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Bottom sediments of a spring watercourse as a filter for microplastic – on the example of the Młynówka in Stary Imielnik (municipality of Stryków) – preliminary studies

Osady denne cieku źródliskowego jako filtr dla mikroplastiku – na przykładzie Młynówki w Starym Imielniku (gmina Stryków) – badania wstępne

Abstract

Microplastic (MP) are currently one of the most serious and emerging environmental problems that involve rivers and streams with particular clarity. In the present study of the spring-fed watercourse bed sediments, the presence of microplastic particles was demonstrated and the pathway of their penetration into this environment was identified. The presence of microplastic in the form of fine plastic particles, taking the shape of fibres and fragments in dark and light colours within the hyporheic zone was found. This occurs directly beneath the lowland watercourses with sandy bottoms. There, groundwater is in contact with surface water and mixing takes place. This is an important ecological zone, where chemical and physical processes are crucial to the river environment. In the hyporheic zone there is an exchange of nutrients and oxygen between river water and groundwater, which is crucial to the ecological health of the river and its surroundings. This zone can play an important role in the processes of microplastic transport and retention, as it is where microplastic is washed into the channel infiltration (downwelling) zones and sediment is deposited on the sand filter penetrated by the mixture of river water and groundwater.

Keywords

Microplastic, riverbed sediments, hyporheic zone, vertical hydraulic gradient.

Zarys treści

Mikroplastik (MP) jest obecnie jednym z najpoważniejszych i nowych problemów środowiskowych, który obejmuje ze szczególną wyrazistością rzeki i strumienie. W niniejszej pracy, dotyczącej badań osadów dennych cieku źródliskowego, wykazano obecność mikrocząstek tworzyw sztucznych oraz wskazano drogę ich przenikania do tego środowiska. Stwierdzono obecność mikroplastiku w postaci drobnych cząstek tworzyw sztucznych, przybierających kształt włókien i fragmentów w ciemnych i jasnych barwach w obrębie strefy hyporeicznej. Występuje ona bezpośrednio pod ciekami nizinnymi o piaszczystym dnie. Woda podziemna ma tam kontakt z wodą powierzchniową i dochodzi do ich mieszania. Jest to ważna strefa ekologiczna, gdzie procesy chemiczne i fizyczne mają kluczowe znaczenie dla środowiska rzecznego. W strefie hyporeicznej zachodzi wymiana substancji odżywczych i tlenu pomiędzy wodą rzeczną a podziemną, która jest kluczowa dla zachowania dobrej kondycji ekologicznej cieku i jego otoczenia. Strefa ta może odgrywać istotną rolę w procesach transportu mikroplastiku i jego retencji, gdyż dochodzi tam do wmywania mikroplastiku w strefach infiltracji korytowej (*downwelling*) i osadzania na filtrze piaszczystym osadów penetrowanych przez mieszaninę wód rzecznych z podziemnymi.

Słowa kluczowe

Mikroplastik, osady denne, strefa hyporeiczna, pionowy gradient hydrauliczny.

1. Introduction

Plastics, which are relevant to the modern economy, became the focus of scientific research less than five decades ago, essentially in relation to the marine ecosystem. Synthetic particulates were first detected in the oceans in the 1970s (Carpenter, Smith 1972), and advanced research into micro- and nanoplastic began in the 21st century. Microplastic, consisting of synthetic polymers, are less than 5 mm in size and are classified as either primary (intentionally produced) or secondary (resulting from degradation) (EU, Scientific Opinion 6/2019). Microplastic present in aquatic ecosystems have the ability to adsorb hazardous substances and move from primary producers to consumers within the food web (Dalvand, Hamidian 2023). Plastic production began in the 1950s, initially at a scale of up to about 2 megatonnes per year. Low production costs and the wide range of applications for polymers led to a dramatic increase in production, reaching 368 MT by 2019 (Schütze et al. 2022). By 2014,

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global production had reached 311 million tonnes, of which 19% was attributed to Europe. Only 30% of this waste was recycled or converted into energy (Horton et al. 2016), with the remaining surplus released into the environment. In 2021, the amount of plastics produced in Europe reached 16.13 million tonnes (EU, Article 25 June 2024). Annually, more than 10 million tonnes of plastic are dumped into the oceans and 79% of global plastic waste ends up in landfills, where it can remain for centuries (Wang et al. 2023). Estimating riverine plastic waste emissions to the ocean is fraught with challenges due to different observation and measurement methodologies (Emmerik et al. 2018). There is a lack of international testing standards moreover, different wastewater treatment technologies for MP exacerbate these difficulties (Mintening et al. 2016). Plastics are chemically and physically stable, but are subject to mechanical fragmentation and dispersion by air and water in the environment. The main sources of these pollutants are wastewater treatment plants, landfill sites, plastic pellets, paints and synthetic textiles. The textile industry contributes 20% of water pollution, and mechanical washing of clothes is responsible for 35% of secondary microplastic emissions (Mossotti et al. 2022).

2. Purpose of the study

The main purpose of the studies was to identify the presence of microplastic in the spring watercourse bed sediments, in the valley of which there was an old rural farm waste dump. Springwater areas, are usually perceived as minimally altered by human activities. Given that microplastic studies usually concern watercourses in urban areas and lower sections of rivers (estuaries), this study focused on the initial section of the river system to assess whether microplastic pollution also occurs here. The research work took into account the concept of the hyporheic zone to link its functioning to the introduction and deposition of microplastic in the bottom sediments.

3. Characteristics of the environment

The Łódź region is distinguished by numerous spring areas, among which the Młynówka valley is particularly rich in natural groundwater self-outflows (Fig. 1). The spring density index for the Młynówka basin area is 1.17 spring per square km, which places it among the areas with the largest spring resources in central Poland (Jokiel *et al*. 2007). This indicates large groundwater resources and favourable conditions for their drainage. The groundwater recharge rate of the Młynówka River is 84.8%, with 72% of the basin area being well-permeable formations (Jokiel, Tomalski 2005; Jokiel *et al*. 2007).

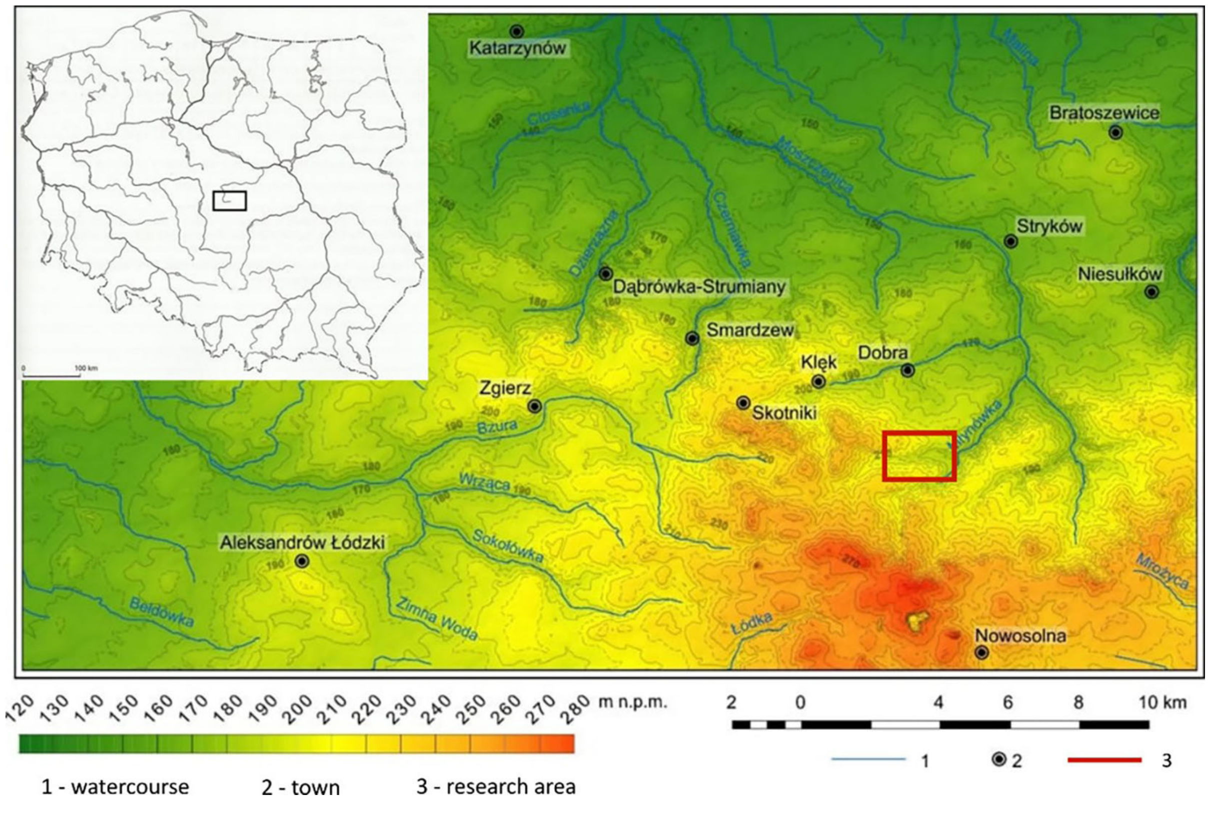

Fig. 1. Location of the study area in the Łódź region
Rys. 1. Położenie obszaru badań w regionie łódzkim

The northern creek of the Młynówka River (NM) is an 852 m long watercourse and the sub-basin area covers 7.59 km^2. The highest point of the basin area reaches an ordinate of 279.3 meters above sea level (m a.s.l.), while the lowest point, located at the junction of the two creeks of the Młynówka River in the Struga Dobieszkowska Nature Reserve, reaches an ordinate of 179.5 m a.s.l. The average slope of this basin is 1.13%.

The sub-basin of the dry valley, defined for the surveyed section of the watercourse, covers an area of approximately 8 472 m^2. It has its highest point at 195.0 m a.s.l. and its lowest point in the NM valley bottom at an ordinate level of 180.6 m a.s.l. The average slope of the area is 7.36%.

Field reconnaissance showed that the landfill fills a significant part of a dry lateral valley, leading the valley of the spring watercourse in the Stary Imielnik village. Profiling of this form (Fig. 2) showed that in the northern part of it is characterized by a V-shaped profile (Fig. 2 – PROFILE I) with a slope on the western slope (W) amounting of 45% and eastern slope (E) amounting of 40%, while in the lower part towards the south, the dry valley softens and acquires a U-shaped profile (Fig. 2 – PROFILE II). Its western slope has a gradient amount of 15% and the eastern slope 11%. Rural buildings border the upper part of the dry valley, while the waste itself is located in its lower part.

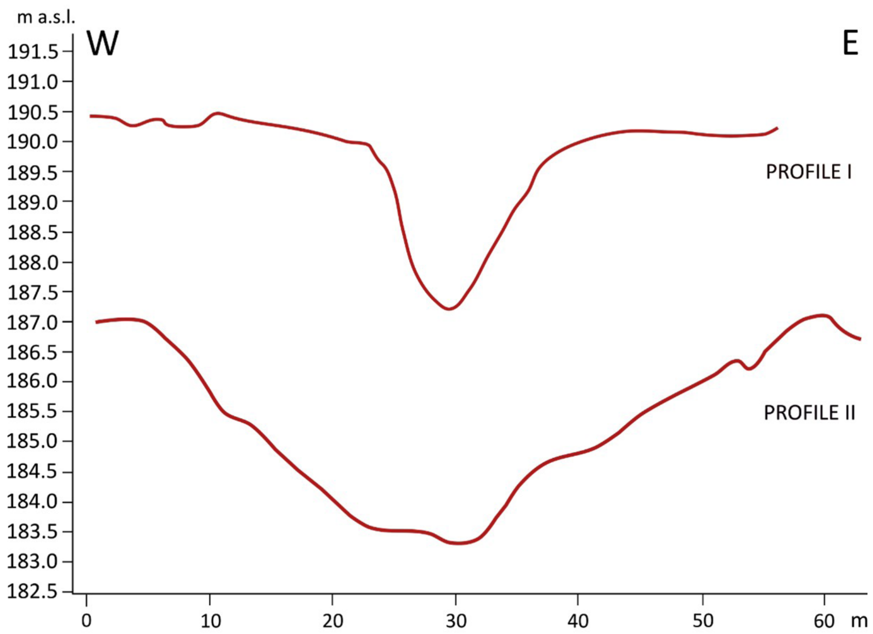

Fig. 2. Transverse hypsometric profile of the lateral valley at the head of which the rubbish dump is located (https://scalgo.com)

Rys. 2. Poprzeczny profil hipsometryczny bocznej doliny, u zwieńczenia której znajduje się śmietnisko (https://scalgo.com)

Rural waste deposited on the slope of the spring watercourse valley is subject to mass movements and moves down the slope. Lateral erosion of the watercourse and back erosion of the groundwater outflows operating there cause the waste, after the first grinding stage in the heap, to end up in the watercourse. As a result, the rubbish dump originally located on the upper part of the northern slope of the valley has slid down to the lower part of the valley, becoming the northern bank of the stream for some distance. Larger pieces of waste remain scattered on the slope or deposited in the Młynówka River bed sediments (Photo 1).

Taking into account the degree of land sealing, the rainwater runoff that takes place as surface runoff from natural areas is 10%, and ranges from 20 to 55% for sealed areas (Rosiek 2017). Surface runoff can also transport solid pollutants. In the case of the area described, in addition to the location of the landfill, attention should be paid to the shape of the dry valley described earlier, through which surface run-off takes place. Both factors – the form of the terrain and the location of the landfill – create a risk of mechanical fragmentation of the plastic waste and its movement directly into the channel of the Młynówka River. The basin of the northern arm of the Młynówka River is 56% transformed by man, the sub-basin of the dry valley 52% (https://scalgo.com). The difference is not in the proportion of surface area transformed but in the intensity of surface runoff resulting from the proportion of impermeable surfaces, i.e. buildings or tarmac roads. This is 16% for the whole NM basin and 35% for the dry valley sub-basin. Another issue is the proportion of woodland, which provides an adequate level of rainwater retention in the environment and delays its runoff. For the NM basin this is 14%, while for the dry valley sub-basin it is only 1%.

Photo 1. Household waste banks of the spring watercourse and in its bed (photo: K. Serwach)
a – undercutting caused by back erosion of groundwater outflows at the foot of the valley slope with dissected wastes
b – a tin disintegrated on the bank of the stream
c – disintegrated waste directly in the stream course

Fot. 1. Odpady gospodarcze na brzegach cieku źródliskowego oraz w jego korycie (fot. K. Serwach)
a – podcięcie wywołane erozją wsteczną wypływów wód podziemnych u podnóża stoku dolinki z wypreparowanymi odpadami
b – puszka wypreparowana na brzegu cieku
c – rozpadający się odpad bezpośrednio w korycie strugi

4. Methods

The present studies were divided into several phases. Chamber work, field work and laboratory analyses. The field trips took place over several weeks in October and November 2023. The first stage involved the selection of bottom sediment sampling points, the collection of sediment samples (Fig. 3) from a depth of 0–20 cm with a volume of 1 litre into glass containers, together with morphological and hydrological measurements of the river flow, vertical hydraulic gradient (VHG), water velocity, width and depth of watercourse. These measurements made it possible to calculate the Reynolds number and Froude number determining the nature of the water movement in the watercourse and thus approximating the hyporheic exchange conditions.

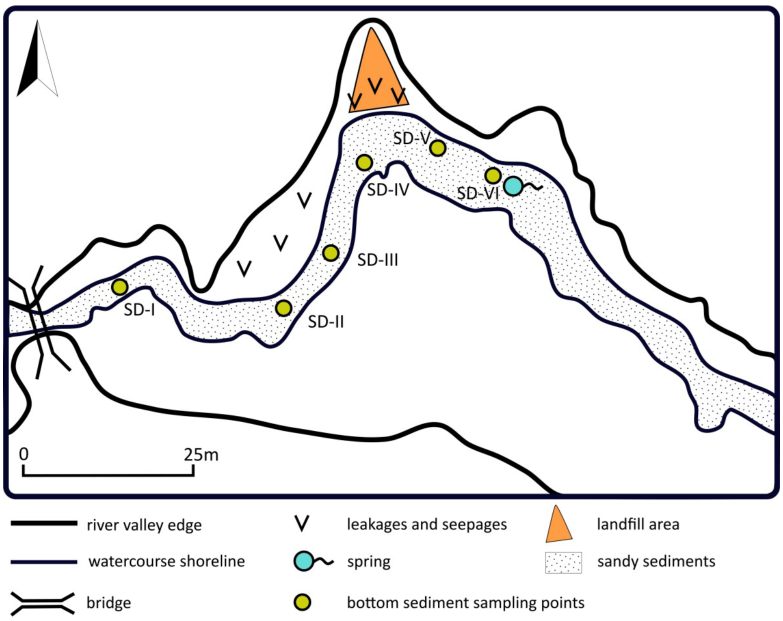

Fig. 3. Location of bottom sediment sampling points

Rys. 3. Rozmieszczenie punktów poboru prób osadów dennych

The Reynolds number was calculated according to the formula:

$$Re = \frac{v \cdot l}{y} \quad \text{(f. 1)}$$

where: v – average swimming velocity [m/s], l – quadruple water depth [m], y – water viscosity dependent on temperature and pressure.

The Froude number was calculated using the formula (Klimaszewski 1981):

$$Fr = \frac{v}{\sqrt{g \cdot d_k}} \quad \text{(f. 2)}$$

where: v – average swimming velocity [m/s], d_k – riverbed depth [m], g – earth acceleration.

To measuring of magnitude and direction of the VHG using a gradientometer (Marciniak, Chudziak 2015) and to collect water samples for chemical analysis. The assessment of the water exchange between the headwater stream and its hyporheic zone (HZ) was an important part of the study, as it clarified the mechanism of MP deposition in the sediments. The study allowed verification of the hypothesis that the HZ is essential for the capture and storage of contaminants, such as microplastic particles, which can be transported down the river system via the watercourse. The hyporheic zone has an important filtering function, which influences the distribution of pollutants carried by river water. Surface waters naturally undergo purification processes in the HZ. Contaminants retained on the sandy sediments, which are a natural filter, are neutralised biochemically, either chemically precipitated when mixed with groundwater or mechanically retained (Lewandowski *et al*. 2019). Studies of the hyporheic zone primarily emphasise mechanisms related to contaminant transport. These mechanisms can be correlated with the erosion and translocation of sediments that form the bedding and banks of the riverbed (Ghinassi *et al*. 2023).

Consequently, the hyporheic zone functions not only as a repository of contaminants, but also as a sphere with a significant impact on the further spread of contaminants in the aquatic ecosystem (Wondzell 2011).

The definition of a hyporheic zone states that it is a zone of mixing of surface water and groundwater, with intermediate conditions between the two (Gooseff 2010). To identify the hyporheic zone in the bed of the Młynówka River, a simplified model of the End-Member Mixing Analysis (EMMA) proposed by Battin *et al*. (2003) (f. 3) using chloride concentrations. Although, as stated by Ziułkiewicz *et al*. (2023), the presence of anthropogenic pollutants in the study waters limits the applicability of such a computational model. To calculate the share of river water in the hyporheic zone used a formula (Battin *et al*. 2003):

$$C_{10} = x \cdot C_{SW} + (1 - x) \cdot C_{GW} \quad \text{(f. 3)}$$

where: C_{10} – concentration of an indicator ion in water from 10 cm below the riverbed[1], C_{SW} – concentration of an indicator in river water, which is the first final element of mixing, C_{GW} – concentration of an indicator in the groundwater, which is second end of mixing.

VHG measurements determine whether trough drainage (upwelling) or trough infiltration (downwelling) is occurring at a given measurement point (Marciniak, Chudziak 2015). The formula used to calculate VHG was:

$$VHG = \frac{h}{l_o} \quad \text{(f. 4)}$$

where: h – difference in groundwater and river water pressure [mm/mm], l_o – measurement depth in sediments [mm].

Laboratory work included granulometric analysis, including the calculation of coefficient of graining non--uniformity (5) and grain-size distribution curve (6). Formulae were used to calculate the *Cu* and *Cc* indices:

$$Cu = \frac{d_{60}}{d_{10}} \quad \text{(f. 5)}$$

$$Cc = \frac{d_{30}^{2}}{d_{60} \cdot d_{10}} \quad \text{(f. 6)}$$

where: d_{10}, d_{30} i d_{60} are grain diameters which, together with the finer grains, represent respectively 10, 30 and 60% by weight of the sediment (Racinowski *et al*. 2001).

The granulometric composition was determined using a direct method, sieve analysis, which involves the actual measurement of soil particle dimensions under laboratory conditions (Myślińska 2019). This was supplemented by an indirect method, the areometric analysis, based on a sedimentation process in which a homogeneous suspension of the sample is prepared and its bulk density is determined using an areometer (Szymański 2007). In addition, *Cu* and *Cc* indices were calculated, which provide information on the degree of particle differentiation. Higher values of these indices indicate less homogeneity of the soil (Jermołowicz 2019). The EN ISO 14688-2 standard was used to classify the sediments (Majer *et al*. 2021).

An essential element of the study was the separation of microplastic particles from the environmental matrix – the spring watercourse bed sediments. This procedure, according to the literature (Vermeiren *et al*. 2020; Yang *et al*. 2021), included the following steps:

I. Drying and fractionation of the samples (550 g each), while ensuring that the correct temperature is maintained and that contamination with plastic particles is prevented; selection of appropriate sieves on the shaker to obtain the desired fractions: 5–2 mm, >1 mm, >0.500 mm, >0.200 mm, >0.100 mm, >0.056 mm and <0.056 mm;
II. Density separation, using NaCl solution;
III. Removal of organic material with H_2O_2 to prepare samples for optical analysis;
IV. Identification of microplastic under a DELTA OTPICAL optical microscope for brightfield observation, including fraction, colour and shape of MP particles.

[1] The design of the gradiometer allows measurement and sampling from a depth of 20 cm.

The entire analytical procedure was developed and carried out to document the presence of microplastic in the collected sediment samples (Fig. 4).

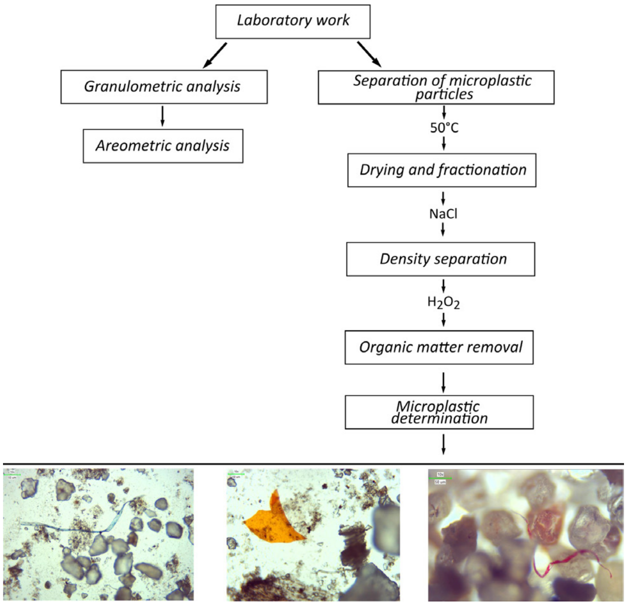

Fig. 4. Laboratory procedure developed for the study of microplastic in riverbed sediments (self-elaboration)

Rys. 4. Procedura laboratoryjna opracowana na potrzeby badań nad mikroplastikiem w osadach rzecznych (oprac. własne)

5. Results

The Reynolds number calculated for the study section was 12 306, indicating turbulent water movement. In addition, the results of the Froude number calculations for the study points indicate the subcritical stream character of the flow of the northern creek of the Młynówka River in the study section.

There was a variable quantitative presence of microplastic in the sediment samples collected. The study yielded a total of 825 particles of microplastic in all samples. The points vary in the number of microplastic (Table 1) and the average microplastic densities are 0.25 pieces per gram (pcs./g).

Table 1. Concentration of microplastic particles per unit of sediment mass

Tabela 1. Zagęszczenie drobin mikroplastiku w jednostce masy osadu

	SD-I	SD-II	SD-III	SD-IV	SD-V	SD-VI	TOTAL
Sum of all MP	165	116	112	194	83	155	825
Densification [pcs./g]	0.30	0.21	0.20	0.35	0.15	0.28	0.25
Densification [pcs./kg]	**300.00**	**210.90**	**203.60**	**352.70**	**150.90**	**281.80**	**250.00**

The *Cu* index, which refers to the uniformity of grain size, for samples SD-I to SD-V ranges from 2.26 to 2.53, indicating that these sediments are evenly grained. In contrast, the *Cc* index, which determines the curvature of the grain size, in the same samples is in the in the range 1.02 ÷ 1.14, indicating that the sediments are moderately to poorly sorted. In the compilation (Table 2), the SD-VI point stands out, where the results of the indices are different: *Cu* is 4.02, which documents a change in the sediment from an even grained sediment towards a differentiated sediment, while the *Cc* index for this point is 1.83, which confirms that the sediment is moderately to poorly sorted.

Table 2. Summary of indicator results: coefficient of graining non-uniformity (*Cu*) and grain-size distribution curve (*Cc*) in each sample

Tabela 2. Zestawienienie wyników wskaźników: współczynnik nierównomierności uziarnienia (*Cu*) i wskaźnik krzywizny uziarnienia (*Cc*) w każdej próbce

	Cu	*Cc*
SD-I	2.53	1.14
SD-II	2.42	1.10
SD-III	2.26	1.09
SD-IV	2.42	1.13
SD-V	2.31	1.02
SD-VI	**4.02**	**1.83**

The analysis showed that 89% of the identified microplastic particles were smaller than 2 mm, and 80% of them were fibre shaped, among which 76% were dark in colour (Photo 2).

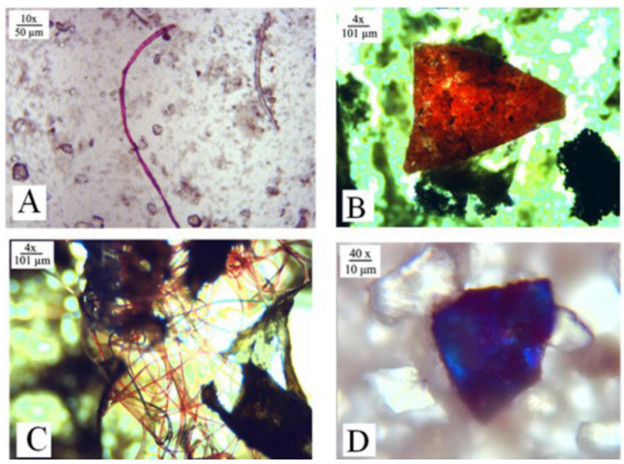

Photo 2. Extracted microplastic particles from the bottom sediment of a spring-fed watercourse (photo: K. Serwach)
A – pink fibre from the 0.2–0.5 mm fraction; B – red fragment from the 0.5–1.0 mm fraction; C – multicolor fibre from fraction 1–2 mm; D – blue fragment from fraction < 0.056 mm

Fot. 2. Wyodrębnione cząstki mikroplastiku z osadu dennego cieku źródliskowego (fot. K. Serwach)
A – różowe włókno z frakcji 0,2–0,5 mm; B – czerwony fragment z frakcji 0,5–1,0 mm; C – kolorowe włókna z frakcji 1–2 mm; D – niebieski fragment z frakcji < 0,056 mm

To verify the research hypothesis that a hyporheic zone is functioning in the studied section of the spring watercourse, the proportion of river water in the HZ was calculated based on chloride ion concentrations in the watercourse and in groundwater flowing from the spring (Table 3). Due to the village water supply system and the decommissioning of wells, it was not advisable to test the chloride ion concentration at local shallow groundwater intakes. Therefore, measurements were taken at the 'Stormy' spring at point SD-VI. For technical reasons, it was not possible to take measurements at sampling point SD-I.

Table 3. Vertical hydraulic gradient (VHG) and chloride ion measurements at the sampling points

Tabela 3. Pomiary pionowego gradientu hydraulicznego (VHG) oraz jonu chlorkowego w punktach poboru prób

		SD-II	SD-III	SD-IV	SD-V	SD-VI	River waters	Spring waters
VHG [mm/mm]*	P1	0.125	–0.350	0.275	0.380	0.415	–	–
	P2	0.390	–0.050	0.350	0.350	0.510		
Cl^- [mg/l]		12.8	37.3	68.8	47.2	19.4	21.5	51.9
Share of river water [%]		**	48.0	–	15.5	–	–	–
Share of groundwater [%]		–	52.0	–	84.5	–	–	–

* P1 – measure one, P2 – measure two.
** Negative values resulting from chloride ion concentrations in hyporheic waters exceeding the limits of the range of concentration values in the mixing end elements, i.e. river and groundwater, have been omitted.

According to Triska *et al*. (1993), the hyporheic zone occurs when the share of river waters is between 10–99%.

The results of the similarity analysis of the sediment samples in terms of MP content and the nature of these particles are presented as dendrograms in Fig. 5 and Fig. 6.

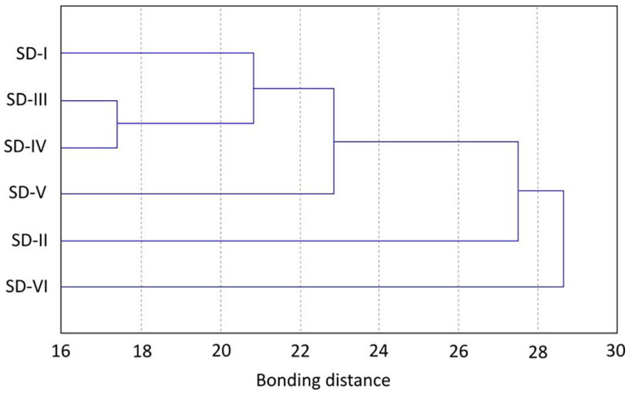

Fig. 5. Dendrogram (I) of sample similarity in terms of the nature of MP contamination

Rys. 5. Dendrogram (I) podobieństwa prób pod względem charakteru zanieczyszczenia MP

Dendrogram I (Fig. 5) documents the dissimilarity of sample SD-VI compared to the others and the high similarity of samples SD-III and SD-IV, i.e. those taken above the landfill.

Dendrogram II (Fig. 6) shows that the microplastic particles found in the samples form three groups: (1) light fibres and fragments between 0.1 and 1 mm in the samples (2) dark fibres between 0.1 and 0.5 mm and (3) dark fibres between 0.5 and 5 mm.

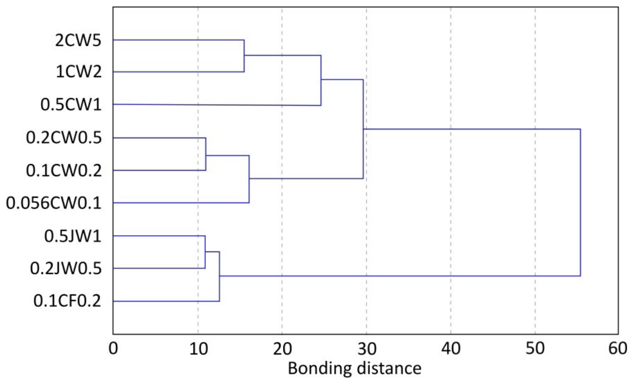

Fig. 6. Dendrogram (II) of the similarity of the selected MP groups in the studied sediments: C – dark; J – light; W – fibres; F – fragments.
The numerical values identify the range of fractions, e.g. 2CW5 is the dark fibres in the 2–5 mm fraction

Rys. 6. Dendrogram (II) podobieństwa wytypowanych grup MP w badanych osadach: C – ciemne; J – jasne; W – włókna; F – fragment.
Wartości liczbowe identyfikują zakres frakcji, np. 2CW5 to ciemne włókna we frakcji 2–5 mm

6. Discussion

The calculated average concentration of isolated plastic microparticles, which was 0.25 pcs./g for all samples is lower than the average particle concentration shown in some of the world's rivers classified as heavily polluted and ranging from 0.44 to 5.68 pcs./g (Ghinnasi *et al*. 2023). The values obtained by the author are almost 12 times lower than the average concentration across Europe of 2.9 pcs./g. These results refer to soil tests at 14 locations, for which reagents with a density of 1.70 g/cm^3 were used (Büks, Kaupenjohann 2020). The results obtained, which are lower than the European average, depend not only on the reagent used (1.20 g/cm^3), which excluded higher density polymers such as PVC (1.28 g/cm^3) from the analysis, but also on the type of sediment. It is difficult to relate the values obtained to the literature, as it does not provide specific data for spring watercourse bed sediments.

About 95% of the isolated plastics in the study by Lwanga *et al*. (2017) were less than 50 μm in size, while in the study by Zhang and Liu (2018), 82% of isolated MP were < 250 μm in size and fibre shape was predominant. The author's analytical results showing an 89% predominance of particles smaller than 2 mm, dominated by dark-coloured fibres, can be compared with the study of Liu *et al*. (2018), which was also based on a density limit of 1.2 g/cm^3, where 54.3% of the particles were < 1 mm in size, also with fibre dominance (Büks, Kaupenjohann 2020). It should be noted that the presence of microplastic particles at point SD-I, i.e. above the landfill site, may be due to the presence of other small foci of household waste scattered along the watercourse from the beginning (Grulke 2022).

The calculated *Cu* and *Cc* indices at points SD-I to SD-V show no significant differences in the in the structure of the bottom sediments. The SD-VI point stands out in the comparison, with results of *Cu* = 4.02, which indicates a change in sediment from equi-granular to differentiated sediment and *Cc* = 1.83, which also, as for the other points, indicates moderately to poorly sorted sediment (Pisarczyk 2014; Racinowski *et al*. 2001).

At point SD-III, there is a trough infiltration (downwelling) phenomenon, which is also confirmed by the results of calculating the river waters share into HZ (Table 3). This phenomenon is referred to in the highest number of MP fines occurring at the point below, which falls at SD-IV and is 194 pcs. The turbulent movement of water in the study section of the spring watercourse is, according to the results of Froude number calculations for each study point (from 0.16 at SD-VI to 0.27 at SD-V), subcritical streaming (Klimaszewski 1981).

It favors the injection of particles into the sediment in downwelling zones. The potential for hyporheic exchange development (HYPPOT) according to Grulke *et al*. (2025) for the northern arm of the Młynówka River is 2.54E-04 (Grulke *et al*. 2025). This is lower than the value determined for another spring watercourse in the vicinity of Łódź, the Malinka, where HYPPOT ranges from 3.69E-05 to 3.31E-04 (Ziułkiewicz, Grulke 2024). According to Wondzell (2011), these values are high and favor hyporheic exchange in both headwaters.

According to the hydrochemical criterion, only points SD-III and SD-V show the presence of HZ, as the share of river waters exceeds 10%, which is a condition for the presence of this zone (Triska *et al*. 1993). When verifying the presence of downwelling or upwelling, it is important to look at measurements of chloride ion concentrations.

At point SD-II and SD-VI, the concentration of Cl^-, is lower than the chloride ion concentration of river water (21.5 mg/dm^3). Point SD-IV, with a Cl^- result of 68.8 mg/dm^3, should be treated as an effect of anthropogenic pollution (Macioszczyk, Dobrzyński 2002). According to Ziułkiewicz *et al*. (2023) in areas where the effects of anthropogenic pollution are clear, the application of the EMMA model is a major difficulty. Taking all the data into account, it can be concluded that point SD-III is characterised by downwelling and point SD-V by upwelling. These phenomena favor the introduction of pollutants into the bottom sediments and their transport under the bed of the spring watercourse. Downwelling results in MP particles floating in the river waters being washed into the bed sediment, while upwelling, lifts stripped MP water back into the riverbed. The stage of temporary storage of MP in the bottom sediment of the watercourse may contribute to their further mechanical fragmentation during the movement of sediment batches during flood events, or even their secondary mobilization into the watercourse.

Attention should be drawn to the study of Mancini *et al*. 2023, who showed that hydraulic load and time are not very important in the infiltration of MP into the sediment and do not determine this phenomenon, but the diameter of the MP particles and the mean of the sediment grains in the bed of the trough do, while hydraulic load alone contributes to the distribution of MPs in the first 15 cm of sediment. Waldschläger and Schüttrumpf (2020) confirm the dependence of MP infiltration depth in sediments on the correlation of sediment grain size and MP particle shape and size. A study by Ling *et al*. 2022 on the correlation of MP concentration in freshwater and saltwater sediments showed that it is freshwater systems with low salinity and high flow velocities that may favor an increase in the occurrence of MP particles in sediments.

The similarity assessment of the samples illustrated on the dendrograms (Fig. 5 and 6) showed that point SD-VI, shows complete distinctness from the others, which only confirms the differences shown by the *Cu* and *Cc* indices. The similarity assessment in the structure of the MP contamination (Fig. 6) shows the distinctness of the light fibers and fragments in the size range from 0.1 to 1 mm. The next group consists of dark fibers between 0.1 and 0.5 mm, and the last group consists of dark fibers between 0.5 and 5 mm. This may suggest a common origin of the particles in question from one larger whole in the waste group, and thus also a separation from other groups, particle entry pathways into the trough or fragmentation efficiency.

A study by Radfort *et al*. (2023) showed differences in soil MP content between the summer and winter seasons. During the summer months, when rainfall was lower, more MP particles were isolated, while during the winter month with higher rainfall, almost half as many particles were counted (*ibid*). On this basis, the conclusion was drawn that rainfall and consequently surface run-off may contribute to the leaching of MP from the soil. The samples for the present study were taken during the autumn period, so on this basis it can be expected that the amount of isolated MP particles at other times would be different.

With an average daily rainfall, in the driest month, which is February, it was calculated that in the lower part of the NM sub-basin, taking into account the initial losses due to saturation of the ground with moisture, through the dump, can flow approx. 0.056 dm^3/s of precipitation.

Assuming that, for the study area, the 100-year precipitation is 89 mm (https://klimat.imgw.pl) then the volume of runoff in the lower part of the NM sub-basin could be as high as 40.5 dm^3/s (https://scalgo.com). The flow in NM on the two measurement days was 9.8 dm^3/s and 13.4 dm^3/s. This means that during heavy rainstorms, the flow of rainwater through the garbage dump can be 4 times the average NM flow.

The intensity of surface runoff depends on the vegetation covering the area. The winter months interrupt the growing season and, in our latitudes, areas of river valleys become exposed as a result of the death of the green parts of plants. The samples for the present study were taken in autumn, after the growing season but before winter. Studies of spring waters show some correlation in the abundance of microplastic particles in spring waters and the presence of humans in their vicinity (Yanuar *et al*. 2024). Research by Horton *et al*. (2016) suggest that direct runoff of microplastic particles from the land surface into rivers, is more important than inflows of these particles with wastewater. They stress that rivers are sinks for dense plastics and other anthropogenic pollutants that may affect the environment, while the hyporheic zone itself acts as the 'liver of the river' (Fischer *et al*. 2005).

7. Summary

The results obtained were related to literature data and provided insight into the representation of microplastic particles in relation to the grain size of the bottom sediments and the hydraulic loading of the riverbed of the study watercourse. They indicate that this is particularly relevant for trough infiltration of microplastic into the hyporheic zone (HZ). It has been assumed that hydraulic loading alone facilitates microplastic decomposition in the upper 15 cm of sediment (Mancini *et al*. 2023), but this phenomenon was not observed during the study. Immediately below the downwelling zones, there is generally an increase in microplastic particles in the bottom sediments. The main conclusions of the research work carried out in the Młynówka River include:

- Documentation of a new form of anthropogenic pressure, previously undetected within a spring watercourse in the Lodz Heights region;
- Identification of the hyporheic zone in the studied section of the northern arm of the Młynówka (NM) stream;
- Development of a downwelling zone, indicating infiltration of river water into the riverbed and infiltration of microplastic into NM bottom sediments;
- Variation in the granulometric structure of spring stream bottom sediments explaining their ability to retain microplastic particles in the intergranular spaces of filtering, HZ-flowing waters, especially in sediments with increased grain size irregularity;
- Presence of an upwelling zone, potentially creating the possibility of releasing the smallest, unfilterable fraction of microplastic back into the watercourse bed;
- Demonstration of turbulent spring stream water flow, facilitating hyporheic exchange between the stream bed and its hyporheic zone.

The observed presence of a hyporheic zone in the studied section of the watercourse and the demonstration of the presence of MP in the bottom sediments of the stream between the downwelling and upwelling, together with the reported characteristics of surface water movement in the channel and the magnitude of the HYPPOT index, indicates the potential ability of microplastic to be washed into the HZ and temporarily retained in the sandy filter of the bottom sediments of the river channel.

The results indicate an urgent need for further research and interventions to mitigate the influx of microplastic into the river environment from its origins in the spring zone. In addition, it should be noted that a potential threat of hydrological effects of urbanization of peri-urban villages has been identified, which will lead to increased surface run-off over time, thus intensifying the leaching of pollutants from old landfills and MP accumulated in the sediments of the initiation courses.

8. References

Battin T.J., Kaplan L.A., Newbold J.D., Hendricks S.P. 2003. A mixing model analysis of stream solute dynamics and the contribution of hyporheic zone to ecosystem function. Freshwater Biology 48: 995–1014.

Büks F., Kaupenjohann M. 2020. Global concentrations of microplastics in soils – a review. Soil 6: 649–662.

Carpenter E., Smith K. 1972. Plastics on the Sargasso Sea Surface. Science 175 (4027): 1240–1241.

Dalvand M., Hamidian A.H. 2023. Occurrence and distribution of microplastics in wetlands. Science of the Total Environment 862.

Emmerik T., Kieu-Le T.C., Loozen M., Oeveren K., Strady E., Bui X.T., Egger M., Gasperi J., Laberton L., Nguyen P.D., Schwarz A., Slat B., Tassin B. 2018. A Methodology to Characterize Riverine Macroplastic Emission Into the Ocean. Frontiers in Marine Science 5.

Fischer H., Kloep F., Wilzcek S., Pusch M.T. 2005. A river's liver-microbial processes within the hyporheic zone of a large low-land river. Biogeochemistry 76: 349–371.

Ghinassi M., Michielotto A., Uguagliati F., Zattin M. 2023. Mechanisms of microplastics trapping in river sediments: Insights from the Arno river (Tuscany, Italy). Science of The Total Environment 866: 161273.

Gooseff M.N. 2010. Defining Hyporheic Zones – Advancing Our Conceptual and Operational Definitions of Where Stream Water and Groundwater Meet. Geography Compass 4 (4): 945–955.

Grulke R. 2022. Wymiana wód powierzchniowych i podziemnych w korycie północnego ramienia Strugi Dobieszkowskiej [Praca magisterska, Uniwersytet Łódzki]. Archiwum Prac Dyplomowych Uniwersytetu Łódzkiego.

Grulke R., Górowski J., Markowicz P., Ziułkiewicz M. 2025. Hydrochemical aspects of river and groundwater exchange in the bed of a spring stream in the suburban area of the Łódź agglomeration (in preparation – in review).

Horton A., Svendsen C., Williams R., Spurgeon D., Lahive E. 2016. Large microplastic particles in sediments of tributaries of the River Thames, UK – Abundance, sources and methods for effective quantification. Marine Pollution Bulletin.

Jermołowicz P. 2019. Problematyka zagęszczania i stabilizacji gruntów w budownictwie. Technologie i ich skuteczność. Zasady projektowania i wykonawstwa (materiały szkoleniowe). Opole.

Jokiel P., Moniewski P., Ziułkiewicz M. (Ed.) 2007. Źródła Polski – wybrane problemy krenologiczne. Łódź: Regina Poloniae, Częstochowa.

Jokiel P., Tomalski P. 2005. Odpływ oraz fizykochemiczne właściwości wód płynących w sąsiedztwie węzła autostrad A1 i A2 w okolicy Łodzi. Acta Scientiarum Polonorum. Formatio Circumiectus 4 (2): 3–20.

Klimaszewski M. 1981. Geomorfologia. PWN, Warszawa.

Lewandowski J., Arnon S., Banks E., Batelaan O., Betterle A., Broecker T., Coll C. Drummond J.D., Garcia J.G., Galloway J., Gomez-Velez J., Grabowski R.C., Herzog S.P., Hinkelmann R., Höhne A., Hollender J., Horn M.A., Jaeger A., Krause S., Löchner Prats A., Magliozzi C., Meinikmann K., Mojarrad B.B., Mueller B.M., Peralta-Maraver I., Popp A.L., Posselt M., Putchew A., Radke M., Raza M., Riml J., Robertson A., Rutere C., Schaper J.L., Schirmer M., Schulz H., Shanefield M., Singh T., Ward A.S., Wolke P., Wörman A., Wu L. 2019. Is the Hyporheic Zone Relevant beyond the Scientific Community? Water 11: 2230.

Ling X., Yan Z., Lu G. 2022. Vertical transport and retention behavior of polystyrene nanoplastics in simulated hyporheic zone. Water Research 219.

Liu M., Lu S., Song Y., Lei L., Hu J., Lv W., Zhou W., Cao C., Shi H., Yang X., He D. 2018. Microplastic and mesoplastic pollution in farmland soils in suburbs of Shanghai, China. Environmental Pollution 242 (Pt A): 855–862.

Lwanga E.H., Mendoza J.V., Ku Quej W., de los Angeles Chi J., del Cid L.S., Chi C., Segura G.E., Gertsen H., Salánki T., van der Ploeg M., Koelmans B., Geissen V. 2017. Field evidence for transfer of plastic debris along a terrestrial food chain. Scientific Reports 7 (1): 14071.

Macioszczyk A., Dobrzyński D. 2002. Hydrogeochemia strefy aktywnej wymiany wód Podziemnych. Wydawnictwo Naukowe PWN, Warszawa.

Majer E., Roguski A., Grabowska A., Łukawska A. 2021. Oznaczanie, opis i klasyfikacja gruntów według norm PN-EN ISO 14688-1 oraz 14688-2. Przegląd Geologiczny 69 (12): 937–948.

Mancini M., Francalanci S., Innocenti L., Solari L. 2023. Investigations on microplastic infiltration within natural riverbed sediments. Science of the Total Environment 904: 167256.

Marciniak M., Chudziak Ł. 2015. Nowa metoda pomiaru współczynnika filtracji osadów dennych. Przegląd Geologiczny 63 (10/2): 919–925.

Mintening S.M., Int-Veen I., Löder M.G.J., Primpke S., Gerdts G. 2016. Identification of microplastic in effluents of waste water treatment plants using focal plane array-based micro-Fourier-transform infrared imaging. Water Research 30: 1–8.

Mossotti R., Fontana G.D., Anceschi A., Gasparin E., Battistini T. 2022. Preparation and Analysis of Standard Microplastics, [In:] Advances and Challenges in Microplastics: 1–16.

Myślińska E. 2019. Laboratoryjne badania gruntów i gleb (wydanie 3). Wydawnictwo Uniwersytetu Warszawskiego, Warszawa.

Pisarczyk S. 2014. Gruntoznawstwo inżynierskie (wydanie drugie poprawione i uzupełnione). Wydawnictwo Naukowe PWN, Warszawa.

Racinowski R., Szczypek T., Wach J. 2001. Prezentacja i interpretacja wyników badań uziarnienia osadów czwartorzędowych (wydanie drugie poprawione i uzupełnione). Nauki o Ziemi, Wydawnictwo Uniwersytetu Śląskiego, Katowice.

Radford F., Horton A., Hudson M., Shaw P., Ian Williams I. 2023. Agricultural soils and microplastics: Are biosolids the problem? Frontiers in Soil Science 2: 1–14.

Rosiek K. 2017. Wody opadowe jako przedmiot gospodarowania. Gospodarka w Praktyce i Teorii 3: 61–67.

Schütze B., Thomas D., Kraft M., Brunotte J., Kreuzig R. 2022. Comparison of different salt solutions for density separation of conventional and biodegradable microplastic from solid sample matrices. Environmental Science and Pollution Research 29: 81452–81467.

Szymański A. 2007. Mechanika gruntów. Wydawnictw SGGW, Warszawa.

Triska F.T., Duff J.H., Avanzino R.J. 1993. The role of water exchange between a stream channel and its hyporheic zone in nitrogen cycling at the terrestrial-aquatic surface. Hydrobiologia 251: 167–184.

Vermeiren P., Muñoz C., Ikejima K. 2020. Microplastic identification and quantification from organic rich sediments: A validated laboratory protocol. Environmental Pollution 262: 114298.

Waldschläger K., Schüttrumpf H. 2020. Infiltration behavior od microplastic particles with different densities, size, and shapes-from glass spheres to natural sediments. Environmelntal Science Technology 54 (15): 9366–9373.

Wang Y., Okochi H., Tani Y., Hayami H., Minami Y., Katsumi N., Takeuchi M., Sorimachi A., Fujii Y., Kajino M., Adachi K., Ishihara Y., Iwamoto Y., Niida Y. 2023. Airborne hydrophilic microplastics in cloud water at high altitudes and their role in cloud formation. Environmental Chemistry Letters 21: 3055–3062.

Wondzell S.M. 2011. The role of the hyporheic zone across stream networks. Hydrological Processes 25: 3525–3532.

Yang L., Zhang Y., Kang S., Wang Z., Wu C. 2021. Microplastics in soil: A review on methods, occurrence, sources and potential risk. Science of The Total Environment 780: 146546.

Yanuar A.T., Pramudia Z., Susanti Y.A.D., Kurniawan A. 2024. Analysis of microplastics in spring water. Emerging Contaminants 10: 100277.

Zhang G.S., Liu Y.F. 2018. The distribution of microplastics in soil aggregate fractions in southwestern China. The Science of the Total Environment 642: 12–20.

Ziułkiewicz M., Grulke R. 2024. Hydrochemical aspects of water exchange through the bottom of headwater stream in suburban zone on the example of the Malina watercourse in Zgierz (Central Poland). Geology, Geophysics & Environment 50 (3): 231–251.

Ziułkiewicz M., Fortuniak A., Górowski J., Ajzert M., Kaźmierczak K., Lik K., Mytkowska N., Ślusarczyk T. 2023. Zintegrowana ocena stanu hydrochemicznego doliny rzecznej w obszarze podmiejskim na przykładzie Strugi Dobieszkowskiej (Młynówki) (gm. Stryków). Acta Universitatis Lodziensis. Folia Geographica Physica 22: 19–36.

https://klimat.imgw.pl

https://scalgo.com

Resolutions/Directives

European Union, European Parliament. Directorate General for Communication. Article 20181212STO21610. 25 June 2024.

European Union, Group of Chief Scientific Advisors. Scientific Opinion 6/2019. (Supported by SAPEA Evidence Review Report No. 4). Brussels, 30 April 2019.