INVITED ORAL

FROM LINEAR TO CIRCULAR: UPCYCLING INDUSTRIAL BY-PRODUCTS INTO SUSTAINABLE SILICON CARBIDE (SIC) MEMBRANES FOR WASTEWATER TREATMENT

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The ceramic sector is at a crossroads. While technical innovation is accelerating, the traditional "take-make-dispose" lifecycle of membrane production remains a heavy environmental burden. Today's industry is squeezed between two major pressures: the massive energy demands of high-temperature sintering and the mounting problem of end-of-life ceramic waste.

This presentation argues that the solution lies in a fundamental shift from linear manufacturing to a circular economy. By upcycling industrial by-products, we can engineer advanced silicon carbide (SiC) membranes tailored specifically for wastewater treatment. These sustainable filtration systems do not just match, but often exceed, the performance of traditional materials in removing emerging contaminants. We will explore how this transition does more than just cut carbon emissions; it opens the door to new functional properties for complex water separation and purification processes. By bridging the gap between fundamental research and industrial scaling, this talk outlines how we can stop seeing "waste" as a liability and start treating it as a strategic resource for the next generation of clean water technology.

Keywords: Circular economy, sustainable filtration systems, Silicon carbide, wastewater treatment

PFAS: NOVEL TOXICITY MECHANISMS BASED ON THEIR SURFACTANT PROPERTIES

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Often referred to as "forever chemicals," per- and polyfluoroalkyl substances (PFAS) are a large class of human-made chemicals that exhibit high persistence in the environment and that have been found in a variety of consumer products, environmental media, and biological samples across the globe. However, limited toxicology data exist for many of the over 15,000 chemicals belonging to the PFAS family. Here, we will briefly review some of the well-accepted toxicity mechanisms associated with PFAS exposure before presenting some of our recent work comparing the toxicity of a legacy PFAS (PFOS) and an emerging PFAS (6:2 Cl-PFESA). We will present our recent evidence collected in vitro and in vivo suggesting that a unifying mechanism of their toxicity can be found in their surfactant properties that disrupt the function of intracellular molecular condensates, essential for proper cellular functioning and for reproduction.

Keywords: Toxicity mechanisms, legacy PFAS, Emerging PFAS, surfactant

SCIENCE, POLICY AND INNOVATION FOR SAFEGUARDING PYRENEAN WATER RESOURCES UNDER GLOBAL CHANGE

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The Pyrenees constitute a strategic water source for the surrounding territories, sustaining ecosystems, rural communities, agriculture, hydropower, tourism and urban water supply across a broad trans-boundary region. Yet this mountain system is increasingly affected by global change, including climate warming, changes in precipitation patterns, shrinking snowpack and glaciers, land-use change, and growing pressures on water quality. These processes are altering not only the quantity of available water, but also its seasonal distribution, ecological functioning and capacity to dilute pollutants, with consequences that extend far downstream. This lecture will present an holistic vision of Pyrenean water resources, examining the links between the cryosphere, hydrology, ecosystems, society and regional economies. Special attention will be paid to the dual challenge of water quantity and water quality, and to the need to understand mountain water not only as a physical resource, but also as a foundation for territorial resilience. The lecture will connect this diagnosis with the theme of the symposium, discussing how emerging technologies may support more adaptive and integrated responses to protect water resources.

Keywords: Pyrenees, climate warming, water resources, mountain water, ecosystems

FROM SCIENCE TO REGULATION, BRIDGING THE GAP

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Chemical regulatory frameworks are already among the most complex pieces of legislation in Europe, even for conventional substances. When additional variables such as those introduced by nanomaterials, polymers and microplastics are added, traditional frameworks are often no longer fit for purpose. As a result, moving from science to legislation is rarely a direct or straightforward process. It is usually iterative, with progress and setbacks.

In this talk, I will discuss how this process works in practice, using examples such as regulatory discussions on nanomaterials, the registration of polymers in the EU, and the microplastics restriction. The aim is to show what actually happens, where the main challenges arise, and why. This includes questions such as what it means to generate data that are useful for regulatory decision making, how uncertainty is handled when evidence is incomplete, and why the timelines of science and policy rarely align.

I will also address some of the recurring tensions in this space, such as how to translate complex material properties into operational regulatory criteria, or how to simplify in order to develop frameworks that are both pragmatic and implementable. In the case of polymers and microplastics, this leads to very practical questions, such as how to define what is being regulated, how to measure it, and how to estimate exposure in a consistent way.

Drawing on the experience of ECETOC, I will describe the role of organisations working at this interface, helping to bring together industry, academia and regulators. This includes developing frameworks, recommendations and practical tools that make science more usable for decision making, for example in exposure assessment or in the integration of different types of evidence.

The aim is to make this process more transparent and to show why progress depends on bringing together the relevant actors, each with a different perspective, to help complete the puzzle. Ultimately, the goal is to open a discussion on how research can be better aligned with regulatory needs, particularly in areas where methods and approaches are still evolving.

Keywords: Regulatory frameworks, nanomaterials, microplastics, legislation, polymers

METAL-ORGANIC FRAMEWORKS FOR WATER PURIFICATION

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Water is essential in all aspects of life, being one of the defining characteristic of our planet. In the last years, water pollution is becoming a major concern due to novel and dangerous anthropogenic pollutants. Of particular concern are the called “Emerging Organic Contaminants (EOCs)”, term used not only to cover already known contaminants species but also newly developed compounds with novel negative effects for the environment and human health. EOCs are found as hundreds contaminating water resources and include a wide different array of compounds: pharmaceuticals and personal care products, pesticides, veterinary products, industrial compounds, etc. On the other hand, plastic pollution is one of the main worldwide environmental concerns, as these substances are found everywhere, even in our body, pushing to identify new water remediation strategies. Despite several strategies have been proposed for the EOCs and microplastic exclusion, the insufficient contaminants removal of these processes makes necessary to search new efficient alternatives.

Among the novel technologies considered in water remediation processes, Metal-Organic Frameworks (MOFs) are regarded as promising materials for the elimination of EOCs and microplastics, since they present many properties that commend them in water treatment: large surface area, easy functionalizable cavities, some are stable in water, synthesized at large scale, etc (Figure 1).[1] In this regard, we are investigating the applications of highly stable and porous MOFs in the removal (adsorption and/or photodegradation) of EOCs and plastics from water under real or comparable conditions (using tap or river water, studying the recyclability of MOFs, under continuous flow conditions, etc.). To further improve the EOCs and microplastic elimination capacity of MOFs, we reduced particle size, introduced different functional groups on the aromatic linker, create defects on the MOFs structure or stabilize metallic nanoparticles or enzymes in their surface.[2] These porous materials can incorporate or degrade both EOCs and microplastics achieving different elimination efficiencies. Furthermore, we have demonstrated the utility of MOFs in water purification, through the elimination of potentially dangerous inorganic by-products normally produced during water chlorination. All these results evidenced the potential of MOFs in the reduction of environmental contamination, envisioning their future real application.

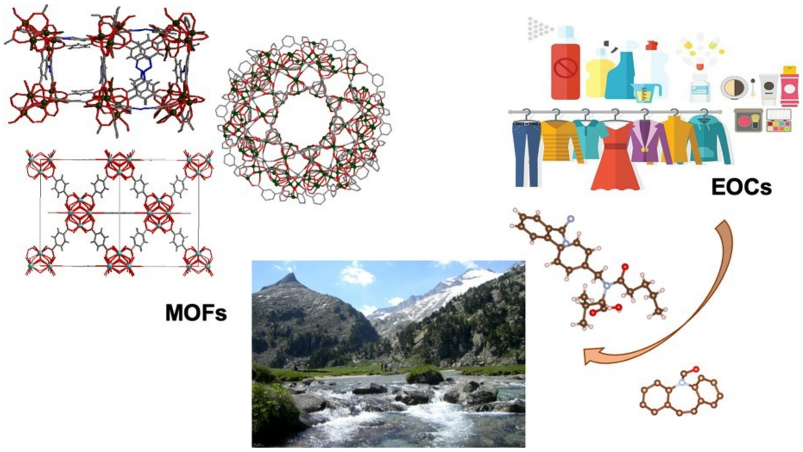

Figure 1 – Scheme of the use of MOFs in water treatment.

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CHARACTERIZING AND TRACING MICRO AND NANO-PLASTICS

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Micro- and nanoplastics are now recognized as ubiquitous contaminants across environmental systems, spanning terrestrial, atmospheric, and aquatic compartments. Within aquatic environments, from surface waters to groundwater and even drinking water systems, they pose particular concern due to their mobility and potential for human exposure. According to recent ISO definitions, microplastics are typically defined as plastic particles ranging from 1 µm to 1 mm, with “large microplastics” spanning from 1 mm to 5 mm, while nanoplastics extend below the micrometre scale. These materials originate from both primary sources (e.g., industrial products) and secondary fragmentation of larger plastic debris. Their small size, physicochemical heterogeneity, and persistence raise growing concerns regarding their environmental fate, transport, and potential impacts on ecosystems and human health. As a result, robust analytical approaches are urgently needed to detect, quantify, and trace MNPs in complex environmental matrices.

This talk will focus on current advances and persistent challenges in the characterization and tracing of micro- and nanoplastics. Particular emphasis will be placed on the integration of complementary analytical techniques, such as spectroscopy, thermal analysis, and high-resolution imaging, to improve particle identification and size distribution assessment across a wide range of scales. The limitations of existing methods in detecting nanoplastics and distinguishing them from natural colloids will be critically discussed.

The presentation will critically assess current methodologies and outline key gaps, including the lack of harmonized pre-treatment procedures and the need for environmentally relevant test and reference materials to support robust, comparable, and reproducible measurements.

Keywords: Micro- and nanoplastics, aquatic environments, analytical techniques, MNP characterization

DEVELOPING MICROBIAL APPROACHES FOR PLASTIC REMEDIATION

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Plastic pollution represents a major and complex environmental challenge due to the persistence of both polymer backbones and their associated chemical additives. Microbial metabolism offers a promising avenue for mitigating these pollutants, but effective strategies to identify and characterise active degraders remain limited.

Here, we investigated microbial communities from contrasting natural and engineered environments, including coastal sediments, recycling facilities, and wastewater treatment plants. Enrichment experiments focused on common plastic-associated additives, including di(2 ethylhexyl) phthalate (DEHT) and tetradecane, alongside no-additive controls. A combined biochemical and molecular approach was used to link community structure and function, integrating high-throughput assays of growth, redox activity, and esterase activity with 16S rRNA amplicon sequencing.

Microbial consortia displayed clear substrate-dependent responses. DEHT enrichments supported the highest levels of growth and esterase activity, consistent with ester hydrolysis, whereas tetradecane treatments showed enhanced redox activity, reflecting distinct metabolic pathways for alkane utilisation. Community profiling revealed substantial restructuring driven by substrate type, with enrichment of taxa linked to plastic degradation, such as Nocardiaceae, alongside previously uncharacterised families including Vermiphiliaceae, suggesting underexplored biodegradative potential.

These findings demonstrate that diverse microbial communities can metabolise plastic-associated additives potentially through functionally distinct pathways and highlight the value of integrated screening platforms for identifying active degraders. Ongoing work is extending this approach to polymer substrates such as polyethylene terephthalate and polypropylene using multi-omics analyses to further resolve the functional mechanisms underpinning microbial plastic transformation.

CONTRIBUTED ORAL

ADVANCING BIO-BASED AND BIODEGRADABLE AS MORE SUSTAINABLE SOLUTIONS TO MITIGATE PLASTIC AND MICROPLASTIC POLLUTION IN EUROPEAN RIVER SYSTEMS

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The growing accumulation of litter, plastics, and microplastics in aquatic environments, including rivers, groundwater, and marine ecosystems—presents a critical threat to global biodiversity. With plastic waste projected to nearly triple by 2040 [1] the European Commission’s mission "Restore our Ocean and Waters" [2] has prioritized the development of innovative strategies to intercept and prevent pollution at the source. Within this framework, the UPSTREAM project [3] addresses the full lifecycle of plastic pollutants through five strategic pillars: monitoring, prevention, elimination at wastewater treatment plants (WWTPs), river remediation, and plastic valorisation.

A central challenge in water protection is the persistence of conventional plastics, which do not truly disappear but instead fragment into secondary microplastics. These tiny particles are nearly impossible to remove mechanically and can accumulate in ecosystems for centuries [4]. To address this, current research under the UPSTREAM prevention pillar focuses on transitioning toward advanced biodegradable materials. Unlike traditional petroleum-based plastics, certified biodegradable bioplastics are designed to be fully metabolized by microorganisms in natural environments. This prevents the formation of permanent micro-fragments that would otherwise contaminate the food chain and water supply.

As a foundational step, a comprehensive mapping and analysis of alternative biopolymers—such as PLA, PBAT, PBS, and starch-based compounds—was conducted [5]. This study evaluated their intrinsic biodegradability and technical properties to identify the most effective substitutes for fossil-based materials. This evaluation provided the scientific basis for developing specialized polyhydroxyalkanoate (PHA) based blends. These materials have been specifically engineered for food packaging applications, achieving the required mechanical and processing performance while enabling accelerated biodegradation under industrial composting conditions. Furthermore, their ability to biodegrade in freshwater environments may provide a mitigation pathway in the event of unintended or uncontrolled environmental release. By reducing persistence lifetimes in natural ecosystems, these bio-based solutions contribute directly to maintaining water quality and restoring the health of European river basins.

Keywords: Biodegradable, prevention, microplastics, biodegradability, UPSTREAM-project

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BEYOND CLASSICAL TREATMENT, PERMANENT DEGRADATION OF OMP WITH UVC/H_2O_2

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Emerging contaminants are a current and future challenge in the water sector and the implementation of quaternary treatment in municipal wastewater treatment plants is growing past pre-studies. The UPSTREAM project focuses on both microplastics and micropollutants in municipal and industrial wastewater.

Advanced oxidation processes (AOP) are the degradation of organic micropollutants (OMP) with hydroxyl radicals (OH*) and they are one of the potential solutions to the issue of emerging contaminants. UV/H2O2 is an AOP method with no risk for NDMA or bromate formation compared to e.g. ozonation, while efficiently degrading the OMP permanently. This abstract will cover some case studies of Advanox technology, a low-pressure UV/H2O2 method designed and produced by Van Remmen UV Technology B.V.

Siden, an association of municipalities for wastewater treatment in northern Luxembourg performed tests with the Advanox technology at Heiderscheidergrund WWTP with the intent on implementing full scale UV/H2O2 treatment on multiple sites in Luxemburg. The OMP of the new EU directive was used as the benchmark and the tested doses were 3000-18000 J/m2 UVC and 0-20 mg/L H2O2. The removal efficiencies found were >80% from 7500 J/m2 with 5 ppm H2O2, or from 5000 J/m2 with 12,5 ppm H2O2. By assessment of the University of Luxemburg, Advanox would be suitable in 10 of 15 potential WWTPs without additional economic investments. Benchmark TOTEX is currently 0,17 €/m3 with 0,10 kWh/m3.

Hoogheemraadschap De Stichtse Rijnlanden (HDSR), a waterboard in the Utrecht area of the Netherlands, tested the newly designed Advanox Flow reactor on their municipal wastewater effluent. The tests included a direct comparison to a pre-study with Advanox from 2019 in Växjö, Sweden, and the tested doses were 2500-12000 J/m2 UVC and 10-30 mg/L H2O2. The results showed a removal efficiency of >85% at an energy consumption of 0,11 kWh/m3 which was a three-fold improvement in performance compared to the 2019 trial. The TOTEX found was 0,05-0,07 €/m3 excl. energy. Bioassay analysis for several markers indicated increased oxidation activity but decreased hormonal and hydrocarbon activity at HDSR. In the 2019 trials, the ecotoxicological effects on direct toxicity, growth-, and movement inhibition were found to be low to negligible.

A sustainability assessment by Witteveen+Bos on Advanox compared to ozonation, GAC, and PACAS. The results were presented in ECI and CO2-eq. Increasing the UV transmittance (UVT) from 45% T10 to 70% T10 by pre-treatment, the impact was reduced by >75%. Renewable energy sources reduced the impacts of ozone and Advanox significantly. At increased UVT or use of renewable energy, Advanox had a comparable to or lower impact than ozone.

In all cases where UVC/H2O2 functions as a chemical barrier, it also functions as a microbial barrier due to the UVC light. UVC disinfection is typically performed at 160-400 J/m2, with the EU drinking water norm stating 400 J/m2, and many horticultural contexts using 2500 J/m2. The lowest UVC doses for AOP are usually several times higher than for disinfection. In consideration for antibiotic resistance reduction UVC/H2O2 has shown a triple effect: destruction of antibiotic-resistant bacteria through UVC disinfection, destruction of residual antibiotics through AOP, and destruction of antibiotic-resistant genes through photolysis from 2000-4000 J/m2.

When the data on cost and performance at different scales is combined with the sustainability assessment and implications for antibiotic resistance it becomes clear that UV/H2O2 and Advanox™ is a viable technology to be used in full scale to handle emerging contaminants at municipal wastewater treatment plants. This means that it is valuable technology to have in the toolbox and take into consideration when choosing a solution.

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CONTINUOUS PHOTOCATALYTIC REMOVAL OF ACLONIFEN USING BIOCOMPATIBLE Fe-MOFs

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The removal of herbicide residues from water is a major environmental concern due to their persistence and potential ecological impact. One compound of particular importance is Aclonifen (ACF), a biphenyl ether herbicide detected in natural water sources at concentrations between 29–42 ng·L-1, characterized by its high persistence and toxicity toward aquatic fauna.1-2 Due to its potential regulatory restriction (currently approved until October 2026) and associated environmental risks, the development of effective strategies for its removal from water is urgently needed. In this context, photocatalysis represents a promising approach for the elimination of biphenyl ether herbicides such as ACF, particularly because it can be driven by renewable energy such as solar irradiation. Metal–organic frameworks (MOFs) are porous materials composed of metal nodes interconnected by organic linkers, forming extended hybrid networks with well-defined structures. In particular, iron-based MOFs (Fe-MOFs) stand out for their biocompatibility, low toxicity, and their previously demonstrated efficiency in the photocatalytic degradation of organic contaminants.3 In this work, two well known biocompatible Fe-MOFs, MIL-127 and MIL-88B-NH2, were synthesized, characterized, and evaluated as photocatalysts for the degradation of ACF in aqueous solution. Firstly, batch photocatalytic experiments demonstrated excellent performance for both materials, achieving over 95% degradation of the contaminant while preserving their structural integrity, as confirmed by powder X-ray diffraction (PXRD), and exhibiting less than 1% MOF degradation determined by ligand leaching. Moreover, both materials maintained high photocatalytic activity over at least six consecutive cycles. To further assess their practical applicability, MIL-127 was used due to its better processability for continuous flow experiments using packed-bed columns. These experiments were carried out under conditions simulating real wastewater treatment plants (0.479 m3·h-1·m-2). The system exhibited remarkable operational stability, maintaining high degradation efficiency over extended periods with low MOF degradation (<5% ligand leached). Notably, column saturation was reached after 36 days of continuous operation, highlighting the strong resistance of the Fe-MOFs to deactivation and their potential for long-term water treatment applications. This is highly relevant in the context of wastewater treatment plants, where long operational lifetimes and reduced maintenance frequency are critical parameters. Overall, these results demonstrate that biocompatible Fe-MOFs are efficient and stable photocatalysts for the removal of ACF from water. The successful translation from batch to continuous operation under realistic conditions highlights their strong potential for implementation in advanced water treatment technologies.

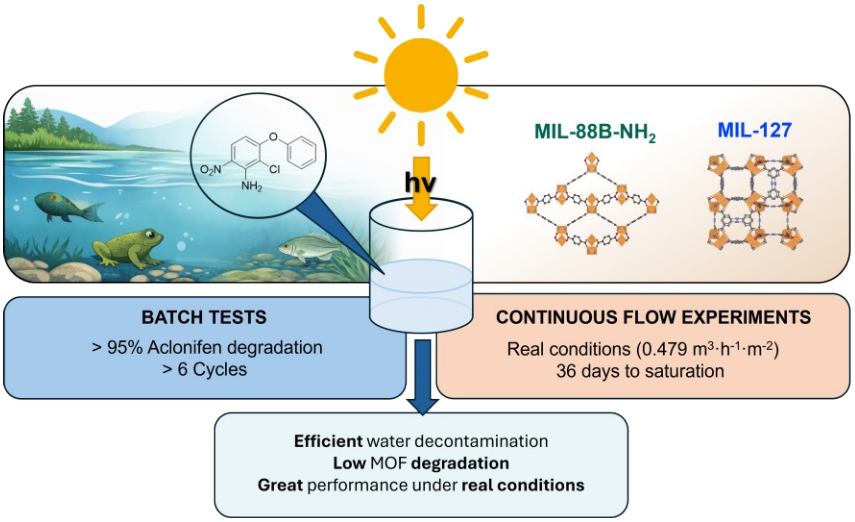

Figure 1 – Scheme of Aclonifen photocatalytic removal using Fe-MOFs

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CURRENT CHALLENGES IN PFAS ANALYSIS: FROM SAMPLE PREPARATION TO REGULATORY COMPLIANCE

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Per- and polyfluoroalkyl substances (PFAS) are among the most intensively discussed groups of emerging contaminants due to their extreme persistence, environmental mobility, and potential adverse effects on ecosystems and human health. Their long-term use in industrial applications, firefighting foams, surface treatments, food contact materials, and numerous consumer products has led to their widespread occurrence in water, soil, sediment, biota, and waste-related matrices. As a result, PFAS have become a major topic in environmental monitoring, risk assessment, and regulatory control, with particular attention currently focused on drinking water.

This contribution will address current analytical challenges associated with PFAS determination, from sampling and sample preparation to instrumental analysis and final data interpretation. Particular attention will be paid to environmental and water matrices, where reliable quantification is often complicated by trace concentration levels, matrix interferences, the risk of background contamination, and the broad structural diversity of PFAS. The presentation will outline key steps of the analytical workflow, including sampling strategy, prevention of secondary contamination, sample preparation, extraction and clean-up procedures, instrumental determination, and quality assurance and quality control requirements.

A major part of the presentation will focus on the practical implementation of the requirements arising from EU Directive 2020/2184 on water intended for human consumption. Since the beginning of 2026, the assessment of two PFAS-related parameters has become mandatory in drinking water. The first of these, Sum of PFAS, is defined in EN 17892 and is based on targeted determination by LC-MS/MS. The presentation will describe our experience with the implementation of this targeted method in routine laboratory practice, including validation, accreditation, and the practical evaluation of the required 20 individual compounds. At the same time, the method has proven suitable for a substantially wider analytical scope, and in our laboratory, it has currently been validated and accredited for the determination of 56 PFAS compounds.

The second parameter, Total PFAS, represents a significantly greater analytical challenge. According to current technical guidance, this parameter may be assessed using one of several approaches, including the TOP assay, EOF-CIC, or LC-HRMS-based strategies. In this presentation, particular attention will be paid to the implementation of the TOP assay (total oxidisable precursor assay) in routine laboratory conditions. This approach is highly relevant because it enables the estimation of oxidisable precursor compounds that are not captured by conventional targeted LC-MS/MS analysis. At the same time, the final evaluation of Total PFAS requires inclusion of TFA analysis in accordance with the applicable technical guidance. The presentation will therefore discuss not only the analytical principle of the TOP assay itself, but also the practical challenges related to oxidation efficiency, interpretation of transformation products, integration of TFA results, and overall evaluation of Total PFAS.

An important message of this contribution is that compliance with current European drinking water legislation cannot be ensured by a single analytical technique alone. Rather, it requires a combination of complementary analytical approaches, including targeted LC-MS/MS determination for Sum of PFAS, oxidation-based assessment of precursor contribution, and additional evaluation steps required for the final assessment of Total PFAS. The presentation will highlight the advantages and limitations of these approaches and discuss their applicability in routine high-quality laboratory practice.

Finally, the presentation will provide an overview of currently available monitoring data and observed trends in PFAS occurrence in environmental samples. Our findings confirm the frequent occurrence of PFOA and PFOS across a wide range of environmental matrices. However, with the extension of the monitored PFAS spectrum, we increasingly observe the presence of ultrashort- and short-chain PFAS, especially in water samples. These observations further support the need for systematic monitoring and for robust analytical tools capable of providing reliable data for regulatory compliance, environmental assessment, and future mitigation measures.

Overall, this contribution aims to provide an integrated overview of PFAS analysis from both analytical and regulatory perspectives, with particular emphasis on the practical implementation of Sum of PFAS and Total PFAS determination in drinking water and on the key challenges laboratories currently face in meeting evolving regulatory expectations.

DESIGN AND COMPUTATIONAL FLUID DYNAMIC OPTIMIZATION OF SPIRAL PASSIVE FILTERS FOR MICRO AND NANOPLASTIC SEPARATION IN WASTEWATER TREATMENT

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The pervasive presence of micro and nanoplastics (MNPs) in water bodies necessitates the development of efficient, large-scale separation technologies. This study proposes a novel passive separation strategy for a wastewater (WW) filter layer designed to sort MNPs based on density and size exclusion principles without external energy requirements. The design is based on a three-revolution Archimedes spiral with a rectangular cross-section (7x3 mm) to induce specific hydrodynamic phenomena. Separation technology selection was a result from a machine learning comparation among flotation methods, sluice systems, dense medium separation and spiral separators using decision trees as hierarchical decision-making tool to guide the selection process based on particle size and density difference. Operating in a laminar flow regime, the system leverages the interplay between inertial lift forces and transverse Dean flows. These forces drive the lateral migration of plastic particles, focusing them into predictable equilibrium positions for effective sorting. By utilizing intrinsic forces (wall-interaction and shear gradients) the spiral geometry accelerates the focusing process compared to straight channels, allowing for a compact and efficient filter footprint. The CFD simulation using COMSOL® Multiphysics

6.3 reveals the velocity profiles and the particles trajectories across the WW filter layers. The use of 90º turns inlet were engineered to couple the filter inlet with the spiral reactor and optimize the fluid velocity (0.01, 0.02, 0.03, 0.04, 0.05, 0.06, and 0.1 m/s) for particle dragging using sand particles (ρ=2650 kg/m^3) and plastic (ρ=1050 and 2200 kg/m^3). CFD validate that particle equilibrium is dominated by Dean forces, which can be tuned by regulating flow rates to accommodate different MNP densities. Assessments of flow velocity, pressure distribution, and particle migration (from 0.5 s to 20 s) ensure high separation efficiency thought particle tracing module. Real validation was achieved processing the optimized model in DLP and evaluating the separation performance using sand particles.This passive approach offers a sustainable, scalable solution for upgrading WWTPs to combat MNP pollution while maintaining low operational costs, with future stages focusing on the toxicity analysis of treated effluents.

DEVELOPMENT OF THIN-FILM NANOCOMPOSITE MEMBRANES WITH METAL-ORGANIC FRAMEWORKS FOR PFAS REMOVAL FROM DRINKING WATER

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Studies of contamination by per- and polyfluoroalkyl substances (PFAS) are becoming more frequent. PFAS are considered persistent, bioaccumulative, and toxic substances, which have been frequently detected in drinking water sources across the globe [1]. The extreme stability of PFAS, mainly attributed to the strong bond between carbon and fluorine atoms, makes them challenging to degrade and therefore difficult to remove from water. However, nanofiltration (NF) is considered an efficient technology for the removal of contaminants, including PFAS from drinking water [2]. Membranes with NF properties can filter out the majority of contaminants of concern at relatively low pressures compared to reverse osmosis membranes [3]. However, conventional NF membranes suffer from some shortcomings such as low water permeability, poor stability and a decrease in rejection of short-chain compounds following the membrane cleaning process. To address these challenges, this study investigates the development of polyamide-based thin-film nanocomposite (TFN) NF membranes incorporating metal-organic frameworks (MOFs). While TFN membranes have shown potential for improving permeability, selectivity, and fouling resistance, the influence of MOF type and functionality on PFAS removal performance remains insufficiently understood [2]. This work aims to systematically evaluate the effect of different MOFs, including ZIF-8, ZIF-94, ZIF-L, NH-ZIF-8, and UiO-66-NH_2 on membrane structure, surface properties, and separation performance. Membranes will be fabricated via interfacial polymerization and characterized using complementary techniques to assess morphology, chemical composition, thermal stability, and surface charge. Their filtration performance will be evaluated in terms of water permeability and rejection of various PFAS compounds. It is anticipated that the incorporation of functionalized MOFs will enhance membrane performance by improving water permeability while maintaining or increasing PFAS rejection, particularly for short-chain PFASs. Furthermore, differences in MOF structure and surface chemistry are expected to play a critical role in governing PFAS separation mechanisms. The outcomes of this study will provide new insights into the design of advanced TFN membranes and contribute to the development of more efficient and sustainable technologies for PFAS removal from drinking water.

Acknowledgments

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DUAL ADSORPTION–THERMAL REGENERATION CLAY-BASED SYSTEMS FOR SUSTAINABLE ELIMINATION OF EMERGING WATER CONTAMINANTS

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The rapid increase in emerging contaminants, including pharmaceutical residues, industrial dyes, and nutrient pollutants, poses significant challenges to water safety and environmental sustainability. Many of these contaminants are persistent, toxic, and resistant to conventional water treatment processes, creating an urgent need for innovative, cost-effective, and environmentally friendly purification technologies. This study presents a sustainable water treatment strategy based on thermally stable natural clay that integrates adsorption and thermal regeneration to achieve efficient contaminant removal while maintaining adsorbent reusability.

The developed clay-based system was evaluated for the removal of representative emerging contaminants, including pharmaceutical compounds such as phenazopyridine and tetracycline, industrial dyes including methyl orange and methylene blue, and nitrate ions. Batch adsorption experiments conducted under optimized operational conditions (pH

≈ 4, temperature of 25 °C, and pollutant concentrations ranging from 10 to 40 mg/L) demonstrated high removal efficiencies, ranging from 84% to 93% for organic pollutants and approximately 89% for nitrate ions. The adsorption performance was strongly influenced by surface charge interactions, pollutant characteristics, and the porous structure of the clay material. To assess the practical applicability of the proposed system, continuous-flow column experiments were performed, confirming the stability and effectiveness of the adsorbent under dynamic treatment conditions.

Thermal regeneration of the spent clay at 600 °C resulted in complete mineralization of the adsorbed contaminants into environmentally safe byproducts such as carbon dioxide and water vapor, without producing secondary waste. The regenerated clay maintained adsorption efficiencies exceeding 85% across five consecutive reuse cycles, demonstrating excellent structural stability and long-term operational reliability. Comprehensive characterization using X-ray diffraction, scanning electron microscopy, thermogravimetric analysis, and elemental analysis confirmed the high crystallinity, porosity, and thermal robustness of the clay, which are essential for its dual functionality.

The proposed closed-loop adsorption–thermal regeneration approach provides a sustainable, reusable, and economically viable alternative to conventional water treatment technologies and shows strong potential for large-scale implementation, particularly in regions facing water scarcity and limited treatment resources [1-4].

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EMERGING CONTAMINANTS IN THE INDUSTRY (MICRO-, NANO-PLASTICS): TENDENCIES AND CHALLENGES FOR ENFORCEMENT

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The term Emerging Contaminants became widely acknowledged as improved analytical techniques allowed detection of previously overlooked substances. Among them highlight Micro/Nanoplastics (MP/NP).

Despite there is not a uniform definition for MNP, it is widely adopted an upper size of 5 mm for MP and 0.1 µm for NP (Kahnna, 2024). They come primarily from the fragmentation of larger plastics, though MP can also be intentionally added to products. MNP travel via air, water and soil, accumulating in the environment due to their persistence and moving up the food chains, so that human health concerns have been assessed (Balali, 2024).

Europe, encouraged by increasing consumer demand for sustainability, is betting on early regulation even with research gaps (PwhC, 2023). Regulation (UE) 2023/2055 modifies Annex XVII of REACH and establishes restrictions on MP intentionally added to products. After a phased implementation across the different sectors, it aims to reach complete elimination in all products by 2035. Nordiik (2023) estimates preventing 500,000 tonnes of MP releases into the environment over 20 years, with estimated cost for the society up to 19.1 billion €. Regulation (UE) 2025/2265 aims to eliminate plastic pellet losses throughout the entire supply chain, with an intermediate goal of reducing these losses by 30% before 2030 and, in the long term, achieving zero loss.

Although being a ubiquitous matter, there is neither a harmonized definition nor consistent worldwide policies. While regulatory bodies prioritize enforceability and clarity, scientific agencies prefer precision for risk assessment. Standards' organizations align with analytical feasibility, whereas policy bodies simplify for communication (ISO, 2023). National policies vary in scope, reflecting differences in plastic use, consumer behaviour, availability of waste management practices, analytical readiness and legislative priorities relying on structural factors (Allan, 2021). Europe, Canada, Australia and South Korea enforce bans on microbeads and single-use plastics (EC, 2021). Differently, U.S. has opted for evidence-based approach, promoting early research and later regulation (EPA, 2023). China and Japan emphasize circular economy principles, local pollutant control, technological innovation and biodegradable alternatives (UNEP, 2021). India and Brazil, with emerging regulatory frameworks, prioritize the development of standards, analytical capabilities and legislative roadmaps (Prata, 2020).

Despite notable advancements, critical research gaps remain a challenge for enforcement. For MP, the absence of fully harmonized sampling and analytical protocols continues to hinder comparability and reproducibility across studies (ISO, 2023). NP detection at environmentally relevant concentrations poses a significant challenge due to their nanoscale dimensions, aggregation behaviour and limitations in current analytical sensitivity (Koelmans, 2022). Furthermore, the long-term toxicological effects and combined impacts of these particles on ecosystems and human health are insufficiently understood. To address these gaps, international initiatives are underway, such as ISO (2023) developing standardized vocabularies and methodologies, NIST (2023) enhancing metrology and developing reference standards and the European CUSP (2023) cluster evaluating environmental fate, exposure and health risks, while developing harmonized protocols. These coordinated actions are essential to establish robust, globally accepted protocols and support evidence-based regulatory frameworks.

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ENZYME ENGINEERING FOR PROGRAMMABLE IMMOBILIZATION ON POLYOXOMETALATE-IONIC-LIQUID–COATED CERAMIC SCAFFOLDS FOR BHET REMOVAL FROM WASTEWATER

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BHET (bis(2-hydroxyethyl) terephthalate) is a key intermediate produced during the degradation of PET plastic or chemical recycling processes. It can accumulate in industrial wastewater streams from PET recycling plants and polymer processing. PET-degrading enzymes, such as PETases, cutinases, or esterases, can hydrolyze BHET into terephthalic acid and ethylene glycol, contributing to wastewater remediation. An interesting model for study is Candida antarctica lipase B (CALB), as its high catalytic promiscuity enables it to carry out pH-dependent regioselective hydrolysis of BHET1. However, a common disadvantage of this type of enzyme is that in free format they suffer from low stability in aqueous media, are difficult to recover, and have limited reuse. Therefore, immobilization on solid supports is crucial for the practical remediation of this type of wastewater. The objective of the present study was to engineer the lysines exposed on the surface of CALB by reductive amination without a catalyst using benzaldehyde, which allowed us to perform programmed immobilization (load 1.5 mg protein gscaffold-1, yield: 100%) on ceramic scaffolds coated with a 50 mg/mL suspension of polyoxometalate-base ionic liquid (POM-IL). The performance of the immobilized enzyme on structural scaffolds coated with POM-IL1 (M50) was evaluated using wastewater from the secondary (A) and tertiary (B) treatment stages of the Baix Llobregat Wastewater Treatment Plant, located in El Prat de Llobregat, Barcelona, and with two artificial water samples (C and D). Sample C evaluated the effect of the salt present in waters A and B, while sample D examined the extreme legal limits for pH and surfactant content. All samples were doped with 5 mM BHET and monitored in 24-hour cycles. When A and B were used as reaction media, BHET degradation stopped at MHET (99% conversion for 13 days), while when C and D were used, conversion was completed at TPA (80% conversion for 6 days). A kinetic analysis of pH revealed that the level of BHET degradation is modulated by the pH of the reaction medium. Reducing the pH to 4 in samples C and D significantly reduces the stability of the system. To evaluate the hydrophobic binding strength of the enzyme to M50, we labeled the model protein with a fluorophore and used it to generate an M50 system. With this system, we were able to track protein leaching under operating conditions with the four water samples mentioned above. Surprisingly, less than 4% of the protein was leached, demonstrating the strength of the enzyme's hydrophobic bond. After enzymatic depletion during BHET degradation, we wash with acetone to remove the exhausted enzyme and leave the inorganic scaffolds ready for a new cycle of coating and immobilization with fresh enzyme. In the future, it will be essential to extrapolate this system with enzymes that maintain high catalytic activity over a wider pH range, including alkaline conditions, to improve degradation efficiency without compromising long-term operational stability in real-world environments.

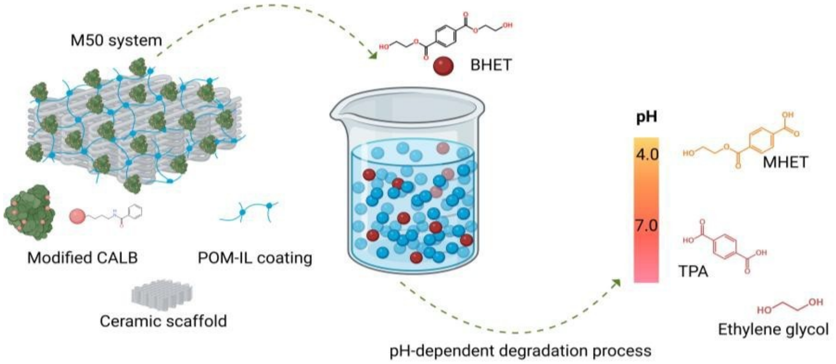

Figure 1 – Prototype from modified CALB immobilized on polyoxometalate-ionic-liquid coated ceramic scaffolds for BHET degradation from wastewater.

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FROM URBAN WASTEWATER TO RIVERS: INSIGHTS INTO THE BEHAVIOR OF PHARMACEUTICAL AND ANTIBIOTIC RESIDUES IN THE POCTEFA TERRITORY

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Figure 1 – POCTEFA (green) and study area (blue)

Pharmaceuticals and antibiotics are continuously released into urban water systems and may persist through wastewater treatment, contributing to contamination of receiving rivers (Moles et al. 2022, Rodriguez-Mozaz 2020). Here, we report the first campaign of a multi-matrix monitoring study in the POCTEFA transboundary territory (north-eastern Spain/south-western France) designed to characterize the occurrence, mobility and fate of pharmaceuticals, antibiotics, and selected transformation products across an urban water continuum including sewer/collector nodes, indirect discharges, WWTP influent–effluent pairs, and upstream/downstream river sections. Figure 1 show the regions involved in the study (blue) and the POCTEFA territory (green). A total of 41 sampling points were investigated across five catchments representing contrasting urban sizes and treatment configurations (WWTPs from 13,000 to 527,000 equivalent inhabitants). Forty target Contaminants of Emerging Concern (CECs) (18 antibiotics/antibiotic-related compounds and 22 non-antibiotic pharmaceuticals) were analyzed using targeted SPE-LC-MS/MS. The dataset revealed a consistent “urban baseline” dominated by high-consumption pharmaceuticals (e.g., paracetamol, beta-blockers) together with antibiotics and β-lactam transformation products. However, strong spatial heterogeneity was observed, even when indirect discharges were excluded: in urban sewer/collector nodes, total quantified pharmaceuticals ranged from 17.80 to 120.46 µg/L and total quantified antibiotics from 0.31 to 33.41 µg/L. These results indicate that hotspot-like maxima may arise even within otherwise ordinary urban branches. Source attribution was further supported by diagnostic compounds: contrast media such as iopromide pointed to clinical inputs, whereas a node impacted by pharmaceutical industry discharges showed atorvastatin concentrations of up to 1.6 mg/L (semi-quantitative result), clearly distinguishing this site from the diffuse community-use pattern observed. WWTP performance was compound-specific: paracetamol showed consistently high attenuation (97–99.9%), diclofenac displayed variable removal, and carbamazepine showed persistent or apparent “re-emerging” behavior in some plants. These plant-scale patterns were reflected in receiving waters (Ebro, Arga and Adour), where upstream–downstream contrasts confirmed measurable WWTP imprints, including persistent pharmaceuticals and antibiotics at environmentally relevant ng/L levels (e.g., ciprofloxacin increases downstream in selected reaches). Overall, the results support a conceptual model of a diffuse urban pharmaceutical fingerprint superimposed by localized hotspots, highlighting the need for combined upstream source control and downstream treatment/monitoring strategies. The study provides timely scientific evidence for the implementation of the recast EU Urban Wastewater Treatment Directive (Directive (EU) 2024/3019), particularly by supporting CEC surveillance, the identification and prioritization of critical control points, and the evidence-based management of urban discharges in transboundary river basins, in line with the Directive’s strengthened requirements on CECs, monitoring, and integrated wastewater management

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FROM WATER MANAGEMENT TO WATER RESILIENCE: A CROSS-SECTOR INNOVATION PERSPECTIVE

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Water is vital to the operation of most economic activities and societal systems, yet its strategic importance is often overlooked. Unlike other essential resources, it usually gains attention only during times of scarcity, pollution, or regulatory restrictions. This paradox has led to fragmented water management, despite the fact that water, along with energy, represents a fundamental resource across nearly all sectors and economic activities.

Climate change is intensifying water scarcity and flood risks, while emerging pollutants, digitalisation, and increasingly water-intensive activities add further threats and pressures to water systems. In this context, it is becoming evident that these challenges extend well beyond the water sector. They are inherently cross-sectoral and systemic, a perspective that is now firmly reflected in European policy discussions. The EU Water Resilience Strategy[1] presents water resilience not only as an environmental priority but also as a matter of competitiveness and security, advocating for integrated governance, innovation, and cross-sector collaboration. This systemic approach aligns with the broader analysis in Mario Draghi's Report on the Future of European Competitiveness[2], which emphasises the need to reduce fragmentation, strengthen innovation ecosystems, and foster coordinated action across sectors and policy domains. In the water sector, these dynamics are further supported by the updated regulatory framework for drinking water[3] and urban wastewater treatment[4], which raises quality standards, addresses emerging pollutants, promotes energy neutrality, and strengthens data and governance requirements, thereby increasing demand for integrated and innovative solutions.

Within this evolving context, ZINNAE, the Cluster for the Efficient Use of Water in Aragón, works as a key enabler at the interface between the water sector and a wide range of cross-sectoral stakeholders. Rather than acting as a traditional sectoral association, ZINNAE functions as a collaborative platform that promotes dialogue, cooperation, and joint innovation among companies, research and technology organisations, public authorities, and societal actors at regional, national, and European levels. Its role is especially important in transforming shared challenges into collaborative innovation pathways, aligning technological progress with regulatory, territorial, and market needs.

ZINNAE is recognised as a Water-Oriented Living Lab within the Water4All Partnership, reflecting its role in the water innovation ecosystem in Aragón. In this capacity, ZINNAE provides a trusted environment to facilitate innovative collaboration, co-creation, and solution validation, while reinforcing the regional ecosystem’s links to European research and innovation agendas. Simultaneously, ZINNAE engages with a European network of clusters beyond the water sector, including ICT, agri-food, GreenTech, and advanced industrial technologies. This interaction fosters natural links between water-related challenges and solutions developed in other fields.

Ultimately, ZINNAE serves as a catalyst for collaborative innovation, an approach endorsed by its participation in 30 projects (6 regional, 19 national, and 5 European) over the past four years, both as a partner and as coordinator. This experience reinforces ZINNAE’s belief that the major challenges facing the water sector cannot be addressed through unilateral approaches. Tackling water resilience, security, and sustainability requires coordinated effort from industry, research, policymakers, and society as a whole. Water-dependent sectors, along with citizens, play a crucial role in recognising the true value of water and in shaping the priorities that guide innovation. By encouraging cooperation across sectors, ZINNAE helps build a more resilient, competitive, and water-smart economy.

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METAL REMOVAL FROM ACIDIC ZINC-PLATING EFFLUENTS USING THE INVASIVE MACROALGA *RUGULOPTERYX OKAMURAE*

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The invasive brown macroalga Rugulopteryx okamurae has produced substantial ecological and socioeconomic impacts on coastal ecosystems, particularly along the Algarve coast and the Mediterranean shores of Spain, where its massive accumulation has disrupted local habitats and affected fisheries and tourism [1]. This study evaluated its potential as a bioremediation agent for metal removal from a zinc-plating effluent, as its high abundance makes it a promising material for environmental remediation. The effluent, collected at a zinc galvanizing plant, exhibits very low pH (<2) and high Fe and Zn concentrations. Dry biomass of R. okamurae collected on the Algarve coast was pre-washed, milled, and sieved; the 20–100 µm fraction was selected. Batch assays were carried out for 5 h under orbital agitation using both the original effluent and a 50% dilution. Each assay used 3 g of biomass with 100 mL of effluent. Metal removal was assessed at 60, 120, and 300 min by measuring pH and Fe and Zn concentrations (Figure 1). Biomass addition caused a pH increase, particularly in the diluted effluent (1.80 to 4.20), while in the original effluent pH rose from 1.49 to 2.52, indicating acid-neutralizing capacity. The macroalga also showed capacity for metals removal. For Fe (4689.8 mg/L), efficiencies of 35.9–53.0% were obtained in the original effluent and 61.2–61.7% in the diluted effluent after 300 min. For Zn (1452 mg/L), removal reached 24.6–26.0% in the original effluent and 53.2–55.9% in the diluted effluent. Lower efficiencies in the original effluent reflect the higher metal load. These results confirm the potential of R. okamurae for removing heavy metals from highly acidic industrial effluents. Further work is underway to elucidate the underlying mechanisms, likely involving both adsorption and precipitation, to support the valorisation of this invasive species for bioremediation purposes.

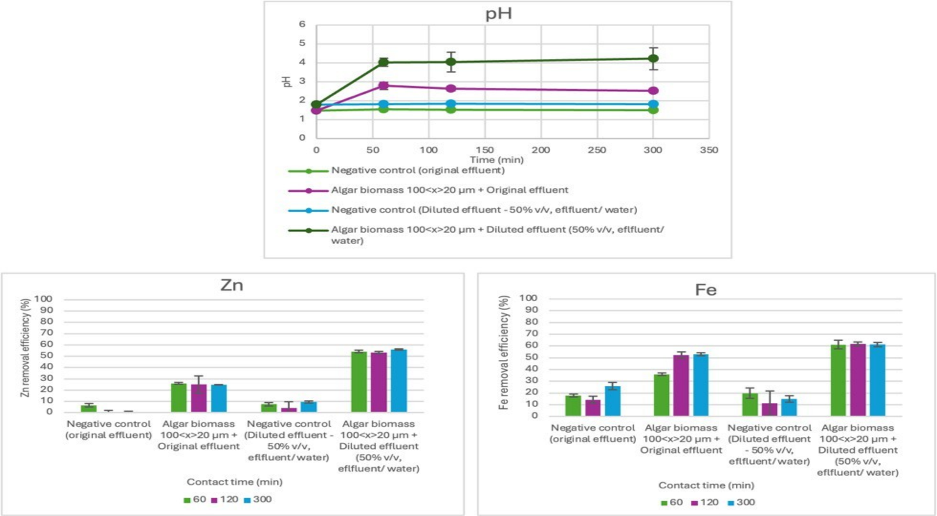

Figure 1 - Removal efficiency of Zn and Fe (%) by Rugulopteryx okamurae biomass over time (60, 120 and 300 min) in original and diluted (50% v/v) effluent, and corresponding pH evolution during the batch assays.

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METAL-ORGANIC FRAMEWORK BASED BIOPOLYMERIC MEMBRANES FOR METALS RECOVERY FROM POLLUTED WATERS

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Metal–Organic Frameworks (MOFs) have emerged as highly promising porous, crystalline materials to address heavy metal pollution, surpassing the adsorption capacity and kinetics of conventional adsorbents [1]. Among the wide variety of MOFs, those constructed from—or functionalized with—metal-chelating organic ligands and Zr(IV) ions are particularly attractive, owing to their exceptional hydrolytic stability and their ability to coordinate target metals through multiple binding sites. As demonstrated in this work, these materials show great potential for the selective, high-capacity recovery not only of heavy metals from water, but also of high-value rare earth elements, among other.

We have followed two different synthetic routes to develop metal-chelator-like MOFs. In the first approach, several new Zr-based MOFs were assembled from C4-dicarboxylate linkers bearing lateral metal-coordinating groups such as –SH, –NH$_3$, –Br, –COOH, and –SO$_3$ (C4MOFs). In the second approach, the MOF-808 host material was employed as a platform to incorporate various metal-chelating molecules, including EDTA (Ethylenediaminetetraacetic acid), DTPA (Diethylenetriaminepentaacetic acid) and EDTP (Ethylenediamine tetra(methylenephosphonic acid). In comparison with the state of the art, we have observed record adsorption capacities for soft and intermediate heavy metals in the Zr–C4 MOFs, as well as outstanding capacities for the recovery of rare earth elements, with partial selectivities achieved using metal-chelator-functionalized MOF-808 systems. Once the materials were developed and their initial metal-adsorption performance screened using multielement solutions, we proceeded with their integration into highly permeable polysaccharide–protein hybrid scaffolds [2] (Figure 1).

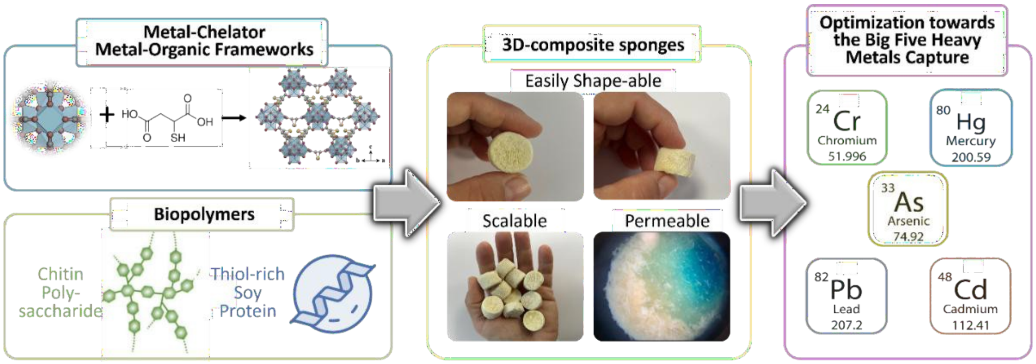

Figure 1.- Strategy for the assembly of 3D-sponge composites for heavy metals capture

The interplay between the MOFs and the biopolymeric scaffolds, in terms of metal adsorption capacity and affinity, was elucidated by studying the performance of the individual components and comparing it to that of the MOF–biopolymer hybrid scaffolds. Adsorption kinetics and isotherms of the individual components are modulated when both materials are combined, as the surface charge of the biopolymeric scaffold can either hinder or enhance the migration of cationic or anionic metal species through the hybrid sponge structures. From an application perspective, simply immersing the 3D composite sponges in solutions of varying acidity or basicity allows for a significant switch in adsorption affinity. Overall, the hybrid technologies developed in this work represent a promising alternative to current methods, with potential as point-of-care devices for the treatment of polluted and mining waters.

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MODELING THE TRANSPORT AND FATE OF EMERGING CONTAMINANTS IN SHALLOW WATER FLOWS

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Emerging contaminants (ECs), including pharmaceutical residues and personal care products, are increasingly detected in aquatic environments and pose threats to ecological systems and human health due to their potential toxicity and persistence. However, their spatio-temporal dynamics remain difficult to quantify due to trace concentrations and the high cost of field measurements. Numerical modeling provides an effective alternative for investigating the transport and fate of ECs in water bodies (Liu et al., 2025). Nevertheless, most existing shallow-water transport models either treat ECs as passive tracers or rely on steady-flow assumptions (Behzadi et al., 2018; Metcalfe et al., 2022). Such simplifications limit their applicability under transient hydraulic conditions and neglect the complex biochemical and physicochemical processes governing contaminant fate.

In this study, we address this gap by developing and validating a dynamically coupled hydrodynamic-ECs modeling framework that explicitly integrates shallow water hydrodynamics with ECs-specific kinetic processes. The hydrodynamic module solves the shallow water equations in both one-dimensional (1D) and two-dimensional (2D) domains (Gordillo et al., 2020a; Gordillo et al., 2020b), while the EC module accounts for advection, dispersion, and biochemical/physicochemical reactions, including biolysis, hydrolysis, photolysis, volatilization, bioconcentration, depuration, sorption and desorption. This framework moves beyond conventional advection-dispersion formulations and enables the simultaneous simulation of flow dynamics and contaminant fate under both steady and unsteady flow conditions. To support large-area and high-resolution 2D applications, a GPU-accelerated implementation on unstructured meshes is developed, substantially improving computational efficiency while preserving numerical accuracy.

The accuracy of the numerical schemes was verified against an analytical solution. A real-world application is shown in which the 2D GPU solver successfully reproduces a flood event in the Ebro River. The simulated downstream peak flow discharge (2038 m3/s) exhibited a relative error of 7.06% compared with the measured peak (2182 m3/s). In addition, the spatio-temporal distribution of sulfamethoxazole was resolved, enabling visualization of antibiotic contamination on agricultural land due to overbank flooding. In this case, the GPU-accelerated implementation achieved a 3.52-fold speedup relative to the multi-CPU OpenMP version (parallelized in 24 cores). Notably, the 2D CPU model and 2D GPU model produced identical results, demonstrating that GPU implementation significantly improves computational efficiency without compromising numerical precision. In addition, a global Sobol sensitivity analysis provides insights into the key parameters governing ECs variability, offering guidance for model parameterization and uncertainty assessment.

In summary, this study presents a computationally efficient, physically consistent, and validated modeling framework that advances the state-of-the-art in predicting the fate and transport of ECs for dynamic shallow-water systems. The integration of GPU acceleration, dynamic coupling, and comprehensive process representation offers a versatile tool for researchers and practitioners in water quality management, risk assessment, and environmental forecasting.

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MOFs & COFs: NEXT GENERATION MATERIALS FOR WATER REMEDIATION

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Keywords: Metal–Organic Frameworks (MOFs), Covalent Organic Frameworks (COFs), Water remediation Emerging organic contaminants (EOCs)

Emerging organic contaminants (EOCs) are increasingly detected in aquatic environments due to their widespread use and incomplete removal in conventional wastewater treatment plants1. Among them, the antibiotics trimethoprim (TMP) and sulfamethoxazole (SMX), commonly co-administered, are of particular concern due to their environmental persistence and their role in promoting antimicrobial resistance.[1][2] heir complementary chemical structures and pH-dependent speciation make them suitable model compounds to systematically investigate the influence of charge on removal processes and to evaluate combined treatment strategies

Porous framework materials such as metal–organic frameworks (MOFs) and covalent organic frameworks (COFs) have emerged as promising alternatives to conventional and advanced treatments (e.g., activated carbon adsorption, oxidation processes), which often suffer from limited selectivity, high energy demand, or poor reusability. These crystalline materials offer high surface areas, tunable porosity, and adjustable chemical functionality, enabling selective interactions with target pollutants.[1][3]

In this work, TMP removal was investigated through adsorption using the biocompatible zirconium ellagate SU-102, a chemically stable MOF with a negatively charged framework that favors the adsorption of cationic species.3 The adsorption performance was evaluated at different pH (3, 7 and 10) and in increasingly complex water matrices (Milli-Q water, tap water and wastewater), revealing higher enhanced removal under acidic conditions and decreasing efficiency with matrix complexity. In contrast, SU-102 showed negligible affinity toward SMX under the studied conditions, highlighting the limitations of SU-102 for anionic or neutral contaminants.[3]

Complementarily, SMX removal was addressed through visible-light-driven photocatalytic degradation using π-conjugated COFs based on amines and terephthalaldehyde linkers,4 which enable a fast and almost complete photodegradation of the SMX.[4]

Overall, this combined approach highlights the potential of MOFs and COFs as complementary platforms for the efficient removal of antibiotic contaminants, integrating adsorption and photocatalysis to tackle structurally diverse and co-occurring pollutants in water.

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POLYOXOMOLYBDATE-BASED HYBRID MATERIALS AS ANTIMICROBIAL SURFACES TO PREVENT BIOCOLONIZATION IN WATER SYSTEMS

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Microbial colonization of surfaces in water-related environments often leads to biofilm formation, which can facilitate the persistence and spread of pathogenic microorganisms and antimicrobial resistance. Preventing the initial attachment and growth of microorganisms on surfaces is an important and promising strategy to limit biocolonization and improve the safety of water-related systems.[1] Polyoxometalates (POMs) are metal–oxide clusters that have attracted increasing attention due to their structural diversity and interesting biological properties. When combined with organic cations, they can form polyoxometalate ionic liquids (POM -ILs), hybrid materials that merge the stability of inorganic clusters with the flexibility of organic components. This combination makes them attractive candidates for the development of antimicrobial materials and protective surface coatings.[2]

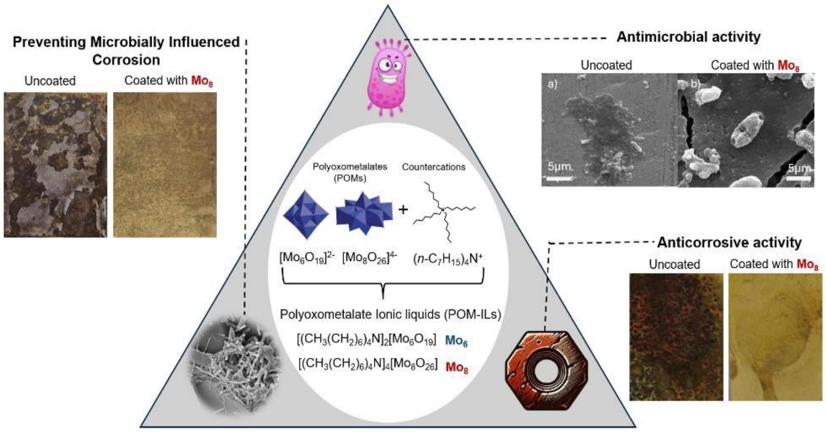

Figure 1: Illustration of the material development together with ESEM and photographic images of uncoated brass and POM-IL coated brass exposed to aqueous acetic acid (10%) and microbial colonization.

In our previous work[3], we developed polyoxomolybdate-based ionic liquids containing tetraalkylammonium cations together with the clusters $[Mo_6O_{19}]^{2-}$ and $[Mo_8O_{26}]^{4-}$.These materials demonstrated strong antimicrobial activity as well as hydrophobicity and high chemical stability. When applied as coatings, they formed durable layers that were able to limit microbial colonization and protect metal surfaces exposed to harsh environmental conditions (Figure 1). Based on these results, we are currently exploring a new generation of materials based on phosphonium cations. A series of phosphonium salts with different alkyl chain lengths were synthesized and combined with polyoxomolybdate clusters to form new hybrid systems. Their antimicrobial activity was evaluated against representative Gram-positive and Gram-negative bacteria, including Escherichia coli, Bacillus subtilis, Streptococcus mutans, and Staphylococcus epidermidis. In addition, cytotoxicity studies using HaCaT keratinocyte cells were performed to assess their biocompatibility.The results show that the structure of the phosphonium cations plays an important role in antimicrobial performance. At the same time, the presence of polyoxomolybdate clusters appears to improve selectivity by reducing cytotoxicity while maintaining antibacterial activity. Overall, these results highlight the potential of phosphonium-based polyoxomolybdate hybrids as promising materials for preventing biocolonization and controlling microbial growth in water-related environments.

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CURRENT LIMITATIONS AND ADVANCES IN THE DETECTION OF MICRO- AND NANOPLASTICS IN WATER

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The presence of water contaminants, such as micro/nano plastics (MNPs), pathogenic microorganisms or heavy metals, reduces the availability of fresh-water in the world, especially in less developed countries. Hence, the simultaneous removal of organic, inorganic, and microbial contaminants from water by a multi-functional material, offers significant advantages when fast, straightforward and robust water purification is required. Despite the growing concern, the response from the chemical and materials science communities has been slow, with few studies dedicated to developing procedures or devices for efficiently monitoring or removing MNP pollutants.

In the case of MNPs the most current sampling methods in the literature rely on sieves or nets to collect and sort them. This reveals a significant lack of standardized methods for sampling, separation, and characterization of MNPs, particularly in the nanometric range (<0.1 µm). These conventional techniques are inadequate for detecting nanoplastics (NPs) because environmental samples often contain biogenic particles of similar size. Additionally, the analytical techniques used, such as µ-Raman spectroscopy and µ-FTIR, are limited, requiring large particle sizes and substantial sample volumes. This underscores the urgent need for standardized methodologies for MNP sampling and analysis, as well as the development of efficient systems for MNP removal from real-world environments.

The EIC Pathfinder project “BMRex” (https://www.bmrex-project.eu/) is developing specific reactors for wastewater effluents based on porous inorganic scaffolds functionalized with polyoxometalate-ionic liquids (POM-ILs) capable to remove MNPs and pathogenic microorganisms simultaneously. The inorganic scaffolds materials provide a highly robust structural support with adjusted structural features for the capture of MNPs, and it is functionalized with the specific POM-ILs materials. These multifunctional POM-ILs are capable of removing MNPs, heavy-metals and microbial contaminants from water[1,2]. The POM-ILs activity against microorganisms such as pathogenic bacteria, which also helps to avoid membrane blockages by preventing biofouling formation[4].

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RECOVERY OF PHOSPHORUS AND MAGNESIUM FROM WASTEWATER USING BIOCHAR OBTAINED THROUGH PYROLYSIS OF PAPER AND PULP INDUSTRY SLUDGE

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Phosphorus (P) and magnesium (Mg) are Critical Raw Materials (CRM) in Europe due to their strategic relevance and supply risks. P is essential for fertilisers and green technologies, while European Mg remains limited and largely imported. A considerable proportion of these CRM is present in different industrial wastewaters (IWW), making sustainable management, recovery and recycling crucial. Adsorption using low-cost and high-capacity adsorbents derived from mineral-rich industrial sludge offers an effective method to valorising waste while recovering CRM. Within the framework of the EU RESURGENCE project, this study focuses on IWW treatment for P and Mg recovery using biochars obtained from paper and pulp industrial sludges (PPIS).

Primary sludge (PS) from PPIS was characterised and pyrolysed in a batch reactor using an open tubular furnace equipped with a condensation system for oil collection. Pyrolysis conditions were carried out in two steps (2ST), with highest heating temperatures of 650 and 700 ºC, a heating rate of 2 ºC/min and residence time of 60 min at maximum temperature. Biochars achieved a 67 % yield, mineral predominance (57 % ash, 17 % Carbon content), high calcium content (>300 mg/g), and low specific surface area (SSA) (65 m²/g). Biochars presented reduced heavy metal content and low environmental risk[1]. The adsorption capacity of Mg and P by the produced biochars was evaluated through a 24-hour test and kinetic studies with adsorption capacities assessed at different time intervals. Experiments were conducted with individual solutions of P (1.5 mg P-PO_4^{3-}/L) and Mg (45 mg Mg^{2+}/L), respectively, as well as a combined solution containing the same concentrations of both analytes. To benchmark adsorption efficiency, the assay was also performed using a commercial biochar (brand: LivingChar; type: wood; composition: almond, olive, carob). Finally, P isotherms test was carried out with simulated complex IWW (260 mg Mg2+/L, 670 mg Na+/L, 480 mg Ca2+/L, 1,100 mg Cl-/L, 1350 mg SO_4^{2-}/L, 80 mg NO_3^-/L, 7 mg F-/L, 3.5 mg Br-/L, 4 mg Mo2+/L 150 µg Cu2+/L, 130 µg Zn2+/L, 20 µg Al3+/L, 210 µg Mn2/L,) and different concentrations of P (1.5, 5, 22, 81 and 387.5 mg P-PO_4^{3-}/L).

A 100% recovery of P and Mg from the combined solution was achieved after 24 hour for PS pyrolysed at 700 °C without ground or washing steps (UGUW) after pyrolysis (PS-700-2ST (UGUW)), in contrast with the negligible recovery of the commercial biochar (Fig 1). Despite its lower SSA, the higher capacity of the biochar for both CRM can be attributed to its high mineral salt content[2], particularly Ca. Kinetic studies for both individual and combined solutions indicated that adsorption was predominantly described by a chemisorption mechanism, as supported by the pseudo-second order kinetic model. Equilibrium adsorption capacities obtained (q_e) for individual solutions were 0.75 ± 0.01 mg P-PO_4^{3-}/g and 20.19 ± 1.24 mg Mg^{2+}/g, with slightly lower q_e for combined solution. Equilibrium test with simulated IWW reported high recovery of P (~10 mg P-PO_4^{3-}/g) while Mg recovery was negligible.

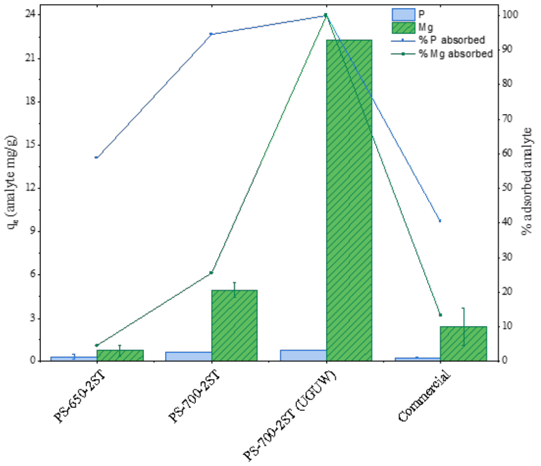

Figure 1 – Adsorption of P and Mg from a combined solution after 24 h of contact time

In conclusion, biochar obtained from PPIS reported high recovery of P from simulated complex IWW (~10 mg P-PO_4^{3-}/g). Moreover, this biochar also reported capacity for Mg recovery in cleaner wastewaters. Based on the results, this biochar had high potential for sustainable wastewater treatment and CRM recovery.

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ROTATING DESK ELECTRODE ENRICHED WITH NANOPARTICLES FOR THE DETECTION OF ULTRATRACE AMOUNTS OF BISPHENOL A IN TAP WATER

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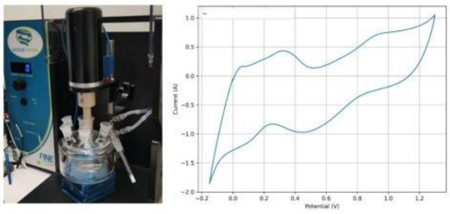

Figure 1 – CV voltamogramm of BPA in PBS using RDE.

This work addresses bisphenols a class of high-volume synthetic chemicals of emerging concern (CECs) widely used in plastics and resins production, these compounds can leach into the drinking water systems, raising concerns due to their potential toxicity and adverse impacts on both human health and environment. This work focuses on two complementary approaches for monitoring contaminants in wastewater: 1) 3D-printed passive samplers for the collection of Bisphenol A (BPA) and 2) electrochemical methods for its detection),

Contaminants of relevance (such as BPA) are detected at low concentration employing Direct Analysis in Real Time Mass Spectrometry (DART-MS) for fast, non-targeted screening with minimal sample preparation and high throughput, The other approach, employs an electrochemical sensors based on nanocomposite modified glassy carbon rotating desk electrodes (GCRDEs) as rapid and reliable methods for detecting the trace amounts of BPA in drinking water.

The GCRDEs are modified with bimetallic nanoparticles such as gold and platinum (Au and Pt) deposited on high-surface-area carbon. The integration of the metallic nanoparticles enhances the electron transfer rate at the surface of the electrode, and the electrochemical signal results in improving the sensitivity toward the BPA analyte oxidation. Under optimized conditions, the Au/Pt-NPs electrodes showed a strong and highly sensitive signal for BPA with a very low limit of detection in phosphate buffer solutions (PBS) at pH 7.4. Cyclic voltammetry CV is used as the main detection tool to measure the potential peak for BPA. The CV analysis was carried out in the potential range from 0.0 V to 1.0V. The Combining electrochemical detection with passive sampling provides a highly complementary strategy for rapid analysis and measurement of BPA contamination in water matrices. This approach demonstrates high sensitivity, selectivity, stability, and reproducibility, supporting the development of a reliable method for the routine detection of BPA in water systems.

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SPATIAL AND TEMPORAL VARIABILITY OF MICROPLASTICS IN A LACUSTRINE NETWORK IN NORTHERN SPAIN

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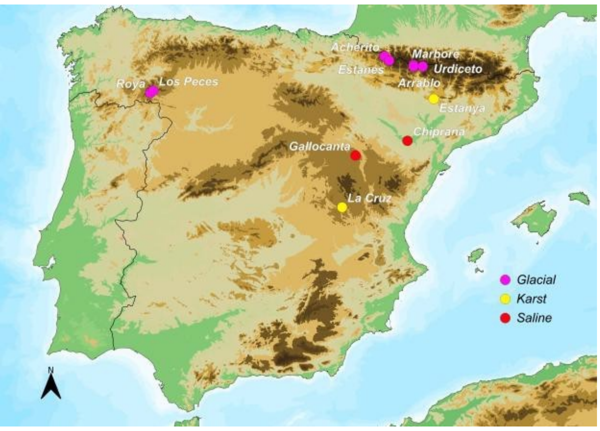

Lakes are sensitive systems that behave as sinks for emerging pollutants and particularly microplastics[1]. In order to assess the ecological conservation status of these ecosystems, it becomes essential to include the quantification and characterization of microplastics (plastics <5mm in any dimension) in lake surveys.

To this end, sampling campaigns were conducted in the summer and autumn of 2023 and 2024 across 11 lakes in several locations in northern Spain (Figure 1), the majority of which are located within protected natural areas. Surface water samples and replicates were collected using stainless steel bottles (1-3 L). In certain instances, bottom water (2-5 L) was also sampled using a Niskin bottle. Samples were then digested in 15% H_2O_2 at 50°C for 48 hours and filtered through 0.45µm polyethersulfone filters. In addition, control samples consisting of Milli-Q water were exposed to fieldwork and laboratory procedures in the same manner as the samples. Filters were observed under a magnifier to identify potential microplastic particles, and at least 25% of the filter area was analysed using µFTIR to verify particle chemical composition.

Results from 2023 showed higher microplastic concentrations in surface waters compared to bottom waters in all lakes. The maximum surface concentration was observed in Estanya (3.8±0.8 items/L), followed by Estanés, Chiprana, Acherito, and Marboré. In bottom waters, the highest concentration was recorded in Estanés (1.7±0.5 items/L). In contrast, in 2024 microplastics were only found in surface waters of Acherito and in bottom waters of Estanya. No microplastics were detected in La Cruz, Roya, Los Peces, Arrablo, Urdiceto and Gallocanta.

Gallocanta Lake is an endorheic system characterised by an irregular hydrological cycle, alternating between desiccation and refilling periods. For the purpose of capturing the complex dynamics of microplastic pollution in this system, a monthly monitoring programme was conducted over one year. In August 2024, the lake approached complete desiccation, while in autumn it replenished due to intense rainfall affecting much of the Iberian Peninsula. Consequently, microplastic concentrations varied considerably, ranging from 3.0±0.9 items/L in July 2024 to an absence of microplastics in October.

The chemical composition of the isolated microplastics was variable, with polycarbonates, polyesters and polymethacrylates being the most abundant polymers. In high-mountain lakes, particles ranging between 20 and 100 µm in length were predominant (37%), whereas, in the other lakes, larger particles prevailed. Overall, fibres (50–81%) and transparent/white particles (>30%) were the most common, except in Estanya, where black particles dominated (39%). The spatial and temporal variability of microplastics observed in this study underscores the necessity for long-term monitoring initiatives. Such data may facilitate the management and effective conservation of protected natural areas.

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TRACKING MICROPLASTICS IN RIVERS: MODELING TRANSPORT AND ENVIRONMENTAL FATE

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Microplastics (MPs) are an emerging environmental contaminant that has recently been detected in concerning concentrations in freshwater systems and even in domestic water supplies [1]. Their presence raises growing public health concerns due to the potential ingestion of MPs and their associated effects on humans and wildlife [2]. Moreover, MPs can act as vectors for pathogens, chemical pollutants, and invasive species, amplifying their ecological impact on aquatic environments. Urban areas, where plastic production and consumption are particularly intense, are recognized as major sources of riverine MPs [3]. Consequently, the development of monitoring strategies, mitigation plans, and predictive tools to understand the behavior and fate of MPs in fluvial environments has become a priority. The transport of MPs in natural waters is governed by several interacting physical and biogeochemical processes. Particle properties such as size, shape, and density determine settling or rising velocities, which influence whether particles remain suspended, travel near the water surface, or accumulate near the bed. At the same time, turbulence-driven dispersion controls the spreading of fine particles within the flow. Additional processes can significantly alter the behavior of MPs once they enter aquatic environments. Biofouling, for instance, changes particle density as microorganisms colonize plastic surfaces, potentially shifting buoyant particles towards the bed. Degradation processes progressively modify particle properties over time, while aggregation with organic matter can further alter transport pathways. Understanding how these mechanisms interact with hydrodynamic conditions is essential to predict where MPs accumulate and how long they remain in aquatic systems.

In this work, we present a numerical modeling approach to investigate the transport and fate of MPs in river environments. The model represents MPs as individual particles transported by the flow and incorporates the main processes affecting their dynamics in shallow water systems, including advection by the current, turbulent dispersion, settling, degradation, and biofouling. This approach allows the simulation of large numbers of particles and the identification of preferential pathways, retention zones, and potential accumulation areas within river systems. By reproducing how MPs move through channels and interact with flow structures, the model provides insights into the mechanisms that control MP transport in fluvial environments. Beyond improving the understanding of MP behavior, this modeling framework can support the development of strategies aimed at reducing MP concentrations in aquatic environments. Numerical simulations can help evaluate the effectiveness of mitigation measures such as retention structures, modified channel morphologies, or nature-based solutions designed to enhance particle trapping and removal. In this way, the proposed model constitutes a useful tool for assessing MP pollution in rivers and for supporting water safety strategies aimed at protecting freshwater resources.

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UPSTREAM - CIRCULAR AND BIO-BASED SOLUTIONS FOR THE ULTIMATE PREVENTION OF PLASTICS IN RIVERS INTEGRATED WITH ELIMINATION AND MONITORING TECHNOLOGIES

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Plastic and microplastic pollution in freshwater ecosystems is a critical environmental challenge due to its strong link with marine contamination, ecosystem degradation, and potential risks to human health [1,2]. Rivers act as the main transport pathways for land-based plastic waste, conveying a substantial fraction of mismanaged plastics from terrestrial sources to marine environments [3]. Recent studies estimate that a relatively small number of rivers are responsible for the majority of plastic emissions to the oceans, highlighting the strategic importance of river-focused prevention and mitigation measures [3,4]. In response, the Horizon Europe Innovation Action UPSTREAM introduces a paradigm shift from end-of-pipe remediation towards a comprehensive upstream prevention strategy [5]. The project is fully aligned with the EU Mission “Restore our Ocean and Waters by 2030”, which aims to protect and restore marine and freshwater ecosystems while preventing and eliminating pollution through systemic, basin-scale approaches [6].

The overarching objective of UPSTREAM is to achieve a 50% reduction in plastic litter and a 30% reduction in microplastic pollution in European rivers by 2030. This ambition is addressed through a holistic framework structured around five interconnected pillars: (i) precision monitoring, (ii) prevention through material design, (iii) elimination at wastewater treatment plants (WWTPs), (iv) direct river remediation, and (v) circular valorisation of recovered plastics. The approach is demonstrated through the deployment of 15 innovative solutions across seven representative European rivers—Severn, Trent, Ebro, Ticino, Olona, Queich, and Danube—covering diverse hydrological, environmental, and socio-economic contexts.

A key component of UPSTREAM is the development of harmonised and validated monitoring protocols capable of detecting microplastics below 25 µm. Advanced analytical techniques, such as fluorescent staining and leachable compounds screening, are combined with AI-enabled unmanned aerial systems to identify pollution hotspots along riverbanks and water bodies. These tools generate high-resolution spatial and compositional data that support targeted intervention strategies and evidence-based decision-making.

Prevention by design is addressed through the development of biodegradable and bio-based polymeric materials for applications prone to environmental release, such as single-use items and WWTP components. By addressing material properties at the design stage, UPSTREAM reduces the burden on downstream treatment and remediation systems. At the wastewater treatment level, the project demonstrates a portfolio of advanced elimination technologies aiming to achieve macro- and microplastic removal efficiencies exceeding 90%. These include cellulose recovery systems, optimised membrane filtration, nature-based solutions, and advanced oxidation processes that enable efficient plastic separation at reduced operational costs. Complementary photocatalytic approaches are explored to degrade plastic additives and contaminants under visible light.

Direct river remediation is implemented through floating platforms and in-river capture systems operating under real conditions. Finally, UPSTREAM integrates circular economy principles by valorising collected plastics via mechanical and chemical recycling pathways, targeting the reuse of up to 90% of recovered materials. Through its systemic, prevention-oriented approach, UPSTREAM contributes directly to the restoration of European freshwater and marine ecosystems.

Keywords: UPSTREAM-project; plastics; microplastics; monitoring; prevention; elimination; valorization;

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