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SPATIAL–TEMPORAL DISTRIBUTION OF MICROPLASTICS IN LOWLAND RIVERS FLOWING THROUGH TWO CITIES (NE POLAND)

Wojciech Pol · Angelika Żmijewska · Emilia Stasińska · Piotr Zieliński

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Abstract Urbanised areas are known to cause plastic pollution, which consequently ends up in water sources. In this study, we measured microplastic concentrations in two lowland rivers flowing through two different cities. In both cases, the lowest downstream sites were located below local wastewater treatment plants. Samples were processed according to ricin oil separation and visual counting methods (considering abundance as well as shape, size, and colour groups). Microplastic concentrations in the surface water within the two studied rivers were found to be similar despite the differences in the cities they flow through. Mean microplastic abundance in the rivers was 10.83 MP/L in the Biała River and 10.29 MP/L in the Czarna Hańcza River. Regarding microplastic shapes, films were the dominant type (Biała River 47.8%, Czarna Hańcza River 51.9%), but higher proportions of less abundant plastic types such as fragments (Biała River 20.6%, Czarna Hańcza River 18.6%), foams (Biała River 12.1%, Czarna Hańcza River 14.2%), and fibres (Biała River 12.9%, Czarna Hańcza River 11.1%) were also found. The least common type of plastic was pellet (Biała River 6.6%, Czarna Hańcza River 4.2%), which was increasing significantly on stations situated downstream, behind the wastewater treatment plants. The results of our study show that city river systems are influenced by plastic waste, especially after precipitation and the snowmelt season. For small and medium urban rivers, hydrology does not play as important a role as it does for large rivers.

Keywords Microplastic · River · Urban area · WWTP · Pollution · Contamination · Freshwater

1 Introduction

Plastics are present in everyday life, and it is difficult to imagine humans functioning without them. It is known that they are very durable, and depending on type of material used, estimate decomposition time is usually 450–1000 years for non-biodegradable plastics (Gibovic & Bikfalvi 2021) or even more than a thousand years (Allouzi et al. 2021). Some scientists claim that plastic can degrade for even up to 4,500 years (Gawande et al., 2012). In the environment, the breakdown of plastics into smaller fractions, called microplastics (MP, < 5 mm), occurs through physical (mechanical disintegration, photodegradation), chemical (oxidation, hydrolytic degradation), and biological factors (biodegradation with microorganisms) (Woodall et al., 2014; Lehner et al., 2019). Global plastic production has been on an upward trend since the 1950s, now reaching over 335 million tonnes per year (Blair et al., 2018; Parthasaraty et al.,

W. Pol (✉) · A. Żmijewska · E. Stasińska · P. Zieliński
Department of Water Ecology, Faculty of Biology, University of Białystok, Ciołkowskiego 1J, 15-245 Białystok, Poland
e-mail: w.pol@uwb.edu.pl

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2019), and estimated to reach 69.14 million tons of mismanaged plastic waste annually by 2025 (Watt et al. 2021). A sizable amount of plastic waste ends up in waterways. In 2014, the microplastic content in marine waters was estimated to be at least 5.25 trillion particles (Bergmann et al., 2015). Recent studies show that rivers supply the oceans with an amount of plastic from 7,000 to as much as 35,000 metric tonnes per year (Mai et al., 2020). The microplastic found in oceanic, marine, and inland waters comes not only from the breakdown of plastic packaging but also from direct pollution by plastic particles that are an ingredient of cosmetics or cleaning products (Mintening et al., 2017; Möhlenkamp et al., 2018). Current studies clearly show a higher occurrence of plastic waste in areas with increased human activity, including human settlements, transportation, and industrial activity (Driedger et al., 2015; Tibbetts et al., 2018). Wastewater treatment plants (WWTP) are indicated as one of the substantial sources that increase the level of microplastic in waters (Kay et al., 2018). An important problem identified in the literature is the variation in the river MP density in time (Nel et al., 2018; Rodrigues et al., 2018). The vast majority of research on MP in freshwater is conducted in Asia (Peng et al., 2018; Xu et al., 2020; Yang et al., 2021), North America (Baldwin et al., 2020; Said & Heard, 2020), and Western Europe (Klein et al., 2015; Meng et al., 2020; Tamminga & Fisher, 2020). Few studies on MP in rivers have been carried out in Eastern Europe and those that have concerned mainly bigger rivers (Zima et al., 2017; Połeć et al., 2018; Sekudewicz et al., 2021). Microplastics in waters pose not only a threat due to pollution but also through ecosystem disruption (Arias Andres, 2018). Fine plastic, due to its size and morphology, similar to phytoplankton, is often taken up by zooplankton (Cole et al., 2013; McNeish et al., 2018; Ašmonaitė and Almroth, 2018) which ultimately leads to MP passing through a trophic cascade.

The multifaceted nature of this problem led us to undertake a study focused on the impact of urbanised areas, hydrometeorological conditions, and WWTP location on the level of river contamination with MP in medium-sized cities. The other goal of the study was to describe the variation in the amount, size, colour, and shape of MP and their changes over time. This research can fill a gap in the study of microplastic pollution in the rivers flowing through these types of cities.

2 Study area

The study was conducted on two lowland rivers located at a distance of approximately 100 km from each other, being the Biała River and Czarna Hańcza River, flowing through the cities of Białystok (city area 102 km^2, ~295,000 residents, with a density of ~2,890 people/km^2) and Suwałki (city area 65.5 km^2, ~70,000 residents, with a density of ~1,068 people/km^2), respectively. Both cities represent different land use and catchment areas, with Białystok being a mostly urbanised area (~45% of land use) and Suwałki with 31% use for both urbanised and grassland. Water covers twice as large an area in Suwałki as in Białystok (Tab. 1; Fig. 1). Both studied rivers differ considerably regarding their length, land cover of the catchment, areas through which they flow (including protected areas) and the population density of the cities through which they pass. The studied rivers also differ in the number of storm sewer outlets—148 on the Biała River (between sites B1 and B3, there are 125, and between B4 and B5 there are 23) and 26 on the Czarna Hańcza River. In total, 10 sampling sites were selected, 5 on each of the studied rivers, taking into account the location of WWTP just above B5 and CH5 sites (Fig. 1 and Tab. 2). The studied rivers do not differ significantly in mean annual flow, with 0.88 m^3/s in the Biała River (Tyszewski & Kardel 2009) and 0.95 m^3/s in the Czarna Hańcza River (Dybkowska-Stefek 2016).

Both cities are located in a temperate climate with continental influences. Climatological regionalisation includes Białystok into the Podlasie climatic region, but also into the Białystok subregion (Górniak, 2000).

In the year of the study, the annual sum of precipitation in Białystok was 617.6 mm and the

Tab 1 Land usage in the cities of Białystok and Suwałki

Type of land use	Białystok	Suwałki
Urbanised areas	44.9%	31%
Grasslands	14.1%	30.8%
Forests	32.3%	21.6%
Waters	8.7%	16.6%

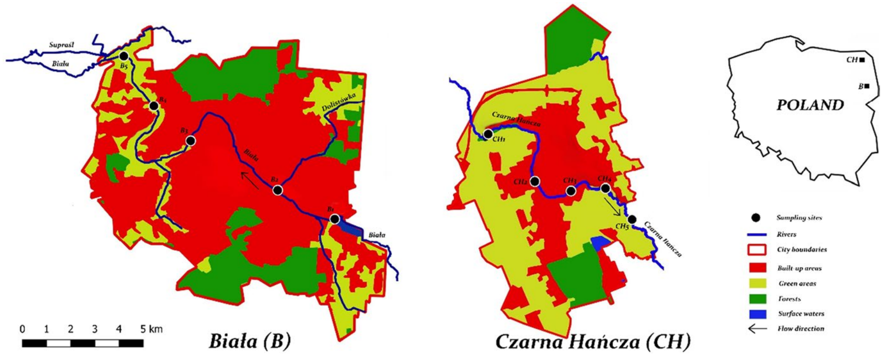

Fig. 1 Location of sampling sites on the Biała River and Czarna Hańcza River with characteristics of the city land cover

Tab 2 Geographical coordinates of sampling sites located on the Biała River and Czarna Hańcza River as well a distance from the first site and the type of site

Sampling site	Latitude / Longitude	Distance from first site (km)	Location type
B1	53°06′43.5"N 23°12′56.6"E	0	Built-up areas
B2	53°07′29.2"N 23°10′53.5"E	3.98	Built-up areas
B3	53°08′42.1"N 23°07′48.0"E	9.03	Built-up areas
B4	53°09′32.3"N 23°06′29.3"E	14.43	Green areas
B5	53°10′42.2"N 23°05′32.3"E	17.02	Green areas
CH1	54°07′06.0"N 22°53′31.7"E	0	Forests / Green areas
CH2	54°05′58.7"N 22°55′12.4"E	4.68	Built-up areas
CH3	54°05′43.3"N 22°56′32.5"E	6.70	Built-up areas
CH4	54°05′37.0"N 22°58′02.4"E	8.98	Green areas
CH5	54°05′00.9"N 22°58′48.8"E	10.90	Green areas

highest monthly precipitation was recorded in July (113.5 mm), while the lowest was in April, amounting to only 4.1 mm (Fig. 2).

The annual sum of precipitation in Suwałki was smaller than in Białystok, reaching 487 mm. August was the most abundant month in terms of precipitation, with a monthly sum of 85.7 mm. Similar as in Białystok, April was the driest month in Suwałki, with the monthly sum of precipitation equal to only 5.8 mm (Fig. 2). The average monthly temperature in both cities was very similar, with the lowest value in January and the highest in June (Fig. 2).

Both investigated rivers receive rainwater from the city (especially from impermeable surfaces, e.g. roads, pavements, roofs). Pollution from these areas, which have not been well managed, is carried to the rivers by surface run-off.

3 Methods

Sampling was carried out over a seven-month period from March to September in 2019. The water samples (50 L) were taken on each site and filtered through a

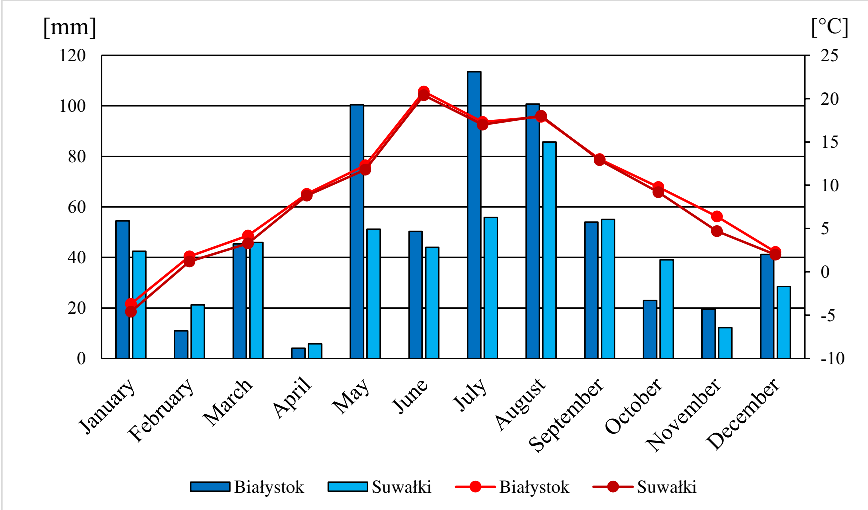

Fig. 2 Changes in average monthly precipitation and air temperature in Białystok and Suwałki in 2019, (Compiled based on The Institute of Meteorology and Water Management data)

plankton net with a mesh diameter of 40 μm (Fig. 1), which established the lower size limit of the studied MP. Concentrated samples were stored in sterile dark glass bottles to avoid contamination (Połeć et al., 2018).

For the separation of MP, we used method described by (Mani et al. 2019) with castor oil as a substance that absorbs artificial material from water. The validation of the method was carried out under laboratory conditions, which ensured reliable results from the analyses. For the validation polyethylene particles (125 μm size) were used (ALDRICH, USA). The method of MP isolation consisted of creating a two-phase dispersion system of two difficult-to-mix liquids, in this case polar and non-polar liquids. The isolation process was started by shaking dark glass bottles, which contained concentrated water samples, in order to take into account any particles that fell to the bottom of the vessel. After pouring the sample into the cylinder, the bottle was rinsed with deionised water. The contents of the sample were poured into the separation funnel. The oil was then added in a 1:10 ratio to each sample. In the next step, separators were shaken for 2 min to produce an oil/water emulsion. The vessel was then set aside in a stand for a full hour so that the substances could pass the separation process into the upper oil phase and the lower water phase fully spontaneously. After an hour, the water part, together with the heavier natural organic impurities, was drained into the beaker. The remaining oil phase together with the MP was the base for the filtration. The contents of the oil phase were mixed with 50 ml 96% EtOH in order to dilute the liquid. In the next stage, we used a vacuum pump and GF/C filters to separate MP particles. The inner walls of the distributor and the pump cup were rinsed with alcohol, which was also filtered. The filter was then put into a glass petri dish to evaporate the alcohol. The filters prepared in this way were visually analysed with the Olympus BX 43 stereoscopic microscope with × 63 magnification. The microscope was equipped with a polarised light source in the form of a Schott KL 300 LED and a camera for photographic documentation. Plastic particles were counted and divided into six size fractions (0.04–0.5 mm, 0.5-1 mm, 1–2 mm, 2–3 mm, 3–4 mm, 4–5 mm), groups by colour (red, green, blue, black, transparent, and other), and type (fibres, foams, irregular fragments, pellets, and plastic films) (Graca et al., 2017; Barrows et al., 2018; Ding et al., 2009; Ghosh et al. 2021). The hot needle method, combined with visual identification, made it possible to pick out MP with thermal properties with high probability (Loppi et al. 2021; Cypull et al., 2021). As organic particles potentially resembling plastics also remained on the filter, the hot needle method was used for identification. This method consists of heating a needle above the burner and bringing the needle into gentle contact with the particle. If the particle deforms, it is considered to be plastic. Before the beginning of the experiment, all glass and laboratory equipment was thoroughly washed and rinsed three times with deionised water. The glass was dried and disinfected in an electric laboratory dryer. During sampling, the testing team performed all activities wearing nitrile gloves and cotton aprons. A blind test was also performed in the laboratory using deionised water.

4 Data analysis

The content of MP in river water was expressed in pieces per L. All statistical analyses were performed using SPSS Statistics software. One-way ANOVA analysis was used to determine differences in microplastic abundance between sampling sites. Multivariate analysis was performed to calculate correlation coefficients. A one-way analysis of variance and multiple comparisons tests were then performed to identify the statistical significance of the differences. The spatial data analysis software QGIS 3.16 HANNOVER was used to map the test area. Meteorological results were compiled using The Institute of Meteorology and Water Management data.

5 Results

The study has shown that microplastic is a common contaminant in the investigated rivers as its presence was observed at all sampling sites. The average MP concentration for the whole study period in the Biała River was 10.83 MP/L and 10.29 MP/L in the Czarna Hańcza River with similar SD and CV (Tab. 3). The highest amount of MP was found in a sample from station CH5 in March – 25.2 MP/L, while the lowest amount was found in a sample from CH1 site in July – 4.9 MP/L, and from B1 site in April—5.1 MP/L. No statistically significant differences in MP concentration were found between the studied rivers. Average MP content at individual sites in the Biała River ranged from 9.42 to 13.57 MP/L (Fig. 3), while in Czarna Hańcza River—from 8.17 MP/L to 12.88 MP/L (Fig. 4). For both rivers, the highest average MP values were found at sites downstream of the WWTP (Figs. 3 & 4). The average MP content in the Biała River before the WWTP was 9.42 MP/L, while after the WWTP, it was 15.57 MP/L, an increase of 65%. In the Czarna Hańcza River, the increase in MP after WWTP was statistically significant at 58%, increasing average MP from 8.17 MP/L to 12.88 MP/L (Figs. 3 & 4). The most significant increase was noted in August, which was the month of highest precipitation.

Tab 3 Summary statistics of MP (MP/L) in Biała River and Czarna Hańcza River

Parameter	Biała River	Czarna Hańcza River
Average	10.83	10.29
Median	10.48	9.04
Minimum	5.1	4.9
Maximum	23.6	25.2
SD	3.96	3.9
SE	0.67	0.66
Variance	15.69	15.23
Coefficient of variation	36.57%	37.92%

In the Biała River, the density of MP was highest in late summer (August–September) and lowest in spring (April–May). In spring and summer, the density of plastic particles was statistically significantly lower than in September ($p = 0.0149$). In the case of the Czarna Hańcza River, we also observed seasonal changes of MP abundance, with the highest concentration occurring in spring (Fig. 5).

The number of microplastic particles in the Biała River and Czarna Hańcza River was positively correlated with monthly precipitation and also with the sum of precipitation from 10 days before sampling. In the case of the Biała River, the correlation coefficient of monthly precipitation with MP density was $r = 0.874$, with a significance level of $p = 0.0001$ (Fig. 6). A similar positive correlation was found for the Czarna Hańcza River, being $r = 0.793$ (Fig. 7). The sum of precipitation from 10 days before sampling significantly influenced MP concentration in the waters of the Biała River; $r = 0.798$, and in the waters of the Czarna Hańcza River; $r = 0.728$.

Analysing various types of MP, more film-type MP (Fig. 8B) was present in the Czarna Hańcza River (accounting for 51.90% of all forms) than in the Biała River (47.83%). Fragments (Fig. 8C) accounted for 18.66% and 20.59%, foams (Fig. 8A) 14.19% and 12.10%, fibres (Fig. 8D) 11.08% and 12.93%, and pellets 4.18% and 6.56% for the Czarna Hańcza River and Biała River, respectively (Fig. 9). Both lowland rivers demonstrated similar distribution in type of MP shape.

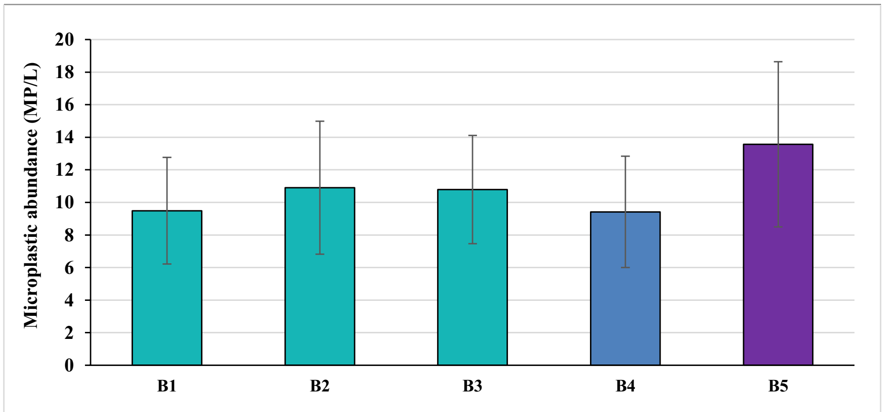

Fig. 3 Mean microplastic abundance in water (± SD) at individual sites along the Biała River (results from March to September 2019). Stations: B4 – before WWTP, B5 – after WWTP

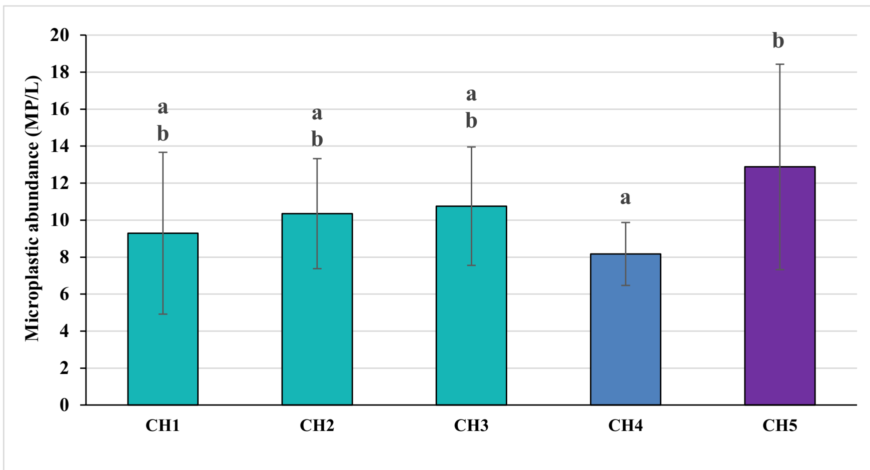

Fig. 4 Mean microplastic abundance in water (± SD) at individual sites along the Czarna Hańcza River (results from March to September 2019)

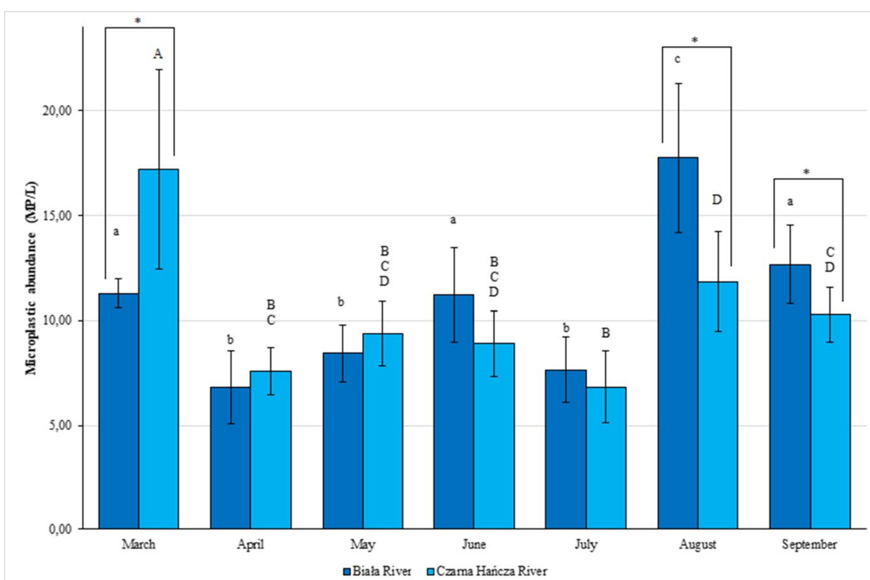

Fig. 5 Seasonal variation in microplastic abundance in the waters of the Biała and Czarna Hańcza Rivers (mean results ± SD) (*—differences between MP pollution between the two rivers in the same month; Small letters—differences between MP abundance in different months in the Biała River; Capital letters—differences between MP abundance in different months in the Czarna Hańcza River)

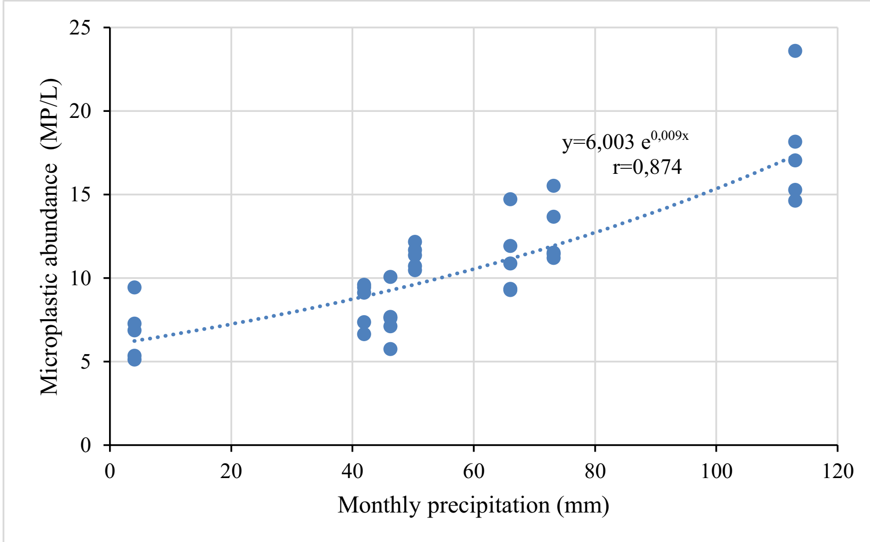

Fig. 6 Relationship between total monthly precipitation and microplastic density in the Biała River water

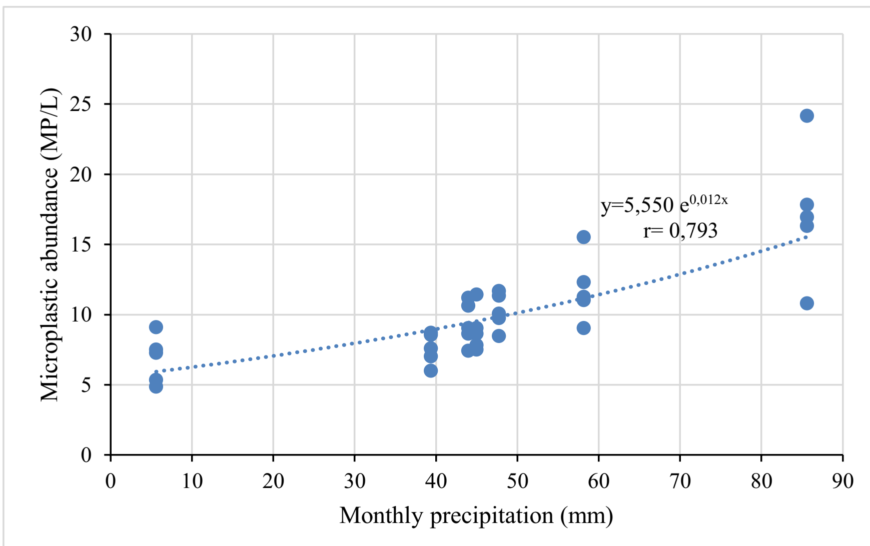

Fig. 7 Relationship between total monthly precipitation and microplastic density in the Czarna Hańcza River water

The largest proportion of all samples detected in both the Biała River (58.22%) and the Czarna Hańcza River (59.28%) was plastics in the 1–2 mm size range. MP in the size range 0.5–1 mm accounted for 27.24% and 25.68%, respectively. MP in range of 0.04–0.5 mm in the Biała River amounted to 7.93% and in the Czarna Hańcza River 8.11%, and in the range 2–3 mm, 3.25% and 2.91%, respectively. MP in the 3–4 mm size class in these two rivers amounted to 2.15% and 2.29%, respectively. The largest pieces of MP (4–5 mm) in the Biała River represented 1.20%, and in the Czarna Hańcza River, 1.73% of total MP (Fig. 10).

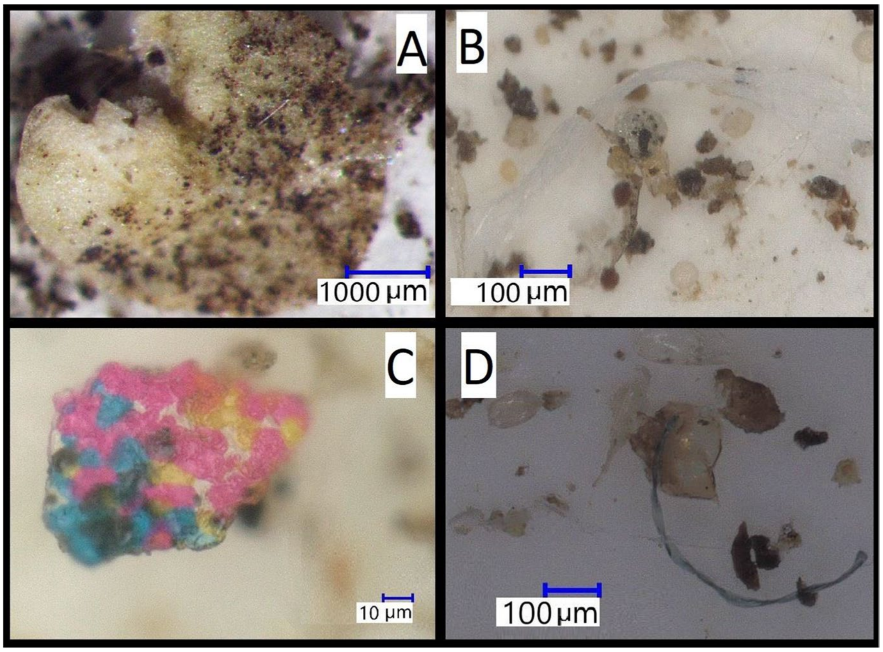

Fig. 8 Photographs of a foam (**A**), film (**B**), fragment (**C**) and fibre (**D**) of isolated microplastic

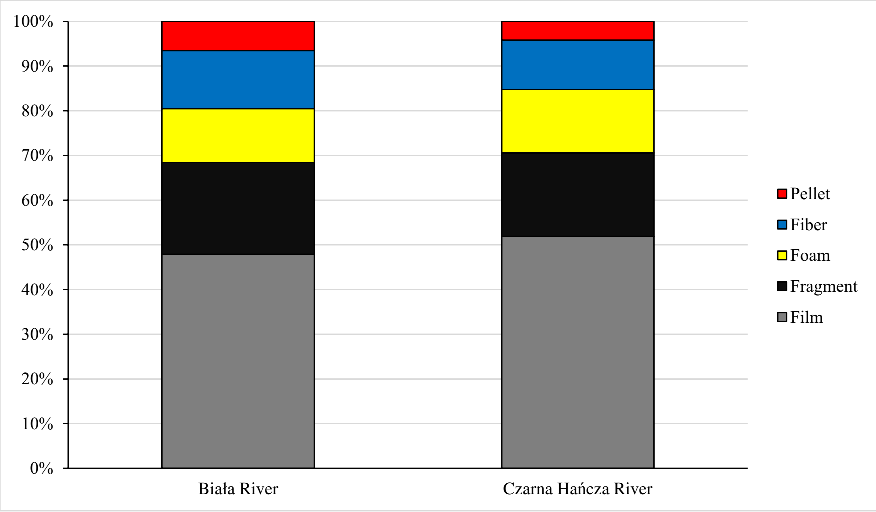

Fig. 9 Comparison of the percentage of individual microplastic shapes in the Biała River and Czarna Hańcza River (results from March to September 2019)

In both investigated rivers, transparent and other colours of MP predominated at all sites. There was no significant difference between the studied rivers in terms of MP colouring (Fig. 11).

MPs were also characterised by the shape at the sites before and after the WWTP (Figs. 12 & 13). In the case of the Biała River, at site B4, MP in the form of fibres occurred in the amount of 1.07 MP/L,

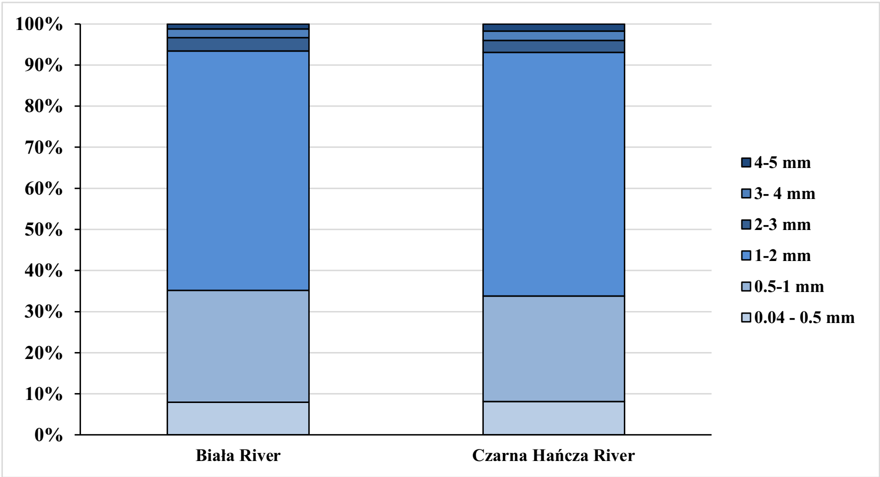

Fig. 10 Comparison of the percentage of individual microplastic sizes in the Biała River and Czarna Hańcza River (results from March to September 2019)

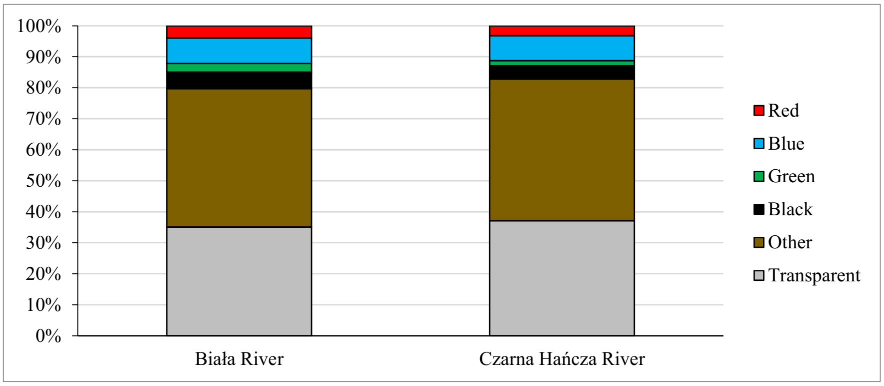

Fig. 11 Comparison of the percentage of individual microplastic colours in the Biała River and Czarna Hańcza River (results from March to September 2019)

while at the site after the sewage treatment plant an increase in the content of this group by 117% was observed. Microplastic in the form of granules was present in the amount of 0.57 MP/L before the treatment plant, while after the treatment plant an increase of 107% was recorded, up to 1.18 MP/L. In both cases, the differences indicate statistical significance (Fig. 12).

At the site behind the sewage treatment plant on the Czarna Hańcza River, we observed an increase in the content of all shapes, with the greatest increase observed in the case of pellet-shaped MP. At site CH5, their number increased by 212%, from 0.25 MP/L reaching 0.78 MP/L. At site B5, their number increased by 107%, from 0.57 MP/L to 1.18 MP/L. Both increases showed a statistically significant difference (Fig. 13).

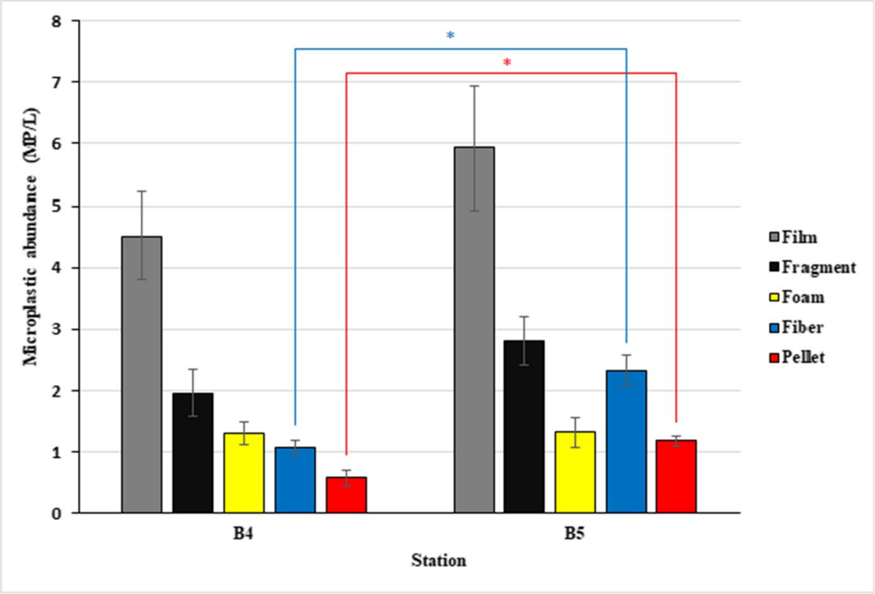

Fig. 12 Comparison of mean microplastic density in water (± SD) by shape at sites along the Biała River located upstream and downstream of the WWTP (results from March to September 2019)

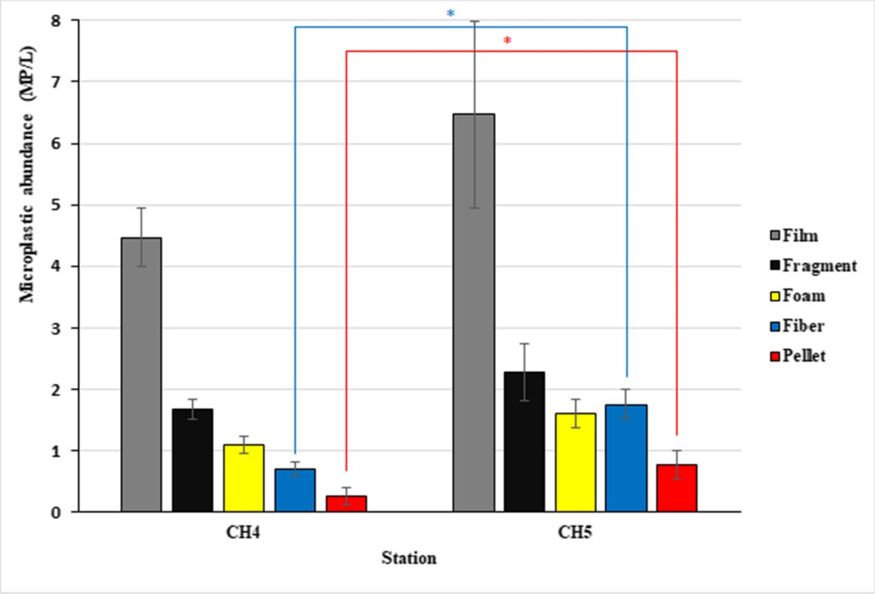

Fig. 13 Comparison of mean microplastic density in water (± SD) by shape at the Czarna Hańcza River sites located upstream and downstream of the WWTP (results from March to September 2019)

6 Discussion

Our results showed that both investigated rivers were polluted with microplastic, which were found in all collected water samples. The study surprisingly presents a similar level of MP pollution in both urban rivers (Figs. 3 & 4; Tab. 3), despite differences in the city populations, development, or land use. For both rivers, there is a noticeable decrease in MP pollution on sites B4 and CH4 (Figs. 3 & 4) in the section of the city where the river flows through green areas (Fig. 1). In the case of the Czarna Hańcza River, it is statistically significant (Fig. 4).

MP abundance in the aquatic environment is highly variable and dependent on many factors. In the light of recent studies, river microplastic is widespread, which confirms the level of MP contamination of rivers in different parts of the world (Tab. 4); therefore, the presence of MP in the rivers of north-eastern Poland exceeding an average of 10 MP/L is not surprising.

The differences in the abundance of microplastic in the world's rivers are considerable, ranging from 1.6 MP/L to over 60 MP/L (Tab. 4). According to studies conducted on various rivers, the reasons for these differences are usually related to type of land use, geological and hydrological conditions, or population density (Bordos et al., 2019; Kataoka et al., 2019) as well as increased human activity—including tourism and industrialisation (Driedger et al., 2015; Magnuson et al., 2016; Tibbetts et al., 2018) or WWTPs (Kay et al., 2018). Differences could also be caused by changing seasons when conducting the study (Nel et al., 2018; Rodrigues et al., 2018).

In the case of the Biała River, a clear increase in MP was observed in the spring–summer period—in June, where a statistically significant difference was noted, while in the Czarna Hańcza River, from April to June no statistically significant differences in mean plastic quantity were found (Fig. 5). We assume that most MP enters the river channel with surface runoff after rainfall and is flushed from impervious surfaces such as roads and car parks, resulting in a significant increase in MP during snowmelts and wet seasons (Figs. 2 & 5). The amount of precipitation has been shown to be one of the significant factors influencing the amount of MP in the studied rivers, which is confirmed by the obtained correlation (Figs. 6 & 7). As there is a high concentration of MP in urbanised catchment areas, both in the Biała River and Czarna Hańcza River, it can be assumed that human activity has led to higher concentrations of MP, for example, through the introduction of storm drains directly into the rivers, the creation of illegal landfills, illegal sewage discharge, and the general pollution of the rivers with plastic. In addition, during and after precipitation in urban rivers, the rate of water flow increases quite suddenly, and this can cause agitation of the bottom sediments, often polluted with MP (Fig. 5). As a consequence, some of the MP in the water body, after precipitation, may come from the bottom sediments. Precipitation may also wash away the MP contained in the ground and transports it to the rivers (Zbyszewski et al., 2011).

Among the main factors pointed out in the literature that play an important role are hydrology and the amount of water carried by the river, something which is not, however, confirmed by our study. Small differences in the hydrological conditions of the studied rivers are not able to change the amount of MP as might be seen when compared to say, the Yangtze or Hangijang (Zhao et al., 2014; Wang et al., 2017; Peng et al., 2018), both very large rivers which have almost 10 times less MP than the studied rivers in Poland. Perhaps small differences in the flow rate of the rivers studied will not affect the level of MP pollution. However, in large rivers such as the Yangtze, the influence of hydrology on MP levels is very clear. Large rivers carry a very large volume of water, and MP pollution is thereby diluted. In manmade waterways such as canals, where the flow is usually minimal and often

Tab 4 Summary of MP abundance in different rivers of the world

Study area	Location	Abundance (MP/L)	Literature
Yangtze	China (Asia)	4.70	Zhao et al. 2014
Hangjiang	China (Asia)	3.2	Wang et al. 2017
Antuã	Portugal (Europe)	12.65	Rodrigues et al. 2018
Amsterdam Canal	Netherlands (Europe)	18.7	Leslie et al. 2017
Gallatin	USA (North America)	67.5	Barrows et al. 2018
Huangpu	China (Asia)	1.6	Peng et al. 2018
Meuse	Netherlands (Europe)	4.9	Leslie et al. 2017
Three Gorges Dam	China (Asia)	12.6	Di & Wang 2018
Biała River	Poland (Europe)	10.83	Own results
Czarna Hańcza River	Poland (Europe)	10.29	Own results

in both directions, the MP content is much higher, as found, e.g. in the Amsterdam Canal system (Leslie et al., 2017), which is almost twice as high as in the Biała River and Czarna Hańcza River (Tab. 4). In this case, water tested in the Amsterdam Canal contained about 8 MP/L more than the studied rivers. We assume that the other key factor affecting such a difference is the population density level in the compared cities, which shows us that population level can also play an important role; the higher the population density, the higher the MP content (Mani et al., 2016).

In the Biała River and Czarna Hańcza River, which are comparable in size to the Antua River, MP content was found in similar density as well as both the Biała River and Czarna Hańcza River showing seasonal changes of MP (Fig. 5). In addition, variability in MP contamination over time depended on proximity to urban areas, seasonal, and hydrological conditions (Rodrigues et al., 2018). On the other hand, we observed higher contamination with MP after the snowmelt, which in 2019 was later and higher in Suwałki than in Białystok (Fig. 5). (Bergmann et al. 2019) studied snow cover, leading them to the conclusion that (in particular, on communication routes) snow is contaminated with MP particles, which after the snowmelt increases the MP density in rivers.

In both rivers, five types of MP shapes were found, being film, fibres, foam, fragments, and pellets. The most dominant shape of MP in both rivers was film, which differs from most of the prevailing work indicating the dominance of fibres among MP contaminants (Zhao et al., 2014; Barrows et al., 2018; Simon-Sanchez et al., 2019). However, many studies conducted worldwide have not considered sites upstream of sewage treatment plants. The Biała River and Czarna Hańcza River showed no statistically significant differences in their MP morphology (Fig. 9). The greatest differences were indicated between sites upstream and downstream of the WWTP—B4 and B5, and CH4 and CH5 (Figs. 12 & 13), where a twofold increase in fibre and pellet MP was recorded, similar to the work of (McCormick et al. 2016), where the increase in pellets behind the WWTP is explained as being derived from cosmetics and personal care products.

Our studies show that in both analysed rivers, MP in range of 0.04–0.5 mm, accounted for approximately 8% of MPs, and the vast majority of identified MP was between the size of 0.5 and 2 mm (Fig. 10), which accounted for approximately 85% of total MP collected from the analysed rivers. This is in line with studies available in the literature, e.g. the Yangtze (Zhao et al., 2014), the Saigon River (Lahens et al., 2018), or the Zhangjiang River (Pan et al., 2020). MP of this size can be consumed easily by aquatic fauna and ultimately pass through a trophic cascade or even accumulate in plants and thus enter the food chain (Kalcikova, 2020). The results of ongoing studies have shown the harmful effects of plastic particles on living organisms through increased mortality, decreased fertility, and histopathological changes (Fleituch, 2016). Microplastic is becoming an increasingly serious problem so, seeing the threat it poses to the aquatic environment and living organisms, its place in the aquatic environment should be investigated.

The most numerous group in terms of colour in the Biała River and the Czarna Hańcza River was marked as 'other', as the colour was either not uniform or difficult to categorise unambiguously—the MP of difficult to define colour was 44% and 46%, respectively. The second most abundant group was transparent MPs—35% in the Biała River and 37% in the Czarna Hańcza River (Fig. 11), i.e. similar to the Gallatin River, where the amount of transparent particles was determined to be 30%, indicating the possibility that this type of plastic was formed due to discolouration while in the water (Barrows et al., 2018). Blue is the dominant colour in most studies, as it is the colour of the majority of fibre MPs (Miller et al., 2017; Barrows et al., 2018; Yan et al., 2019). In our work also, fibres were mostly found in this colour.

Our study revealed that despite various factors examined and despite the obvious differences between the two cities, no significant differences were found between MPs in the two rivers studied; therefore, further research in this direction, extended with samples collected below and above the city, would be desirable.

7 Conclusions

1. Microplastic was commonly found in the water of both lowland rivers, despite their differences in land cover, and at all studied sites irrespective of their location in the city.

2. In both studied rivers, 5 forms (shapes) of MP were found, out of which film was the most common.
3. In both lowland rivers, MP particles of 1-2 mm in size predominated out of the six size groups.
4. In the case of both studied rivers, it was found that the main factors affecting the density of MP include the operation of the WWTP and the hydro-meteorological conditions.
5. Despite the differences in the two cities studied (population density, land use), there were no differences in levels of MP pollution.

Data Availability The authors declare that data supporting the findings of this study are available within the article.

Declarations

Conflict of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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