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Microplastics in surface water under strong anthropopression

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ABSTRACT

The occurrence of microplastics in the aquatic environment is discussed in the scientific literature mainly in the aspect of "large garbage spots" formed especially in the oceans. It is estimated that about 80% of plastics found in seas and oceans are introduced there via rivers. It seems to be very important the recognition of microplastics problems occurring in rivers and the substantive preparation for taking up the challenges posed by EU legal acts. The research was aimed at identifying the problem of microplastics contamination of surface water subjected to strong anthropogenic influence. The research objects presented in the article are rivers flowing through urbanized areas. They are characterized by a high degree of transformation of the catchment and riverbed. Samples were taken from the Bytomka River, the Kłodnica River and the Bielszowicki Stream. In case of the Bytomka River and the Kłodnica River samples were collected upstream and downstream waste water treatment plants (WWTPs). Whereas samples from the Bielszowicki Stream were collected downstream the coal mine. The research showed that typical components of the microplastics in these samples were foil film fragments observed in all sampling points. There were also textile fibers, granules and particles of irregular shape, which are difficult to identify. It has been observed that the amount of microplastics particles is significantly higher in sampling points located under WWTPs. The research shows the need to identify sources of microplastics in surface water and to determine the degree of their harmfulness to aquatic ecosystems.

Keywords: Microplastics; Surface water; Anthropopressure; WWTP

1. Introduction

The annual production of plastic has increased significantly from 1.5 million tons in the 1950s to 322 million tons in 2015 [1]. Plastics demand in Europe in 2016 was estimated at approximately 50.5 million tons, which means an increase of 3.2 million tons compared with 2015. In 2016 Polish plastics processing industry consumed approximately 3.3 million tones of this material, showing an increase by approximately 6.9% in comparison with 2015. Poland is an important plastic consumer in Europe (is ranged sixth, at the sixth position followed Germany, Italy, France, Spain and Great Britain) [1].

Plastics are semi-synthetic or synthetic organic polymers that are relatively cheap, lightweight, durable, strong and corrosion resistant [2,3] and for these reasons, plastics are willingly and commonly used in every branch of industry. The most commonly used polymers are high-density polyethylene, low-density polyethylene, polyvinyl chloride, polystyrene, polypropylene (PP) and polyethylene terephthalate, which together account for approximately 90% of the total worldwide plastic production [4]. These polymer wastes are also the most

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commonly found plastics in the environment and are dangerous to the natural aquatic ecosystem because organisms can ingest the plastic or can entangle in plastic wastes [5,6].

Microplastics (MPs) are usually defined as plastic particles which are smaller than 5 mm. MPs intentionally manufactured in small sizes, such as microbeads in personal care products, virgin resin pellets, industrial scrubbers used in abrasive cleaning agents and plastic powder used for moulding, are called primary microplastics [7]. Very often MP particles are generated as the effect of larger plastic particles fragmentation. These are called secondary microplastics [8]. The fragmentation can be caused by the use of materials (e.g., textiles, tires, paints). All kinds of plastics are found in environmental samples [9]. Plastic particles have the potential to adsorb persistent organic pollutants as well as trace metals from the water environment [10,11].

Millions tones of plastics enter seas, oceans and landfills each year. All oceans have been polluted by plastic particles [12]. The presence and consequences of microplastics pollution in the marine environment were known and first described in 1972 [13]. MPs are also present in rivers; it especially concerns rivers, which flow through highly urbanized and anthropogenically transformed areas. Wastewater treatment plants (WWTPs) have been identified as an important source of microplastics in surface water, for example, in the studies by McCormick et al. [14], it was stated that mean concentration of MPs downstream of WWTPs could be 100%–300% higher than upstream one. The literature data indicate that conventional wastewater treatment including primary (e.g., sieving, sedimentation, flotation) and secondary treatment (e.g., activated sludge) is efficient in microplastics removal. However after conventional treatment of wastewater, still about 1%–10% of effluent load of microplastics are discharged to the receivers. During wastewater treatment microplastic particles are removed mainly during mechanical treatment (90% of the influent load) [15], biological processes are less important in the case of these micropollutants removal. High efficiency of the microplastics removal from wastewater is connected with the fact that they mingle with cellulose fibers from toilet papers or plant residues. Effectiveness of microplastics removal during mechanical treatment depends also on the density and diameter of particles. It was stated that microplastics particles of >20 μm are effectively removed from wastewater. The larger ones, with diameters of >100 μm, can be also effectively removed by microscreens [16].

As it was indicated by Magnusson and Wahlberg [17], effluents collected from conventional wastewater treatment plants still contain about 1% of microplastics with diameter >300 μm, and even 10%–30% of the articles with diameters in the range of 20–300 μm. Based on this, it can be stated that the results presented by various authors are affected not only by the treatment technology but also by the fractions of microplastics which were analyzed.

The effectiveness of microplastics removal from wastewater can be achieved by using tertiary treatment of wastewater, for example, using rapid filtration over 97% of effluent microplastics can be removed [18]. Rapid filtration is, however, not so effective in the case of the particles smaller than 300 μm. Particles of 1 μm and smaller are practically not removed from wastewater during rapid filtration [14]. Effective process in the case of microplastic removal is membrane filtration. Use of MBRs (membrane biological reactors allows for practically 100% removal of microplastics present in influent) [18].

Concentrations of microplastics in freshwater reported by various researchers are in the range of 30 to more than 100 items/m^3 [19], but the problem of microplastics abundance known is not recognized well [20].

As it was mentioned above, the problem of the accumulation of microplastics particles has been observed and widely described primarily in relation to the seas and oceans. In Poland, no studies have been conducted to understand the issue of the occurrence of microplastics molecules in the aquatic environment. The aim of the present research was to recognize the problem of the occurrence of microplastics in rivers, whose basin areas are under strong anthropogenic stress.

2. Materials and methods

2.1. Study area

The Upper Silesian agglomeration in Poland belongs to one of the most transformed regions not only in the country but also in Europe. Fig. 1 shows the localization of Poland on the map of Europe.

The heavy industry (specific coal mining) has had a significant impact on environmental degradation in the region for several decades. Almost the entire area of the western part of the Upper Silesian agglomeration lies within the upper and middle basin of the Kłodnica River. The Kłodnica River drainage basin (especially its upper part) is one of the most transformed areas of human activity in Poland. The Kłodnica River with its tributaries (in particular right bank, i.e., the Bielszowicki Stream, the Czarniawka River and the Bytomka River) flows through densely populated and heavily industrialized areas, so water is heavily polluted with municipal and industrial sewage [21].

The Kłodnica River is a right-bank tributary of the Odra River. The total length of the river is over 80 km, and the total catchment area is over 1,120 km^2 [22]. Through the area of the Upper Silesian agglomeration, the Kłodnica River flows on a section of about 40 km (this section has been covered by research). The sources of the Kłodnica River are located in Katowice, and the tributary to the Odra River is located in the city of Kędzierzyn-Koźle. From the sources to Zabrze Makoszowy, the river flows from east to west. In this section, the riverbed is regulated and artificially fortified. Only on a few kilometer length, between Katowice and Ruda Śląska, the riverbed fortifications have mainly been destroyed and the river flows meandering between wetlands and forest [23,24]. Large cities such as Katowice, Mikołów, Ruda Śląska, Świętochłowice, Bytom, Gliwice and Zabrze are located in the upper part of the river's catchment. These cities have WWTPs, from which treated wastewater is discharged directly to the Kłodnica or its tributaries. On this section, the Kłodnica River also has its most significant tributaries: the left-bank Jamna and the right-bank tributaries: the Bielszowicki Stream (included in the present study), the Czarniawka River and the Bytomka River (also included in the research). The Kłodnica River basin area belongs to densely populated areas. The number of residents is estimated at over 900,000 and the average population density is over 1,000 inhabitants/km^2.

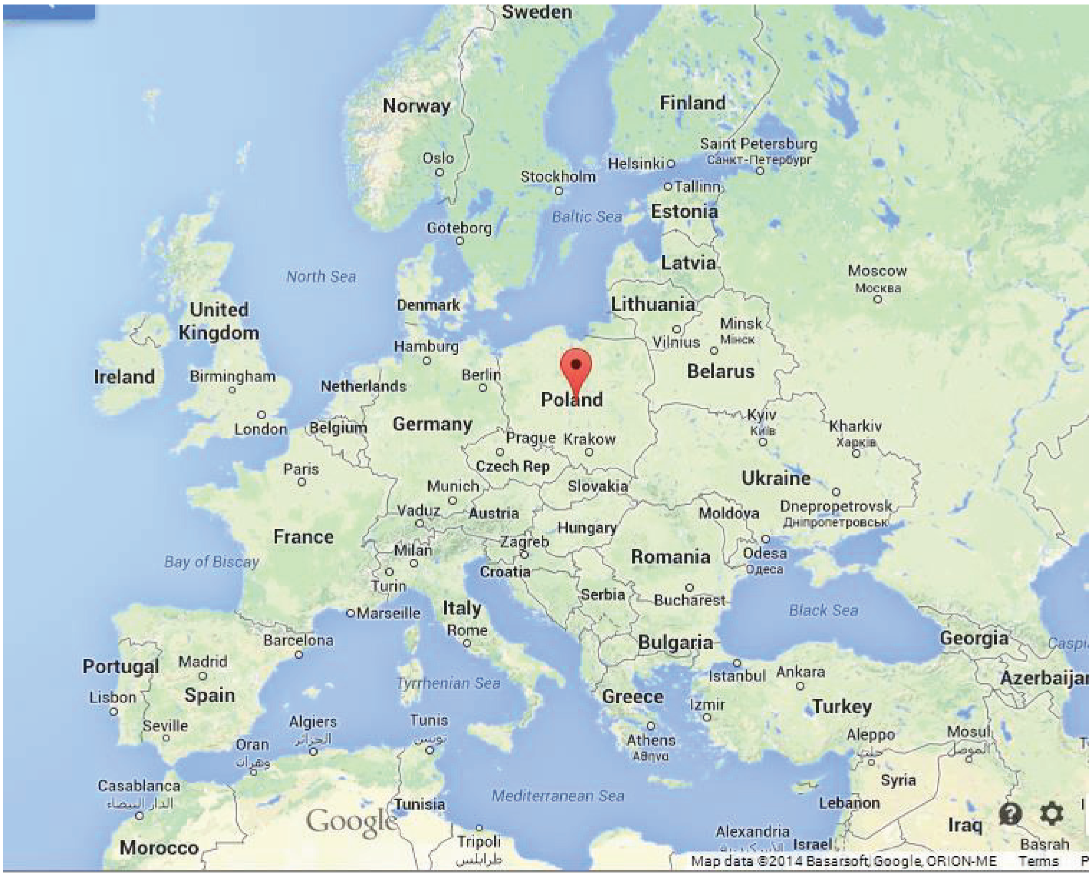

Fig. 1. Localization of Poland on the map of Europe (www.googlemaps.com).

The Bielszowicki Stream also known as the Kochłówka, is the right-bank tributary of the Kłodnica River, with a catchment area of 32 km^2 and the total length of 13.6 km. The Bielszowicki Stream flows into Kłodnica at its 58.4 km. A measuring point was located in the lower reaches of the river near the border of the cities Ruda Śląska and Zabrze. The location of this point is marked on Fig. 1 [21].

The Bytomka River is one of the most contaminated rivers in Poland. All the watercourse leads across the central part of Upper Silesian conurbation. The length of the river from the source to the estuary to the Kłodnica is about 22 km. The river basin area is 147.8 km^2 [25]. Its watercourse does not have natural sources. It begins at the Karbowski Ditch (Rów Karbowski), which drains municipal and industrial wastewater. Then it flows through the cities: Ruda Śląska, Zabrze and Gliwice, where it finally flows into the Kłodnica. The whole river course is situated in a highly urbanized area [21]. The Bytomka is supplied chiefly with mine wastewater, industrial wastewater discharges, municipal wastewater and rainwater [25]. The content of trace metals in bottom sediments is higher than that in the sediments of those Polish rivers that are not subjected to the intense anthropogenic impact on the environment.

2.2. Sampling

Samples were taken from the Bytomka River, the Kłodnica River and the Bielszowicki Stream. In case of the Bytomka River (points B1, B2), samples were collected upstream and downstream of WWTP "Zabrze" located in Zabrze. Samples from the Kłodnica River (points K1, K2) were taken in Ruda Śląska, above the WWTP "Halemba" and on the border of Zabrze and Gliwice (downstream the WWTP "Halemba"). Samples from the Bielszowicki Stream were collected from one sample point (PB1) in Ruda Śląska. Despite the fact that any WWTP is located in the Bialszowicki Stream basin area, it has been selected as a measuring point due to the high anthropopressure caused by coal mine wastewater.

Localization of all sample points is presented in Fig. 2.

Samples were collected in the specified points with circular polyamide plankton net (0.26 m diameter with 250 µm mesh size). Samples were taken in three series from September to November 2017. Authors took samples during the medium flow of each river. The net was fixed perpendicular to flow of the river surface, with half of net opening submerged to collect floating particles. During the sampling, water velocity was measured using hydrometric grinder Hega-2, and 10 m^3 of water flowed through the net. The determined water flow rate was used to calculate the flow time of 10 m^3 of water through the plankton net (except for the Bielszowicki Stream – samples were taken from 2 m^3 of water).

2.3. Analysis

Due to the lack of quality assurance procedures and standardized method to sample and isolate microplastics from water, the procedures were based on the literature [5,14].

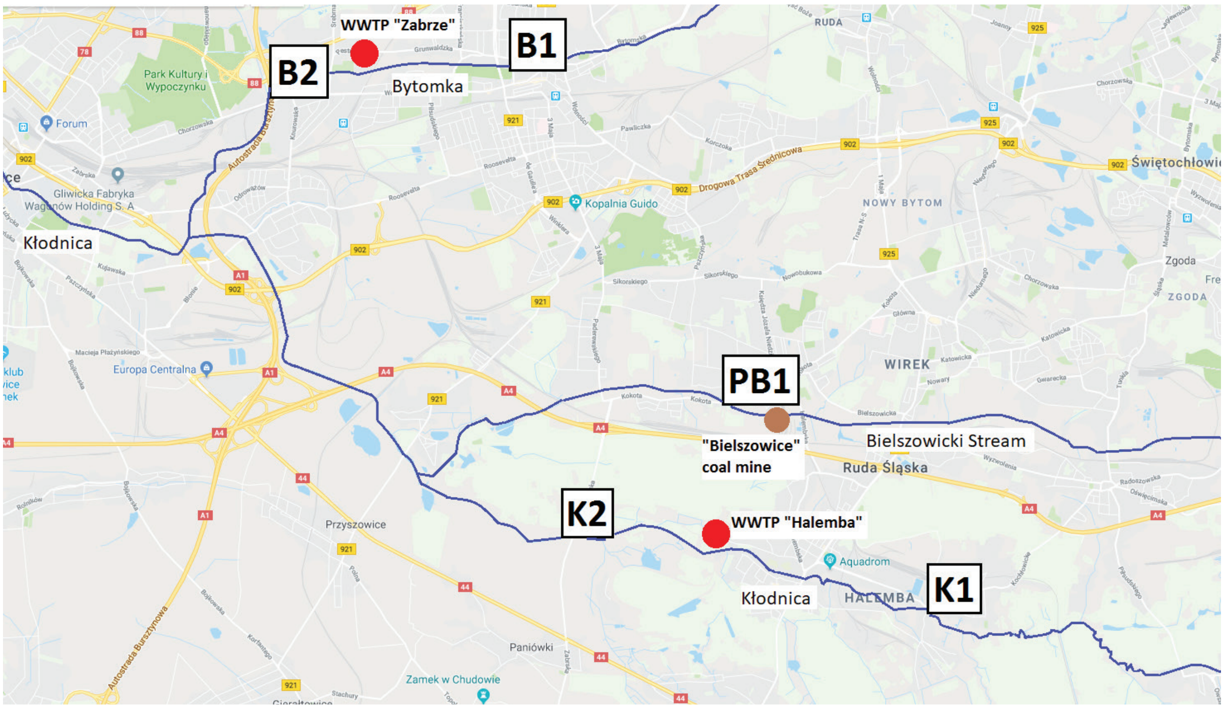

Fig. 2. Localization of sample points (www.googlemaps.com).

To isolate microplastics particles, the sample of suspended solids was taken to a laboratory jar fulfilled with distilled water. The most important part of the sample preparation was the removal of natural organic matter which was present in the suspended matter probe. It was done by Fenton's reaction (25 mL H_2O_2, 30% and 1 g of $FeSO_4 \cdot 7H_2O$). The probe was heated to accelerate and support the decomposition of natural organic substances contained in the suspended solids which were taken from the river. Each sample was evaporated to a volume of 20 cm^3. Despite the applied treatments, significant quantities of autochthonous suspended matter remained in the sample. It was mainly plant material, sand and other mineral components of the suspended matter. The sedimentation process separated the sand and other mineral components. There were still not degraded plant parts after the gravitational separation in the samples. Therefore the plant origin material was clearly distinguishable from the microplastics particles and was not counted during the microscopic observation. The same sample volumes (1 mL) were then taken by automatic pipette and fed into the Sedgewick Rafter's Chamber. Recovered particles were visualized under Delta Optical SZH-650 B/T microscope and the exact number of particles in the precise volume of 1 mL of the sample. For the size 500 μm, plastics were counted directly.

3. Results

Fig. 3 shows the number of microplastics particles above the WWTP (point B1). It can be seen that the most frequently appearing particles are fragments of the foil, on average about 15 particles in 1 m^3 of water. Clearly more fragments of the foil were observed in samples taken below the WWTP – point B2 (Fig. 4) – on average about 22 particles in 1 m^3 of water.

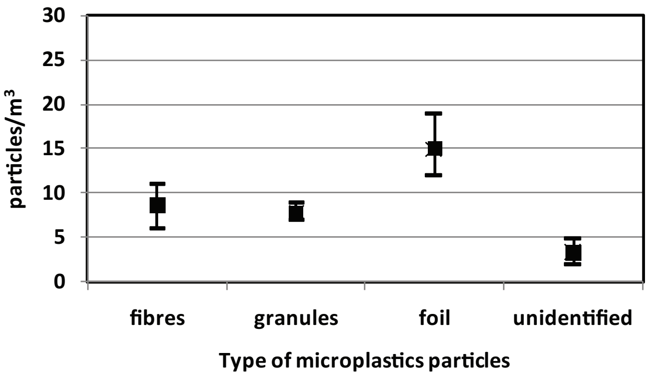

Fig. 3. Microplastics particles in the Bytomka River upstream WWTP (point B1).

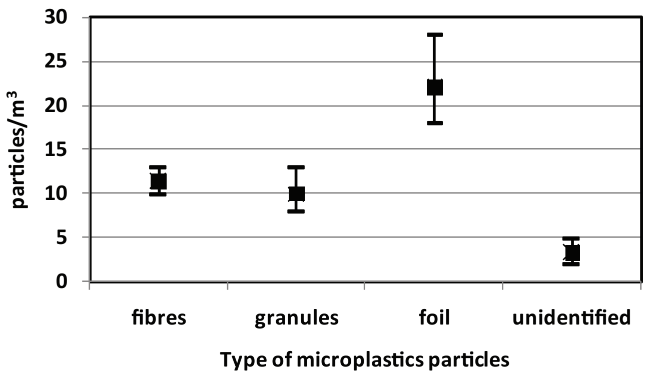

Fig. 4. Microplastics particles in the Bytomka River downstream WWTP (point B2).

It is also noteworthy that in the Bytomka River below the wastewater discharge from the WWTP, fragments of foil (foil packaging) are generally smaller (Fig. 5), which may indicate the possibility of shredding larger particles during the technological process of wastewater treatment. Both sites observed similar amounts of fibers and granules. There were also particles of an unidentified structure.

The wastewater is discharged from several WWTPs (directly and via the tributaries) to the Kłodnica River. Above point K1, wastewater is discharged from the WWTP in Katowice-Ligota and the area of Mikołów (via the Jamna stream). Therefore, it should be assumed that the amount of microplastics particles should be large. However, in this case, it should be noted that above the WWTP in the city of Ruda Śląska (above point K1), the river flows for several kilometers through a riverbed which was not regulated since several years. Lack of interest in introducing anthropogenic changes in the course of the river influenced positive changes in its course – the speed of water flow was slowed down, meanders were formed and the banks were overgrown with ascending vegetation. As a consequence, it could affect the retention of certain amounts of microplastics particles on the tissues of vegetation and forced by water flow (e.g., the formation of backward currents within the meanders of the river). On Fig. 6, it can be observed a noticeably smaller number of foil fragments (on average about 11 in 1 m^3 of water), compared with about 19 in 1 m^3 of water below the WWTP "Halemba" in Ruda Śląska – point K2 (Fig. 7). At a very similar level, the number of synthetic fibers and granules and particles that could not be recognized to any of the above categories was observed in both sampling points.

The Bielszowicki Stream is the shortest river with the smallest catchment and the lowest flows. However, it carries heavily polluted water. The difficulty in collecting the research material resulted from the nature of the slurry – it was a material of anthropogenic origin, that is, coal sludge coming from a coal mine. This type of suspended material quickly prevented the taking of a reliable sample, because it clogs the pores in the planktonic net. Because of that samples were taken from 2 m^3 of water. In contrast to the other rivers, the main component of the microplastics was granules (Fig. 8). It may be caused by discharges of sewage from the bath located in the coal mine into the Bielszowicki Stream (microgranules are the ingredients of most cosmetics products). It should be noted that samples were collected around midday when many people did not use the bath. On the other hand, this creates the possibility of a significant increase in the amount of these microplastics components in the periods in which wastewater coming from bathing in the bath gets to the river.

The results of this research posed several questions about the source of microplastics particles in surface water under strong anthropopressure. During the research, the microplastics particles were divided into four shape categories:

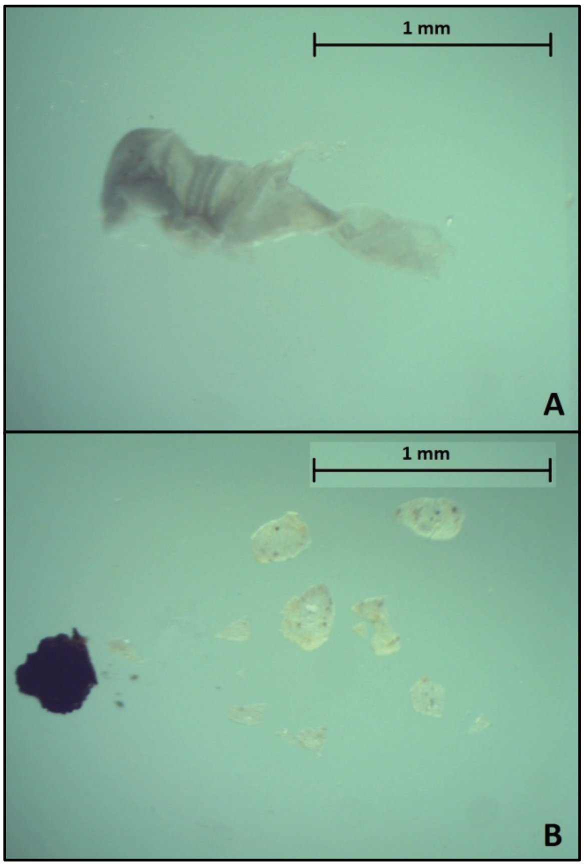

Fig. 5. Foil fragments from the Bytomka River upstream (A) and downstream (B) WWTP "Zabrze".

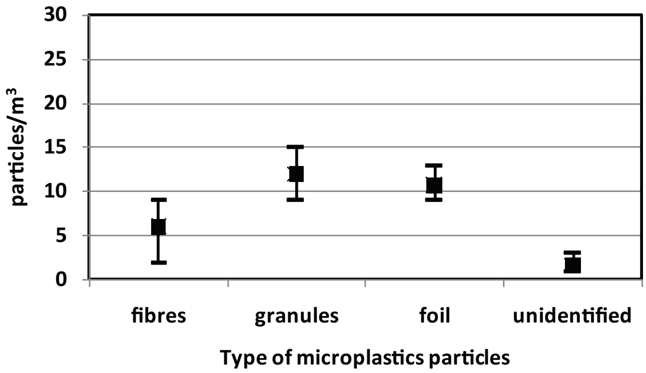

Fig. 6. Microplastics particles in the Kłodnica River upstream WWTP (point K1).

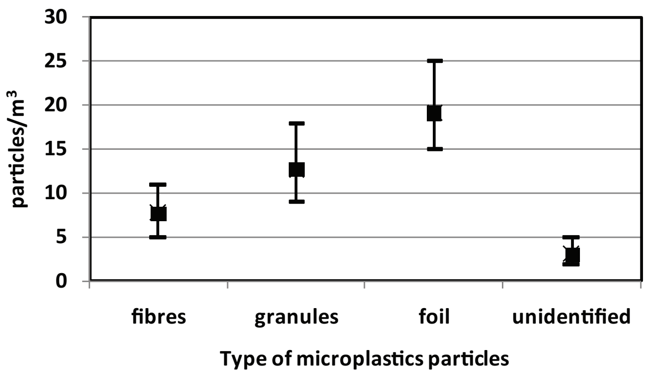

Fig. 7. Microplastics particles in the Kłodnica River downstream WWTP (point K2).

microgranules, artificial fibers, foil fragments and unidentified ones. Multi-colored spherical particles in the size class <1 mm may be linked to consumer products. Some personal care products (e.g., facial cleansers) contain spherical microgranules labeled on the product as polyethylene (0.91–0.96 g/cm^3) or PP (0.91 g/cm^3), which would float in freshwater systems (Fig. 9).

Artificial fibers are usually polyester ones and probably derived from fabric washing wastewater (Fig. 10). Artificial fibers were observed upstream and downstream WWTP. As it is shown on more fibers were noticed below the WWTP (Figs. 3 and 6).

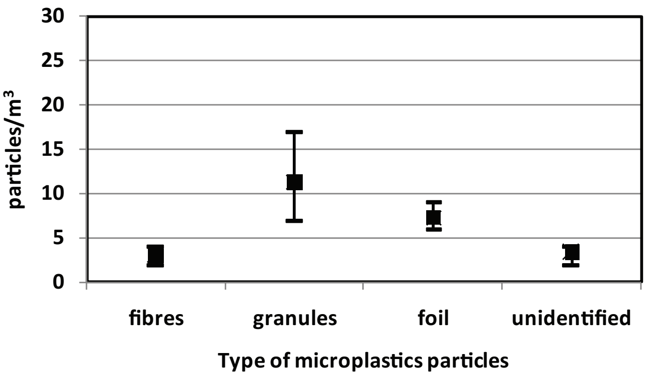

Fig. 8. Microplastics particles in the Bielszowicki Stream (point PB1).

The most common type of microplastics in surface water of the researched rivers was foil film fragments (Fig. 11). Upstream the WWTP, generally fragments of foil with dimensions distinctly larger than below the treatment plant were observed (Fig. 4). Moreover, in the river upstream the WWTP, as in case of all microplastics particles, fragments of the foil film were significantly less. It may indicate that during the process of wastewater treatment, fragmentation of larger pieces of these microplastics particles occurs and that not all are stopped during the mechanical cleaning process.

There is a possibility that microgranules, used by the consumer, flow to the WWTP but not all floating, non-biodegradable particulate smaller than 0.5 mm could be captured during the wastewater treatment.

4. Discussion

According to the authors' knowledge, this type of research has not yet been conducted in Poland. Therefore, it is not yet possible to compare the results of microplastics particles abundance in various rivers. However, when comparing with works carried out in Western Europe and the United States [26,27], one can pay attention primarily to the way of expressing the content of microplastics in water. In general, the authors accept two methods: the number of molecules per km^2 of the surface of the water table and, assumed in this work, the number of particles per m^3 of water. Both methods do not fully reflect the "concentration" of microplastics, because plastic

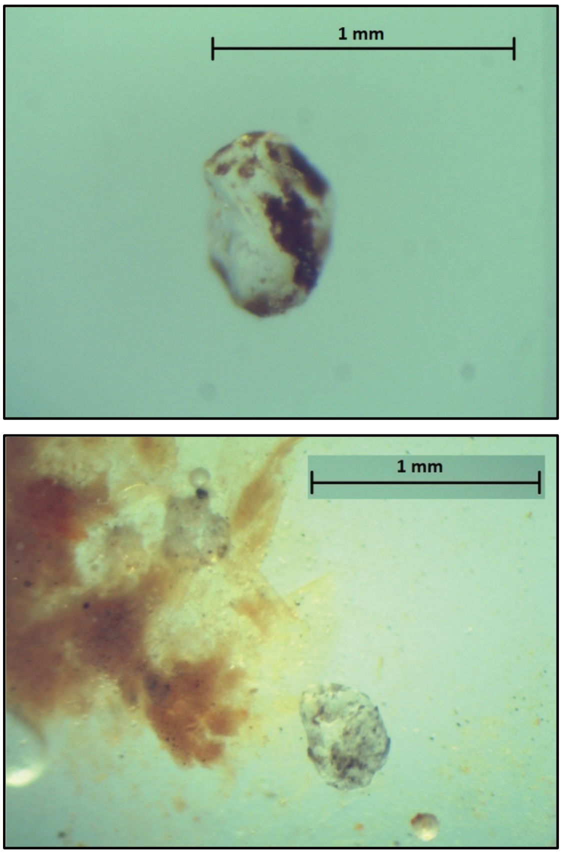

Fig. 9. Examples of microplastics particles – granules.

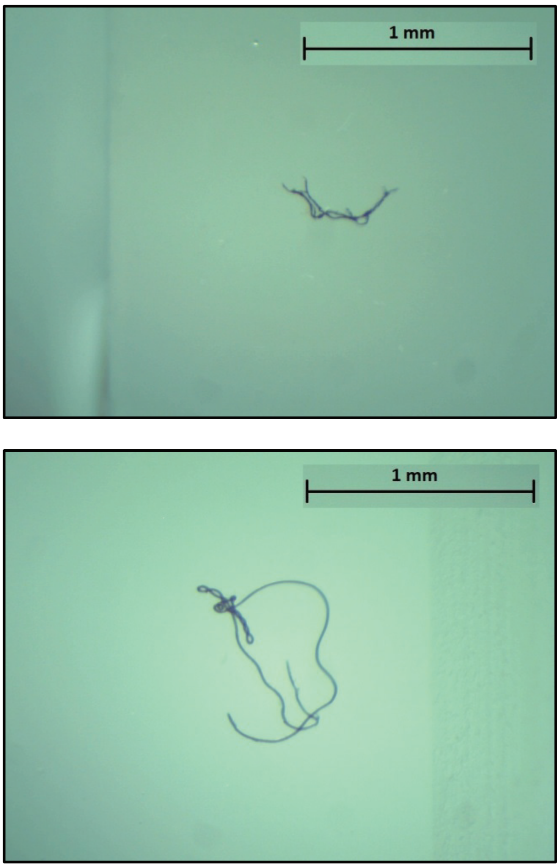

Fig. 10. Examples of microplastics particles – artificial fibers.

Table 1
Microplastics content upstream and downstream WWTPs

Localization	Upstream WWTP (particles/m^3)	Downstream WWTP (particles/m^3)	Authors
Raritan River	24±11.4	71.7±60.2	[30]
Chicago River	1.8±0.8	17.9±11.0	[14]
Bytomka River	34.7±5.5	46.7±2.1	This study
Klodnica River	30.3±8.6	42.3±9.0	This study

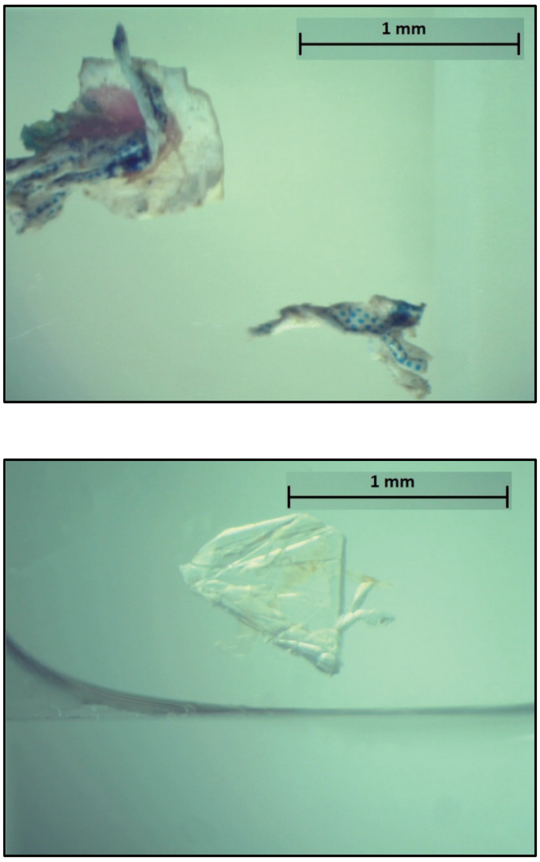

Fig. 11. Examples of microplastics particles – foil fragments.

particles not only float on the surface but also occur under the surface of the water – in water body. However, they take into account the fact that these particles occur in the surface layer of water. Expression of the microplastics content in the number of particles/km^2 will be appropriate for lakes, dam reservoirs and large, slow flowing rivers. In contrast, in smaller rivers characterized by a faster flow, in the authors' opinion, the number of particles/m^3 of water is better. However, taking into account irregularity of water flow, disturbances of flow caused by shaping the bottom and banks of the river, and above all the ease with which microplastics particles located in the coastal zone can be "restarted" into the environment, research should also be undertaken to determine their mobility in water.

Many factors can cause changes of microplastics in rivers. However, in general microplastics particles can be found even in unpolluted parts of rivers [28]. The primary source of microplastics is the widely understood industry. High concentrations of these pollutants occur in rivers which flow through big cities and industrial regions [14,20,29]. The highest concentrations of microplastics are noticed especially in waters from sea and ocean shores [8,11]. So the rivers which were the objects of this study concentration of microplastics particles can be described as "strongly contaminated".

Studies have shown that below the discharge of treated wastewater from the WWTPs, an increase in the number of microplastics particles in water is noticeable. In the beginning, it should be noted that, as research shows [18,29], WWTPs have a very high efficiency of removing this group of pollutants, because they remove even more than 90% of the total microplastics charge that flows with raw sewage. However, this does not change the fact, that none of the modern sewage treatment plants operating in Poland was designed to remove this type of pollution. All pumps, but also, for example, gratings and physical processes accompanying the flow of sewage (e.g., mixing) can be the cause of the fragmentation of relatively large plastic particles present in raw sewage. The comparison with the other studies which concern the microplastics particles upstream and downstream the discharge of wastewaters from WWTPs is shown in Table 1. It can be noted that the Kłodnica and the Bytomka are highly polluted with microplastics, but the relatively low rise of microplastics particles can be noticed downstream from the WWTPs.

It leads to further research, first to increase the possibility of removing microplastics from wastewater, and second to limit the creation of microparticles from larger plastic fragments present in raw wastewater. The most important, however, seems to be the broad educational campaign and environmental awareness of the society, because from households a considerable amount of all kinds of plastic particles goes to the wastewater without any control.

5. Conclusions

- MPs contamination commonly occurs in the Upper Silesian surface water.
- Typical components of the microplastics were foil film fragments observed in all sample points. There were also textile fibers, granules and difficult to identify colored particles of irregular shape.
- It has been observed that the amount of microplastics particles was significantly higher in sampling points located under WWTPs. It could suggest that these impurities are not completely removed from the wastewater during mechanical and biological wastewater treatment.
- The studies indicate the need to identify sources of microplastics and to determine the degree of their harmfulness to aquatic ecosystems.

Acknowledgement

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References

[1] PlasticsEurope, Plastics – The Facts 2016, 2016. Available at: www.plasticseurope.org/Document/plastics---the-facts-2016-15787.aspx?FolID=2 (Accessed 02 November 2017).
[2] J.G.B. Derraik, The pollution of the marine environment by plastic debris: a review, Mar. Pollut. Bull., 44 (2002) 842–852.
[3] R.C. Thompson, C.J. Moore, F.S. vom Saal, S.H. Swan, Plastics, the environment and human health: current consensus and future trends, Philos. Trans. R. Soc. B, 364 (2009) 2153–2216.
[4] A.L. Andrady, M.A. Neal, Applications and societal benefits of plastics, Philos. Trans. R. Soc., B, 364 (2009) 1977–1984.
[5] A. Stefatos, M. Charalampakis, G. Papatheodorou, G. Ferentinos, Marine debris on the seafloor of the Mediterranean Sea: examples from two enclosed gulfs in Western Greece, Mar. Pollut. Bull., 36 (1999) 389–393.
[6] W.J. Sutherland, M. Clout, I.M. Côté, P. Daszak, M.H. Depledge, L. Fellman, E. Fleishman, R. Garthwaite, D.W. Gibbons, J. De Lurio, A.J. Impey, F. Lickorish, D. Lindenmayer, J. Madgwick, C. Margerison, T. Maynard, L.S. Peck, J. Pretty, S. Prior, K.H. Redford, J.P.W. Scharlemann, M. Spalding, A.R. Watkinson, A horizon scan of global conservation issues for 2010, Trends Ecol. Evol., 25 (2010) 1–7.
[7] C. Arthur, J. Baker, H. Bamford, International Research Workshop on the Occurrence Effects and Fate of Microplastics Marine Debris, University of Washington Tacoma, Tacoma, WA, USA, 9–11 September, 2008.
[8] V. Hidalgo-Ruz, L. Gutow, R.C. Thompson, M. Thiel, Microplastics in the marine environment a review of the methods used for identification and quantification, Environ. Sci. Technol., 46 (2012) 3060–3075.
[9] GESAMP, Sources, fate and effects of microplastics in the marine environment: a global assessment (P.J. Kershaw, Ed.), (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN /UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection), Rep. Stud., GESAMP No. 90, 2015, 96 p.
[10] L.M. Rios, P.R. Jones, C. Moore, U.V. Narayan, Quantitation of persistent organic pollutants adsorbed on plastic debris from the Northern Pacific Gyre's "eastern garbage patch", J. Environ. Monit., 12 (2010) 2226–2236.
[11] C.M. Rochman, A. Tahir, S.L. Williams, D.V. Baxa, R. Lam, J.T. Miller, F.C. Teh, S. Werorilangi, S.J. Teh, Anthropogenic debris in seafood: plastic debris and fibers from textiles in fish and bivalves sold for human consumption, Sci. Rep., 5 (2015) 14340.
[12] S.L. Wright, R.C. Thompson, T.S. Galloway, The physical impacts of microplastics on marine organisms: a review, Environ. Pollut., 178 (2013) 483–492.
[13] E.J. Carpenter, K.L. Smith, Plastics on the Sargasso sea surface, Science, 175 (1972) 1240–1241.
[14] A.R. McCormick, T.J. Hoellein, M.G. London, J. Hittie, J.W. Scott, J.J. Kelly, Microplastic in surface waters of urban rivers: concentration, sources, and associated bacterial assemblages, Ecosphere, 7 (2016) e01556.
[15] Remy, F. Collard, B. Gilbert, P. Compere, G. Eppe, G. Lepoint, When microplastic is not plastic: the ingestion of artificial cellulose fibers by macrofauna living in seagrass macrophytodetritus, Environ. Sci. Technol., 49 (2015) 11158–11166.
[16] Technical Review of Microbeads/Microplastics in the Chesapeake Bay, Report number: STAC Publication 16-002, Scientific and Technical Advisory Committee.
[17] K. Magnusson, C. Wahlberg, Mikroskopiska skräppartiklar i vatten från avloppsreningsverk, IVL - Swedish Environmental Institute (cited after: M. Bethanie, A. Carney, L. Åström, S. Roslund, H. Petersson, M. Johansson, N. Persson), Quantifying shedding of synthetic fibers from textiles; a source of microplastics released into the environment, Environ Sci. Pollut. Res. Int., 25 (2014) 1191–1199.
[18] J. Talvitie, A. Mikola, A. Koistinen, O. Setäla, Solutions to microplastics pollution, Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies, Water Res., 123 (2017) 401–407.
[19] M. Wagner, C. Scherer, D. Alvarez-Muñoz, N. Brennholt, X. Bourrain, S. Buchinger, E. Fries, C. Grosbois, J. Klasmeier, T. Marti, S. Rodriguez-Mozaz, R. Urbatzka, A.D. Vethaak, M. Winther-Nielsen, G. Reifferscheid, Microplastics in freshwater ecosystems: what we know and what we need to know, Environ. Sci. Eur., 26 (2014) 12.
[20] D. Eerkes-Medrano, R.C. Thompson, D.C. Aldridge, Microplastics in freshwater systems: a review of the emerging threats, identification of knowledge gaps and prioritisation of research needs, Water Res., 75 (2015) 63–82.
[21] M. Działoszyńska-Wawrzkiewicz, K. Moraczewska-Majkut, E. Szymura, W. Nocoń, Impact assessment of anthropopressure in the Klodnica basin on the characteristics of the Potok Bielszowicki bottom sediments, Ochr. Sr., 37 (2015) 51–54 (in Polish).
[22] W. Nocoń, K. Barbusiński, K. Nocoń, J. Kernert, Changes in trace metal load in suspended solids carried along the river, Ochr. Sr., 35 (2013) 33–38 (in Polish).
[23] W. Nocoń, M. Kostecki, J. Kozłowski, Hydrochemical characteristic of the Kłodnica River, Ochr. Sr., 28 (2006) 39–44 (in Polish).
[24] K. Barbusiński, W. Nocoń, Heavy metal compounds in the bottom sediments of the River Kłodnica (Upper Silesia), Ochr. Sr., 33 (2011) 13–17 (in Polish).
[25] W. Nocoń, M. Kostecki, Hydrochemical characteristics of the Bytomka River, Arch. Environ. Prot., 31 (2005) 31–42.
[26] J.R. Jambeck, R. Geyer, C. Wilcox, T.R. Siegler, M. Perryman, A. Andrady, R. Narayan, K.L. Law, Plastic waste inputs from land into the ocean, Science, 347 (2015) 768–770.
[27] S. Klein, E. Worch, T.P. Knepper, Occurrence and Spatial Distribution of Microplastics in River Shore Sediments of the Rhine-Main Area in Germany, Environ. Sci. Technol., 49 (2015) 6070–6076.
[28] T. Mani, A. Hauk, U. Walter, P. Burkhardt-Holm, Microplastics profile along the Rhine River, Sci. Rep., 5 (2015) 17988.
[29] S. Ziajahromi, P.A. Neale, L. Rintoul, F.D. Leusch, Wastewater treatment plants as a pathway for microplastics: development of a new approach to sample wastewater-based microplastics, Water Res., 112 (2017) 93–99.
[30] S. Estahbanati, N.L. Fahrenfeld, Influence of Wastewater Treatment Plant Discharges on Microplastic Concentrations in Surface Water, Chemosphere, 162 (2016) 277–283.