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Changes in the microplastic content depending on the changes in the river catchment development structure – preliminary studies

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ABSTRACT

The problem of microplastics (MP) is increasingly discussed in the context of surface water pollution. Preliminary studies were carried out for an unusual river basin. The researched catchment is characterized by the presence of areas under legal protection and high pressure related to tourist traffic. Three series of tests of microplastic content in the waters of the Upper Vistula were carried out on the section from the Wisła Czarne (above the dam reservoir) to the town of Ochaby. Six sampling points were selected. The research material (suspended solids) was collected using a plankton net with a diameter of 0.25 m and a mesh size of 250 µm, each time from 1 m^3 of river water. During the tests microplastics were found in all the taken samples. The least amount of microplastic was observed at sample points 1 and 2. An increase in the microplastic content in the waters of the Vistula was shown, especially in the cities of Wisła and Skoczów. The increase in microplastic content was also observed downstream of the wastewater treatment plant, although it should be noted that it was not as significant as in the case of rivers flowing through the central part of the Upper Silesian Agglomeration. Also noticeable is the decrease in the microplastic content in the samples collected in Ochaby (sampling point 6). This may be caused by both the dilution of the Vistula waters with streams flowing above this point, as well as the natural processes responsible for the removal of suspended solids from the river (sedimentation, retention of suspended particles on the vegetation growing on the river banks or in natural ponds and fragments of the riverbed with reverse current). The Vistula River may be contaminated with microplastics even from their entire length, regardless of whether they flow through legally protected areas, with residual anthropogenic development of the catchment area and the riverbed, or through tourist resorts.

Keywords: Microplastics; Surface water; Suspended solids; Vistula River; Anthropopression

1. Introduction

The issue of microplastics is increasingly discussed in the scientific literature, but most often it concerns the microplastic pollution of the seas and oceans. This is because such pollution is the most spectacular, covers very large areas, and is noticeable to ordinary citizens. However, it is important, that the main source of microplastics that occur

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in marine waters is microplastics supplied by fresh waters of rivers flowing into the seas and oceans [1–3]. Because most plastics are produced, consumed, and disposed of on land, the amount and extent of MP sources in river waters often show elevated MP concentrations compared to marine water [4]. It has been found that rivers carry huge amounts of microplastic particles [5,6], but some of these particles probably settle down with suspended matter. In this way, rivers become reservoirs of huge amounts of microplastics [7–10]. Soils also contain high concentrations of microplastics in some terrestrial areas and from there they can migrate to rivers and water reservoirs [11]. Aside from supplying seas and oceans, rivers are also complex ecosystems in which life processes occur. When considering the transport and storage of MP in river waters, the physical properties of MP (e.g., density, shape, and size of plastic particles) play a key role [12] and the morphological characteristics of the river [13]. Rivers are highly complex and dynamic systems that can collect, store and move microplastic particles across a variety of spatial and temporal scales [14]. For this reason, research on microplastics in river waters requires well-developed methodologies and is very difficult to conduct. Among other things, for this reason, there are still few scientific reports on the various sources and transport of microplastics in freshwater and soil. Therefore, it seems advisable to perform preliminary research in this area, in which an attempt is made to demonstrate the relationship between the content of microplastics in river waters and how the river basin is managed. Determining these relationships may help understand the potential threat to human and animal health related to the presence of MP in river waters.

The research area is an example of an unusual catchment, as it includes both the source river areas under legal protection as a nature reserve, as well as catchment areas that have been transformed by anthropogenic activities and are subject to strong pressure from tourism. This catchment is completely unrecognized in the field of MP pollution.

2. Materials and methods

2.1. Study area

The study area lies within the catchment area of the Little Vistula, which covers about 1,820 km^2. In terms of nature, the most attractive area of Little Vistula's catchment area is the Silesian Beskids. Due to the presence of natural areas or areas slightly transformed by man, a landscape park of the Silesian Beskids, numerous reserves, and protected landscape areas have been created in the catchment area of the Little Vistula. In the catchment's geological structure, the Alpine orogeny's structural forms are visible. The northern part of the catchment is located on the Silesian-Cracow monocline, the central part is part of the Carpathian Foredeep, and the southern part is a fragment of the eastern part of the Outer Carpathians. Hydrogeological conditions are determined by the complex geological structure, the length of the Little Vistula is 106 km. The section covered by the research is approx. 35 km long [15].

2.2. Sampling points

Sampling point No. 1 was located above the Wisła-Czarne dam reservoir. The anthropogenic impact on the Vistula above this site is small. The river carries water from the Barania Góra massif. No industrial activity has been located there, there is a nature reserve. Nevertheless, due to the attractiveness of the surrounding areas, hundreds of thousands of tourists visit the catchment area every year.

Sampling point no. 2 was located below the Wisła-Czarne reservoir, several hundred meters below the dam crest. Apart from the water flowing out of the reservoir (which acts as a settling tank), no inflows from other sources have been found.

Sampling point no. 3 is already a river several dozen meters wide, characterized by Si variable depth, variable water flow velocities in the cross-section of the channel, and the presence of small stone islands. It is located in the town of Wisła at the intersection of provincial roads DW 941 and DW 942.

Sampling point no. 4 is located on the border of Wisła and Ustroń. A characteristic object in this site's catchment area is the municipal sewage treatment plant.

Sampling point no. 5 was located in Skoczów below the bridge along the provincial road DW 944. In its catchment there is a sewage treatment plant for the city of Ustroń and, among others, breeding ponds.

Sampling point no. 6 is located by the road bridge in Ochaby.

The localization of sampling points in Europe is presented in Fig. 1. and a section from a detailed map of the study area is in Fig. 2.

2.3. Methodology of sampling and samples preparation

Three series of tests of the content of microplastics in the waters of the Upper Vistula were carried out on the section from Wisła Czarne (above the dam reservoir) to the town of Ochaby. The samples were collected in the spring-summer season (series 1: 23rd April; series 2: 6th May; and series 3: 24th June). During series 1 and 3 it was sunny, while during series 2 there were occasional showers and light rain. Six sampling points were selected as described above (Fig. 2). The research material (suspension) was collected using a plankton net with a diameter of 0.25 m and a mesh size of 250 μm, each time from 1 m^3 of river water. For this purpose, the instantaneous water flow velocity at the sampling site was determined using a Hega-2 water current meter. The suspended matter was collected to a depth of 12–13 cm below the water surface. Sample volumes ranged from 100 to 200 cm^3. The samples collected in this way were transferred to glass vessels. Microplastic particles were then isolated from the samples in the laboratory. A large part of the collected suspended matter consisted of mineral components (sand), which were separated already at the initial stage of sample preparation in the sedimentation process. Large fragments of plants and animal origin (e.g., grass blades, leaves, chitin shells of aquatic crustaceans) were removed manually using tweezers. The rest of the suspended matter was oxidized. The next step of MP isolation was the oxidation of natural organic matter using Fenton's reaction and heating to 85°C–90°C to accelerate the decomposition of natural organic substances in samples. Next, each sample was evaporated to a volume of about 20 cm^3. The sedimentation process allowed for the separation of the sand and other mineral components that occurred in samples. Microplastic particles, after filtering the sample through a membrane filter and pore diameter of 0.45 μm, were counted using a Delta Optical SZ-630 optical microscope.

2.4. Statistical analysis

The data for each sampling point was expressed as a mean with standard deviation (SD) and relative standard deviation (RSD). The statistical parameters were calculated by using Microsoft Excel Spreadsheet Software.

3. Results and discussion

During the tests, microplastics were found in all samples taken. The smallest amount of microplastics were observed at sampling points 1 and 2. An increase in the content of microplastics in the waters of the Vistula was shown, especially in the cities of Wisła and Skoczów (Figs. 3 and 4). An increase in the content of microplastics was also observed downstream of the sewage treatment plant. The decrease in the content of microplastics in the samples collected in Ochaby seems surprising. This may be influenced by both the phenomena of dilution of the Vistula waters with streams flowing in above this point, as well as natural processes responsible for the removal of suspended matter from the river (sedimentation, retention of suspension particles on the vegetation growing on the banks of the river or in natural pools and fragments of the bed with a reverse current). Microplastics isolated from the waters of the Vistula were most often in the form of blue/black and red fibers (Fig. 5.)

The colors and proportions found in the river are not similar to previous studies of Taiwan rivers, where transparent particles of microplastics were dominated (up to 52% and 65%) [17,18]. In the case of our studies, transparent particles were significantly lower (17% to 35% of the total amount of microplastic particles (Fig. 6)).

Blue and black microplastic particles had a significantly higher share (41%–83%). According to the literature [19], this may indicate that the microplastic particles are in the water for a short time and are not yet discolored by UV radiation. It was observed that the average proportion of the darkest microplastic particles decreases along the course of the river.

During each series of tests, microplastic particles were determined in the collected samples of the suspension at each measuring station. During three series of tests, from 2 to 17 microplastic particles were determined in 1 m^3 of water. These smallest amounts are typical for waters subjected to relatively low anthropopressure. This corresponds to the results of research from other European countries [5,20–26]. Equally important is the fact that these pollutants of anthropogenic origin are present practically along the entire length of the examined section of the Vistula. It is not surprising that

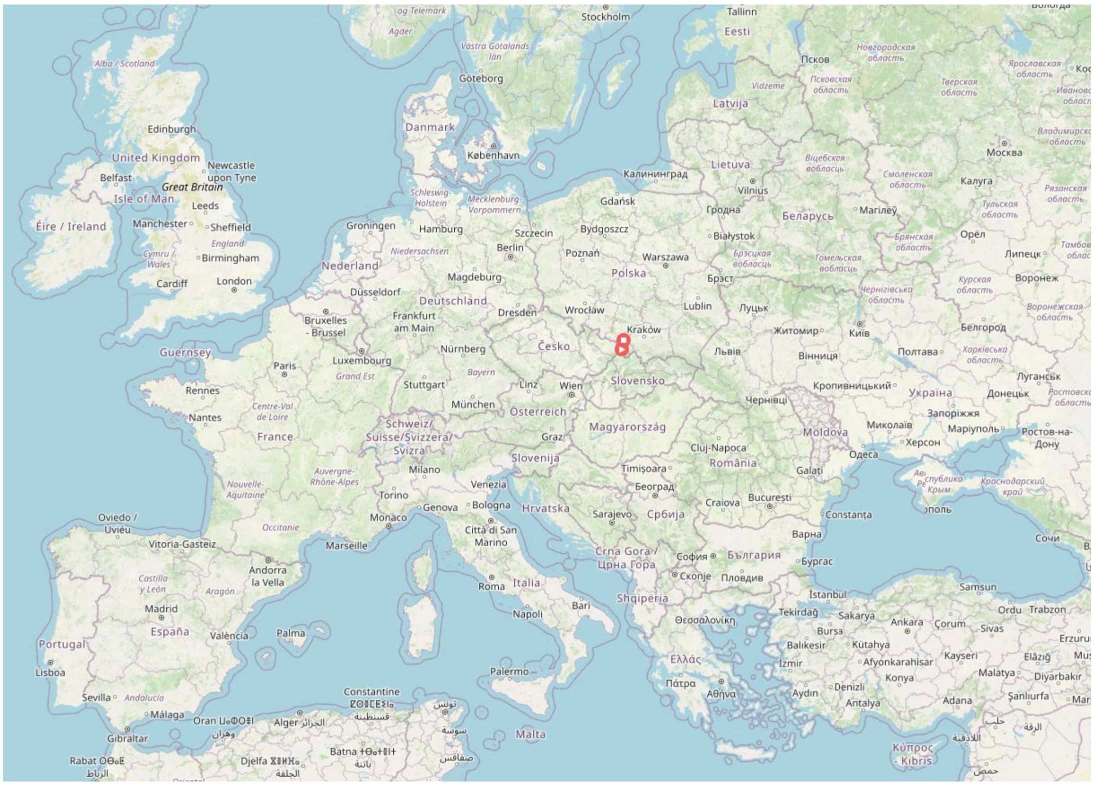

Fig. 1. Localization of study area on Europe's map [www.traseo.pl].

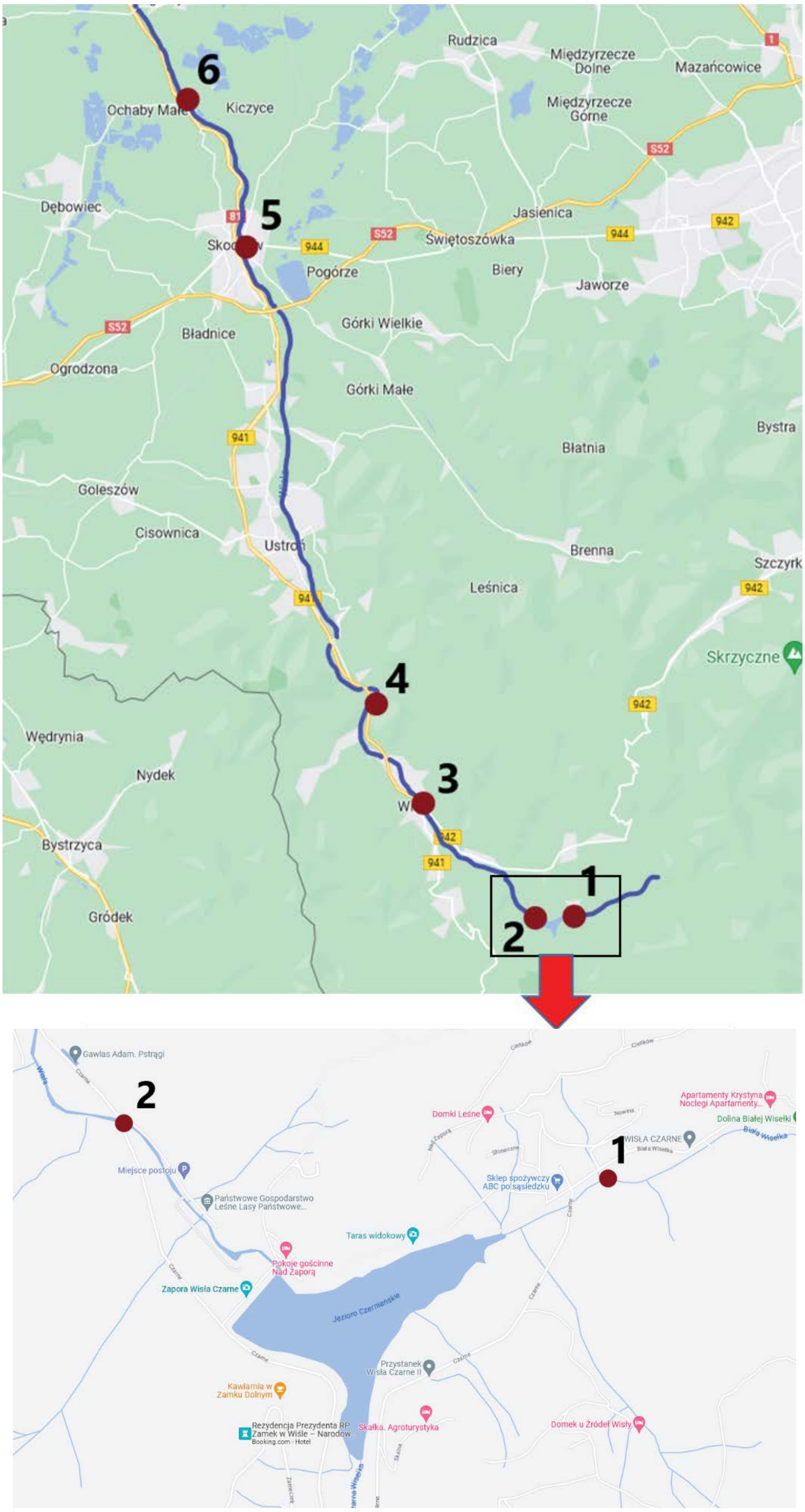

Fig. 2. Localization of sampling points [16].

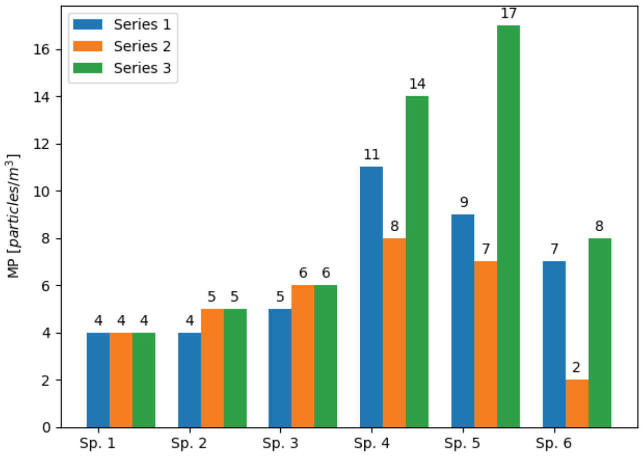

Fig. 3. Content of MP (particles/m^3) in sampling points 1–6.

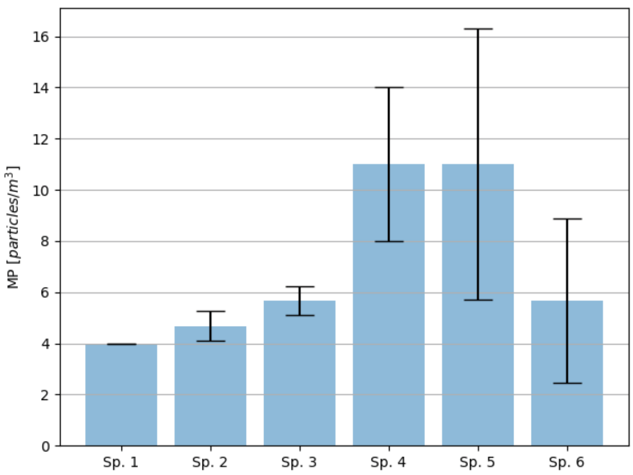

Fig. 4. Average content of MP in sampling points 1–6.

in samples collected in tourist destinations, where anthropopressure is much stronger than in the vicinity of the Barania Góra nature reserve, the content of microplastics in river water increases. Comparing the upper section of the Vistula (except for sampling points 1–3), it can be seen that similar amounts of microplastic particles were observed in Polish rivers, for example, in Kłodnica or Bytomka [5]. In these two rivers, a significant increase in the content of microplastics was demonstrated downstream of the inflows of treated wastewater from the areas of municipal wastewater treatment plants. The situation was similar in Wisła (Sampling point 4). However, it is noteworthy that at site 6, located several kilometers below the sewage treatment plant, a smaller amount of microplastic particles was observed, despite the constant presence of factors related to anthropopressure (cities, including the largest in the studied catchment, that is, Skoczów, agricultural areas, pressure related to tourist traffic, etc.). At the moment, we can only speculate what could have influenced this state of affairs. One of the possibilities is the deposition of microplastics within the riverbed and in the areas directly adjacent to it. The Vistula is a river heavily devastated by cascade development. Taking into account

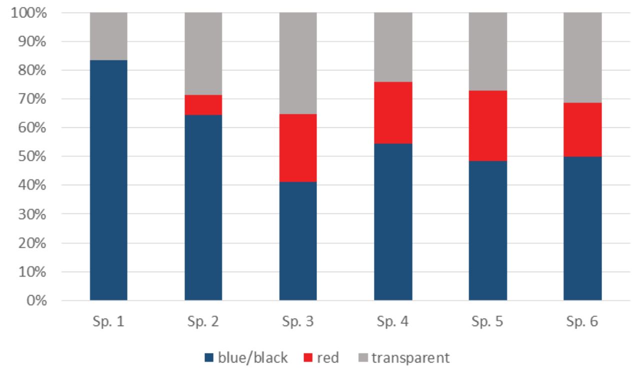

Fig. 5. Average percentage of different colors of microplastics in samples taken from sample points 1–6.

the fact that for decades it has been functioning as several dozen separate reservoirs without the possibility of migration of water organisms upstream, there are areas before each water threshold where the flow of water is often imperceptible. These observations are confirmed by other authors who note that all kinds of water structures, both artificial, for example, dams, weirs, bridges, and natural structures (e.g., water vegetation, reverse currents, natural slowdowns of the current) can create conditions conducive to the deposition of microplastics [27–32]. This creates favorable conditions for the development of aquatic vegetation and enables the deposition of undissolved pollutants in bottom sediments. This can also occur in the case of microplastic particles, and the mechanism responsible for this may be the so-called biofouling [33–35]. Microplastics are very often particles lighter or similar in specific gravity to water, but as a result of colonization of the surface by algae, blue-green algae, diatoms, and other microorganisms, they become heavier than water and, under appropriate conditions, can sediment, which is also confirmed by other studies [36]. Another phenomenon observed below water thresholds is the formation of reverse current phenomena. This can be explained by observing, for example, a plastic bottle or a piece of styrofoam floating on the surface of the water below the water threshold, which circulates within the so-called pool and for many hours, and sometimes even days, does not flow down. According to the authors, similar phenomena may also apply to the lightest microplastic fractions. Similar conclusions were drawn by Xiong et al. [37] referring to the Three Gorges Reservoir in China. A comparison of the microplastic content upstream and downstream of the discharge of treated sewage indicates that the treatment plant contributes to the increase in the content of these pollutants in the river. Compared with similar studies carried out in the Upper Silesian Agglomeration [5,6], it can be seen that the increase in the content of microplastics is at a similar or even lower level in Wisła. This is related to the completely different nature of the area from which wastewater is discharged to the treatment plant, because in the area of the Agglomeration, industrial wastewater also flows to municipal treatment plants, while there is no significant industrial activity in the area covered by this study.

The statistical tests were carried out for the quantitative determination of microplastics contained in samples taken

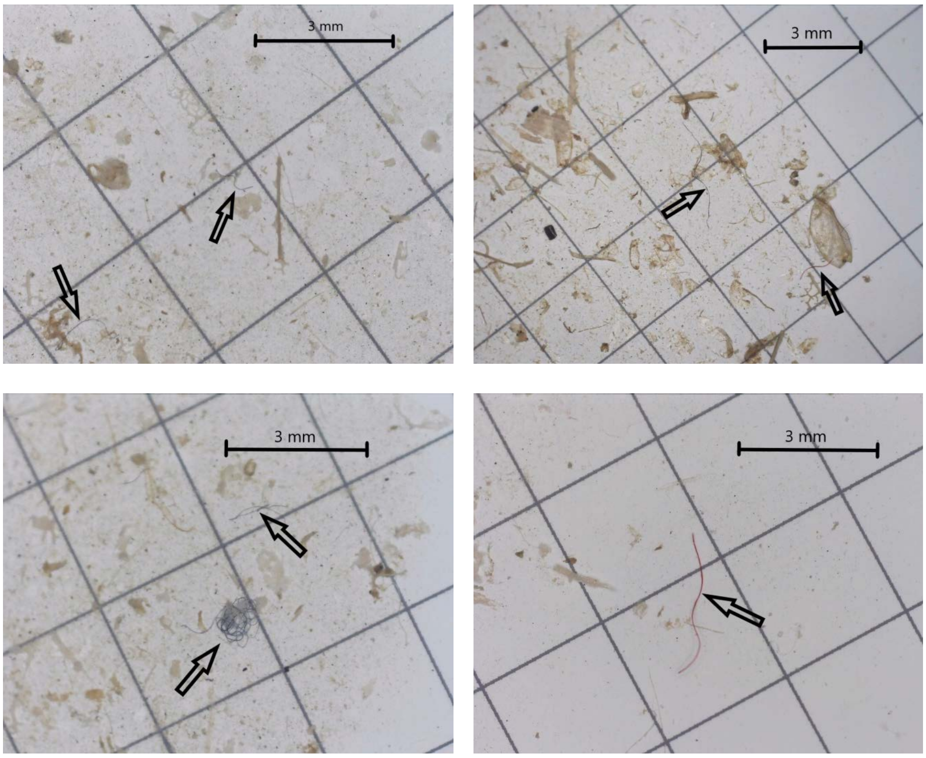

Fig. 6. MP particles found in samples from the Vistula River.

Table 1
Microplastic in samples taken from sample points 1–6

Sampling point	Average	SD	RSD
Sp. 1	4.00	0.00	0.0
Sp. 2	4.67	0.58	12.4
Sp. 3	5.67	0.58	10.2
Sp. 4	11.00	3.00	27.3
Sp. 5	11.00	5.29	48.1
Sp. 6	5.67	3.21	56.7

from sample points 1–6. Table 1 summarizes the average concentrations of microplastics with SD and RSD values.

At the first three sampling points, no or low variability of microplastic content in water was observed (Table 1). The further away from the sources, this variability, known as the coefficient of variation (RSD), has been increasing. This may indicate a time-varying load of the river with microplastic particles introduced into it (through treated wastewater or surface runoff).

Both SD and RSD for different colors of isolated microplastic particles do not show any regularity (Table 2). Especially in the upper section of the researched river, these statistical parameters changed within very wide limits. This may indicate a certain randomness and unevenness in the stream of pollutants containing microplastic particles discharged into the river. Such randomness may indicate that the amount of MP particles at the level of several/m^3 is a background, even for a section of the river that is not subjected to strong anthropopressure.

Table 2
Statistical parameters (SD, RSD) for colors of MP particles

Sampling point	Blue/black MP particles		Red MP particles		Transparent MP particles	
	SD	RSD	SD	RSD	SD	RSD
Sp. 1	0.6	17.3	0.0	–	0.6	86.6
Sp. 2	0.0	0.0	0.6	173.2	0.6	43.3
Sp. 3	0.6	24.7	0.6	43.3	1.0	50.0
Sp. 4	1.7	28.9	1.5	65.5	0.6	21.7
Sp. 5	3.5	65.8	1.2	43.3	1.0	33.3
Sp. 6	1.5	57.3	1.0	100.0	1.2	69.3

4. Conclusion

- The Vistula River polluted with microplastics practically along their entire length, regardless of whether flows through areas subject to legal protection, with residual anthropogenic development of the catchment and riverbed, or through tourist destinations.
- The number of microplastics increased further away from the source of the river. Higher content of microplastics was observed in samples collected within, especially below the sewage treatment plant.
- The conditions in the river and near the river-bed can play an important role in the removal of microplastics from the water and its deposition on the river bank or, under appropriate hydraulic conditions, also in the river bed. However, this requires further research.

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