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Microplastic in the Snow on Sledding Hills in Green Areas of Krakow

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Abstract: Every year we are more and more exposed to the negative impact of microplastic. Our research aimed to determine the amount of microplastic in the snow on sledding hills in green areas of Krakow. The sledding hills in winter are very intensively used by children and it is very important to monitor the condition of these places in terms of microplastic contamination. In our research, we assessed whether children playing on sledding hills may be exposed to microplastic. Our research covered 10 sledding hills of various sizes located in the green areas of Krakow. Our research has confirmed the presence of significant amounts of microplastics in snow collected on sledding hills. Three times as much microplastic was found in the snow on the higher hills (2.78 mg/L) compared to the lower sledding hills (0.96 mg/L). In the snow collected on sledding hills from the green areas of Krakow, a large diversity of microplastic in terms of type, size, color, and shape was noted. The dominant type of microplastic found during the research was polypropylene (PP), polyurethane (PU), hydrocarbon resin (HCR), and polyester (PES). The share of two microplastic fractions of 1.1–2.0 mm and 2.1–3.0 mm accounted for over 50% of the whole amount. After melting the snow, microplastic goes to the soil surface, which can lead to changes in the properties of the soil, and due to its strong hydrophobicity, it will play an important role in the transport of toxic compounds, e.g., polycyclic aromatic hydrocarbons (PAHs). Our research suggests limiting the use of plastic sleds and replacing them with wooden sleds, which will not be a source of pollution for urban green spaces used by residents regardless of the season.

Keywords: children's playground; FTIR; land uses; microplastic; urban areas

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1. Introduction

Plastic pollution is a global problem in terrestrial and aquatic ecosystems and enters the environment through landfills, atmospheric deposition, sewage treatment, and agricultural, urban, and industrial runoff [1–4]. Globally, the annual production of plastic is approximately 322 million tons and, despite the increase in plastic recycling, most of the plastic waste ends up in the environment [5]. Microplastics are plastic particles smaller than 5 mm often derived from the fragmentation of meso and macroplastics [6]. Under the influence of anthropogenic or environmental factors, large pieces of plastic are fragmented, becoming a source of microplastic in the environment [7]. In most studies conducted so far, the dominance of plastic particles of smaller fractions was indicated [4]. The most common microplastics detected in stormwater were rubber and asphalt particles from road surfaces, followed by textile fibers, films, fragments, and paint particles [8]. Most plastic garbage is generated on land, making soil an important long-term sink for microplastics [9]. About 79% of all plastic waste produced in the years 1950–2015 ended up in the soil and is the source of microplastic deposited in the soil [10,11]. Microplastic is released into the environment as a result of the deterioration of discarded plastic products through physical, chemical, and biological processes [12]. In the case of microplastic pollution, depending on its type and size, different environmental impacts were noted. Microplastics significantly reduce bacterial diversity, change pH, and the content of some nutrients in the soil, but it also has a significant negative impact on the survival, growth, and reproduction of soil fauna [11]. Microplastic pollution regulates soil bacterial communities, promoting the growth of Ascomycota fungi and inhibiting the growth of Basidiomycota [13]. Microplastic pollutes soils and serves as a vector for other pollutants, which can also cause ecotoxicological effects on the soil ecosystems [14]. Microplastic can affect the formation of physicochemical and microbiological properties as well as soil fauna [15–17]. Microplastic can also be the carrier of hydrophobic organic pollutants, such as polychlorinated biphenyls, polycyclic organochlorine pesticides, and aromatic hydrocarbons, as well as heavy metals such as nickel, zinc, cadmium, and lead [5]. As a result of the degradation and fragmentation of polymeric materials, so-called secondary microplastics are formed. There is a reduction in the molecular weight of the polymer, and the released bonds are susceptible to microbiological degradation that occurs in aerobic and anaerobic environments, and decomposition to CO_2, H_2O, N_2, H_2, CH_4, and mineral salts can be complete or partial [18]. On the other hand, primary microplastics are polymer powders and micro granulates present, among others, in cosmetics and cleaning products. The European Chemicals Agency ECHA [19] published a proposal to limit the use of polymer plastics in cosmetic products. The document contains a list of 19 polymers and currently known cosmetics companies aware of the risks, out of concern for the good of the consumer, have eliminated the polymers on this list from the composition of their products [20].

The problem of plastic contamination has been described in variously managed areas [21–23]. Corradini et al. [24] identified microplastic in soils under four different land use systems with different management intensities (croplands, pastures, rangelands, and natural grasslands). Some studies show a clear relationship between the increasing abundance of microplastic and increasing levels of urbanization and industrialization [25]. Urban areas are heavily polluted with microplastic as a result of the high concentration of people [26]. Green spaces in urban areas are considered natural filters of pollution in cities due to the retention capacity of soil and vegetation [27]. Urban green spaces, such as parks, gardens, and squares, have several potential benefits for city dwellers and their use can improve physical and mental health through recreation and reduce anxiety and stress [28]. Therefore, the study of green areas is important in the context of risk assessment.

Krakow is the second largest city in Poland in terms of the number of inhabitants and area. The area of the city is 327 km^2, and its length from north to south is 18 km and from east to west is 31 km. Green areas in Krakow have arranged areas with technical infrastructure and buildings functionally related to them, covered with vegetation, and performing public functions. The area of public green areas with a recreational function per inhabitant is on average approximately 8.3 m^2/person [29]. Our research aimed to determine the abundance of microplastic in the snow on sledding hills in green areas of Krakow. The sledding hills in winter are very intensively used by children and it is very important to monitor the condition of these places in terms of microplastic contamination. In our research, we assessed whether sledding hills pose a risk for children using them, and whether children playing on sledding hills may be exposed to microplastic. Our research covered 10 sledding hills of various sizes located in the green areas of Krakow. There are no studies on microplastic in big cities in Poland such as Krakow. Therefore, this study aims to clarify the following questions: (1) How much microplastic ends up in the snow in different parts of sledding hills depending on their size?; (2) What types of microplastic are found in the sledding hills area?; (3) What amounts of microplastic get into the soil environment every year as a result of using sledding hills?

2. Materials and Methods

2.1. Study Area and Snow Sampling

The research was carried out in the green areas of Krakow, southern Poland (50°03′41″ N; 19°56′18″ E). The Municipal Greenery Authority in Krakow has prepared a map with the location of the sledding hills for children. There are 43 sledding hills of various sizes in Krakow. Most of them are located in parks and each of them is properly secured against road traffic with fencing, while others are located deep in the park away from roads and cars. The research covered 10 sledding hills made available to children during the winter (Figure 1). The sledding hills covered by the research varied in size. We divided the sledding hills into two groups, the first group was characterized by the slope length of sledding hills below 10 m, and the second group had the slope length of sledding hills exceeding 10 m. Five sledding hills represented low sledding hills (G2, G3, G8, G9, and G10) and five were high sledding hills (G1, G4, G5, G6, and G7). Each sledding hill has been divided into three parts (upper, middle, and lower). Snow samples from ten locations were taken from each section for further testing. Ten sub-samples were used to prepare an aggregate sample. A 1 L snow sample was taken from each point using a metal sampler. Ten sub-samples of snow from each part of the sledding hills were combined into one and the microplastics were isolated after being transported to the lab. In total, laboratory analyses included 30 snow samples (3 parts of sledding hills × 10 sledding hills = 30 snow samples). Snow samples were collected in December 2022.

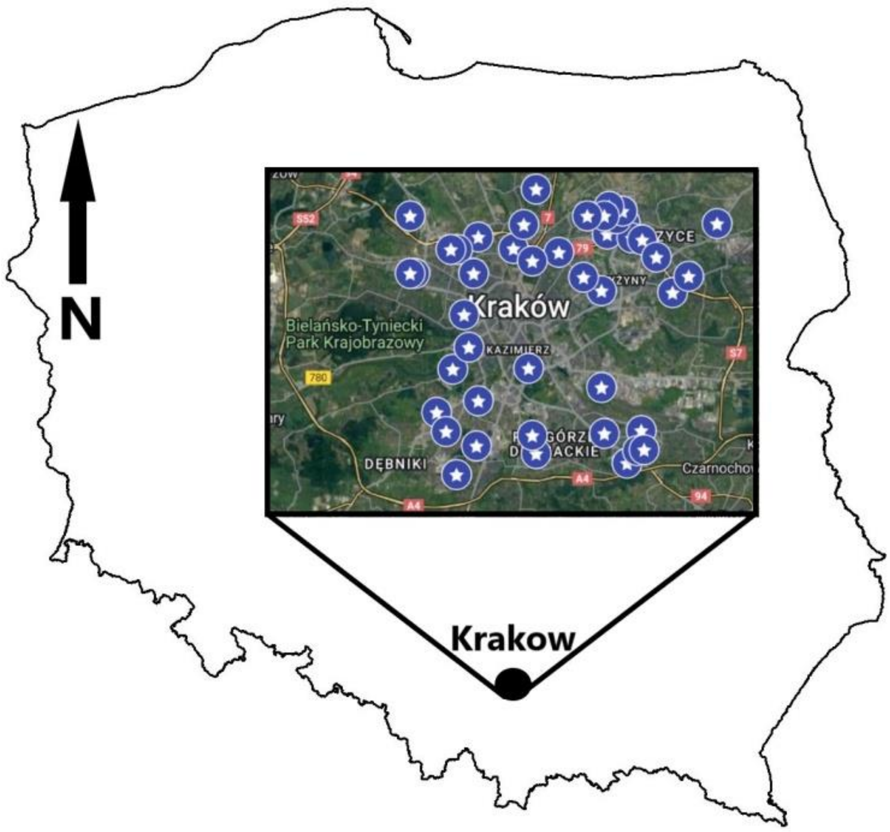

Figure 1. Location of sledding hills (blue star) in Krakow (source: Municipal Greenery Authority in Krakow).

2.2. Laboratory Analysis

Upon arrival at the laboratory, the snow samples were melted and filtered through filters (0.45 µm glass microfiber filters). Snow samples were placed in glass beakers and melted at room temperature. Plastic was extracted from the filters and transferred to a Petri dish. Visual analysis and sorting were performed. Microplastics were defined as particles made of synthetic polymers, smaller than 5 mm. Separated plastic samples were subjected to spectrophotometry analysis. Qualitative identification of the remains was obtained using an FTIR microscope Nicolet iN10 (ThermoFisher Scientific Inc., Waltham, MA, USA) with a cooling detector for sample mapping. The equipment used allows the detection of microplastic particles from 0.01 mm. Infrared spectroscopy was performed in the reflectance mode. The collected spectra were analyzed using Omnic Spectra software with its database. To reduce the possible error due to cross-contamination, the microplastic abundance of the blank was used to correct all the results. Before starting the analysis in the laboratory, 5 Petri dishes with filter paper on which microplastic particles from the air could settle during the analysis were prepared. Blanks thus prepared were last analyzed on an FTIR microscope. Microplastic particles were classified by type, color, shape, and size. In the case of type and color, the percentage by weight was specified. In the case of size and shape, the percentage was determined by count. At the time of analysis, the library included reference spectra for Polyurethane (PU), Polyethylene terephthalate (PET), Polyester (PES), Polyvinyl butyral (PVB), Thermoplastic elastomer (TPE), Polyvinyl chloride (PCV), Polypropylene (PP), Polystyrene (PS), Hydrocarbon resin (HCR), Phenoxy resin (PHR), and Poly (isobutene isoprene) (PIBP).

2.3. Statistical Analysis

The principal component analysis (PCA) method was used to evaluate the relationships between analyzed variables. A general linear model (GLM) was used to investigate the effect of the sledding hills' size and location on sledding hills on the microplastic content. The Shapiro–Wilk test was used to assess normality, and Levene's test was used to check the homogeneity of variances. The Kruskal–Wallis test was used to assess the differences between the average values of microplastic amount between different locations on sledding hills. The U Mann–Whitney test was used to assess the differences between the average values of microplastic amount between different sizes of sledding hills. Statistical analyses were performed in the statistical programs R (R Core Team 2020), and R Studio (R Studio Team 2020).

3. Results

In the snow collected on sledding hills from the green areas of Krakow, a high content of microplastic and a large diversity of microplastics in terms of type, size, color, and shape were noted. The dominant type of microplastic noted during the research was polypropylene (PP), polyurethane (PU), hydrocarbon resin (HCR), and polyester (PES). In the case of one sledding hill (G1), a high proportion of urethane alkyd was noted (Figure 2). A small amount of phenoxy resin (PHR), poly(isobutene isoprene) (PIBP), and polystyrene (PS) was found in the samples of the tested snow (Figure 2). In the snow collected from the higher sledding hills, polypropylene, polyethylene terephthalate, and thermoplastic elastomer (TPE) appeared more often compared to the lower sledding hills. On the other hand, in the snow from the lower sledding hills, polyurethane was more often marked (Figure 2).

The microplastics determined in the snow samples varied in size (Figure 3). The highest content was recorded in the case of microplates of 1.1–2.0 mm and 2.1–3.0 mm. The share of these two microplastic fractions accounted for over 50% of all. The smallest share was recorded for microplastics sized 3.1–4.0 mm. This microplastic fraction was more present in the snow collected on the upper sledding hills (G1 and G4–G7). The highest-sized microplastics (4.1–5.0 mm) were more common in the snow from the higher sledding hills, while it was absent from the snow from the two low sledding hills (G8–G9) (Figure 3).

In snow samples collected from sledding hills, four types of microplastic shapes were noted, i.e., fiber, fiber ball, flake, and fragment (Figure 4). Fragments had the largest share, often their share accounted for over 75% of all microplastic shapes. Only the snow from the three sledding hills had less than 50% microplastic in the form of fragments. Flake-shaped microplastics had a significant share. Fiber and fiber balls were not recorded on all the study plots. Fiber and fiber balls were not recorded in the snow of the lower sledding hills (G2–G3 and G8–G10) (Figure 4).

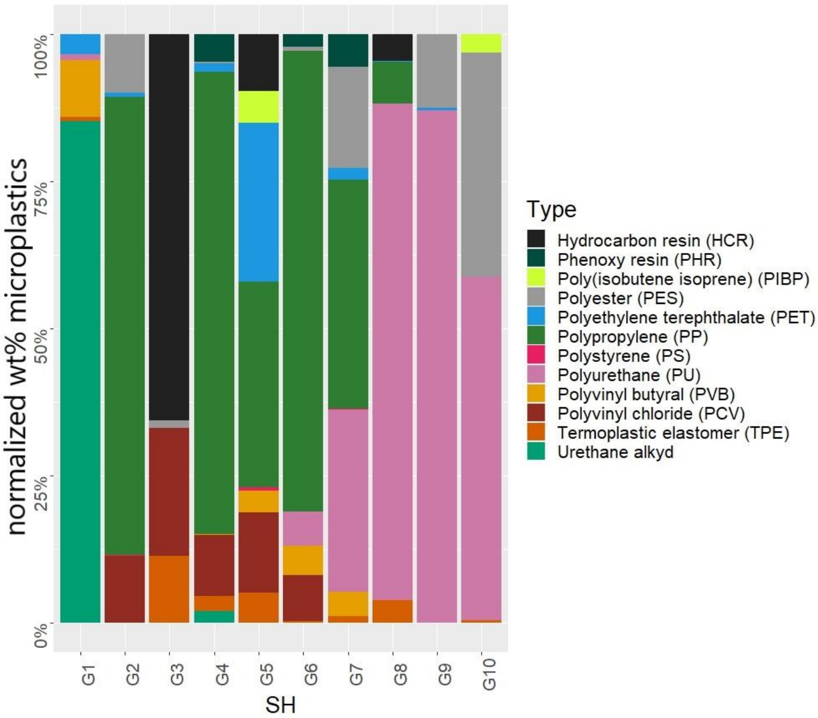

Figure 2. Microplastic particles (MCs) characterization by type of component in snow on different sledding hills (SH) (the percentage by weight was specified). The higher the percentage, the more of a particular microplastic compared to the others in the collected samples.

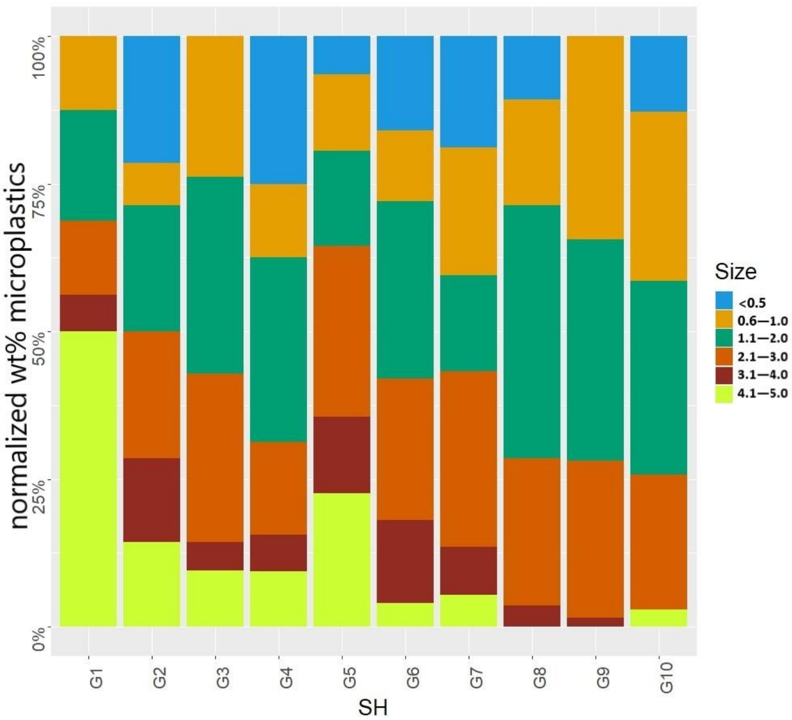

Figure 3. Distribution of microplastic particles (MCs) by size (mm) in snow on different sledding hills (SH) (the percentage by count was specified). The higher the percentage, the more of a particular microplastic compared to the others in the collected samples.

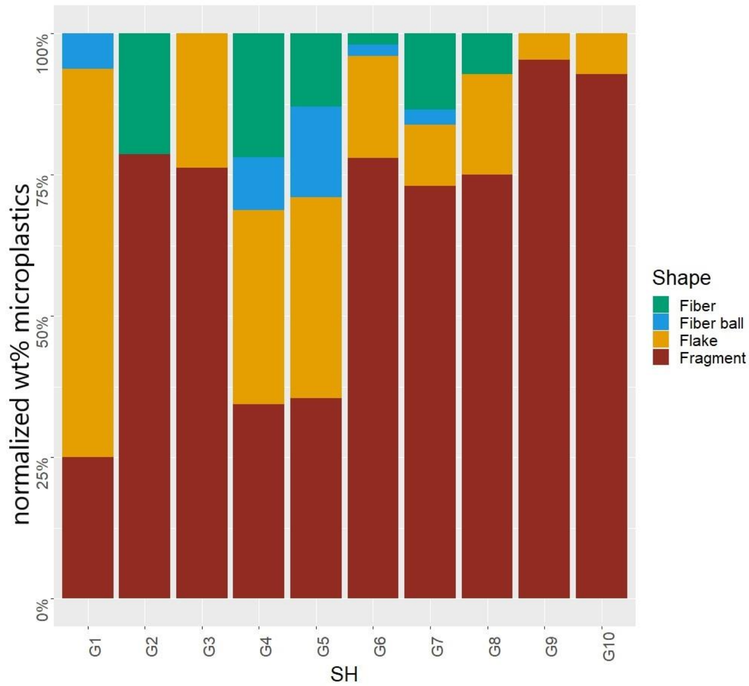

Figure 4. Distribution of microplastic particles (MCs) by shape in snow on different sledding hills (SH) (the percentage by count was specified). The higher the percentage, the more of a particular microplastic compared to the others in the collected samples.

The presence of microplastics in ten colors was determined in snow samples collected from sledding hills (Figures 5 and 6). The largest share was recorded for black microplastics. Blue, red, pink, and green microplastics also had a significant share. In the snow samples covered by the analyses, a small share of plastic in brown, violet, and white colors was noted (Figure 5).

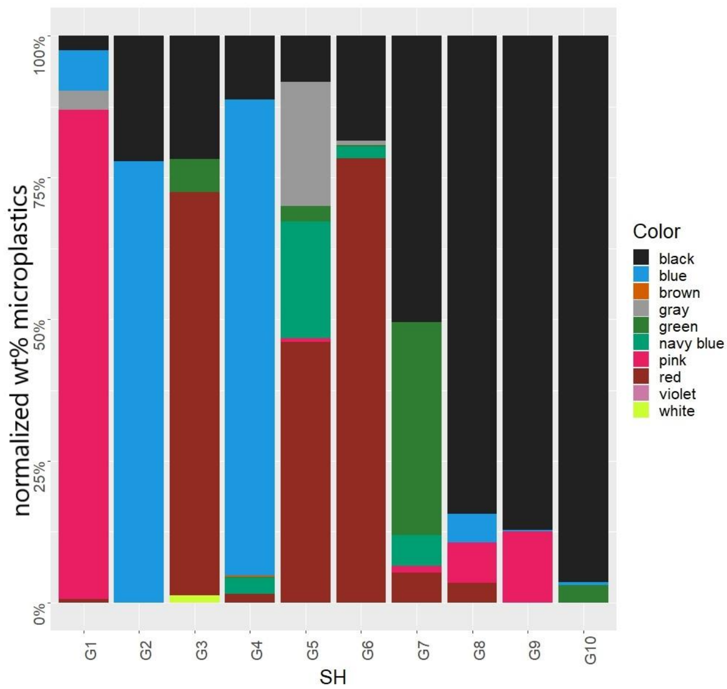

Figure 5. Distribution of microplastic particles (MCs) by color in snow on different sledding hills (SH) (the percentage by weight was specified). The higher the percentage, the more of a particular microplastic compared to the others in the collected samples.

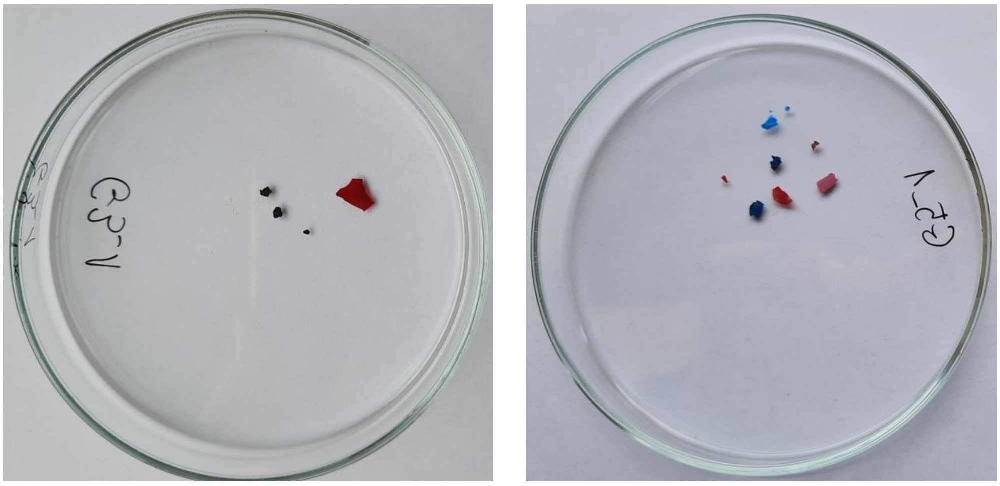

Figure 6. Examples of various microplastic particle types recorded in the snow on different sledding hills.

The conducted GLM analysis confirmed the importance of the size of sledding hills and the location of sledding hills in shaping the amount of microplastics (Table 1).

Table 1. GLM analysis for the microplastic weight (MCs weight mg/L) depends on the size of the sledding hill and the location of the sledding hill.

	MCs Weight	
	F	***p***
Size of sledding hill (S)	5.8367	*0.0236*
Location on sledding hill (L)	7.9621	*0.0022*
S × L	4.4017	*0.0235*

Significance effects ($p < 0.05$) are shown in italic.

In addition, the GLM analysis indicated an interactive effect of the size of sledding hills and the location of sledding hills in shaping the amount of microplastic. Within the examined sledding hills, the content of microplastics in snow varied from 2.8 mg/L to 61.0 mg/L (Figure 7). The median weight of microplastic in the snow samples from the upper sledding hills was three times higher compared to the lower sledding hills (2.78 mg/L and 0.96 mg/L, respectively) (Figure 8). The differences in the weight of the microplastics in the snow samples from the upper and lower sledding hills were not statistically significant. Statistically significant differences in the amount of microplastics were noted between the sledding hill locations. Lower locations (bottom) were characterized by a significantly higher content of microplastics compared to the middle and upper lower parts of the sledding hills. In the lower part of the sledding hill, the median content of microplastics was 20 times higher compared to the lowest part (Figure 8). The median microplastic content in the upper sledding hill was 0.50 mg/L, in the middle was 1.27 mg/L, and the lower 9.33 mg/L (Figure 8).

The performed PCA analysis confirmed the relationship between the studied characteristics of microplastic and the size of the sledding hill (Supplementary Figure S1). Two main factors contributed to the observed variance (51.6%): factor 1 accounts for 30.2% of the variance, while factor 2 explains 21.4% of the variance. Factor 1 is related to the size of the microplastic, while factor 2 is related to the type of microplastic. In addition, the PCA analysis confirmed the separation of high and low sledding hills concerning the type and size of the microplastic (Supplementary Figure S1). The lower hills were characterized by a higher share of PES and PU and a share of microplastics of 1.1–2.0 mm and 0.6–1.0 mm. Higher sledding hills were characterized by the highest mass of microplastics (MCs weight) and the share of microplastics with larger sizes (Supplementary Figure S1).

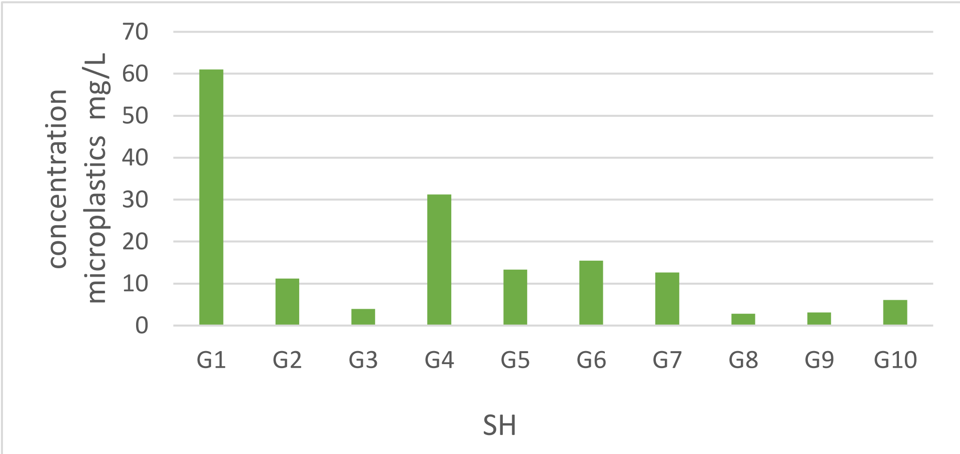

Figure 7. The content of microplastics (mg/L) in snow depends on the sledding hill.

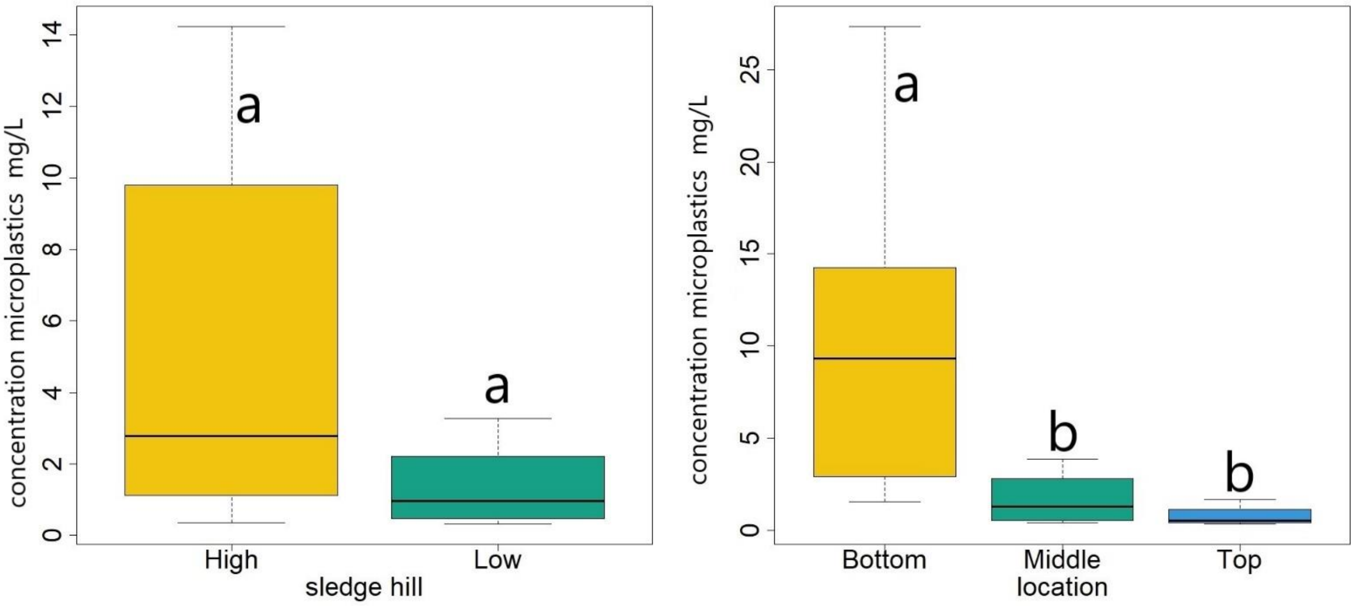

Figure 8. The content of microplastics (mg/L) in snow depends on the size of the sledding hill (high and low) and the location on the sledding hill (bottom, middle, top); colors indicate different variants of different sledding hill and different location on sledding hill, letters (a, b) mean significant differences between types of sledding hill and between different location on the sledding hill.

4. Discussion

In Krakow, the Municipal Greens Authority has prepared a map of 44 sledding hills that can be used during the winter, and 10 of them were tested for microplastic contamination. Our research shows significant contamination of the sledding hills in the green areas of Krakow with microplastics. Our research indicates the presence of a significant amount of microplastics that vary in type, size, color, and shape. Due to the high anthropogenic impact, the urban environment is considered to be one of the main sources of microplastic [25,26,30]. Microplastics have been commonly detected in the urban atmosphere, dust or soil, and urban rivers and are mainly produced in tire wear, landfill and wastewater treatment, and industrial activities [3,31]. Our study shows significant microplastic contamination of green areas as a result of using plastic sleds, shoes, and clothes on sledding hills. It should be emphasized that this microplastic, after melting the snow, ends up in various components of the environment. Microplastics migrate and transform in many urban environments through physical and biochemical factors [5,32]. Due to their lightweight and low density, microplastics can easily float and transform between different environmental matrices in urban ecosystems. Through the runoff of rainwater, microplastics can end up in urban rivers, and by wind be transported to other urban ground surfaces. Microplastics from sledding hills and snow pose a potential health risk for urban residents. Microplastic pollutants were detected in all environmental matrices [33]; therefore, on the examined sledding hills they can be carried with dust or come from road pollution. Microplastics entering the soil environment are carried through food chains and food webs, which pose potential threats to human health [34]. The tissue accumulation of microplastics may cause a variety of inflammations that affect gene expression and cause cell lesions and maybe even cancer [35].

The dominant types of microplastics noted during our study were polypropylene, polyurethane, hydrocarbon resin, and polyester. According to the United Nations Environmental Program report, of the 388.2 million tons of plastics produced, 16% are polypropylene [36]. PP are dominant microplastic types found on sand and leaves in playgrounds, while playgrounds contain more microplastics than other areas in urban parks [37]. The natural aging process significantly changes the physicochemical properties of PP and enhances its sorption capacity, as a result of which PP presents a more vital ecological risk [38]. Microplastics can be vectors for transporting heavy metals in soils and increase the bioavailability of heavy metals posing negative biological effects [39]. According to Cao et al. [40], PP microplastics increased the concentration of bioavailable Cd in soils through decreasing soil retention. Microplastics in the form of biodegradable polyurethanes are prone to accumulation of PAHs from the soil and concentrations of PAHs in biodegradable polyurethanes were 70 times higher than in soil [41]. The high polyurethane contents noted in our studies confirm the possibility of higher contamination risk because the flexibility of the polyurethane polymeric network could be the main driving factor for the sorption. HDPE was detected in previous soil studies [34], but no such microplastic has been detected in our studies.

The microplastic marked in the sledding hills snow varied in size. The share of two microplastic fractions of 1.1–2.0 mm and 2.1–3.0 mm accounted for over 50% of all amounts. Microplastics sized less than 1.0 mm showed a significant share, often over 25%. Previous studies indicate that most or all of the microplastic particles extracted from different environments were below 1000 μm [42,43]. In the study of Leitão et al. [26], the average size of a microplastic was 116 μm; more than 80% of the particles in the general urban area sample measured less than 250 μm. According to Zhang et al. [44], the small-size microplastics favored the increase of pH, water content, organic matter, and adsorption capacities with Cd in the paddy soil compared with the large-size microplastics. The small-sized microplastics are more harmful to organisms because they have a larger surface area to absorb toxic chemicals [45]. Our research shows a relationship between the size of the microplastic and the size of the sledding hill. On the higher sledding hills, we recorded a greater share of microplastics of the largest sizes, i.e., 3.1–4.0 mm and 4.1–5.0 mm. Higher hills give the possibility of faster descents, stronger hits, and more friction, which leads to larger fragments of the plastic sled breaking off.

Microplastic shapes are generally classified as pellet/spherule, fragment/sheet, foam, fiber/line, and film [46]. In our study area, fragments had the largest share, often their share accounted for over 75% of all microplastic shapes. As a result of sliding down on plastic sleds, mechanical abrasion occurs and microplastics in the form of fragments are released into the environment. In the future, microplastic fragments will be fragmented as a result of ultraviolet radiation and biodegradation. A weathering experiment conducted in the laboratory indicates that 12 months of exposure to UV radiation and 2 months of mechanical abrasion of PP can produce 6084 $\pm$ 1061 particles [47]. In addition to the variation in the shape of the microplastic, we noted a large variation in the color of the microplastic. In our research, we isolated microplastics in 10 colors. This is probably the effect of using sledding hills, especially by children, for whom colorful toys and clothes are produced.

The conducted GLM analysis indicated the importance of the size of the sledding hills and the location on the sledding hills in shaping the amount of microplastics. A total of 3 times more microplastic was recorded on the higher hills compared to the lower hills. Higher sledding hills are more likely to be chosen by children and have higher speed descents, which result in more microplastic. A statistically significantly higher content of microplastic was recorded in the snow in the lower part of the sledding hills, where the sled reached the highest speed and braking occurred at the same time. By presenting the number of microplastics on sledding hills and their variation in type and size, we show that plastic snow slide devices and other products used for downhill can contribute to elevated concentrations of microplastic. It is justified to promote sliding equipment made of natural materials, such as wood. It is really important to consider switching from plastic gear to wooden gear (as long as they are not painted or varnished). Wood has long been widely used as a construction material due to its low cost and high strength, and is increasingly being seen as a viable alternative to plastic. Microplastics in urban green spaces from sledding hills can have negative effects on the soil environment. In the long term, microplastic pollution can have a potentially significant impact on the biodiversity of soil systems. Microplastic contamination in the soil strongly affects soil biota, and it particularly reduces the number of soil mesofauna and changes the structure of the microorganisms [48,49].

5. Conclusions

Our research shows significant microplastic contamination in the sledding hills located in the green areas of Krakow. Our analyses have confirmed that significant amounts of microplastics of various types, sizes, shapes, and colors get into the snow as a result of winter activity, especially by children. The higher sledding hills had a higher content of microplastics compared to the lower sledding hills. Our research suggests promoting children's use of wooden sleds and avoiding plastic products. The occurrence of microplastics in soil is a cause for concern. Microplastics on sledding hills can break down with exposure to sunlight or high temperatures and pose a serious threat to humans, animals, and plants. It is important to conduct further research on microplastic contamination of urban green spaces that are intensively used by residents.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su151712995/s1. Figure S1. Projection of variables on the plane of the first and second PCA factors (Polyurethane (PU), Polyethylene terephthalate (PET), Polyester (PES), Polyvinyl butyral (PVB), Termoplastic elastomer (TPE), Polyvinyl chloride (PCV), Polypropylene (PP), Polystyrene (PS), Hydrocarbon resin (HCR), Phenoxy resin (PHR), Poly(isobutene isoprene) (PIBP); High SH—high sledding hill, Low SH—low sledding hill).

Author Contributions: Conceptualization, J.L., W.P. and E.B.; Methodology, E.B.; Formal analysis, J.L. and E.B.; Investigation, J.L., W.P. and E.B.; Data curation, J.L. and E.B.; Writing—original draft, J.L., S.T. and E.B.; Writing—review & editing, W.P.; Visualization, E.B.; Funding acquisition, S.T. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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