Interreg
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MicroDrink

MICROPLASTIC RESEARCH

MONOGRAPH
of the MicroDrink project

"Capacity building for management and governance of MICROplastics in DRINKing water resources of Danube Region"

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May 2026

CAPACITY BUILDING FOR MANAGEMENT AND GOVERNANCE OF MICROPLASTICS IN DRINKING WATER RESOURCES OF DANUBE REGION

This project is supported by the Interreg Danube Region Programme co-funded by the European Union.

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MicroDrink

(Photo credit: Jaka Babnik)

In memory of

prof. dr. Mihael Brenčič

(1967 – 2026)

whose vision and original idea laid the foundation for the MicroDrink project.

FOREWORD

Access to safe and high-quality drinking water remains one of the fundamental pillars of public health and societal well-being. Yet, even as water management across Europe continues to advance, new and complex challenges are emerging. Among these, microplastics represent a particularly pressing and still insufficiently understood category of emerging contaminants. Their ubiquitous presence in the environment, diverse composition, and capacity to adsorb and transport other pollutants raise important questions regarding their occurrence, behaviour, and potential impacts on both ecosystems and human health, positioning them at the forefront of contemporary water research and policy discourse. Microplastics occurrence in drinking water is an issue calling for coordinated attention and action across disciplines, sectors and national boundaries. It is within this context that the MicroDrink project has emerged as both a timely and essential initiative.

Implemented under the Interreg Danube Region Programme, MicroDrink brings together a diverse network of institutions, researchers and professionals with a common purpose: to improve the quality and safety of drinking water by strengthening knowledge, harmonising monitoring practices, and supporting evidence-based decision-making. Beyond its technical contributions, MicroDrink serves as a model for integrated water management and policy alignment within the European framework. The findings presented herein provide valuable guidance for decision-makers, practitioners, and researchers alike, supporting evidence-based approaches to mitigate microplastic contamination in drinking water systems.

This monograph reflects the collective expertise, dedication, and collaborative spirit of all project partners. It documents the harmonised approach to microplastics monitoring, the data collected, and the insights gained through extensive research and pilot actions across the Danube Region. Beyond its scientific contributions, it stands as a testament to the value of transnational cooperation in addressing complex environmental challenges that no single institution or country can resolve alone.

As Lead Partner, the Croatian Geological Survey considers it both a privilege and a responsibility to acknowledge the commitment and professionalism of all members of the MicroDrink consortium. Their contributions have been instrumental in advancing our shared objectives and in strengthening the capacity of the Danube Region to respond proactively to emerging contaminants in drinking water. It is our sincere hope that the knowledge and recommendations presented in this monograph will support informed decision-making, inspire further research, and contribute to safeguarding water quality for present and future generations.

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MicroDrink Project Fact & Figures

The MicroDrink (Capacity building for management and governance of MICROplastics in DRINKing water resources of the Danube Region) project was approved for co-financing within the Interreg Danube Region, under the Programme Priority 2: A greener, low-carbon Danube Region. With a total budget of 2,351,480.00 €, co-funded by Interreg Funds, the project aimed to achieve the Programme priority specific objective 2.3: Sustainable, integrated, transnational water and sediment management in the Danube River Basin ensuring good quality and quantity of waters and sediment balance.

The MicroDrink project started on 01 January 2024 and lasted until 30 June 2026. The project was divided into 5 periods, each lasting 6 months. Joint cooperation among 11 project partners from 8 countries (Austria, Bosnia and Herzegovina, Croatia, Czech Republic, Germany, Hungary, Slovenia, Serbia) was supervised by the Lead Partner Croatian Geological Survey.

Table I: Project partners list

Project Partner Institution	Logo	Country
Croatian Geological Survey	HGI 1909 HRVATSKI GEOLOŠKI INSTITUT CROATIAN GEOLOGICAL SURVEY	Croatia
Institute of Public Health Zadar	ZAVOD ZA JAVNO ZDRAVSTVO ZADAR	Croatia
University of Ljubljana	UNIVERZA V LJUBLJANI University of Ljubljana	Slovenia
Public company Kovod Postojna, water supply, sewerage, Ltd.	KOVOD	Slovenia
Environment Agency Austria	ENVIRONMENT AGENCY AUSTRIA	Austria
T. G. Masaryk Water Research Institute	VÚV MGT	Czech Republic

Eurofins Environment Testing Hungary Kft	eurofins | Environment Testing	Hungary
University of Belgrade, Faculty of Mining and Geology		Serbia
Institute for Public Health of the Federation Bosnia and Herzegovina	ZAVOD ZA JAVNO ZDRAVSTVO FBiH INSTITUTE FOR PUBLIC HEALTH FB&H	Bosnia & Herzegovina
Public Utility Service Company "Drugi oktobar" Vršac	ВРШАЦ	Serbia
Friedrich-Alexander-Universität Erlangen-Nürnberg	FAU Friedrich-Alexander-Universität Erlangen-Nürnberg	Germany

The MicroDrink project is organised around three specific objectives (SO1, SO2 and SO3) aimed at achieving the project objectives through the implementation of planned activities, and their corresponding deliverables and outputs. The leader for Specific objective 1 (SO1), titled "Developing transnational knowledge base on microplastics in Danube region drinking water resources", was Friedrich-Alexander-Universität Erlangen-Nürnberg. The leader for Specific objective 2 (SO2), titled "Occurrence of microplastics in the water environment used for drinking water supply", was Eurofins Environment Testing Hungary Kft. The leader for Specific objective 3 (SO3), titled "Capacity building for management of microplastics in drinking water facilities (from source to tap)", was the University of Ljubljana.

Table II: Project time plan

Period 1	Period 2	Period 3	Period 4	Period 5
SO1 Developing transnational knowledge base on microplastics in Danube region drinking water resources				
A1.1 Microplastics in the drinking water (SOA)				
			D1.1.1, D1.1.2	
A1.2 Synergy creation				
		D1.2.1, D1.2.2	D1.2.3	
A1.3 Review of available sampling methods				
D1.3.1				
A1.4 Review of available laboratory...				
D1.4.1, D1.4.2, D1.4.3				
A1.5 Capitalization and dissemination across Danube Region and beyond				
	D1.5.2			D1.5.1, D1.5.3, D1.5.4, O1.1
SO2 Occurrence of microplastics in the water environment used for drinking water supply				
	A2.1 Establishing pilot action clusters			
		D2.1.1, D2.1.2, D2.1.3	D2.1.4, D2.1.5	
	A2.2 Transferring knowledge			
	D2.2.1, D2.2.2, D2.2.3		O2.1, O2.2, O2.3	D2.2.4
SO3 Capacity building for management of microplastics in drinking water facilities (from source to tap)				
A3.1 MicroDrink Board for microplastics drinking water pollution in Danube River Basin				
				D3.1.1, D3.1.2
	A3.2 Identification of needs and elaboration of capacity building concept for practitioners			
			D3.2.1, D3.2.2	D3.2.3, D3.2.4, D3.2.5
			A3.3 Governance strategy for microplastics in drinking water	
			D3.3.1	D3.3.2, D3.3.3, D3.3.4, D3.3.5, O3.1, O3.2, O3.3, O3.4, O3.5

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O2.1 Microplastics in drinking water obtained from karst water resources in Danube region
O2.2 Microplastics in drinking water obtained from intergranular water resources in Danube region
O2.3 Microplastics in drinking water obtained from surface/river bank filtration water resources in Danube region

O3.1 MicroDrink Board
O3.2 Decision-making support tool for microplastics
O3.3 Testing of DMST in drinking water obtained from karst water resources in Danube region
O3.4 Testing of DMST in drinking water obtained from intergranular water resources in Danube region
O3.5 Testing of DMST in drinking water obtained from surface/river bank filtration water resources in Danube region

Result 1 – *2.3.3:* *Solutions taken up or up-scaled by organizations* – enhanced cooperation and knowledge exchange beyond borders, uptake of harmonized best practices

Result 2 – *Organizations with increased institutional capacity due to their participation in cooperation activities across the borders* – end users take part in roundtable discussions, webinars, sampling training sessions, elaboration of practical implementation of best monitoring practices

Result 3 – *2.3.1:* *Organizations with increased institutional capacity due to their participation in cooperation activities across the borders* – MicroDrink Board network of experts

Result 4 – *2.3.3:* *Solutions taken up or up-scaled by organizations* - DMST for end users

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1 Introduction

Plastics are an increasingly significant environmental pollutant. In 2024, global plastic production reached 430.9 million tons, contributing to greater leakage of microplastics (MP) into hydrological systems (Rashid et al., 2026). The Joint Danube Survey 4, conducted in 2019, established a baseline for MP occurrence in the Danube River Basin (DRB), confirming their presence along the entire river, its major tributaries, and in aquatic organisms. Polyethylene, commonly used in plastic bottles and packaging, was identified as the most abundant type. Continuous emissions of MP contribute to long-term contamination of ecosystems and food chains, resulting in (eco)toxic effects on living organisms. MP in surface waters and marine environments have been widely reviewed, whereas their occurrence and behaviour in groundwater have received much less attention (Rashid et al., 2026).

The lack of integrated MP management frameworks in the water environment represents a major challenge for European countries, highlighting the need for effective monitoring tools and coordinated policies to reduce emissions and pollution. Due to their persistence, widespread distribution, multiple sources, and insufficiently understood impacts on ecosystems and human health, MP constitute a serious transboundary environmental threat. Despite growing global interest, only a limited number of studies have focused on MP in drinking water, emphasising the need for more comprehensive research and management approaches.

The MicroDrink project addresses these gaps by strengthening institutional, managerial, and technical capacities while raising awareness among stakeholders and the public. It promotes cross-border and cross-sector cooperation, focusing on harmonised methods for sampling, analysis, monitoring, and risk assessment of MP in drinking water resources. A key component of the project was the development of an open online MicroDrink knowledge base, providing a comprehensive overview of sampling methods, laboratory instruments, and analytical techniques. The project also fostered synergies with past and ongoing EU initiatives in water management and protection, and engaged relevant stakeholders through targeted meetings, workshops and events.

MicroDrink implemented a harmonised approach to MP monitoring across 8 Danube Region countries, tested through 9 pilot actions at selected sites distributed in 3 clusters representing major drinking water resource types (karst, intergranular, and surface/river bank filtration). The project enhanced governance by improving collaboration and knowledge-sharing among policymakers and by delivering a Decision-making support tool for MP, a transnational capacity building Roadmap towards MP strategy, and strategic recommendations for MP management in drinking water resources at both utility and transnational levels. The project results provide a foundation for future assessment of MP-related risks and impacts on the environment and human health, while strengthening the resilience of water supply systems and supporting the effective implementation of the EU Drinking Water Directive.

This monograph provides an overview of the activities carried out within the MicroDrink project, as well as their results, which are presented in the following chapters. The MicroDrink project broadened stakeholders' knowledge, supported decision-makers and raised awareness of the importance of preventing and mitigating MP pollution from source to tap.

2 Microplastics in drinking water

2.1 Definition

Microplastics (MPs) are tiny plastic particles, typically defined as polymers smaller than 5 mm and larger than 1 µm (Koelmans et al., 2019, EC, 2024). These particles originate from a range of sources, including the breakdown of larger plastic debris, synthetic textiles, personal care products, industrial activities, and various consumer goods (Eerkes-Medrano et al., 2019). In the context of drinking water, microplastics refer to minuscule fragments, fibers, or beads that have been detected in multiple water sources, including raw and treated water, bottled water, groundwater, surface water, and spring water (Danopoulos et al., 2020; Ghosh et al., 2023). Most microplastics identified in drinking water are smaller than 10 µm, with the predominant polymer types being polyethylene terephthalate (PET), polypropylene (PP), and polyethylene (PE), all widely used in packaging and consumer products (Sun et al., 2019; Zhu et al., 2024).

2.1.1 Characteristics of Microplastics

Microplastics vary widely in size, shape and morphology, polymer type, origin, and physical and chemical properties (Koelmans et al., 2019; Rochman et al., 2019).

- Size: Microplastics are generally classified as plastic fragments smaller than 5 mm, but those found in drinking water are often much smaller, commonly below 10 µm and sometimes even down to 1 µm or less (Koelmans et al., 2019; WHO, 2019).
- Shape & Morphology: Microplastics occur in a range of morphological forms - fragments, fibers, films, beads. They are further classified according to their origin as either primary microplastics (intentionally manufactured at small sizes) or secondary microplastics (resulting from the environmental fragmentation and weathering of larger plastic materials) (Cole et al., 2011; Rochman et al., 2019).
- Polymer Type: The most common polymers constituting microplastics in water resources are PET, PP, and PE, but other polymers such as polyamide (nylon) and polycarbonate have also been detected (Koelmans et al., 2019; Wright et al., 2013).
- Sources: Microplastics enter drinking water systems through various pathways, including urban stormwater runoff, wastewater treatment plant effluents, deterioration of pipe infrastructure, and atmospheric deposition (Eriksen et al., 2014; Horton et al., 2017).
- Physical and Chemical Properties: Microplastics are characterised not only by size, morphology, and composition but also by their capacity to adsorb and facilitate the transport of other environmental contaminants such as persistent organic pollutants, heavy metals, and pathogenic microorganisms (Cole et al., 2011; Rochman et al., 2019), thereby compounding their potential ecological and public health significance.

2.1.2 Pathways into Drinking Water

Microplastics infiltrate water supplies through direct discharges into surface or groundwater, including wastewater treatment plant effluents and certain industrial outflows (Browne et al., 2011;

Murphy et al., 2016), environmental weathering and fragmentation of plastic waste, and urban and agricultural runoff. Non-point sources, such as urban stormwater runoff, can transport microplastics derived from tire wear particles, degraded agricultural films, and synthetic textile fibers into rivers and lakes (Dris et al., 2016; Kole et al., 2017). Studies have confirmed the presence of microplastics in groundwater, particularly within karst aquifers, where development and septic systems likely contribute fiber-type microplastics to drinking water sources (Panno et al., 2019). Other investigations have demonstrated that even in groundwater-sourced drinking water, microplastics (50–150 µm) persist through treatment processes, albeit at low concentrations (Mintenig et al., 2019). Nanoplastics, which are considerably smaller and harder to detect, are presumed to infiltrate groundwater with greater ease, are, adding another layer of uncertainty to exposure assessment (Gigault et al., 2018).

Atmospheric deposition represents an additional and increasingly recognised route of MPs, whereby airborne plastic particles are transported and subsequently deposited into water bodies or even directly into water distribution systems (Horton et al., 2017; Zhang et al., 2020). Plastic particles may also originate from the materials constituting water distribution infrastructure, including polyethylene pipes, epoxy-based coatings, and sealing gaskets (Pivokonsky et al., 2018).

Research has demonstrated the persistence of microplastics through the various stages of conventional water treatment. Although modern treatment techniques significantly reduce their concentrations, they cannot entirely remove the smallest particles (Acarer, 2023), leading to the inevitable presence of microplastics in finished drinking water (WHO, 2019). The occurrence of MPs has been documented across multiple countries within the Danube River Basin, with both varying concentrations and polymer types reflecting regional differences in contamination sources and infrastructural conditions (Lechner et al., 2014; Scherer et al., 2018).

Microplastics have been detected in both tap and bottled water, raising considerable concern regarding human exposure, but the extent and nature of associated health risks remain insufficiently explored due to limited empirical evidence (WHO, 2019). While laboratory and animal studies have provided preliminary indications of possible inflammatory responses and cellular damage, definitive findings of adverse health effects in humans are still missing (Leslie et al., 2022; Prata et al., 2020). Current evidence has prompted scientists and regulatory bodies to adopt a precautionary approach to the monitoring and mitigation of microplastics in drinking water resources. Given the absence of a universally accepted regulatory definition or standardised thresholds for microplastics in water, the establishment of consistent analytical protocols and definitional frameworks is considered essential for advancing research, enabling robust risk assessment, and informing evidence-based policy development (Koelmans et al., 2019; WHO, 2019).

2.2 Available laboratory instruments and analytical techniques

The detection and characterisation of microplastics in drinking water relies on advanced laboratory instruments and analytical techniques. The reliability of microplastic research depends on these tools to efficiently isolate, identify, and quantify tiny plastic particles within complex environmental samples. Despite significant technological advancements, establishing standardised and universally accepted protocols for sampling and analysis remains a core challenge in the field (Hidalgo-Ruz et al., 2012; Lusher et al., 2020).

2.2.1 Sample Preparation and Pre-Treatment

Accurate microplastic analysis begins with sample preparation, which typically involves filtering water through membranes with pore sizes ranging from approximately 0.45 µm to 10 µm. For samples containing organic or inorganic matter that may interfere with subsequent analysis, additional pre-treatment steps are used, including hydrogen peroxide (H_2O_2) oxidation, enzymatic digestion, or density separation with solutions such as zinc chloride. These procedures remove background contaminants and concentrate MPs for subsequent detection and characterisation (Cole et al., 2011; Nuelle et al., 2014).

2.2.2 Instruments and analytical techniques

Fourier Transform Infrared (FTIR) Spectroscopy, particularly in its micro-FTIR (µFTIR) configuration, is one of the most widely adopted methods. It enables identification of polymer types based on their unique infrared absorption spectra, with spatial detection limits generally in the 5–10 µm range and, in some advanced systems, down to 1 µm. The process is non-destructive and suitable for a range of matrices, making it a cornerstone for microplastic analysis in both research and routine monitoring contexts (Hidalgo-Ruz et al., 2012; Lusher et al., 2020).

Raman Microscopy complements FTIR by achieving even higher spatial resolutions often below 1 µm and excels in identifying both the composition and morphology of microplastics, including small or colored particles. However, Raman analysis is susceptible to fluorescence interference from certain samples, requires longer measurement times, and demands a comparatively higher level of operator expertise (Hidalgo-Ruz et al., 2012; Lusher et al., 2020).

Laser Direct Infrared (LDIR) Imaging is a more recent high-throughput alternative, enabling rapid scanning and mapping of filtered microplastics. Its automated workflows reduce analysis times while maintaining robust chemical identification capabilities (Ourgaud et al., 2022).

Pyrolysis-Gas Chromatography/Mass Spectrometry (Py-GC/MS) is essential for mass-based quantification. This thermal technique decomposes polymers into their constituent monomers or fragments, which are then separated and detected by mass spectrometry. Py-GC/MS is particularly effective for bulk analysis regardless of particle morphology or size, but as a destructive method, it does not provide information about particle counts or shapes (Du et al., 2020; Fischer & Scholz-Böttcher, 2017).

Scanning Electron Microscopy (SEM) provides detailed visualisation of microplastic surface morphology and supplies size, shape, and surface structure information, often used alongside µFTIR or Raman to verify particle identity (Hidalgo-Ruz et al., 2012; Lusher et al., 2020).

Fluorescence Microscopy has emerged as an effective screening tool, with specific dyes enabling the visualisation and quantification of microplastics based on their fluorescence response. While less precise for polymer identification, this technique allows rapid, cost-effective particle counting, especially in high-throughput monitoring scenarios (Erni-Cassola et al., 2019; Maes et al., 2017).

2.2.3 Analytical Practice Across Countries

Methodological diversity exists across the Danube River Basin. For examples, laboratories in Croatia and the Czech Republic use both Raman and FTIR microscopy to determine polymer type and particle dimensions, while those in Hungary and Austria focus mainly on FTIR imaging for detailed mapping. Multiplexed analytical approaches are particularly valuable: combining filtration, spectroscopic identification, and advanced imaging ensures accurate assessment of both particle numbers and polymer composition (Lechner et al., 2014; Scherer et al., 2018). In June 2025, the JRC released the first reference material for microplastics, enabling laboratories to calibrate and validate their measurement methods, thereby aligning results across different facilities and supporting more reliable monitoring and policy action (JRC, 2025).

2.2.4 Strengths and Limitations

Each technique has clear strengths and limitations, as described in Table 1.

Table 1: Strengths and limitations of analytical techniques commonly used to analyse microplastics

Method	**Strengths**	**Limitations**
FTIR (μFTIR, imaging)	Non-destructive, high specificity, established protocols	Costly, limited to particles >5 μm, slower for high samples (Hidalgo-Ruz et al., 2012; Lusher et al., 2020)
Raman microscopy	High spatial resolution, polymer ID, works for colored MPs	Fluorescence interference, slower, requires expertise (Hidalgo-Ruz et al., 2012; Lusher et al., 2020).
Py-GC/MS	Mass quantification, suitable for complex mixtures	Destructive, no shape/size data, high equipment cost (Du et al., 2020; Fischer & Scholz-Böttcher, 2017).
LDIR	High-throughput, automated, good for mapping large samples	Newer technology, significant investment required (Ourgaud et al., 2022; Primpke et al., 2018).
SEM	Morphology and surface analysis	Requires polymer ID support (e.g. FTIR), sample prep intensive (Hidalgo-Ruz et al., 2012; Lusher et al., 2020).
Fluorescent microscopy	Quick screening, high throughput	Limited to stained MPs, requires confirmation by spectroscopy (Erni-Cassola et al., 2019; Maes et al., 2017).

Despite considerable technological capabilities, the lack of unified standards for sampling, sample preparation, and analysis leads to substantial inconsistencies in reported data, complicating both risk assessments and public health evaluations. Costs vary widely, with per- sample expenditures ranging from several hundred to over one thousand euros, depending on matrix complexity, instrument type, and required detection limits (Koelmans et al., 2019; WHO, 2019).

The progression of microplastic research in drinking water is closely linked to advances in laboratory instrumentation and the systematic optimisation of analytical methodologies. Harmonisation of procedures across all stages, from sample collection to detection remains a pressing need, not only for scientific understanding but also for regulatory evaluation and the maintenance of public confidence in drinking water safety (Koelmans et al., 2019; WHO, 2019).

2.3 Current regulation

In response to growing public demand for better protection of drinking water, the European Union updated its core legislation governing water intended for human consumption. This legislative update known as the recast Drinking Water Directive was adopted in December 2020 and became legally effective across the EU in January 2021. Member States were required to transpose its provisions into their national laws by 12 January 2023 (Dettori et al., 2022).

The update followed the Right2Water initiative, a grassroots campaign that urged the EU to prioritise clean and accessible water as a fundamental human right. The European Commission launched a public consultation to evaluate the existing framework and gather input on necessary changes. This led to the development of a revised directive that emphasises not only improved water quality standards, but also broader access, especially for people in vulnerable or socially excluded situations (EC, 2014). One of the key changes in the revised Drinking Water Directive (EU 2020/2184) is the introduction of updated thresholds for several chemical contaminants, alongside a new watch list mechanism to monitor emerging substances of concern. These include microplastics and endocrine-disrupting compounds, which were not addressed under the previous directive. Their inclusion reflects growing scientific and regulatory concern regarding pollutants that may pose long-term health risks even at low exposure levels.

Beyond stricter quality controls, the directive imposes stronger obligations on governments to ensure that everyone has reliable access to safe drinking water, regardless of income, location, or social status. This aligns with the EU's broader social goals and reflects a shift toward recognising clean water as more than just an environmental or technical issue, it is now framed as a matter of social equity and public health (EP, 2025).

The recast Drinking Water Directive (EU 2020/2184) represents a fundamental shift in how drinking water is managed in Europe, promoting more consistent, transparent, and socially inclusive governance. While the directive introduces a watch list for emerging contaminants and identifies microplastics as a potential candidate for inclusion, formal threshold limits are still under development. Among eight examined European jurisdictions, Austria, Bosnia and Herzegovina, Croatia, Czech Republic, Germany, Hungary, Serbia, and Slovenia, regulatory approaches to microplastics vary. EU Member States are mandated to implement harmonised methodologies for measuring microplastics in drinking water under Directive (EU) 2020/2184 and Commission Delegated Decision (EU) 2024/1441, whereas non-EU countries such as Bosnia and Herzegovina and Serbia are not legally bound by the directive, although some are beginning to align through

harmonisation and accession processes. The evolving policy landscape highlights gaps in enforcement and indicates emerging corrective trends.

The only binding text currently in force that explicitly refers to microplastics in connection with potable water is Directive (EU) 2020/2184 ("recast Drinking Water Directive", DWD). Article 8 obliges every Member State to carry out a risk assessment addressing microplastics by 12 January 2029 and empowers the Commission to adopt standard analytical methods via delegated acts (European Parliament and Council, 2020). The Commission published a first standardised monitoring methodology in March 2024 (EC, 2024). No EU act, nor any national law in the eight examined countries, prescribes quantitative limit values for MPs in finished drinking water.

2.3.1 Regional Legislative Landscape

All EU members participating in project MicroDrink have fully or partially transposed the Single-Use Plastics Directive 2019/904, banning certain items (e.g., straws, EPS cups) and introducing producer levies (EC, 2019; EEA, 2023). Germany implemented key elements of Directive (EU) 2019/904 through the Single-Use Plastics Ban Ordinance (Einwegkunststoffverbotsverordnung), the Single-Use Plastics Labelling Ordinance (Einwegkunststoffkennzeichnungsverordnung), and the Single-Use Plastics Fund Act (Einwegkunststofffondsgesetz), covering market restrictions, product labelling requirements, and extended producer responsibility (BMUV, 2023; Bundesgesetzblatt I, 2023). The Czech Republic introduced Act No. 243/2022 Coll. on reducing the environmental impact of selected plastic products, which entered into force in October 2022 and restricts selected single-use plastic products (Sbírka zákonů č. 243/2022). Austria bans non-biodegradable plastic carrier bags and restricts intentionally added microplastics in cosmetics from 2020 onwards (Republik Österreich, 2020). Croatia controls single-use plastics and mandates 25% PET content in PET bottles by 2025 (Official Gazette no. 137/23). Hungary adopted Act XCI/2020 and Decree 349/2021, going beyond EU minima by taxing ultra-light bags and planning a deposit-refund scheme for PET (Government of Hungary, 2020, 2021).

Slovenia's legislation under ZPDPPEUT bans a wide range of single-use plastic items in line with Directive (EU) 2019/904, such as cotton bud sticks, cutlery, plates, straws, drink stirrers, balloon sticks, food containers and cups made of expanded polystyrene, as well as all oxo-degradable plastic products (ZPDPPEUT, 2021). Non-EU candidates Serbia and Bosnia & Herzegovina are drafting analogous bans as part of their accession negotiations but have not yet enacted binding measures (EC, 2020). While regulations targeting plastic products are expanding, they remain largely disconnected from laws governing drinking water safety in relation to microplastic contamination.

Across the eight countries reviewed, none currently have binding legal provisions that explicitly regulate microplastics in drinking water, although legislative activity varies. In Austria, the legal basis for drinking water remains the Trinkwasserverordnung, first issued in 2001 and updated in 2023. However, it still does not include microplastics, and, like many other countries, the transposition of the updated EU Directive remains behind schedule. Austria's Environment Agency offers voluntary testing services for MPs, but there is no legal obligation (Umweltbundesamt, 2025). In Bosnia and Herzegovina, environmental governance remains fragmented: there is no harmonised national law implementing the EU Drinking Water Directive 2020/2184, nor is there cohesive legislation transposing the Single-Use Plastics Directive. A UNDP-supported review found that responsibility for waste and water regulation is dispersed across the two entities (Federation

of Bosnia and Herzegovina (FBiH) and Republika Srpska (RS)) (EU, 2024; UNDP, 2021). Croatia has taken steps towards alignment through its Law on Water for Human Consumption (OG 30/23), which transposed core EU provisions. However, tasks related to microplastics have been deferred, and MPs remain off the regulatory watch-list. Policy discussions in the Croatian Parliament (Sabor) have emphasised reducing PET bottle use by encouraging tap water consumption (Croatia Parliament, 2023; Office, 2024).

In the Czech Republic, drinking water is regulated by the Water Act No. 254/2001 and related ordinances. No legal threshold for MPs exists, despite studies reporting up to 180 particles per liter in tap water (Halfar et al., 2024). Germany incorporated the 2020 Drinking Water Directive into national law with the revised Trinkwasserverordnung, effective from June 2023. The ordinance introduces new chemical parameters and risk-based controls but does not designate microplastics as a regulated contaminant. Although the standard DIN EN ISO 24187 for microplastic analysis exists in Germany, its use remains voluntary; mandatory testing or enforcement protocols for microplastics are not specified in current legislation (JRC, 2024). In Hungary, water quality is defined under Government Decree 201/2001, with an additional decree issued in 2023. The revised directive's transposition deadline was missed. While microplastics have been acknowledged by the National Public Health Center (NNK) in scientific contexts, they are not currently subject to binding monitoring requirements or legal standards (Bufa-Dőrr, 2017).

Serbia, a non-EU country working towards alignment prepared a draft Law on Drinking Water in October 2022, developed under the PLAC III initiative with EU alignment in mind (PLAC III, 2022). While parliamentary approval timelines are unclear, the government introduced a national microplastics reduction strategy in 2024, indicating increased regulatory focus on emerging pollutants (Stojic et al., 2024). For Slovenia, existing public sources do not confirm whether the 2023 Regulation on Drinking Water formally addresses microplastics. The European Commission issued a formal notice in July 2025 for incomplete transposition. Despite the legal gap, Slovenia has contributed to early-stage microplastics research, becoming the first country to document microplastics in hailstones (Kozjek et al., 2023). However, no binding standards have followed these findings.

In most of the countries reviewed, microplastics are still addressed mainly through waste management and pollution prevention policies, rather than being treated as a direct contaminant in drinking water. Although the recast EU Drinking Water Directive (DWD) provides a shared framework and sets a deadline for microplastics risk assessment by 2029, its impact on national drinking water legislation remains limited so far. Domestic laws across the region generally fall short in three key areas: they do not set numeric, health-based limits for microplastics in tap water; they exclude microplastics from required monitoring routines; and they rely heavily on voluntary testing by research institutions or laboratories, which is neither standardised nor enforceable.

Looking ahead, progress in this area will depend on several interlinked developments. First, national governments need to fully and promptly transpose the DWD into domestic law, including clear protocols for contamination incidents and accessible systems for public reporting, which are crucial for rebuilding public confidence in tap water (EC, 2025). Second, there must be greater alignment between upstream plastic control policies, such as levies on packaging, regulations on industrial pellet loss, and extended producer responsibility schemes and downstream water safety planning. By connecting plastic production and waste frameworks with drinking water policy, countries can more effectively prevent microplastics from entering the supply system (EEA, 2023).

Further investment in laboratory capacity is needed, particularly in the ability to detect and analyse microplastics smaller than 20 µm. Regional collaboration projects such as MicroDrink in the Danube River Basin have demonstrated the value of harmonised sampling and cross-border data sharing. Involving countries such as Austria, Bosnia and Herzegovina, Croatia, Germany, Hungary, Serbia, Slovenia, and the Czech Republic, in these efforts is an important step towards building transnational cooperation, leading to a consistent evidence base to inform future policy decisions (Halfar et al., 2024).

2.4 MicroDrink Knowledge Base

The MicroDrink Knowledge Base, developed as part of the MicroDrink project, is an open-access online platform dedicated to consolidating and sharing information on microplastics in drinking water resources across the Danube River Basin. The platform is publicly available at: https://microdrink.wordpress.com/.

2.4.1 Purpose and Scope

Microplastics are an emerging environmental concern, and their presence in drinking water resources presents complex scientific, technical, and regulatory challenges. The Knowledge Base was established to address fragmented and inconsistent information in this field by bringing together sampling methods, analytical techniques, legislative frameworks, mitigation approaches, and institutional capacities into a single, centralised, and openly accessible resource. Its main objectives are twofold:

- To support cross-border and cross-sector cooperation by providing harmonised, reliable information for a wide range of stakeholders, including scientists, policymakers, water suppliers, NGOs, and the public.
- To address scientific and practical gaps in the monitoring and management of microplastics in drinking water.

Additionally, the Knowledge Base also contributes to broader regional and EU-level strategic frameworks, such as the EU Strategy for the Danube Region (EUSDR) and the Circular Economy Action Plan, by facilitating informed decision-making and encouraging standardised monitoring and management practices.

2.4.2 Structure and Content

The Knowledge Base is organised into six main sections, each containing curated project-based and externally sourced content linked to dedicated data sheets available in eight languages. These sheets provide detailed technical, regulatory, and operational information and can be downloaded or accessed directly through the platform. All sections include a submission form that allows users to contribute verified information, ensuring the resource remains dynamic and up to date.

2.4.2.1 Sampling Methods

Contains detailed records of MP sampling techniques used in drinking water environments. Each entry includes the method name, technical description, instruments used, sample preparation procedures, supplier information, source of sampled water, geographic locations where the method was applied, users of the method, and relevant references. Advantages and disadvantages are listed to help compare approaches. Linked multilingual data sheets provide all details, alongside references and contact information. A submission form is available for adding new sampling methods.

2.4.2.2 Analytical Methods

Provides descriptions of analytical approaches for identifying and quantifying microplastics. Entries include the method name, developer, publication status with references, target quantities, cost of analysis, source of sampled water, locations used, laboratory name, and relevant references. Advantages and disadvantages are documented to support performance evaluation and method selection. Multilingual data sheets contain the complete dataset with contact details for method developers or service providers. A submission form allows new or updated analytical techniques to be added.

2.4.2.3 Instruments

Lists laboratory and field instruments for MP detection and analysis. For each instrument, information includes the name, technical description, producer and supplier details, estimated cost, detection capabilities, detection limit, water types sampled, locations of use, users, and references. Linked multilingual data sheets provide all details along with supplier contact information. Users can submit new instruments or propose updates to existing entries via the submission form.

2.4.2.4 Projects

Presents field applications, research initiatives, and pilot actions on MP monitoring and mitigation within the Danube River Basin. Each record contains the project name, type and funding institution, duration, partners, website link, and designated contact person. Multilingual data sheets include complete project summaries and contact information. A submission form allows additional projects to be shared.

2.4.2.5 Legislation and Guidelines

Summarises relevant laws, regulations, and guidelines for MP monitoring, analysis, and prevention. Each entry provides the legislation or guideline name, country or region, official website link, and contact person or organisation responsible. Multilingual data sheets include references to official sources. Users can submit updates or new legislative documents through the form.

2.4.2.6 Laboratories

Provides a structured directory of laboratories with demonstrated capacity for advanced MP analysis. Each listing includes the institution or organisation name, contact person, address, telephone, email, website, and remarks. Linked multilingual data sheets present standardised profiles. Laboratories can use the submission form to add or update existing information.

The MicroDrink Knowledge Base is not a static repository but a dynamic, multilingual resource whose value lies in the integration of carefully reviewed content, multilingual accessibility, and active contributions from the scientific community, industry stakeholders, and public authorities. This collaborative and participatory approach ensures that the Knowledge Base continues to expand in both scope and accuracy, reflecting new developments in technology, methodology, and policy.

3 Pilot site descriptions

3.1 Characterisation of drinking water obtained from karst water resources in DRB

3.1.1 Summary

Three pilot action sites **Kupica Spring and Iševnica Water Facility in Croatia** (LP and PP2), **Spring in Austria** (PP6), and **Crni dol in Bosnia and Herzegovina** (PP10) represent karstic groundwater systems. All sites are located in carbonate rocks (mainly limestone and dolomite) with strong karstification and rapid subsurface drainage, making them highly vulnerable to contamination.

Kupica Spring is located in highly dissected mountainous terrain (Gorski kotar), with Triassic and Jurassic–Cretaceous carbonates and a highly dynamic hydrological regime (rapid response to precipitation, strong discharge fluctuations). Spring PP6 in Austria represents a more stable karst aquifer (Wetterstein limestone) with high storage capacity and balanced discharge. Crni dol covers a wider geological range from Paleozoic to Mesozoic formations, with predominant Triassic limestones and dolomites.

All three areas have high precipitation rates, which contribute substantially to groundwater recharge. Gorski kotar in Croatia is influenced by both continental and Mediterranean climates, receiving up to 4,000 mm of rain per year. The Austrian site has a continental precipitation regime (~1,800 mm/year) with additional Mediterranean influence in late summer and autumn. The Crni dol area is dominated by a continental climate with mountain influences and strong seasonal and altitudinal variations.

All pilot sites provide drinking water of generally high quality, though their treatment processes differ according to local conditions. At the Croatian Iševnica facility, raw water undergoes a multi-step treatment process (flocculation, sedimentation, sand filtration, UV disinfection, and chlorination) due to occasional turbidity and anthropogenic impact. In contrast, the Austrian Spring PP6 requires only UV disinfection and rare chlorination in case of high turbidity, providing naturally clean water. Crni dol source relies on disinfection in reservoirs after gravity transport from the spring.

Infrastructure density and population coverage vary in scale. The Iševnica water facility supplies around 15,000 residents across the Gorski kotar region. About 90% of the population is connected to the water supply network, but the sewage connection rate is lower, approximately 75% in Delnice and only 9% in surrounding villages. Spring PP6 in Austria provides drinking water for roughly 2,300 inhabitants, with 98% connected to the public water supply and 92% to the sewage system. The Crni dol source supplies the town of Gornji Vakuf–Uskoplje.

All catchment areas are formally protected, though the degree of implementation varies. Austria established a strictly regulated protection zone in 1998 (~32 km²) with clear land-use restrictions, while in Croatia, four protection zones were defined in 2013 for the entire 340 km² Kupica catchment, which includes urban settlements such as Delnice. The Crni dol water source also has a defined protection area, but forest degradation and erosion still pose challenges.

Potential microplastic sources are broadly similar, including tire and road abrasion, littering, tourism, and forestry operations. However, their intensity differs: the Croatian site shows the

strongest anthropogenic influence, with urban runoff, wastewater treatment, and illegal waste disposal into karst features directly connected to the spring. The Crni dol area experiences diffuse pressures from increased population. The Austrian site serves as a near-pristine reference area with only diffuse microplastic inputs such as atmospheric deposition.

Although all three sites share high vulnerability due to high karst permeability and the need for integrated protection, they differ in degree of anthropogenic influence and infrastructure development. Together, they provide a representative spectrum of karstic groundwater settings for evaluating microplastic contamination under different hydrogeological and socio-environmental conditions.

3.1.2 Croatia: Kupica Spring Catchment

Location

The Croatian pilot site, Kupica spring, is situated in the heart of the mountainous Gorski kotar region of Croatia (Figure 1). The catchment area of Kupica spring spans 340 km^2 and features diverse topography with significant variations in elevation. Most of the catchment is covered by forests, with only 2.4% of the total area covered by urban fabric, industry, roads and railways, construction sites, etc. The water facility where sampling was conducted processes raw water from Kupica spring, supplying drinking water to approximately 15,000 residents, including those in the city of Delnice.

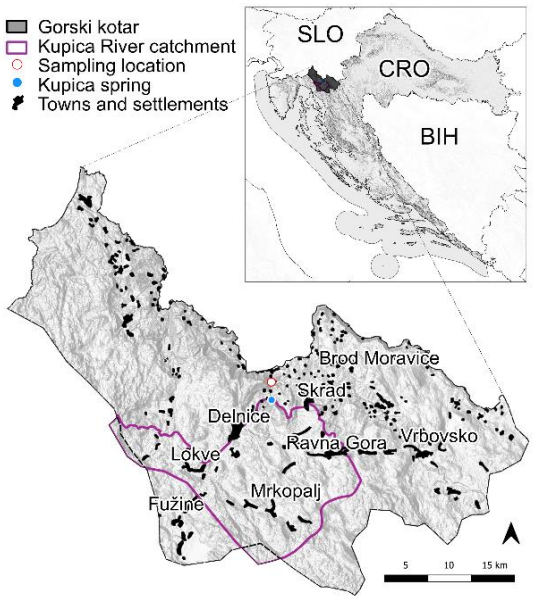

Figure 1: Location of the Croatian pilot site

Geology/Hydrogeology

The geological structure of the region is highly complex. Thick deposits of Triassic dolomites and Jurassic and Cretaceous limestones, which form the Dinaric karst are hydrogeologically the most significant.

Severe karstification of the carbonates is attributed to tectonic disruption, resulting in a complex network of fractures, caves and cavern systems. Kupica is recharged from the Mala Kapela and Bitoraj mountains and springs from a karst fenster, with an average annual discharge of approximately 5 m^3/s. It is characterised by significant fluctuations between minimum and maximum discharges and responds to precipitation within 24 hours, which is typical for karst springs.

Hydrology/Climate

Gorski kotar is directly influenced by two contrasting climates: the continental climate of northern Croatia and the mild Mediterranean climate from the south. The mean annual temperature is around 6°C, with harsh winters and mild summers, and abundant precipitation during the winter

months, which is an important source of aquifer recharge. Annual precipitation in the mountains is between 1,800 and 2,500 mm, reaching up to 4,000 mm in higher elevation areas.

Water quality

Croatian Waters conducts regular water quality analyses at the Kupica spring, and the Teaching Institute for Public Health of Primorje – Gorski kotar County provides public data on drinking water quality sampled at end-point locations such as schools, hotels, or other public or private facilities. Data on drinking water collected at end-point locations between 2022-2024 (Croatian Institute of Public Health) indicate high drinking water quality: pH ~8, electrical conductivity ~306 µS/cm, very low nitrates (0.86 mg/L) and dissolved metals (Fe ~21 µg/L and Mn ~1.3 µg/L). Although raw water is generally of good quality, anthropogenic impact is evident.

Drinking water protection zones

Sanitary protection zones were established for the Kupica spring and its catchment in 2013. Four zones have been established for the entire catchment and the spring itself is protected and fenced off (Zone I).

Groundwater sampling site

Kupica spring is formed as a small lake, approximately 18 m in both width and length (Figure 2). The riverbanks are lined with stone, and raw water flows to the facility by gravity through a ~2 m long pipeline; no plastic materials are used. The spring is used for water supply in maximum capacity of 20-100 L/s.

Figure 2: Pilot site Kupica spring

Drinking water treatment

Raw water from the spring is treated using a four-step process. The raw water enters the facility gravitationally, first reaching a flocculator where aluminium sulphate is added. It is then divided into two sedimentation tanks in a UV-lit chamber to ensure microbiological safety. After sedimentation, the water flows through sand filters and finally chlorine disinfection is applied. The entire process takes approximately 8–10 days, with coagulants occasionally added due to high turbidity in the raw water.

Water infrastructure

Approximately 15,000 residents obtain their drinking water from Kupica spring. 90% of the public is connected to the water supply system, however, connection to sewage disposal (wastewater treatment plant Delnice) is much lower: 75% in the city of Delnice, and only 9% in surrounding settlements, which consequently have to rely on alternative solutions.

Potential sources for microplastics in groundwater

Several potential sources of microplastics in groundwater have been identified in the region (Delnice urban area, tire and road abrasion, littering, wastewater disposal, wastewater treatment plants, landfills and recycling facilities, and tourism). Littering is a significant concern, as waste is illegally disposed into sinkholes, ponors and caves that have been confirmed through tracer tests to be connected to Kupica spring.

3.1.3 Austria: Spring

Location

The spring is located in a karst area at an elevation of approximately 730 m a.s.l. and with a catchment altitude of ~1,500–1,600 m (

Figure 3). The catchment area is uninhabited and forested. Therefore, the spring is considered a background monitoring site.

Figure 3: Reservoir of spring (photo: H2O-Fachdatenbank, 2025).

Geology/Hydrogeology

The karst massif consists primarily of intensely karstified Wetterstein limestone. Precipitation infiltrates almost completely through dolines and fissures, and drainage occurs almost exclusively underground.

Large karst springs, including spring PP6, emerge at the foot of the karst massif where carbonate rocks are thrust over Neogene sediments. The spring is characterized by high storage capacity and relatively stable discharge even during droughts. A tracer test confirmed the connection between infiltration points near ~1,500 m a.s.l. and the spring (reappearance after ~6 weeks).

Hydrology and Climate

The region has a continental precipitation regime with peaks in July/August and again in October/November. Mean annual precipitation is around 1,800 mm. Infiltration of precipitation forms the main part of the average annual groundwater recharge, which is estimated at around 670 mm.

Water quality

Monitoring data (2022–2024) indicate excellent groundwater quality: pH ~8, electrical conductivity ~208 µS/cm, low nitrate (3.2 mg/L), very low dissolved metals (Fe, Mn < 0.002 mg/L), and no detection of pesticides, VOCs, PFAS, or pharmaceuticals. The water is moderately hard (total

hardness ~6.2 °dH) and has a very low organic load (DOC < 0.5 mg/L). Accordingly, the drinking water is also of excellent quality.

Drinking water protection zones

A water protection zone (ca. 30 km²) was established in 1998. Mining, waste disposal, sewage spreading, and storage of hazardous substances are prohibited; construction activities require special permits.

Groundwater sampling site

Spring PP6 consists of two spring branches, whose water is collected in a common reservoir. Maximum abstraction is limited to 30 L/s. The pipeline to the reservoir is made of PVC. Other materials used are concrete and metal for the pipes in the reservoir.

Drinking water treatment

The spring water shows slight natural bacteriological loading due to the low filtering capacity of the karst system. To ensure microbiological safety, the water is disinfected with UV light. Chlorination is applied only in rare cases of high turbidity. No other treatment steps are required

Water infrastructure

Spring PP6 contributes to the water supply of a town with ~2,300 inhabitants, with ~98% connected to the public water supply system. Wastewater is treated in a central wastewater treatment plant (connection rate: ~92%) and discharged into a nearby river. No contamination of the spring water occurs, as the catchment lies above the settlements and is within a legally protected area.

Potential sources of microplastics in groundwater

Potential sources of microplastics in groundwater are limited to diffuse sources such as tire abrasion (atmospheric deposition), littering (hikers), and forestry operations. There are no point sources (hot spots) of microplastic inputs in the spring's catchment area. However, due to the highly karstified geology, there is a general vulnerability to contamination if land use intensifies in the future.

3.1.4 Bosnia and Herzegovina: Crni dol Water Source

Location

Gornji Vakuf-Uskoplje is a settlement and municipality in the Central Bosnia Canton of Bosnia and Herzegovina (Figure 4). It is located in the Skopaljska Valley, which extends along the upper reaches of the Vrbas River. In 2001, according to the decision of the international community in Bosnia and Herzegovina, the continuation of Uskoplje was added to the name of the municipality and town of Gornji Vakuf.

The municipality of Gornji Vakuf-Uskoplje, covering an area of 395.95 km², is located in the upper reaches of the Vrbas River, and administratively belongs to the Central Bosnia Canton, Federation of Bosnia and Herzegovina. It borders the municipality of Bugojno to the northwest, Novi Travnik to the north and northeast, Fojnica to the east, Prozor-Rama and Konjic to the south, and Kupres to the west. The altitude range of the municipality of Gornji Vakuf–Uskoplje ranges from 610 m (near Humac in the Skopaljska Valley) to 2,112 m (Nadkrstac, the highest peak of Vranica).

The Pilot area karst source “Crni dol” is managed by the public utility company “Water supply and sewerage Gornji Vakuf – Uskoplje” that supplies drinking water to the town of Gornji Vakuf – Uskoplje. Water source “Crni dol” is located near the locality of “Crno vrelo” approximately 10 km from Gornji Vakuf – Uskoplje. Geographically, the boundary of the protection zone extends from “Crno vrelo” across the slopes of “Govednjača” and elevation 1,684 m a.s.l., then east to “Medvednjača” at 1,818 m a.s.l., along the ridge to 1,730 m a.s.l., from which it descends north along the ridge to “Rasova” at 1,260 m a.s.l. and continues towards “Dobro” at 1,778 m a.s.l., then northwest to 1,683 m a.s.l., from where it descends along the natural border (ridge) to “Crni dol”.

Since the war in the 1990s, increased population pressure has caused forest degradation and river basin erosion, which must be assessed and mitigated.

Geology

The geological structure of the terrain of the Gornji Vakuf-Uskoplje municipality is relatively simple. East of the Voljevac-Vrba fault, Silurian-Devonian formations predominate, followed by Upper Permian formations. In addition to Silurian-Devonian slates, Devonian limestones and acidic igneous rocks are also present in this area. The Upper Permian deposits make the transition to the area west of the mentioned fault, where Triassic limestones and dolomites dominate. The geological structure of the Vrbas basin consists of Palaeozoic, Mesozoic and Cenozoic sediments. Mesozoic Carbonate rocks are predominant, followed by clastic sediments of the Mesozoic, Palaeozoic and Tertiary. Igneous rocks and Palaeozoic carbonates are less represented. Palaeozoic sediments are represented by the Silurian, Devonian, Carboniferous and Permian periods.

The primary soil types in the basin are cambisols and leptosols, influenced by the underlying geology. Podzols, the most fertile soils, are limited to the lower part of the Vrbas watershed around Lijevča Polje.

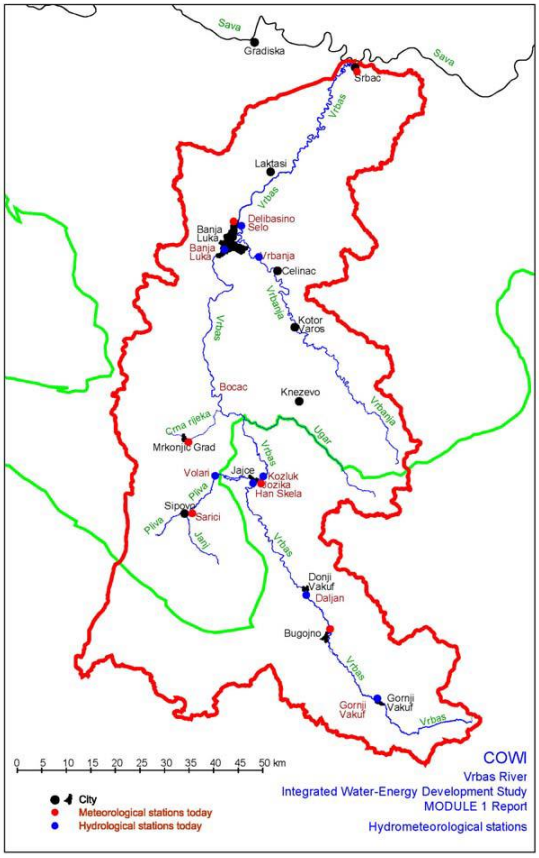

Figure 4: General location of the pilot area.

Humus content on agricultural land is about 50% lower than on land covered by forest vegetation. Agricultural practices have reduced the humus content in agricultural land, which continues to decline and requires attention. Land use within the basin is primarily forestry, covering 60% of the area and agriculture, covering 39%, with smaller areas allocated to wetlands, abandoned land and urban areas.

Numerous deposits of mineral raw materials are registered in the territory of the Gornji Vakuf-Uskoplje municipality. The Gračanica lignite mine is located on the right bank of the Vrbas in the

Rosulje settlement. Lignite is exploited from the Dimnjač deposit with reserves of 12,095,012 tons. Part of the Radovan magnetite deposit is located northeast of Bojska and there are gypsum deposits in the areas of Bistrica and Voljica. The Bistrica deposit contains reserves of 3,211,541 tons. Barite occurs in Dobruška Vranica and in the localities of Baška and Oštrika in the north of the municipality with smaller occurrences in the Sabljine Pećine, Grnica and Smrdivode. Mercury mining occurs in the areas of Mačkara, Mračaj, Cvrč, Kulentaš, Valica and Borova Ravni. In Mačkara, Dobrošin, Seoc and Borova Ravni there are deposits of tetrahedrite in the wider area of Smrčevica, in the extreme east of the municipality, there are three active quartzite deposits. Significant non-metallic mineral raw materials are limestone and dolomite, whose significant deposits are located in Pidriš, Smrčevac near Voljica, Veliki Guser, Suhodol, Lisina, Rog and other locations.

The Vrbas basin can be further divided into areas according to different structural types of porosity:

- Intergranular porosity
- Intergranular and crack porosity
- Crack porosity
- Karst-fissure porosity
- Karst porosity
- Conditionally arid terrains (without important aquifers).

Hydrogeology

The Vrbas River drains the central parts of the northern slopes of the Dinaric Mountain range. Drainage in the catchment shows a mixture of patterns from gridded/rectangular – indicating strong structural control due to geology indicating areas of very steep relief or where flow is over incoherent material. The bedrocks, which were axially displaced during the formation of the Dinaric Mountains and under the present climate regime, have undoubtedly shape the terrain. The catchment area is mainly characterised by mountainous and hilly-mountainous relief, occupying 90% of the land surface (~5,800 km^2) in the upper and lower parts, while the lower river plain of the Vrbas catchment occupies the remaining 10% of the catchment area (~600 km^2), which are mainly located near “Lijevča polje” and “Skopaljska dolina”. Geomorphological relief types include karst, purely fluvial, fluvial-glacial, limno-glacial, alluvial and erosive types.

Climate

The Vrbas river valley has a completely continental climate and is surrounded on all sides (except the north) by mountainous terrain. The mountains increase in elevation towards the south of the basin, approaching the watershed that divides the flow towards the Black Sea (via the Danube system) and smaller river basins flowing towards the Adriatic Sea. In the north, the terrain opens onto the great Pannonian plain, which is cut in half by the Danube system. These topographic forms influence the climate, resulting a continental climate in the northern lowlands and in the central valley areas, while southern part of the basin is characterised by a sub-mountainous and mountainous climate.

Average annual air temperatures depend significantly on altitude, ranging from 8–10 °C in the north to 16–17 °C in the south. The following graph shows average monthly air temperatures for four selected meteorological stations in the Vrbas basin.

Drinking water protection zones

The water source “Crni dol” is located near “Crno Vrelo” mountain “Vranica” on a locality about 10 km from Gornji Vakuf – Uskoplje. Geographically, the border of the water protection zone

extends from the spring across “Crni do” along the slopes of “Govednjača” at elevation 1,684, then east to “Medvednjača”, at elevation 1,730, from which it descends north to “Rasova” at elevation 1,260.

The first protection zone of the source includes the area surrounding the water catchment facilities, which protect the water catchment facilities from accidental or intentional pollution or damage to the source.

Groundwater sampling site and drinking water treatment

Water from the “Crni dol” source is transported to the “Zvizde” reservoir through a drainage pipeline made of spiral pipes, 8,253 m long (Figure 5). The spring consists of a catchment and collection gallery (Zvizde reservoir with a capacity of 2,000 m^3) of several springs (spring profile I, profile II and profile III). The catchment is a reinforced concrete building with a collection gallery, which captures the karst spring over a length of approximately 150 m. The collecting gallery, about 150 m long, collects water and directs it to the catchment and catch basin. The flow is carried out via a right-angled overflow, where measurements of the collected quantities can be made. From the catchment basin, water is transported by gravity pipeline to the existing reservoirs. Disinfection of the water is carried out in the reservoirs.

“Water Supply and Sewerage” Gornji Vakuf - Uskoplje supplies drinking water to the town of Gornji Vakuf - Uskoplje. Drinking water from this location will be analysed for microplastics contamination. MicroDrink project activities in this pilot area are of great importance, as they will determine the current state regarding contamination of drinking water with microplastics at this site. Having data on contamination will enable the adoption of measures aimed at reducing contamination and protecting public health, as well as raising awareness at the local level.

Figure 5: Source “Crni dol”.

Potential sources of microplastics in groundwater

Potential sources of microplastics in groundwater include tire abrasion (atmospheric deposition), littering (hikers), forestry operations, and tourism activities.

3.2 Characterisation of drinking water obtained from intergranular water resources in DRB

3.2.1 Summary

Three pilot action sites: **Kőszárhegy in Hungary** (PP8), **Pavliš in Serbia** (PP11), and **Neufahrn bei Freising in Germany** (PP12) exploit intergranular aquifers. Pore groundwater is an essential resource for public drinking water supply in many regions. The sites represent diverse hydrogeological and management conditions across Central and Southeastern Europe.

At the three pilot action sites, water utilities extract groundwater from depths ranging from several tens to over a hundred meters below the surface. These deep aquifers are characterised by long groundwater residence times in the subsurface, sometimes spanning decades or even centuries. The Hungarian pilot site comprises two deep confined aquifers within Miocene and Eocene sediments overlain by clay layers. Long groundwater residence times (> 50 years) indicate a well-protected system with minimal surface influence. The Serbian site exploits a confined Neogene sandy-gravel aquifer covered by approximately 30 m of low-permeability sediments, providing strong protection against surface infiltration. The groundwater is characterised by mean residence times of approximately 9,900 ± 100 years. The German pilot action site features a dual aquifer system: an unconfined Quaternary and a confined Tertiary aquifer, hydraulically connected to the Isar River. While recharge from river infiltration occurs particularly during high-flow events, the deep aquifer used for drinking water abstraction remains effectively protected. Generally, such deep pore groundwater is considered particularly well protected against anthropogenic pollution, as natural filtration processes and long underground flow paths significantly delay the transport of potential contaminants.

All three sites supply high-quality drinking water, though treatment intensity reflects local natural hydrogeochemical conditions. In Germany, only aeration is required to remove iron and manganese, as nitrate and contaminants are absent. At the Hungarian site, chlorination and polyphosphate dosing are applied, but no filtration or aeration is required. Serbia operates the most complex treatment, including aeration, sand filtration, and chlorination, due to locally elevated ammonium and iron/ manganese concentrations.

Infrastructure density and population coverage differ in scale. The German pilot action site supplies about 63,000 residents through a modern network and six deep wells. The Hungarian site serves 22,000 inhabitants in eight rural settlements, relying on six production wells. Serbia's system serves 32,000 people, using 17 wells and a central treatment plant. All three areas achieve at least 95% network coverage, reflecting robust public water supply systems.

Each site is legally protected through designated drinking water zones. The German site has a large and well-established protection zone (1.8 km², since 1992) and minimal external pressures. Hungary's zone is relatively small (0.011 km², established in 2001) but sufficient due to low pollution risks. Serbia's system is extensive (6 km^2 across three zones, since 2009) because of higher agricultural and infrastructural exposure.

Inputs into pore groundwater typically occur diffusely, for example through tire wear, agricultural practices, infiltrating precipitation, or surface water infiltration. In intensively used catchment areas, the likelihood increases that microplastics enter the unsaturated zone and depending on the soil's filtration capacity also reach deeper aquifers. Preventing microplastic pollution at its

source is particularly important. This includes improved waste and wastewater management, adapted agricultural practices, and advanced technologies in wastewater treatment.

Despite differences in aquifer configuration, climatic setting, and water treatment requirements, all three sites demonstrate stable groundwater systems of high quality and with long groundwater residence times, effective protection measures, largely no evidence of anthropogenic impact and generally low susceptibility to microplastic contamination. Potential sources of microplastics, such as road traffic, agriculture, and wastewater, are minimal or even negligible at all sites.

However, microplastic particles exhibit high mobility in permeable sediments, especially when these are coarse-grained and well-flushed. Depending on particle characteristics, such as size, density, shape, and surface properties, as well as the geological structure of the subsurface, microplastics can be transported over long periods and potentially reach deeper groundwater zones.

3.2.2 Hungary: Kőszárhegy Water Base

Location

Kőszárhegy is situated between the Velence Hills and Lake Balaton, bordered by the Sárrét region to the north and the Mezőföld to the south (Figure 6). The area features gently rolling hills reaching up to 228 m above sea level, with a landscape dominated by agricultural land and small settlements. The pilot site was selected for its large-scale water utility network operated by Fejérvíz, which mainly exploits intergranular aquifers (99%).

Geology and Hydrogeology

The geological sequence comprises Paleozoic basement rocks, primarily quartz phyllite, schist, and Devonian limestone, overlain by Eocene and Miocene formations. The aquifer system consists of two confined layers: a shallow aquifer (70–120 m) and a deeper one (160–180 m), both composed mainly of sandy and gravelly sediments with alternating clay aquicludes. Groundwater flows from the southeast towards the wells, with minor inflow from karst systems to the northwest. The groundwater residence time is mostly over 50 years, indicating well-protected and stable water resources.

Hydrology and Climate

The site is situted in a temperate continental climate with annual precipitation between 560–600 mm and an average temperature of 10 °C. The Sárvíz River and its tributaries dominate the local hydrology. Human regulation has influenced flow conditions, but recharge is primarily from distant infiltration zones.

Water Quality and Infrastructure

Groundwater has a stable pH ~7.5, electrical conductivity ~620 µS/cm, and total hardness ~19 °H. Nitrate and trace metal concentrations remain below regulatory limits. Water is disinfected with chlorine gas and treated with polyphosphate; no filtration or aeration steps are applied. The supply system serves approximately 22,000 inhabitants across eight settlements, with 99% connected to the water network and 81% to sewerage.

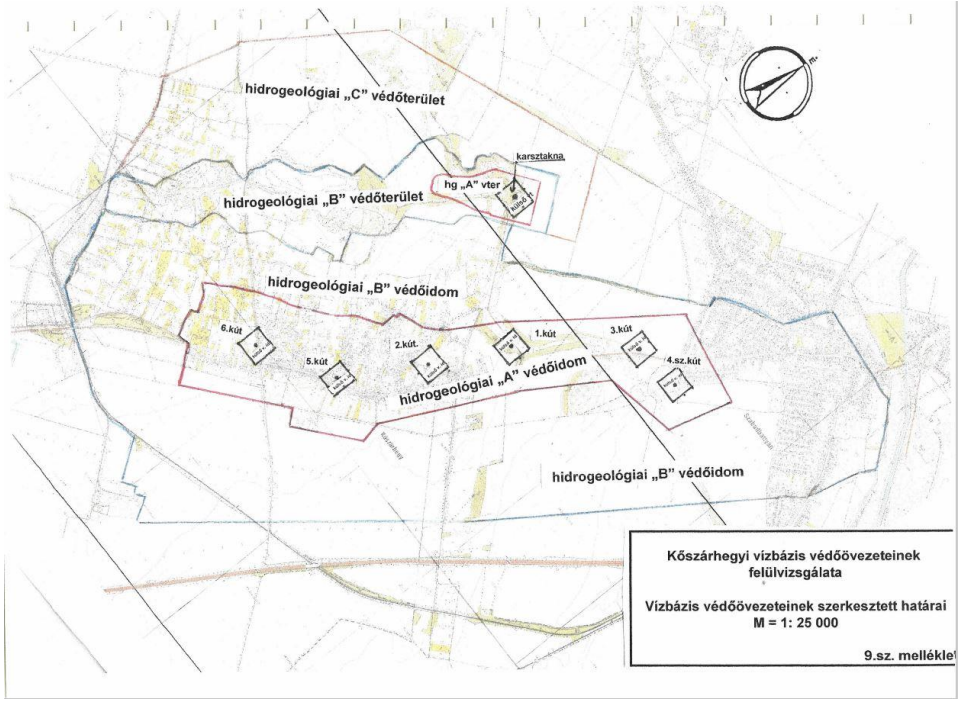

Figure 6: Location of the pilot site.

Abstraction and Facilities

The network includes six production wells, with depths ranging from 64 m to 210 m. Water is pumped into 250 m³ mixing tanks and distributed via elevated storage reservoirs. The main pumps are submersible Grundfos and EMU models, with flow rates between 12–60 m³/h.

Protection and Anthropogenic Factors

A drinking water protection zone (0.011 km², established in 2001) enforces usage restrictions under national law. Potential microplastic sources include road abrasion, irrigation, and vegetable farming. Other sources such as wastewater or industry are negligible.

3.2.3 Serbia: Pavliš Water Source Area

Location

The pilot area is located in the village of Pavliš, which lies in the immediate vicinity of the city of Vršac. Vršac is situated in the northeastern part of Serbia, in the southeastern region of Vojvodina, along the edge of the Pannonian Plain, at the foothills and slopes of the Vršac Mountains (Figure 7). The city's geographical coordinates are 45°07'11'' north latitude and 21°17'54'' east longitude, at an altitude of approximately 118 meters above sea level. Vršac is located 84 km northeast of Belgrade and about 14 km from the state border with Romania, which it borders on its eastern and northeastern sides. The municipality of Vršac also borders the territories of Plandište to the northwest, Alibunar to the west, and Kovin and Bela Crkva to the south.

Geology/Hydrogeology

Most of the investigated area is covered by Quaternary and Neogene sediments. Beneath these sediments lies a Pre-Neogene basement of Paleozoic and Precambrian age. The Pre-Neogene basement is composed of metamorphic and magmatic rocks, which outcrop exclusively within the Vršac Mountains. The aquifer exploited for water supply is formed within the Neogene sediments. Data analysis has identified a continuous distribution of sandy-gravel deposits. As these sediments are the dominant component of the Pliocene sedimentary sequence in the investigated area, they have the greatest hydrogeological significance.

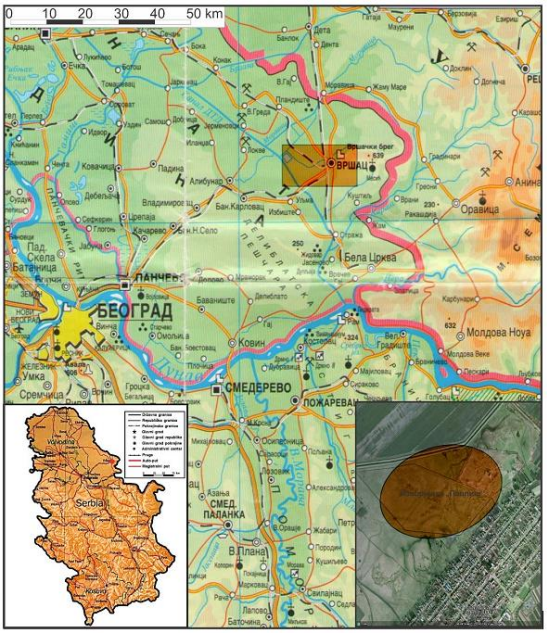

Figure 7: Location of the pilot site

Hydrology/Climate

The Vršac Meteorological Station is located at an elevation of 83 meters above sea level. For the analysis of precipitation, the period from 1946 to 2019 was selected. The average mean monthly precipitation for the analysed period ranges from 36.4 mm in March to 86.2 mm in June. The main maximum occurs at the end of spring and in the first half of summer, while minimum values are recorded at the beginning of spring and in mid-autumn. The average annual precipitation for the analysed is 651.6 mm. The absolute maximum of mean monthly precipitation was recorded in July 2014, reaching 275 mm, whereas the minimum occurred in March 1972 and October 1965, when no precipitation was recorded. The highest precipitation typically occurs in summer, averaging around 220 mm, followed by spring with approximately 160 mm, and autumn and winter with about 140 mm each. As the aquifer is confined type, there is no direct recharge from atmospheric precipitation.

Water quality

The chemical composition of the groundwater is characterised by low overall mineralisation, with a dry residue ranging between 280–420 mg/L, and locally up to around 600 mg/L. The pH values range from 7.4 to 7.6. Total hardness varies between 12–20 °dH. Permanganate consumption is low, not exceeding 5 mg/L. Ammonium concentrations are almost consistently above the maximum permissible limit (0.6–1.2 mg/L), while locally, iron levels reach up to 2.2 mg/L and manganese up to 1 mg/L. All other components remain within the limits prescribed for drinking water quality.

Drinking water protection zones

The “Pavliš” water source area holds a Decision on Sanitary Protection Zones issued in 2009, based on the prepared Elaboration on Sanitary Protection Zones. The immediate sanitary protection zone (Zone I) is established in the area directly surrounding the water intake facility. Zone II is formed

around the source, covering 108 hectares, while Zone III encompasses an additional 371 hectares surrounding the source area.

Groundwater sampling site

Water is extracted through 17 deep wells with an average depth of approximately 100 meters. The well are constructed of steel and equipped with bridge-type, ribbed, and Johnson screens. The pipelines from the wells to the water treatment plant are constructed of asbestos-cement, steel, stainless steel, and polyethylene pipes.

Drinking water treatment

The water treatment plant, where ammonia and manganese are removed from the raw water, is located at the Pavliš wellfield. Treatment is carried out through aeration of the raw water in closed aerators (polyester tanks where the raw water is dispersed and mixed with oxygen supplied from the external environment) and filtering the aerated water in sand filters (steel tanks filled with quartz sand and a small amount of anthracite). The treated water is then directed to storage reservoirs (two reservoirs with a capacity of 1,500 m^3 each), from which it is pumped into the distribution network supplying the city. The reservoirs are lined with a special PVC foil to facilitate maintenance. At the plant's outlet, before entering the distribution network, the water is disinfected with gaseous chlorine. All pipe galleries within the plant are constructed from stainless steel.

Water infrastructure

According to the 2022 population census, the city of Vršac has 31,946 inhabitants, of whom over 95% are connected to the water supply network. The water supply network in the city of Vršac covers approximately 160 kilometres and is constructed from various materials: asbestos-cement (52.14%), polyethylene (38.62%), plastic (PVC) (5.96%), steel, polyester, galvanised, and cast-iron pipes. There are around 17,000 service connections. Drinking water is treated at the city's water treatment plant. The water supply system of Vršac includes five elevated reservoirs with a total capacity of 5,720 m^3. Wastewater is treated at the Vršac Wastewater Treatment Plant before being discharged into the recipient "Maloritski Canal."

Potential sources of microplastics in groundwater

Potential contamination by microplastics from the surface is minimal, as the aquifer is of an intergranular, porous type and is covered by an overlying protective layer approximately 30 meters thick, which effectively neutralises the impact of surface pollutants.

3.2.4 Germany: Germany–Bavarian Drinking Water Wellfield

Location

The pilot site is located in Bavaria, approximately 20 km north of a major metropolitan area. The study area covers about 20 km^2 and represents a mixed landscape characterised predominantly by agricultural land, with some urban and light industrial features. The drinking water supply system includes several shallow and deep groundwater wells managed by a regional water utility. The catchment is also influenced by treated wastewater originating from a large municipal wastewater treatment facility serving a significant urban population.

Geology/Hydrogeology

The site is located in the Munich gravel plain within the Alpine foreland basin. It includes two porous aquifers: an unconfined Quaternary aquifer (gravel and sands) and a confined Tertiary aquifer (silt, sand, gravel), separated by clay and marl layers. Groundwater flows mainly from south to north, with infiltration occurring near the Isar River, particularly during flood events. The deep aquifer is the primary source of drinking water, with an average extraction rate of 580 L/s.

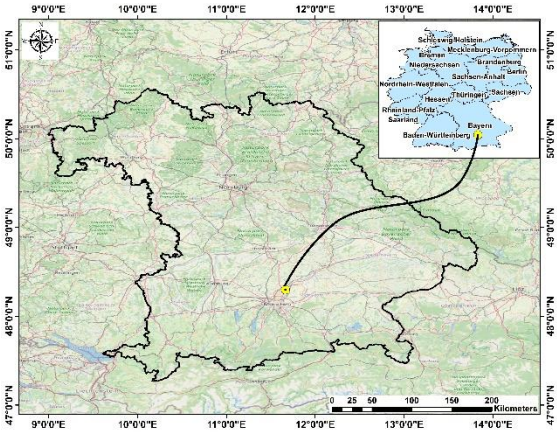

Figure 8: Location of the pilot site.

Hydrology/Climate

The region has a warm-moderate climate. The mean annual temperature is 9.1 °C. Average precipitation is about 762 mm, with summer months contributing most to recharge. Actual evapotranspiration is 522 mm/a, potential evapotranspiration 656 mm/a. The Isar River is the main surface water body and is regulated for hydropower. Flood events lead to increased infiltration into groundwater, but extraction wells are not significantly impacted.

Water Quality

Measurements (2023–2024) indicate good groundwater quality. Parameters include: pH 7.54–7.62, electrical conductivity 464–613 µS/cm, oxygen 2.04–8.23 mg/L, water temperature 11.7–12.2 °C, calcium 55–69 mg/L, magnesium 23–25 mg/L, sodium 30–38 mg/L, potassium 1.1 mg/L, chloride 14–22 mg/L, sulphate 6.9–17 mg/L, nitrate <1 mg/L, nitrite <0.1 mg/L, iron 0.26 mg/L, manganese 0.094 mg/L. Pesticides and VOCs were not detected. Water hardness is around 14 °dH.

Drinking Water Protection Zones

A drinking water protection zone was established in 1992 to protect the well field. The zone covers 1.8 km² and is managed by a Bavarian water utility.

Groundwater Abstraction & Infrastructure

The well field consists of six deep wells (drinking water) and three shallow wells (process water). Deep wells are screened in the confined aquifer at depths of 30–80 m. About 75% of the local water supply is drawn from these wells. About 63,000 people are connected to the public drinking water supply.

Drinking Water Treatment

Raw water from the deep wells requires only minimal treatment. Iron and manganese are removed by aeration. No other treatment steps (such as filtration, UV, or chlorination) are applied.

Potential Sources of Microplastics in Groundwater

The pilot site assessment did not identify relevant sources of microplastics in the catchment area.

3.3 Characterisation of drinking water obtained from bank filtration in DRB

3.3.1 Summary

Three pilot action sites: **Malenščica spring in Planinsko polje in Slovenia** (PP3, PP4), **Ivančice waterworks in the Czech Republic** (PP7), and **Staničenje in Serbia** (PP9) were selected for the investigation of microplastics in bank filtrate. Malenščica spring in Slovenia is a karst spring strongly influenced by nearby surface waters. It was therefore categorised within the bank filtration/surface water cluster, similar to the Staničenje pilot action site in Serbia.

All three pilot action sites demonstrate close interaction between surface waters and groundwater. Bank filtrate, derived from surface water through natural filtration processes in the subsurface, is an important source for drinking water supply. Due to their small size and variable physicochemical properties, microplastic particles can partially or even completely bypass natural filter barriers in the bank filtration zone. The permeability of the subsurface, the residence time of water within the sediment, and particle characteristics, such as size, shape, density, and surface charge, play a crucial role in determining whether microplastics are retained in or transported through the bank filtrate. While some microplastic particles may be retained in the upper sediment layers, smaller, lighter, or chemically inert particles pose a particular risk of further migration into the groundwater. Groundwater in karst regions connected to surface water is especially vulnerable due to high permeability and limited natural filtration in such systems (e.g., Malenščica spring in Slovenia).

Malenščica Spring in southwestern Slovenia drains a complex karst system composed mainly of Cretaceous and Jurassic limestones with high permeability and strong hydraulic connectivity. With a recharge area of 726 km² and an average discharge of 6.7 m³/s, it is among Slovenia's most important drinking water resources. Ivančice Waterworks in the Czech Republic operates at the confluence of the Jihlava and Rokytná Rivers, where water production relies on natural bank filtration through coarse Quaternary sands. The Staničenje site in southeastern Serbia is located in the alluvial sediments of the Nišava River, characterised by riverbank filtration within terrace gravels and sands of high hydraulic conductivity. All three systems are marked by intense surface–groundwater interactions.

Climatic conditions vary considerably among the sites. The Slovenian catchment lies in a transitional Mediterranean–continental regime with high precipitation (1,776 mm/year), Ivančice experiences a warm and relatively dry climate (about 508 mm/year), and Staničenje is influenced by a temperate-continental climate (584 mm/year).

Groundwater quality at all sites is generally very good. Malenščica Spring shows low concentrations of nitrates and trace elements, microbiological parameters are removed by various water treatment steps, ensuring the drinking water is microbiologically compliant. Ivančice raw water contains elevated nitrogen compounds and traces of pharmaceuticals and tritium linked to cooling water from an upstream nuclear power plant, which are efficiently removed by carbon filtration. At Staničenje, analyses reveal good chemical quality and no detectable micropollutants. In all cases, the drinking water complies with legal requirements.

Protection and management practices differ significantly. Malenščica Spring benefits from a well-established protection zone since 1971, strictly limiting agricultural and construction activities.

Ivančice site, maintains an internal fenced protection area covering the immediate vicinity of the wells, while no formal protection zones exist at Staničenje.

Water treatment complexity also varies: Slovenia employs coagulation, ultrafiltration, and dual-stage chlorination; Ivančice Waterworks relies on natural filtration and activated carbon; Serbia applies basic sedimentation and disinfection with sodium hypochlorite.

Water supply systems also differ in scale. The Slovenian system serves about 22,900 inhabitants, the Ivančice Waterworks Association supplies 41,000 people across 31 municipalities, and the Staničenje network covers around 600 permanent residents (up to 800 in summer) with full connection rates. Despite these differences, all systems ensure reliable delivery of potable water through regularly maintained infrastructure.

All three pilot action sites are characterised by intensive anthropogenic use of their catchment areas, which can result in significant microplastic pollution of surface waters. All pilot sites have multiple potential sources of microplastic contamination in groundwater. At Malenščica Spring, the extensive karst recharge area is exposed to a wide range of possible pollution sources, including transport, waste management, wastewater, agriculture, forestry, landfills, industry, and tourism. In the Ivančice Waterworks area, the main potential source is the river basin, which receives effluent from several wastewater treatment plants serving nearby towns. At Staničenje, microplastic inputs may originate from tire wear, road abrasion, littering, waste handling, and wastewater disposal, as well as from compost, landfills, agriculture (mulching films, polytunnels), forestry, and tourism.

3.3.2 Slovenia: Malenščica spring in Planinsko polje

Location

The Malenščica Spring is located at the southern border of the Planina karst polje in southwestern Slovenia (

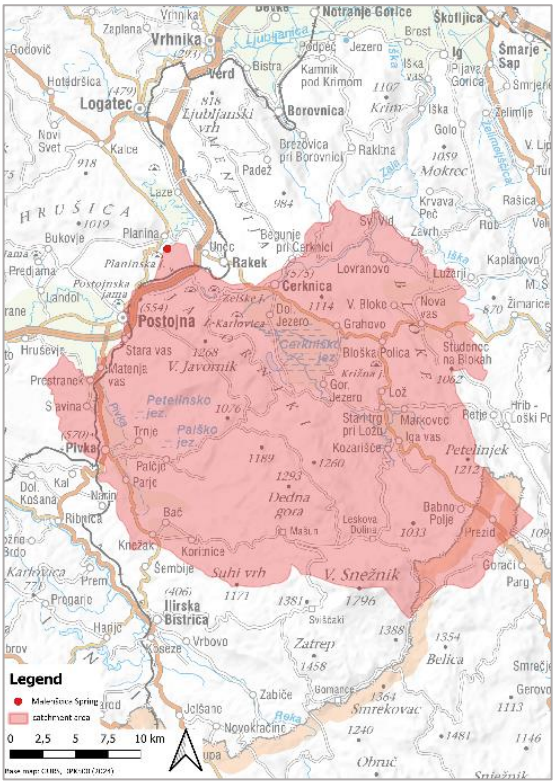

Figure 9). The Spring is one of several located in a distinct pocket valley. The most important and only permanent spring is the lower one, which is captured for the water supply of two municipalities (Petrič, 2010; Kovačič, 2011). The recharge area covers 726 km², with elevations ranging from 448 m to 1,796 m a.s.l. and a relatively flat terrain, with an average slope of 11° (Kovačič, 2011). The closest catchment area is a diverse karst landscape with numerous sinkholes and other karst landforms (Kovačič, 2011). The largest part of the catchment area (77%) is forested, followed by agricultural areas (17%). Artificial surfaces are minimal and mainly located near settlements.

Figure 9: Malenščica spring catchment area.

Geology/Hydrogeology

The oldest rocks in the catchment are Norian–Rhaetian dolomites intersected by the Idrija Fault Zone. The catchment is also composed of Jurassic limestone, Cretaceous limestone, which form the central karst aquifer, as well as poorly permeable Eocene flysch and Quaternary alluvial sediments along streams and poljes. The immediate hinterland of the Malenščica Spring consists of Lower Cretaceous limestone (Petrič, 2010). The recharge area forms a complex karst system divided into three separate but hydrologically interconnected parts – the Javorniki, Pivka, and Cerknica parts of the catchment area (Petrič, 2010). Inflows from these areas mix within the karst system, and their respective contributions to the discharge of the Malenščica Spring vary depending on the hydrological conditions (Kogovšek and Petrič, 2010). Highly permeable rocks with karst-fissure porosity (Cretaceous and Jurassic limestones) cover over 73% of the catchment (Kovačič, 2011).

Hydrology/Climate

The average discharge of the Malenščica is 6.7 m^3/s, with peaks in April and December. A unique feature of the spring is its ability to maintain low flows that never drop below 1.1 m^3/s (Kovačič, 2011). The recharge area of the Malenščica Spring is located in the transition zone between the Mediterranean and continental precipitation regimes. The average annual precipitation is 1,776 mm. Precipitation peaks occur in November and June, with minima in February and July. The average annual air temperature ranged between 5.6°C and 8.4°C (Kovačič, 2011).

Water quality

Monitoring data (2022–2024) indicate good raw groundwater quality, with a pH ~7.6, electrical conductivity ~350 µS/cm, and low concentrations of most ions and trace elements. Organic matter levels are low, and contaminants such as nitrite, ammonium, pesticides and VOCs are below detection limits. Microbiological parameters are frequently detected in raw water but are removed by various water treatment steps, ensuring that the treated (drinking) water is microbiologically compliant.

Drinking water protection zones

The water protection zone for the water source was established in 1971. The narrower protection zone (protection zone I) covers 0.13 km^2 and prohibits different activities.

Groundwater sampling site

The pumping station has two intakes (Figure 10). In the dry season, intake I dries up and cannot be fully used. After reconstruction in 2018, three vertical turbine pumps with a capacity of 50 l/s were installed in intake I. Intake II was built approximately 20 m downstream from intake I. In 2018, the facility was reconstructed into a shaft, where three submersible pumps with capacity of 50 l/s are installed. The total capacity of both intakes after reconstruction is 150 l/s.

Figure 10: Malenščica spring in Planinsko polje.

Drinking water treatment

At the pumping station, a dosing system for the coagulant PAH is installed. The water is then pumped to the water treatment plant, where it is treated by ultrafiltration and a two-stage disinfection process using chlorine. Under normal operating conditions, sedimentation, activated carbon, and UV light are not used.

Water infrastructure

The system supplies drinking water to approximately 22,900 residents across the Postojna and Pivka municipalities, covering an area of 493 km². Based on the average discharge of the Malenščica Spring, ~211 million m³ of water is available annually. However, the actual pumped volume is limited to the capacity of the intakes (~4.73 million m³ annually), depending on demand and operational constraints. Wastewater treatment is conducted at the Postojna and Pivka wastewater treatment plants.

Potential sources of microplastics in groundwater

The Malenščica Spring has an extensive karst recharge area with numerous varied potential sources of pollution, such as transport, waste management, wastewater, agricultural practices, forestry, landfills, industry, and tourism.

3.3.3 Czech Republic: Ivančice Waterworks

Location

The Ivančice waterworks is a relatively unique location within the Czech Republic (Figure 11), offering several advantages for the MikroDrink project. The waterworks is located at the confluence of two watercourses, each with distinct natural conditions, land use, population density and catchment area. The waterworks uses the process of bank infiltration for the drinking water production, which involves the natural pre-treatment of surface water from both watercourses. Therefore, at this pilot site, it is possible to monitor the behaviour of microplastics under various conditions of drinking water production, from raw water to delivery to the end user.

Figure 11: Location of the pilot site.

Geology/Hydrogeology

The catchment area of the Ivančice waterworks covers of 0.15 km^2 and is located within the Quaternary fluvial sediments of the Jihlava River at its confluence with the Rokytná River. It lies on the border of two geological units. The Brno Massif to the southeast is formed by deep-seated igneous rocks from the granodiorite group, and the Boskovice Trough to the northwest is

represented by Permocarbonite sedimentary rocks. From a hydrogeological perspective, in both cases it is a poorly permeable subsoil beneath the main groundwater aquifer, which is located in the Quaternary sediments. Fluvial Quaternary sediments, with a variable thickness of 5 to 8 meters are deposited on the more or less impermeable subsoil. These sediments are mainly composed by coarse-grained sands, which are covered on the surface by clayey flood loams. The confluence of the Jihlava and Rokytná rivers is a significant source of high-quality drinking water. Currently, average withdrawals are around 10 l/s, however, the theoretical potential for use is significantly higher.

Hydrology/Climate

The two rivers Rokytná and Jihlava play a decisive role in influencing the quality of raw water used for the production of drinking water at the Ivančice waterworks. The Rokytná is a right-hand tributary of the Jihlava River, whose length is 88 km, and the basin area is 584 km^2. The average flow of the Rokytná before the confluence with the Jihlava is 1.38 m^3/s. The Jihlava River has a flow length from the source to the confluence with Rokytná of 146 km, and a catchment area of 2,682 km^2. Jihlava has an order of magnitude higher flow rate than Rokytná in the confluence area, the average annual value of this parameter here is 10.4 m^3/s. On the Jihlava River are the Dalešice and Mohelno dams, which can function as a sedimentation basin in terms of the spread of contamination. Climatically, the South Moravia region within the Czech Republic is a warm and relatively dry area. The long-term average air temperature in Ivančice for the period 1931–1960 was 8.9 °C, but in the period 1981–2010 it increased by 9.1 to 10 °C. The average precipitation for the period 1931–1960 was 508 mm and is currently more or less at the same value.

Water quality: Monitoring of raw river water from both watercourses shows satisfactory quality with increased contents of nitrogenous substances and pharmaceuticals. The specific feature is the increased contents of tritium - a result of the discharge of cooling waters from the Dukovany nuclear power plant. However, the produced drinking water meets the strictest standards, among other things thanks to the inclusion of a carbon filter.

Figure 12: Ivančice Waterworks.

Drinking water protection zones

The waterworks has only an internal protection zone, enclosed by a fence, covering the immediate vicinity of the wells (Figure 12). This area is defined by the triangle of the confluence of the two rivers. The external protection zone, which would include the entire basin of both watercourses, is not defined due to their large size.

Groundwater sampling site

Monitoring of microplastics occurrence is carried out at monthly at five sampling points. Sampling points 1 and 2 represent raw, untreated river water from Jihlava and Rokytná. Sample 3, taken from a collection well, represents groundwater used for drinking water production and reflects qualitative changes resulting from the seepage of surface water through the rock environment. Sample 4 represents the quality of the produced drinking water, indicating the effectiveness of the waterworks technology in removing microplastics. Finally, sample 5 shows the quality of the water that reaches the end user in the household.

Drinking water treatment

All raw water used in the Ivančice waterworks for the production of drinking water is pumped through a system of shallow wells. All these wells are not in operation at the same time; pumping is put into operation individually according to the current need. Therefore, a heterogeneous mixture of groundwater primarily originating after filtration in the rock environment from both watercourses always arrives at the waterworks.

Water infrastructure

The town of Ivančice has a population of approximately 10,000. The town is the administrative centre of the wider area. Among other things, it is home to the Ivančice Water Supply and Sewerage Association, whose members are 31 municipalities with a total population of 41,000. The association owns 8 water sources, 2 water treatment plants, 23 reservoirs and 6 pumping stations.

Potential sources for microplastics in groundwater

The river basin is a potential source of microplastics, because wastewater treatment plants from Rokytnice nad Rokytnou (830 inhabitants), Moravské Budějovice (7,200 inhabitants) and Moravský Krumlov (5,700 inhabitants) flow into the watercourse.

3.3.4 Serbia: Dug well

Location

The pilot site is located in the southeastern part of Serbia and is within the territory of the city of Pirot (Figure 13). The dug well is situated in the alluvium of the Nišava river, where it achieves river-bank filtration. In the wider vicinity of the dug well pilot site, according to CORINE Land Cover 2018, the following units are found: Complex cultivation patterns, Non-irrigated arable land, Land principally occupied by agriculture, with significant areas of natural vegetation, Broad-leaved forest, Natural grasslands, Transitional woodland-shrub and Pastures.

Geology/Hydrogeology

The dug well pilot site terrain is mainly formed by the youngest Quaternary formations, i.e. the Nišava river terraces on the valley sides, composed of gravel with limestone, then rock-scree on the slopes of Belava Mt. and alluvial deposits represented mainly by gravel and sand, often clayey. Sands, sandy clays and gravels of Plio-Pleistocene age lie discordantly over the older formations. The catchment area is determined by the spatial distribution of terrace sediments in which groundwater accumulates.

Figure 13: The dug well in the pilot area (photo: Petrović, 2025)

Filtration characteristics investigated through experimental pumping tests of dug wells in the wider area indicate that the hydraulic conductivity of the hydrogeological medium is generally high (K = 1.77 x 10-4 to 4.09 x 10-1 cm/s), while in the central part, further from the river, the values range from K = 3.7 x 10-2 to 7.55 x 10-2 cm/s. The thickness of the terrace sediments is up to 1 m, and the groundwater flow direction is from and to the aquifer towards the Nišava riverbed, depending on the current hydraulic conditions and hydrological state. This secures an intensive and constant hydraulic connection between the Nišava River and the groundwater accumulated in the terrace sediments is established, confirming the riverbank filtration process.

Hydrology/Climate

The region is characterised by a typical temperate-continental climate, with elements of a mountain climate, at higher altitudes. The pluviometric regime consists of a larger amount of precipitation during the warmer part of the year, which defines a continental precipitation regime.

The average annual precipitation is 584.3 mm and the average air temperature is 11.8°C. The dominant river flow is the Nišava River, with a mean annual discharge in Pirot of 17.4 m3/s.

Water quality

The Public Health Institute "Pirot" performs monthly inspections of untreated water from the well. Analyses have shown good water quality: pH ~7.18, EC 651 µS/cm, T 13,3 °C, Nitrate 7,54 mg/l, Chloride 34,6 mg/l, with no contaminants (e.g. pharmaceuticals, PFAS) detected.

Drinking water protection zones

No drinking water protection zones have been established.

Groundwater sampling site

The well used for water analyses to detect microplastics is 5 meters deep. It is a dug well with a diameter of 300 mm. Although the depth of the well is 5 meters, the well casing is 4 meters long and made of PVC material. The well pump is located 20 cm above the bottom of the well. Inside the casing, there is a slotted filter without a screen.

Drinking water treatment

Water treatment consists of brief sedimentation at the pumping station, followed by disinfection with sodium hypochlorite before distribution to users to ensure microbiological safety.

Water infrastructure

While some households use individual wells and springs, over 80% in the pilot area are connected to the central water supply system. This central system, supplied by the main well, has operated for approximately 20 years. Water is pumped from the well into the suction well of Pumping Station 1, then transported through a 63 mm diameter pipeline to a reservoir with a capacity of 50 m³. From the reservoir, water is distributed to consumers through both old and new pipelines. Each year, approximately 30,000 m³ of water is pumped and supplied through the system. The water network is regularly maintained, and plumbing system failures are repaired upon notification. Since the system came under the jurisdiction of the Public Utility Company “Water Supply and Sewerage” Pirot, around 500 meters of pipeline, out of a total of 3,550 meters, have been replaced. Maintenance activities mainly include flushing the pipes with highly chlorinated water once or twice a year due to limited funding, which prevents a complete system overhaul.

Potential sources of microplastics in groundwater

Several potential sources of microplastic pollution have been identified in the area. The most relevant sources include tire wear and road abrasion, littering, waste management activities, and wastewater disposal. Additional sources include compost, landfills, vegetable farming practices (such as the use of mulching films and polytunnels), forestry, and tourism.

4 Monitoring of microplastics

4.1 Literature review

4.1.1 Sampling for microplastics in drinking water and drinking water resources

Sampling is the foundational step in microplastics (MP) research. Koelmans et al. (2019) emphasise that sampling is one of the greatest sources of uncertainty in MP studies demonstrating that inconsistent sample volumes, inadequately controlled environments, and heterogeneous sampling tools produce incomparable results. In the context of drinking water and drinking water resources, MP concentrations are typically extremely low, so small sample volumes or open-vessel approaches often used in earlier MP studies (e.g., Kosuth et al., 2017) are no longer considered adequate due to contamination risk and unrepresentative sample size (WHO, 2019; Mintenig et al., 2018). More recent studies consistently demonstrate that robust MP assessment requires harmonised **large-volume, closed system sampling and strict contamination control protocols**. Mintenig et al. (2019) and Johnson et al. (2020) showed that filtering 1,000-2,500 L markedly improves representativity and reduces contamination bias. Examples of equipment used for large-volume sampling are presented in Figure 14.

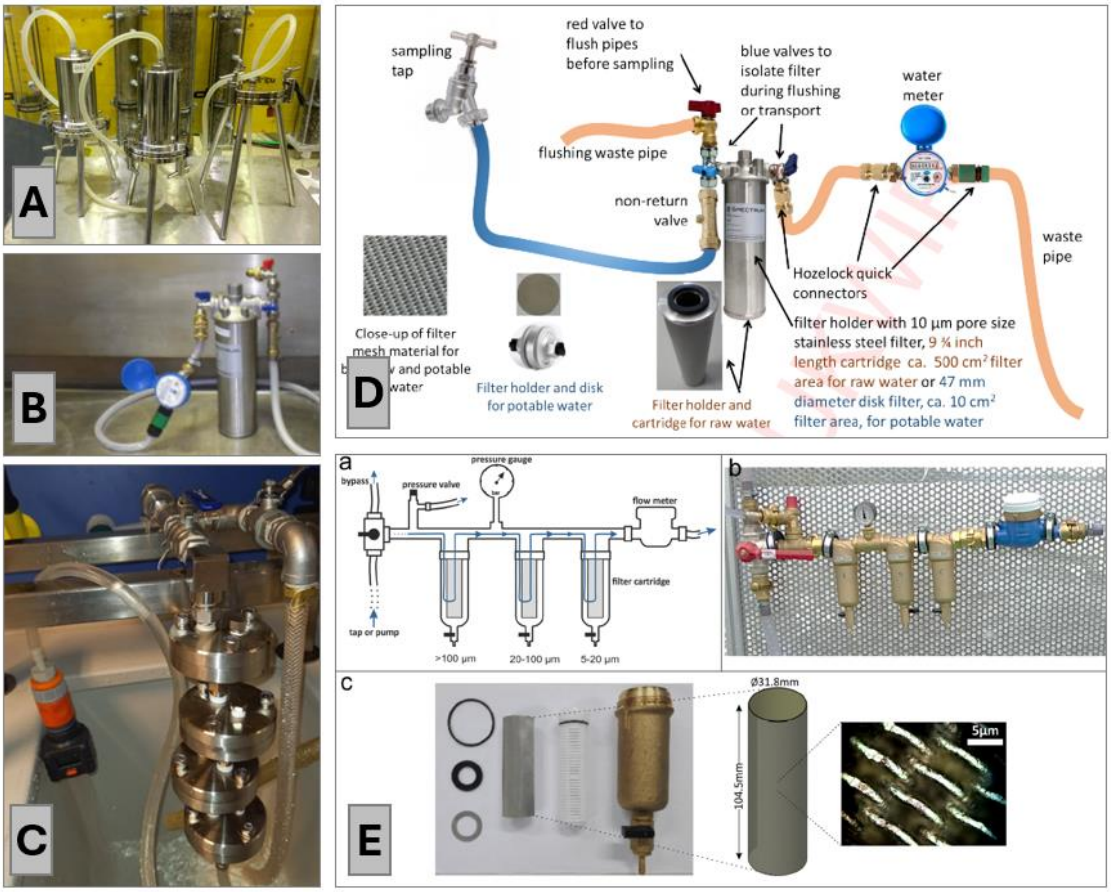

Figure 14: Examples of sampling equipments used for high-volume sample collection (A: Vymetal, 2020; B: Johnson et al., 2020; C: JRC, 2025; D: Ball et al., 2020; E: Pitroff et al., 2020)

4.1.2 Sample processing, sample pre-treatment steps

Pretreatment is a crucial step in microplastic analysis, as it determines how effectively organic matter, minerals, and biofilms are removed before identification. Hydrogen peroxide digestion is the most commonly used method because it reliably breaks down organic material without significantly damaging most polymers. Diluted hydrochloric acid is applied more selectively, especially to remove carbonate or iron deposits that interfere with subsequent analysis. Enzymatic digestion methods are increasingly explored to minimise polymer damage and reduce fluorescence in Raman spectroscopy (Mintenig et al., 2019; WHO, 2019; Johnson et al., 2020)

Density separation is mainly used for raw waters with high mineral content, with zinc chloride being the preferred medium due to its effectiveness and polymer stability. Sodium iodide is an alternative but is less stable and more expensive. In treated drinking water, density separation is often unnecessary due to low particulate content (Mintenig et al., 2019; AWI, 2021).

After pretreatment, samples are transferred onto filters suitable for FTIR or Raman analysis, such as aluminium oxide or gold-coated filters. Contamination control is essential, as procedural blanks often contain synthetic fibres and can exceed actual sample concentrations ((Johnson et al., 2020; AWI, 2021). Pretreatment must be compatible with analytical techniques, as FTIR requires clean surfaces, Raman is sensitive to fluorescence, and pyrolysis-GC/MS needs low inorganic content. Overall, pretreatment strongly influences detection limits, recovery rates, and data comparability. In summary, **pretreatment remains one of the most critical steps in MP analysis**, directly influencing detection limits, particle recovery, and data comparability.

4.1.3 Laboratory analysis with different instruments

Analytical instrumentation significantly affects the resolution, accuracy, and comparability of microplastic data, especially in drinking water. FTIR spectroscopy, particularly FPA-FTIR imaging, is the most widely used method as it enables automated full-filter scanning and reliable identification of particles ≥20 µm (Mintenig et al., 2019; WHO, 2019). However, FTIR can be time-consuming and depends on high-quality spectral libraries, with weathered plastics sometimes producing unclear results. Raman microspectroscopy offers higher spatial resolution, detecting particles as small as 1–5 µm (Strand et al., 2018) and providing detailed characterisation. It performs well with dark or mineral-coated particles but is limited by fluorescence interference and slower analysis speed. **Automated image-analysis systems** are increasingly used alongside FTIR and Raman.

Pyrolysis–GC/MS complements these methods by measuring polymer mass and detecting very small or degraded particles, though it does not provide particle counts or shapes. Automated image-analysis software further improves efficiency and reproducibility by reducing operator bias.

Overall, FTIR remains the reference method, while Raman and Py-GC/MS provide complementary strengths, making multi-method approaches the most reliable for MP analysis.

4.1.4 Numerical results, comparision of different sites, temporal and geographical variations

Reported microplastic concentrations in drinking water vary widely across the scientific literature, although treated European waters generally show very low levels, typically below one particle per

litre. Much of this variability is attributed to inconsistencies in methodologies rather than true environmental differences. Notably, studies using rigorous spectroscopic identification methods consistently report low MP concentrations, unlike earlier visual-based studies, which often overestimated values. Reported concentration extremes in the literature are largely associated with unreliable methods lacking polymer-specific identification.

Groundwater-based systems generally show minimal MP presence, often near detection limits, with studies reporting only sporadic findings. Similarly low levels are observed in distribution networks, where concentrations are often comparable to background contamination. Surface water and bank-filtration systems show greater variability due to environmental and hydrological influences. Seasonal changes, river discharge, and runoff can affect MP levels in raw water, although treatment significantly reduces concentrations.

Conventional water treatment processes such as coagulation and filtration typically remove over 90% of MPs above certain size thresholds. However, very small particles may still pass through undetected. Overall, MP levels in treated drinking water remain low, and observed variability is mainly driven by source type, environmental conditions, and methodological differences.

4.1.5 Uncertainties, QA/QC protocols and questions

Uncertainty is a major challenge in microplastic analysis, especially because concentrations are often near or below detection limits. **Uncertainty arises at all stages**, beginning with sampling, where contamination from airborne fibres can distort results. Many studies report that procedural blanks contain more fibres than actual water samples, complicating interpretation. Laboratory contamination further contributes to uncertainty, as synthetic fibres can originate from clothing, equipment, and air ventilation systems despite strict controls. Instrumental limitations also play a role in analytical uncertainty, with FTIR being unable to detect very small particles and Raman affected by fluorescence. In addition, incomplete or variable spectral libraries can lead to misidentification or ambiguous results. Pretreatment and processing steps may cause particle loss or polymer degradation, affecting recovery rates and quantification accuracy. Differences between manual and automated analytical approaches can introduce either bias or misclassification errors. Quality assurance measures such as blanks, standardised protocols, and multi-method approaches help reduce uncertainty but do not eliminate it. **Quality assurance and quality control (QA/QC)** frameworks have expanded significantly in recent years. The WHO (2019) report emphasised the necessity of procedural blanks, field blanks, and transparent reporting of detection limits, while simultaneously acknowledging substantial gaps in global methodological standardisation. The European Commission's Delegated Act under the Drinking Water Directive represents a major step towards harmonisation, requiring defined size bins, shape categories, and polymer groupings, as well as strict contamination control measures and mandatory documentation of blanks. Studies show that contamination in blanks can sometimes exceed real sample signals, significantly influencing detection limits. Overall, improving contamination control, detection methods, and standardisation is essential to increase confidence in MP data and support reliable, comparable monitoring.

4.1.6 Development needs

Key development needs include improving detection capabilities for particles smaller than 20 µm, expanding spectral libraries to include weathered and pigmented polymers, and establishing certified reference materials to support interlaboratory comparability (Primpke et al., 2020). Further improvements are also required in blank interpretation, uncertainty reporting, and long-term monitoring strategies, particularly for surface water-derived supplies. These advancements will be essential for implementing the EU Drinking Water Directive's monitoring requirements and for generating robust, transferable datasets.

4.2 Legislation on microplastics in drinking water – the EU Drinking Water Directive

Directive (EU) 2020/2184 on the quality of water intended for human consumption (the "Drinking Water Directive", DWD) introduces new tools to address emerging contaminants, such as microplastics. One of these tools is the **watch list mechanism**, which allows the Commission to identify substances of potential concern and to require EU-wide monitoring before deciding on possible limit values.

The European Commission has adopted a **harmonised methodology (sampling, analysis) including strict QA/QC protocols to measure microplastics** in drinking water as a prerequisite for including them on the watch list. This mandate is implemented by Commission Delegated Decision C(2024)1459 of 11 March 2024, which establishes a common analytical approach to generate **comparable, quality-assured data** on microplastics across Member States.

The Decision acknowledges that microplastics are ubiquitous in the environment and have been detected in food and drinking water, but that current evidence on human health risks remains limited and inconclusive because of major data gaps on exposure and effects. At the same time, **microplastics are highly heterogeneous** in size, shape, composition and degradation state, which makes their detection and quantification technically challenging. For these reasons, the EU approach focuses first on **standardised monitoring** rather than on setting a binding parametric value.

4.3 Sampling procedure and analytical methods

4.3.1 Harmonised sampling and analysis approach

As the MicroDrink project was launched at the beginning of 2024, there is not yet any accepted regulation for microplastic analysis in drinking water. However, draft methods were present and building on these, and considering the need for harmonisation emphasised in the literature review, a harmonised protocol for sampling and analysis, aiming for future EU DWD compatibility, was established – to ensure comparability of microplastic data generated across project pilot areas, while accounting for financial constraints and optimising resource efficiency.

4.3.1.1 Sampling minimum criteria

The minimum criteria applied in the project are aligned with the EU Drinking Water Directive's methodological requirements and complementary ISO guidance, also covering requirements described in the currently released ISO 16094-2:2025 standard.

- **General principles**

Sampling activities follow a plastic-free, contamination-controlled approach. All equipment in direct contact with water samples must be made from **stainless steel, glass or rubber**, avoiding synthetic polymer materials wherever possible. Hoses should be made of rubber or silicone, with seals and gaskets made from rubber, silicone or natural materials such as wool or hemp. Prior to each sampling event, all sampling equipment is thoroughly cleaned using **microplastic-free water**. This water is produced by filtrating deionised water through an **inorganic filter with a mesh size below 1 µm**, thereby ensuring that neither reagents nor rinse water introduce artefacts. Special attention is given to preventing atmospheric contamination. All equipment is kept closed or covered whenever not in use, and operators avoid wearing clothing containing synthetic fibres during sampling activities.

- **Sampling procedure and minimum volume requirements**

To obtain reliable results at environmentally relevant low concentrations, the **minimum sampling volume is set at 1,000 L**, consistent across all project sites. This requirement reflects both the EU Delegated Act and the ISO 5667-27:2025 guidance. The rationale is twofold: first, concentrations in drinking water are often close to blank levels; second, variability decreases significantly when larger volumes are filtered. Sampling of smaller volumes may result in particle counts too low for meaningful interpretation.

The project uses a **filter-cascade system**, where water is passed directly from the sampling point into a stainless-steel cascade fitted with the required filter sizes. A sampling scheme, similar to previous studies (Mintenig et al., 2019; Johnson et al., 2020; Ball et al., 2020; Pitroff et al., 2020), applied for most pilot areas in the MicroDrink project is presented in Figure 15**.** Consistent with EU-level methodology, the **smallest mesh size used during sampling is 20 µm**, ensuring that all particles within the regulatory size window are retained. To detect and quantify potential contamination introduced during sampling, the harmonised sampling methodology includes a **blank generation** procedure, implementing a subsequent filter of identical mesh size. A **difference compared to the EU DWD** during the MicroDrink project is that the filter cascade was not built as 100-20-100-20 µm, but as 20-20 µm. The rationale behind is to **develop a cost-effective sampling approach, while meeting the minimum particle size and procedural blank preparation requirements**. As no large particles or turbid water were expected during sampling, the large filter area used was considered a viable option to collect 1,000 L of water sample without clogging. Reducing the number of filters by 50% significantly reduced the number of separate analyses and thus costs. However, particles could still be divided into the required size range classes with spectroscopy-driven data post-processing.

All operational variables – including sample volume, flow conditions, site characteristics, weather, and deviations from standard procedures – are documented on **harmonised sampling sheets**.

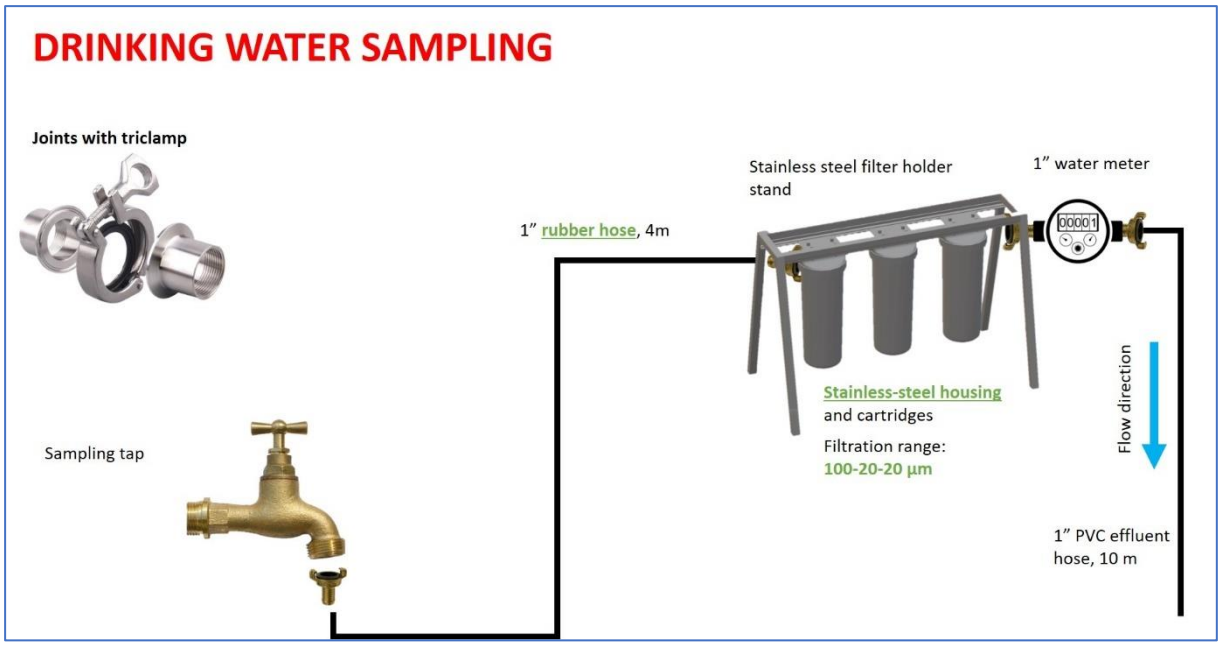

Figure 15: Sampling scheme, similarly to previous studies (Mintenig et al., 2019; Johnson et al., 2020; Ball et al., 2020; Pitroff et al., 2020), applied in MicroDrink project

4.3.2 Analysis minimum criteria

4.3.2.1 Equipment requirements and preparation

All analytical work must avoid the use of conventional plastic consumables to minimise false positives and reduce the risk of polymer shedding. Sample-contact materials must be **glass, stainless steel, ceramic or other non-plastic components**. Before use, all laboratory items – including beakers, filtration units, tweezers and sample supports – are thoroughly cleaned with detergent, rinsed with **microplastic-free water**, and, where appropriate, treated with 96% ethanol. Microplastic-free water is produced by filtering deionised water through an inorganic filter with a mesh size of <1 µm, ensuring no polymeric particles are introduced during cleaning or sample transfer. All reagents used during pretreatment or digestion must also be filtered through <1 µm inorganic filters to eliminate background contamination. Throughout the procedure, sample handling steps should be performed under a **laminar flow hood** equipped with HEPA filtration to reduce airborne fibre deposition.

4.3.2.2 Sample processing and analytical workflow

The MicroDrink project adopts a "**whole sample**" principle: all material recovered from the sampling filters must be processed and analysed. Only when full processing is technically impossible may a subsample be used, and in such cases the decision must be justified and documented. At minimum, **10% of the homogenised total sample** must be analysed if subsampling is unavoidable, ensuring representativeness and comparability across laboratories.

All samples are analysed using vibrational spectroscopic methods suitable for low-particle drinking water matrices: **µ-FTIR, µ-Raman or QCL-IR**. These techniques provide the polymer-specific information required by the EU methodology and allow reliable identification down to the 20 µm size threshold. As a general rule, the **entire filter or analytical support** must be scanned. If full-filter imaging is impractical due to high particle counts or time limitations, sub-areas may be analysed but must follow a representative selection strategy that covers **at least 20% of the total filter area** or, alternatively, at least 20% of all detected particles. All subsampling decisions must be transparently reported, including the ratio of analysed to total filter area or particle count.

4.3.2.3 Reporting requirements

To ensure interoperability with the EU watch-list methodology, the MicroDrink project classifies identified microplastics by:

- **polymer identity**, focusing on the priority polymers (PE – Polyethylene; PP – Polypropylene; PET – Polyethylene terephthalate; PS – Polystyrene; PVC – Polyvinyl chloride; PA – Polyamide; PU – Polyurethane; PMMA – Polymethyl methacrylate; PTFE – Polytetrafluoroethylene; PC – Polycarbonate)
- **size categories:** 20–100 µm and >100 µm
- **shape classes:** particles (length:width <3) and fibres (length:width ≥ 3)

All laboratories must report the number of microplastics per sample in these categories, along with metadata on total sample volume, sample treatment steps, spectroscopic methods used, any subsampling performed, and the chemical composition of any polymeric materials present in sampling or analysis equipment.

4.3.2.4 Quality control and contamination monitoring

Strict quality-control measures are necessary due to the low expected MP levels in drinking water. Atmospheric contamination is mitigated by covering equipment when not in use, working under laminar flow where possible, and avoiding synthetic clothing that may release fibres. To quantify background contamination, each laboratory processes **at least ten procedural blanks** under identical conditions to the sample workflow. These blanks establish the mean and standard deviation of background MP contamination, forming the basis for defining the **limit of quantification (LOQ)** as: **LOQ = mean blank concentration + 10 × standard deviation.**

This approach ensures that only concentrations significantly above typical blank levels are interpreted as true microplastic occurrence. In addition, laboratories must verify the **recovery efficiency** of the full analytical procedure. Spike experiments are performed using particles between **120–200 µm** and **30–70 µm**, including at least one polymer with density greater than water (e.g., PET) and one with lower density (e.g., PE). A spike count of 50–150 particles is recommended for each size range. Analytical recovery is considered acceptable when it falls within **100% ± 40%**, consistent with the EU methodology.

4.4 Monitoring results

Within the MicroDrink project, nine pilot sites across the Danube River Basin implemented a largely harmonised, yet locally adapted, approach to sampling and laboratory analysis of microplastics in drinking water. The pilots cover karst (Croatia, Austria, Bosnia and Herzegovina), bank-filtration and surface-water systems (Slovenia, Czech Republic, Serbia – Staničenje) and intergranular aquifers (Hungary, Serbia – Pavliš, Germany).

4.4.1 Sampling and laboratory practice in the Danube River Basin for microplastic analysis

- **Sampling and laboratory instrumentation**

Sampling and analysis techniques implemented during the project are summarised in Figure 16.

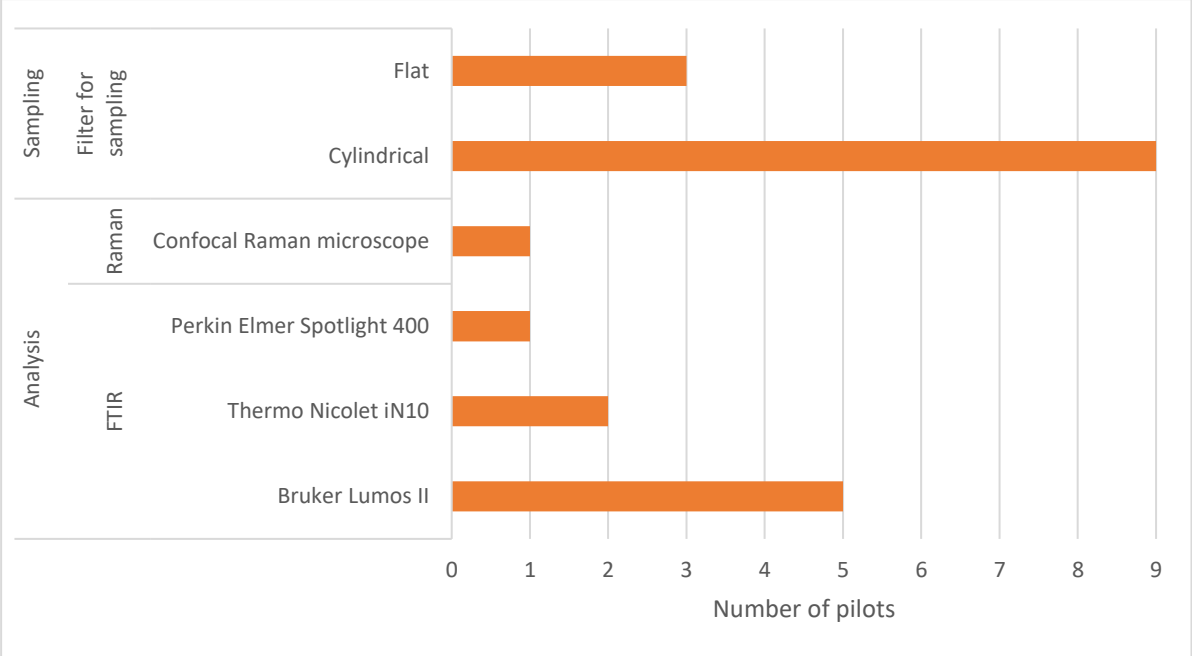

Figure 16: Sampling and analysis techniques in the DRB pilot sites applied in MicroDrink project

- **Sample processing and analysis**

Sample processing within the DRB pilots followed similar principles but was adapted to local water quality and laboratory capabilities. An overview of processing and analysis is presented in Table 2**.** Several pilots reported **matrix-related challenges** that affected processing and analysis. Bank-filtration and surface-water sites experienced **high total particle loads**, including organic debris and iron oxides, which clogged filters and required robust digestion and density separation.

Table 2: Processing and analysis overview

Pilot	Sampling equipment	Pretreatment (short)				Subsample in lab	Size-classification method
		Oxidation	Alkaline digestion	Acidic digestion	Density separation		
Croatia	cylindrical	Fenton	no	no	no	10%	Longest axis (Purency-derived size classes)
Slovenia	flat	no	no	no	NaCl	no	Feret max
Austria	cylindrical	30% H_2O_2	NaOH	HCl	K_2CO_3	20–26%	Feret max
Czech Republic	flat	H_2O_2 (48°C)	no	no	$ZnCl_2$	no	Longest axis (Purency-derived size classes)
Hungary	cylindrical	Fenton	no	no	$ZnCl_2$	no	Area-equivalent diameter
Serbia–Staničenje	cylindrical	15% H_2O_2	10% KOH	no	no	no	Digital ruler
Bosnia and Herzegovina	cylindrical	Fenton	no	no	no	10%	Longest axis (Purency-derived size classes)
Serbia–Pavliš	cylindrical	15% H_2O_2	10% KOH	no	no	no	Digital ruler
Germany	cylindrical	no	no	no	no	no	Stack of sieves

4.4.2 Quality assurance and quality control

Quality assurance and quality control (QA/QC) were central to the Danube River Basin study, with all laboratories applying blanks, contamination controls, and in some cases recovery experiments. Blank frequencies and procedures varied across sites, but all partners systematically monitored contamination. Several partners defined reporting limits and conducted spiking experiments, achieving recovery rates of approximately 60% to 80%, confirming acceptable but imperfect method performance. Despite rigorous controls, blank contamination often approached or exceeded environmental signals, highlighting the need for strict QA/QC protocols and further harmonisation in microplastic monitoring. Key QA/QC measures across pilot laboratories are shown in Table 3, while key uncertainties are presented in Figure 17.

Table 3: Implementation of key QA/QC measures across pilot laboratories.

Pilot	Cotton clothes	No plastic consumables	Laminar flow	Covered samples	Nitrile gloves
Croatia	yes	yes	no	yes	yes
Slovenia	yes	yes	yes	yes	yes
Austria	yes	yes	yes	yes	yes
Czech Republic	yes	yes	yes	yes	no
Hungary	yes	yes	yes	yes	no
Serbia–Staničenje	yes	yes	yes	yes	yes
Bosnia and Herzegovina	yes	yes	yes	yes	yes
Serbia–Pavliš	yes	yes	yes	yes	yes
Germany	yes	yes	yes	yes	yes

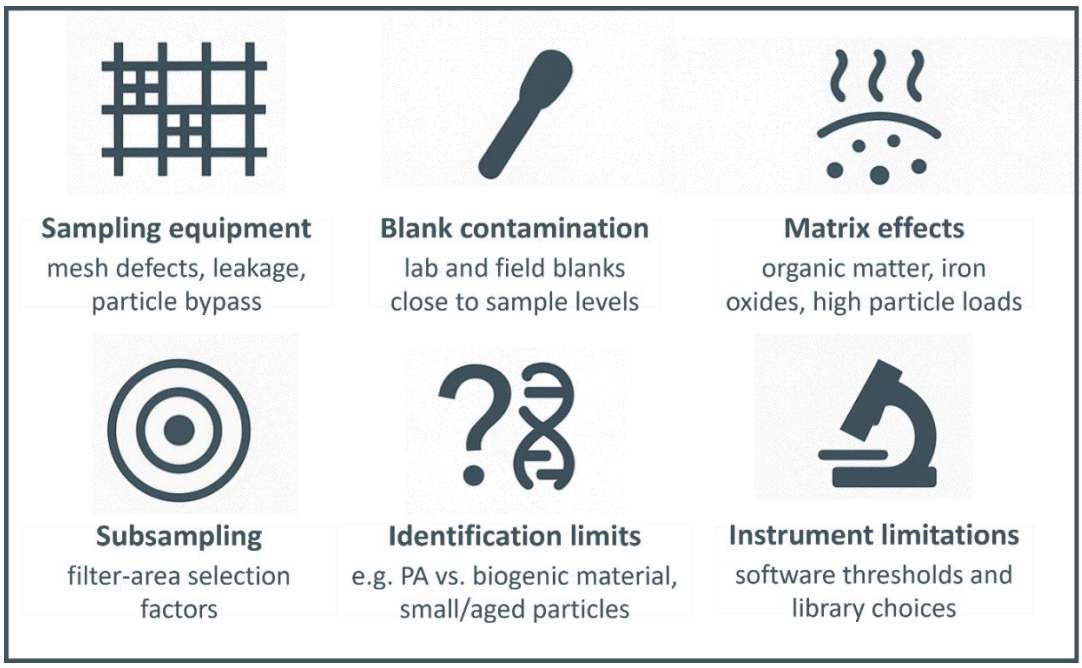

Figure 17: Key uncertainties of sampling and analysis

4.4.3 Microplastic occurrence in drinking water resources

Disclaimer: *The implementation of the requirements for sampling and analysis of microplastics in accordance with Commission Delegated Decision (EU) 2024/1441 still presents challenges. Specifically, the sampling method is not yet fully developed, and no validated or certified equipment is available, and the analysis methods applied might not fully meet the required specifications and quality criteria. Therefore, the results presented are solely for documentation purposes and should not be used for quantitative assessments or comparisons. The results do not reflect actual microplastic concentrations in water intended for human consumption, however, they provide the first comprehensive data collection*

experience on microplastic occurrence at the international level using the harmonised approach of the cited legislation.

4.4.3.1 Karst pilot sites

The karst pilot sites of the MicroDrink project – Croatian Kupica spring, Austrian spring and Bosnia and Herzegovina Crni dol water source – represent fast-responding fractured and conduit-dominated aquifers with highly variable hydrodynamics.

Overall, MP counts were **low to moderate**, and strongly dominated by the smallest size class considered in the project. Typical total counts per cubic metre were reported in the range of 50–150 particles in the 20–100 µm fraction and 0–20 particles above 100 µm. These ranges applied to the combined raw and treated water datasets and already indicate that most detected MPs are near the lower size boundary of the FTIR-based monitoring framework.

A relatively simple MP polymer spectrum is observed across the sites, with **polypropylene (PP) and polyethylene (PE)** consistently reported as the most frequent polymer types. At some sites, PET and other polymers are occasionally reported. The simplicity of the polymer mix is consistent with the expectation that the main inputs are diffuse land-based sources (packaging, household plastics, textiles) transported through the karst catchments, with limited industrial signatures. Size-class information shows that **the vast majority of MPs fall in the 20–100 µm range**, with only small numbers of particles above 100 µm. Regarding **particle shape**, **fragments are clearly more abundant**. Fibres were present but did not dominate in any campaign. Overall, the karst pilots indicate that **MP concentrations in karst-derived drinking water are low, dominated by small PE/PP fragments, and often close to blank levels**, with limited evidence of strong temporal or treatment-related gradients. Results are summarised in Figure 18 as average of a one year long sampling campaign with quarterly sampling.

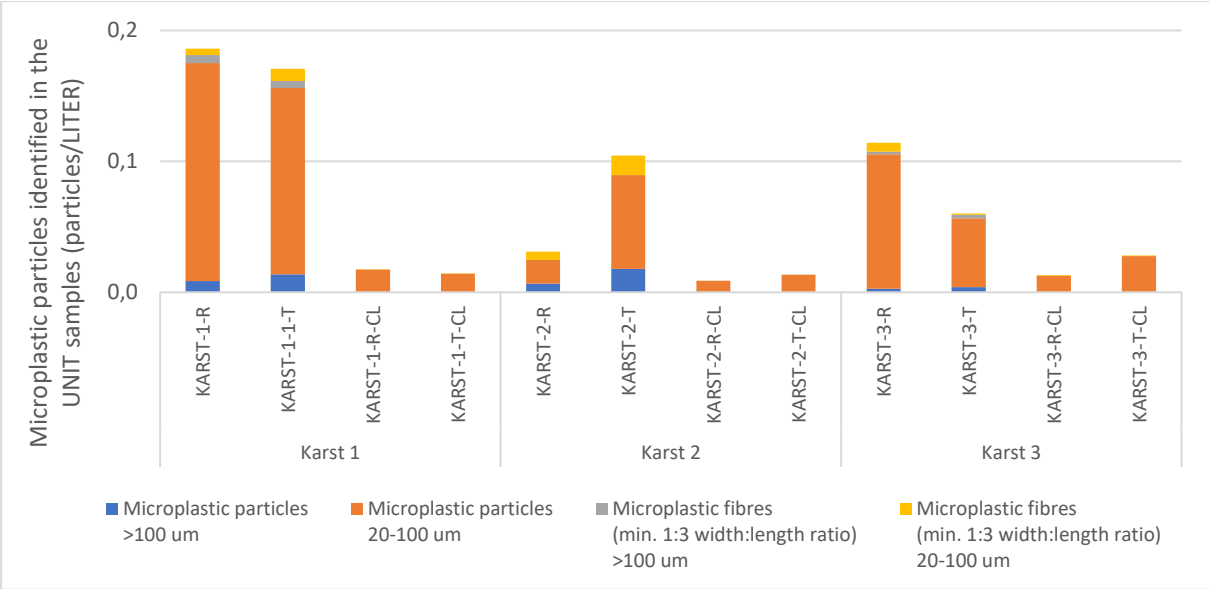

Figure 18: Microplastic occurrence in karst pilot sites. (R: Raw; T: Treated; CL: Central lab)

4.4.3.2 Intergranular pilot site

The intergranular pilot sites – Kőszárhegy (Hungary), Pavliš groundwater source (Serbia) and Bavarian drinking water wellfield (Germany) – represent porous aquifer systems with relatively stable hydraulic conditions and high natural residence times. These settings are expected to buffer short-term fluctuations in surface inputs and to provide comparatively "clean" raw water to drinking water treatment plants. The MicroDrink data broadly support this expectation: **MP levels in intergranular systems are consistently low, sometimes at or below detection limits**, and differences between raw and treated water are generally small or negligible.

MP **particle counts are generally very low**, **near or below the reporting limits** of the methods used, with occasional high counts, between 50 and 100 particles mainly in the 20 – 100 µm size category. Despite these low counts, the polymer types identified follow a pattern broadly similar to that seen in other clusters as **PE and PP are the most frequent polymers**, with additional detections of PET and PA, and occasional occurrences of PU, PS and PVC. Size-class information shows that at all three intergranular sites, MPs fall primarily in the **20–100 µm range**, with very few, if any, particles detected above 100 µm. In terms of shape, sites report that MPs are overwhelmingly fragments rather than fibres. Results are summarised in Figure 19 as the average of a one-year long sampling campaign with quarterly sampling.

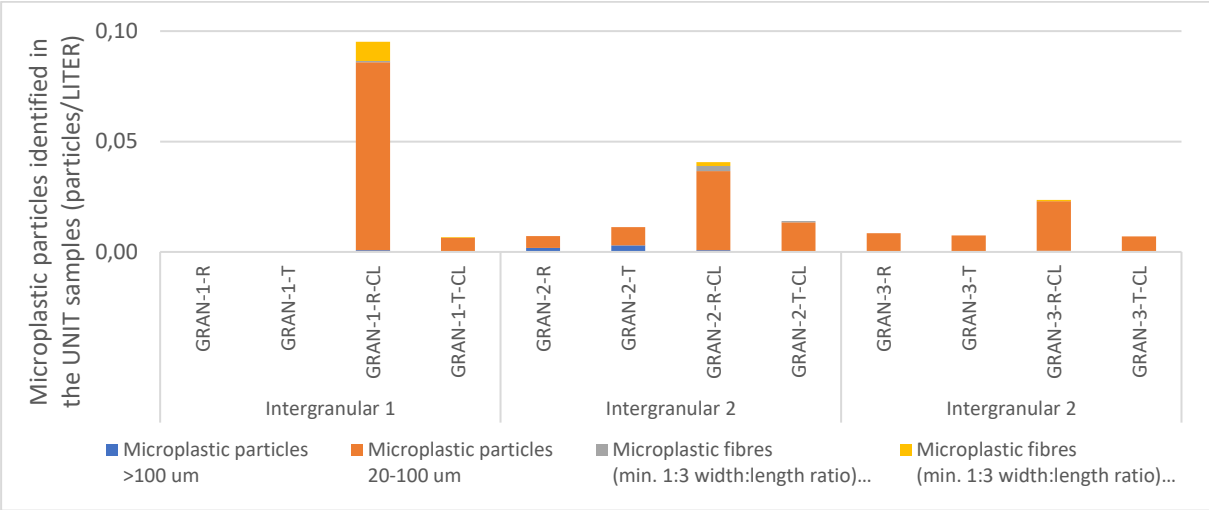

Figure 19: Microplastic occurrence in intergranular pilot sites. (R: Raw; T: Treated; CL: Central lab)

4.4.3.3 Bank filtration/surface water pilot site

The bank filtration and surface water cluster – Malenščica (Slovenia), Ivančice (Czech Republic) and Dug well (Serbia) – provides insight into MP behaviour in systems more directly connected to surface waters. MP inputs and removal processes are expected to be most variable.

Total MP counts in raw water typically reach up to 150 particles per cubic metre, while treated water samples contain around 100 particles per cubic metre for the Czech and Serbian pilots, whereas at the Slovenian pilot site, results were generally lower, reaching up to 10 particles per cubic metre. These values are appreciably higher than those observed in intergranular systems but

remain relatively low compared to many surface water studies. The polymer spectrum is dominated by **PP, PET and PE**, with PC and PMMA detected only occasionally. Size-class information shows that MPs are present in all size ranges considered, but the **most abundant particles are within the 20–100 µm size class**, which dominates the MicroDrink dataset. Shapes are almost exclusively **fragments**. Results are summarised in Figure 20 as average of a one year long sampling campaign with quarterly sampling.

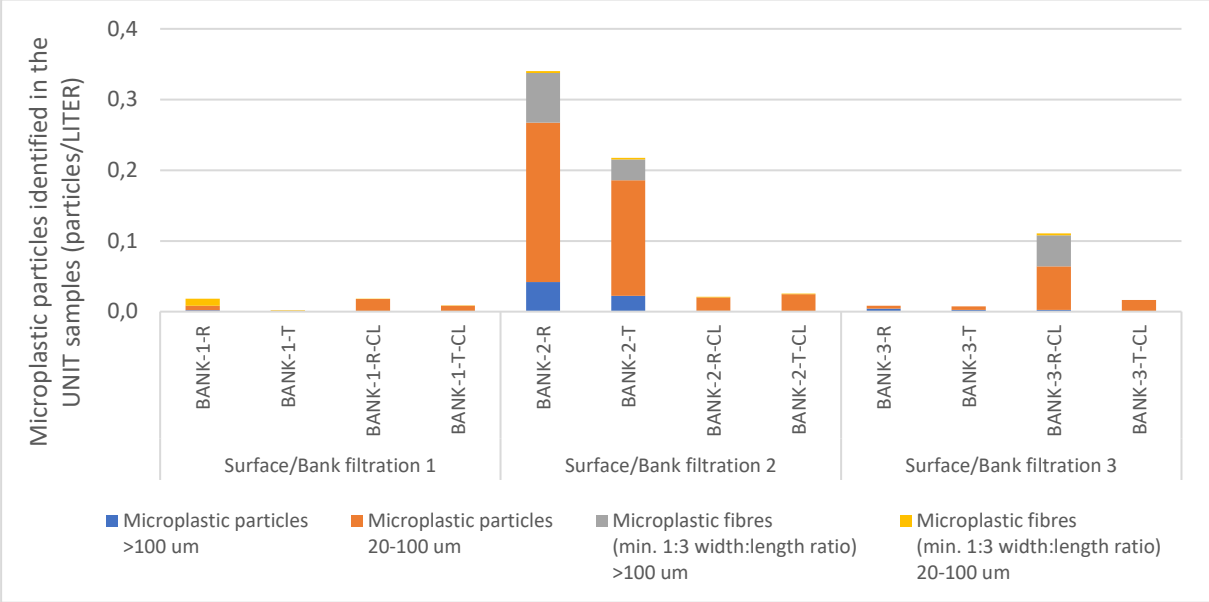

Figure 20: Microplastic occurrence in bank filtration and surface water pilot sites. (R: Raw; T: Treated; CL: Central lab)

4.4.4 Comparative assessment

Taken together, the comparative analysis reveals an environmentally coherent gradient in MP occurrence: **intergranular aquifers < karst springs < bank-filtration/surface-water systems**. Bank-filtration and surface-water sites show the clearest reduction in MP concentrations during treatment. Polymer patterns across all pilots are dominated by PE and PP, but diversity increases in systems more connected to surface-water. Size distributions consistently show a dominance of 20–100 µm fragments, reflecting both environmental degradation processes and the detection range of the methods applied.

4.5 Lessons learned and guidelines for future samplings

4.5.1 Experiences and suggestions on sampling

The implementation of harmonised microplastic sampling across the nine pilot sites of the MicroDrink project has generated extensive field evidence on the practicality, robustness, and limitations of the sampling equipment and procedures used. While partners successfully collected the required water volumes at their respective pilot sites, the reported experiences show substantial variation between sites, highlight several systemic issues with the used filtration hardware, and provide a strong basis for methodological improvement in subsequent project phases.

Across pilots, the **cylindrical stainless-steel filter cartridges, with designs similar to those reported in previous studies (**Johnson et al., 2020; Ball et al., 2020; Pitroff et al., 2020), formed the backbone of field sampling, although flat filter holders were also used. Partners generally considered the equipment functional, and many highlighted its ability to collect the intended 1,000 L volumes even under variable raw water conditions. However, nearly all pilots using cylindrical cartridges reported notable operational challenges.

A recurring observation across pilots was that the **internal water volume was inconsistent**, with several partners reporting that cartridges overflowed when opened, resulting in immediate sample loss. Several pilots expressed uncertainty about whether the entire contents of the cartridge could be retrieved consistently for laboratory processing. The **mechanical robustness and manufacturing consistency of the metal mesh** emerged as a central problem. Multiple pilots noted that mesh layers allowed particles significantly larger than the nominal 20 µm cut-off to pass through. In addition, several pilots noted **issues with gasket sealing and mechanical alignment**. Another frequently reported practical difficulty concerns is **cleaning and reusability** of the multi-layer stainless-steel mesh filters.

The **designation of the second filter in the cascade as a "blank"** became a major methodological question. Multiple partners observed that the so-called blank filters frequently contained more particles than the sample filters. **It is worth considering, not calling the second filters blanks, as these are also exposed to the analyte**. **The second filter is intended to control filtration efficiency, which is unlikely to reach 100% under field conditions.** Another theme across pilots concerns **personnel training and operational clarity**. Several partners identified the need for "more explicit guidance on equipment operation for sampling procedures and cleaning protocols."

Finally, experiences highlight the broader need for methodological harmonisation and equipment validation. **Despite the challenges identified, MicroDrink is "the first in the EU to test Delegated Act harmonised filtration concept across many sampling locations**. The project's role is not only to generate data but also to compile a comprehensive feedback package for the Joint Research Centre (JRC) and the European Commission. This includes recognising that it is not yet clear to what standard the MicroDrink system should be compared, as this has not been done previously, and other national filtration systems with different designs have not yet been benchmarked in terms of filtration efficiency.

4.5.2 Experiences and suggestions on analysis

A primary difference among laboratories was **full sample versus subsample processing**. Several partners processed the entire recovered sample volume, enabling maximum representativity. In contrast, some could not process whole samples due to high suspended-solid loads or filter clogging. These experiences reflect an inherent challenge: when total particulate loads are large or sample recovery is incomplete, **subsampling becomes unavoidable**, yet it introduces additional uncertainty related to particle heterogeneity, clustering on filter surfaces, and incomplete transfer. Relatedly, pilots differed in whether and how subsampling was performed **on analytical filters themselves**.

A major determinant of analytical feasibility was the **total particle load**, which in most cases was dominated by natural organic matter, mineral particles, or biofilm fragments. These matrix effects directly influenced the **reliability of particle identification**. Multiple pilots reported persistent difficulties distinguishing polyamide (PA) from biological residues, and in identifying very thick, weathered, or pigmented particles. Collectively, these experiences confirm that **size, morphology, and chemical state strongly influence spectral clarity**, and that manual verification remains essential – especially for particles below 50–70 µm or for irregular shapes.

A recurring technical theme across all laboratories was the role of **background contamination control**. Most partners employed strict measures – cotton laboratory clothing, exclusion of plastic consumables, ethanol cleaning, filtered solutions, and the use of laminar-flow cabinets where available. Nonetheless, several sites detected polymer types in laboratory blanks (e.g., PC, PVC), highlighting that airborne contamination and laboratory cross-transfer remain unavoidable. Importantly, all laboratories agreed that the second filter in the sampling cascade cannot be considered a blank because it is exposed to the analyte stream. **Filtration efficiency of 100% cannot be expected**, and therefore blank interpretation must be based solely on laboratory-prepared controls rather than in-line filters.

Experiences with **experimental verification through spiking** also varied, but results demonstrate that laboratories can achieve moderately high recoveries with controlled, well-defined particles. However, several partners noted limitations in obtaining representative reference materials, **surrogate particles that are traceable:** chemically stable, and spectrally robust.

Similarly important were experiences related to **contamination prevention and cleaning**, which influenced analytical uncertainty even in laboratories with rigorous protocols. Partners generally performed thorough cleaning of tools with filtered water and ethanol, used aluminium foil to protect surfaces, and ensured that glassware was rinsed immediately before use. Nevertheless, as noted in internal discussions, contamination "must be prevented but also accepted as partially unavoidable," and the purpose of quality control is to quantify and bound contamination rather than eliminate it entirely.

In summary, the pilot laboratories demonstrated strong analytical capability but also revealed a consistent set of challenges affecting measurement reliability. The collective experiences provide the evidence base for improving analytical protocols, harmonising subsampling strategies, advancing QA/QC design, and providing recommendations to the European Commission and the JRC.

4.5.3 Key findings on microplastic occurrence by water resource type

For drinking water suppliers, the findings confirm that **groundwater-based systems, especially intergranular aquifers, are the most resilient resources**, requiring mainly routine monitoring and standard precautionary measures. **Karst systems remain vulnerable to short-term pulses**, particularly after high recharge events, and would benefit from targeted monitoring during hydrological extremes. **Bank-filtration and surface-water-fed facilities require the most robust MP management**, including verification of treatment-barrier performance, as raw-water MP loads are higher and more variable. Across all resource types, operators should ensure validated sampling procedures, apply strict contamination prevention, and maintain a clear distinction between true laboratory blanks and second filters in sampling cascades.

The results confirm that MP occurrence is not uniform across water-resource types, and therefore regulatory monitoring strategies under the EU Drinking Water Directive (EU DWD) should reflect hydrogeological differences. A risk-based approach is appropriate: high-frequency MP monitoring is most justified in surface-water and bank-filtration systems, whereas lower-frequency or confirmatory monitoring may suffice for protected groundwater. Policy makers should also consider that MP concentrations often lie near the detection limits of current methods; therefore, consistent QA/QC frameworks, validated sampling hardware and harmonised reporting thresholds are essential for credible data generation.

Laboratories face the challenge of analysing MP concentrations that are often extremely low. The project highlights the need for **improved detection limits, stable reference materials, and harmonised subsampling and identification criteria**. Particular attention is required for distinguishing polymers from biogenic particles (e.g., PA versus natural organic matter) and ensuring reliable spectra in samples with high matrix loads. Technical partners should also account for the fact that **100% filtration efficiency cannot be assumed** during sampling, and that sampling hardware plays a central role in data quality. Coordinated interlaboratory comparisons and cross-method validation (FTIR, Raman) will improve analytical robustness.

4.5.4 Transferability of findings beyond DRB

The most robust and widely transferable conclusion is the gradient in MP occurrence across water-resource types. Intergranular aquifers, characterised by thick sedimentary layers and long residence times, show low MP concentrations in the DRB, frequently at or near detection limits. This finding can be confidently extended to other regions where groundwater is drawn from well-confined porous aquifers. In such settings, natural filtration processes remove larger and many smaller particles, while hydrological isolation limits MP introduction from surface sources.

Karst aquifers share hydrological traits such as rapid infiltration, conduit-driven flow and strong responsiveness to rainfall. The DRB data show that karst systems contain slightly higher but still relatively low MP levels, dominated by small PE and PP fragments linked to diffuse surface inputs. Thus, for karst regions beyond the DRB, the MicroDrink results provide a realistic expectation of low but hydrologically sensitive MP presence, suggesting the need for event-based monitoring.

Bank filtration and surface-water-influenced systems in the DRB display the highest MP concentrations and greatest polymer diversity. The DRB pilots indicate that MP levels in bank filtered systems reflect upstream pressures – urbanisation, wastewater effluent, stormwater

drainage and industrial sources. These relationships are highly transferable to any setting where drinking water production relies on river infiltration, especially where catchments contain mixed land uses, urban concentrations or industrial corridors. Internationally, this insight reinforces the need for catchment-focused MP management, linking water-resource protection to wastewater treatment, stormwater infrastructure and urban planning.

A key strength of the MicroDrink project is its harmonised methodology, which follows the specifications introduced by the EU DWD and the Joint Research Centre. This methodological consistency allows MP results from nine pilot sites – using multiple laboratories, instruments and hydrogeological conditions – to be compared on a common basis. Beyond the DRB, such standardisation enables two major pathways of transferability.

First, harmonised **large-volume sampling** (around 1,000 L), defined **size classes**, common **polymer-identification protocols**, and agreed **QA/QC criteria** form an operational framework that can be adopted directly by other regions. The fact that partners representing karst, porous aquifers and surface water systems successfully applied the same core methodology demonstrates that the approach is robust across resource types. For countries preparing to implement microplastic monitoring, the DRB experience shows that consistent detection thresholds and unified reporting fields (polymer type, size class, and shape) create results that are comparable not only within one region but internationally.

Second, the MicroDrink monitoring database – built from harmonised field and laboratory inputs – serves as a **reference dataset** for environmental baselines. Because many regions worldwide have limited microplastic data for drinking water sources, the DRB database provides a template for what to expect. The structure of the database also supports interoperability with future EU-level repositories, enabling cross-country and multi-basin comparisons. This interoperability is crucial for global research communities aiming to develop models of MP transport, identify transboundary pollution patterns, and benchmark treatment performance.

4.5.4.1 Lessons learned for implementing EU DWD MP monitoring

The DRB experience provides several clear lessons for the upcoming EU-wide implementation of mandatory microplastic monitoring under the DWD.

First, **resource-type-specific monitoring strategies** are essential. The DRB shows that surface-water-influenced systems require higher sampling frequency and more detailed analyses, while deep intergranular aquifers may need only periodic confirmatory monitoring. Karst systems, which fall between these, benefit from targeted sampling after high-recharge events. This resource-based differentiation aligns directly with the DWD's risk-based approach and can be broadly applied across the EU.

Second, the DRB pilots demonstrate the crucial importance of **validated sampling equipment**. Several sites experienced sampling-system performance issues, resulting in unreliable data. As EU Member States begin to apply the DWD's microplastic requirements, equipment validation – including mesh integrity checks, flow-characterisation tests and blank stability assessments – must be considered a prerequisite rather than an optional step.

Third, the harmonised MicroDrink approach demonstrates that **cross-laboratory consistency** can be achieved even when different FTIR and Raman systems are used. This reinforces the DWD's expectation that laboratories follow common data-evaluation principles and use interoperable

spectral libraries. The DRB experience supports the development of EU-wide training, interlaboratory comparisons and shared QA/QC documentation.

4.5.4.2 Overall transferability

Taken together, the DRB findings are widely applicable to other European and global regions with similar hydrogeological and catchment characteristics. The natural filtering capacity of intergranular aquifers, the responsive but generally low-MP nature of karst systems, and the higher MP loads typical of bank-filtration and surface-water supplies are consistent with international observations. The project also demonstrates that harmonised sampling and analysis enable robust cross-country comparisons, which are essential for future EU DWD implementation. As other regions adopt similar monitoring systems, the DRB experience provides a strong operational model, showing that environmental context, methodological harmonisation and structured data reporting together form the foundation for meaningful and transferable microplastic assessments, while thoroughly addressing technical challenges identified throughout the entire sampling and analysis workflow and detailed during the project.

4.5.5 Additional recommended literature

Kirstein, I. V., Hensel, F., Gomiero, A., Iordachescu, L., Vianello, A., Wittgren, H. B., Vollertsen, J. (2021): Drinking plastics? – Quantification and qualification of microplastics in drinking water distribution systems by μFTIR and Py-GCMS. Water Research, Volume 188, 2021. https://doi.org/10.1016/j.watres.2020.116519

Pivokonský, M., Cermakova, L., Novotna, K., Peer, P., Cajthaml, T., Vaclav, J. (2018): Occurrence of microplastics in raw and treated drinking water. Science of the Total Environment, 2018 Dec 1;643:1644-1651. doi: 10.1016/j.scitotenv.2018.08.102.

Mintenig, S., Löder, M. G. J., Primpke, S., Gerdts, G. (2019). Low numbers of microplastics detected in drinking water from groundwater sources. Science of The Total Environment, Volume 648, 2019, Pages 631-635, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2018.08.178

5 Capacity building for management of microplastics

5.1 Microplastics hotspots in drinking water systems

Water supply systems vary in terms of their natural conditions, age, stage of modernisation, size, importance, frequency and efficiency of maintenance, renovation, and reconstruction works. Water from these systems can be supplied to private households for domestic (municipal) use, as well as to industrial and agricultural buildings and systems at different rates.

The size and importance of the systems are closely connected to water supply risk and can be expressed in the population that is provided with the water and the annual volume supplied. Risk assessment for the water system of the same size is relative and depends on the total population and total water availability in the region.

To determine the risk of microplastic contamination, the path of water from its origin at the surface to the end users should be considered. The first step towards this is a microplastic hotspot analysis, intended to identify and examine all possible sources of microplastics in drinking water production and supply from source to tap. To perform the hotspot analysis, a detailed knowledge of the water supply system chain is needed.

Any drinking water system can generally be composed of the following five parts:

- land use at the recharge or catchment area
- water source (spring capture or groundwater well)
- treatment system (if present, containing one or more water treatment stages)
- drinking water storage and distribution network
- end users (municipal, industrial, or agricultural)

Potential microplastic hotspots can be present at any part of the water supply and distribution network, including land use in the area recharging the water resources. For drinking water systems specifically, it is worth noting that materials used for their construction are usually made of high-quality materials specifically designed for use with drinking water. Given this, the hotspots within the systems may be few, especially if plastic parts present a low proportion of all materials used in the system as well.

The following schematic (Figure 21) provides a general representation of a water system with its main parts and identified potential microplastic hotspots, which are further discussed on in the following paragraphs.

5.1.1 Land use at the recharge or catchment area

To accurately identify all possible anthropogenic factors contributing to potential microplastic pollution, the recharge area of the water source used for drinking water supply must be correctly delineated and analysed. Before entering the water supply network, the water may already have potentially been exposed to sources of microplastic pollution, either in the atmosphere or in the surface and groundwater components of the water cycle.

Tire-wear or tire abrasion, road abrasion, littering and vegetable farming were most frequently identified as potential microplastic sources during the hotspot analyses performed by the MicroDrink project partners in their pilot areas, followed by solid waste management, wastewater disposal, landfills, and irrigation. In some cases, wastewater treatment plants, compost, pellet loss from industry, vineyards, sewage sludge, and fermentation residues from biogas plants were also identified as a potential microplastic sources in the catchment areas.

Figure 21: Schematic representation of drinking water system parts with identified microplastics hotspots.

5.1.2 Water source

The water sources use either underground wells or surface captures to produce drinking water from the resource. If the water is extracted using a pump, its plastic parts and any plastic piping delivering water from the source to treatment and distribution can represent a potential microplastic source. In some cases, the well casing may also be made from plastic materials. Plastic pipes can release microplastics due to ageing, abrasion or scaling. They may also contain fittings or seals made from plastic materials.

5.1.3 Treatment system

Water treatment differs according to the natural conditions and anthropogenic pressures in the recharge area of the supply system water source. Some water systems have additional treatment stages prepared and ready to employ should the need arise.

There is typically at least one treatment stage used per water system. Examples of water treatment include: disinfection (with chlorination or UV light), filtration, sedimentation, coagulation, aeration, flocculation, ultrafiltration, sequestration, activated carbon, and ozone.

While some parts of the water treatment system can help remove microplastics from the drinking water, others can present an additional potential hotspot, if they are made from plastic components, or contain plastic lining, coating or paint. Additionally, any open surfaces may be exposed to atmospheric sources of microplastics.

5.1.4 Drinking water distribution network

Drinking water distribution networks can be made from plastic piping, along with plastic fittings, plastic sealing, and plastic reservoirs, and can therefore also present an additional entry point for microplastics into drinking water. The same applies to household water distribution networks as well as any other storage reservoirs and pumping stations in between.

5.2 Decision support tool for water managers

To better understand and address the issue of microplastics in drinking water from the supplier's perspective, a Decision-Making Support Tool (DMST) was developed within the MicroDrink project. This tool was based on national consultations of project partners with their respective stakeholders where they presented their knowledge gaps and needs.

Table 4 gives an overview of the quantified findings arranged in descending order of percentage, which enabled the identification of the most pressing issues.

Table 4: Identification of issues and their quantification in percentage

Issue regarding microplastic management in water supply	Percentage
Familiarity with microplastic definition	91 %
Familiarity with microplastic types	59 %
Knowledge of potential sources of microplastic pollution in the recharge area	59 %
Possibility of microplastic pollution outside of local water supply system	59 %
Knowledge of sources of information	43 %
Familiarity with systems for sampling and analysis	38 %
Availability and usefulness of sources of information	36 %
Knowledge of institutions or laboratories performing microplastics analysis	36 %
Plan for communicating the results to the public	32 %
Awareness of guidelines or regulations	24 %
Familiarity with the cost of analysis	23 %
Access to results of microplastics analysis	18 %
Ability to interpret the results of microplastic analysis	18 %

Colour scale:

100 %	90 %	80 %	70 %	60 %	50 %	40 %	30 %	20 %	10 %	0 %

Stakeholders were generally familiar with the definition, sources, and different types of microplastics. However, their knowledge of sampling and analytical methods was identified as an area that could be improved. This includes knowledge of microplastic detection, identification, quantification and comparative assessment and interpretation of microplastics, as well as guidelines, regulations, and communication strategies related to microplastics in drinking water.

These results formed the basis for the design and development of the MicroDrink project Decision-Making Support Tool (DMST), which guides users through an interactive process of problem identification and decision-making. It enables users, such as drinking water operators, authorities, and other interested target groups, to engage with various possible scenarios depending, among others factors, on the nature of their water supply system. The tool provides an overview of best practices and guidance for informed decision-making to mitigate and address microplastic issues at different levels.

Developed as executable software for the Windows operating system based on the Python programming language, the tool is distributed as a packaged (zip) file available for download from the project website (add link). The interface of the Decision-Making Support Tool (DMST) is shown in Figure 22. The Decision-Making Support Tool (DMST) consists of two main parts: the first enables users to build a scenario (Main and Water resource type menus), while the second provides a collection of information on microplastics in drinking water (Info menu).

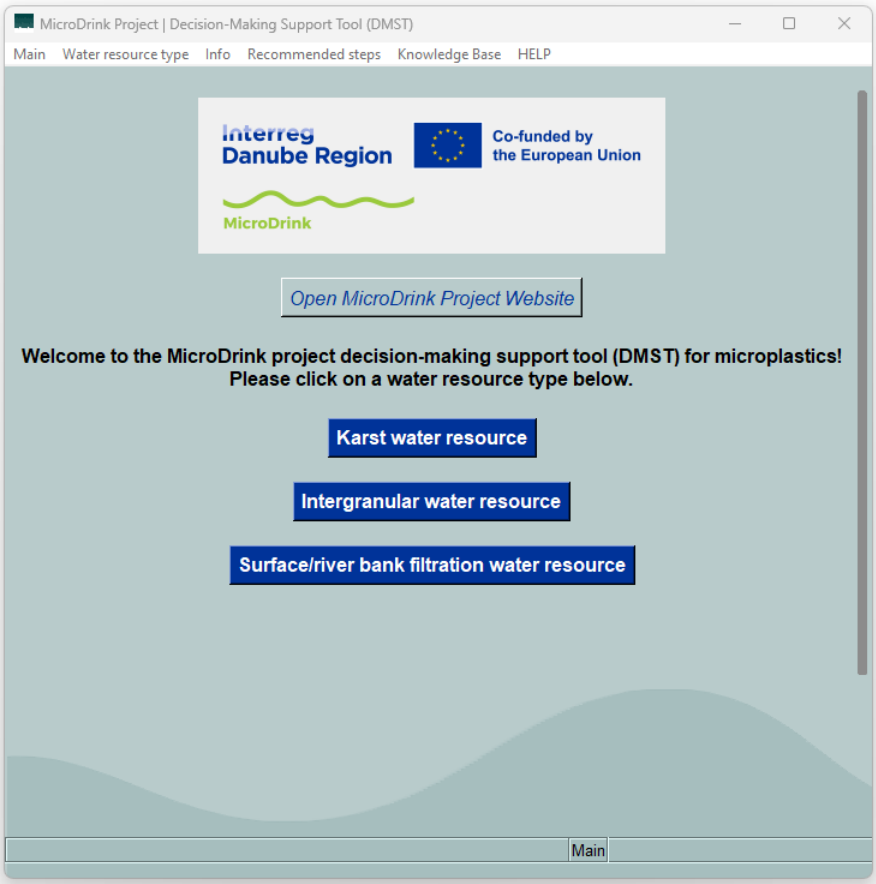

Figure 22: Decision-Making Support Tool (DMST) interface

5.2.1 Building a scenario with the DMST

To start building a new scenario, the user first selects one of the three water resource types characterised within the MicroDrink project: karst water resources, intergranular water resources, and surface water or bank filtration water resources.

The tool then guides the user through a series of questions to build a real or hypothetical scenario. These questions address the user's experience regarding the sampling and their knowledge of the microplastics issue within their water resource and supply system.

Based on their answers, a set of different information tailored to the individual scenario is provided. This may include: risk assessment for microplastics pollution, monitoring strategies, measures to reduce microplastics input, interpretation of microplastics analysis, requirements and best practices for conducting sampling and microplastics analysis, variability and uncertainties of microplastics sampling and analysis, hotspot analysis, and microplastics source mapping.

5.2.2 Browsing information on microplastics

The second possible use of the Decision-Making Support Tool (DMST) is intended to offer information on the MicroDrink project activities and microplastics in drinking water without using the decision tree to build scenarios and consists of the following:

- information on the laboratories performing microplastics analyses within the MicroDrink project
- visual representations of the microplastics cycle
- a brief summary of the contents of the EU Delegated Decision regarding microplastic sampling
- schematic representation and video links of the systems used to sample microplastics in drinking water by the MicroDrink project
- an example of a microplastic hotspot analysis in a drinking water supply system

5.3 Capacity building training courses for stakeholders

The national capacity building training courses brought together 184 participants from across the Danube River Basin to exchange knowledge and engage with the key activities of the MicroDrink project. During these events, participants were introduced to the MicroDrink Knowledge Base, received detailed insights into pilot actions and sampling activities, and explored the Decision Making Support Tool (DMST). Developed through national consultation processes, the DMST serves as a practical instrument designed to address real needs in water management by providing scenarios, best practices, and guidelines that support informed decision-making and strengthen microplastics management across governance levels.

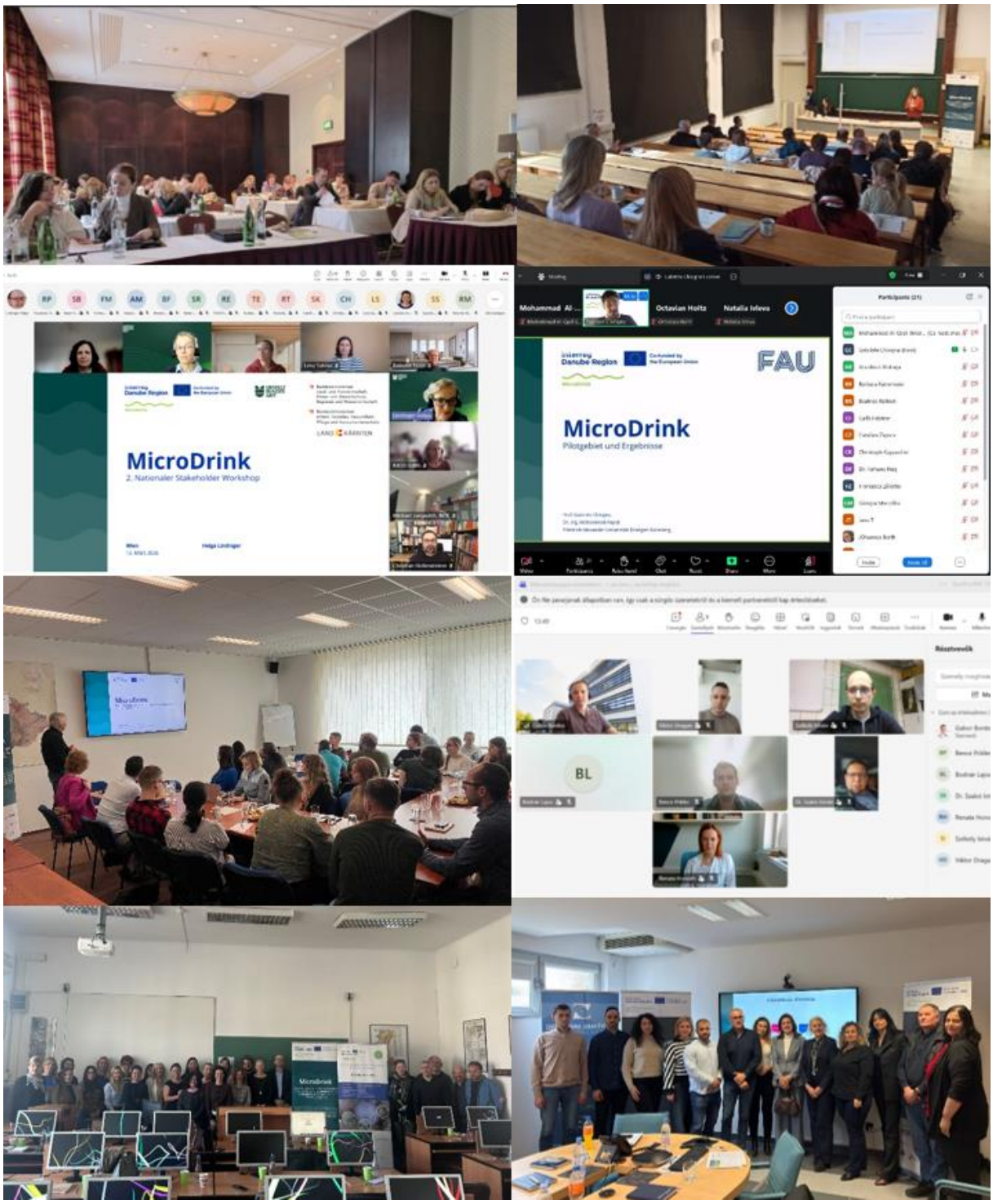

Figure 23: Capacity building training courses of the MicroDrink project

A dedicated session focused on developing strategic guidelines for microplastics management, during which participants discussed and shared their experiences, challenges, and

recommendations. These exchanges provided a comprehensive overview of the current state of microplastics monitoring and management in the participating countries.

Across all training courses, stakeholders showed growing awareness of microplastics as an emerging issue for drinking water safety, yet the overall level of implementation, technical readiness, and regulatory clarity remains low. Discussions confirmed that monitoring is still in an early, exploratory phase: most institutions have not conducted systematic sampling or analysis, and existing activities are largely research-driven rather than operational.

Stakeholders identified catchment-area pollution particularly illegal waste disposal, diffuse pollution, and the vulnerability of aquifer systems as the main sources of microplastics in water resources. Treatment and distribution systems were viewed as more controlled environments, though concerns persist regarding incomplete removal of small particles and potential release from plastic infrastructure.

Participants highlighted limited technical knowledge and practical experience, especially regarding sampling protocols, analytical methods, and sample pre-treatment. Methodological requirements under Commission Delegated Decision (EU) 2024/1441 were considered insufficiently detailed for practical use. High analytical costs, limited laboratory capacity, and the absence of standardised, ISO aligned protocols further constrain progress, with many institutions dependent on external laboratories.

Stakeholders emphasised the need for detailed, practical guidance on sampling, analysis, reporting, and equipment, as well as hands-on training and transparent information on costs and good practices. Clear regulatory definitions, coherent legislation, and accessible digital guidelines were identified as essential for future monitoring obligations.

Testing of the MicroDrink Decision Making Support Tool (DMST) generated strong interest, with participants finding it clear, accessible, and useful for supporting decision-making, while also offering constructive suggestions for improvement.

Overall, the capacity building training courses confirmed that microplastics monitoring in drinking water is still developing, marked by knowledge gaps, technical challenges, and resource limitations. At the same time, stakeholders expressed strong motivation to advance monitoring, harmonise methodologies, and strengthen cooperation. Continued capacity building, exchange of experience, and access to high-quality educational materials – such as those provided by MicroDrink – are key to establishing a reliable, evidence-based approach to microplastics management and preparing for future regulatory and operational demands.

5.4 Roadmap towards microplastics strategy in drinking water

The roadmap (Figure 24) provides a structured pathway for countries to progress from initial knowledge gathering to the integration of microplastics monitoring and management in drinking water systems. It outlines five stages: knowledge base, monitoring and research, risk assessment and regulation, communication and education, and implementation, each assigning responsibilities to key actors in the water sector.

Figure 24: Roadmap graphic Towards MP Strategy in Drinking Water

5.4.1 Starting Points: Establishing the Knowledge Base

The first step in developing a microplastics (MP) strategy for drinking water is to map existing information, beginning with reviewing scientific literature, previous studies, and ongoing projects to understand the occurrence and behaviour of microplastics in water systems. At the same time, a legislative review identifies current obligations, regulatory gaps, and opportunities for alignment with international standards. In addition to these desk-based reviews, surveys, questionnaires, and national stakeholder exercises serve as practical tools for mapping existing knowledge, practices, and gaps across institutions and regions. This stage ensures that strategies are evidence-based

and legally coherent, providing a solid foundation for subsequent monitoring and risk management.

In the Starting Points stage, the main actors are policymakers, regulators, and researchers. Policymakers set the strategic direction and initiate coordinated reviews, while regulators analyse existing legislation to identify regulatory gaps and alignment needs. Researchers synthesise available scientific evidence and define the knowledge gaps that must be addressed before monitoring can begin.

5.4.2 Monitoring and Research: Building the System

Monitoring and research on microplastics should prioritise the standardisation of sampling and analysis methods, in line with the harmonised methodology set out in Commission Delegated Decision (EU) 2024/1441, to ensure consistent and reliable results. This requires close cooperation with laboratories, including providing equipment and training to build technical capacity. A comprehensive monitoring system should be established to assess MP presence in raw water, treated water, and at the tap, enabling a complete picture of contamination across the supply chain. In parallel, identifying the main sources of pollution is essential to guide mitigation strategies. Finally, creating a centralised database on MP in water will provide a valuable resource for tracking trends, supporting research, and informing policy decisions.

During the Monitoring and Research stage, responsibilities shift mainly to regulators, water suppliers, laboratories, and researchers. Regulators establish standardised sampling and analytical methods and define reporting requirements, while water suppliers implement monitoring programmes for raw, treated, and tap water. Laboratories conduct analyses using validated methods and ensure quality assurance, while researchers continue to refine methods and investigate the sources and behaviour of microplastics in water systems.

5.4.3 Risk Assessment and Regulation: Protecting Public Health

Once sufficient data on microplastics in drinking water resources are available, countries can conduct risk assessments to evaluate human exposure and potential health impacts. These assessments provide the basis for developing risk management tools, which may include upgrading filtration technologies, replacing or modifying materials used in water systems, or avoiding contaminated sources. Over time, regulatory frameworks can evolve to incorporate guidance values or establish limit thresholds, once scientific consensus provides a reliable foundation. This process ensures that monitoring and research efforts lead to protective action, safeguarding public health and strengthening water safety management.

In the Risk Assessment and Regulation stage, regulators, public health authorities, researchers, and water suppliers play central roles. Regulators coordinate risk assessments and translate findings into regulatory and technical requirements, while public health authorities interpret potential health risks and provide recommendations to protect public health. Researchers provide scientific evidence on exposure and toxicity, and water suppliers assess system-specific risks and implement mitigation measures based on assessment outcomes.

5.4.4 Communication, Awareness, and Education: Engaging Stakeholders

Communication, awareness, and education are essential components of effective microplastic management. Engaging stakeholders begins with public information and education initiatives that raise awareness about plastic management, identify the main sources of MP, and promote actions to limit these sources. Targeted education for water facility managers ensures that operational practices follow best standards for reducing MP contamination. To support these efforts, workshops, campaigns, manuals, and social media posts should be developed, providing accessible tools and platforms for knowledge sharing. Together, these activities foster a culture of responsibility and empower both professionals and the public to help reduce MP pollution.

In the Communication, Awareness, and Education stage, responsibilities are shared mainly among policymakers, regulators, water suppliers, and public health authorities, with significant contributions from the education sector and news media. Policymakers lead national awareness initiatives and promote stakeholder engagement, while regulators prepare technical guidance and communicate regulatory expectations. Water suppliers inform consumers about monitoring results and train operational staff, and public health authorities provide clear health-related messages and support risk communication. The education sector reinforces long-term behavioural change by integrating topics related to plastic management and environmental protection into curricula and training programmes, while news reporters play a key role in translating complex information into accessible stories that raise public awareness and encourage responsible practices.

5.4.5 Implementation: Embedding into Water Management

Finally, implementing microplastic (MP) management involves preparing for the future integration of MP parameters into routine drinking water monitoring programmes, even though this is not yet required under the Drinking Water Directive (EU) 2020/2184, which instead foresees a watch-list mechanism for water intended for human consumption. Monitoring results should be reviewed systematically and at regular intervals to identify trends, evaluate the effectiveness of interventions, and adjust strategies as necessary. To support decision-making, a structured reporting and assessment system must be established to enable authorities to translate monitoring data into actionable measures, complementing the risk-based approach required under the Drinking Water Directive (EU) 2020/2184.

In the Implementation stage, regulators, water suppliers, and laboratories have the primary responsibilities. Regulators enforce compliance, review monitoring results, and update regulatory frameworks as new evidence emerges. Water suppliers incorporate microplastics into routine monitoring and maintain transparent reporting to authorities and consumers, while laboratories provide ongoing analytical support and ensure consistent application of validated methods.

The implementation phase should also be supported by practical instruments and guidance material, such as the MicroDrink Knowledge Base, Video guidelines for sampling, and the Decision-Making Support Tool (DMST) developed under project MicroDrink. The DMST provides a practical solution tailored to drinking water operators, authorities, and other relevant target groups, developed through national consultation processes. It offers scenarios, best practices, and guidance, enabling informed decision-making to mitigate and address microplastic challenges at different levels.

5.4.6 Synthesis

The roadmap offers a flexible yet coherent framework for countries to build capacity and gradually integrate microplastics monitoring into drinking water management. It emphasises collaboration among institutions, alignment with international standards, and the application of scientific knowledge to practical action. Ultimately, it supports long-term resilience, public health protection, and transparent water management across the Danube Region.

5.5 Transnational strategic guidelines for microplastics management in drinking water

Microplastics present an emerging challenge for drinking water management across the Danube Region Basin. Although concentrations detected during coordinated pilot activities were generally low and often close to analytical detection limits, the pilots also revealed clear differences between water-resource types, methodological constraints, and varying levels of institutional readiness. These findings highlight the need for a coherent, transnational strategy to support countries and drinking water facilities as they progressively integrate microplastics into routine monitoring and risk-based management.

5.5.1 Strategic direction for integrating microplastics into drinking water management

Across DRB project countries, a common strategic vision is emerging: to build the technical, organisational, and governance capacity required to integrate microplastics into routine drinking water management. This vision emphasises:

- **Laboratory readiness**, including analytical capacity (FTIR, Raman), trained personnel, and quality assurance.
- **Pilot monitoring and baseline data collection**, enabling facilities to understand microplastic occurrence and variability.
- **Gradual integration into Water Safety Plans**, reflecting the risk-based approach of the Drinking Water Directive.
- **Alignment with national methodologies and EU standards**, ensuring comparability and regulatory coherence.
- **A precautionary and adaptive approach**, recognising scientific uncertainty and the evolving regulatory landscape.

This strategic direction supports long-term resilience and prepares facilities for future EU requirements.

5.5.2 Operational insights from Pilot activities

The pilot actions showed that drinking water facilities across the DRB can successfully implement harmonised sampling and analytical methodologies when supported by clear procedures and laboratory collaboration. Several operational lessons also emerged:

- **Sampling integration requires preparation**, including staff training, contamination controlled procedures, and careful selection of sampling points, particularly in karst and bank-filtration systems where hydrological variability affects representativeness.
- **Handling large sample volumes** (e.g., 1,000 L) and multi-filter cascades requires well-defined internal procedures for cleaning, transport, and documentation.
- **Close cooperation between operators and laboratories** is essential to ensure reliable results, especially when addressing with matrix effects, subsampling decisions, and equipment performance.
- **Resource type differences**: bank-filtration sites require more frequent monitoring and verification of treatment performance, while intergranular aquifers may require only periodic confirmatory checks.

These insights highlight the importance of tailored monitoring strategies that reflect local hydrogeological conditions and operational realities.

5.5.3 Transnational strategic actions for drinking water facilities

The MicroDrink pilot activities showed that drinking water facilities across the DRB differ significantly in their readiness to implement microplastic monitoring, but all were able to integrate the harmonised methodology with appropriate support. Facilities participating in the pilot activities reported that introducing sampling required adjustments to operational routines, including staff training, preparation of sampling locations, and coordination with laboratory schedules. These experiences highlight the importance of establishing a clear baseline understanding of each facility's infrastructure, raw water characteristics and potential microplastic sources before routine monitoring begins. Pilot action operators also noted that the placement of sampling points, particularly in bank filtration and karst systems strongly influenced sample representability, reinforcing the need for careful selection of sampling locations.

As facilities begin to integrate microplastics into their monitoring programmes, the pilot activities highlight the need for close collaboration between operators and laboratories. Several facilities reported challenges with sample handling, transport, and documentation, especially when dealing with 1,000 litre volumes and multi-filter cascades. These experiences show that facilities must develop internal procedures for contamination control, equipment cleaning, and sample transfer to ensure reliable results. Once analytical data become available, facilities should incorporate microplastics into their Water Safety Plans, using pilot findings that showed clear differences in vulnerability across resource types. For example, bank filtration locations would require more frequent monitoring and verification of treatment performance, while intergranular aquifers would require only periodic confirmatory checks. Pilot operators also emphasised the importance of internal communication and staff awareness, noting that successful implementation depended on clear instructions and a shared understanding of the monitoring objectives. Over time,

integrating microplastics into routine practice will require trend analysis, periodic review of operational measures, and continuous alignment with evolving regulatory expectations.

5.5.4 Transnational framework for managing microplastic detection

The MicroDrink pilots showed that microplastic detections in drinking water are often close to blank levels, making verification a crucial first step in any response framework. Several laboratories reported that initial detections required repeat sampling due to uncertainties related to equipment performance, matrix effects, or background contamination. Facilities should therefore treat any detection as a trigger for confirmation rather than immediate corrective action. Pilot experiences also showed that hydrological conditions, particularly in karst and bank filtration systems, can influence microplastic presence, so follow-up sampling should consider rainfall events, river conditions or operational changes at the facility.

Once detections of microplastics are verified, facilities should assess potential sources using insights from the pilots. Operators in bank filtration systems frequently observed that upstream wastewater discharges and storm water inputs influenced raw water microplastic loads, while groundwater based facilities rarely identified internal sources. These observations indicate that facilities should evaluate both internal and external pathways, including treatment processes, infrastructure materials, and catchment-related pressures.

Medium term responses may involve optimising filtration or coagulation processes, as several pilot sites observed reductions in microplastic counts after treatment. Where upstream pressures are significant, collaboration with wastewater operators and catchment managers is essential.

Over the long term, microplastics should be fully integrated into Water Safety Plans, supported by the structured reporting and QA/QC practices tested during the pilots. Facilities should document all actions and contribute data to national or regional databases to support regulatory development and trend analysis.

5.5.5 Strategic Outlook for Future Implementation

Pilot activities across the Danube Region Basin show that microplastic concentrations in drinking water are generally low, yet clear differences exist between resource types: intergranular aquifers show the lowest levels, karst systems reflect hydrological variability, and bank filtration sites exhibit higher and more variable concentrations influenced by upstream pressures. These patterns support a risk-based monitoring approach.

The pilots also demonstrated the importance of validated sampling equipment, harmonised analytical procedures, and robust quality assurance frameworks. Variability in equipment performance, subsampling decisions, and matrix effects confirms that microplastic monitoring remains technically demanding and requires continued refinement. Despite these challenges, the successful application of the harmonised methodology across nine pilot sites shows that coordinated, cross-country monitoring is feasible and provides a solid operational model for future practice.

A shared strategic direction is emerging across the region, centred on laboratory readiness, baseline data collection, alignment with EU standards, and an adaptive approach to risk management. Strengthening transnational cooperation will be essential as microplastics become

a formal component of drinking water management. By advancing these measures, drinking water facilities can enhance preparedness, support regulatory evolution, and contribute to a coherent European framework for microplastics management.

6 Stakeholder engagement and public awareness

6.1 Stakeholder engagement

During the implementation of the MicroDrink project, a dynamic and highly productive exchange of knowledge, experiences, and perspectives was established across the Danube Region, engaging researchers, practitioners, and decision-makers at all governance levels, as well as the wider public. This interaction reflects the project's core mission: to strengthen capacity and cooperation in addressing microplastic (MP) pollution in drinking water through a truly transnational and cross-sectoral approach.

Through the active involvement of all project partners, the complex issue of microplastics has been successfully translated into accessible, relevant, and actionable knowledge for diverse audiences. By raising awareness and fostering understanding, MicroDrink contributes not only to scientific advancement but also to informed societal engagement and behavioural change.

Stakeholder engagement has been at the heart of the project, implemented through a wide range of communication and dissemination activities. These included the project website (https://interreg-danube.eu/projects/microdrink), social media (Facebook, Instagram, LinkedIn) channels (Figure 25), knowledge-transfer webinars (Figure 26), national workshops (Figure 27), bilateral and multilateral meetings, and participation in international conferences and scientific events. The consortium's efforts to engage stakeholders and network with professionals and experts in the field of water management and microplastics research facilitated the collection of valuable knowledge, feedback, experience, and expertise, which proved instrumental in preparing project outputs and results.

Figure 25: Example of one of the Instagram posts, made to note World Environment Day 2025

Figure 26: Announcement of the MicroDrink knowledge transfer webinar No. 1 (Instagram)

Figure 27: Participants of one of sixteen organized workshops

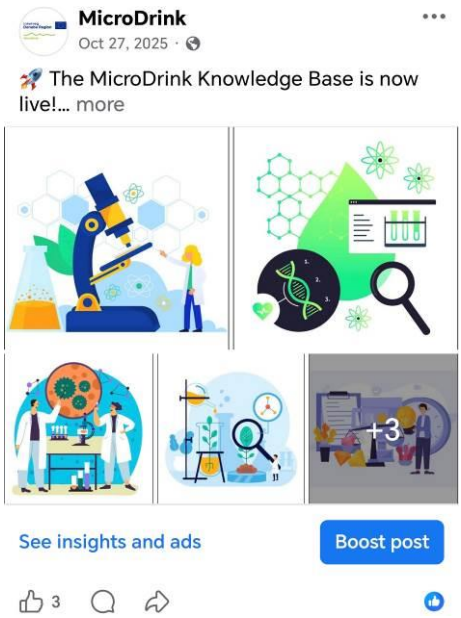

Figure 28: Announcement of the MicroDrink Knowledge Base public availability (Facebook post)

Figure 29: Visits to educational institutions and public lectures – Germany (Instagram post)

One of the first results of the project is the MicroDrink Knowledge Base (MDKB), developed to overcome fragmentation in MP monitoring and management. The MDKB brings together sampling protocols, analytical methods, laboratory capacities, instruments, legislation, and ongoing projects into one comprehensive resource (Figure 28). It supports scientists, policymakers, water utilities, NGOs, and other stakeholders with reliable, harmonised information and promotes cross-border cooperation in the Danube Region. Each section of the MDKB offers multilingual data sheets and

invites users to submit new information, ensuring that the Knowledge Base remains dynamic and up to date.

In addition to online social media communication with stakeholders and general public, targeted outreach activities, such as visits to educational institutions and public lectures have ensured that knowledge reaches all levels of society (Figure 29, Figure 30 and Figure 31)

This multi-channel approach has enabled MicroDrink to connect key actors and support the development of harmonised methods, tools, and practices for monitoring and managing microplastics in drinking water resources.

Figure 30: Visits to educational institutions and public lectures – Serbia (Instagram post)

Figure 31: Visits to educational institutions and public lectures – Croatia (Instagram post)

The largest share of stakeholders came from the general public (Figure 29, Figure 30 and Figure 31) and the higher education and research sector, reflecting both the relevance of the topic and the project's strong scientific foundation. Most of the communication with the higher education and research sector has been achieved through meetings and various scientific events (Figure 32, Figure 33 and Figure 34).

Figure 32: MicroDrink presented at EGU General Assembly 2025 (Facebook post)

Figure 33: MicroDrink presented at the Conference MICROM 2025 (Facebook post)

MicroDrink has successfully established connections with infrastructure and public service providers, as well as with education and training institutions, national authorities, NGOs, healthcare institutions, business support organisations, and sectoral agencies. The project has demonstrated its capacity to mobilise a broad and diverse stakeholder community, engaging them as active participants in determining the presence of microplastics in drinking water.

At the start of its implementation, Project MicroDrink, published two online surveys on the official project website for experts on existing sampling procedures, laboratory instruments, analytical and detection methods for microplastics as well as on policies, legislation, challenges and current practices in addressing microplastics in drinking water and raising awareness. These surveys were also disseminated during the first national stakeholder workshops. By analysing the survey results, the consortium established a deeper understanding of current practices and identified areas for improvement in the detection and analysis of microplastics. The project team gathered diverse perspectives and knowledge on research, advocacy efforts, and potential issues related to microplastics. The findings from both surveys helped to identify key trends, knowledge gaps, and areas for further investigation and action. In order to engage stakeholders in a more direct way, MicroDrink consortium members, during the first year of project implementation, participated in several international events, such as the kick-off meeting and microplastic assessment workshop of the Aquatic Plastic Interreg project, the “Microplastics Days” conference, the first “Microplastics for breakfast” initiative held in Zagreb, among others. The focus was on networking, knowledge exchange, and strengthening cooperation among researchers working on microplastic pollution in the Danube Region. Later, MicroDrink representatives took part in Interreg Programme events, such as the 1st and 2nd Lead Partner Seminars in Budapest and Bucharest respectively. Both events

included synergy-building workshops, aimed at enhancing synergy and cooperation with other water management Interreg projects.

MicroDrink also participated in a two-day workshop organised by the OECD–European Commission initiative for supporting managing authorities and project beneficiaries of the Danube Region. The main activities involved capacity building, governance improvement, and sharing experiences in project implementation.

The MicroDrink team attended the EU Strategy for the Danube Region (EUSDR) Water Quality Priority Area's conference on "Microplastics in drinking water – from source to tap", where the Lead Partner, Croatian Geological Survey, presented key project activities and tools (Figure 34). The event brought together experts and policymakers to discuss monitoring, risk assessment, and policy development.

Figure 34: MicroDrink participated at EUSDR Conference 2024

As part of the MicroDrink project, a hands-on international joint sampling training session was held in Hungary, to harmonise sampling procedures for microplastics in drinking water. Organised by MicroDrink project partner EUROFINS and supported by the Lead partner Croatian Geological Survey, the workshop enabled participants to gain practical experience in the field of MP sampling and discuss harmonised methodologies (Figure 35). The harmonised MP sampling approach developed within the MicroDrink project, in accordance with Commission Delegated Decision 2024/1441 and demonstrated at the international training session, can be viewed in the following video: https://youtu.be/atAYwaUDxas.

MicroDrink project partners, the University of Belgrade, Faculty of Mining and Geology and Public Utility Service Company "Drugi oktobar" Vršac, participated in the opening conference of the Interreg IPA Hungary-Serbia project "MInimizing CROss-border contamination of water with microPLASTICS - MICROPLASTICS", where they had the opportunity to exchange ideas and explore potential synergies between the MICROPLASTICS and MicroDrink projects.

Figure 35: MicroDrink international joint sampling training session, at Fejérvíz ZRt. Hungary

Two Micro(Knowledge) transfer webinars were organised to strengthen knowledge exchange and technical capacity related to microplastics in drinking water at the end of the first year of project implementation (December 2024) (Figure 36). The first webinar focused on practical and methodological aspects, including sampling procedures, laboratory instruments, and analytical techniques such as FTIR and Raman spectroscopy. It provided participants with detailed insights into current monitoring practices across the Danube Region and highlighted key challenges related to harmonisation, equipment availability, and methodological limitations. The second webinar addressed the broader state of the art regarding microplastics in drinking water resources, covering sources, types, environmental and health impacts, and existing policy frameworks. Discussions emphasised persistent gaps, including the lack of standardized methods, limited laboratory capacities, and fragmented regulatory approaches, while promoting the MicroDrink Knowledge Base as a central platform for data sharing and harmonisation across the region. Both webinars were recorded and are available at:

https://www.youtube.com/watch?v=hTBPuioZt38
https://www.youtube.com/watch?v=mDf1rDUInDs.

Figure 36: Micro(Knowledge) transfer webinars (YouTube videos)

Initial stakeholder workshops of the MicroDrink project were organised in all eight partner countries to engage relevant institutions, present project objectives, and identify country-specific challenges related to microplastics in drinking water (Figure 37). These workshops also provided a foundation for future collaboration and stakeholder involvement in each country.

Attendees of the Water Forum - Water Fair 2024 (Serbia) learned more about the MicroDrink project, as well as how raising awareness of this issue can help reduce the harmful effects of microplastics. The Water Forum – Water Fair 2024 (Serbia) was organised on December 6th by the Association of Water Technology and Sanitary Engineering from Belgrade and the BelExpo Plus company. This event was intended for young researchers and attracted a large number of visitors.

The MicroDrink project was highlighted by the European Commission as „significantly contributing to building capacities, particularly within countries that have not yet conducted any microplastics research" (at the start of the second year of implementation). The story of MicroDrink's success was submitted as part of the #WaterWiseEU campaign, which focuses on water resilience, and aims to change the way we see, use, and value water.

Figure 37: The first national stakeholder workshops of the MicroDrink project (continuation)

Members of the MicroDrink team, from the University of Belgrade, Faculty of Mining and Geology, Eurofins and Friedrich-Alexander-Universität Erlangen-Nürnberg had an excellent opportunity to introduce the project to experts engaged in WWF project @microplastics_ibiss and the Interreg project ADRIPLAST (Serbia) and the DALIA project (Germany) respectively (Figure 38).

Figure 38: Networking and synergy between DALIA and MicroDrink projects

A synergy meeting of Croatian partners from all Interreg Danube Region Programme 2021–2027 projects approved under specific objective 2.3 “Sustainable, integrated, transnational water and sediment management in the Danube River Basin” was held in Zagreb in March 2025. The meeting aimed to facilitate the exchange of experiences, present project activities within Croatia, and strengthen cooperation, with emphasis on developing a strategic approach to enhancing the impact of project results at both regional and transnational levels, as well as aligning efforts with the overarching programme’s objectives.

In April 2025, the University of Belgrade, Faculty of Mining and Geology presented the MicroDrink project’s concept and goals to the professional community at the 1st Meeting of micro- and nanoplastic researchers from Serbia, Montenegro, and Bosnia and Herzegovina, entitled "Microplastics for breakfast".

Project partner Eurofins presented the first-year results of the project at the annual assembly of the Laboratory Committee of the Hungarian Water Utility Association organised in May 2025. The event was attended by representatives from most Hungarian water utilities operating drinking water and wastewater treatment facilities.

The roundtable discussion on MP sampling in drinking water, organised in May 2025 by project partner Friedrich-Alexander-Universität Erlangen-Nürnberg, gathered 20 participants, among which were representatives of the European Commission’s Joint Research Centre (JRC) and EU projects LifeCascade, Upstream and DALIA, to support evidence-based decision-making on addressing challenges related to microplastics in drinking water.

A representative of Friedrich-Alexander-Universität Erlangen-Nürnberg also presented at the event “Knowledge Exchange and Capacity Building in Environmental Research”, which took place in May 2025 in Regensburg, bringing together representatives from government, science, business, and civil society from both Bavaria and Ukraine. The event provided a space for intersectoral exchange on shared challenges and practical solutions in the areas of waste, water, and energy.

Engineers from the Dutch Ministry of Infrastructure and Water Management visited the MicroDrink Czech project partner, T. G. Masaryk Water Research Institute, in Prague. The event provided a platform for discussion, knowledge exchange and practical solutions in water management and water protection (Figure 39). T. G. Masaryk Water Research Institute also participated in the 20th Conference of the Czech Limnological Society and the Slovak Limnological Society in Frymburk, presenting a lecture on the results of the MicroDrink project.

Figure 39: Meeting at T. G. Masaryk Water Research Institute in Prague

In June 2025, the Lead Partner, Croatian Geological Survey, presented the project's best management practices at the Lead Partner Seminar and Synergy Building and Capitalisation Workshop in Bucharest, which focused on programme implementation, the exchange of best practices, and strengthening project management capacities (Figure 40). Projects from the 1st and 2nd Interreg Danube Region Programme calls were grouped into broader thematic clusters to explore potential areas for cooperation. MicroDrink participated actively in these discussions and explored opportunities to create synergies with projects from the 2nd call.

Figure 40: Participants of the 2nd Lead Partner Seminar in Bucharest

The project partner University of Ljubljana, Faculty of Natural Sciences and Engineering, presented at the 14th Conference of the Municipal Economics. The talk, "Modern Challenges in Protecting Drinking Water from Emerging Contaminants", highlighted the MicroDrink project and shared insights on the monitoring and occurrence of microplastics in drinking water sources.

The Friedrich-Alexander-Universität Erlangen-Nürnberg team met Dr. Andreas Kerstan and Mrs. Stefanie Ritter from Agilent Technologies. The meeting allowed both sides to present their approaches and explore possible synergies in microplastic detection and water-related studies.

The Lead Partner, Croatian Geological Survey, prepared a video for the 1st Water Resilience Forum held in December 2025, which presented the project to a large and diverse group of stakeholders across water management sectors (https://www.youtube.com/watch?v=Ls5Zx66PKMc). The forum was organised by the European Commission in collaboration with the Economic and Social

Committee (EESC) and the Committee of the Regions (CoR), with the participation of the Commissioner for the Environment, Water Resilience and a Competitive Circular Economy.

During the final period of the MicroDrink project implementation, communication efforts have been concentrated on disseminating results and engaging stakeholders. The official website of the Interreg Danube Region Programme published a news article highlighting the MicroDrink project as one of the key initiatives actively addressing microplastic pollution in drinking water sources across the Danube Region. In addition, EUSDR Priority area 4 Water Quality recognised the MicroDrink project's efforts under the Flagship processes on emerging substances.

T. G. Masaryk Water Research Institute gave a brief presentation on the MicroDrink project, its objectives, and results at a meeting on microplastics held in Brno (the Czech Republic) attended by experts in plastic analysis methods.

National capacity-building training courses within the MicroDrink project were successfully held in 2026 across all participating countries, bringing together a diverse and highly engaged group of experts, water practitioners, and representatives of relevant institutions and organisations (Figure 41). These courses provided an important platform for exchanging knowledge and experiences related to the presence of microplastics in drinking water, as well as for discussing approaches to effectively manage this growing environmental challenge. The training courses also served to test the Decision-Making Support Tool developed within the project, which assists institutions and decision-makers in planning and implementing measures for managing microplastics in drinking water systems.

Figure 41: National capacity building training courses of the MicroDrink project

The Final Conference of the MicroDrink project, scheduled for May in Belgrade, Serbia, will be the most significant opportunity to further strengthen communication with stakeholders. Strengthening cooperation with these actors is essential, as they play a crucial role in implementing policies and measures aimed at reducing microplastic pollution. By further enhancing dialogue

with decision-makers at these levels, MicroDrink contributes to building a solid foundation for effective governance and long-term resilience of drinking water systems in the Danube Region.

Ultimately, MicroDrink demonstrates how collaboration, knowledge-sharing, and stakeholder engagement can drive meaningful change by supporting the development of innovative tools, harmonised methodologies, and strategic recommendations that help safeguard drinking water resources and protect both the environment and human health.

6.2 Public awareness

Microplastics are widely present in the human environment (Figure 42). During the implementation of the MicroDrink project, project partners identified several key challenges related to the presence of microplastics in the environment, while also proposing potential solutions to address these issues. In addition, public awareness and action were also highlighted as key components of microplastic mitigation in the environment.

One of the most significant problems is the lack of appropriate regulation and legislation on microplastics in the Danube region. Addressing this gap requires increased research and funding to determine maximum permissible concentrations of microplastics in the environment, which is a crucial first step towards establishing and implementing effective regulatory frameworks.

Figure 42: Instagram post of the MicroDrink project, made to note Earth Day 2024

Furthermore, stakeholders face several technical and operational challenges, including the absence of standardised reference methods, the complexity of working with microplastics, and the lack of harmonised procedures for microplastic analysis. Reference materials are often inaccessible and expensive, further complicating the process. Moreover, there is a shortage of accredited laboratories capable of conducting microplastic analysis. To address this, it is necessary to support and incentivise laboratories to obtain accreditation, which in turn requires dedicated research funding in the field of microplastics.

Another important issue identified is the low level of public awareness regarding the risks associated with microplastics. Stakeholders emphasise the need for a comprehensive approach

involving government institutions, including the introduction of educational programmes for children in schools, the establishment of clear legal penalties, stronger cooperation with industry, and the implementation of fees for plastic use.

During interactions with decision-makers, project partners observed that there is a certain, albeit limited level of awareness among the general public regarding the issue of microplastics in the environment. As a measure to further raise awareness and encourage behavioural change, decision-makers emphasised the importance of individual actions, behavioural change, as well as advocacy and activism. These include replacing single-use plastic bags with reusable shopping bags, substituting plastic water bottles with reusable or foldable alternatives, reducing the use of plastic packaging, and improving waste separation and recycling practices.

Furthermore, stakeholders highlighted awareness of the presence of microplastics in various sources, including cosmetics, laundry and dishwashing detergents, agricultural practices, wastewater effluent, and urban and industrial runoff. At the same time, publicly available data on microplastic detection remain scarce and insufficiently documented, with only a limited number of studies available despite growing concern, increasing awareness, and the urgent need for action regarding microplastic pollution.

As key measures to be implemented, stakeholders identified source reduction, public education, and policy development as the most crucial steps towards reducing microplastic pollution in the environment.

The MicroDrink project also prepared a survey on policies, legislation, challenges, and current practices related to microplastics in drinking water in the Danube region. The results of the survey highlighted the absence of appropriate regulation and legislation of microplastics, lack of reference methods of MP analysis and lack of accredited laboratories that can conduct MP analysis in a standardised way. Reducing microplastics from households requires interventions across the full waste lifecycle-source reduction, product substitution, capture, and proper disposal. It also requires a combination of measures to prevent plastic from entering households and manage the disposal of items that inevitably shed particles. Key actions include reducing plastic waste at the source, proper segregation of household waste, improved textile (laundry) management, appropriate disposal of personal care and cleaning products, prevention of mechanical fragmentation of plastics in waste streams, and optimisation of recycling and disposal pathways.

7 Conclusions and future perspectives

The MicroDrink project represents the first coordinated, transnational effort to assess the occurrence of microplastics in drinking water resources across the Danube River Basin, using a methodology aligned with the recommendations and requirements of Commission Delegated Decision 2024/1441. Despite methodological challenges and the absence of fully validated sampling equipment, the project demonstrated that large-volume sampling and spectroscopic analysis can be implemented across diverse hydrogeological settings, generating comparable datasets and revealing clear patterns in microplastic occurrence.

Across all nine pilot sites, microplastic concentrations in drinking water were generally low and often close to analytical detection limits, consistent with recent European assessments. The results indicate a consistent gradient across resource types: intergranular aquifers have the lowest levels, karst systems show slightly higher but still limited presence, and bank-filtration and surface water influenced systems display the highest and most variable concentrations. Polymer profiles were dominated by polyethylene (PE) and polypropylene (PP), with most particles in the 20–100 µm size range, reflecting both environmental degradation processes and the detection window of current analytical methods.

The project also highlighted the technical complexity of microplastic monitoring. Sampling equipment performance varied, filter integrity was inconsistent, and the second filter in the cascade proved unsuitable as a procedural blank, confirming that true blanks must be prepared in the laboratory. Laboratories reported matrix-related challenges, difficulties distinguishing polymers from biogenic material, and the persistent influence of airborne contamination, even under strict QA/QC conditions. These findings underscore the need for validated equipment, certified reference materials, and harmonised subsampling strategies, as well as continued refinement of analytical protocols.

Beyond technical insights, MicroDrink demonstrated the importance of capacity building and stakeholder engagement. Training courses, national workshops, and knowledge transfer webinars revealed that awareness of microplastics is increasing, yet institutional readiness, laboratory capacity, and regulatory clarity remain limited. Stakeholders expressed a strong need for practical guidance on sampling, analysis, interpretation, and communication of results. The Decision Making Support Tool (DMST) and the MicroDrink Knowledge Base directly address these gaps by providing structured information, scenario-based guidance, and harmonised resources for water suppliers, regulators, and researchers.

Looking ahead, the project provides a solid foundation for implementing the EU Drinking Water Directive's microplastic monitoring requirements. The findings support a risk-based monitoring approach, where resource type determines sampling frequency and analytical needs. Intergranular aquifers may require only periodic confirmatory monitoring, while karst systems benefit from event-based sampling during hydrological extremes. Bank filtration and surface water systems, influenced by upstream pressures, require more frequent monitoring and verification of treatment performance.

Future progress will depend on several interconnected developments. First, validation and standardisation of sampling equipment are essential to ensure reliable, comparable data across countries. Second, investment in laboratory capacity, trained personnel, and accredited procedures will be necessary to meet emerging regulatory expectations. Third, integrating

microplastics into Water Safety Plans will support proactive risk management, by linking catchment protection, treatment optimisation, and infrastructure assessment. Finally, continued transnational cooperation will be crucial for building a coherent evidence base, sharing best practices, and supporting policy development at regional and EU levels.

MicroDrink has shown that coordinated, cross-border monitoring of microplastics in drinking water is both feasible and valuable. By combining harmonised methodologies, stakeholder engagement, and strategic tools, the project strengthens the region's preparedness for future regulatory requirements and contributes to safeguarding drinking water resources. The insights gained provide a roadmap for continued research, improved monitoring, and long-term resilience in the face of emerging contaminants.

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