Riverine microplastics in the Hungarian Danube: distribution, sources, and characterisation

Pegah JAHANPEYMA[1,2,3], Sándor BARANYA[1,2]

[1] Department of Hydraulic and Water Resources Engineering, Faculty of Civil Engineering, Budapest University of Technology and Economics, Műegyetem rkp. 3., H-1111 Budapest, Hungary.
(email: pegah.jahanpeyma@edu.bme.hu, baranya.sandor@emk.bme.hu)
[2] National Laboratory for Water Science and Security, Department of Hydraulic and Water Resources Engineering, Faculty of Civil Engineering, Budapest University of Technology and Economics, Műegyetem rkp. 3., H-1111 Budapest, Hungary
[3] Corresponding author: baranya.sandor@emk.bme.hu

DOI:10.59258/hk.24053

Abstract
Microplastics, defined as plastic particles smaller than 5 mm, have become a pressing global environmental issue. Ineffective recycling practices allow plastics to enter and persist in the environment, breaking down into smaller particles that travel through pathways like rivers. These microplastics can accumulate in ecosystems, where they pose significant risks to flora, fauna, and potentially human health. This study focuses on riverine microplastic pollution in the Hungarian section of the Danube River, Europe's second-largest river, as well as in its tributary system. The Danube is a vital water source for Budapest and plays a crucial role in the region's economy and ecological balance. Water samples were collected at varying river depths using a Multilevel Manta Net. Advanced laboratory techniques, including Fourier-transform infrared spectroscopy and digital microscopy, were used to identify and characterise microplastics collected. Additionally, flow measurements were conducted to estimate mass-flux rates. These findings contribute to developing practical measures for understanding, managing, and reducing microplastic pollution in freshwater systems. The findings revealed an average microplastic concentration of 0.311 mg/m³, corresponding to 142 particles/m³. The most frequently identified polymers were polystyrene, polyethylene, and polypropylene, which appeared predominantly as fragments, foam, and flakes. The microplastics exhibited a range of colours, including yellow, black, grey, and green.

Keywords
Microplastics, FTIR spectroscopy, microplastic characterisation, riverine microplastics, plastic pollution.

Mikroműanyag-szennyezés vizsgálata magyarországi folyószakaszokon

Kivonat
A mikroműanyagok, azaz az 5 mm-nél kisebb műanyag részecskék napjaink egyik legsürgetőbb globális környezeti problémájává váltak. A nem megfelelő újrahasznosítási gyakorlatok következtében a műanyagok bejutnak és hosszú ideig megmaradnak a környezetben, miközben kisebb részecskékre bomlanak. Ezek a részecskék folyók által terjedhetnek, felhalmozódhatnak az ökoszisztémákban, ahol jelentős kockázatot jelentenek a növény- és állatvilágra, valamint potenciálisan az emberi egészségre is. Ez a tanulmány a folyami mikroműanyag-szennyezést vizsgálja Európa második legnagyobb folyója, a Duna magyar szakaszán és annak mellékfolyóiban. A Duna létfontosságú vízforrást jelent Budapest számára, és kulcsfontosságú szerepet játszik a régió gazdaságában és ökológiai egyensúlyában. A vízmintákat a folyó különböző mélységeiből gyűjtöttük egy többszintes planktonháló segítségével. Korszerű laboratóriumi technikákat, köztük Fourier-transzformációs infravörös spektroszkópiát és digitális mikroszkópiát alkalmaztunk a gyűjtött mikroműanyagok azonosítására és jellemzésére. Emellett áramlásméréseket végeztünk a tömegáramok becsléséhez. Ezek az eredmények hozzájárulnak a mikroműanyag-szennyezés megértéséhez, kezeléséhez és csökkentéséhez szükséges hatékony intézkedések kidolgozásához. Az eredmények alapján az átlagos mikroműanyag-koncentráció 0,311 mg/m³ volt, ami 142 részecske/m³-nek felel meg. A leggyakrabban azonosított polimerek a polisztirol, a polietilén és a polipropilén voltak, amelyek főként törmelék, hab és pelyhek formájában fordultak elő. A mikroműanyagok színe változatos volt, többek között sárga, fekete, szürke és zöld árnyalatokat mutattak.

Kulcsszavak
Mikroműanyagok, FTIR spektroszkópia, mikroműanyag-jellemzés, folyami mikroműanyagok, műanyagszennyezés.

INTRODUCTION
Plastic pollution is a primary global concern, intensified by the steady rise in plastic production. In 2020, global output reached about 380 million tonnes and is expected to exceed 460 million tonnes by 2025 *(Plastics Europe 2024).* Yet nearly one-third of this plastic is mismanaged and ultimately released into natural environments such as rivers, oceans, and soil (*Houssini et al. 2025, URL2, Shahira 2025, URL3*). Owing to their durability, low recycling rates, and inadequate waste treatment, plastics persist for decades, fragmenting into smaller pieces through UV radiation, abrasion, temperature changes, and microbial activity *(Andrady 2011, Barnes et al. 2009, Cole et al. 2011, Crawford and Quinn 2017, Derraik 2002, Hopewell et al. 2009, Moore 2008, Rios et al. 2010, Roy et al. 2011*).

Plastic debris is generally classified by size into mega- (>1 m), macro- (1 m to 2.5 cm), meso- (2.5 mm to 5 mm), micro- (between 1µm to 5 mm, and nanoplastics (<1 µm). Microplastics (MPs, <5 mm) are of particular concern because of their ubiquity and persistence *(Andrady 2011, Cole et al. 2011, Crawford and Quinn 2017, Hartmann et al. 2019, Jahanpeyma and Baranya 2024, Kutz 2002, Moore 2008*). They are categorized as primary MPs, produced intentionally for use in products such as cosmetics and plastic pellets, and secondary MPs, which arise from the breakdown of larger items *(Browne et al. 2011, Cole et al. 2011, NOAA-Marine Debris Program 2009*). MPs enter aquatic and terrestrial environments via wastewater, runoff, and atmospheric deposition, and rivers are the main transport route, carrying an estimated 1.15-2.41 million tonnes of plastic debris annually into marine ecosystems (*Adomat and Grischek 2021, Campanale et al. 2020, Lebreton et al. 2017, Waldschläger et al. 2020*). Key sources of MP pollution include wastewater from laundry (35%), tire wear (28%), construction activities (24%), road markings (7%), shipping and vessel coatings (3.7%), cosmetics (2%), and plastic manufacturing pellets (0.3%) (*Fadare and Okoffo 2020, Jahanpeyma and Baranya 2024*).

The ecological and health risks of MPs are increasingly evident. They have been detected in seafood, bottled water, salt, and honey, while inhalation and dermal exposure are also possible pathways for human intake *(Cook and Halden 2020)*. MPs and their additives may cause toxic effects, ranging from gastrointestinal problems to DNA damage, and they act as carriers for other pollutants and pathogens (*Cook and Halden 2020, Crawford and Quinn 2017, Geyer et al. 2017, Gouin et al. 2011, Hahladakis et al. 2018, House of Commons Environmental Audit Committee 2016, Laist 1997, Marturano et al. 2019, Mato et al. 2001, Ogata et al. 2009, Rios et al. 2007, Teuten et al. 2009, Waldschläger et al. 2020*). In aquatic systems, MPs are ingested by a wide range of species, leading to digestive blockages, reproductive impacts, and behavioral changes *(Cook and Halden 2020, Crawford and Quinn 2017, Geyer et al. 2017, Gouin et al. 2011, Hahladakis et al. 2018, House of Commons Environmental Audit Committee 2016, Laist 1997, Marturano et al. 2019, Mato et al. 2001, Ogata et al. 2009, Rios et al. 2007, Teuten et al. 2009, Waldschläger et al. 2020*). MPs also alter soil structure and microbial communities, reducing seed germination and plant growth (*Boots et al. 2019, Windsor et al. 2019*). Furthermore, plastics exhibit a complex relationship with global warming and are increasingly recognised as potential drivers of global environmental change (*Nel et al. 2018, Revell et al. 2021, Windsor et al. 2019*).

The behavior of MPs in aquatic environments is governed by their size, density, polymer type, and interactions with environmental factors such as flow velocity, salinity, and biofilm development *(Alfonso et al. 2021, Kaiser et al. 2017, Petersen and Hubbart 2021*). Polyethylene and polypropylene often remain buoyant and travel long distances, while denser polymers like PET and PA tend to settle near their sources *(Alfonso et al. 2021, Kaiser et al. 2017, Petersen and Hubbart 2021*). Hydrodynamics, turbulence, and sediment interactions further influence their transport and deposition (*Ballent et al. 2016, He et al. 2021, Nel et al. 2018, Porter et al. 2018, Waldschläger et al. 2020, Hahladakis et al. 2018, Marturano et al. 2019*).

Various sampling strategies have been developed to investigate MPs in aquatic environments, including selective, bulk, and volume-reduced sampling (*Eerkes-Medrano et al. 2015, Frias et al. 2010, Yang et al. 2021*). Net-based methods such as manta or neuston nets (60–300 µm mesh) are widely used in river and marine studies, although methodological differences often complicate cross-study comparisons *(Obbard 2018, Liu et al. 2020, Yang et al. 2021*). Standardization is therefore critical for reliable monitoring and assessment *(Hidalgo-Ruz et al. 2012, Rocchia et al. 2017, Petersen and Hubbart 2021*). The summarized workflow for sampling, preparation, and analysis of microplastic samples, as outlined in *Figure 1*, is constructed based on different methodologies reported in prior studies.

Several European studies highlight the scale of MP contamination in rivers. For instance, research in Portugal and Spain has reported concentrations ranging from a few to over 1,000 particles per cubic meter, with polyethylene and polypropylene as the dominant polymers (*Rodrigues et al. 2018, Díez-Minguito et al. 2020, Bermúdez et al. 2021*). In the Danube, surveys in Austria, Romania, and Hungary found a variety of polymers, with PE, PP, and PS the most common *(Liedermann et al. 2018, Pojar et al. 2021a, Bordos 2021, Braun et al. 2022*). These findings confirm that the Danube is one of the significant pathways for MPs in Europe.

As the continent's second-largest river and an important international waterway, the Danube plays a central role in regional ecosystems and economies. However, limited research has focused specifically on the Hungarian stretch, where urban wastewater, tributary inputs, and industrial activities are likely to intensify MP contamination. This study addresses that gap by conducting detailed sampling along the Hungarian Danube using a Manta Net device combined with Fourier-transform infrared (FTIR) spectroscopy. The aim is to provide quantitative and qualitative insights into MP distribution and composition, to advance understanding of their behavior and to support effective management strategies.

Moreover, the distribution of MPs in river systems is strongly influenced by inputs from tributaries, wastewater treatment plants (WWTPs), and urban proximity. Tributaries contribute MPs based on land use, connectivity, and local activities, particularly those draining urban, industrial, or agricultural regions. WWTPs, as significant point sources, release MPs through effluents and sludge, with smaller particles like fibres and microbeads often bypassing filtration. Urban areas exacerbate MP pollution through stormwater runoff, industrial discharges, and waste mismanagement, creating pollution hotspots near WWTP discharge points or where tributaries join main rivers. In May 2024, a longitudinal sampling campaign was conducted along the Danube River and its tributaries, including the Rába, Marcal, and Mosoni-Duna Rivers, to understand these dynamics better, offering detailed insights into MP sources and distributions.

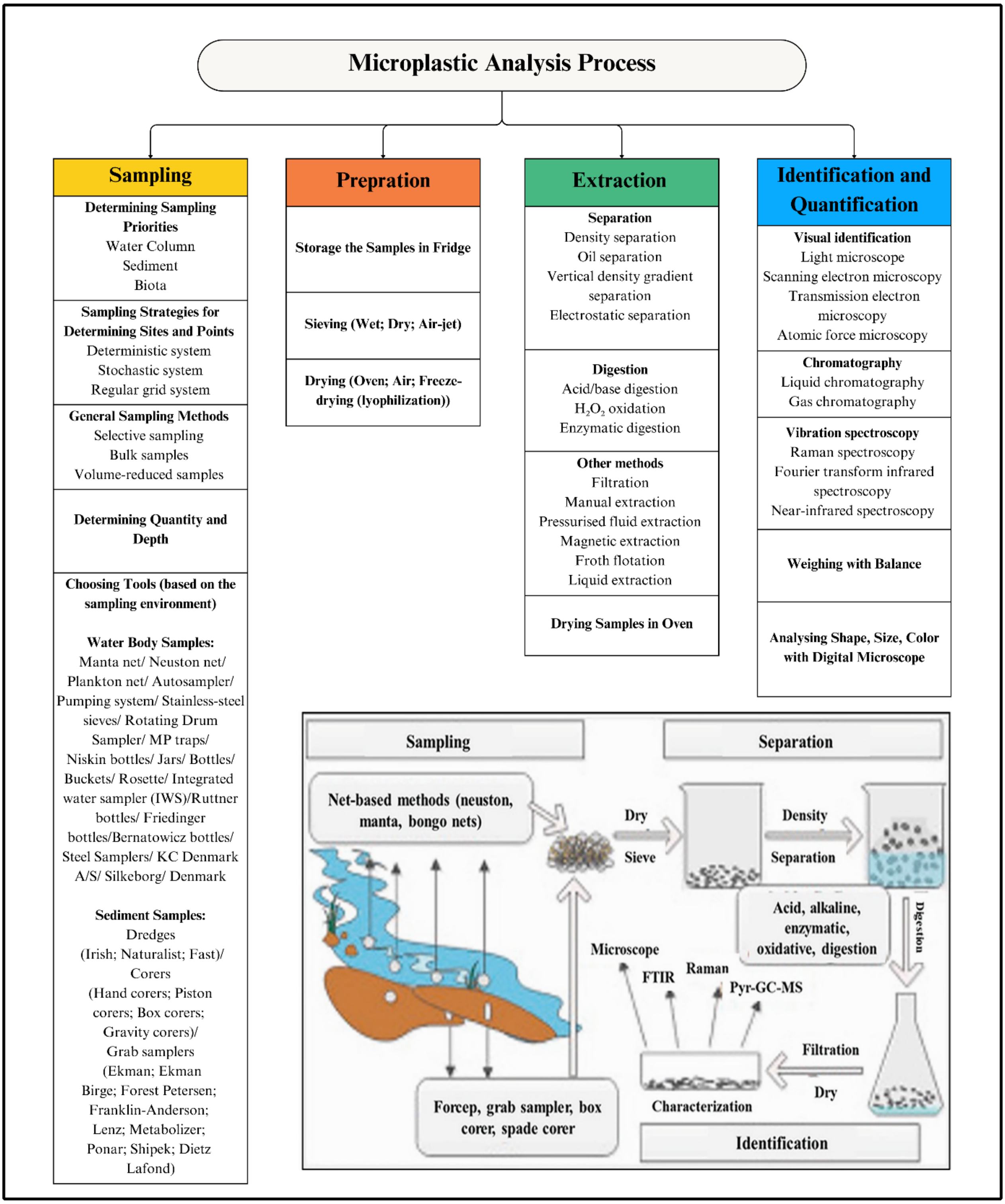

Figure 1. Microplastic sampling and analysis processes
1. ábra. Mikroműanyag mérési és elemzési eljárások

MATERIALS AND METHODS

Field sampling was conducted at two distinct river cross-sections located at 1640+000 rkm and 1642+000 rkm to study microplastic pollution in the Hungarian section of the Danube River in August 2022 and 2023, as shown in *Figure 2*. Water samples were collected from three vertical columns at each cross-section (two sampling points were positioned near the riverbanks, while the third was in the thalweg), with samples taken at three different depths within each column (one from the surface, one near the riverbed, and one at a mid-depth level). This approach ensured a comprehensive representation of the river's vertical profile. Proximity to urban areas, factories, industries, and sewage treatment systems can affect microplastic investigations. The selected cross-sections were chosen for their proximity to the Budapest Central Wastewater Treatment Plant (WWTP), which treats 80% of the city's sewage and discharges effluent into the Danube River (in the thalweg).

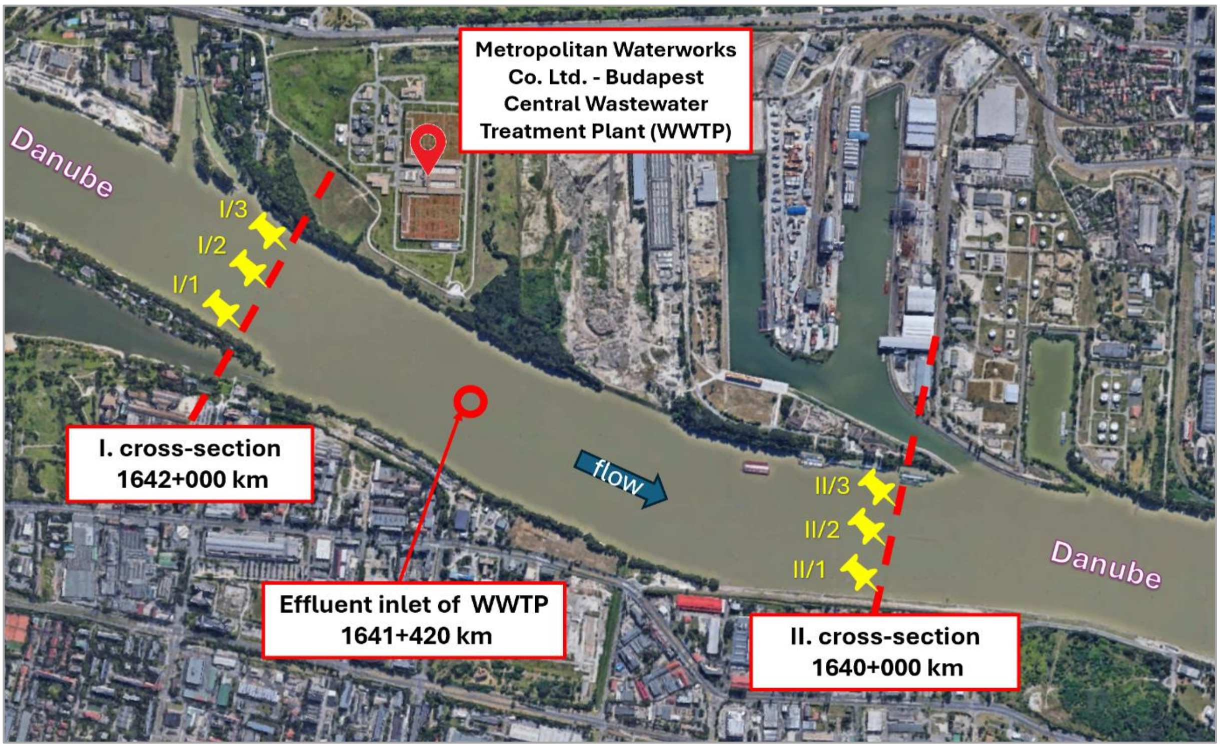

Figure 2. Sampling locations in the Danube River
2. ábra. Mintavételi helyszínek a Dunán

To collect water samples from specific depths within the water column, the Budapest University of Technology and Economics research team developed a specialised device called the Multilevel Manta Net (MLM Net), inspired by previous work conducted by *Liedermann et al. (2018)* on the Austrian stretch of the Danube River (*Liedermann et al. 2018*). The device features three nets positioned at different depths within the water column, suspended vertically using a crane mounted on a boat or a pontoon (*Figure 3*).

Each manta net was built with sturdy metal frames measuring 0.6×0.6 m^2 and featured conical polyamide (PA) nets with a mesh size of 500 µm and a length of 1.5 m. This mesh size captured MP particles ranging from 500 µm to 5 mm. Based on preliminary tests, a 500 µm mesh size was selected as the best compromise between minimizing net clogging and capturing smaller particles. At the end of each conical net, a polyvinyl chloride (PVC) container with a 0.25 m diameter was attached, fitted with a matching net to collect suspended particles from the water. The openings of the manta nets were oriented to align with and face the direction of the river's flow. The nets were fixed at the specified depth by stoppers beneath the net frames. The horizontal position of the nets was provided by blades attached to the ends of the rods attached to the frames. The nets were submerged in the water for 30 minutes. Afterwards, the nets were lifted and rinsed thoroughly using high-pressure clear water. The material and sediments gathered in the bottom container were transferred to a container, taken to the laboratory for analysis, and refrigerated until further steps.

In addition to gaining a deeper understanding of the dynamics of MPs in river systems influenced by tributaries, urban proximity, and other factors, a longitudinal sampling campaign was conducted along the Danube River and its tributaries in 2024. The study included the Rába River (7 samples collected), the Marcal River (8 samples collected), the Mosoni-Duna River (7 samples collected), and the Danube River itself (20 samples collected), providing detailed insights into MP sources and distribution patterns.

For the Rába, Marcal, and Mosoni-Duna Rivers, sampling was performed on the water surface using a portable Manta Net with a frame measuring 0.12 m × 0.35 m and a 0.70 m long conical net equipped with a 1 000 µm mesh to capture suspended particles. In contrast, the Danube samples were collected using MLM nets, as previously described. Sampling was conducted over 20 minutes, with the collected samples stored in containers and transported to the laboratory for further analysis.

A high-frequency, 1200-kHz Acoustic Doppler Current Profiler (ADCP) device from Teledyne was used to measure the water flow discharge and velocity. However, since the ADCP measurements were less accurate within 0.5 m of the riverbed, an Acoustic Doppler Velocimeter (ADV) device was attached to a net positioned close to the bed for more precise data collection.

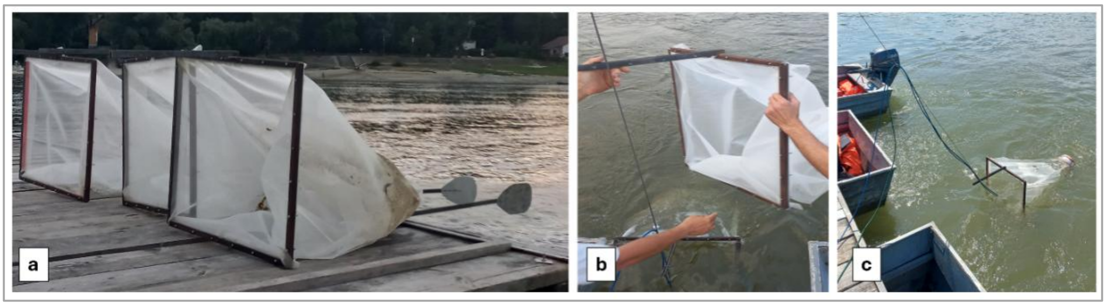

Figure 3. a) Multilevel Manta Net device. b,c) Manta nets are placed in the water column
3. ábra. a) Többszintű hálós mintavételi eszköz. b,c) Planktonhálók beeresztése a függélyben

In the laboratory, preliminary steps were taken to separate and analyse microplastic particles (*Figure 4*). The collected samples were placed in beakers containing a saturated sodium chloride (NaCl) solution and left to settle for 24 hours to separate denser materials from the samples, which were less likely to be plastics. The floating particles and possible plastic particles were carefully collected, and the samples were immersed in a 35% hydrogen peroxide (H_2O_2) solution for at least 24 hours to clean the plastic particles and remove organic materials and microorganisms. The floating particles were carefully collected and dried in an oven at 40°C for 24 hours to remove moisture. The dried samples were then sieved, isolating particles smaller than 5 mm for further analysis. Visible plastic particles were carefully removed from the samples using tweezers and transferred to Petri dishes for further study. To ensure accuracy, only visible particles were included, while fibres or particles too small to be identified by the naked eye were excluded at this stage.

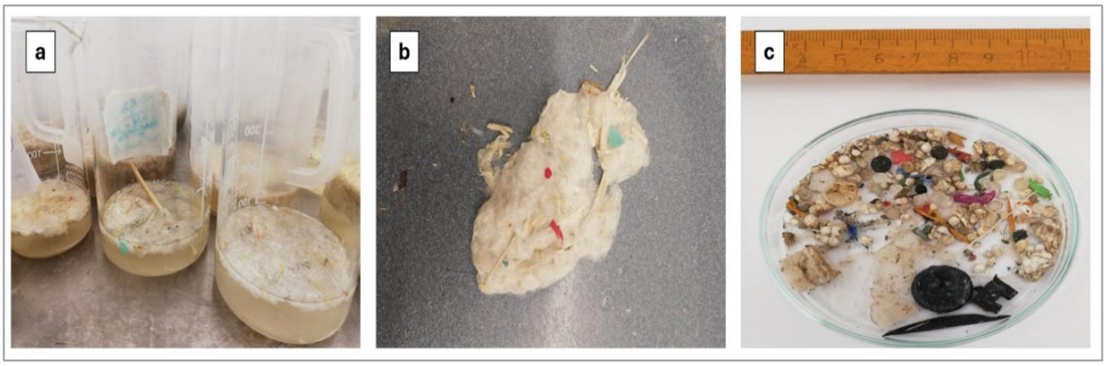

Figure 4. a) Sample purification process. The collected samples were subjected to a 24-hour immersion in a 35% H_2O_2 solution. b) Sample after laying in NaCl and H_2O_2 and drying in the oven. c) MPs extracted from one sample
4. ábra. a) Minta tisztítási folyamata. A begyűjtött mintákat 24 órán át 35%-os H_2O_2-oldatba merítették. b) A minta NaCl- és H_2O_2-kezelés, majd kemencében történő szárítás után. c) Egy mintából kivont mikroműanyagok (MP-k)

The MP polymer types were identified using a Bruker Tensor 37 FTIR spectrometer (with an attenuated total reflection attachment, 400–4000 cm^{-1} wavenumber range, 2 cm^{-1}resolution, and 16 scans per sample (*Figure 5a*). The FTIR technique works by analysing the light absorption spectrum emitted by the sample, which reveals the energy characteristics of chemical bonds within the material. Each polymer has a unique energy absorption pattern, enabling the differentiation and identification of polymer types through comparison with a spectral library stored in the instrument.

A digital microscope (Keyence VH-Z20UR, 20x-200x) was employed to measure the MPs' size, shape, and colour (*Figure 5b*). The total mass of the collected MPs was weighed and recorded by using an exact digital balance (Shimadzu AUW120D semi-micro analytical balance, with accuracy levels of ±0.01 mg for weights up to 42 g and ±0.1 mg for weights up to 120 g).

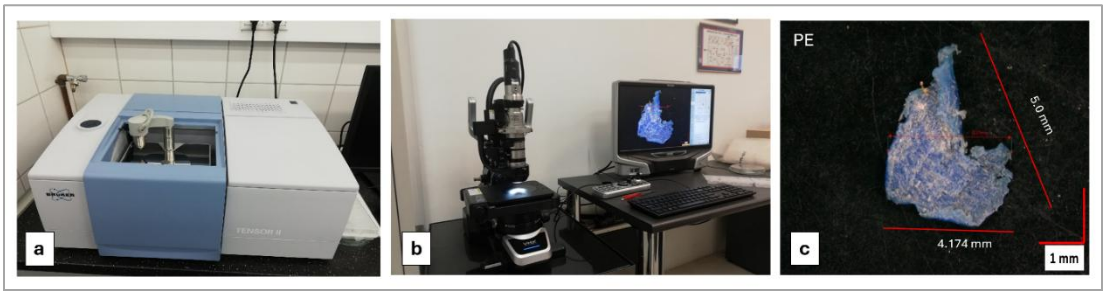

Figure 5. a) FTIR spectroscopy device. b) Digital microscope. c) MP particle under the digital microscope for shape, size, and colour analysis
5. ábra a) FTIR-spektroszkópiai eszköz. b) Digitális mikroszkóp. c) MP-részecske a digitális mikroszkóp alatt az alak, méret és szín elemzéséhez

RESULTS

The MP concentration (C_{MP}) and transport rate (q_{MP}) were determined at specific points within the study area. The C_{MP} was calculated by dividing the MP sample mass (m) in kg (or number of MP particles) by the volume of water passing through the designated sections (i.e., the volume of the filtered water, V) in m^3. V was estimated by multiplying the net entrance area (A) in m^2, flow velocity (v) in m/s, and sampling time (t) in s.

Mass-based unit methods offer a more reliable approach to quantifying C_{MP} (g/m^3) in environmental samples than particle counting alone (particles/m^3). By accounting for particle size, composition, and density variations, this method provides a more comprehensive and accurate assessment of the total plastic load within a sample. For instance, in two samples with an identical number of microplastics, variations in the density and size of the particles can lead to significant differences in the actual estimation of plastic pollution amounts.

The q_{MP} was calculated by multiplying the concentration of plastic material by the water flow rate, which was measured with the ADCP device during the sampling. The flow discharge was 1 500 m^3/s in 2022, and 2,126 m^3/s in 2023. The results from the experimental trials and subsequent calculations are presented in *Table 1*.

Table 1. The MP delivery rate (q_{MP}) and concentration (C_{MP}) at each sampling point (#) in two cross-sections in 2022 and 2023, (s: surface of water, m: middle level of water column, b: near bed)

1. táblázat. Az MP-szállítási sebesség (qMP) és koncentráció (CMP) az egyes mintavételi pontokon (#) két keresztmetszetben, 2022-ben és 2023-ban (s: a vízfelszín, m: a vízoszlop középső szintje, b: a mederhez közeli szint)

Year	Cross-section	# of points	Flow Velocity (m^3/s)	Filtered volume (m^3)	MP mass (g)	MP amount (particle)	CMP (µg/m^3)	qMP (mg/m^2 h)	CMP (particle/m^3)	qMP (particle/m^2 s)
2022	I	1-s	1.18	765.38	0.14897	24	195	828	31.36	37.04
		1-m	1.10	710.69	0.00204	11	3	11	15.478	16.98
		1-b	0.45	291.60	0.01366	18	27	76	61.73	27.78
		2-s	1.25	821.15	0.16471	147	201	900	179.02	223.13
		2-m	1.12	738.47	-	-	-	-	-	-
		2-b	1.06	698.33	0.02906	31	42	159	44.39	47.06
		3-s	1.23	795.75	0.08484	40	107	471	50.27	61.73
		3-m	1.11	717.34	0.03913	21	55	217	29.27	32.41
		3-b	0.70	451.35	0.05913	32	131	329	70.90	49.38
	II	1-s	1.13	743.71	0.05032	64	68	276	86.05	97.66
		1-m	1.05	688.40	0.13952	25	203	767	36.32	38.15
		1-b	0.91	596.36	0.02298	41	39	126	68.75	62.56
		2-s	1.48	980.37	0.01741	21	18	95	21.42	31.70
		2-m	1.31	865.25	0.03458	24	40	188	27.74	36.23
		2-b	1.07	708.85	0.02268	54	32	123	76.18	81.51
		3-s	1.31	846.43	0.25643	41	303	1 425	48.44	63.27
		3-m	1.20	779.17	0.09083	63	117	505	80.86	97.22
		3-b	0.75	486.00	0.22761	113	468	1 264	232.51	174.38
2023	II	1-s	1.13	735	1.03	319	1,398	1,975.1	433.79	492.28
		1-m	1.05	681	0.41	190	598	723.8	279.13	293.21
		1-b	0.79	513	0.37	193	719.9	495	376.21	297.84
		2-s	1.82	1,176	0.33	114	277.1	1,001.9	96.91	175.93
		2-m	1.69	1,097	0.26	114	234.9	738.9	103.89	175.93
		2-b	1.27	820	0.34	115	417.1	733.7	140.16	177.47
		3-s	1.56	1,009	0.12	123	114.8	305.6	121.86	189.81
		3-m	1.40	910	0.27	104	296.8	641.7	114.32	160.49
		3-b	0.87	566	0.24	167	425.1	355.4	295.23	257.72

The average C_{MP} and q_{MP} in each cross-sectional area of a specific vertical and the total cross-section Q_{MP} were calculated in 2022 and 2023 using sedimentation engineering methods. Q_{MP} was calculated by integrating the particular q_{MP} along the total cross-sectional area and summing up for a given period (e.g., g/s, t/year). The results are presented in *Table 2*.

Table 2. The average MP concentration and transport rate in two cross-sections and the overall area in 2022 and 2023 under the specified flow rate and condition
2. táblázat. Az átlagos MP-koncentráció és szállítási sebesség két keresztmetszetben és a teljes vizsgált területen 2022-ben és 2023-ban, a meghatározott vízhozam és feltételek mellett.

Year of sampling	Cross-section	Flow rate	The average MP concentration (CMP,avg)		The average MP transport rate (qMP,avg)	The total MP transport rate (QMP)		
		m^3/s	$\mu g/m^3$	Particle/m^3	mg/s	g/s	kg/day	t/year
2022	I	1,500	104	54	156	0.2	16.2	6
	II	1,500	143	75	215			
2023	II	2,126	498	218	1,059	1.06	91.5	33.39

FTIR analysis identified the polymer types in the collected samples, providing insights into their potential sources. The findings suggest that inadequate recycling and storage practices may play a significant role in releasing these materials into surface water bodies. Those listed in *Table 3* were found in the highest concentrations among the identified polymers. Their potential sources are also outlined in the table. Among the various polymers identified, PS, PE, and PP were found to be the most abundant.

Table 3. The types of MP polymers identified in the collected samples through FTIR analysis and their potential sources
3. táblázat. Az FTIR-elemzéssel a begyűjtött mintákban azonosított MP-polimertípusok és azok lehetséges forrásai

Polymer Type	Polymer Type abbreviation	Amount (%)	Possible Source
Polystyrene	PS	37.97	In packaging and construction insulation
Polyethylene	PE	18.15	In the plastic bag and shampoo bottle production
Polypropylene	PP	10.96	Commonly used in packaging and food storage containers
other polymers		24.66	
Thermoplastic Vulcanizates	TPV	4.20	Used in automotive components, building and construction products, household appliance parts, and electrical components
Polyamide (commonly known as nylon)	PA	2.03	Used in textiles, the automotive industry, carpets, kitchen utensils, and sportswear
Styrene-Ethylene-Butylene-Styrene	SEBS	1.03	Used in items such as grips, handles, bumpers, and other requiring soft-touch and medical devices
High-Density Polyethylene	HDPE	0.85	Used in the production of plastic bottles, corrosion-resistant piping, geomembranes, and plastic lumber
Polyethylene terephthalate	PET	0.04	Used in bottle manufacturing
Thermoplastic Elastomer/Thermal Plastic Styrene	TPE/TPS	0.07	Used in toothbrushes, dashboards, and cable covers
Polyvinyl chloride	PVC	0.04	Used in pipe and floor covering production, and cable insulation

A detailed microscopic analysis was performed on the collected samples to assess MP particle size distribution. *Figure 6* illustrate the observed particle size, shape, and colour diversity. The study revealed that the predominant MP particle shapes were fragments, fibres, foams, and flakes. The most frequently identified colours among the particles were yellow, black, semi-yellow, grey, and green.

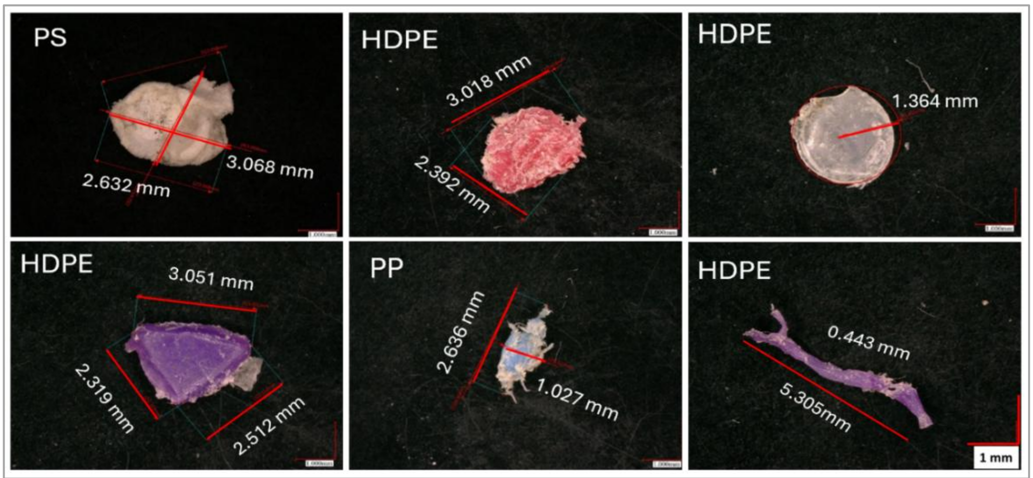

Figure 6. MP particles with different sizes, colours, and polymer types under a digital microscope
6. ábra. Különböző méretű, színű és polimer típusú MP-részecskék digitális mikroszkóp alatt

Based on the results of the longitudinal sampling campaign conducted in May 2024 along the Danube River and its tributaries, the spatial distribution of microplastic (MP) concentrations reflects distinct patterns shaped by anthropogenic pressures and hydrological features. As shown in *Figure 7*, the Danube exhibits significantly higher MP concentrations compared to its tributaries, with the most pronounced pollution hotspots located downstream of wastewater treatment plants (WWTPs) and urban areas. These regions are critical sources of MPs, mainly due to stormwater runoff, industrial discharges, and WWTP effluent, which contribute substantial MP loads to the river system. Tributaries such as the Rába and Marcal Rivers present varying MP levels, which are influenced by their land use, including agricultural activities and smaller-scale urbanisation in their catchments. The Mosoni-Duna tributary, in particular, plays a notable role, with the floodgate influencing MP transport and deposition patterns, as indicated by localised shifts in concentration levels. These findings highlight the complex interplay between tributary inflows, urban pressures, and point-source discharges in shaping MP distribution within the Danube River system. Understanding the relative contributions of these factors is crucial for developing targeted strategies to mitigate MP pollution, particularly at critical junctions where tributaries merge with the main river. This study underscores the importance of continued monitoring and tailored interventions to address the challenges posed by MP pollution in large riverine networks.

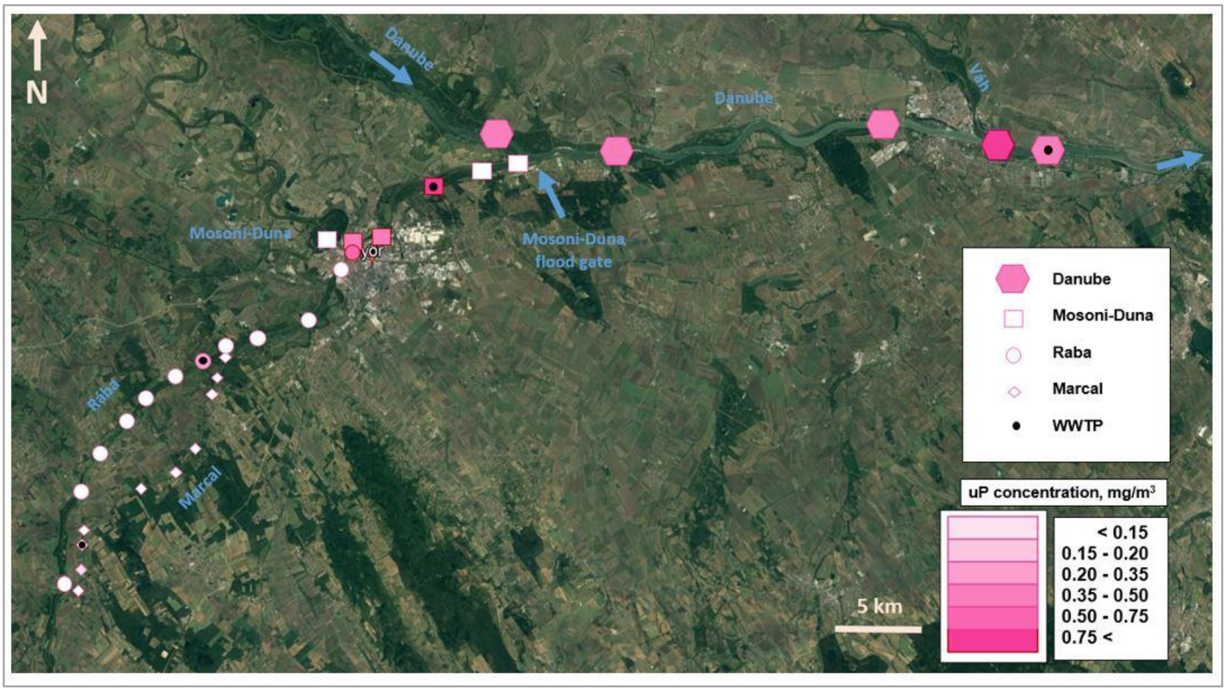

Figure 7. Spatial distribution of microplastic (MP) concentrations (mg/m³) along the Danube River and its tributaries, including the Mosoni-Duna, Rába, and Marcal rivers, based on the 2024 longitudinal sampling campaign
7. ábra: A mikroműanyag (MP) koncentrációk térbeli eloszlása (mg/m³) a Duna és mellékfolyói, köztük a Mosoni-Duna, a Rába és a Marcal folyók mentén, a 2024-es longitudinális mintavételi kampány alapján

DISCUSSION

To capture and analyse smaller MP particles, including microfibers, effectively, our findings align with prior research indicating that rivers serve as key pathways for transporting plastic pollutants to seas and oceans, contributing significantly to global plastic pollution. Studies estimate that rivers deliver between 1.15 and 4 million metric tons of plastic to the ocean annually, underscoring their critical role in this environmental issue (*Pojar et al. 2021a*). The Danube River is a major contributor to plastic pollution in the Black Sea, transporting significant amounts of MPs and other plastic debris *(Pojar et al. 2021a, Pojar et al. 2021b*). The Danube River begins in Germany and flows through Austria, Hungary, and Romania before discharging into the Black Sea. Estimates suggest that the Danube carries approximately 4.2 tons of plastic daily, amounting to an annual load of 1,533 tons delivered to the Black Sea (*Lechner et al. 2014*). Given the Danube River's critical role in Budapest as a vital waterway, a key water source, and a cornerstone of the region's tourism, economy, and ecological balance, studying plastic pollution in this river is essential.

Between 2010 and 2012, researchers from the University of Vienna and the University of Natural Resources and Life Sciences Vienna (BOKU) studied the Austrian section of the Danube River, downstream of Vienna, using the MLM Net device (*Liedermann et al. 2018*). Their analysis reported an average plastic concentration exceeding 17 particles/m³ (*Liedermann et al. 2018*). A follow-up survey in 2014 at two Austrian sampling sites estimated an annual Q_{MP} of up to 17 tonnes at Hainburg, with a total plastic load reaching 41 tonnes per year at the same location (*URL1 2019, Liedermann et al. 2018*).

Within the framework of the Tiny Plastic Puzzle project by Wessling Hungary Ltd., C_{MP} was assessed in Budapest. Measurements revealed a concentration of 45 particles/m³ at the Megyeri Bridge in the northern section of the city, which was lower than the 55 particles/m³ recorded at the Csepel Freeport in the southern part of

Budapest (*URL1 2019, Kiss et al. 2021*). These results align closely with our findings for the region. Data collected as part of our study confirm the presence of MPs in the Danube River, with notable variability in concentrations depending on sampling locations and conditions. For instance, upstream and downstream measurements near the Budapest Central WWTP in the Csepel area highlighted the influence of urban runoff and untreated effluents on MP pollution. In 2022, C_{MP} upstream of the WWTP in Budapest was recorded at approximately 54 particles/m³, increasing to 75 particles/m³ downstream. By 2023, these levels had risen substantially, reaching 218 particles/m³ downstream, likely due to increasing anthropogenic activity, changes in sampling conditions, or changes in hydrological and hydraulic factors. Our results highlight the pronounced heterogeneity of MP occurrence within the Danube. Concentrations varied strongly across cross-sections, depths, and sampling periods (*Table 1*), with surface values occasionally an order of magnitude higher or lower than mid- or bottom samples. Such variability reflects the dynamic interplay of hydrodynamic conditions, particle properties, and point-source inputs. Similar findings have been reported in other large rivers, where near-bed samples often contain more MPs due to resuspension processes (*Liedermann et al. 2018; Mani et al. 2015*). Seasonal factors such as rainfall and discharge fluctuations also contribute to irregular distribution patterns (*Moses et al. 2023, Nguyen et al. 2024*). This heterogeneity complicates both sampling and upscaling, underscoring the importance of multi-depth and multi-point approaches in future monitoring strategies.

The distribution of MPs within the water column was assessed using specialised sampling techniques. However, several factors suggest that our findings may underestimate actual C_{MP}. Limitations in sampling, such as using nets with a 500 µm mesh size, restrict the detection of smaller particles, including microfibers and transparent MPs, which are difficult to identify visually. Furthermore, purification processes and laboratory methods can inadvertently degrade or fragment MPs, affecting the accuracy of results. Regarding the laboratory procedures, the margin of error was found to be negligible. Bulk sampling methods, such as pump sampling, are highly recommended to capture and analyse smaller MP particles, including microfibers effectively. These approaches improve sensitivity and accuracy in detecting and characterising these minute particles. It is worth noting that pump sampling involves distinct methodologies, which fall beyond the scope of this article for detailed discussion. Research in this area has been conducted by our team using both the net sampling and pump sampling methods, with the results to be presented in future publications.

The composition of MPs observed in this study primarily consisted of fragmented particles, which is consistent with other studies that report fragments as the dominant form of MPs in river systems. However, fibres, which are frequently associated with textile and wastewater sources, were underrepresented, likely due to methodological constraints. Future investigations should employ alternative techniques, such as pump sampling, to better capture smaller particles and fibres. Various factors, including urban runoff, WWTPs, and geomorphological features, influence microplastic pollution in the Danube River system. The most frequently identified polymers in our study were PS (37.97%), PE (18.15%), and PP (10.96%), consistent with findings from other studies in the region. These polymers, often associated with packaging and household waste, highlight the significant role of urban centres as sources of MP pollution.

Although our study focused exclusively on MPs in the water column, sediment sampling is essential for a comprehensive understanding of MP dynamics in the Danube River system. Sediments act as sinks where MPs accumulate and are resuspended under certain conditions, influencing their transport and deposition downstream. Existing studies highlight significant MP accumulation in upstream impoundments, floodplains, and coastal sediments, particularly in areas with reduced sediment flux caused by river regulation and hydropower activities. The inclusion of sediment analysis in future studies will provide valuable insights into the interplay between MP deposition and resuspension processes.

In conclusion, our study underscores the complexity of MP pollution in riverine systems, influenced by diverse sources and environmental processes. Addressing these challenges requires methodological advancements to capture a broader spectrum of MP types and sizes. Future research should prioritise integrating water and sediment sampling to provide a more holistic view of MP transport and accumulation within the Danube River and its contribution to marine pollution in the Black Sea.

CONCLUSION

This research evaluated MP pollution in the Hungarian section of the Danube River, addressing rising concerns about MPs' environmental and health impacts. A structured sampling and analysis methodology was developed, inspired by established approaches, to obtain robust data on MP prevalence. Water samples were collected using an MLM net with a 500 µm mesh, allowing for systematic assessment of MP concentrations across varying depths. This study collected and identified microplastic particles ranging from 5 mm to 500 µm through visual inspection. Laboratory protocols facilitated the isolation and identification of MPs, followed by FTIR spectroscopy to characterise polymer types and potential sources.

Results from 2022 revealed an average MP concentration of 124 µg/m³ (65 particles/m³), equalling approximately 0.2 g/s, or 16.2 kg/day, and around 6 tons/year of MPs passing through the investigated area. In 2023, these values increased significantly, with a mean concentration of 498 µg/m³ (218 particles/m³), corresponding to 1.06 g/s, 91.5 kg/day, and approximately 33.39 tons/year. MPs detected near the riverbed might point to a potential tendency for accumulation through deposition, a hypothesis that requires confirmation in future studies. The most prevalent polymers identified were PS (37.97%), PE (18.15%), and PP (10.96%), appearing in various forms such as fragments, foam, and flakes, and in colours like yellow, black, grey, and green.

It is important to note that these estimates are conservative. Factors such as flow rate variability, sampling methods, mesh size limitations, and the inability to visually identify certain particles influence the results. For instance, smaller particles like microfibers and microbeads may not be captured. For smaller microplastic particles (<500 µm), future studies are encouraged to employ methods such as pump-based sampling to improve capture efficiency.

This study underscores the urgent need for effective mitigation strategies and policy interventions to address MP pollution. Raising awareness about MPs' pervasive nature and potential risks remains a critical step towards safeguarding aquatic ecosystems and human health.

ACKNOWLEDGEMENT

We extend our gratitude to the technician team at Budapest University of Technology and Economics, particularly Mr. Károly Tóth, Mr. István Galgóczy, and Mr. András Miklós Rehák, for their valuable technical assistance, which made this research possible. The authors would like to express their heartfelt gratitude to their esteemed colleagues, Dr. Flóra Pomázi, Dr. Alexander Anatol Ermilov, Anna Szöllősi, Dr. Dániel Gere, and Dr. Andrea Toldy, for their invaluable contributions, insightful discussions, and continuous support throughout this research. Their expertise and collaborative efforts have been instrumental in completing this study. The research presented in the article was carried out within the framework of the Széchenyi Plan Plus program with the support of the RRF 2.3.1 21 2022 00008 project. The support of the OTKA K 143623 and PD146135 projects is greatefully acknowledged.

REFERENCES

Adomat, Y., Grischek, T. (2021). Sampling and processing methods of microplastics in river sediments - A review. In Science of the Total Environment. Vol. 758. Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2020.143691

Alfonso, M.B., Arias, A.H., Ronda, A.C., Piccolo, M.C. (2021). Continental microplastics: Presence, features, and environmental transport pathways. In Science of the Total Environment. Vol. 799. Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2021.149447

Andrady, A.L. (2011). Microplastics in the marine environment. In Marine Pollution Bulletin.Vol. 62, Issue 8, pp. 1596-1605. https://doi.org/10.1016/j.marpolbul.2011.05.030

Ballent, A., Corcoran, P.L., Madden, O., Helm, P.A., Longstaffe, F. J. (2016). Sources and sinks of microplastics in Canadian Lake Ontario nearshore, tributary, and beach sediments. Marine Pollution Bulletin, 110(1), pp. 383-395. https://doi.org/10.1016/j.marpolbul.2016.06.037

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), pp. 1985-1998. https://doi.org/10.1098/rstb.2008.0205

Bermúdez, M., Vilas, C., Quintana, R., González-Fernández, D., Cózar, A., Díez-Minguito, M. (2021). Unravelling spatio-temporal patterns of suspended microplastic concentration in the Natura 2000 Guadalquivir estuary (SW Spain): Observations and model simulations. Marine Pollution Bulletin, 170. https://doi.org/10.1016/j.marpolbul.2021.112622

Boots, B., Russell, C.W., Green, D.S. (2019). Effects of Microplastics in Soil Ecosystems: Above and below Ground. Environmental Science and Technology, 53(19), 11496-11506. https://doi.org/10.1021/acs.est.9b03304

Bordos, G. (2021). Investigation of microplastics in the environment. Hungarian University of Agriculture and Life Science.

Braun, U., Kittner, M., Kerndorff, A., Ricking, M., Bednarz, M., Obermaier, N., Lukas, M., Asenova, M., Bordós, G., Eisentraut, P., Hohenblum, P., Hudcova, H., Humer, F., István, T. G., Kirchner, M., Marushevska, O., Nemejcová, D., Oswald, P., Paunovic, M., ... G. Bannick, C. (2022). Microplastics in the Danube River Basin: A First Comprehensive Screening with a Harmonized Analytical Approach. ACS ES and T Water, 2(7), pp.174-1181. https://doi.org/10.1021/acsestwater.1c00439

Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., Thompson, R. (2011). Accumulation of microplasticson shorelines woldwide: Sources and sinks. Environmental Science and Technology, 45(21), pp. 9175-9179. https://doi.org/10.1021/es201811s

Campanale, C., Stock, F., Massarelli, C., Kochleus, C., Bagnuolo, G., Reifferscheid, G., Uricchio, V.F. (2020). Microplastics and their possible sources: The example of Ofanto river in southeast Italy. Environmental Pollution, 258. https://doi.org/10.1016/j.envpol.2019.113284

Cole, M., Lindeque, P., Halsband, C., Galloway, T.S. (2011). Microplastics as contaminants in the marine environment: A review. In Marine Pollution Bulletin. Vol. 62, Issue 12, pp. 2588-2597. https://doi.org/10.1016/j.marpolbul.2011.09.025

Cook, C.R., Halden, R.U. (2020). Ecological and health issues of plastic waste. In Plastic Waste and Recycling, pp. 513-527. Elsevier. https://doi.org/10.1016/b978-0-12-817880-5.00020-7

Crawford, C.B., Quinn, B. (2017). Microplastic pollutants. Elsevier. https://doi.org/https://doi.org/10.1016/c2015-0-04315-5

Derraik, B. (2002). The pollution of the marine environment by plastic debris: a review. https://doi.org/https://doi.org/10.1016/s0025-326x(02)00220-5

Díez-Minguito, M., Bermúdez, M., Gago, J., Carretero, O., Viñas, L. (2020). Observations and idealised modelling of microplastic transport in estuaries: The exemplary case of an upwelling system (Ría de Vigo, NW Spain). Marine Chemistry, 222. https://doi.org/10.1016/j.marchem.2020.103780

Eerkes-Medrano, D., Thompson, R.C., Aldridge, D.C. (2015). Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritisation of research needs. In Water Research, Vol. 75, pp. 63-82. Elsevier Ltd. https://doi.org/10.1016/j.watres.2015.02.012

Fadare, O.O., Okoffo, E.D. (2020). Covid-19 face masks: A potential source of microplastic fibers in the environment. Science of the Total Environment, 737. https://doi.org/10.1016/j.scitotenv.2020.140279

Frias, J.P.G.L., Sobral, P., Ferreira, A.M. (2010). Organic pollutants in microplastics from two beaches of the Portuguese coast. Marine Pollution Bulletin, 60(11), pp. 1988-1992.
https://doi.org/10.1016/j.marpolbul.2010.07.030

Geyer, R., Jambeck, J.R., Law, K.L. (2017). Production, use, and fate of all plastics ever made. https://doi.org/10.1126/sciadv.1700782

Gouin, T., Roche, N., Lohmann, R., Hodges, G. (2011). A thermodynamic approach for assessing the environmental exposure of chemicals absorbed to microplastic. Environmental Science and Technology, 45(4), pp. 1466-1472. https://doi.org/10.1021/es1032025

Hahladakis, J.N., Velis, C.A., Weber, R., Iacovidou, E., Purnell, P. (2018). An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. In Journal of Hazardous Materials, Vol. 344, pp. 179-199. Elsevier B.V. https://doi.org/10.1016/j.jhazmat.2017.10.014

Hartmann, N.B., Hüffer, T., Thompson, R.C., Hassellöv, M., Verschoor, A., Daugaard, A.E., Rist, S., Karlsson, T., Brennholt, N., Cole, M., Herrling, M.P., Hess, M.C., Ivleva, N.P., Lusher, A.L., Wagner, M. (2019). Are We Speaking the Same Language? Recommendations for a Definition and Categorization Framework for Plastic Debris. Environmental Science and Technology, 53(3), pp. 1039-1047. https://doi.org/10.1021/acs.est.8b05297

He, B., Smith, M., Egodawatta, P., Ayoko, G.A., Rintoul, L., Goonetilleke, A. (2021). Dispersal and transport of microplastics in river sediments. Environmental Pollution, 279.
https://doi.org/10.1016/j.envpol.2021.116884

Hidalgo-Ruz, V., Gutow, L., Thompson, R.C., Thiel, M. (2012). Microplastics in the marine environment: A review of the methods used for identification and quantification. Environmental Science and Technology, 46(6), pp. 3060-3075. https://doi.org/10.1021/es2031505

Hopewell, J., Dvorak, R., Kosior, E. (2009). Plastics recycling: Challenges and opportunities. In Philosophical Transactions of the Royal Society B: Biological Sciences, Vol. 364, Issue 1526, pp. 2115-2126. Royal Society. https://doi.org/10.1098/rstb.2008.0311

House of Commons Environmental Audit Committee (2016). Environmental impact of microplastics Fourth Report of Session 2016-17.

Houssini, K., Li, J., Tan, Q. (2025). Complexities of the global plastics supply chain revealed in a trade-linked material flow analysis. Communications Earth and Environment, 6(1). https://doi.org/10.1038/s43247-025-02169-5

Jahanpeyma, P., Baranya, S. (2024). A Review of Microplastic Identification and Characterization Methods in Aquatic Environments. Periodica Polytechnica Civil Engineering. https://doi.org/10.3311/ppci.22886

Kaiser, D., Kowalski, N., Waniek, J.J. (2017). Effects of biofouling on the sinking behaviour of microplastics. Environmental Research Letters, 12(12). https://doi.org/10.1088/1748-9326/aa8e8b

Kiss, T., Fórián, S., Szatmári, G., Sipos, G. (2021). Spatial distribution of microplastics in the fluvial sediments of a transboundary river – A case study of the Tisza River in Central Europe. Science of the Total Environment, 785.
https://doi.org/10.1016/j.scitotenv.2021.147306

Kutz, M. (2002). Handbook of Materials Selection. J. Wiley.
https://doi.org/https://doi.org/10.1002/9780470172551

Laist, D.W. (1997). Impacts of Marine Debris: Entanglement of Marine Life in Marine Debris Including a Comprehensive List of Species with Entanglement and Ingestion Records. Springer Series on Environmental Management. Springer, New York, NY. https://doi.org/https://doi.org/10.1007/978-1-4613-8486-1_10

Lebreton, L.C.M., Van Der Zwet, J., Damsteeg, J.W., Slat, B., Andrady, A., Reisser, J. (2017). River plastic emissions to the world's oceans. Nature Communications, 8. https://doi.org/10.1038/ncomms15611

Lechner, A., Keckeis, H., Lumesberger-Loisl, F., Zens, B., Krusch, R., Tritthart, M., Glas, M., Schludermann, E. (2014). The Danube so colourful: A potpourri of plastic litter outnumbers fish larvae in Europe's second largest river. Environmental Pollution, 188, pp. 177-181. https://doi.org/10.1016/j.envpol.2014.02.006

Liedermann, M., Gmeiner, P., Pessenlehner, S., Haimann, M., Hohenblum, P., Habersack, H. (2018). A methodology for measuring microplastic transport in large or medium rivers. Water (Switzerland), 10(4). https://doi.org/10.3390/w10040414

Liu, K., Courtene-Jones, W., Wang, X., Song, Z., Wei, N., Li, D. (2020). Elucidating the vertical transport of microplastics in the water column: A review of sampling methodologies and distributions. In Water Research, Vol. 186. Elsevier Ltd.
https://doi.org/10.1016/j.watres.2020.116403

Mani, T., Hauk, A., Walter, U., Burkhardt-Holm, P. (2015). Microplastics profile along the Rhine River. Scientific Reports, 5. https://doi.org/10.1038/srep17988

Marturano, V., Cerruti, P., Ambrogi, V. (2019). Polymer additives. Physical Sciences Reviews, 2(6). https://doi.org/10.1515/psr-2016-0130

Mato, Y., Isobe, T., Takada, H., Kanehiro, H., Ohtake, C., Kaminuma, T. (2001). Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. Environmental Science and Technology, 35(2), p. 318-324. https://doi.org/10.1021/es0010498

Moore, C.J. (2008). Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. Environmental Research, 108(2), pp. 131-139. https://doi.org/10.1016/j.envres.2008.07.025

Moses, S.R., Löder, M.G.J., Herrmann, F., Laforsch, C. (2023). Seasonal variations of microplastic pollution in the German River Weser. Science of the Total Environ-ment, 902. https://doi.org/10.1016/j.scitotenv.2023.166463

Nel, H.A., Dalu, T., Wasserman, R.J. (2018). Sinks and sources: Assessing microplastic abundance in river sediment and deposit feeders in an Austral temperate urban river system. Science of the Total Environment, 612, pp. 950-956. https://doi.org/10.1016/j.scitotenv.2017.08.298

Nguyen, T.T., Bui, V.H., Lebarillier, S., Vu, T.K., Wong-Wah-Chung, P., Fauvelle, V., Malleret, L. (2024). Spatial and seasonal abundance and characteristics of microplastics along the Red River to the Gulf of Tonkin, Vietnam. Science of the Total Environment, 957. https://doi.org/10.1016/j.scitotenv.2024.177778

NOAA-Marine Debris Program (2009). Proceedings of the International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris. www.MarineDebris.noaa.gov

Obbard, R.W. (2018). Microplastics in Polar Regions: The role of long-range transport. In Current Opinion in Environmental Science and Health, Vol. 1, pp. 24-29. Elsevier B.V. https://doi.org/10.1016/j.coesh.2017.10.004

Ogata, Y., Takada, H., Mizukawa, K., Hirai, H., Iwasa, S., Endo, S., Mato, Y., Saha, M., Okuda, K., Nakashima, A., Murakami, M., Zurcher, N., Booyatumanondo, R., Zakaria, M. P., Dung, L. Q., Gordon, M., Miguez, C., Suzuki, S., Moore, C., Thompson, R.C. (2009). International Pellet Watch: Global monitoring of persistent organic pollutants (POPs) in coastal waters. 1. Initial phase data on PCBs, DDTs, and HCHs. Marine Pollution Bulletin, 58(10), 1437-1446. https://doi.org/10.1016/j.marpolbul.2009.06.014

Petersen, F., Hubbart, J.A. (2021). The occurrence and transport of microplastics: The state of the science. In Science of the Total Environment, Vol. 758. Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2020.143936

Plastics Europe (2024). Plastics – The Fast Facts 2024. https://plasticseurope.org/knowledge-hub/plastics-the-fast-facts-2024/

Pojar, I., Kochleus, C., Dierkes, G., Ehlers, S.M., Reifferscheid, G., Stock, F. (2021a). Quantitative and qualitative evaluation of plastic particles in surface waters of the Western Black Sea. Environmental Pollution, 268. https://doi.org/10.1016/j.envpol.2020.115724

Pojar, I., Stănică, A., Stock, F., Kochleus, C., Schultz, M., Bradley, C. (2021b). Sedimentary microplastic concentrations from the Romanian Danube River to the Black Sea. Scientific Reports, 11(1). https://doi.org/10.1038/s41598-021-81724-4

Porter, A., Lyons, B.P., Galloway, T.S., Lewis, C. (2018). Role of Marine Snows in Microplastic Fate and Bioavailability. Environmental Science and Technology, 52(12), pp. 7111-7119. https://doi.org/10.1021/acs.est.8b01000

Revell, L.E., Kuma, P., Le Ru, E.C., Somerville, W.R.C., Gaw, S. (2021). Direct radiative effects of airborne microplastics. Nature, 598(7881), pp. 462-467. https://doi.org/10.1038/s41586-021-03864-x

Rios, L.M., Moore, C., Jones, P.R. (2007). Persistent organic pollutants carried by synthetic polymers in the ocean environment. Marine Pollution Bulletin, 54(8), pp. 1230-1237. https://doi.org/10.1016/j.marpolbul.2007.03.022

Rios, L.M., Jones, P.R., Moore, C., Narayan, U.V. (2010). Quantitation of persistent organic pollutants adsorbed on plastic debris from the Northern Pacific Gyre's "eastern garbage patch." Journal of Environmental Monitoring, 12(12), pp. 2226-2236. https://doi.org/10.1039/c0em00239a

Rocchia, M., Ruff, I., Vianello, A. (2017). Microplastic identification and characterization by Raman imaging spectroscopy.

Rodrigues, M.O., Abrantes, N., Gonçalves, F.J.M., Nogueira, H., Marques, J.C., Gonçalves, A.M.M. (2018). Spatial and temporal distribution of microplastics in water and sediments of a freshwater system (Antuã River, Portugal). Science of the Total Environment, 633, pp. 1549-1559. https://doi.org/10.1016/j.scitotenv.2018.03.233

Roy, P.K., Hakkarainen, M., Varma, I.K., Albertsson, A.C. (2011). Degradable polyethylene: Fantasy or reality. In Environmental Science and Technology, Vol. 45, Issue 10, pp. 4217-4227. https://doi.org/10.1021/es104042f

Shahira M. (2025). Plastic bank- Plastic pollution by country: latest statistics and insights. Https://Plasticbank.Com/Blog/Plastic-Pollution-by-Country/. Letöltve: 2025, March 26

Teuten, E.L., Saquing, J.M., Knappe, D.R.U., Barlaz, M.A., Jonsson, S., Björn, A., Rowland, S.J., Thompson, R.C., Galloway, T.S., Yamashita, R., Ochi, D., Watanuki, Y., Moore, C., Viet, P.H., Tana, T.S., Prudente, M., Boonyatumanond, R., Zakaria, M.P., Akkhavong, K., Takada, H. (2009). Transport and release of chemicals from plastics to the environment and wildlife. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 2027-2045. https://doi.org/10.1098/rstb.2008.0284

Waldschläger, K., Lechthaler, S., Stauch, G., Schüttrumpf, H. (2020). The way of microplastic through the environment – Application of the source-pathway-receptor model (review). In Science of the Total Environment, Vol. 713. Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2020.136584

Windsor, FM., Durance, I., Horton, A.A., Thompson, R.C., Tyler, C.R., Ormerod, S.J. (2019). A catchment-scale perspective of plastic pollution. In Global Change Biology, Vol. 25, Issue 4, pp. 1207-221). Blackwell Publishing Ltd. https://doi.org/10.1111/gcb.14572

Yang, L., Zhang, Y., Kang, S., Wang, Z., Wu, C. (2021). Microplastics in freshwater sediment: A review on methods, occurrence, and sources. In Science of the Total Environment, Vol. 754. Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2020.141948

URL1: EU Strategy for the Danube Region (EUSDR) (2019). Plastic pollution of rivers in the Danube region. www.danube-region.eu

URL2: Plastic Overshoot Day 2025.Plastic… is… everywhere. https://Plasticovershoot.Earth/. Letöltve: 2025, April 1

URL3: Waste Direct 2025. Plastic Waste Statistics & Trends. https://Wastedirect.Co.Uk/Blog/Plastic-Waste-Statistics/. Letöltve: 2025, April 27

AUTHORS

PEGAH JAHANPEYMA received her bachelor’s degree in project management engineering from Paramour University in Tehran in 2012, and her master's degree in Hydraulic Structures from Azad University in South Tehran in 2015. She is currently a doctoral student and research assistant at the Department of Hydraulic Engineering and Water Management of the Budapest University of Technology and Economics. Her doctoral research topic is "Analysis of Microplastic Transport in Rivers". Her research interests include the study of plastic pollution in rivers, flow conditions, and sediment migration using various field methods.

SÁNDOR BARANYA received his Civil Engineering degree from the Budapest University of Technology and Economics (BME) in 2003 and his PhD from the same university in 2010. He is currently the head of the Department of Hydraulic Engineering and Water Management at BME and an associate professor. His research interests include the study of riverbed morphology, flow dynamics, and sediment migration using field methods and computer modelling. He has been a member of the Hungarian Hydrological Society since 2003.