conducted.
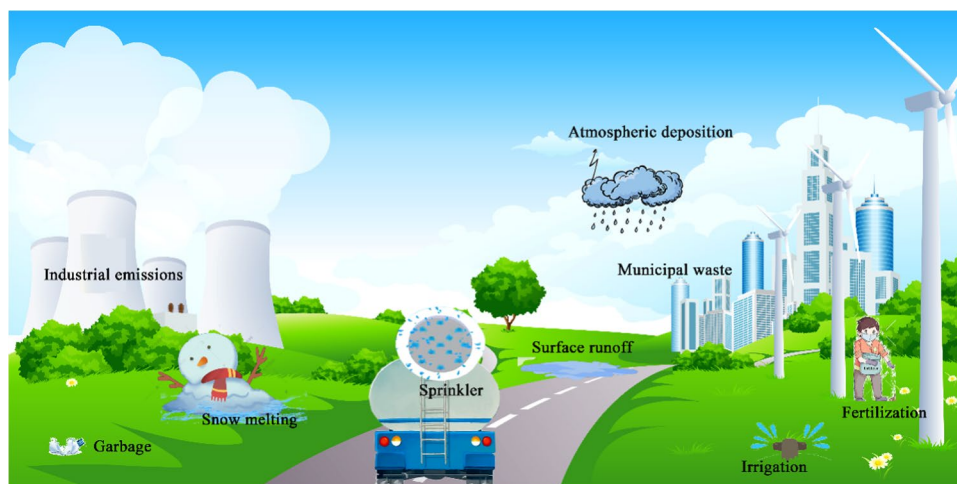
Many sources of MPs in agricultural soil have been reported; however, source analysis of urban green-belt soil MPs is relatively limited. In this study, infrared spectroscopy showed that PS, which is widely used in the light industry market, such as food packaging (daily and fishery), building insulation, electrical and electronic equipment, inner liner for fridges, and eyeglasses frames (PlasticsEurope 2019), was the main component of MPs. Therefore, PS products are one of the main sources of urban MPs, and it is necessary to strengthen the research and development substitute products, to protect the urban environment. At the same time, the government needs to take measures to improve and strengthen the infrastructure for plastic collection.

This study can only analyze the source of MPs through the shape of MPs. It is speculated that the pollution of MPs of various shapes in this area is mainly from a neighborhood, but the specific potential source of MPs cannot be studied for its contribution to the urban greenbelt. For example, many studies have shown that there are MP pollution in atmospheric deposition (Dris et al. 2015), surface runoff caused by rainy season (Dris et al. 2015), snow melting in winter (Bergmann et al. 2019), irrigation water, and fertilization of urban green space (Blasing and Amelung 2018) (Zhang et al. 2020). These sources are one of the sources of soil MP in urban greenbelt (Fig. 7). How to study its contribution to soil pollution will be considered in the future.

Conclusions

In this study, the characteristics and spatial distribution of MPs in the urban green-belt soil of Shihezi City were investigated. The green-belt soil in Shihezi was polluted by MPs, and the average abundance of MPs was lower than that in most agricultural soils. However, the highest abundance of

Fig. 7 Potential sources of microplastics

MPs was close to that detected by other scholars in agricultural soils, which means that there are other important sources of MPs besides agricultural activities. Low abundance of MPs was found in the soils after loosening, thereby indicating that tillage activities contribute to the migration of MPs, which requires further study. The MPs were mainly fiber-shaped, black, and small. The main MPs materials were PS and PE. Compared with those in agricultural soil, the color and composition of green-belt soil MPs were diverse, which means that the source of green-belt soil MPs is more diverse. In different types of green-belt soil, MP pollution of industrial green land and commercial green land was more serious. Using cluster analysis and spatial distribution, fragments and fibers were found to have similar sources and mainly originated from food and textile industrial activities. In addition, the potential sources of MPs in green-belt soil should be detected and analyzed in the future to better control the source of pollution. Future research should focus on the detection of MPs in different types of soil and different industries to better understand the source and migration of MPs. This study is significant for soil MP pollution detection and can provide a basis for future MP control and the establishment of environmental standards.

Author contribution Xiaodong Liu: validation, conceptualization, investigation, visualization, writing — original draft, writing — review & editing. Shaohua He: validation, conceptualization, investigation, visualization, writing — original draft, writing — review & editing. Yanbin Tong: validation, supervision. Zilong Liu: validation, supervision. Weijun Li: validation, investigation. Nuerguli Xiayihazi: validation, investigation. Jianjiang Lu: validation, resources, conceptualization, supervision, writing — review & editing.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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