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Traffic Intensity as a Factor Influencing Microplastic and Tire Wear Particle Pollution in Snow Accumulated on Urban Roads

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Abstract: Communication pathways are an underestimated source of synthetic particles in the environment. This study investigated the impact of traffic volume on microplastics (MPs) and tire wear particles (TWPs) pollution in road snow. An examination was conducted in a medium-sized city situated in northeastern Poland, known for being one of the cleanest regions in the country. MPs and TWPs were found at all 53 sites, regardless of the intensity of traffic. The average concentration for all samples was 354.72 pcs/L. Statistically significant differences were found between the average values of particles concentration on low, medium, and heavy traffic roads amounted 62.32 pcs/L, 335.97 pcs/L and 792.76 pcs/L respectively. Within all three studied groups of roads, MPs and TWPs with the smallest size, ranging from 50 to 200 μm, were prevalent. In all studied groups of roads, 4 analyzed shapes of particles were found, with irregular fragments being the most abundant form (89.23%). The most frequently recorded color among the collected samples was black (99.85%), and the least frequently recorded was blue, constituting only 0.01%. This study suggests that snow cover on the roads may act like temporary storage of pollutants during winter in the temperate climate zone and after thaw can significantly increase the concentration of MPs and TWPs in surface waters. Possible measures to decrease the release of MPs and TWPs into the environment in the city may include reducing traffic volume and speed, implementing street sweeping, utilizing filtration chambers, and installing stormwater bioretention systems or settling ponds.

Keywords: road snow; tire wear particles; microplastics; urban roads; transport

1. Introduction

Communication routes are an underestimated source of environmental pollution. Verschoor and De Valk (2017) suggest that tires, paint, components of vehicles made of plastic, and abrasive cleaning agents are some of the biggest sources of synthetic particles related to transportation. Sommer (2018) and Järlskog (2020) claimed that as much as 30% of all microplastics (MPs) pollution in rivers and oceans is related to road use, with tire wear particles (TWPs) playing a major role. Throughout their lifespan, automotive tires gradually wear down and release particles into the environment. Wear rate depends on the volume of traffic, speed, type of road surface, model of the vehicle, and weight (Pohrt, 2019). The main component of tires is synthetic rubber (an elastomer) that does not belong to plastics according to ISO 472:2013. However, Verschoor (2016) proposed a more general definition of plastics, covering all multi-molecular materials that are man-made, including synthetic rubber.

Car traffic is conducive to mechanical degradation and allows for the fragmentation of synthetic materials into smaller and smaller fragments (Carpenter & Smith, 1972). Those microscopic debris smaller than 5 mm in diameter are defined as microplastics (MPs) (Thompson et al., 2004). Among all types of polymers, fragments from synthetic rubber are considered one of the main factors polluting the environment in urbanized areas (Luo et al., 2021). Particles from other potential sources, such as recycled tire crumb (RTC), produced for applications such as filling artificial grass on

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basketball courts with rubber granules, or tire repair-polished debris (TRD), generated from the inner lining during mechanical polishing to repair a tire after a puncture (Luo et al., 2021) play a lesser role.

Street dust contains residues of petrol, grease, and other harmful traffic-related substances (Skorbiłowicz et al., 2023; Sommer et al., 2018). These substances can be accumulated on the road surface, be mobilized by wind (Goßmann et al., 2023), runoff into sewerage systems (Sommer et al., 2018; Ziajahromi et al., 2023) and subsequently deposit into surface water (F. Liu, Olesen, et al., 2019), groundwater, soil (Baensch-Baltruschat et al., 2021) influencing vulnerable organisms (Capolupo et al., 2021; Z. Liu et al., 2022; Sathicq et al., 2022; Shin et al., 2022). Due to the increased number of vehicles, and people, roads serve as accumulators of waste, including plastic and other synthetic materials. Analyzes of the dispersion of waste tire fragments resulting from heavy traffic indicate that about 50% of the dry matter of TWPs can be expected to remain in the roadside soil for a long time, while the rest of the fraction is carried off the road by surface runoff (Hann et al. 2018; Unice et al. 2019).

Although the significant role of transportation routes in pollution emissions is obvious, there is a lack of reports simultaneously considering the concentration of MPs, TWPs on the background of traffic intensity. Currently, over 96% of researches on MPs is related to marine and freshwaters (Peng et al., 2020), and the influence of polymer pollutants on living organisms, including humans (Shin et al., 2022). Due to the fact that most research to date has focused on aquatic environments, terrestrial ecosystems are still insufficiently studied (Deoniziak et al., 2022). The research on MPs and TWPs from roads was mainly conducted using water collected from the sewer system (Jan Kole et al., 2017a; Lange et al., 2021a). Other studies on the number of synthetic particles on communication routes were usually conducted in relation to rainwater (Bondelind et al. 2020; Treilles et al. 2021) and road dust (Worek et al. 2022).

Research using the mathematical model indicates that 12 to 20% of particles originating from tires end up in surface waters, depending on the efficiency of treating stormwater from roads (Baensch-Baltruschat et al., 2021). There are few reports on the accumulation of MPs and TWPs in snow but not collected on roads. These studies considered various places with differing human activity levels, such as urban agglomerations (Chernykh et al., 2022), or places with limited accessibility (Parolini et al., 2021). In other studies, concerning transportation routes in cities Goßmann (2022) used the potential of spiders' webs as biomonitor of summer urban pollution with MPs and TWPs, hence gained insights in the spatial and temporal trends in polymer contamination. In temperate climate zone snow can act as an urban dust collector. We assume that sampling from snowbanks is novel approach in assessing winter urban routes pollution. This is particularly important because winter conditions promote accelerated fragmentation of plastics due to temperatures below zero, resulting in easier crushing of plastic and rubber (Rathnaweera et al., 2023).

The aim of this research was quantitative and qualitative analysis of MPs and TWPs in snow collected from urban roads with different traffic intensity. This paper contributes knowledge on the role of traffic intensity in environmental pollution with synthetic particles from various roads running through a medium-sized city in the winter period.

2. Study Area and Methods

2.1. Study Area

The research was carried out in the Suwałki city located in lake district of north-eastern Poland. The city of Suwałki represents the coldest climatic region of Poland, namely in the Wigry-Augustów subregion (Górniak 2021). The city's area, according to data from The Central Statistical Office in 2021 is 66 km^2, with the population density 1,050 people per 1 km^2, while the population size is 69,758 inhabitants. There are 194.49 km of public roads within the city border, of which 79% are municipal and district roads, and the remaining 21% are national and provincial roads (www.um.suwalki.pl). There are big transport routes nearby – from Berlin through Warsaw to St. Petersburg and from Warsaw to Helsinki (S61 – fragment of Via Baltica). Samples of road snow were taken from previously selected streets with varying traffic intensity (low – L - with less than 5,000 vehicles per day; medium

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- M - with 5,000 to 10,000 vehicles per day, and high – with more 10,000 vehicles per day). A total of 54 sampling stations were selected (Table 1, Figure 1), considering places with very busy streets (e.g., Armii Krajowej Street - site no. H3) and many residential buildings (e.g., Tadeusza Kościuszki Street - site no. H10), as well as places where human activity is limited (e.g., Innowacyjna Street - station no. L13). The number of low-traffic stations was 18, medium-traffic - 23, and high-traffic - 13. The geographic coordinates of the sampling stations in Suwałki are presented in Table 1.

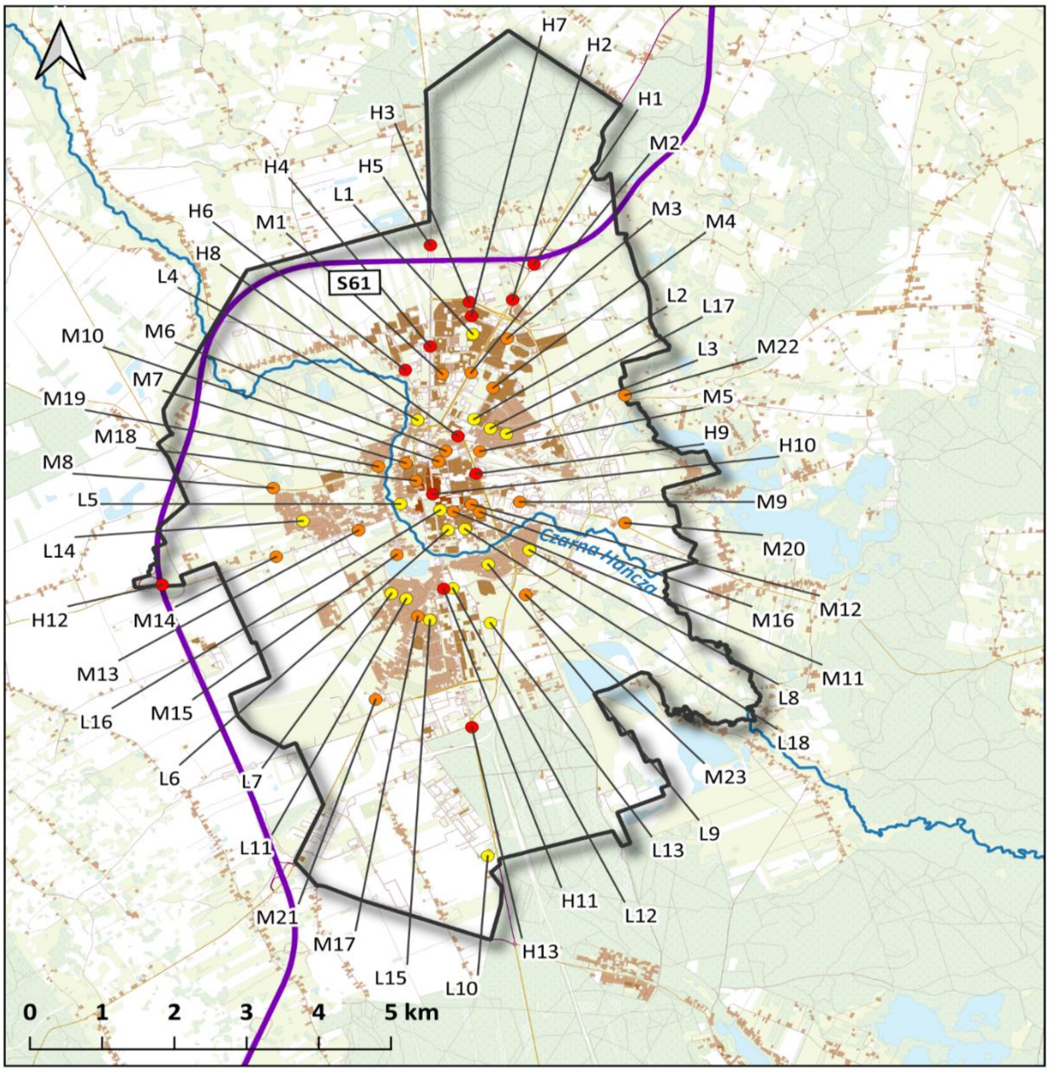

Figure 1. Location of sampling stations in Suwałki City, Poland. The level of road traffic intensity has been marked with colors (yellow - low, orange - medium, red - high).

Table 1. List of sampling stations with street names and traffic intensity levels; (L - low, M- medium, H- high), geographic coordinates located in Suwałki City, Poland.

Number	Street name	Traffic intensity	Latitude	Longitude
L1	Gen. W. Andersa	low	54°07′25″N	22°56′19″E
L2	Jana Pawła II	low	54°06′43″N	22°56′16″E
L3	Świerkowa	low	54°06′35″N	22°56′40″E
L4	Szpitalna	low	54°06′44″N	22°55′33″E
L5	Gałaja	low	54°06′03″N	22°55′16″E
L6	Wesoła	low	54°05′49″N	22°55′51″E
L7	Powstańców Wielkopolskich	low	54°05′19″N	22°55′05″E
L8	Klasztorna	low	54°05′37″N	22°56′52″E
L9	Łąkowa	low	54°05′31″N	22°56′20″E

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L10	Bursztynowa	low	54°03′07″N	22°56′06″E
L11	Kawaleryjska - Kosynierów	low	54°05′16″N	22°55′16″E
L12	Sportowa	low	54°05′20″N	22°55′52″E
L13	Innowacyjna	low	54°05′02″N	22°56′19″E
L14	Wł. Jagiełły	low	54°05′57″N	22°54′01″E
L15	Gdańska	low	54°05′05″N	22°55′33″E
L16	ks. Zawadzkiego	low	54°05′59″N	22°55′46″E
L17	Klonowa	low	54°06′38″N	22°56′28″E
L18	Ciesielska	low	54°05′49″N	22°56′04″E
M1	W. Witosa	medium	54°07′06″N	22°55′54″E
M2	Gen. K. Pułaskiego	medium	54°07′06″N	22°56′16″E
M3	F. Chopina	medium	54°07′22″N	22°56′45″E
M4	Nowomiejska	medium	54°06′58″N	22°56′32″E
M5	Kolejowa	medium	54°06′27″N	22°56′19″E
M6	T. Noniewicza	medium	54°06′28″N	22°55′53″E
M7	Gen. W. Sikorskiego	medium	54°06′23″N	22°55′22″E
M8	23. Października	medium	54°06′14″N	22°53′40″E
M9	Sejneńska	medium	54°06′01″N	22°56′47″E
M10	Gen. J. Dwornickiego	medium	54°06′23″N	22°55′47″E
M11	T. Noniewicza	medium	54°05′58″N	22°55′56″E
M12	1. Maja	medium	54°06′01″N	22°56′10″E
M13	Bakałarzewska	medium	54°05′51″N	22°54′43″E
M14	Bakałarzewska	medium	54°05′40″N	22°53′39″E
M15	24. Sierpnia	medium	54°05′38″N	22°55′11″E
M16	L. Waryńskiego	medium	54°05′57″N	22°56′16″E
M17	Raczkowska	medium	54°05′07″N	22°55′24″E
M18	E. Plater	medium	54°06′14″N	22°55′29″E
M19	S. Staszica	medium	54°06′22″N	22°55′01″E
M20	Sejneńska	medium	54°05′48″N	22°58′06″E
M21	655 road	medium	54°04′27″N	22°54′48″E
M22	Północna	medium	54°06′51″N	22°58′12″E
M23	S. Staniszewskiego	medium	54°05′15″N	22°56′47″E
H1	Gen. K. Pułaskiego	high	54°07′58″N	22°57′09″E
H2	Gen. K. Pułaskiego	high	54°07′41″N	22°56′51″E
H3	Armii Krajowej	high	54°07′41″N	22°56′18″E
H4	M. Reja	high	54°07′20″N	22°55′46″E
H5	M. Reja	high	54°08′10″N	22°55′51″E
H6	Szpitalna	high	54°07′09″N	22°55′26″E
H7	A. Wierusza-Kowalskiego	high	54°07′34″N	22°56′19″E
H8	Gen. Z. Podhorskiego	high	54°06′35″N	22°56′03″E
H9	Utrata	high	54°06′16″N	22°56′15″E
H10	T. Kościuszki	high	54°06′07″N	22°55′41″E
H11	Wojska Polskiego	high	54°05′20″N	22°55′45″E
H12	S61 expressway	high	54°05′29″N	22°52′11″E
H13	Wojska Polskiego	high	54°04′11″N	22°56′00″E

2.2. Snow Sampling

In total 54 samples of snow from snowbanks were collected on 21st February 2021 due to heavy snow cover (30,5 cm), previously accumulated on the banks for 5 days. During the sampling as well as five days before and one day after, the average temperature was -5.1°C (Institute of Meteorology and Water Management Polish National Research Institute, 21.02.23). There was no snowfall on the day of sampling. Road snow samples were collected using a metal scoop, at a distance of up to 0.3 m from the edge of the road. Attempts were made to achieve consistent snow sample characteristics, taking into account both density and appearance. Snowbank samples were placed in glass containers with a capacity of 1 L. The samples were secured with tight lids. All samples were then transported to the laboratory for storage in a freezer and detailed testing and analysis.

2.3. Research Quality Assurance

Before starting the experiment, all glassware and laboratory equipment were thoroughly washed and rinsed three times with deionized water. Then the glass was dried and disinfected in an electric laboratory dryer Memmert SF110 (Germany). During the sampling, all quality assurance measures were taken nitrile gloves and cotton aprons were used. A blind test was also carried out in the laboratory, using freshly collected snow in amount of 1 L.

2.5. Polymers Isolation and Analysis

Collected snowbank samples were melted at room temperature before further analysis. The volume of the formed dilution was precisely measured using a measuring cylinder. MPs and TWPs were separated from the liquid with the castor oil method described by Mani (2019). This method consisted of creating a two-phase dispersion system of polar and non-polar liquids (respectfully water and oil). The contents of the sample were poured into the separation funnel, and then the pure castor oil was added in a 1:10 ratio to each sample. Separators were vigorously shaken for 2 min to dispense MPs and TWPs in oil. The emulsion was then set aside for an hour to separate the two phases. After that time, the water part containing heavy natural organic and inorganic impurities settled on the bottom of the funnel and was drained into the beaker. The remaining oil phase was mixed and shaken with 50 ml 96% EtOH in order to dilute the non-polar liquid. The formed mixture was filtered using vacuum pump (KNF Laboport® mini-pump, Germany) on glass GF/C filters to separate synthetic particles. The pump cup and inner walls of the funnel were rinsed with hot alcohol and filtered. The filters were placed into a glass petri dish to evaporate the alcohol.

The next stage was visual analysis of MPs and TWPs on a SZX10 microscope (Olympus Corporation, Japan) under a 40× magnification. The microscope was equipped with a polarized light source (Schott KL 1600 LED), and camera for photographic documentation, so it was possible to count, measure and determine the color and shape type of the particles. All synthetic particles are divided into 4 types depending on their shape: fragment, pellet, fiber, film. Due to their color, MPs and TWPs have been divided into three categories: black, transparent, and blue (Graca et al. 2017; Barrows et al. 2018). The results for the MPs and TWPs particle distribution were calculated and presented in pieces per 1 L of melted snow. Due to the fact that, in addition to microplastic particles, organic fragments also settled on the filters, the hot needle method was used. It involved heating the needle over a burner flame and then touching the particle. If the particle was deformed under the influence of heat and a smell of synthetic material was emanating, it was considered a MPs and TWPs (Pol et al., 2022; Ruggero et al., 2020; Vandermeersch et al., 2015).

2.6. Data Analysis

The content of MPs and TWPs on roads (traffic routes) in snowbank was expressed in pieces per liter of water. The statistical analyzes were performed using JASP 0.18.3. One-way ANOVA analysis was used to determine differences in polymers abundance between types of sampling stations. The QGIS 3.16 spatial data analysis program was used to map the area where the research was conducted. To determine the traffic intensity on the streets of Suwałki, data obtained from the Roads and Greenery Administration in Suwałki after consultation with the Municipal Office in Suwałki and data from the website www.google.com/maps were used.

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3. Results

3.1. MPs and TWPs Concentration

Based on the conducted research, it was found that MPs and TWPs contaminations were common in all snowbank samples at all 54 stations in Suwałki city. The average concentration of polymer particles in road snowbanks was 354.72 pcs/L (±311.72) (Table 2). MPs and TWPs were analyzed in three groups of roads characterized with low, medium, and high traffic intensity. Comparing the average concentration of the polymer fragments in the studied groups, it was found that there was a clear predominance of MPs and TWPs pieces in the group of streets with the highest traffic intensity with a content of 792.76 pcs/L (±257.34). More than twice as low value, amounting to 335.97 pcs/L (±114.16) was found on roads with medium traffic intensity (Figure 2). The lowest average number of studied particles occurred in the group with low traffic intensity (Figure 2). In this case, 62.32 pcs/L (±39.85) particles were noted on average. Statistically significant differences in mean values were found between these three groups of roads (p-value<0.05). The highest content of particles was identified at the H8 site and amounted to 1,180.25 pcs/L (Figure 3). The lowest number of particles was found at the L14 site and was over 600 pcs/L times lower, amounting to 1.94 pcs/L. The coefficient of variation (CV) for all sampling sites was 87.88%, for L sites – 32.46%, for M sites - 33.98%, and for H sites - 63.94%. In general, the concentration of MPs and TWPs increases with traffic intensity, and the CV values decreases.

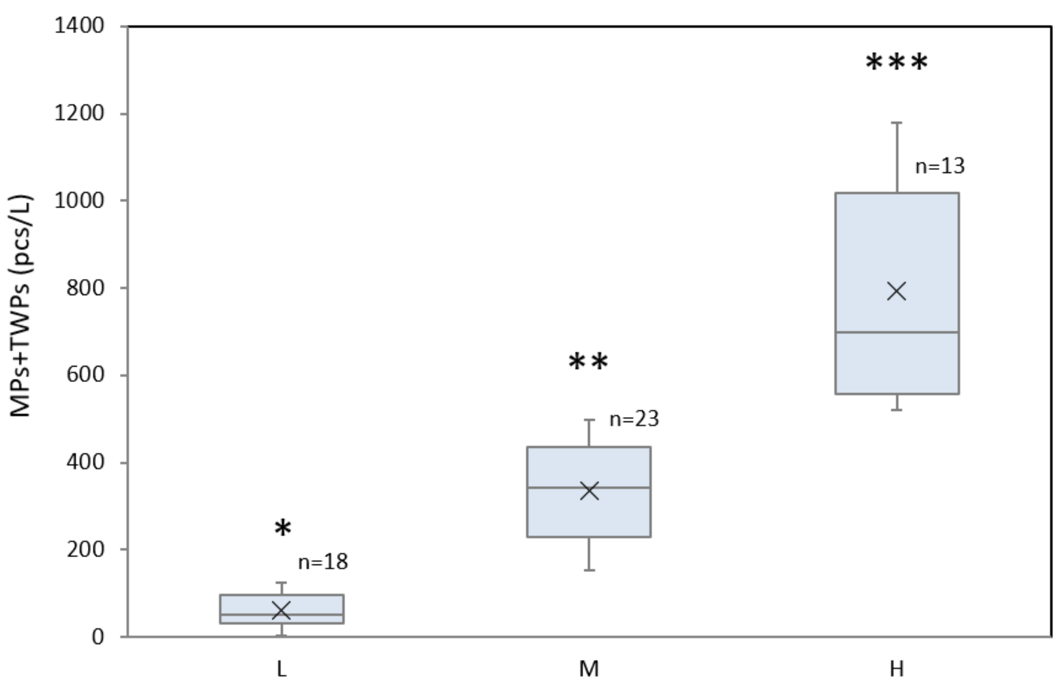

Figure 2. Boxplot showing concentrations (pcs/L) of microplastics (MPs) and tire wear particles (TWPs) in snowbank samples collected in Suwałki City, Poland at locations varying with traffic intensity (low – L - with less than 5000 vehicles per day; medium - M - with 5000 to 10000 vehicles per day; high – H – with more than 10000 vehicles per day). Average values are marked as × inside each box, significant differences are marked as *, the median is marked as a line in each box, and n is the number of samples analyzed per category.

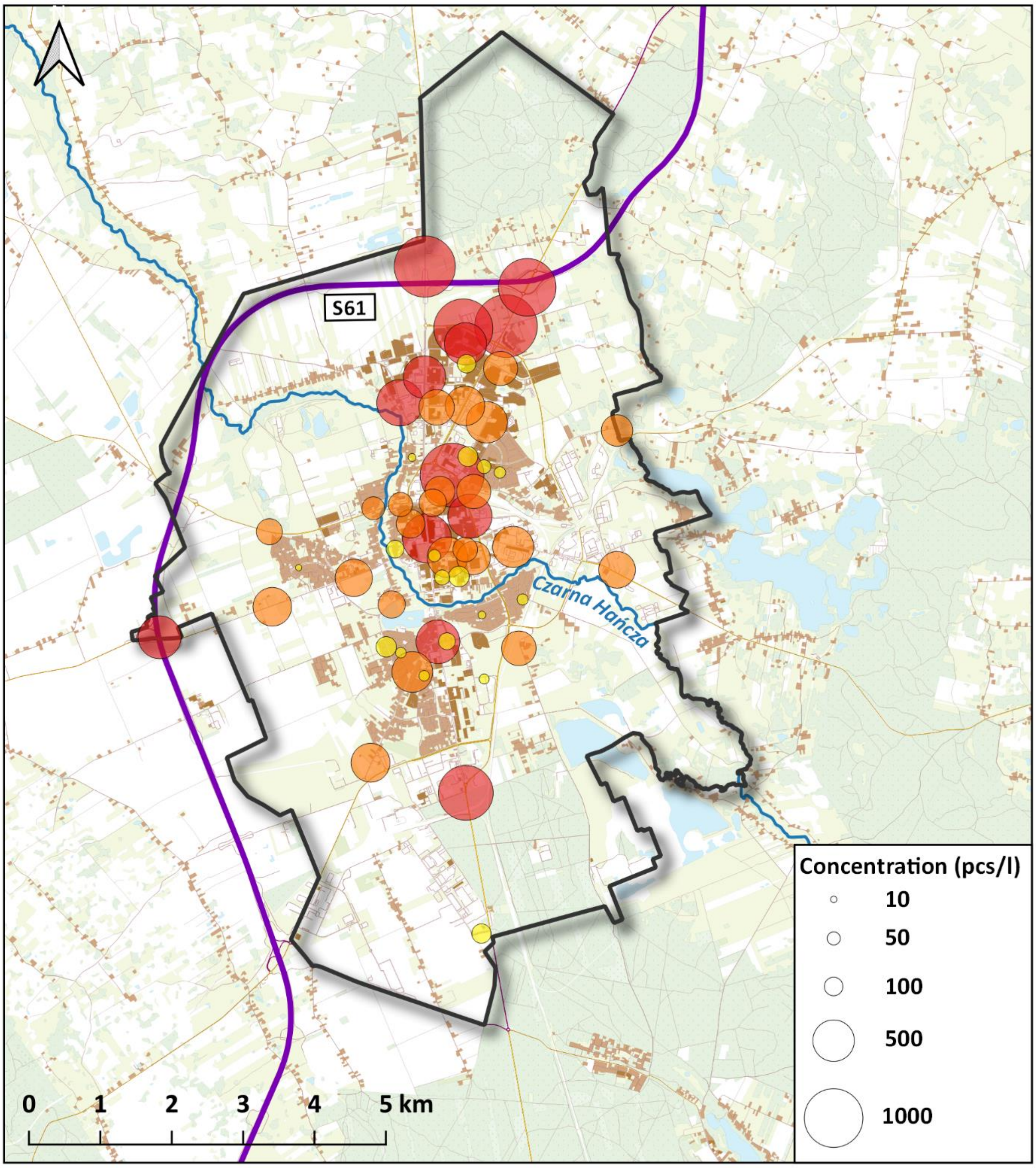

Figure 3. Spatial distribution of MPs and TWPs pollution in road snow considering the concentration of synthetic particles at individual locations in Suwałki city. The level of road traffic intensity has been marked with colors (yellow - low, orange - medium, red - high).

MPs and TWPs are commonly spread in Suwałki city. Highest values focus on the city center and on busy exit roads from the city (Figure 2, Figure 3).

3.1. Particles Size Distribution

An analysis of the particle size distribution of MPs and TWPs in road snow was performed. The obtained results showed that particles in size range from 58 µm to 200 µm prevailed at all sites (Figure 4, Figure 5). The smallest size of particle examined was 56 µm, and this applied to the H3 site, while the largest was 4,680 µm and belonged to the group of roads with high traffic intensity. In the case of streets with medium traffic, the highest number of particles was in the same size range, but the

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number was 4,549 (Figure 5). When analyzing streets with high traffic, the highest number of particles was also in the size range of 50 μm to 200 μm, and their number amounted to 4,719 (Figure 5). The coefficient of variation was as follows: 177.40% for streets with low traffic intensity, 186.83% for medium traffic intensity, and 179.48% for high traffic. Samples are significantly different from which others (p-value<0,05).

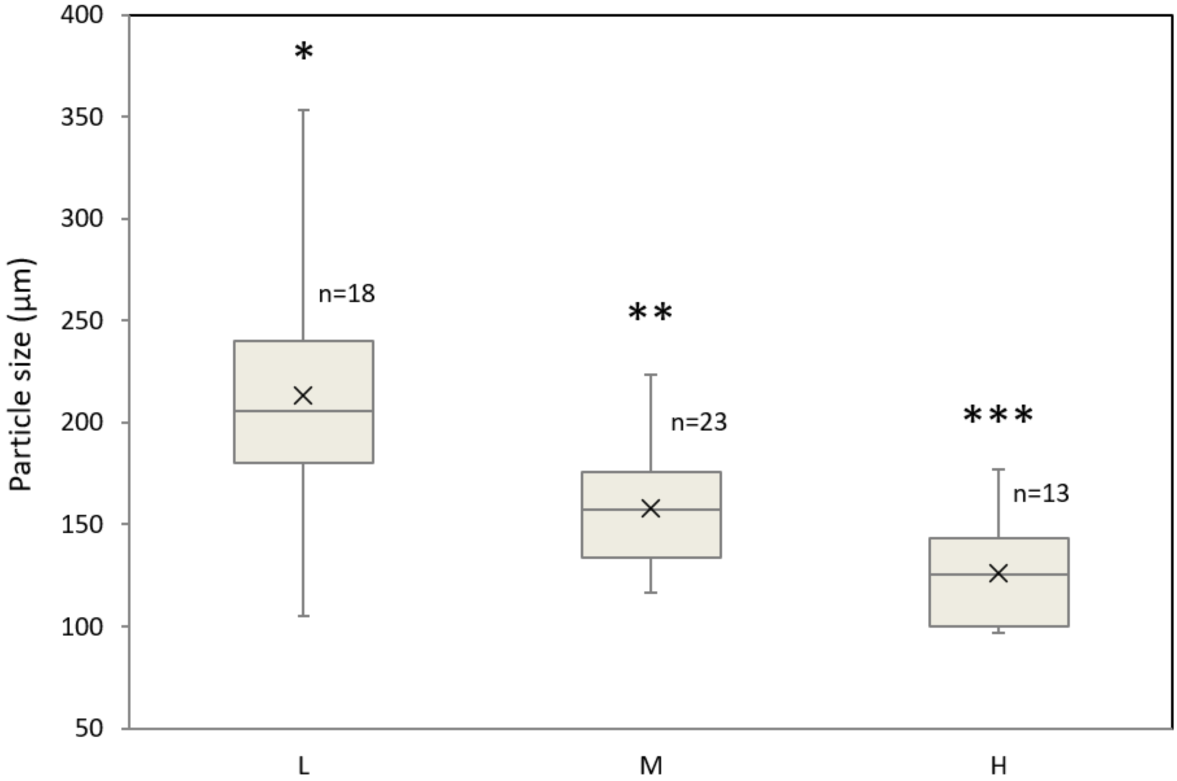

Figure 4. Boxplot showing size (μm) of microplastics (MPs) and tire wear particles (TWPs) in snowbank samples collected in Suwałki City, Poland at locations varying with traffic intensity (low – L - with less than 5000 vehicles per day; medium - M - with 5000 to 10000 vehicles per day; high – H – with more than 10000 vehicles per day). Average values are marked as × inside each box, significant differences are marked as *, the median is marked as a line in each box, and n is the number of samples analyzed per category.

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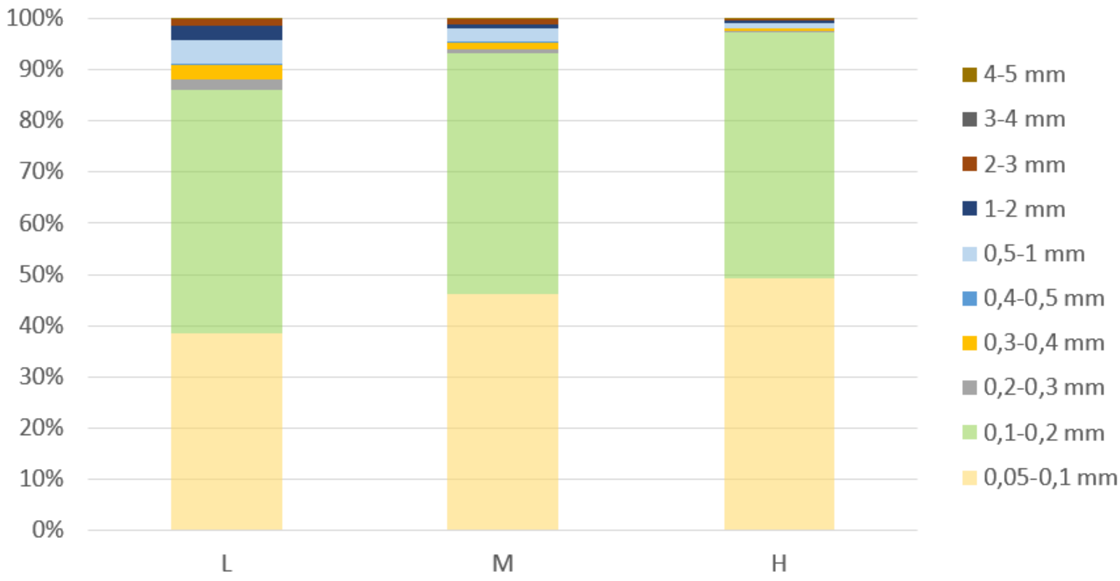

Figure 5. Composition comparison of individual MPs and TWPs particle size classes in groups of sites varying in traffic intensities.

3.3. Particle Shape and Color

Black particles predominated, by far all sampling stations. At each site, the percentage of black-colored particles was over 97%. In many sites it was even 100% (ex. L14). Compared to other colors, the average percentage of black particles was 99.85% (Figure 6A). Transparent particles were much less common. Their percentage was 0.14%. As for the blue color, it was only 0.01%. Blue-colored particles were detected at only one station.

The abundance of fragment-shaped MPs and TWPs as well as pellet was greater than a number of fiber and film shapes. At all sites, the largest part was fragment-shaped particles. The percentage of MPs and TWPs in the fragment-shape indicates that, on average, is 89.23%. In the case of pellet, it is 10.62%, while film accounts for 0.12% and fiber for 0.03% (Figure 6B). The highest number of fragments among all types was observed in the group of streets with high traffic intensity. This value amounted to 9,216 pieces, while in the case of streets with medium traffic intensity, this value was smaller by 2,203 particles. The lowest value was recorded in the group of streets with low traffic intensity. Compared to the previous groups, it was only 863 particles. The second most common type, also in relation to all sites, was pellet. In this case, it was most abundant in the group with high traffic intensity.

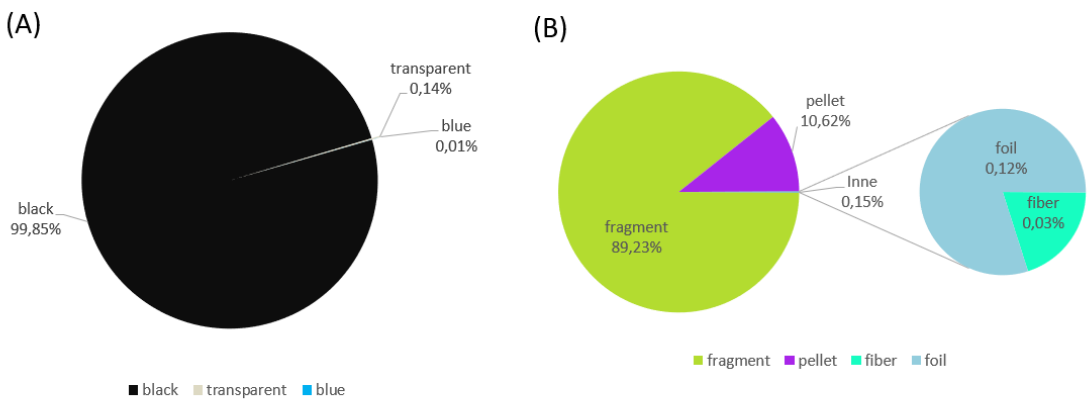

Figure 6. Percental distribution of morphology characteristics of all studied particles (TWPs + MPs): color (A) and shape (B).

3. Discussion

Based on the data published till now, it is evident that the prevalence of synthetic particles, including tire fragments, along with bitumen abrasion from roads, has been widely acknowledged as a potentially significant source of pollution in the environment (Jan Kole et al. 2017; Sommer et al. 2018; Järlskog et al. 2020). Recent studies indicate that some MPs and TWPs are deposited near the curb and/or near the edge of the road, and, as it turns out, in the road snow as well, which is confirmed by our work (Table 2, Figure 3.). This snow when melting delivers particles to surface water while other deposit in nearby soil (Wagner et al., 2018). The level of MPs and TWPs on the road depends on several factors, e.g., road maintenance, tire age and meteorological conditions including precipitation and wind (Järlskog et al., 2020; Jan Kole et al. 2017; Wagner et al. 2018), as well as driving style (i.e., brake use, speed), traffic volume, road surface structure (Müller et al., 2020). Our research confirms strong impact of traffic volume on concentration of both MPs and TWPs (Figure 2). The highest concentration of MPs and TWPs was found on roads with high traffic - average 792.76 pcs/L, while on roads with low traffic it was 10 times less (62.32 pcs/L) (Figure 2).

Table 2. Summary statistics of MPs and TWPs particles concentration on snowbank calculated for all samples.

Scheme 354.	**Value (pcs/L)**
Mean	354.72
Median	307.94
Maximum	1,180.25
Minimum	1.94
Rank	1,178.31
SD	311.72
Total number of MPs and TWPs	19,154.92
Coefficient of variation	87.88%

MPs and TWPs on communication routes, in the light of recent research, are common, which confirms the notably high levels of pollution on roads in various parts of the world. Even in areas generally considered clean, as in the case of Suwałki, these values are high (Table 2, Figure 3). In Paris, the concentration of MPs particles ranged from 3 to 129 pcs/L in storm water with a total number 2,346 particles collected (Treilles et al., 2021), while in the case of Suwałki the values ranged from 1.94 to 1,180.25 pcs/L. The maximum values obtained in Suwałki were several times higher (Figure 2) than in the case of Paris. However, our research concerns the winter period, which is conducive to the accumulation of MPs and TWPs in snow cover, while data gathered by Treilles (2021) came from urban runoff and can be difficult to compare. Furthermore, in the Paris study, only MPs were analyzed, excluding the TWPs fraction. Snow cover, because it remains on the road for a longer time is even more polluted with MPs and TWPs (according to accumulation process) than rainwater, and after thawing, significantly increases the concentration of MPs and TWPs in surface waters (Bergmann et al., 2019). This may also be indicated by the fact that the month in which the research was conducted was characterized by the highest snow cover in the entire year 2021, as well as a very high number of days with snow per month (Institute of Meteorology and Water Management Polish National Research Institute, 21.02.23). On the other hand, low temperature may promote the maintenance of snow cover in the city and lead to gradual accumulation of pollutants during the winter period in a temperate climate zone.

Previous studies conducted in the river Czarna Hańcza flowing through Suwałki show that MPs are common pollutants in the city water (Pol et al., 2022). In addition, precipitation increases the number of MPs and TWPs by intensifying surface runoff from city roads and soil, which causes pollutants transportation to watercourses (Zbyszewski and Corcoran 2011; Pol et al. 2022). Presumably, MPs and TWPs detected within communication routes could have affected the pollution of the Czarna Hańcza in particular sites closest to this river: M7, M19, L4, and L9 (Figure 3). In another research, the occurrence of MPs and TWPs from tire abrasion in city streets dust in Gothenburg, Sweden was investigated (Järlskog et al., 2020). In this case, the number of summed MPs, TWPs and paint particles in sweepsand and washwater ranged from 3 to 5,900 pcs/L (Järlskog et al., 2020). The washout process contributes to leaching all road dust, including TWPs, so the maximum value was much higher compared to the pollution level in our research (Table 2).

Panko et al. (2013) suggest that the majority of TWPs (up to 99.1%) remain on the ground surface, which is conducive to mechanical shredding on the road. Therefore, the presence of MPs and TWPs on the communication routes of north-eastern Poland, exceeding on average of 354.72 pcs/L (Table 2), is not a big surprise. Heavier traffic indicates more tires are subjected to abrasion, thus more TWPs occur in the environment (Wilkinson et al., 2023). Probably, due to plastic debris fragmentation that takes place on roads (especially in low temperatures), we will observe a larger number of TWPs and MPs. The smallest size class of particle size was prevalent in this research (Figure 5) and significant difference between the three traffic groups was noted (Figure 4).

Not surprisingly black color in all MPs and TWPs samples was dominant, what is typical color of tires (Figure 6A). No regularity between MPs and TWPs shape and traffic intensity was found (Figure 6B), and regardless of the intensity of traffic, it does not significantly affect the shape. Observed irregular shapes (fragments) are secondary MPs and TWPs are made in the process of mechanical degradation (Chernykh et al., 2022; Son & Choi, 2022). In other research TWPs were also dominated by fragments (Worek et al., 2022).

As the MPs and TWPs of even medium-sized cities is severe (Table 2, Figure 3), it is necessary to develop ways to remove these common pollutants. Unfortunately, as the use of rubber tires would not be discontinued, it is worth analyzing and evaluating other potential measures that could contribute to reducing polymer pollution emissions in the urban environment. Only a few percent of stormwater or water left over after snow melt is treated, and currently available treatment systems are not designed to effectively remove pollutants such as MPs and TWPs (Järlskog et al., 2020). Since the 1980s, street sweeping has been used to reduce pollution from roads and highways (United States. Environmental Protection Agency. 1982; Järlskog et al. 2020). Some studies have been carried out to investigate the performance of different types of brushes in removing MPs, and whether it is possible to reduce the number of synthetic particles inhaled by humans while sweeping the streets (Järlskog et al., 2020). Maybe hauling snow away from the city to wastewater treatment would be a solution. A study by Amato et al. (2014) showed that sweeping reduces the transport of pollutants associated with polycyclic aromatic hydrocarbon (PAH), metals, and fine particles into surrounding waters. Other studies have shown that sweepers can collect large a number of particles present, including both nanoparticles and organic contaminants (Polukarova et al., 2020), and indicate that street sweeping may be an appropriate measure to reduce the spread of MPs in cities (Hann et al. 2018;Vogelsang et al. 2018). A study by Lange et al. (2021) showed that separator chambers are effective treatment of MPs in road rainwater, with a high percentage (about 70%) removal rate of total suspended solids and other particle-bound contaminants. It has also been suggested that MPs in runoff from cities and highways may be partially removed through ponds and sedimentation tanks but may require further treatment due to the presence of other contaminants (Liu et al. 2019; Olesen et al., 2019). Although knowledge on MPs and TWPs is incomplete, there are efforts by the European Commission to reduce polymer particles loads that come from all sources (Järlskog et al., 2020). Measures that could be taken to decrease the release of TWPs and MPs into the environment include reducing traffic congestion or speed (Verschoor and De Valk 2017). Our results reinforce the steps taken by the European Commission towards reducing pollution of roads and urban areas (Figure 3).

5. Conclusions

1. MPs and TWPs were detected in all 53 road snow samples with average value of 354.72 pcs/L.
2. The influence of traffic intensity on concentration MPs and TWPs level in road snow was confirmed.
3. Black and fragment shaped synthetic particles were prevalent, due to their origin.

4. The smallest particle size class (within the limits of 50-200 μm) was dominant in all traffic intensity groups.
5. Road snow may act like as a temporary storage of pollutants during winter in the temperate climate zone.

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